A new perspective into the discovery of diversity of sea cucumbers (Echinodermata: Holothuroidea)

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Short Report

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Abstract

The study of disarticulated ossicles of recent sea cucumbers from Campos Basin, Rio de Janeiro, Brazil, from various Holocene strata, obtained by micropaleontological methods, resulted in the identification of at least eight holothurian taxa, belonging to the four of the seven orders of Holothuroidea: Apodida (Synaptidae, Chiridotidae), Dendrochirotida (Psolidae and Cucumariidae), Holothuriida (*Holothuria*) and Molpadiida (Molpadiidae, Eupyrgidae). Our paper endorses the importance of studies of recent fauna based on isolated ossicles for taxonomy, biostratigraphy, and ecology. This study represents the first effort at the study of recent fauna of sea cucumbers based on the analysis of preserved ossicles in marine sediments.

Introduction

Of all echinoderm classes, the Holothuroidea (sea cucumbers, sea pigs) stand out by their worm-like body shape devoid of spines. Therefore, the holothuroid skeleton is composed of microscopic ossicles, composed mostly of $CaCo_3$ embedded in the body tissues and a small, ring-like plated structure, called calcareous ring, which protects and supports organs in the anterior region of the body (Hyman, 1955).

The reduced skeletonization provided numerous ecological opportunities to holothuroids and they often are the most abundant echinoderms in various marine ecosystems (Gilliland, 1993). Although some species live epifaunally, most species burrow in soft substrates, and they can be found from the littoral zone to the deep sea (Gallo et al., 2015).

Our knowledge of the holothuroid extant (~ 1700) and fossil (~ 1000) records is extremely poor (Reich, 2013; WoRMS, 2023). South American fossil record is composed of only ~ 10 holothuroid species, most from the Devonian and Cretaceous of Argentina and Chile (Bertels (1965); Haude (1995a, b); Haude (1997); Caramés et al. (2019)). In Brazil, there is only one species described to date—*Calcancora beurleni* Tinoco, 1963 from the Paleocene of northeast of Brazil, and the modern fauna of Holothuroidea is represented by ~ 50 species.

Traditionally, the taxonomy of living species of Holothuroidea is based on the analysis of the complete specimen (Martins and Souto 2020). However, the study of isolated diagnostic ossicles among marine sediments can reveal a great hidden diversity. In addition, it can provide relevant palaeoecological and paleoenvironmental information.

The present contribution represents the first effort to report holothurian ossicles recovered from marine deposits of the Holocene from Campos Basin, Rio de Janeiro, Brazil.

Material And Methods

Marine Sediment Core

The material studied comes from the investigation of a sediment piston core (GL-824) recovery of 2015 cm from the continental slope of the Campos Basin, Rio de Janeiro, Brazil (23°29'17,87" S;41°08'02,99" W), at 532 m depth (Fig. 1). The sediment core GL-824 was collected during an expedition with the Fugro Explorer Vessel.

A total of 10 samples were randomly selected and analyzed. The age of the sediments was previously established by Toledo et al. (2016) based on 14C analysis measured in *Globogerinoides ruber* (d'Orbigny, 1839), and it indicates that the core comprises the last 25.31 k.a.

Modern holothurian ossicles were obtained after sediment washing (sieve sizes: 0.063 mm and 150 mm) and include around 1420 isolated holothurian ossicles. The ossicles were examined by means of optical and electron microscopy, and posteriorly they were identified to the lowest possible taxonomic rank.

Results

Marine Sediment composition

The Core GL-854 was composed at the first 1,500 cm of olive-gray carbonate rich mud (18–30% $CaCO_3$), and from 1,550 to 2015 cm, the sediment is composed of dark gray carbonate-poor mud (5–18% $CaCO_3$) (Pedrão et al., 2022).

