

The paracaudinid sea cucumbers of Australia and New Zealand (Echinodermata: Holothuroidea: Molpadida: Caudinidae)

P MARK O'LOUGHLIN¹, SHARI BARMOS² AND DIDIER VANDENSPIEGEL³

¹ Marine Biology Section, Museum Victoria, GPO Box 666, Melbourne, Victoria 3001, Australia (pmo@bigpond.net.au)

² (shari_barmos@hotmail.com)

³ Musée royal de l'Afrique centrale, Section invertébrés non-insectes, B-3080, Tervuren, Belgium (dvdspiegel@africamuseum.be)

Abstract

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The four *Paracaudina* Hedding species reported in Australia are reviewed: *Paracaudina australis* (Semper); *Paracaudina chilensis* (Müller); *Paracaudina luticola* Hickman; *Paracaudina tetrapora* (H. L. Clark). The New Zealand species *Paracaudina coriacea* (Hutton) is raised out of synonymy with the Chilean species *Paracaudina chilensis* (Müller). Both *Paracaudina chilensis* (Müller) and *Paracaudina coriacea* (Hutton) occur in New Zealand. The synonymy of the Chinese and Japanese species *Paracaudina ransonnetii* (Marenzeller) with *Paracaudina chilensis* (Müller) is maintained. Five new Caudinidae species are erected for Australia, with authors O'Loughlin and Barmos: *Paracaudina ambigua*, *Paracaudina bacillis*, *Paracaudina cuprea*, *Paracaudina keablei*, *Paracaudina tripodata*. A key is provided for *Paracaudina* species in Australia and New Zealand.

Keywords

Sea cucumber, Molpadida, Caudinidae, *Paracaudina*, new species, synonymies, Australia, New Zealand, key.

Introduction

Museum Victoria holds numerous specimens of Caudinidae sea cucumbers, most specimens collected from Victorian beaches after storms. Rowe 1982 recorded a “*Paracaudina* sp.” from Port Phillip Bay in Victoria and southern Western Australia. This species is represented by numerous specimens from southern Australian waters, and we erect a new species. We have examined collections of *Paracaudina* Hedding, 1932 from the Australian, South Australian, Western Australian and New Zealand Museums, and we review all of the species of this genus in Australian and New Zealand waters. As an outcome of this review we erect five new species of *Paracaudina*. Our systematic study is based on traditional morphological characters as there are to date no adequate molecular genetic data.

Four potential Australian and New Zealand species of *Paracaudina* have been intensively studied: *Paracaudina australis* (Semper, 1868) with type locality Australia; *Paracaudina chilensis* (Müller, 1850) with type locality Chile; *Paracaudina coriacea* (Hutton, 1872) with type locality New Zealand; *Paracaudina ransonnetii* (Marenzeller, 1881) with type locality China. Their morphology and systematic status have been researched and debated by numerous authors: Théel 1886; H. L. Clark 1908, 1935; Mortensen 1925; Hozawa 1928; Ohshima 1929; Hedding 1931, 1933; Pawson 1963; Pawson and

Liao 1992. Most recently Pawson 1963 has summarised what has been debated, and agreed with the authors who considered *P. coriacea* (Hutton) to be a junior synonym of *P. chilensis* (Müller). We reject this synonymy, judging that *Paracaudina coriacea* (Hutton) is a good species. But at the same time we have found that *Paracaudina chilensis* (Müller) also occurs in New Zealand waters, and one or possibly more undescribed *Paracaudina* species. A comprehensive review of the many *Paracaudina* specimens held in New Zealand will follow this work. In reporting on the molpadid sea cucumbers of China, Pawson and Liao 1992 agreed with the synonymy of the China and Japan species *P. ransonnetii* (Marenzeller) with *P. chilensis* (Müller). We agree with this synonymy. However, we note that some of these species distributions are such that molecular genetic data may reveal that some of these species are paraphyletic.

Our experience of looking at a range of material leads us to agree with H. L. Clark 1935 that there is considerable variation in morphological form amongst *Paracaudina* specimens that are conspecific, including ossicle form. And we agree also that, although there is considerable variation in ossicle form in the same and conspecific specimens, predominant ossicle form does provide a reliable guide to species identity.

Methods

For scanning electron microscope (SEM) observations by Didier VandenSpiegel ossicles were cleared of associated soft tissue in commercial bleach, air-dried, mounted on aluminium stubs, and coated with gold. Observations were made using a JEOL JSM-6480LV SEM. Measurements were made with Smile view software. Photos of preserved specimens by Shari Barmos were taken with a Nikon D70 DSLR camera, using a Nikon micro 60 mm lens.

Abbreviations

AM Australian Museum (with registration prefix J).
 MRG Marine Research Group of the Field Naturalists Club of Victoria.
 NMV Museum Victoria (with registration prefix F).
 NIWA New Zealand Institute of Water and Atmospheric Research.
 SAM South Australian Museum (with registration prefix K).
 WAM Western Australian Museum (with registration prefix Z).

Numbers in brackets after registrations refer to the number of specimens in a registered lot.

Spelling correction

Some authors have misspelled the species name *ransonnetii*, and the correct spelling only is used throughout our work.

Key to the Australian and New Zealand species of *Paracaudina* Heding

1. Ossicles in body wall small irregular rods only
Paracaudina bacillis O'Loughlin and Barmos sp. nov. (southern Australia)
 — Ossicles in body wall include small buttons or perforated plates or thick cups **2**
2. Ossicles in mid-body predominantly small rods and loops, and in caudal end predominantly spinous perforated plates *Paracaudina ambigua* O'Loughlin and Barmos sp. nov. (central Western Australia)
 — Ossicles similar in mid-body and caudally **3**
3. Ossicles in body wall predominantly octagonal plates with central perforation over which there is a bridging box on the basal side and cross on the outer side **4**
 — Ossicles in body wall rarely octagonal plates with box and cross bridges, or such ossicles completely absent **6**
4. Octagonal plates predominantly with marginal bluntly pointed projections and knobs; perforations not significantly smaller in collective area than the surface area of the plate; body with long thin tail *Paracaudina chilensis* (Müller, 1850) (circum-Pacific, north-western Australia)
 — Octagonal plates predominantly with rounded margin, margin lacking bluntly pointed projections and knobs ... **5**
5. Ossicles predominantly thick and button-like, perforations significantly smaller in collective area than the plate surface area; body with long thin tail *Paracaudina coriacea* (Hutton, 1872) (New Zealand)
 — Ossicles predominantly thin-walled and open mesh-like, perforations not significantly smaller in collective area than the plate surface area; body with short thin tail
Paracaudina keablei O'Loughlin and Barmos sp. nov. (north-eastern Australia) **7**
6. Ossicles in body wall predominantly thick-walled with 4 perforations **7**
 — Ossicles in body wall include irregular plates and buttons with irregular perforations, with marginal and surface knobs and pointed projections variably present; plates with up to 12 perforations **8**
7. Ossicles in body wall predominantly thick, shallow concave crossed cups *Paracaudina luticola* Hickman, 1962 (southern Australia)
 — Ossicles in body wall predominantly thick, knobbed and irregularly oval flat plates *Paracaudina tetrapora* (H. L. Clark, 1914) (southern Australia)
8. Ossicles in body wall predominantly buttons with smooth rounded lateral margin, short thick blunt surface spines, frequently with central perforation bridged by a tripod of rods ... *Paracaudina tripoda* O'Loughlin and Barmos, sp. nov. (north-eastern Australia)
 — Ossicles in body wall plates, most with lateral and surface rounded marginal spines and knobs **9**
9. Deeper mid-body wall with irregular rods, less than 50 μm long; colour never yellowish-red (rusty)
Paracaudina australis (Semper, 1868) (north-eastern Australia)
 — Deeper mid-body wall lacking irregular rods; larger specimens increasingly yellowish-red (rusty) in colour
Paracaudina cuprea O'Loughlin and Barmos sp. nov. (southern Australia)

Remarks. The remaining subspecies and species of *Paracaudina* Heding, 1932 that are not included in this key are: *Paracaudina chilensis obesacauda* (H. L. Clark, 1908), a central American east Pacific and west Atlantic subspecies, retained with subspecific status solely on geographical grounds by Pawson et al. 2001; *Paracaudina delicata* Pawson and Liao, 1992, from the Gulf of Tonkin, has thin-walled *chilensis*-like ossicles, with box and cross bridging a central perforation, and fine digitiform projections around the ossicle margin.

Order *Molpadida* Haeckel, 1896

Diagnosis (emended from Pawson and Liao 1992). Tentacles 15, digitate; body stout, lacking tube feet, usually with an evident tail; anal papillae, tentacle ampullae and respiratory trees present; ossicles may include tables, cups, rods, perforated plates and modified anchors; phosphatic bodies often present.

Remarks. Rods may be present with perforated plates, as in *Paracaudina australis* (Semper, 1868), and rods are not necessarily fusiform (spindle-shaped). We have emended the diagnosis of Pawson and Liao 1992 in these two respects.

Family **Caudinidae** Heding, 1931

Diagnosis (emended from Pawson and Liao 1992). Tentacles without a terminal digit, and with one or two pairs of lateral digits; tail sometimes inconspicuous; ossicles may include large tables, crossed cups, perforated plates and irregular rods; phosphatic bodies usually absent.

Remarks. We have emended the statement concerning which ossicles may be present, but we have not changed the ossicle types listed.

Paracaudina Heding, 1932

Figures 1f, 5c–e, 7, 8, 12a, b

Pseudocaudina Heding, 1931: 283.

Paracaudina Heding, 1932: 455–456.

Type species. *Molpadia chilensis* Müller, 1850 (subsequent designation by H. L. Clark 1935).

Other included species. *Paracaudina ambigua* O’Loughlin and Barmos sp. nov.; *P. australis* (Semper, 1868); *P. bacillis* O’Loughlin and Barmos sp. nov.; *P. coriacea* (Hutton, 1872); *P. cuprea* O’Loughlin and Barmos sp. nov.; *P. delicata* Pawson and Liao, 1992; *P. keablei* O’Loughlin and Barmos sp. nov.; *P. laticola* Hickman, 1962; *P. chilensis obesacauda* (H. L. Clark, 1908); *P. tetrapora* (H. L. Clark, 1914); *P. tripod* O’Loughlin and Barmos sp. nov.

Diagnosis. Cylindrical form, smooth or wrinkled body wall; tentacles 15, each with 2 pairs of digits (figs 1f, 5c); posterior end of body with caudal taper or discrete thin tail; tail may be short or long; 5 radial triangular non-calcareous anal valves, each with up to 4–5 pairs of marginal digitiform papillae, terminal ones longest (fig. 5d); radial plates of calcareous ring with two anterior lateral low blunt projections, one with small notch, posterior digitiform prolongation about half the length of the plate, prolongation divided by terminal notch of variable depth or deeper division (fig. 12a); interradial plates with anterior central blunt point, posterior end truncated (fig. 12a); dorsal short to long tubular stone canal with terminal madreporite, free in coelom or attached to pyloric mesentery (specimen NMV F174894); single ventral, elongate, tubular to globular polian vesicle, usually with dark reddish-brown colouration; longitudinal muscles broad, flat, with distinct longitudinal division (fig. 5e); retractor muscles formed by pair of in-turned outer margins of divided longitudinal muscles (fig. 5e); gonad tubules usually branched, in tufts on each side of dorsal mesentery (fig. 5e); right branch of respiratory tree extending in the coelom to the calcareous ring; ossicles may be concave or flat, thick crossed and knobbed cups, thick knobbed perforated plates, octagonal plates with large central perforation and cross or tripod bridging one side and sometimes square the other side (figs 7, 8, 12b), perforated smooth and knobbed and spinous plates with variably developed secondary layering, and

irregular rods; ossicles never tables; phosphatising of ossicles and calcareous ring may occur, and a red to brown to yellow pigment may occur in the body wall.

Remarks. A comprehensive diagnosis of genus *Paracaudina* Heding, 1932 is provided to avoid diagnoses of species with repetition of characters that all have in common. We recognise that some of the characters listed in this diagnosis of *Paracaudina* are shared with other genera and at family and possibly order level.

Paracaudina ambigua O’Loughlin and Barmos sp. nov.

Figure 1a, 2

Material examined. Holotype. Western Australia, Shark Bay, FWA–WAM RV *Naturaliste* Shark Bay Survey II Feb / Mar 2003, stn 13/173/P, 24°47.02’S 113°21.97’E to 24°46.48’S 113°22.08’E, 24 m, 6 Mar 2003, S. Morrison and S. M. Slack-Smith, WAM Z29767.

Paratype. Western Australia, Ningaloo Marine Park, AIMS RV *Solander*, stn RVS 4545–D069, 23°48’S 113°30’E, 33 m, 1 Feb 2008, M. Salotti and S. M. Slack-Smith, WAM Z23331 (1).

Diagnosis. *Paracaudina* species up to 45 mm long (holotype, caudal taper but anal end and valves missing), body up to 15 mm high (body flattened laterally); body wall thick, soft to semi-gelatinous, white (preserved); posterior body with caudal taper to short discrete tail (evident in paratype); ossicles different mid-body and caudally; mid-body ossicles predominantly small irregular rods, frequently forming a single loop, or small plates with up to 4 perforations, these ossicles up to 40 μ m long; rare mid-body irregularly oval perforated plates with spinous margin and some secondary bridging, about 64 μ m long; caudal ossicles irregularly oval to round to octagonal perforated plates, long pointed spinous margin, surface spines and bridges and secondary development, some plates *chilensis*-like with box and cross bridges over central perforation, caudal ossicles typically 56–64 μ m long.

Type locality. Central Western Australia, Shark Bay.

Distribution. Central Western Australia, Shark Bay, Ningaloo Marine Park; 24–33 m.

Etymology. From the Latin *ambiguus* (of double meaning, uncertain), feminine *ambigua*, referring to the generic uncertainty created by the presence of *Acaudina*-like ossicles mid-body and *Paracaudina*-like ossicles posteriorly.

Remarks. *Paracaudina ambigua* O’Loughlin and Barmos sp. nov. is distinguished diagnostically amongst *Paracaudina* species by having fine irregular rod and loop ossicles in the mid-body wall and marginally spinous *chilensis*-like plate ossicles in the caudal region, some with the characteristic cross and box bridges over a central perforation. Both specimens are in poor condition, but the ossicles are in excellent condition and characterise the new species. Distal pairs of digits are evident on a few tentacles of the holotype, but the condition of the tentacles is such that a second pair is not clearly evident on any tentacle. The caudal part is missing from the holotype, but a distinct narrow tail and soft anal valves are present on the paratype (18 mm long).

