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NEOGENE OSTRACODS FROM THE SOLIMÕES FORMATION (ATALAIA DO NORTE, AMAZONAS STATE, BRAZIL), WITH THE DESCRIPTION OF TWO NEW SPECIES

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ABSTRACT – The analysis of the ostracods from three boreholes (1AS-7D-AM, 1AS-8-AM, and 1AS-31-AM) drilled in Atalaia do Norte town, Amazonas State, Brazil, allowed to recognize 30 species and nine genera. *Cyprideis* is the most abundant and diverse genus and is represented by 19 species already identified for the Solimões Formation, besides two new species described herein: *Cyprideis atalaiensis* sp. nov. and *Cyprideis dictyon* sp. nov. Intraspecific morphological variability, as well as the presence of nodes and tubercles, are observed in some species of *Cyprideis* and interpreted as a response to the paleoenvironmental changes during the Neogene in western Amazon region.

Keywords: *Cyprideis*, morphological variability, paleoenvironmental changes, western Amazonia.

RESUMO – A análise da ostracofauna proveniente de três testemunhos de sondagem (1AS-7D-AM, 1AS-8-AM e 1AS-31-AM) perfurados no município de Atalaia do Norte, Estado do Amazonas, Brasil, permitiu o reconhecimento de 30 espécies e nove gêneros. *Cyprideis* é o gênero mais abundante e diverso, sendo representado por 19 espécies já identificadas para a Formação Solimões, além da descrição de duas novas espécies: *Cyprideis atalaiensis* sp. nov. e *Cyprideis dictyon* sp. nov. Variabilidade morfológica intraespecífica, bem como a presença de nódulos e tubérculos, foram observadas em algumas espécies de *Cyprideis* e são interpretadas como uma resposta às mudanças paleoambientais ocorridas durante o Neógeno na Amazônia Ocidental.

Palavras-chave: *Cyprideis*, variabilidade morfológica, mudanças paleoambientais, Amazônia Ocidental.

INTRODUCTION

The Solimões Formation, western Amazonia, Brazil, unveils a great fossiliferous diversity, represented mainly by mollusks, fishes, palynomorphs, and ostracods (Hoorn, 1993; Monsch, 1998; Wesselingh, 2006; Linhares *et al*., 2011; Gross *et al*., 2014). Since the seminal studies about the ostracods from the Neogene of western Amazonia, a particular endemic and diverse assemblage with new genera and species has been recorded (Purper, 1977a, b, 1979; Shepard & Bate, 1980; Purper & Pinto, 1983, 1985; Purper & Ornellas, 1991). However, Muñoz-Torres *et al.* (1998) studying ostracods from several Neogene localities from Brazil, Peru, and Colombia performed a review of the taxonomic findings, considering the most part of the new genera proposed by the previous authors as synonyms of *Cyprideis* (Jones, 1857). Since then, the genus has become the most diverse and abundant, enabling the authors to propose a phylogenetic tree (Whatley *et al*., 1998) and a biozonation (Muñoz-Torres *et al*., 2006) to the Neogene of western Amazonia.

Posteriorly, Gross *et al*. (2014) studying the *Cyprideis* species flocks from the borehole 1AS-10-AM, in Amazonas State, Brazil, presented and discussed in detail the concept of species and the morphological variability among the specimens, do not discarding the possible occurrence of new genera, as previously proposed by Purper (1977b, 1979). The authors assembled 20 species into groups and subgroups and presented a review of the evolutionary lineage proposed by Muñoz-Torres *et al.* (2006).

Several works indicate that the intraspecific morphological variability has triggered problems for the ostracod classification, and it is a challenge for the identification and description of species of some genera (*e.g*. Gross *et al*., 2008, 2014; Gliozzi *et al*., 2017); consequently, without a detailed morphological and taxonomic study, the results obtained by phylogenetic, biostratigraphic, paleoecological and paleobiogeographic analyses are compromised (*e.g*., Coimbra, 2020; Lord, 2020; Forel *et al*., 2021). In this case, the ecophenotypic plasticity, which is clearly observed in *Cyprideis* (*e.g*., Sandberg, 1964; Ruiz *et al*., 2013), can be a response to environmental changes during the Neogene of the western Amazonia, which are still enigmatic.

The high intraspecific variability in the species of *Cyprideis* of the Solimões Formation (Gross *et al*., 2014), as well as in mollusks (Wesselingh *et al*., 2002), has been recognized. It could be related to a rapid adaptive evolution as a response to environmental changes, such as salinity gradient variations, resulting from of marine ingressions in western Amazonia (Linhares *et al*., 2017, 2019). According to Linhares *et al*. (2011), the presence of structures as nodes in *Cyprideis* valves, as well as the presence of eurytopic microfossils, are indicative of variations in the hydrochemical conditions of the water for the studied region.

Until now, 30 species of *Cyprideis* have been recorded in the Neogene of the western Amazonia (Muñoz-Torres *et al*., 1998; Wesselingh & Ramos, 2010; Gross *et al*., 2014). In this work we present a new contribution to the record of this genus, including the description of two new species from three boreholes (1AS-7D-AM, 1AS-8-AM, and 1AS-31-AM) drilled in Atalaia do Norte town, Amazonas State, Brazil; a discussion on the correlation of the morphological variability, such as the presence of nodes, with the environmental changes is also presented.

MATERIAL AND METHODS

A total of 304 core samples from three boreholes was investigated for microfossils, 112 from 1AS-7D-AM (04°34'S – 70°41´W), 109 from 1AS-31-AM (05°18'S – 71°02´W), and 83 from 1AS-8-AM (04°36'S – 70°16´W) (Figure 1). The boreholes were drilled by the Serviço Geológico do Brasil (**CPRM**), in Atalaia do Norte town, Amazonas State, northern Brazil, during the project Carvão no Alto Solimões, which aimed the lignite exploration (Maia *et al*., 1977). The borehole 1AS-7D-AM reaching a total depth of 304.70 m, 1AS-8-AM reaches the depth of 405 m, and AS-31-AM reaches 302.05 m-depth.

The material was processed following the usual procedures for calcareous microfossils. The samples were washed and sieved through sieves of fractions 0.5 mm, 0.250 mm, 0.180 mm, and 0.125 mm. Wet sieve residuals were dried