A total of about 1420 isolated ossicles were analyzed and identified into seven families and two genera. Almost all higher-level groups of holothuroids were found: Apodida (two families and three species); Holothuriida (one family and species); Molpadida (two families and two species) and Dendrochirotida (two families and two species). The orders Elasipodida, Synalactida, and Persiculida were not found. Synaptidae sp.1, Synaptidae sp.2 and *Eupyrgus* sp.1 represent at least a new record to the Southwestern Atlantic coast. Anchors, anchor plates, and tables (*Eupyrgus*) were the most abundant ossicles. Also, several non-diagnostic ossicles were found (*e.g.,* plates, rods, endplates, and four-pillared tables).

Taxonomy

Class Holothuroidea de Blainville, 1834

Order Apodida Brandt, 1835

Family Chiridotidae Östergren, 1898

Chiridotidae sp.

Family Synaptidae Burmeister, 1837

Synaptidae sp.1

Synaptidae sp.2

Order Dendrochirotida Grube, 1840

Family Psolidae Burmeister, 1837

Psolidae sp.

Family Cucumariidae Ludwig, 1894

Cucumariidae sp.

Order Holothuriida Miller, Kerr, Paulay, Reich, Wilson, Carvajal & Rouse, 2017

Family Holothuriidae Burmeister, 1837

Holothuriidae sp.

Order Molpadiida Haeckel, 1896

Family Eupyrgidae Semper, 1867

Eupyrgus sp.

Family Molpadiidae J. Müller, 1850

Molpadia sp.

Family Chiridotidae

Chiridotidae sp.

Figure 2a, b

Description. Wheels (60–100 μm; Figure 2a, b) stacked in warts, with six spokes, inner margin of rim with denticles, outer margin smooth.

Remarks. The family Chiridotidae is composed of two subfamilies: Chiridotinae Östergren, 1898 and Taeniogyrinae Smirnov, 1998. Both possess wheels in the body wall. However, the presence of sigmoid hooks and radial plates of the calcareous ring without perforation differs Taeniogyrinae from Chiridotinae. Therefore, the described wheel ossicle belongs to Chiridotidae.

Family Synaptidae

Remarks. To date, seven Synaptidae occurs at the South Atlantic, *Epitomapta roseola* (Verrill, 1874), *Euapta lappa* (Müller, 1850), *Protankyra benedeni* (Ludwig, 1881), *Protankyra ramiurna* Heding, 1928, *Synaptula hydriformis* (Lesueur, 1824), *Synaptula secreta* Ancona-Lopez, 1957 and *Yemoja brasiliensis* (Freire and Grohmann,1989).

Synaptidae sp.1

Figure 2c, d

Description. Body wall anchors with smooth arms, vertex and stock (100–150 μm; Figure 2c). Anchor plates oval (130–200 μm long, 110–150 μm wide; Figure 2d), margins smooth and undulating, anterior region broad with seven denticulated holes, bridge denticulate and well developed, posterior region narrow, with two large and three small marginal holes.

Synaptidae sp.2

Figure 2e, f

Body wall anchors with serrate arms. Stock and vertex smooth (200–300 μm; Figure 2e, f).

Remarks.

The species Synaptidae sp. 1 differs from the species of the *Protankyra* by the morphology of anchors plates (multiperforated in *Protankyra vs.*seven-holed), differs from *Y. brasiliesis* and *E. lappa* by the anchor morphology (stock branched in *Y. brasiliesis* and *E. lappa vs.* unbranched), differs from *E. roseola* by the anchor morphology (arms and stock toothed *vs.* untoothed). Finally, it differs from *S. hydriformis* by the anchor stock and vertex toothed *vs.* untoothed and differs from *S. secreta* by the anchor plate morphology (smooth holes in *S. secreta vs* denticulated holes). Due to the absence of characters from internal morphology, it is not possible to designate the genus or species. However, it is a new occurrence of Synaptidae to the Brazilian coast.