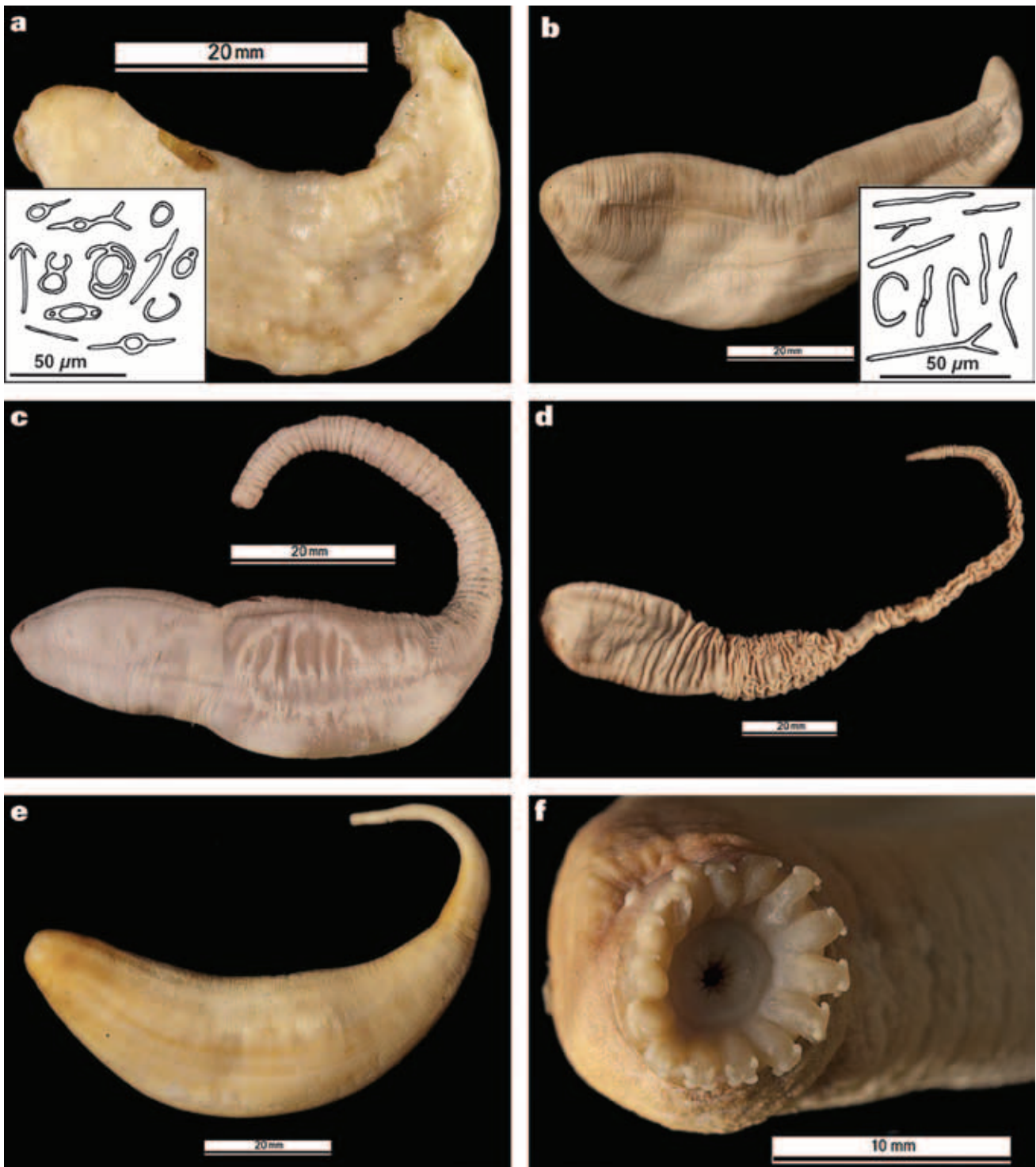


Figure 1. Photos of preserved specimens of species of *Paracaudina* Heding, 1932: a, holotype of *P. ambigua* O'Loughlin and Barmos sp. nov. (insert with drawings of rod and loop ossicles from the mid-body wall; WAM Z29767); b, *P. australis* (Semper, 1868) (insert with drawings of rod ossicles from the mid-body wall; AM J13583); c, *P. chilensis* (Müller, 1850) (WAM Z5638); d, *P. coriacea* (Hutton, 1872) (NIWA 70955); e, *P. coriacea* (Hutton, 1872) (AM J12290); f, mouth and tentacles of *P. coriacea* (Hutton, 1872) (NIWA 70954).

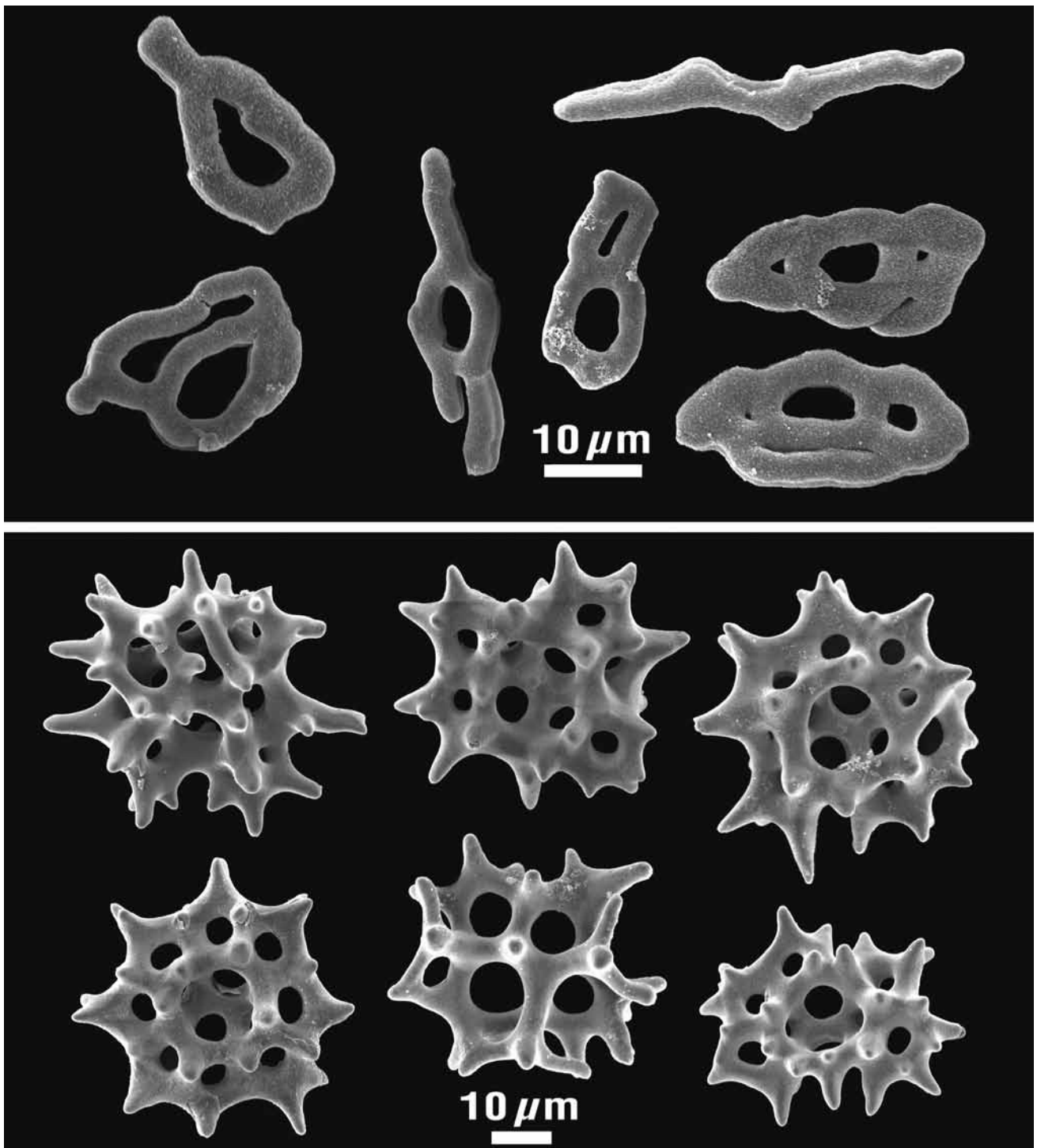


Figure 2. SEM images of ossicles from the holotype of *Paracaudina ambigua* O’Loughlin and Barmos sp. nov. from Shark Bay, central Western Australia (WAM Z29767); upper, forms of predominant ossicles from the mid-body wall; lower, forms of ossicles from the caudal body wall (rarely occurring *chilensis*-like ossicles with cross and box bridging shown lower top right and lower bottom left).

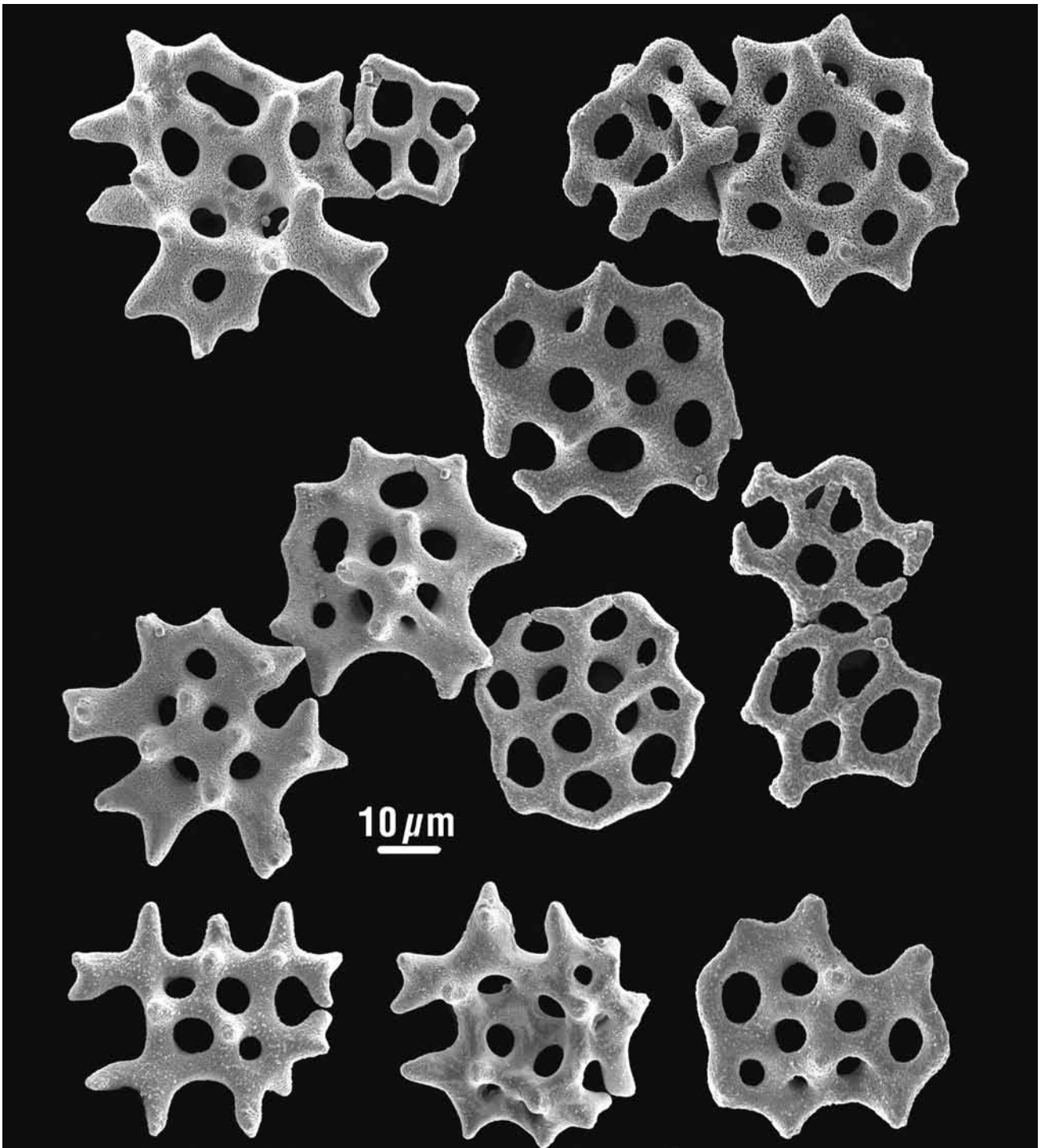


Figure 3. SEM images of ossicles from the mid-body wall of a specimen of *Paracaudina australis* (Semper, 1868) from Dunwich, Moreton Bay, south-east Queensland (AM J13583). Rarely occurring *chilensis*-like ossicle with cross and box bridging shown top right.

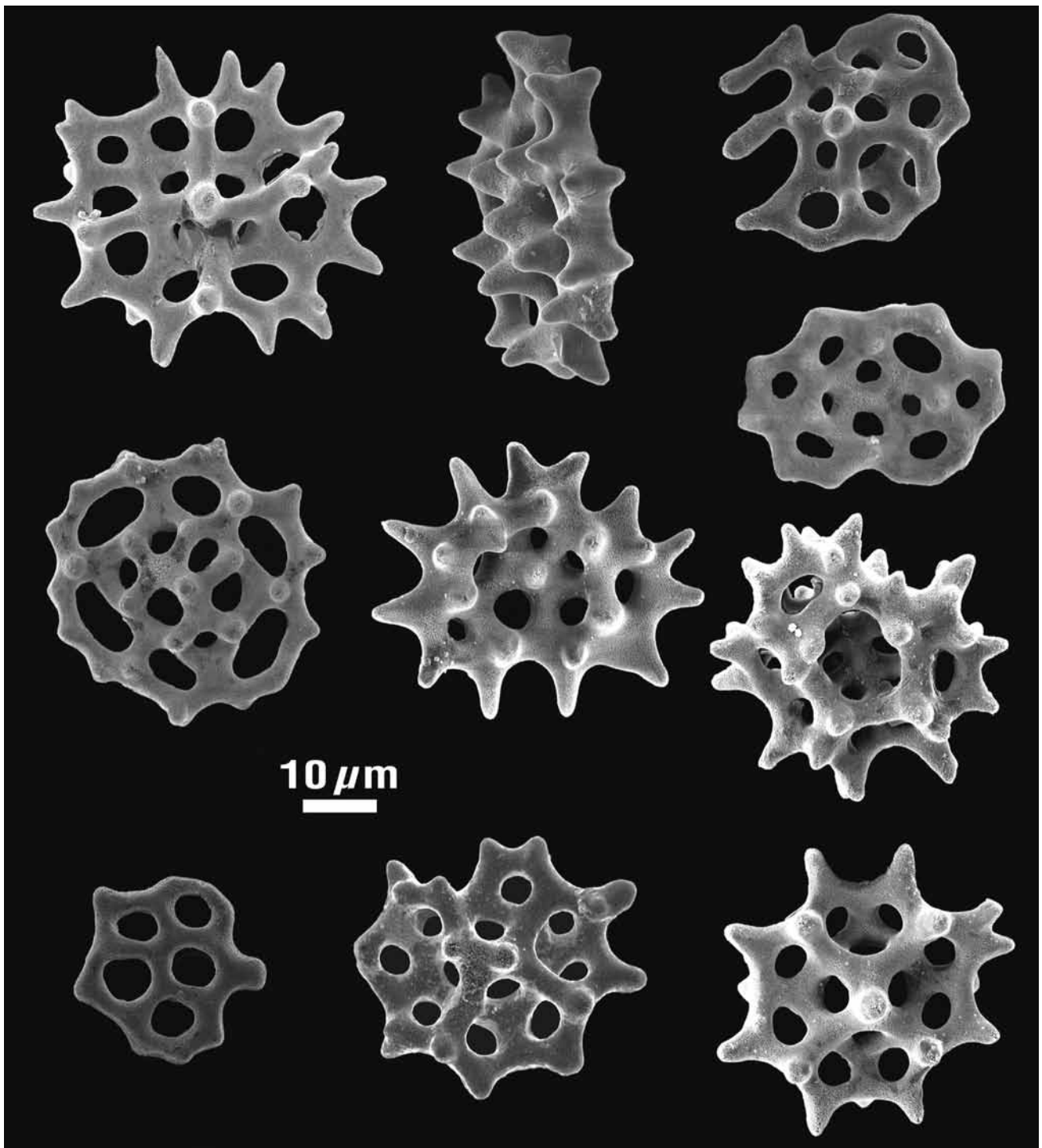


Figure 4. SEM images showing variation in form of ossicles from the mid-body wall of a specimen of *Paracaudina australis* (Semper, 1868) from Dunwich, Moreton Bay, south-east Queensland (AM J13583). Rarely occurring *chilensis*-like ossicle with cross and box bridging shown bottom right.