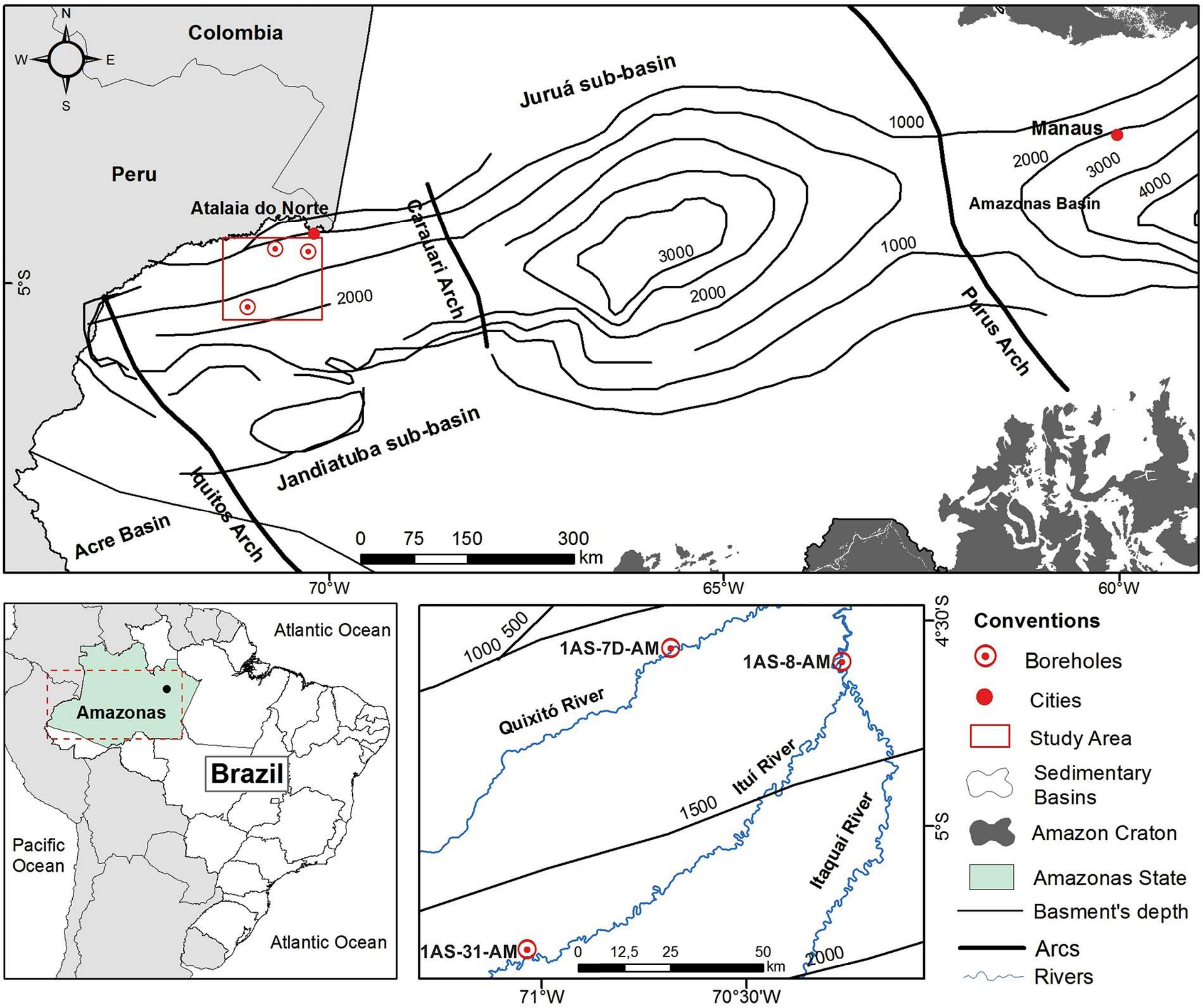

Figure 1. Location of the study area, with tectonic compartmentation of the Solimões Basin, subdivided by the Carauari Arch into the Jurua and Jandiatuba sub-basins, and the location of the studied boreholes (modified of Wanderley Filho *et al*., 2010).

at 60°C and the residuals were picked out completely for microfossil analysis using stereomicroscope and electronic scanning microscope (**SEM**), for subsequent identification. Photographs were taken with a SEM model LEO 1450VP, of Museu Paraense Emílio Goeldi and a SEM model JEOL JSM 6060 of Centro de Microscopia Eletrônica, of Universidade Federal do Rio Grande do Sul, Brazil. For the ostracod count, the following standard was considered: 0–10 = rare; 11–30 = common; 31–50 = abundant and > 50 = very abundant. **Morphological abbreviations: LV**, left valve; **RV**, right valve.

RESULTS

The ostracods analysis allowed to recognize nine genera and 30 species (Figures 2–8). *Cyprideis* is the most diverse and abundant genus, represented by 19 species already identified to other localities of the Neogene sequences from western Amazonia (Figures 5A–Z and 6A–L); two new species are described herein: *C. atalaiensis* sp. nov. (Figure 7) and *C. dictyon* sp. nov. (Figure 8). Other genera and species were also identified (Figure 6M–X): *Cypria aqualica* Shepard & Bate, 1980, *Cytheridella danielopoli* Purper, 1979, ?*Paracypris* sp., *Penthesilenula olivencae* (Purper, 1979), *Perissocytheridea acuminata* (Purper, 1979), *P. ornellasae* (Purper, 1979), *Rhadinocytherura amazonensis* Shepard & Bate, 1980, *Skopaeocythere tetrakanthos* Whatley, Muñoz-Torres & Harten, 2000, and *Pellucistoma curupira* Gross, Ramos & Piller, 2015.

SYSTEMATIC PALEONTOLOGY

Suprageneric taxonomy follows Liebau (2005). Regarding species, for comparative purposes, the following material was used: the type material of Purper (1979): MP-O-517 to MP-O-518, Purper & Ornellas (1991): MP-O-1239 to MP-O-1244, housed in the collection of the Museu de Paleontologia Irajá Damiani Pinto, Universidade Federal do Rio Grande do Sul, Brazil; and Gross *et al*. (2013, 2014, 2015): MPEG-210-M to MPEG-495-M, housed in the Micropaleontology Collection of the Museu Paraense Emílio Goeldi (MPEG), Brazil. Other pertinent articles were consulted (Purper & Pinto, 1985; Muñoz-Torres *et al*., 1998; Whatley *et al*., 1998, 2000; Gross *et al*., 2015).

The figured specimens (Figures 5 and 6) and type-material (Figures 7 and 8) are housed in the Micropaleontology Collection of the Museu Paraense Emílio Goeldi, Pará, Brazil, under catalogue numbers MPEG-929-M to MPEG-985-M.

Class OSTRACODA Latreille, 1802
Order PODOCOPIDA Sars, 1866
Suborder PODOCOPINA Sars, 1866
Superfamily CYTHEROIDEA Baird, 1850
Family CYTHERIDEIDAE Sars, 1925
Subfamily CYTHERIDEINAE Sars, 1925

Cyprideis Jones, 1857

Type species. *Candona torosa* Jones, 1850, subsequently designed by Jones (1857).

Cyprideis atalaiensis sp. nov.
urn:lsid:zoobank.org:act:6E1B36C2-4EFB-405F-8BD5-C38E0A95C4C9
(Figures 7A–L)

1998 *Cyprideis graciosa* (Purper, 1979). Whatley *et al*., p. 234, pl. 1, figs. 11–15.
1998 *Cyprideis graciosa* (Purper, 1979). Muñoz-Torres *et al*., p. 96, pl. 3, figs. 1–3.
2011 *Cyprideis graciosa* (Purper, 1979). Linhares *et al*., p. 100, figs. 3.9–10.
non *Cyprideis graciosa* Purper, 1979, p. 229, pl. 3, figs. 1−9.
2011 *Cyprideis pebasae* (Purper, 1979). Linhares *et al*., p. 101, figs. 4.3–4.
non *Cyprideis pebasae* Purper, 1979, p. 228, pl. 2, figs. 11–23.

Derivation name. From Atalaia do Norte, municipality of Amazonas State where borehole 1AS-31-AM was drilled.
Type material. Holotype. MPEG-977-M, carapace female; RV, length 0.85 mm; height: 0.46 mm; LV, length 0.48 mm; height: 0.88 mm; width: 0.39 mm. Paratypes. MPEG-978-M, Female, RV, length 0.85 mm; height: 0.45 mm. MPEG-979-M, carapace male, LV, length 1.02 mm; height: 0.50 mm; RV, length 0.99 mm; height: 0.49 mm; width: 0.36 mm.
Additional material. 116 specimens.
Type locality. Borehole 1AS-31-AM at Cururu close to Rio Ituí (05°18'S – 71°02´W); Atalaia do Norte town, Amazonas State, Brazil.
Stratigraphic occurrence. Lower Miocene (*Cyprideis cyrtoma* zone in Linhares *et al*., 2019).
Diagnosis. A large and elongated species of *Cyprideis*, with relatively thick carapace. Subrectangular in lateral view; subelliptical in dorsal view. Well-developed ornamentation, with rounded and relatively deep fossae tending to punctuated on the margins. Very delicate flange runs along the posteroventral margin in RV. Anterior margins of both valves with seven to eight very short spines and posterior margin with one spine in RV. Anteromarginal rib evident.
Description. Large sized. Relatively thick shelled. In lateral view, subrectangular and elongate. LV larger than RV. Maximum height at anterior cardinal angle. Dorsal margin slightly arched in the median region. Ventral margin nearly straight in the RV, and gently sinuous in the LV, with apparent oral curvature. Anterior margin broadly rounded with seven to eight very short spines. Posterior margin slightly truncated; discrete flange and small marginal spine in the posteroventral region of the RV. Surface strongly reticulated, with rounded and relatively deep fossae, numerous punctuations in the margins, partially celated in the most anterior region. Anteromarginal rib evident. Sinuous vertical sulcus extending from the median dorsal margin to the centromedian portion of the valve. Dorsal view: subelliptical and slightly inflated in the posterior region, with subparallel sides. Internal view:

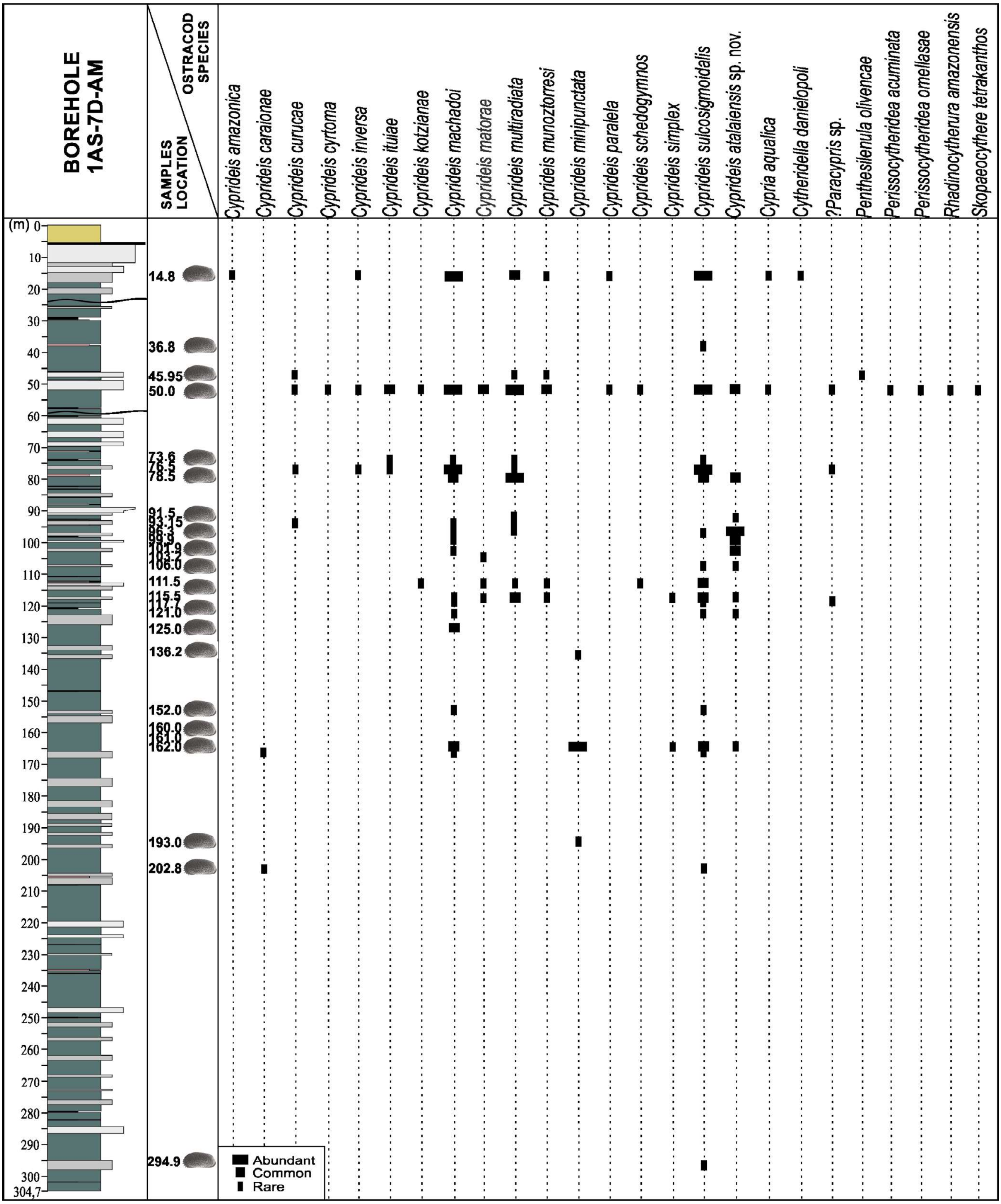

Figure 2. Section of the borehole 1AS-7D-AM (based on nonpublished CPRM reports) and stratigraphical distribution and abundance of the ostracod species.

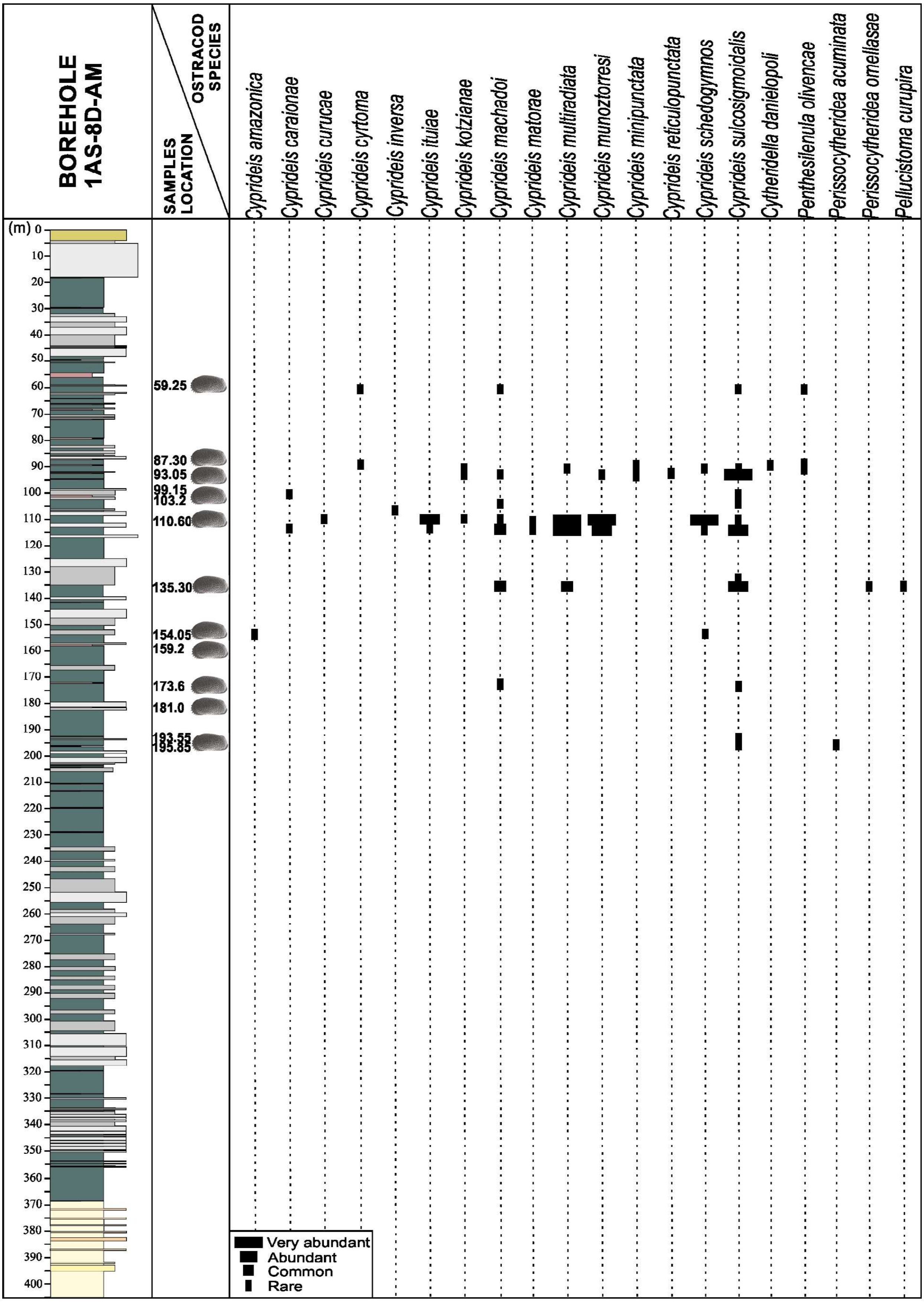

Figure 3. Section of the borehole 1AS-8-AM (based on nonpublished CPRM reports) and stratigraphical distribution and abundance of the ostracod species.