The species Synaptidae sp. 2 differs from *Protankyra benedeni* and *Protankyra ramiurna* by having stock with inconspicuous knobs (*vs.* stock with conspicuous knobs in *P. benedeni* and stock smooth *P. ramiurna*). In addition, it differs by the number of teeth per arm (7–10 in *P. benedeni* andup to 6 in Synaptidae sp. 2) and (arm smooth *P. ramiurna* vs. arms toothed in Synaptidae sp. 2).

It differs from *Y. brasiliesis* and *E. lappa* by the anchor morphology unbranched (*vs.* stock branched in *Y. brasiliesis* and *E. lappa*). Synaptidae sp. 2 differs from *E. roseola* by the anchor morphology (stock with minute teeth *vs.* stock with conspicuous teeth). It differs from *S. hydriformis* by the presence of knobs at the vertex, absent in Synaptidae sp 2 and it differs from by the absence of teeth at the arms, present in Synaptidae sp 2. Finally, it differs from *S. secreta* by the anchor morphology (smooth arms and stock in *S. secreta vs* toothed arms and stock).

Due to the absence of characters from internal morphology, it is not possible to designate the genus or species. However, Synaptidae sp1 and Synaptidae sp 2 represent at least two new occurrences of Synaptidae to the Brazilian coast.

Order Dendrochirotida

Family Psolidae

Psolidae sp.

Figure 2g

Description. Knobbed, perforated plate, irregular in outline, undulating margins (140–200 μm long; Fig. 2g) and rounded holes up to 20 μm in diameter.

Remarks. Knobbed perforated plates are found typically ate the sole of Psolidae, except *Ceto* Gistel, 1848.

Family Cucumariidae

Cucumariidae sp

Figure 2h

Description. Flat perforated rod; without expanded ends. Margins smooth and undulate (800–1000 μm long; Fig. 2h)

Remarks. Flattened rods are uncommon among Holothuroidea. However, this specific type of rod is present among several Cucumariidae species Gilliland (1993)

Order Holothuriida

Family Holothuriidae

Holothuriidae sp

Figure 2i

Description. Regular smooth button, margin undulate. Three pair of holes (250–300 μm long; Fig. 2i).

Remarks. The button described belongs to the clade *Holothuria* + *Labidodemas* (Holothuriidae: Holothuriida) (Samyn et al., 2005; Miller et al., 2017) due to the typical “holothuriid cross”. Although these buttons are like the Dendrochirotida buttons, they vary in shape (oval to elongated) with smooth outline (Gilliland, 1993)

Order Molpadiida

Eupyrgidae

Eupyrgus sp.

Figure 2j,k

Description. Body wall tables with a high and spiny spire placed near the edge of the disc and three pillars connected by crossbeams ending in a tooth. The first type (80–100 μm; Figure 2j) is smaller and the holes are bigger; the second type (200–400 μm; Figure 2k) is bigger and the holes are smaller.

Remarks. The presence of three-pillared tables with multiperforated and irregular disc indicates that the species belong to the monogeneric family Eupyrgidae, genus *Eupyrgus* (Gilliland, 1993; Smirnov, 2012).

Family Molpadiidae

Molpadia sp.

Figure 2l

Description. Tables from body wall triradiate, disc with three large holes. Spire of three fused pillars (80–100 μm; Figure 2l).

Remarks. The presence of three pillared tables with large oval holes is a diagnostic character that indicates that the species belong to the family Molpadidae (Gilliland, 1993; Smirnov, 2012).

Other Holothuroid ossicles:

Figure 3 a-h

Endplate

Figure 3a

Description. Endplate circular with large holes around margin, smaller ones medially.

Remarks. Tube feet endplates occur in the Actinopoda clade (Miller et al. 2017), except Molpadida that lack tube feet, showing a marked homoplasy. The genus *Laetmogon*e (Elasipodida) possesses a stellate endplate. In the other Actinopodans, however, the end plates have a similar morphology.