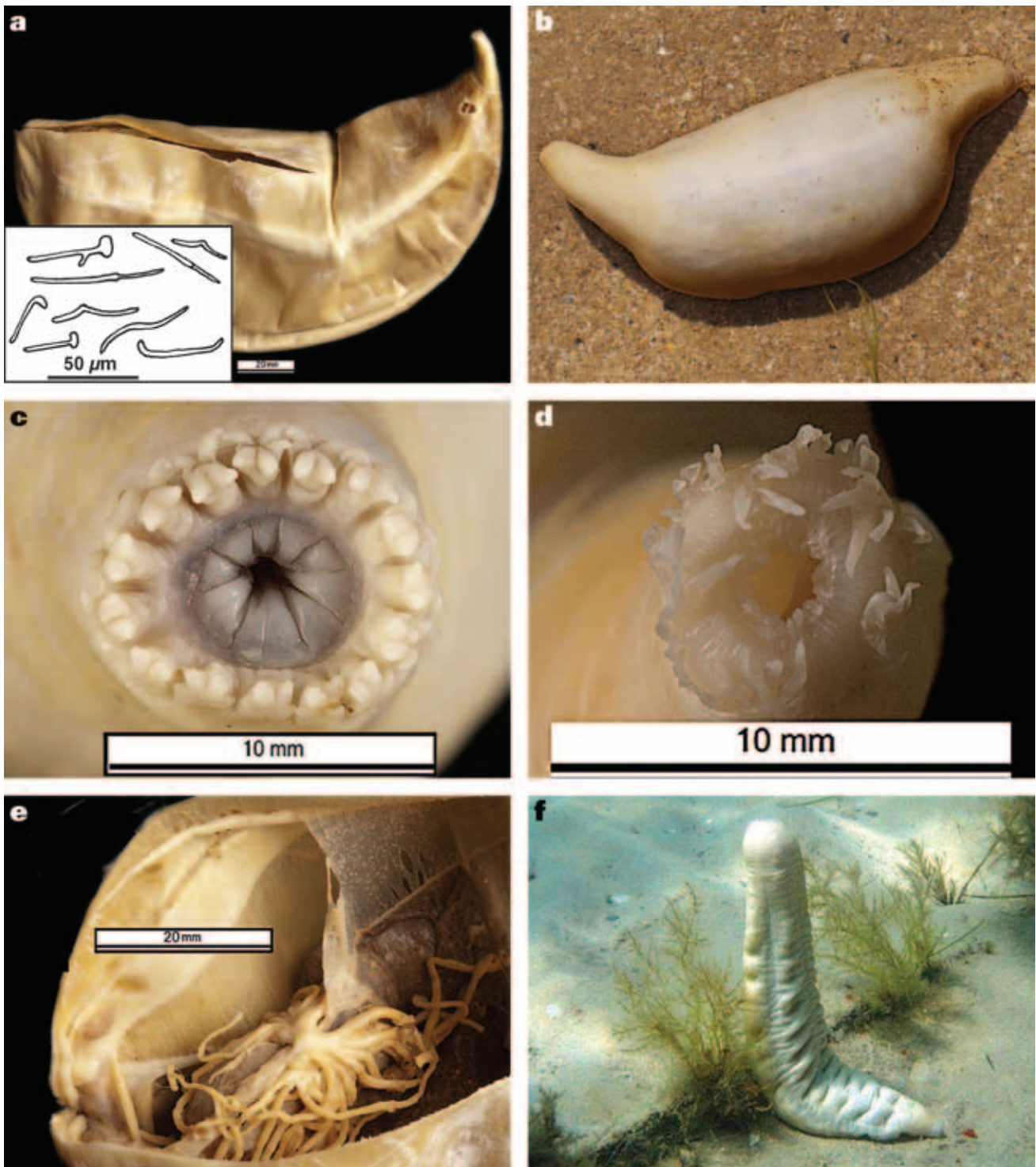


Figure 5. Photos of *Paracaudina bacillis* O'Loughlin and Barmos sp. nov.: a, preserved holotype specimen (insert with drawings of rods from the mid-body wall; NMV F151853); b, photo of live holotype (oral end right; photo by L. Altoff and A. Falconer); c, mouth and tentacles of paratype (NMV F174894); d, anal valves and papillae (holotype); e, dorsal mesentery with tufts of gonad tubules on both sides, divided flat longitudinal muscle with thin retractor muscle (holotype); f, live specimen spawning, Port Phillip Bay, Rye Pier, 4 m, 10 Nov 2007 (photo by D. McKenzie).

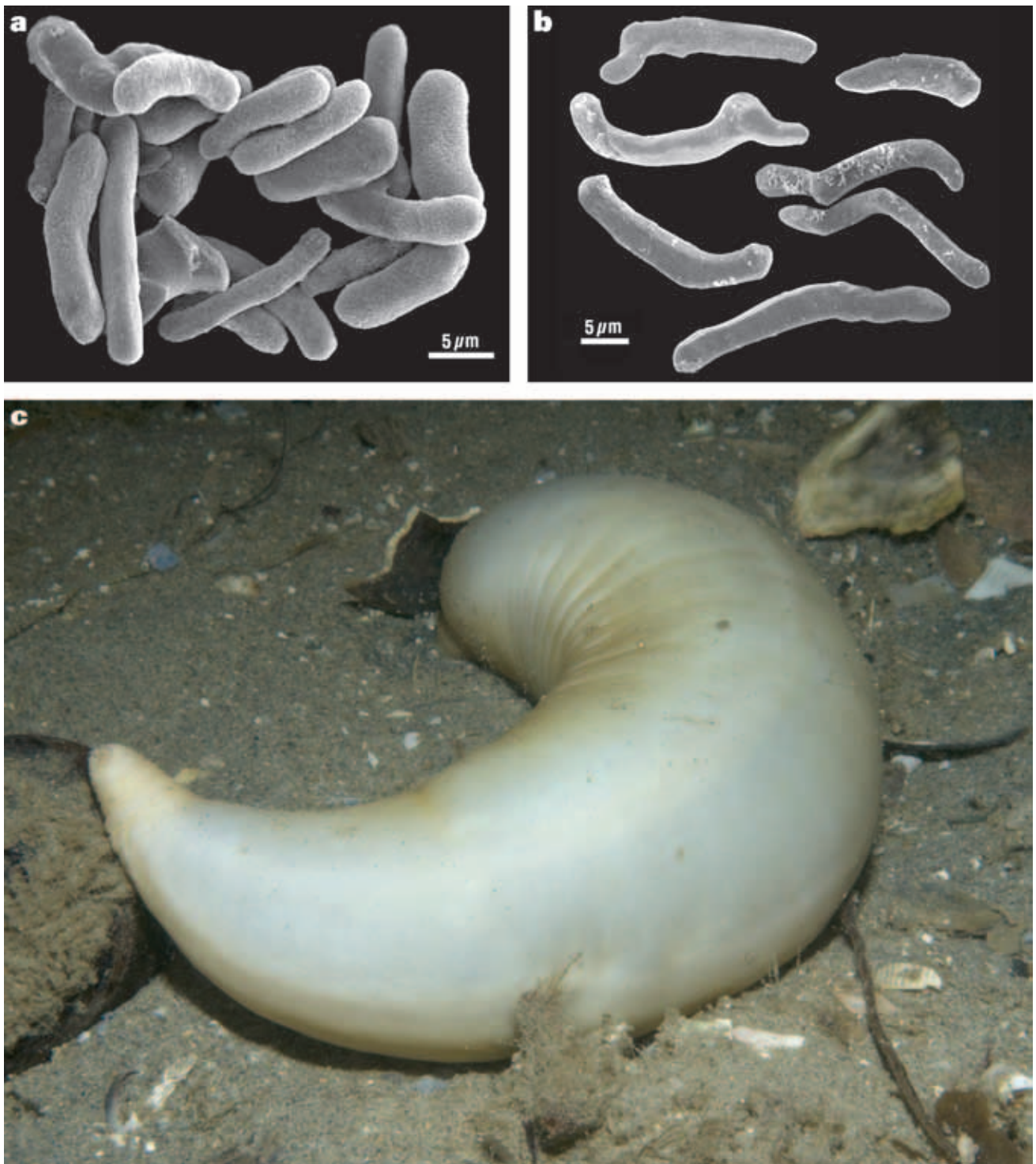


Figure 6. *Paracaudina bacillis* O'Loughlin and Barmos sp. nov. a, b, SEM images of rod ossicles from the mid-body wall of a paratype from Westernport Bay, Victoria (NMV F174893); c, photo of live specimen in Blairgowrie Marina, Port Phillip Bay, at 5 m depth (photo by J. Finn, 18 June 2011).

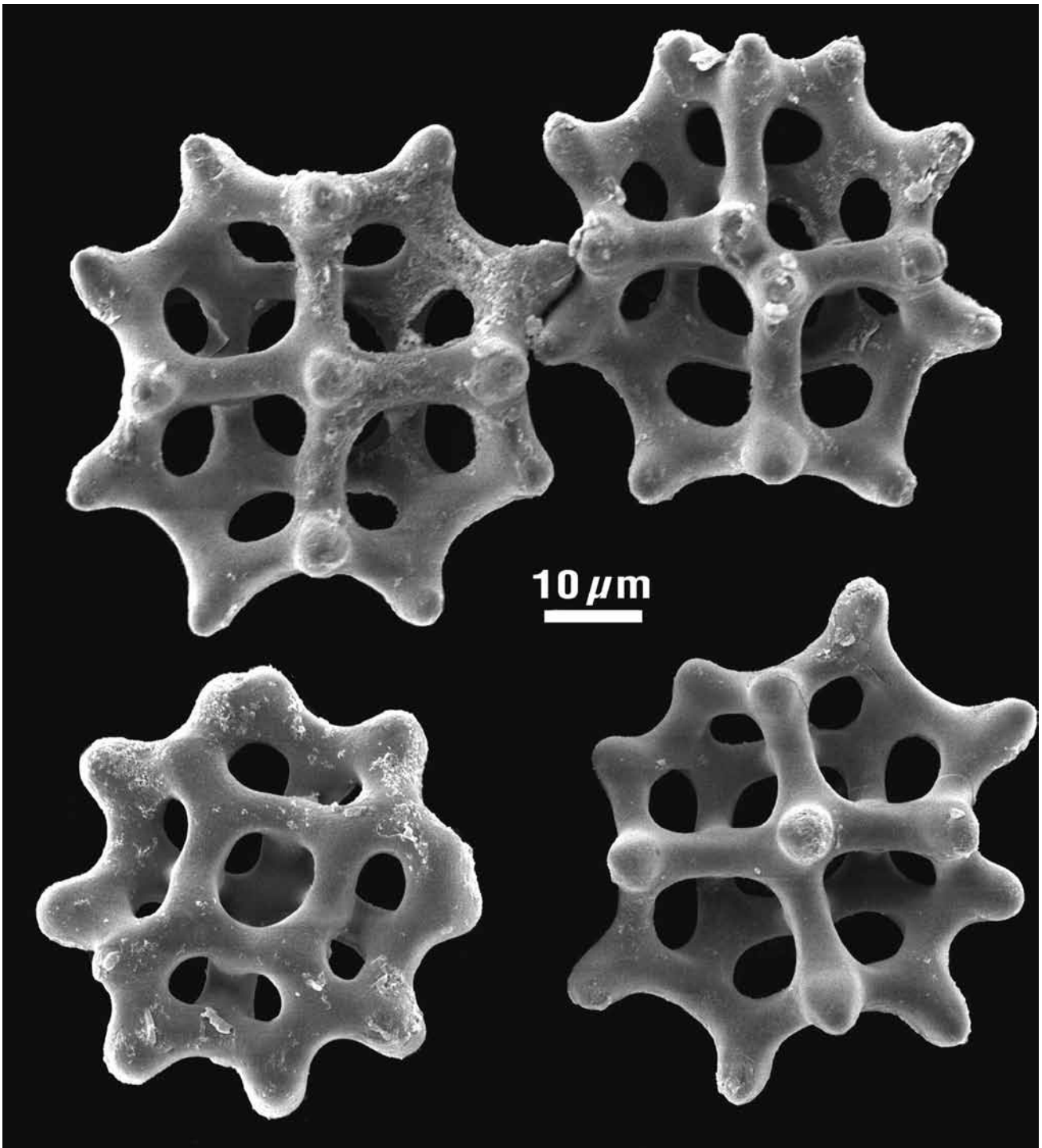


Figure 7. SEM images of ossicles from the mid-body wall of a specimen of *Paracaudina chilensis* (Müller, 1850) from Eighty Mile Beach, NW Australia (WAM Z5640).

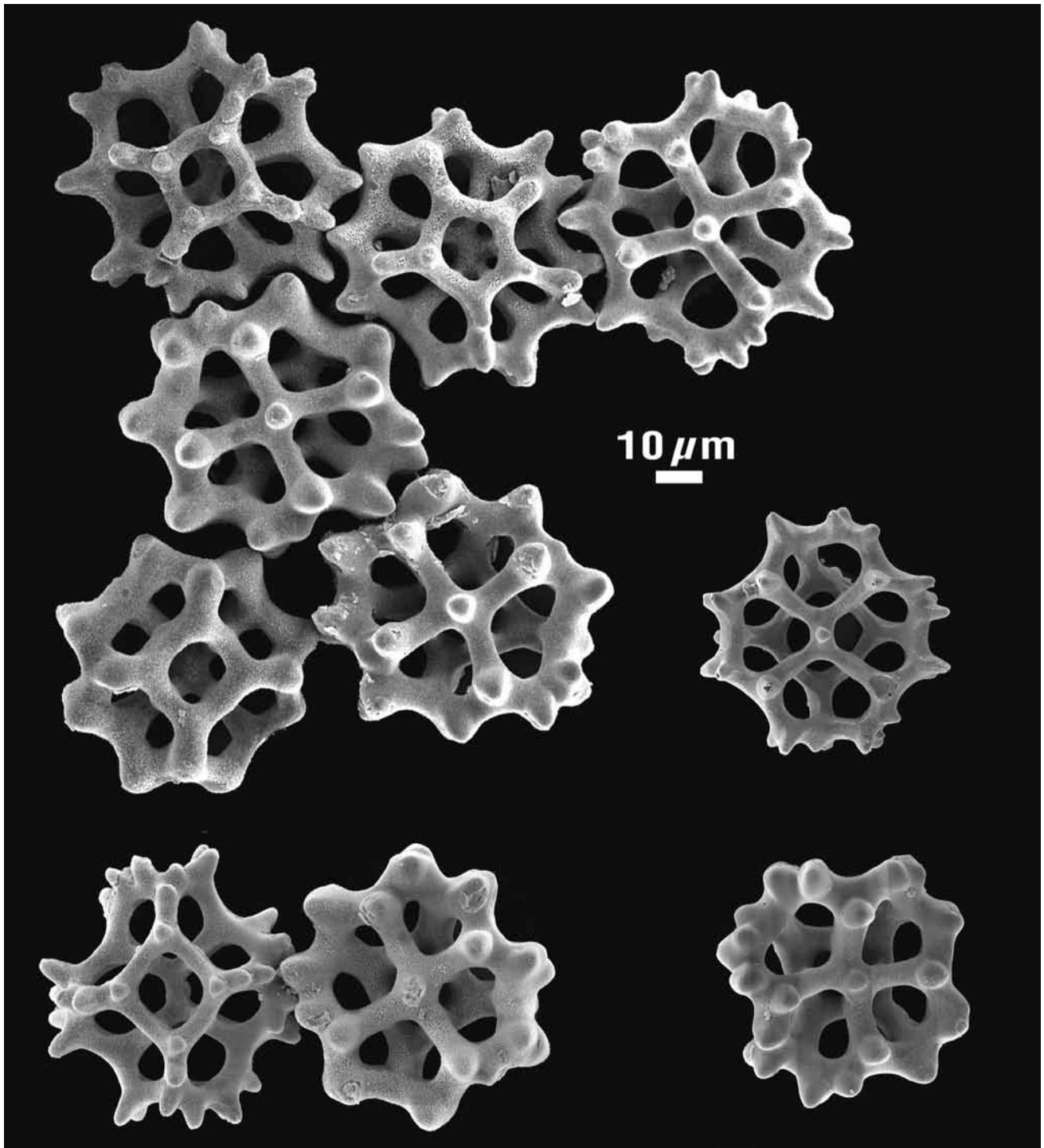


Figure 8. SEM images of ossicles from the mid-body wall of a small specimen of *Paracaudina chilensis* (Müller, 1850) from Tasman Bay, South Island, New Zealand (NIWA 70956).