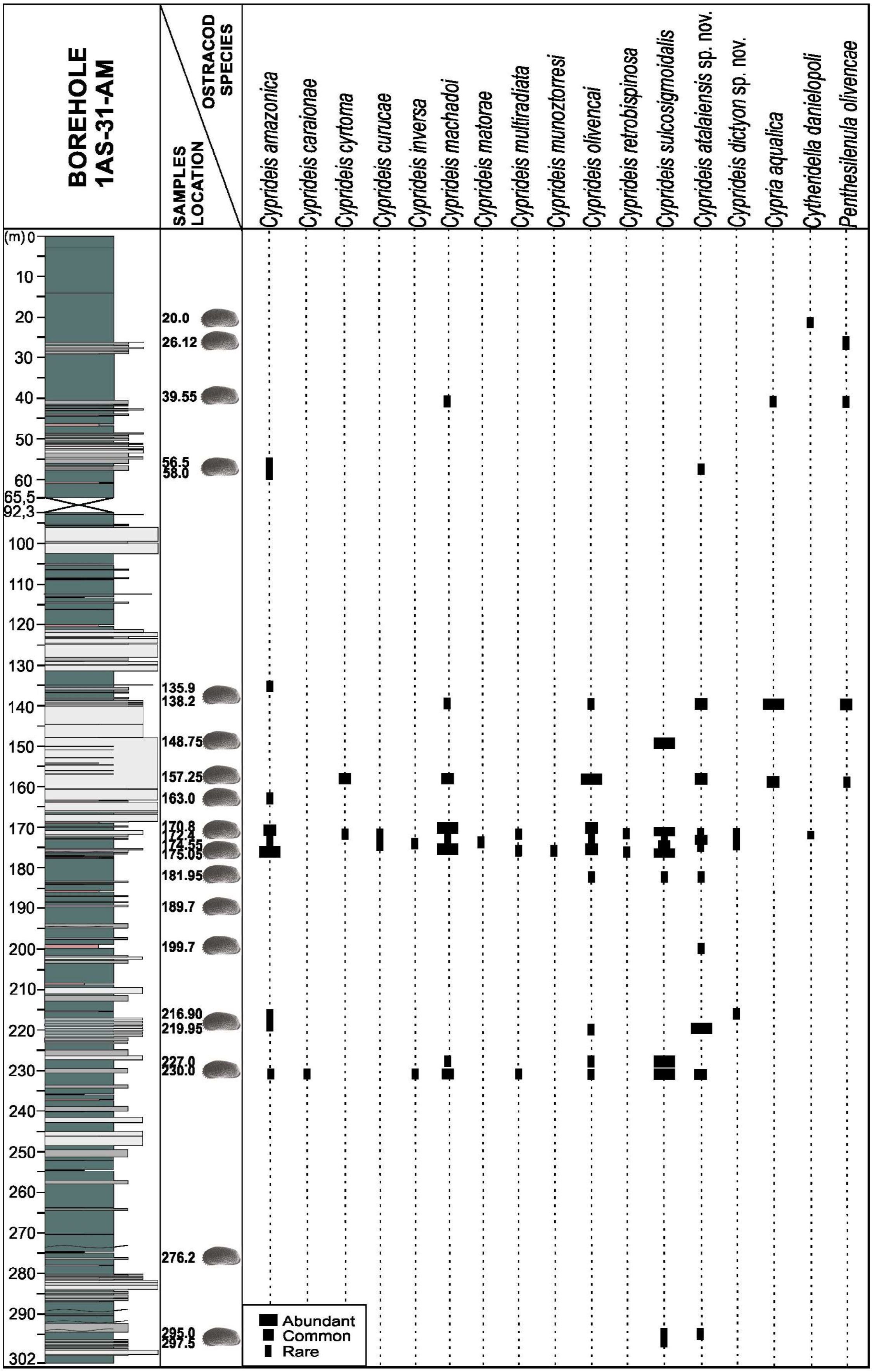

Figure 4. Section of the borehole 1AS-31-AM (based on nonpublished CPRM reports) and stratigraphical distribution and abundance of the ostracod species.