Four-pillared Table

Figure 3b-d

Description. Four pillared tables with multiperforated and circular disk one large central hole; margin undulate; spire fused ending in a crown of spines (80–200 μm; Fig.3 b,c); Four pillared tables with multiperforated and circular disk four central holes; margin undulate (120–150 μm; Fig.3d);

Remarks. Although three pillared tables are an excellent character diagnostic, four-pillared tables are widespread among Holothuroidea, occurring in the Actinopoda clade (Miller et al. 2017), except in Elasipodida, and like endplates, it shows a remarkable homoplasy.

Rods

Figure 3e

Virtually every order of Holothuroidea has rods. Except in Dendrochirotida which has a flattened rod, the remaining orders show fusiform rods with a high degree of morphological variation. Like the four-pillared table, rods also show a marked homoplasy.

Plate

Figure 3 f-h

Description. Circular plates; multiperforated. Holes of same size; undulate margins (200–400 µm long, Fig3 f-h)

Remarks. Perforated plates are found in all families of Dendrochirotida and in the orders Elasipodia and in a few Holothuriida. These plates are usually flat, and they can be thin (most common), thickened and they can have trabecula or eventually more than one layer. Gilliland (1993).

Discussion

The ossicles described herein consist of numerous anchors, anchor plates, wheels, buttons, endplates, plates, tables, and rods. These ossicles were identified into almost all orders of Holothuroidea.

The previous record of holothuroids from Campos Basin (entire individuals) pointed out to the occurrence of 16 species (Moura, 2016). However, eight of the occurrences were found between 938-2057m, beyond our scope (up to 500m). In the other hand, the species *Holothuria (Cystipus) pseudofossor* Deichmann (1930), *Holothuria (Vaneyothuria) lentiginosa brasiliensis* Tommasi & de Oliveira, 1976 *Molpadia parva* (Théel, 1886), *Psolus thandari* Martins & Tavares (2019) and *Psolidium nanoplax* Martins & Tavares (2020), that occurs under 500m were not found (table 1). The present paper shows the occurrence at least of eight species. Surprisingly, the calcareous ring, a robust structure was not found in the analyzed samples as well as noted by Gilliland (1992) regarding to the fossil records.

[Please insert Table 1 here.]

Isolated Holothurian Ossicles As A Taxonomic And Paleoenvironmental Indicator

Traditionally, the taxonomy of recent Holothuroidea is performed beyond a morphological and-or molecular analysis of full specimens. However, samples of disarticulate ossicles can be used for species identifications. Of course, often it is only possible to recognize the occurrence of large taxonomic groups, without the possibility of specifying the taxa. Even so, there is a significant of taxonomic information to be extracted.

From a paleoenvironmental perspective, sea cucumbers are very useful because there is a diverse and widely distributed extant fauna upon which to infer distributions in the past. Also, the information about its depth, ecological and habitat preference provides a powerful local information.

Declarations

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Author contributions

Conceptualization (LM); Methodology (LM, FT); Formal analysis (LM, FT); Investigation (LM); Writing original draft (LM); Writing, review and editing (LM, KC, FT); Resources (LM, KC, FT); Funding acquisition (LM, KC, FT).

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Declaration of conflicting interests

The authors report no competing interests as defined by The Holocene, or other interests that might be perceived to influence the interpretation of the article. The authors have no non-financial competing interests, or other interests that might be perceived to influence the interpretation of the article.

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Tables

Table 1 is available in the Supplementary Files section.