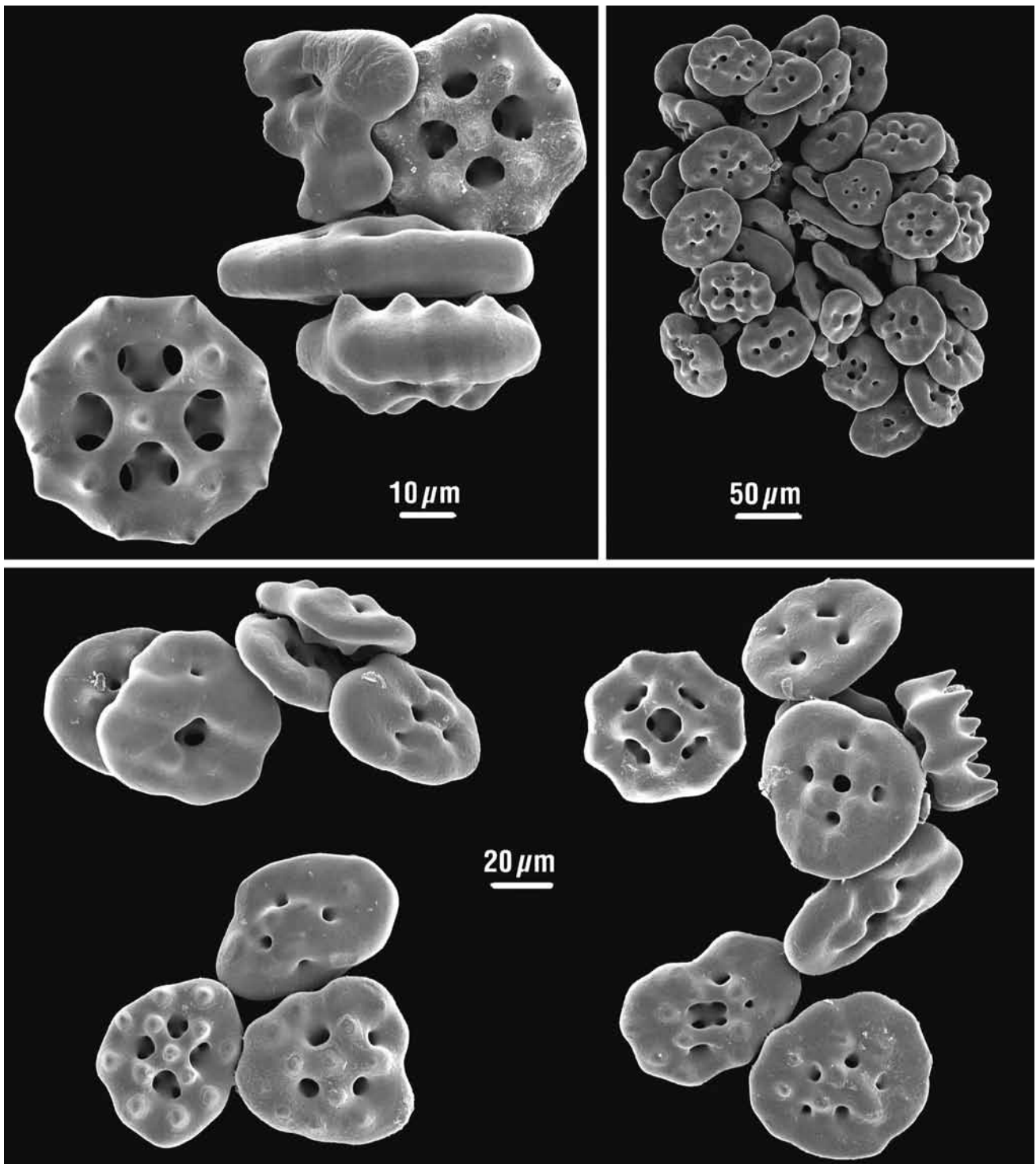


Figure 9. SEM images of ossicles from the mid-body wall of a specimen of *Paracaudina coriacea* (Hutton, 1872) from the west coast of the South Island, New Zealand (AM J12290).

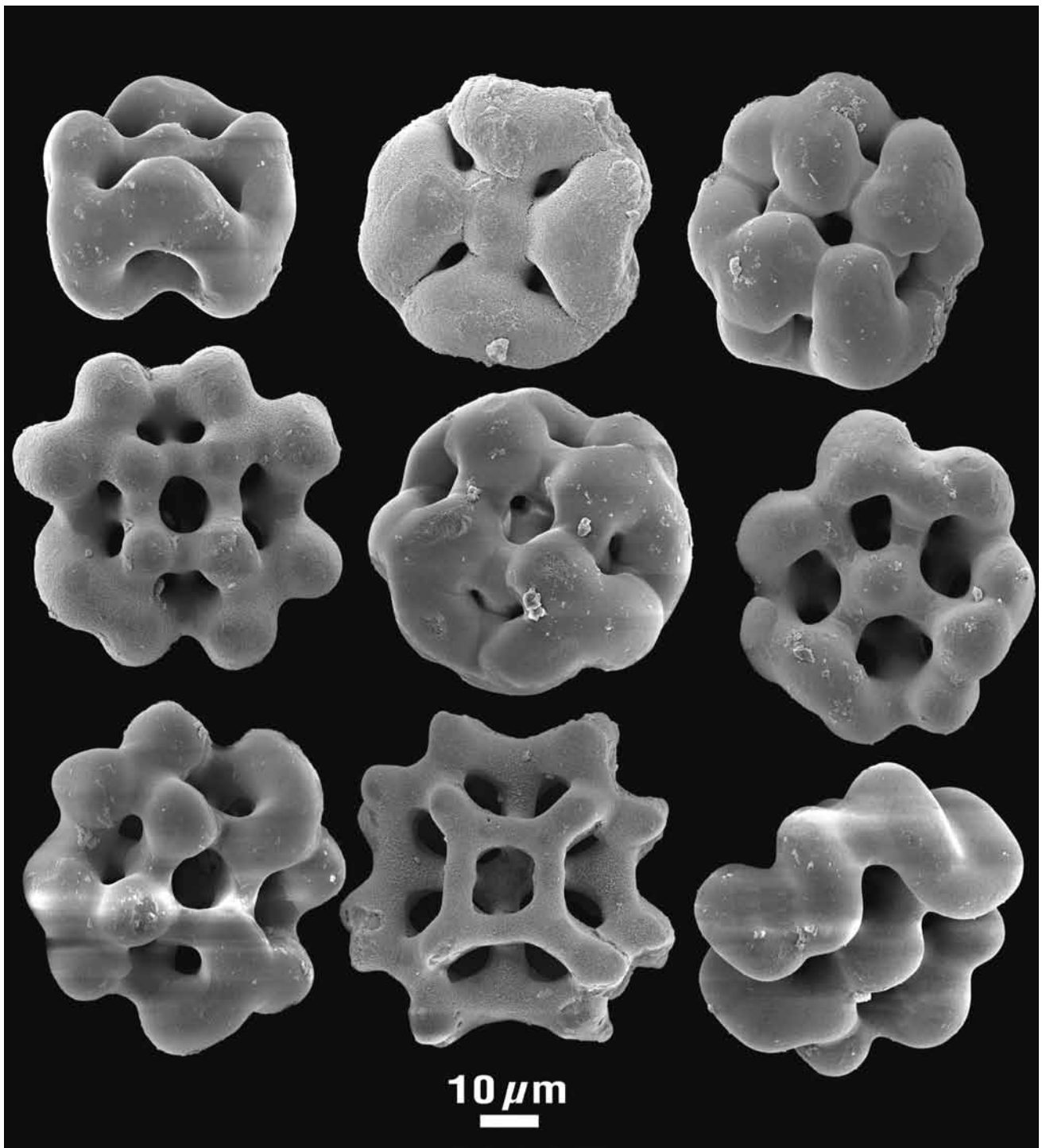


Figure 10. SEM images of ossicles from the mid-body wall of a specimen of *Paracaudina coriacea* (Hutton, 1872) from Cook Strait, New Zealand (NIWA 70954).

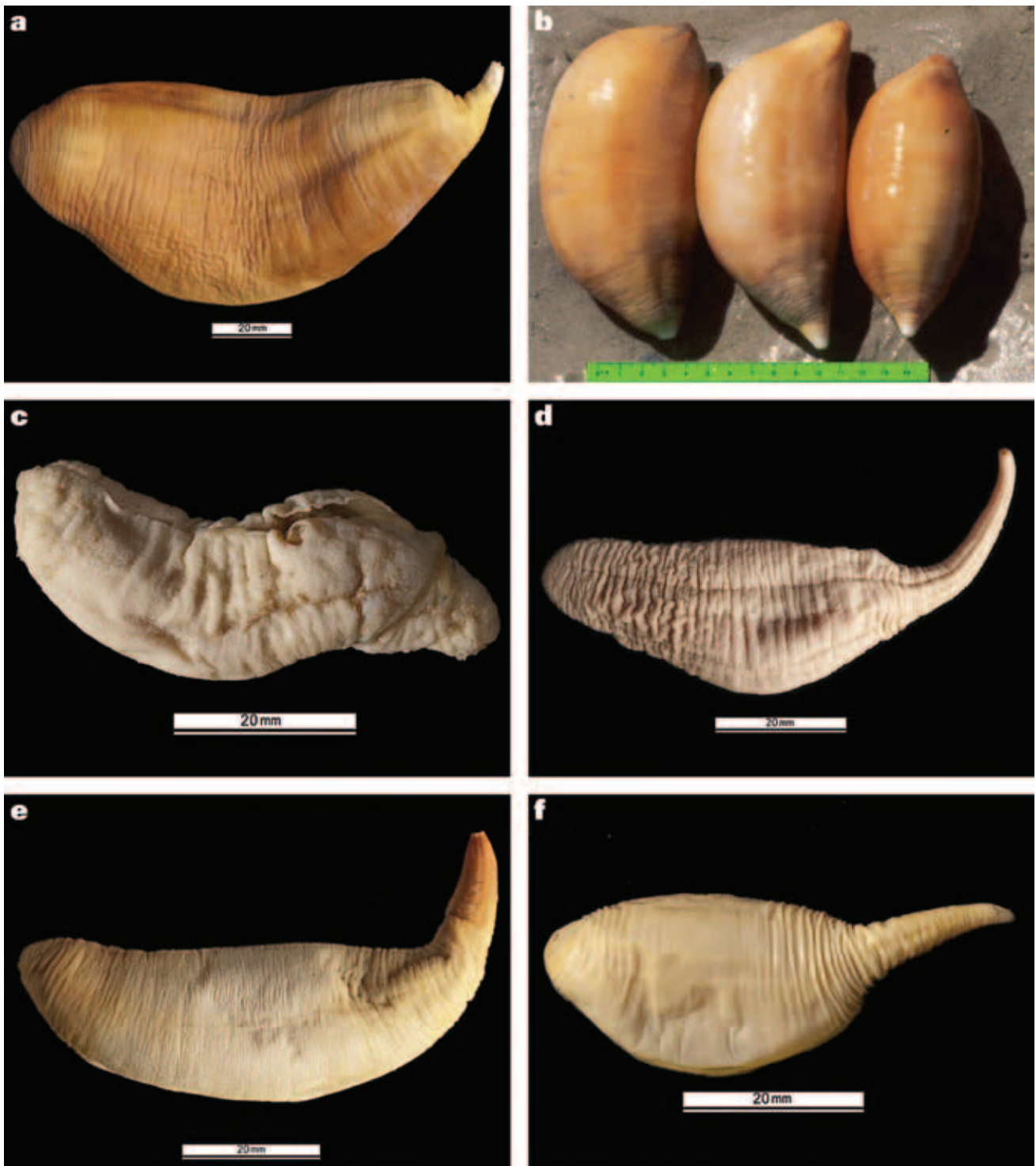


Figure 11. Photos of preserved specimens of species of *Paracaudina* (a, c–f): a, *P. cuprea* O’Loughlin and Barmos sp. nov. holotype (NMV F157396); b, photo of live specimens of *P. cuprea* including holotype (photo by P. Vafiadis); c, *P. keablei* O’Loughlin and Barmos sp. nov. holotype (AM J13579); d, *P. laticola* Hickman, 1962 (NMV F169342); e, *P. tetrapora* (H. L. Clark, 1914) (from Merricks, Westernport Bay, Victoria; NMV F76565); f, *P. tetrapora* (H. L. Clark, 1914) (from off Glenelg, South Australia; AM J24918).

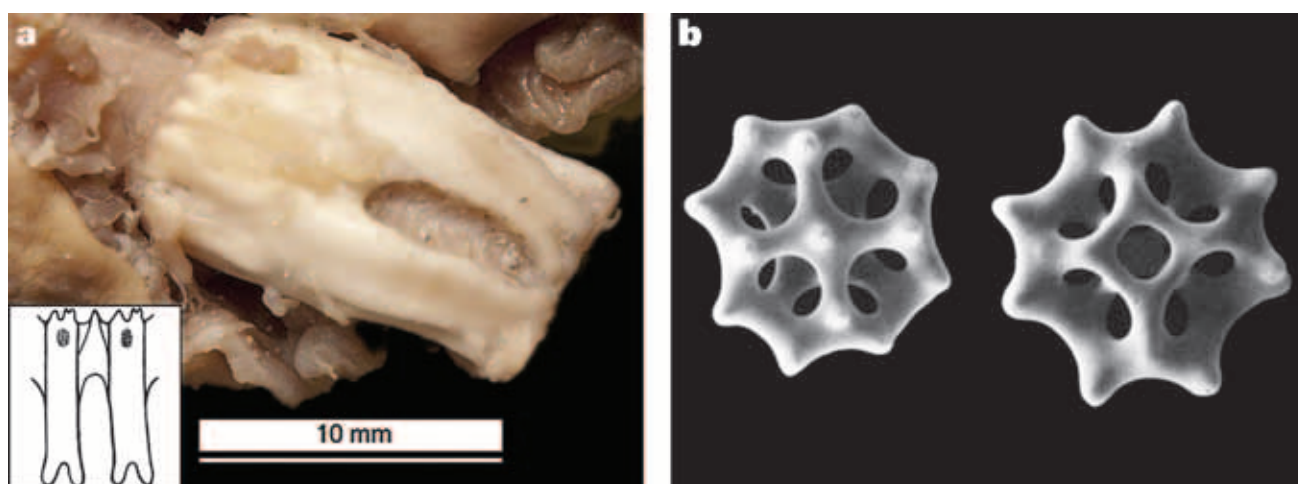


Figure 12. a, Calcareous ring of a specimen of *Paracaudina cuprea* O'Loughlin and Barmos sp. nov. from Portland Bay, Victoria (NMV F174890) (insert with drawing of two radial plates and one interradial plate typical of *Paracaudina* species); b, SEM images of ossicles from a specimen of *Paracaudina chilensis obesacauda* (H. L. Clark, 1908), judged here to be typical of *Paracaudina chilensis* (Müller, 1850) (copied from Pawson et al. 2001).