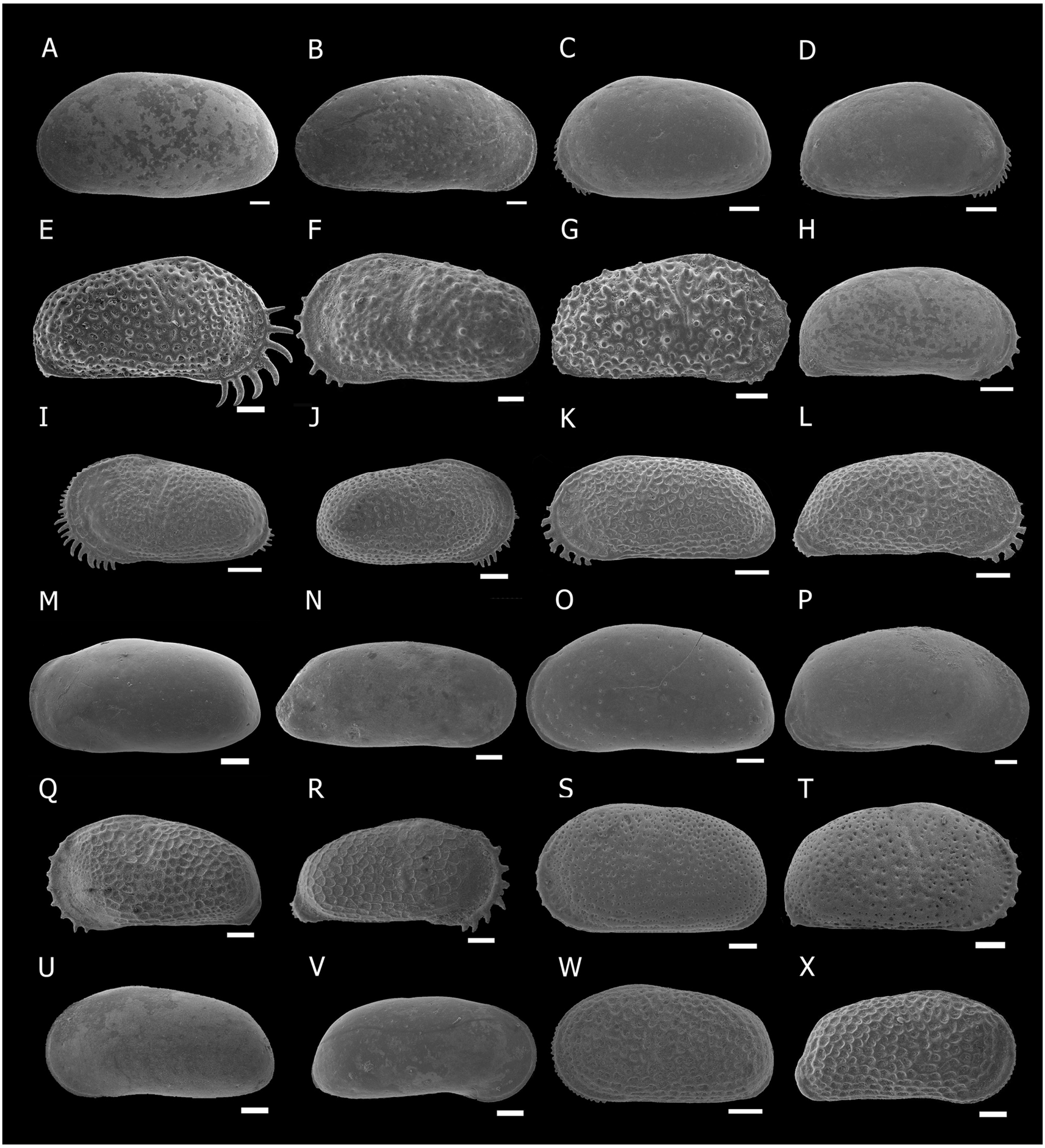

Figure 5. A–B, *Cyprideis amazonica*; **A**, LV, male (MPEG-929-M); **B**, RV, male (MPEG-930-M). **C–D**, *C. caraionae*; **C**, LV, female (MPEG-931-M); **D**, RV, female (MPEG-932-M). **E–G**, *C. curucae*; **E**, LV, female (MPEG-933-M); **F**, LV, male (MPEG-934-M); **G**, RV, female (MPEG-935-M). H, *C. cyrtoma*; RV, female (MPEG-936-M). **I–J**, *C. inversa*; **I**, LV, female (MPEG-937-M); **J**, RV, female (MPEG-938-M). **K–L**, *C. ituiae*; **K**, LV, male (MPEG-939-M); **L**, RV, male (MPEG-940-M). **M–N**, *C. kotzianae*; **M**, LV, female (MPEG-941-M); **N**, RV, male (MPEG-942-M). **O–P**, *C. machadoi*; **O**, LV, female (MPEG-943-M); **P**, RV, female (MPEG-944-M). **Q–R**, *C. matorae*; **Q**, LV, female (MPEG-945-M); **R**, RV, female (MPEG-946-M). **S–T**, *C. minipunctata*; **S**, LV, female (MPEG-947-M); **T**, RV, female (MPEG-948-M). **U–V**, *C. multiradiata*; **U**, LV, female (MPEG-949-M); **V**, RV, female (MPEG-950-M). **W–X**, *C. munoztorresi*; **W**, LV, female (MPEG-951-M); **X**, RV, female (MPEG-952-M). Scale bars = 100 µm.

entomodont hinge, inner lamella in a regular contour, wide anteriorly, narrow ventrally and posteriorly; central muscle scars typical of the genus; depression in posteroventral margin extending to a delicate flange in RV. Sexual dimorphism: males more elongated and with less inclined dorsal margin; posterior cardinal angle more marked; posterior margin more inclined and protruded ventrally.

Remarks. *Cyprideis atalaiensis* sp. nov. resembles *Cyprideis graciosa* (Purper, 1979: pl. 3; figs. 1–9; Purper & Ornellas, 1991: pl. 1; figs. 10–15) by the ornamentation pattern and subrectangular shape, but *C. atalaiensis* sp. nov. differs by the absence of spines in the posteroventral region of the LV and absence of strong constriction on the anterior-superior third. Besides, *C. graciosa* presents, in both valves, a more closed posteroventral curvature, the anterior margin with strong spines, and a more truncate posteroventral margin of both valves of the males. It resembles also *Cyprideis marginuspinosa* (Purper & Ornellas, 1991: pl. 2; figs. 1–6), but it differs from that species because it has a strongly reticulated ornamentation and not punctuated and it does not have the long-spaced spines in anterior margin, which are characteristic of *Cyprideis marginuspinosa*; presents ventral margin nearly straight; and in dorsal view the female of the new species is more elongate. Besides, *Cyprideis* aff. *graciosa* identified by Gross *et al*. (2014) (pl. 6; figs. 34–40) is similar in shape with *C. atalaiensis* sp. nov., but the ventral portion is more sinuous, the female LV is more elongated, presenting larger spines that are absent in *C. atalaiensis* sp. nov; differences in the angle of the posterodorsal region are observed in LV.

Cyprideis dictyon sp. nov.
urn:lsid:zoobank.org:act:0061D7D5-BF58-427C-8F1F-19B4AA03FA16
(Figures 8A–O)

2011 *Cyprideis* sp. 5. Linhares *et al*., pl. 97, fig. 4.9–10.

Derivation of name. From Greek δικτυωτή (reticulated). With reference to its well-developed reticulate ornamentation.

Type material. Holotype. MPEG-981-M, female, RV, length 0.65 mm; height: 0.35 mm. Paratypes. MPEG-980-M (fragmented), female, LV, length 0.67 mm; height: 0.37 mm. MPEG-982-M, female, LV, length 0.67 mm; height: 0.38 mm. MPEG-983-M, female, RV, length 0.62 mm; height: 0.36 mm. MPEG-984-M (fragmented), male, LV, length 0.69 mm; height: 0.37 mm. MPEG-985-M, male, LV, length 0.71 mm; height: 0.40 mm.

Additional material. 10 specimens.

Type locality. Borehole 1AS-31-AM at Cururu, close to Ituí river (05°18'S – 71°02´W); Atalaia do Norte town, Amazonas State, Brazil.

Stratigraphic occurrence. From middle to upper Miocene (Linhares *et al*., 2011).

Diagnosis. A medium-sized species of *Cyprideis*. Posterior margin of the RV truncated to almost straight, with a delicate flange. In the female, dorsal margin strongly arched near the median region. Ornamentation with well-developed reticulation. Deep vertical sulcus bifurcated just after the anterodorsal margin.

Description. Medium-sized. Relatively thick-shelled. Subrectangular in lateral view. Maximum height almost medially; in a noded female morphotype greatest height just mid-length. Dorsal margin strongly arched. Ventral margin almost straight, but with a well-defined oral incurvature, mainly in the RV; LV with straighter ventral margin than RV. Anterior margin well-rounded, projecting beyond the ventral margin, mainly in the RV. Posterior margin almost straight, with a delicate flange extended to the posteroventral margin in RV. Surface with well-developed reticulation; noded morphotypes present six nodes in the female and six to seven nodes in the males; the nodes are arranged in practically the same positions in the different specimens, following the scheme of potential positions proposed by Sandberg (1964). Three parallel ribs at the anterior margin, extend to the first part of the ventral margin. Deep bifurcated vertical sulcus extends from the anterodorsal region to three-quarter of the carapace in the anteromedian region. Dorsal view: elliptical and slightly inflated in the posterior region, with subparallel sides. Internal view: entomodont hinge, inner lamella in a regular contour, wide anteriorly, narrow ventrally and posteriorly; central muscle scars typical to the genus; depression evident in posteroventral margin extending to a delicate flange in RV. Evident sexual dimorphism. Females with a more arched dorsal margin and more developed lateral inflation; morphotypes with up to six nodes or without nodes. Males present six or seven nodes.

Remarks. *Cyprideis dictyon* sp. nov. is similar to *Cyprideis munoztorresi* (Gross *et al*., 2014: pl. 9; fig. 25–44; pl. 10; figs. 1–44, 46, 48–50, 52), but it is more strongly reticulated, and it does not bear the numerous denticles in the anterior margin as in *C. munoztorresi*; it also differs in the outline, that is more subrectangular, whereas *C. munoztorresi* is subrectangular to subtriangular. Besides, the last species presents a more incipient and non-bifurcated sulcus, characteristic of the new species. *C. dictyon* sp. nov. is distinct from all Neogene Amazon species already described to the genus, mainly in the male shape, which presents a truncated posterior margin, with a delicate flange; also differs by the presence of nodes. *C. dictyon* sp. nov. still differs from all the other species reported for the America in the absence of vestibule.