Figures

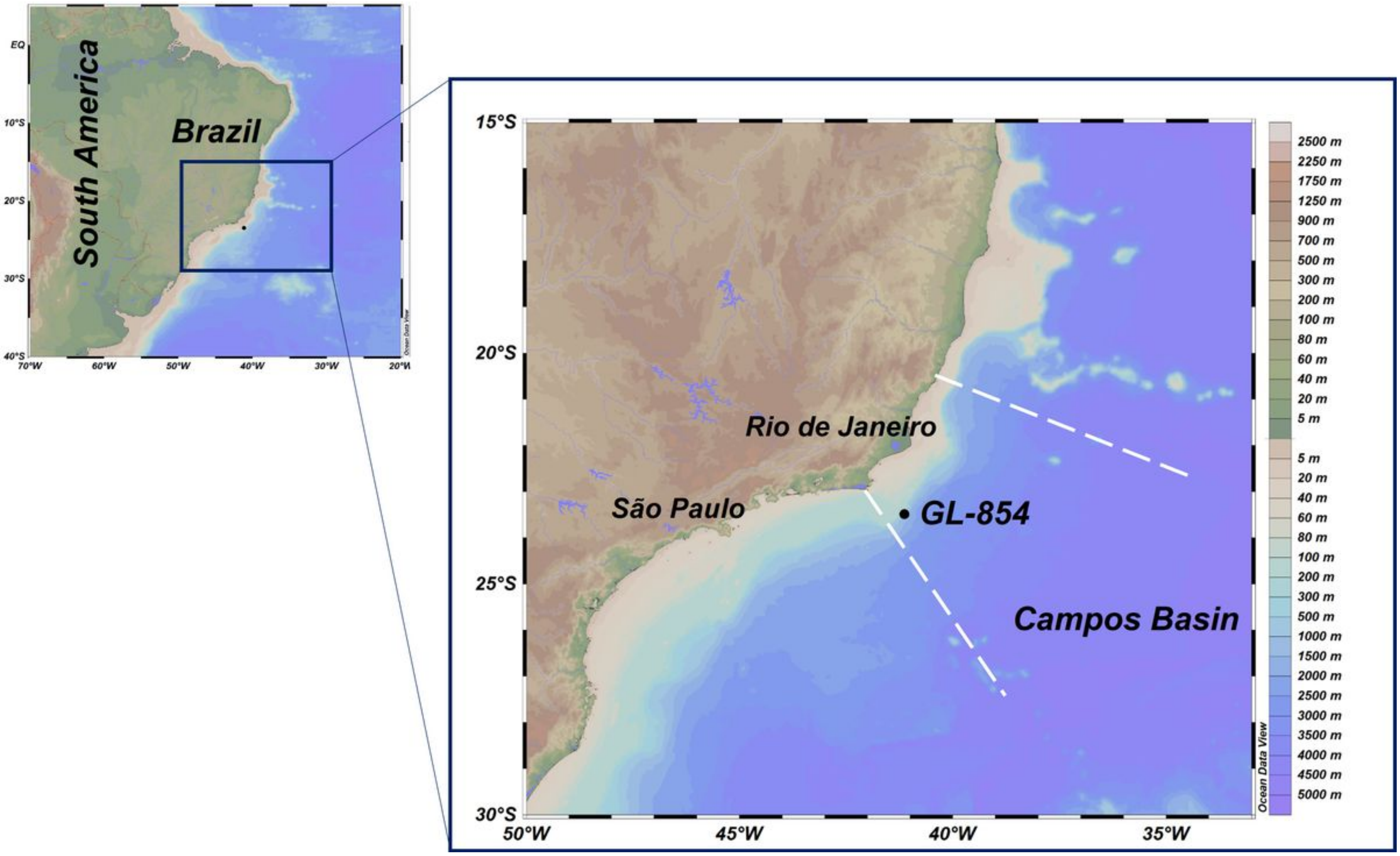

Figure 1

GL-854 Core location. Dashed lines delimit the Campos Basin.