Paracaudina australis (Semper, 1868)

Figures 1b, 3, 4

Molpadia australis Semper, 1868: 233–234, 268, pl. 39 fig 14.—Théel, 1886: 55.

Caudina chilensis.—H. L. Clark, 1908: 175–176. (part non *Molpadia chilensis* Müller, 1850).

Pseudocaudina australis.—Heding, 1931: 283.

Paracaudina australis.—Heding, 1932: 455.—Heding, 1933: 127–142, pl. 6 figs 5–7, pl. 7 figs 8–9, pl. 8 fig. 6.—H. L. Clark, 1935: 267–284.—H. L. Clark, 1946: 45 (part).—A. M. Clark and Rowe, 1971: 193.—Pawson, 1977: 119 (part).—Rowe, 1982: 472 (part), fig. 10.35b.—Cannon and Silver, 1986: 40, figs 8f, 10f.—Rowe and Gates, 1995: 264 (part).

Material examined. Queensland, Moreton Bay, Stradbroke Island, Dunwich, half buried on sandbar, 2 Dec 1978, AM J13583 (1); Port Denison District, AM J4145 (5).

Diagnosis. *Paracaudina* species up to 135 mm long, up to 35 mm diameter (preserved); thin, pliable, soft to firm smooth body wall; colour translucent pink to white live, off-white to pale brown preserved, lacking yellow colouration, at most slight yellowing anteriorly; posterior body with caudal taper to narrow rounded end, sometimes short tail; mid-body ossicles predominantly plates with bluntly spinous margin and surface, smooth plates, rods in deeper body wall; ossicles not thick buttons; spinous plates irregular, pointed marginal projections, surface knobs / blunt spines frequently joined by rods creating secondary layering, rods sometimes bridging a large central perforation as single rod or tripod or cross, rare *chilensis*-like plates with large central perforation bridged by box on one side and cross on the other side, up to 12 perforations, spinous plates up to 56 μm long; smooth plates irregular, up to 12 perforations, margin smooth, lacking marginal and surface spines and knobs, smooth plates up to 48 μm long; rods sparse, irregular, variably straight, bent, Y-shaped, C-shaped, J-shaped, some

with node, rods frequently 24 μm long, up to 48 μm long.

Type locality. Rockhampton, Queensland.

Distribution. Northern Australia, Queensland, south-east coast; Singapore (?).

Remarks. *Paracaudina australis* (Semper, 1868) is distinguished diagnostically by having in the body wall both irregular rods and spinous perforated plates with secondary layering, a body form with tapered caudal end but not long discrete tail, and an absence of distinct yellow or reddish-yellow colour. H. L. Clark 1908 included *Paracaudina australis* in his synonymy of *Caudina chilensis*, but subsequently (1935, 1946) rejected his own synonymy. Southern Australian specimens judged to be *Paracaudina australis* by H. L. Clark 1946, Rowe 1982 and Rowe and Gates 1995 are our new species *Paracaudina cuprea* O'Loughlin and Barmos (below). Mortensen 1925 based his discussion of *Paracaudina australis* on SAM specimens. Based on Mortensen's figures we judge that these specimens were our new species *Paracaudina cuprea* O'Loughlin and Barmos (below). We note that Heding 1933 did not indicate what specimens he used to illustrate ossicles of *Paracaudina australis*.

David Lane (pers. comm. by Ria Tan) identified the common "See-through sea cucumber" in Singapore waters as *Paracaudina australis*. Ria Tan (pers. comm.) has observed the species only on the estuarine northern shores of Singapore near the mouth of the Johor River, floating or partly buried on sand bars near seagrass meadows, as shallow as the intertidal zone at low spring tide. We have to date not been able to confirm the determination as *Paracaudina australis*.

Paracaudina bacillis O'Loughlin and Barmos sp. nov.

Figures 5a–f, 6a–c

Paracaudina sp. Rowe, 1982: 470, fig. 10.34c.

Paracaudina australis.—Gowlett–Holmes, 2008: 263.—Saunders, 2009: 99, fig. 5.19. (non *Molpadia australis* Semper, 1868)

Material examined. Holotype. Victoria, Westernport Bay, Phillip Island, Ventnor, McHaffie Point, MRG, 16 Feb 2008, NMV F151853.

Paratypes. Westernport Bay, San Remo, Griffith Point, 2 Jan 1999, NMV F89700 (1); Merricks beach, 5 Nov 1967, NMV F45254 (1); 27 Jul 1969, NMV F45240 (1); 4 Jun 2011, NMV F174893 (1); 10 Jun 2011, NMV F174894 (1); Shoreham, 26 Aug 1978, NMV F76071 (2); 30 Mar 1902, NMV F173250 (1) (removed from Shoreham lot 60669–71 / H19 (3) examined in part by Joshua 1914).

Other material. Victoria, Westernport Bay, Crawfish Rock, 12 m, 13 Oct 1968, NMV F169343 (1); Somers, 28 Sep 1968, NMV F45273 (1); Port Phillip Bay, Brighton beach, NMV F45020 (1); Rosebud beach, NMV F173247 (1); Rye pier, 6 Apr 2011, NMV F173272 (1); Blairgowrie Marina, 5 m, 18 Jun 2011 (photo J. Finn, NMV); Tootgarook beach, 20 Jun 2011, NMV F174896 (1). South Australia, Yorke Peninsula, Browns Beach, SAM K2493 (6); Edithburgh, sand, 3–4 m, 12 May 1999, SAM K2486 (1); 2–3 m, 11 Jun 2005, SAM K2487 (1); sand, low tide, 26 Oct 2007 SAM K2490 (1); 8 Nov 2003, SAM K2491 (1). Western Australia, east of Duke of Orleans Bay, Nininup beach after storm, Nov 1990, WAM Z31888 (1); Albany, 5 Dec 1983, WAM Z31881 (1).

Diagnosis. *Paracaudina* species up to 180 mm total length, up to 55 mm diameter, caudal taper 45 mm long (SAM K2491, preserved); thin, parchment-like to soft leathery body wall (preserved); live colour off-white, preserved colour off-white to pale yellow or brown; posterior body with caudal taper to narrow rounded end, sometimes short discrete tail, lacking a discrete long thin tail; body wall ossicles small irregular rods only, straight, bent, wavy, J-shaped, sometimes with nodes, rarely with short branches, up to 64 μ m long.

Type locality. Victoria, Westernport Bay, Phillip Island, Ventnor, McHaffie Point.

Distribution. Victoria (Westernport Bay, Port Phillip Bay), South Australia Gulfs, Eyre Peninsula, to southern Western Australia (Albany); 0–145 m (Rowe 1982); 0–230 m (Gowlett–Holmes 2008).

Etymology. From the Latin *baculus* (rod), and its diminutive *bacillus*, referring to the very small rod ossicles only in the body wall.

Remarks. *Paracaudina bacillis* O'Loughlin and Barmos sp. nov. is distinguished diagnostically amongst *Paracaudina* species by having only small irregular rod ossicles in the body wall. Rods of similar form occur also in *Paracaudina australis* (Semper, 1868), a species that also has irregular marginally spinous perforated plate ossicles in the body wall. Rowe 1982 recognised this “undescribed form” from Port Phillip Bay and southern Western Australia, and illustrated (fig. 10.34c) the diagnostically characteristic minute irregular rod ossicles from the body wall. Gowlett–Holmes 2008 illustrated and described a species from southern Australia as *Paracaudina australis* that has the body form, size up to 20 cm long, and off-white colour of *Paracaudina bacillis* O'Loughlin and Barmos sp. nov. Gowlett–Holmes 2008 described the habit as “usually completely buried 5–10 cm below the sediment surface; moves slowly through the sand feeding on detritus, leaving a broad

furrow-like trail”. Saunders 2009 also illustrated a specimen as *P. australis* at Coffin Bay on the Eyre Peninsula that we judge to be *P. bacillis* based on size and form and colour. Joshua 1914 referred two specimens from Westernport Bay and “Mordialloc” (Port Phillip Bay) to *Caudina chilensis* (Müller). We found these two specimens with a third specimen in lot H19 / 60669–71 / NMV F45019, and assigned (below) the two referred to by Joshua 1914 to the new species *Paracaudina cuprea* O'Loughlin and Barmos (F169344) and *Paracaudina tetrapora* (H. L. Clark, 1914) (F45019, original registration). The label indicated all three specimens were collected by J. A. Kershaw at Shoreham. We judge that Joshua's reference to “Mordialloc” was a mistake. We found no specimens from Mordialloc in the NMV collection. The third specimen in the lot, not commented on in Joshua 1914, is the third new species (above) *Paracaudina bacillis* O'Loughlin and Barmos (F173250).

Paracaudina chilensis (Müller, 1850)

Figures 1c, 7, 8, 12b

Molpadia chilensis Müller, 1850: 139.—Müller, 1854: pl. 6 fig. 14, pl. 9 fig. 1.—Semper, 1868: 233.—Théel, 1886: 55.

Microdactyla caudata Sluiter, 1880: 348–351, pl. 6 fig. 1, pl. 7 figs 1–6.

Caudina ransonnetii Marenzeller, 1881: 126–127, pl. 4 figs 5, 5A.—Ludwig, 1883: 158–159.—Lampert, 1885: 210.—Théel, 1886: 54.—Ludwig, 1891: 354.—Mitsukuri, 1912: 261–262, pl. 8 fig. 76.

Caudina caudata.—Ludwig, 1883: 159. (synonymy with *Caudina chilensis* (Müller) by H. L. Clark 1908)

Caudina coriacea.—Théel, 1886: 47, pl. 3 fig 4a–c. (non *Caudina coriacea* Hutton, 1872)

Caudina rugosa R. Perrier, 1904: 16.—R. Perrier, 1905: pl. 4 figs 10–12. (synonymy with *Caudina chilensis* (Müller) by H. L. Clark 1908)

Caudina pigmentosa Perrier, 1904: 16–17.—Perrier, 1905: pl. 4 figs 1–9. (synonymy by H. L. Clark 1935)

Caudina contractacauda H. L. Clark, 1908: 38–39, 173, 177, 178, pl. 9 figs 9–13. (synonymy by H. L. Clark 1935)

Caudina chilensis.—H. L. Clark, 1908: 173, 175–176.—Hozawa, 1928: 361–378, pls 14–17.—Ohshima, 1929: 39–45.

Pseudocaudina chilensis.—Heding, 1931: 283.

Pseudocaudina ransonnetii.—Heding, 1931: 283.

Paracaudina chilensis.—Heding, 1933: 127–142, pls 5–8.—H. L. Clark, 1935: 267–284.—Deichmann, 1938: 383–384, fig. 15.—Pawson, 1969: 139–140.—A. M. Clark and Rowe, 1971: 184–185.—Pawson, 1977: 119 (part).—Cannon and Silver, 1986: 40.—Rowe and Gates, 1995: 264.—Liao and Clark, A. M., 1995: 518–519, fig. 316.—Lane et al., 2000: 491.

Paracaudina ransonnetii.—Heding, 1933: 455.—Djakonov et al., 1958: 377.

Paracaudina chilensis var. *ransonnetii* H. L. Clark, 1935: 281.—H. L. Clark, 1938: 540–541.—H. L. Clark, 1946: 444.—A. M. Clark and Rowe, 1971: 194–195, fig. 96a. (synonymy by Liao and Pawson 1992)

Material examined. Western Australia, Roebuck Bay, Broome, Sep 1929, from H. L. Clark collection, AM J6435 (1); Eighty Mile Beach, 19°20'00"S 121°21'00"E, Annabim Expedition 1999, mudflat, WAM Z5637 (1); WAM Z5638 (2); WAM Z5639 (1); WAM Z5640 (1); WAM Z5641 (1); WAM Z5642 (1); WAM Z5653 (1); WAM Z5654 (1); WAM Z5655 (2 tails). New South Wales, Twofold Bay, Nullica Bay, 9.1 m, 22 Feb 1985 AM J19908 (one 3 mm fragment). New Zealand, South

Island, Tasman Bay, 41.17°S 173.17°E, 0 m, 24 Jan 1972, NIWA 70956 (2).

Diagnosis. *Paracaudina* species up to 150 mm total length, diameter up to 20 mm, caudal taper and long discrete tail 80 mm long; posterior body with discrete long thin tail, up to more than half the length of the body; body firm thin leathery to parchment-like, finely wrinkled, variably transversely creased (preserved), live colour off-white with slight purple colouration (H. L. Clark 1938; Liao and A. M. Clark 1995), preserved colour pale grey to pink-grey; mid-body ossicles predominantly octagonal plates with large central perforation bridged by basal box with 4 supporting arms on one side and cross with 4 supporting arms on the upper side, surface knobbed, margin with 8 bluntly pointed projections, plates up to 56 μ m across.

Type locality. Chile.

Distribution. Circum-Pacific, including northwest Australia and New Zealand; to 1000 m (Pawson 1963).

Remarks. Ludwig 1883, Théel 1886, Heding 1931, 1933, and Djakonov et al. 1958 judged the Chinese / Japanese species *Paracaudina ransonnetii* (Marenzeller, 1881) to be a discrete species. Type locality is Yantai (Cheefoo) on the Yellow Sea. H. L. Clark 1935, 1938, 1946 (based on northern Australia material) and A. M. Clark and Rowe 1971 considered the species to be a variety of *Paracaudina chilensis* (Müller, 1850). H. L. Clark 1908, Hozawa 1928, Ohshima 1929, Pawson and Liao 1992, Rowe and Gates 1995, and Liao and Clark A. M. 1995 considered *Paracaudina ransonnetii* to be a junior synonym of *Paracaudina chilensis*. We agree with this synonymy. We judge that some north-western Australian material is *Paracaudina chilensis*, and that some north-eastern Australia material (from the Gulf of Carpentaria and Moreton Bay) is a new species *Paracaudina keablei* O'Loughlin and Barmos that we describe below.