PALEOECOLOGICAL REMARKS

The ostracod assemblage is dominated by the euryhaline genus *Cyprideis*, which comprises approximately 95% of the total ostracod species and is represented here by 21 species (Figures 5–8), showing the high diversity developed by the genus during the Miocene in the Amazonia. Besides, five marine and brackish taxa (4%) as well as three freshwater taxa (1%) are still recorded, respectively: *Pellucistoma*, *Paracypris*, *Perissocytheridea*, *Rhadinocytherura*, *Skopaeocythere*, *Cypria*, *Cytheridella*, and *Penthesilenula* (Figures 6M–X). In general, the studied area is represented predominantly by a lacustrine system with indications of marine and/or

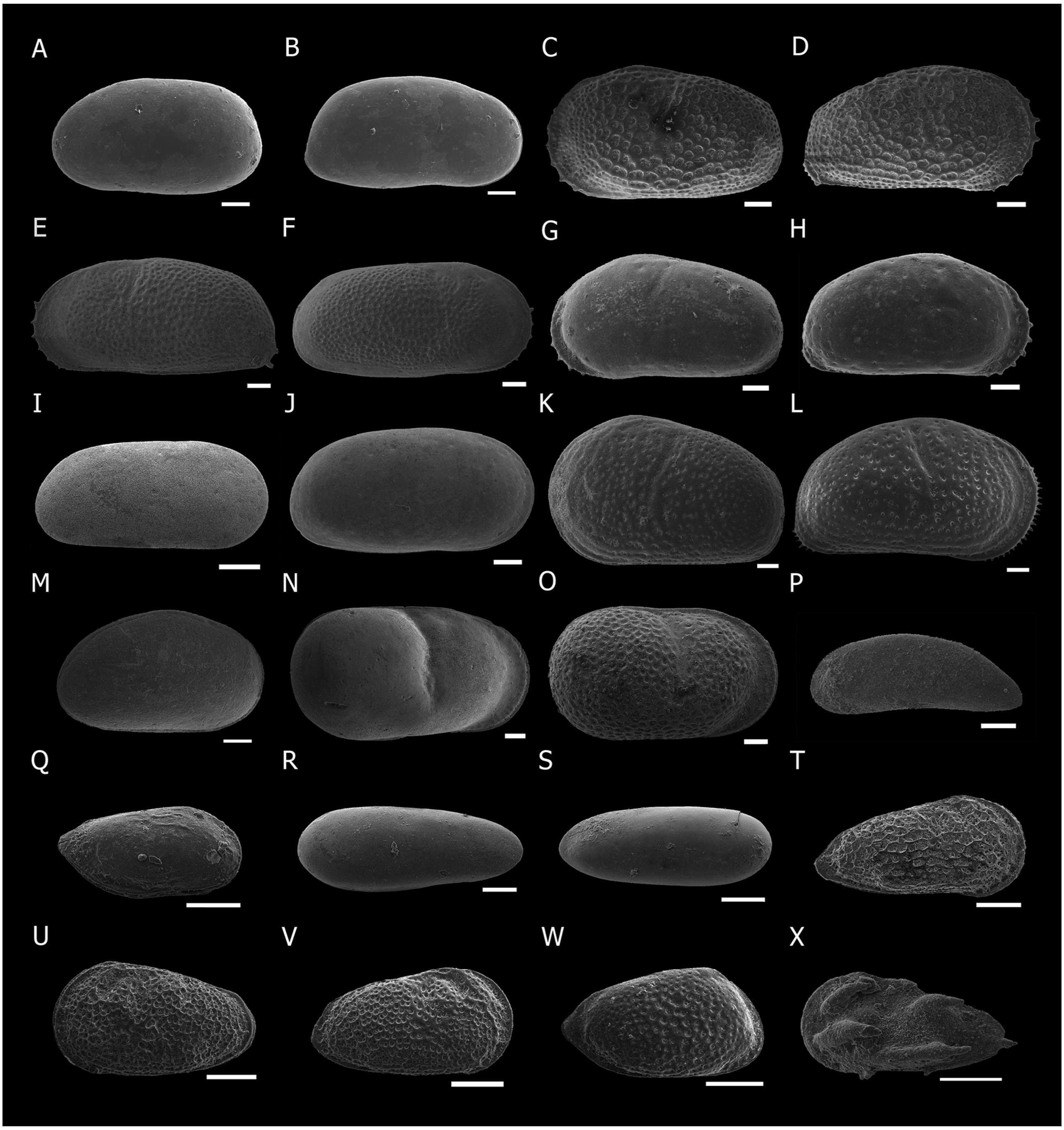

Figure 6. A–B, *Cyprideis olivencai*; **A**, LV, female (MPEG-953-M); **B**, RV, female (MPEG-954-M) (fragmented). **C–D**, *C. reticulopunctata*; **C**, LV, juvenile, female (MPEG-955-M); **D**, RV, juvenile, female (MPEG-956-M). **E–F**, *C. retrobispinosa*; **E**, LV, male (MPEG-957-M); **F**, RV, male (MPEG-958-M). **G–H**, *C. schedogymnos*; **G**, LV, female (MPEG-959-M); **H**, RV, female (MPEG-960-M). **I**, *C. paralela*; RV, male (MPEG-961-M). **J**, *C. simplex*; RV, female (MPEG-962-M). **K–L**, *C. sulcosigmoidalis*; **K**, LV, female (MPEG-963-M); **L**, RV, female (MPEG-964-M). **M**, *Cypria aqualica*; RV, female (MPEG-965-M). **N–O**, *Cytheridella danielopoli*; **N**, LV, male (MPEG-966-M); **O,** LV, female (MPEG-967-M). **P**, ?*Paracypris* sp.; LV, male (MPEG-968-M). **Q**, *Pellucistoma curupira*; RV, female (MPEG-969-M). **R–S**, *Penthesilenula olivencae*; **R**, LV, male (MPEG-970-M); **S**, RV, female (MPEG-971-M). **T**, *Perissocytheridea acuminata*; RV, male (MPEG-972-M). **U–V**, *Perissocytheridea ornellasae*; **U**, LV, female (MPEG-973-M); **V**, RV, female (MPEG-974-M). **W**, *Rhadinocytherura amazonensis*; RV, female (MPEG-975-M). **X**, *Skopaeocythere tetrakanthos*; LV, male (MPEG-976-M) (fragmented). Scale bars = 100 µm.

brackish water influx restricted to some intervals; freshwater conditions dominate towards the top of the studied sequence (see Linhares *et al*., 2011, 2017).

Among the species recognized here, *Cyprideis dictyon* sp. nov., *Cyprideis curucae*, and *Cyprideis sulcosigmoidalis* presented intraspecific morphological variability. In *C. curucae* three morphotypes were identified: without tubercles (Figure 5E); partially tuberculated (Figure 5F); and tuberculated (Figure 5G); some of this variation was also observed by Gross *et al.* (2014); this fact induced some