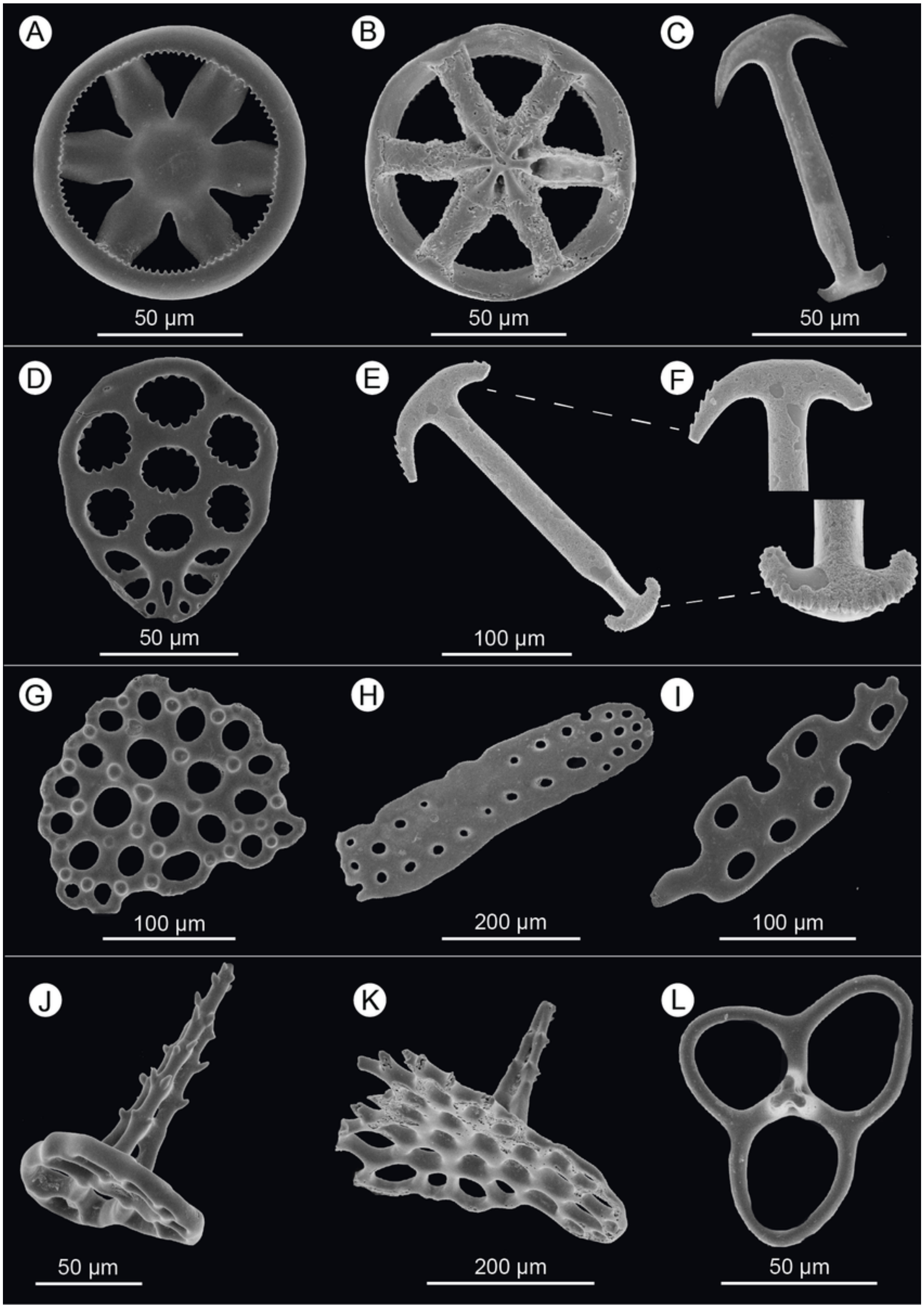

Figure 2

Holothuroidea ossicles recovered from core GL 854. (a-b) Wheels from Chiridotidae; (c-d) anchor and anchor plate from Symaptidae sp.1; (e) anchor and (e) detail of anchor arms (above) and stock (below) from Symaptidae sp.2; (g) knobbed plate from Psolidae; (h) flattened rod from Cucumariidae; (i) Hoolothuriidae button; (j-k) three pillared table from *Eupyrgus* sp. and (l) three pillared table from *Molpadia* sp.