Below we raise the New Zealand species *Paracaudina coriacea* (Hutton, 1872) out of synonymy with the Chilean species *Paracaudina chilensis* (Müller, 1850). Théel 1886 was prompted to refer New Zealand specimens to *Caudina ransonnetii* Marenzeller, 1881 but finally referred them to *Caudina coriacea* (Hutton, 1872). But the ossicles illustrated by Théel 1886 are the predominant ossicle form found in *Paracaudina chilensis*. We examined two small New Zealand specimens (NIWA 70956) from the shallows of Tasman Bay and found the ossicles to be those of *Paracaudina chilensis* (fig. 8). We dismissed our consideration that this ossicle form might be a juvenile developmental stage of *Paracaudina coriacea* on the grounds that Hozawa 1928 found no such significant development changes in his study of *Paracaudina chilensis* at Asamushi. Both *Paracaudina chilensis* (Müller) and *Paracaudina coriacea* (Hutton) occur in New Zealand waters. We note that the distal tail of the specimen of *Paracaudina chilensis* WAM Z5638 is not very thin (fig. 1c), while the distal tails of the two specimens of *Paracaudina coriacea* NIWA 70955 and AM J12290 are both very thin (figs 1d, e).

We also note that some, but not the predominant, ossicles from specimens judged to be *Paracaudina chilensis* from northwest Australia are similar to the ossicles illustrated for

the single type specimen of *Paracaudina delicata* Pawson and Liao, 1992 taken in the Gulf of Tonkin. And some, but not the predominant, ossicles are similar to those in the new species *Paracaudina keablei* O'Loughlin and Barmos (below).

Paracaudina coriacea (Hutton, 1872)

Figures 1d–f, 9, 10

Molpadia coriacea Hutton, 1872: 17.—Hutton, 1879: 307.—Lampert, 1885: 208–209.

Echinostoma (?) *coriacea*. —Hutton, 1879: 307. (synonymy with *Caudina coriacea* (Hutton) by Théel 1886)

Caudina meridionalis Bell, 1883: 58–59, pl. 15 fig. 1.—Lampert, 1885: 210–211. (synonymy with *Caudina coriacea* (Hutton) by Théel 1886)

Caudina coriacea.—Théel, 1886: 54–55.—Dendy, 1897: 28–32, pl. 3 figs 9–18.—Dendy, 1898: 456–464, pl. 29.—Farquhar, 1898: 324.—Ludwig, 1898: 63–64.—Dendy and Hindle, 1907: 95, 108–110, fig. B.—Mortensen, 1925: 364–366, figs 46b, 47b. (synonymy with *Caudina chilensis* (Müller) by H. L. Clark 1908)

Caudina coriacea var. *brevicauda* R. Perrier, 1905: 121–123, fig. N. (synonymy with *Caudina coriacea* by Dendy and Hindle 1907; with *Paracaudina chilensis* var. *coriacea* by H. L. Clark 1935)

Caudina pulchella R. Perrier, 1905: 117–120, pl. 5 figs 14–17. (synonymy with *Caudina coriacea* by Dendy and Hindle 1907; with *Paracaudina chilensis* var. *coriacea* by H. L. Clark 1935)

Caudina chilensis.—Benham, 1909: 110. (non *Paracaudina chilensis* (Müller, 1850))

Paracaudina chilensis var. *coriacea*.—H. L. Clark, 1935: 267–284.

Paracaudina chilensis.—Pawson, 1963: 18–21, pl. 4.—Pawson, 1965: 14.—Pawson, 1970: 49–50, pl. 2 fig. 2.—Pawson, 1977: 119 (part).—Mah et al., 2009: 382, 398, fig. p. 383. (non *Paracaudina chilensis* (Müller, 1850))

Material examined. New Zealand, Cook Strait, 61 m, 26 May 1975, NIWA 70954 (1); Cook Strait, 18 m, 15 Dec 1983, NIWA 70955 (1); South Island, west coast, Arawhata River mouth, washed onto spit, 8 Jul 1969, AM J12290 (3).

Diagnosis. *Paracaudina* species up to 172 mm total length, up to 28 mm diameter, caudal taper and narrow tail 102 mm long (NIWA 70954); discrete thin tail, frequently longer than main body; body wall parchment-like, smooth to wrinkled, frequently with transverse creasing, preserved colour off-white with patches of yellowish-red (rusty) colouration in largest specimens; mid-body ossicles predominantly thick, button-like, octagonal, with central perforation bridged by a box basally and cross on the upper side, perforations small, margin predominantly rounded and lacking projecting knobs and bluntly pointed projections, surface variably knobbed or with short thick spines, ossicles typically 64 μ m, up to 80 μ m long.

Distribution. New Zealand; 0–61 m.

Remarks. In erecting the species *Caudina meridionalis* (junior synonym of *P. coriacea*) for two specimens from New Zealand waters, Bell 1883 noted that in comparison with *Caudina ransonnetii* Marenzeller, 1881 (junior synonym of *P. chilensis*) the ossicles were “stout”, the perforations “small”, and the marginal projections not as distinct. We agree that these are a significant diagnostic difference between the predominant

ossicle forms of *Paracaudina coriacea* and *Paracaudina chilensis*. We raise *Paracaudina coriacea* (Hutton, 1872) out of synonymy with *Paracaudina chilensis* (Müller, 1850).

Perrier 1905 illustrated (pl. 5 figs 16, 17) what he considered to be the predominant ossicle form in his *Caudina pulchella* from New Zealand. Perrier 1905 also illustrated two ossicles (fig. N) for his New Zealand variety *Caudina coriacea* var. *brevicauda*. In both cases these are the thick ossicles with rounded margin and small perforations that we have found and illustrated as the predominant ossicles in New Zealand specimens of *Paracaudina coriacea* examined in this work. This form of ossicle was illustrated for New Zealand specimens by Dendy 1897, Mortensen 1925, Heding 1933 (pl. 6 figs 10–13, New Brighton, Christchurch, specimen), and Pawson 1963 (cups from adult specimen). These are the predominant ossicles of *Paracaudina coriacea* (Hutton).

Perrier 1905 illustrated (pl. 4 figs 11, 12) what he considered to be the predominant ossicle form in his *Caudina rugosa* from Cape Horn, and they are the ossicles of medium thickness with prominent blunt marginal projections that we have found in the Australian and New Zealand specimens of *Paracaudina chilensis* (Müller) examined in this work. This form of ossicle was illustrated by Müller 1854, Marenzeller 1881, Clark 1908, Hozawa 1928, Heding 1933 (pl. 6 figs 1–4, type), Pawson and Liao 1992, Liao and Clark 1995 and Pawson et al. 2001 for material falling within the synonymy of *Paracaudina chilensis*.

We note that Heding 1933 (pl. 6 figs 8–9) illustrated ossicles from a New Zealand specimen from Tiritiri Matangi (north of Auckland) that we judge to be typical of *Paracaudina chilensis*. If this was the predominant ossicle form the specimen was *Paracaudina chilensis*.

Our New Zealand colleagues were unsuccessful in attempting to find the type material for *Molpadia coriacea* Hutton, 1872.

Paracaudina cuprea O'Loughlin and Barmos sp. nov.

Figures 11a, b, 12a, 13

Caudina chilensis.—Joshua, 1914: 6 (part).—Joshua and Creed 1915: 21–22 (part). (non *Molpadia chilensis* Müller, 1850)

Caudina australis.—Mortensen, 1925: 364–367, figs 46c, 47a. (non *Molpadia australis* Semper, 1868)

Paracaudina australis.—Hickman, 1962: 63–64, figs 106–130, pl. 2 fig. 9.—Rowe, 1982: 472 (part), pl. 32.3.—Rowe and Gates, 1995: 264 (part). (non *Molpadia australis* Semper, 1868)

Material examined. Holotype. Victoria, Corner Inlet, Sunday Island, mudflat, MRG, 15 Mar 2004, NMV F157396.

Paratypes. Corner Inlet, Port Welshpool, in sediment, MRG, 5 Mar 2010, NMV F169322 (2).

Other material. Victoria, Seaspray, 8 Mar 1977, AM J10610 (1); Westernport Bay, San Remo, 2 Apr 1972, NMV F169346 (1); Shoreham, 30 Mar 1902, NMV F169344 (1) (removed from Shoreham lot 60669–71 / H19 (3) examined in part by Joshua 1914); Portland Bay, 27–35 m, 29 Aug 1975, NMV F76073 (1); NMV F174890 (1). Tasmania, Seven-mile Beach, 13 Aug 1956, AM J7195 (1); Roches Beach, 6 Mar 1974, AM J8437 (4). South Australia, 24 Jun 1924, SAM K2504 (1); St Vincent Gulf, mixed localities, Aug 1886, SAM K1381 (13); Port Stanvac, dredged 16 m, 6 Feb 1991, SAM K2495 (12); SAM

K2498 (1); Apr 1991, 17 m, SAM K2503 (1); Brighton Beach, 3 Jul ? 1916, SAM K2506 (2); Port Lincoln, 5 m, 22 Aug 1975, SAM K2492 (1). Western Australia, AM J2341 (1; no additional data); AM J2342 (1; no additional data); Rottnest I., 146–155 m, 15 Aug 1962, WAM Z8977 (1); 139–145 m, 12 Aug 1962, WAM Z8979 (1); 183–188 m, 14 Aug 1962, WAM Z8981 (1); 146 m, 10 Aug 1962, WAM Z8985 (1).

Diagnosis. *Paracaudina* species up to 153 mm long (F169346, preserved), main body 144 mm long, width up to 55 mm, tail 9 mm long; cylindrical body sharply tapered at ends to pointed oral end, discrete short narrow caudal end / tail; thick, firm, leathery body wall, smooth, slight wrinkling at oral and anal ends, variable transverse creasing; live and preserved colour variably rusty, orange, copper, yellow, some off-white patches; oval yellow phosphatic bodies present, up to 40 μ m long; mid-body ossicles irregular, variable, round to oval small plates, flat to slightly concave, margin and surface smooth or with pointed spines or knobs, knobs sometimes joined to create secondary layering, up to 12 irregular perforations, frequently with large central perforation and or lacking surrounding perforations, central perforation bridged by 1 or 3 or 4 arms, rarely *chilensis*-like and bridged by cross on one side and box on other side, ossicles up to about 60 μ m long.

Type locality. Victoria, Corner Inlet, Sunday Island, intertidal sediments.

Distribution. Southern Australia, from eastern Victoria (Seaspray), south to Tasmania, and west to Rottnest Island (off Perth); 0–188 m.

Etymology. From the Latin *cupreus* (copper), referring to the coppery, rusty colour of live and preserved specimens

Remarks. The diagnostic characters that distinguish the new species *Paracaudina cuprea* O'Loughlin and Barmos are the distinctive body form with discrete, short narrow tail, the rusty and orange colour, absence of mid-body wall rods, and the predominance of irregular, perforated plate ossicles frequently with irregularly bridged central perforation and with blunt marginal and surface spines and knobs.

Joshua 1914 determined a 100 mm long specimen (seen here, F169344) from “Mordialloc” on Port Phillip Bay as *Caudina chilensis* (Müller), but reported that it tapered sharply posteriorly and could not be described as caudate. Colour was yellow, blotched with brownish pink. The cross in the ossicles was frequently lost by fusion with the disc. He was referring to a specimen of the new species *Paracaudina cuprea* O'Loughlin and Barmos. As discussed in the Remarks under *P. bacillis* (above) we judge from specimen labels that the specimen came from Shoreham on Westernport Bay, not “Mordialloc”. Although they determined specimens from South Australia as *Caudina chilensis* (Müller), Joshua and Creed 1915 described some of them as being up to 125 mm long, lacking the caudate character of the species, and yellow with patches of rusty red in colour. They were referring to specimens of the new species *Paracaudina cuprea*. Hickman 1962 also described and illustrated (as *P. australis*) the new species *Paracaudina cuprea*. Rowe 1982 (pl. 32.3) also illustrated this new species (as *P. australis*), and in describing the colour of southern Australian specimens as “rusty pink and brown” was referring

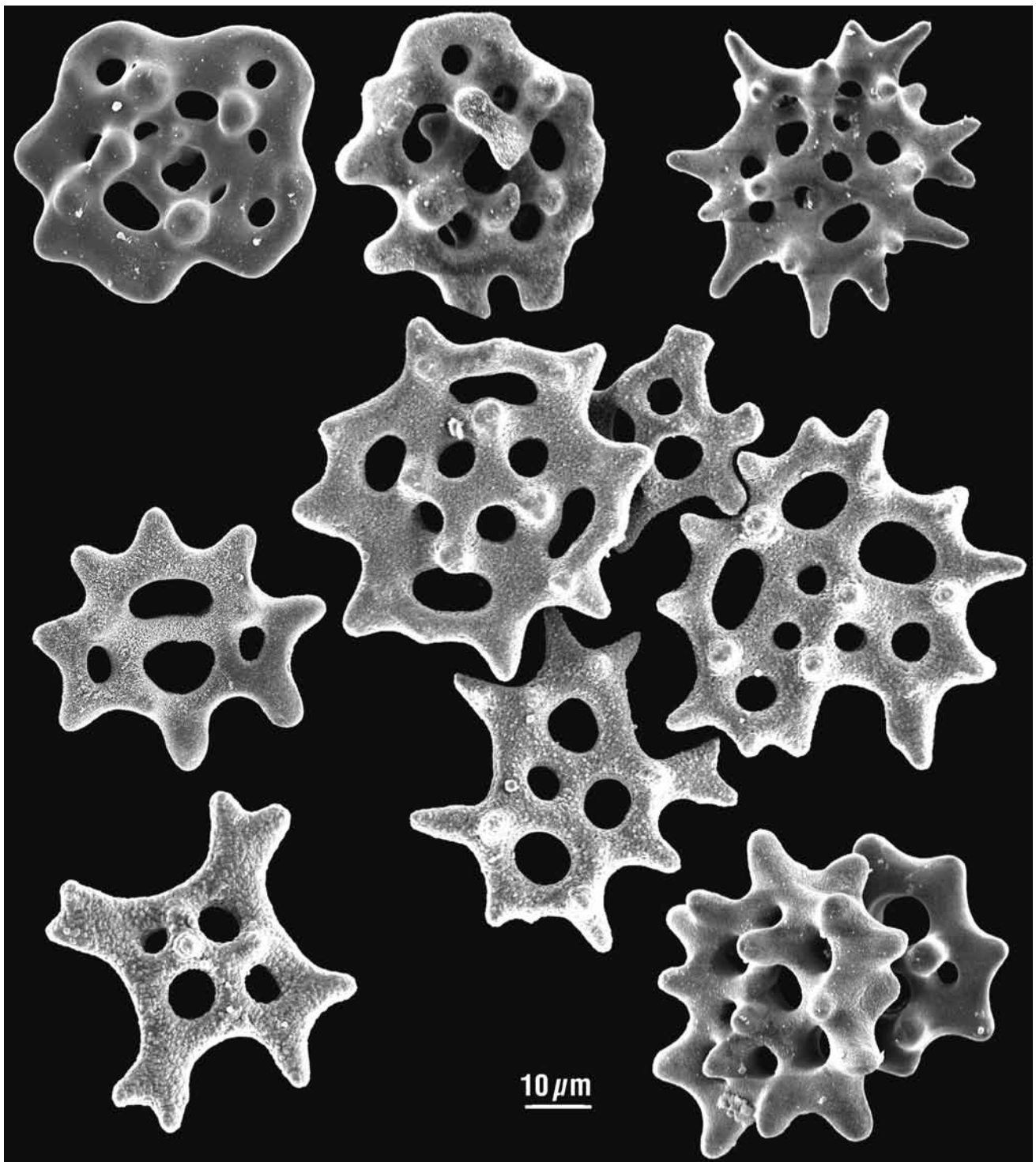


Figure 13. SEM images of ossicles from the mid-body wall of the holotype specimen of *Paracaudina cuprea* O'Loughlin and Barmos sp. nov. from Sunday Island, Corner Inlet, Victoria (NMV F157396).

to the new species *Paracaudina cuprea*. Mortensen 1925 based his discussion of *Paracaudina australis* on SAM specimens. Based on Mortensen's figures we judge that these specimens were our new species *Paracaudina cuprea*.