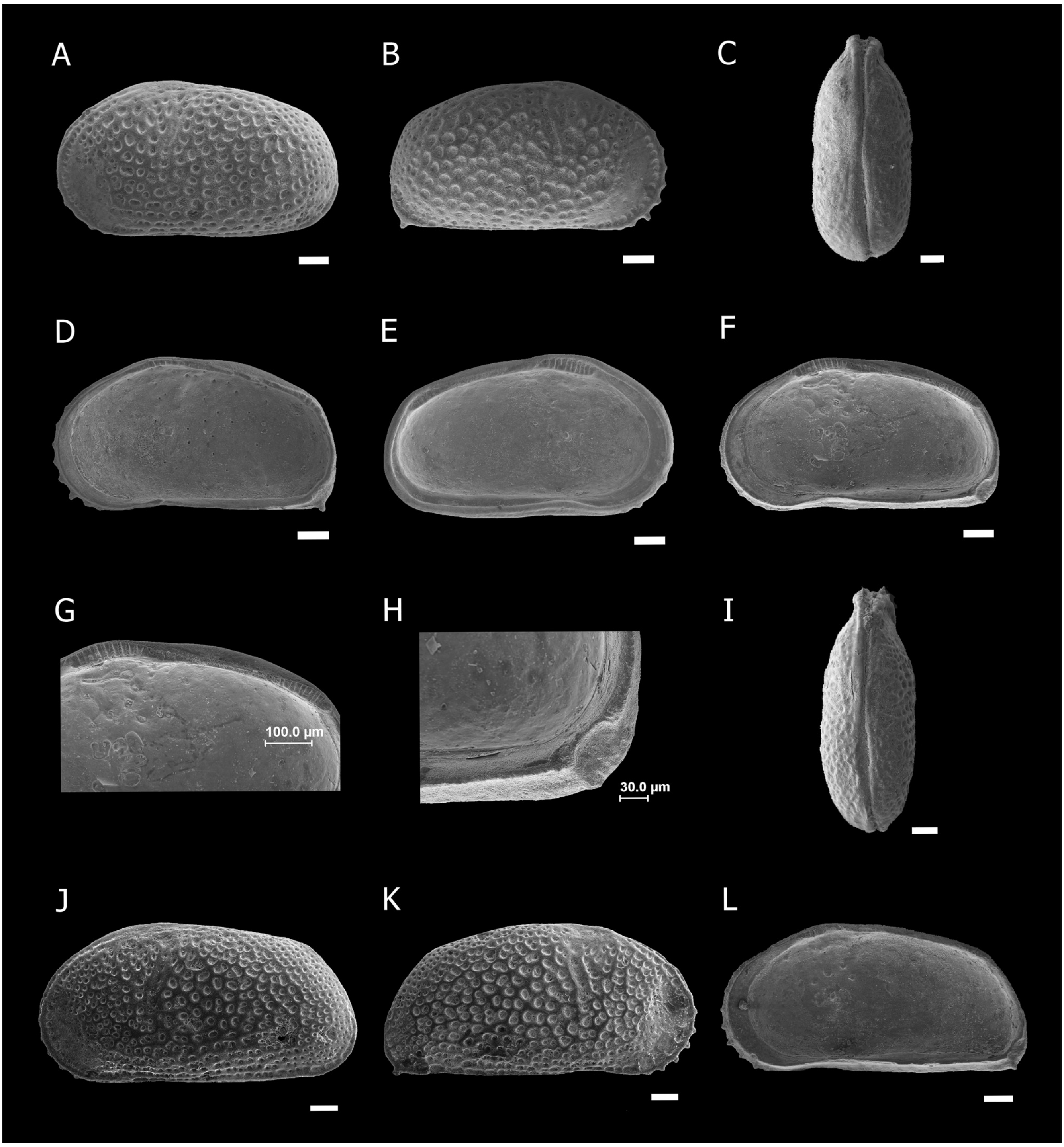

Figure 7. A–L, *Cyprideis atalaiensis* sp. nov.; **A–E**, Holotype, female carapace (MPEG-977-M); **A,** LV, external view; **B**, RV, external view; **C**, dorsal view; **D**, RV, internal view; **E**, LV, internal view. **F–H**, Paratype (MPEG-978-M); **F**, RV, female, internal view; **G**, RV, female; detail of the hinge; **H**, RV, female; detail of the flange. **I–L**, Paratype, male carapace (MPEG-979-M); **I**, dorsal view; **J**, LV, external view; **K**, VD, external view; **L**, RV, internal view. Scale bars = 100 µm.

authors to identify equivocally these different morphotypes as distinct species (Muñoz-Torres *et al.*, 1998; Whatley *et al.*, 1998; Linhares *et al.*, 2011).

Fürstenberg *et al*. (2015) commented that the greater the salinity, the greater the number of tubercles on the ostracods surface; and the more stable environmental conditions, the lesser degree of morphological variations. Thus, the occurrence of different morphotypes in the studied intervals is related to salinity oscillations as previously mentioned by Linhares *et al*. (2011) and shown in the Figure 9, indicating a gradual emergence of some morphological structures after environmental instability related to salinity variation (less to high and vice-versa). The Figure 9 shows the tuberculated and partially tuberculated morphotypes of *Cyprideis*

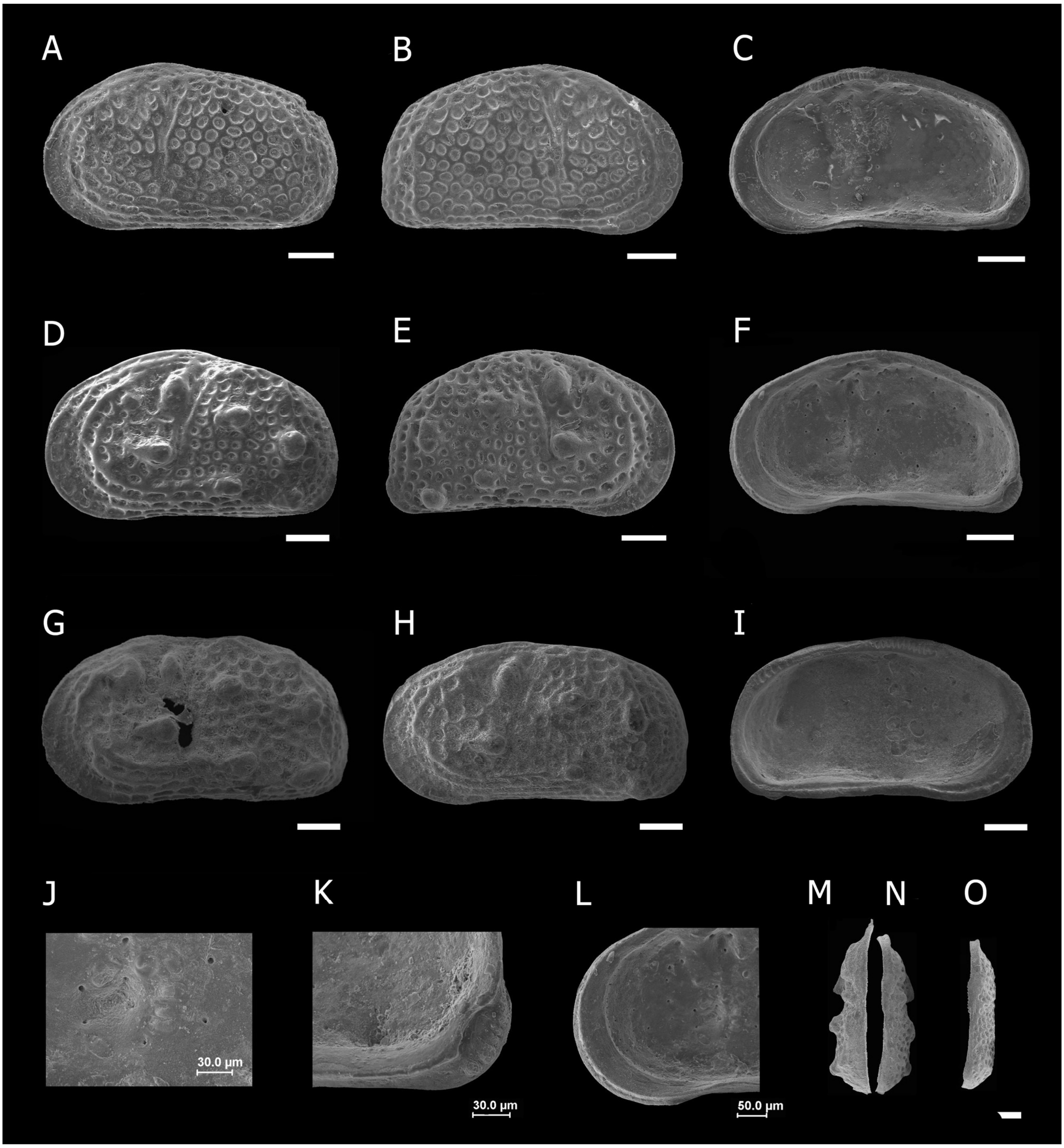

Figure 8. A–O, *Cyprideis dictyon* sp. nov.; **A,** Paratype (MPEG-980-M); LV, female; external view. **B–C**, Holotype female (MPEG-981-M); **B**, RV, external view; **C**, RV, internal view. **D**, Paratype (MPEG-982-M); LV, female, external view. **E–F**, Paratype, female (MPEG-983-M); **E**, RV, external view; **F**, RV, internal view. **G**, Paratype (MPEG-984-M); LV, male. **H–I**, Paratype, male (MPEG-985-M); **H**, LV, external view; **I**, LV, internal view. **J–L**, Paratype, female (MPEG-983-M); **J**, muscle scar; **K**, detail of the flange; **L**, detail of the anterior margin in internal view. **M**, Paratype (MPEG-982-M); LV, female, dorsal view. **N**, Paratype (MPEG-983-M); RV, female, dorsal view; **O**, Paratype (MPEG-981-M); RV, female, dorsal view. Scale bars = 100 µm.

curucae predominating during (Figure 9D) and after marine-influenced levels (Figure 9E); indicating a strong relationship with intervals where salinity variation occurs, supporting Furstenberg *et al*. (2015) arguments.