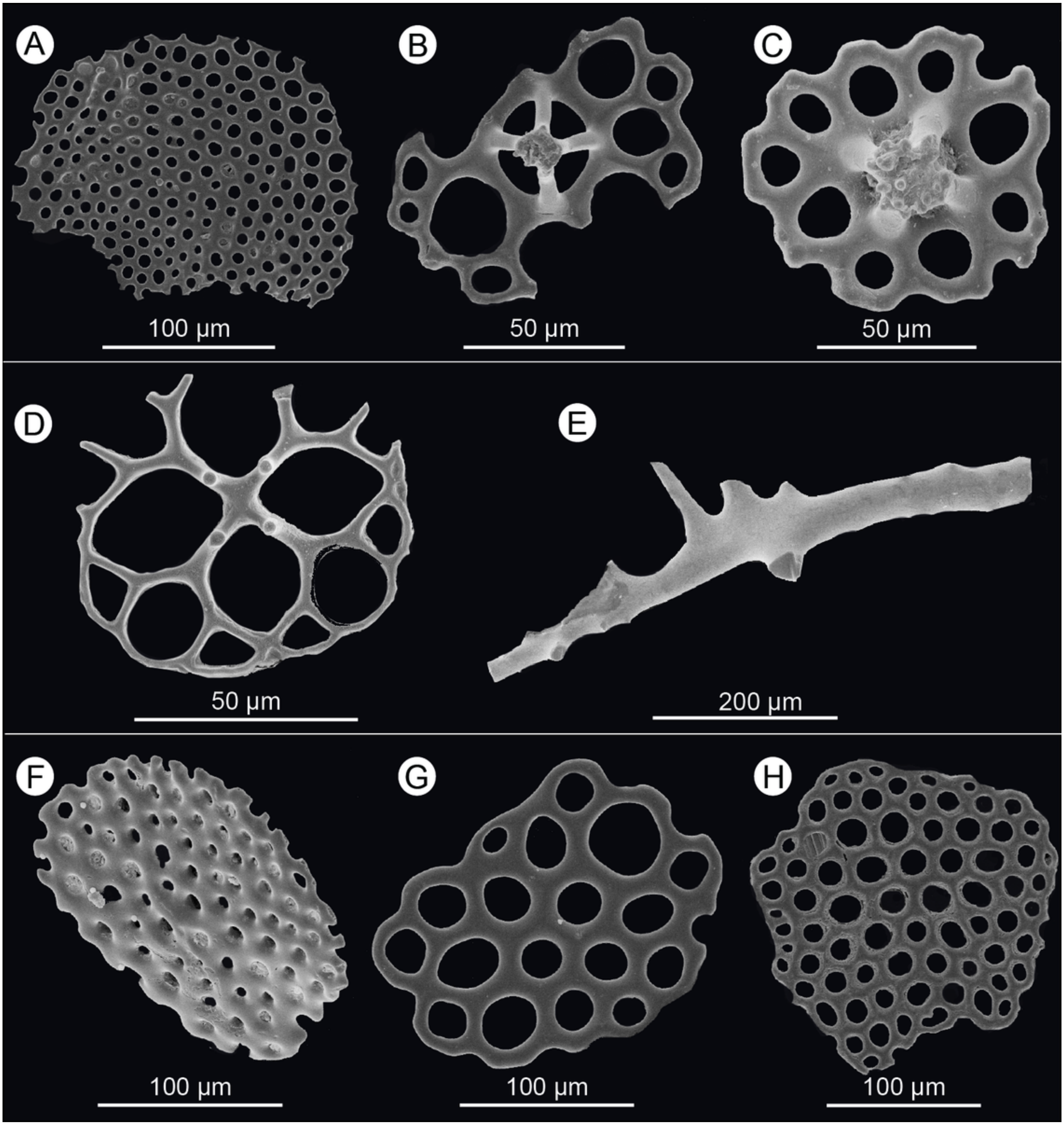

Figure 3

Other Holothuroidea ossicles recovered from core GL 854. (a) end-plate; (b-d) four pillared table; (e) rod; (f-h) plates.

Supplementary Files

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- Table1..xlsx