Paracaudina keablei O'Loughlin and Barmos sp. nov.

Figures 11c, 14

Material examined. Holotype. Queensland, Moreton Bay, Stradbroke Island, Dunwich, sandbar, H. Silver, 2 Dec 1978, AM J13579.

Other material. Queensland, Gulf of Carpentaria, SE corner, 17°24'55"S 140°42'35" E, 4.6 m, CSIRO Rama prawn survey trawl stn 555, 16 Jan 1964, AM J17085 (1); 17°30'15"S 140°40'10" E, 2.3 m, CSIRO Rama prawn survey trawl stn 494, 18 Dec 1963, AM J17051 (3).

Diagnosis. *Paracaudina* species up to 75 mm total length, diameter up to 18 mm, caudal taper and short discrete tail 25 mm long (preserved); body wall firm, not thin, smooth to wrinkled, partly transversely creased, slightly rugose, off-white (preserved); short caudal taper and discrete thin tail; no evidence of phosphatising; mid-body ossicles predominantly thin-walled octagonal plates with large central perforation, basal box with 4 supporting arms bridging one side of ossicle, cross with 4 supporting arms bridging outer side, short blunt spines only around marginal surface and on cross, not on box, lacking prominent marginal sub-digitiform projections and knobs, ossicles up to 70 µm across.

Type locality. Northeast Australia, Moreton Bay.

Distribution. Northeast Australia, Moreton Bay, Stradbroke Island, Gulf of Carpentaria; 0–5 m.

Etymology. Named for Dr Stephen Keable, Collection Manager, Marine Invertebrates (Natural Science Collections), Australian Museum, in appreciation of his prompt and gracious assistance with loans from the Australian Museum for this and other research projects.

Remarks. The holotype specimen of *Paracaudina keablei* O'Loughlin and Barmos sp. nov. is damaged, but the ossicles are in good condition. The ossicles in the additional material are somewhat eroded, but the predominant ossicle form is diagnostically distinguishable. Four *Paracaudina* Heding species have a predominant ossicle form of octagonal plates with a basal box with four supporting arms bridging the ossicle on one side and a cross with four supporting arms bridging the ossicle on the opposite side. The predominant ossicle form in *Paracaudina chilensis* (Müller) is of moderate thickness with prominent knobs and sub-digitiform projections around the margin. The predominant ossicles in *Paracaudina coriacea* (Hutton) are thick buttons with rounded margin and small perforations. *Paracaudina keablei* sp. nov. is distinguished from both these species by having a predominant ossicle form of thin-walled plates with large perforations and lack of prominent marginal projections. The ossicles in *Paracaudina delicata* Pawson and Liao, 1992 are also thin-walled, but have numerous fine digitiform projections around the margin. *Paracaudina keablei* is further distinguished from the other three species mentioned here by having a short thin tail.

Paracaudina luticola Hickman, 1962

Figures 11d, 15

Caudina chilensis.—Joshua and Creed 1915: 21–22 (part) (non *Molpadia chilensis* Müller, 1850).

Paracaudina luticola Hickman, 1962: 65–66, figs 131–139.—Hickman, 1978: 32, figs 25–44, pl. 2.—Pawson, 1977: 119.—Rowe, 1982: 471, fig. 10.35a.—Rowe and Gates, 1995: 265.

Material examined. Syntypes. Tasmania, Derwent Estuary, Ralph's Bay, 13 m, 30 Jun 1959, AM J7205 (2).

Other material. Victoria, Shallow Inlet, mud/sand seagrass, intertidal, 2 Feb 1990, NMV F169342 (2); Wilson's Promontory, Waratah Bay, Sandy Point, 31 Mar 1969, NMV F76072 (1). South Australia, SAM K1379 (1); Aug 1886, SAM K1380 (1); St. Vincent Gulf, donated by SAM, NMV F45018 (3; labelled as determination by Joshua and Creed in 1915 as *Caudina chilensis*); St Vincent Gulf, mixed localities, Aug 1886, SAM K2484 (1); Adelaide Outer Harbour, Feb 1935, SAM K2505 (1); Port Stanvac, 6 Feb 1991, SAM K2499 (1); Henley Beach, SAM K2488 (1); Brighton to Semaphore, SAM K2494 (2); Largs Bay beach, 26 Aug 1971, SAM K2508 (1); Edithburgh, Sultana Point, sand bar, 8 Nov 2003, SAM K2489 (1); Sir Joseph Banks Group, Marum I., in *Posidonia*, 12 m, 11 Jan 1984, SAM K2497 (1); Port Lincoln, 22 Aug 1975, AM J9466 (1); Venus Bay, 1982, SAM K2500 (4); Edward Bay, N of Streaky Bay, 23 Oct 1986, SAM K2483 (1). Western Australia, Bremer Bay, near Albany, on beach after storm, 5 Aug 1984, WAM Z31887 (1).

Diagnosis. *Paracaudina* species up to 137 mm total length, up to 19 mm diameter, caudal taper and discrete thin tail 52 mm long (up to 160 mm long live, Hickman 1978); long thin discrete tail; body wall thin, firm, parchment-like, variably wrinkled and transversely creased, preserved colour off-white to faint pink to grey; ossicles variable in form, similar from mid-body and tail, predominantly thick crossed cups, oval in form, large central perforation, lacking peripheral perforations, about 10–12 projecting marginal knobs, fewer marginal surface knobs, central perforation spanned by discrete cross, each arm of cross with rounded knob-like end; ossicles never with bridging cross on one side and box on other side of central perforation; ossicles up to about 56 µm long.

Type locality. Tasmania, Derwent Estuary, Ralph's Bay, 13 m.

Distribution. Southern Australia; southern Tasmania, north to Shallow Inlet (east of Wilson's Promontory, Victoria), west to Streaky Bay (west side of Eyre Peninsula in South Australia) and Bremer Bay (near Albany in Western Australia); 0–13 m.

Remarks. Hickman 1962 erected this species for caudal part-specimens only, but subsequently (1978) described whole specimens from the type locality. Ossicle size and form do not vary for body wall tissues taken from the main body and tail. The predominant ossicle form of thick four-holed cups with marginal and surface knobs and discrete cross is diagnostically distinctive for *Paracaudina luticola* Hickman, 1962. Joshua and Creed 1915 determined specimens from South Australia to be *Caudina chilensis* (Müller) that showed a "very great variation". We judged above, from their description, that some of the larger specimens were *Paracaudina cuprea* O'Loughlin and Barmos. We judge here, from their description of "about 70 mm long, white colour, markedly caudate discrete tail about

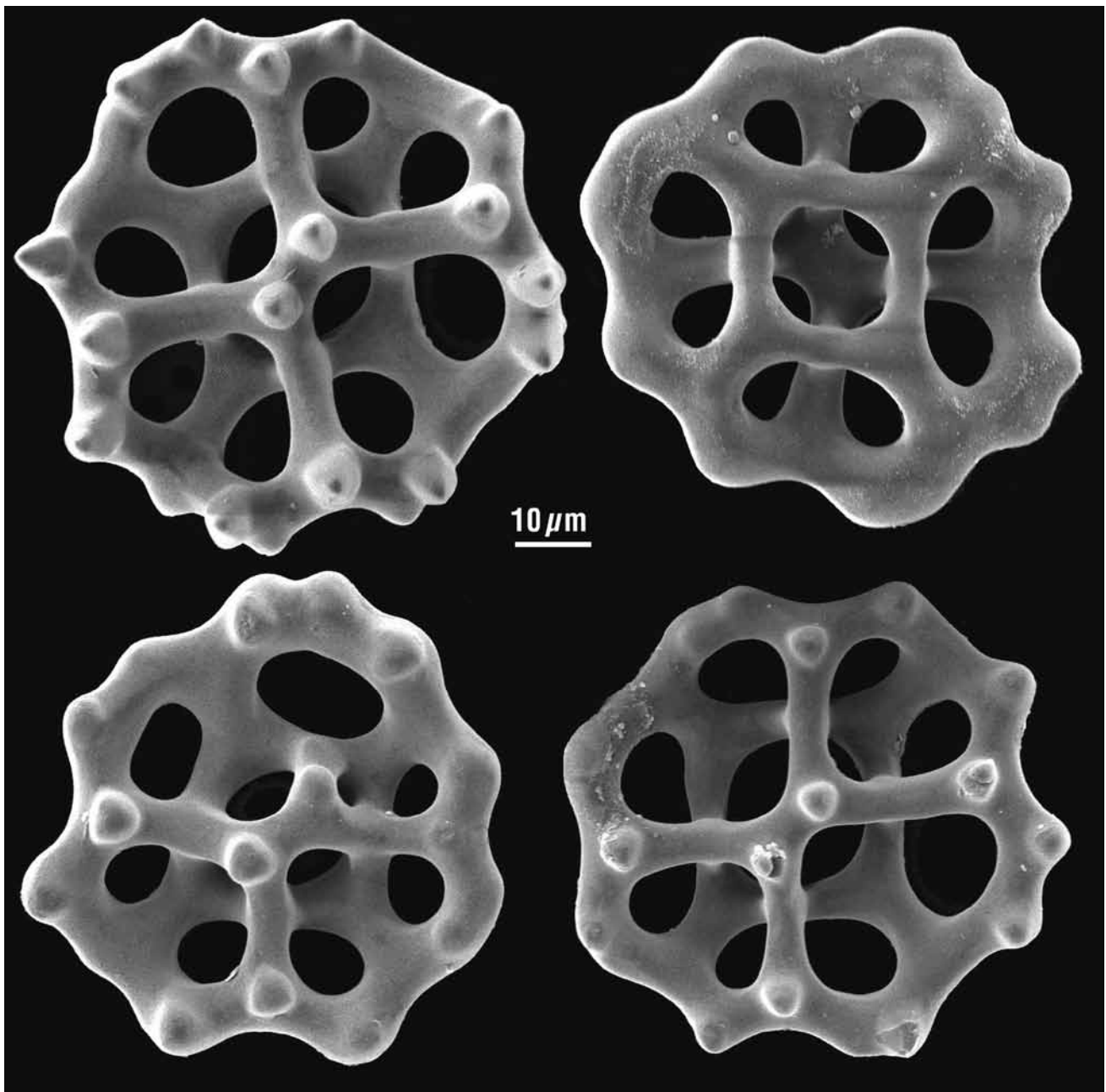


Figure 14. SEM images of ossicles from the mid-body wall of the holotype specimen of *Paracaudina keablei* O'Loughlin and Barmos sp. nov. from Dunwich, Stradbroke Island, Moreton Bay, Queensland (AM J13579).

half the length of the whole specimen", that some of the specimens were *Paracaudina luticola* Hickman.

Paracaudina tetrapora (H. L. Clark, 1914)

Figures 11e, f, 16, 17

Caudina chilensis.—Joshua, 1914: 6 (part) (non *Molpadia chilensis* Müller, 1850).

Caudina tetrapora H. L. Clark, 1914: 170, fig. 1.

Paracaudina tetrapora.—H. L. Clark, 1935: 267–284.—H. L. Clark, 1938: 541.—H. L. Clark, 1946: 445.—Pawson, 1977: 119.—Rowe, 1982: 472.—Rowe and Gates, 1995: 265.

Material examined. Western Australia, Perth, Kwinana beach, Oct 1958, WAM Z31886 (1); South Cottesloe, 8 Nov 2008, WAM Z31883 (1). South Australia, Spencer Gulf, Sir Joseph Banks Group, Marum I., sand, 5 m, 8 Jan 1984, SAM K2496 (1); St. Vincent Gulf, North Haven to Largs Jetty, seagrass, 1 Dec 1980, SAM K2501 (1); Brighton Beach, 14 Feb 1975, SAM K2507 (2); off Glenelg, 10 m, 15 Feb 1969, AM

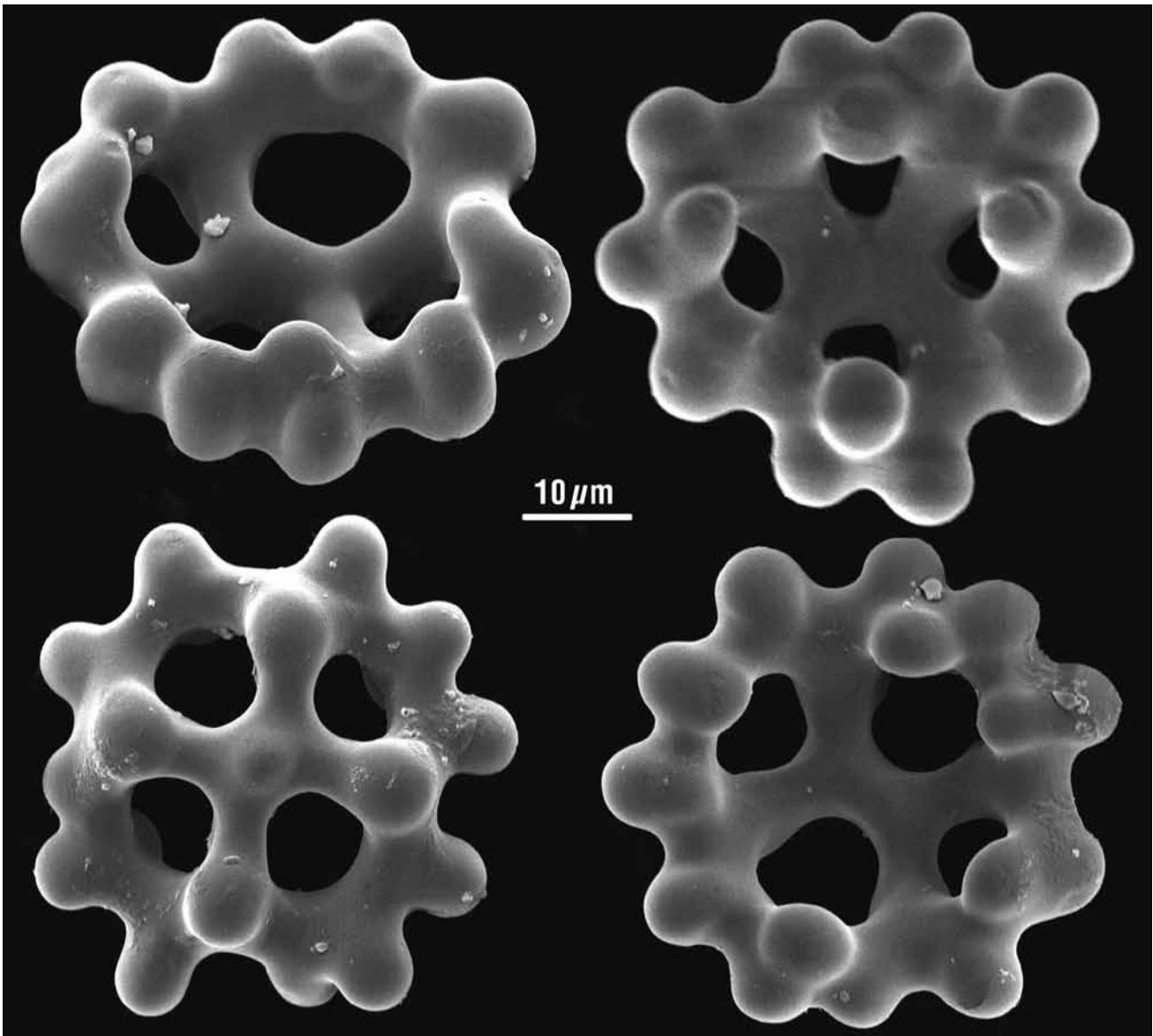


Figure 15. SEM images of ossicles from the mid-body wall of a specimen of *Paracaudina luticola* Hickman, 1962 from Sandy Point, Waratah Bay, Victoria (NMV F76072).