Morphological variation also occurs in *Cyprideis sulcosigmoidalis* a species originally described by Purper (1979) as an ornate species and very similar to a punctate to smooth species, *Cyprideis aulakos* Muñoz Torres *et al*. (1998), (p. 93, pl. 2, figs. 7–11), which were later considered the same species (Gross *et al*., 2014). Here, three morphotypes of *C. sulcosigmoidalis* were observed: weakly punctuated without denticles, strongly punctuated without denticles, and strongly punctuated with denticles in the posterior and anterior margins, in both valves; the latter morphotype is registered

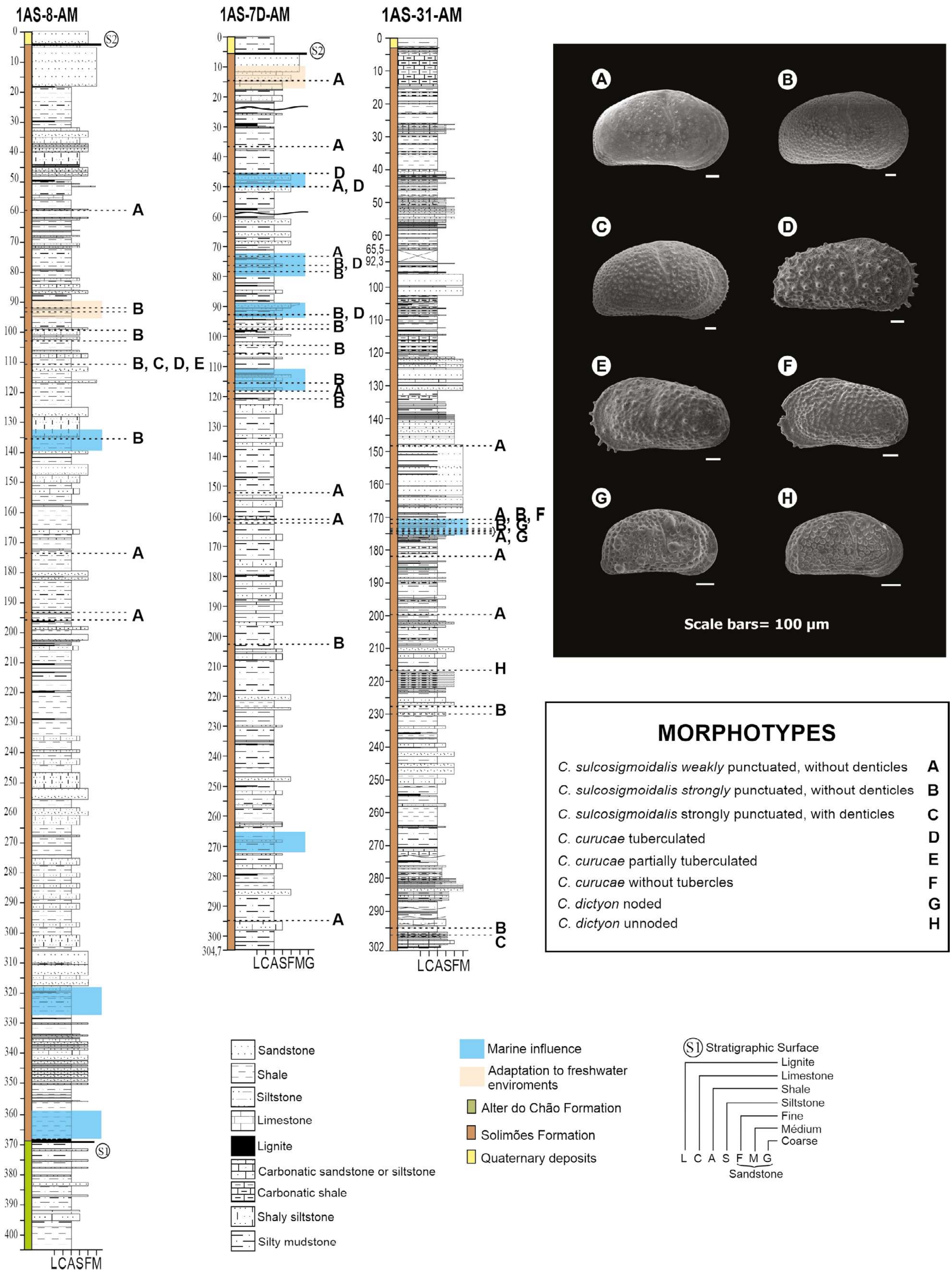

Figure 9. Distribution of the morphotypes of *Cyprideis curucae*, *Cyprideis sulcosigmoidalis*, and *Cyprideis dictyon* sp. nov. throughout the sedimentary sequence of the boreholes 1AS-7D-AM, 1AS-8-AM, and 1AS-31-AM.

for the first time in this paper. It was possible to observe the register of the first two morphotypes in all studied intervals (freshwater, lacustrine, and marine-influenced interval); whereas the strongly punctuated with denticles morphotype was observed only in the lacustrine intervals (Figure 9).

Studies in recent ostracods demonstrated that the punctuated character is associated with warm season and developed on fine sedimentation (Bodergat, 2008). Besides, the shells become either punctuated or smooth at higher salinities, while reticulated shells are more common at low salinities (Gliozzi & Mazzini, 1998). This pattern was not observed in the studied boreholes, although a considerable occurrence of strongly punctuated morphotypes was observed during and after the intervals here related to salinity variation.

Furthermore, species with nodes are recorded here for the first time in the Solimões Formation. The record of nodes in the new species *Cyprideis dictyon* occurs in the transition of lacustrine to marine influence intervals, indicating that the species developed nodes under higher salinity conditions (see also Linhares *et al*., 2011). Nodes has been widely recorded in ostracods, especially in *Cyprideis* (*e.g*., van Harten, 2000). Several studies, including other ostracod genera, have shown that noding occurs from a physiological response related to internal osmotic overpressure during ecdysis (Do Carmo *et al*., 1999; Keyser & Aladin; Keyser, 2005; Almeida-Lima *et al*., 2022). This mechanism results from fluctuations in the chemical composition of water caused by environmental changes (van Harten, 2000; Keyser, 2005). Some studies, suggest that nodes formation is most probably related to environmental stress triggered by variations in water salinity levels (Do Carmo *et al*., 1999; Keyser & Aladin, 2004; Zhai *et al*., 2010).

CONCLUSIONS

The study from the boreholes 1AS-7D-AM, 1AS-8-AM, and 1AS-31-AM allowed to record a relative abundance and diversity of Cyprideis, with 21 species recorded in the studied cores, besides the rare presence of other additional taxa (*Pellucistoma*, *?Paracypris*, *Perissocytheridea*, *Rhadinocytherura*, *Skopaeocythere*, *Cytheridella*, *Penthesilenula*, and *Cypria*). Most of the *Cyprideis* species were already recorded in the Neogene deposits in western Amazonia; however, two new species are described herein, contributing to increasing its specific diversity. Additionally, intraspecific morphological variation (ornamentation, tubercles, and marginal denticles) and the first occurrence of noded specimens were recorded. Presence of nodes and tubercles are related to salinity changes attributed to marine influence during the Miocene in Amazon; however, we did not observe a relationship between differences in the ornamentation of the carapace surface (punctuated and smooth morphotypes) and presence/absence of marginal denticles with these oscillations.

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