J24918 (1); mixed localities, Aug 1886, SAM K2485 (2). Victoria, Westernport Bay, Merricks, 29 Jan 1983, NMV F76565 (1); Flinders, beach, Jul 1967, NMV F45259 (1); Shoreham, 30 Mar 1902, NMV F45019 (remaining specimen from Shoreham lot 60669–71 / H19 (3) examined in part by Joshua 1914); Merricks, beach, Apr 1969, NMV F45274 (1).

Diagnosis. *Paracaudina* species up to 116 mm total length, up to 24 mm diameter, caudal taper and thin tail combined length 53 mm (preserved; WAM Z31886); firm leathery to parchment-like body wall with slight wrinkling; off-white to cream preserved colour, some yellow to yellowish-red colouration, some phosphatising with yellow colouration around eroding ossicles; posterior body with distinct long caudal taper to

narrow rounded end, sometimes tapering to a discrete long thin tail; mid-body ossicles predominantly 4-holed thick buttons, also thick perforated plates and bluntly spinous cups; 4-holed buttons irregularly oval to rectangular, some shallow concave, frequently 4 perforations with 2 large central and 2 small distal, variably thickened and marginally knobbed, up to 48 μm long; some thick irregularly oval to round perforated plates with up to 15 small perforations, margin and surface variably lumpy and knobbed and with blunt pointed projections, rare joining of knobs to create secondary layering, thickened plates up to 72 μm long, more evident in larger specimens; shallow cups with 4 perforations, long blunt thick marginal spines, marginal surface knobs, up to 72 μm long, more evident in larger

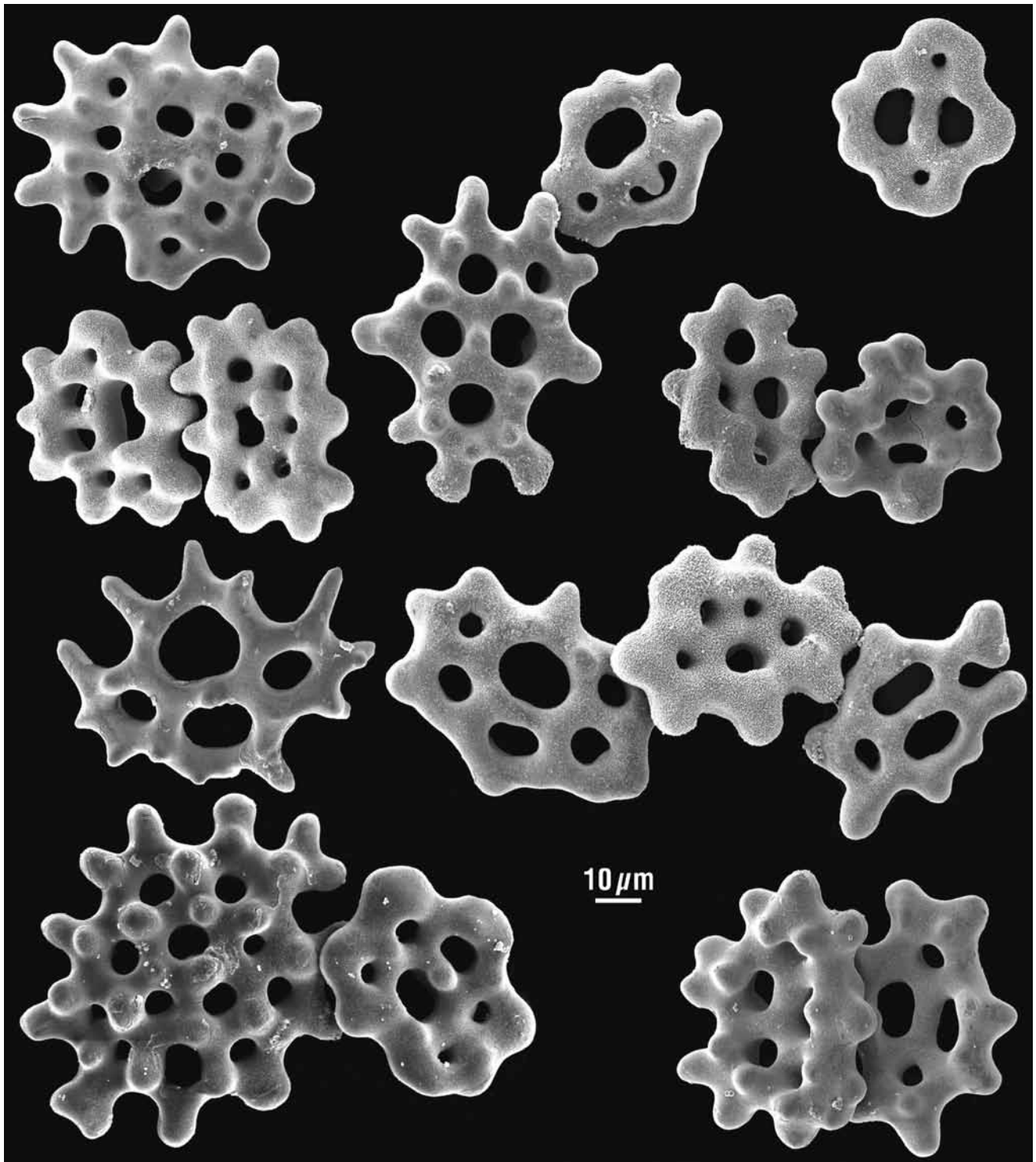


Figure 16. SEM images of ossicles from the mid-body wall of a specimen of *Paracaudina tetrapora* (H. L. Clark, 1914) from Merricks, Westernport Bay, Victoria (NMV F76565).

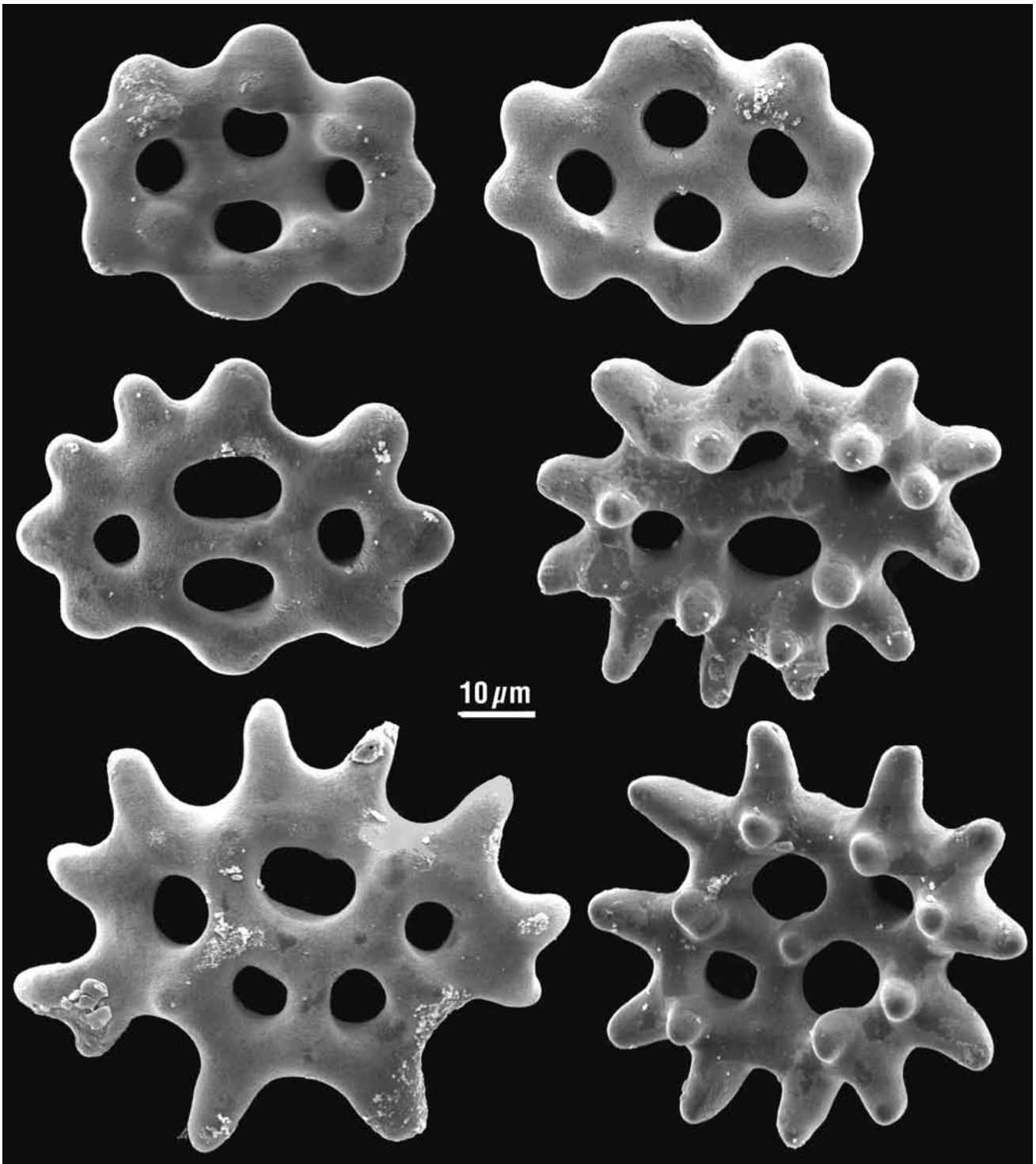


Figure 17. SEM images of ossicles from the mid-body wall of a specimen of *Paracaudina tetrapora* (H. L. Clark, 1914) from off Glenelg, St. Vincent Gulf, South Australia (AM J24918).

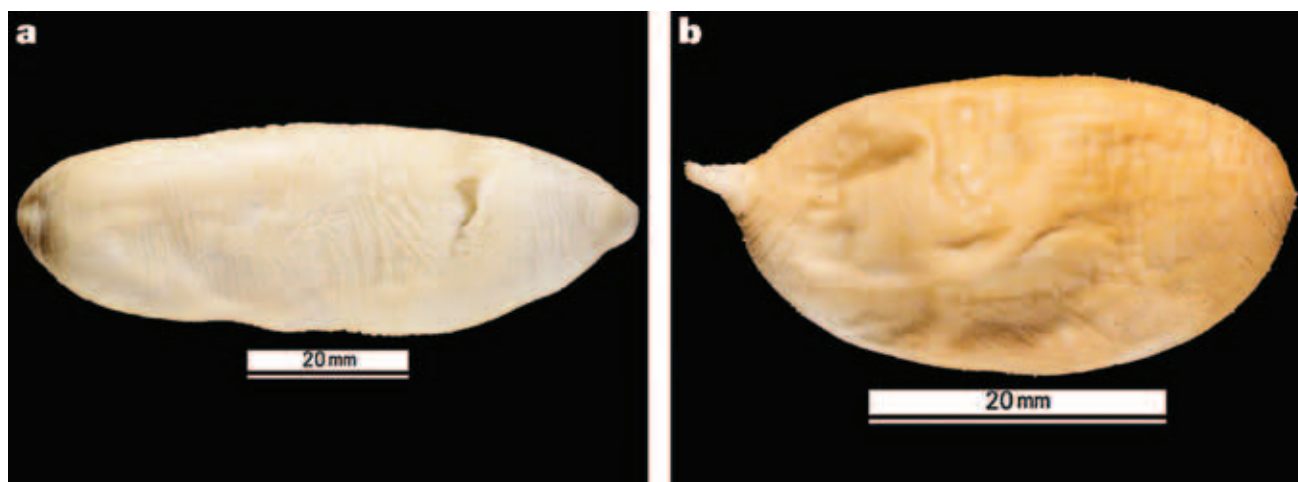


Figure 18. Photos of *Paracaudina tripoda* O'Loughlin and Barmos, sp. nov. (photos by L. Altoff, MRG). a, holotype from Queensland, east of Lady Elliot Island, 230 m (AM J24922); b, small paratype, north of Fraser Island, 137 m, (AM J11150 (7)).

specimens; ossicles never *chilensis*-like with central perforation with box and cross bridges.

Type locality. Western Australia, Perth, Cottesloe beach.

Distribution. Southern Australia, from Abrolhos Islands, Western Australia, to Westernport Bay, Victoria; to 10 m.

Remarks. *Paracaudina tetrapora* (H. L. Clark, 1914) is distinguished amongst Australian species of *Paracaudina* by having ossicles that are thick knobbed irregularly oval buttons with predominantly 2 large central and 2 distal smaller holes. Joshua 1914 reported two specimens from Victoria as *Caudina chilensis* (Müller). Details provided for the larger one (and confirmed here, NMV F169344) indicate that it was *Paracaudina cuprea* O'Loughlin and Barmos sp. nov. (above). The second specimen (seen here, NMV F45019) was *Paracaudina tetrapora* (H. L. Clark). Yellow body wall colouration with phosphatising of ossicles and phosphatic body wall residues is evident in larger specimens. In the largest specimen (SAM K2507) there is dark red phosphatising of the calcareous ring, and the reddish-brown colouration of the polian vesicle is presumed to be due to phosphatising.

***Paracaudina tripoda* O'Loughlin and Barmos sp. nov.**

Figures 18, 19

Material examined. Holotype. Queensland, east of Lady Elliot Island, 24°07'S 152°52'E, 230 m, 7 Jul 1984, AM J24922.

Paratypes. Type locality and date, AM J18814 (3); east of Lady Elliot Island, 24°04'S 152°48'E, 192 m, 7 Jul 1984, AM J18813 (1); north of Fraser Island, 24°23'S 153°17'30"E, 137 m, 15 Dec 1977, AM J11150 (7).

Diagnosis. *Paracaudina* species up to 75 mm total length, diameter up to 27 mm; oral and caudal tapers, lacking long thin tail, sometimes short discrete tail; body wall firm, leathery, slightly rugose; small preserved specimens reddish-yellow (rusty), larger specimens off-white; reddish-yellow pigment

may be present; mid-body with abundant irregularly round to oval, thick button-like ossicles, some slightly concave, up to 64 μ m long; majority of ossicles with rounded edge, short thick surface spines, ossicles frequently with large central perforation with tripod or single rod or cross bridge, up to 11 variably sized perforations; many *australis*-like plates with horizontal marginal projections; some *chilensis*-like plates with bridging box and cross over central perforation, some with bridging tripod; rare *ambigua*-like mid-body plate ossicles with 2–4 perforations, up to 32 μ m long.

Type locality. Northeast Australia, Queensland, E of Lady Elliot Island, 230 m.

Distribution. Northeast Australia, off Lady Elliot and Fraser Islands; 137–230 m.

Etymology. From the Greek *trion* (three) and *podos* (foot), referring to the frequency of a tripod bridge over the central perforation in the ossicles.

Remarks. The holotype specimen of *Paracaudina tripoda* O'Loughlin and Barmos sp. nov. is damaged, but the ossicles are in good condition and the body form is evident. Three *Paracaudina* Heding, 1932 species lack a long thin tail and have irregular small plate or button ossicles in the mid-body wall. In two of these species, *Paracaudina australis* (Semper, 1868) and *Paracaudina cuprea* O'Loughlin and Barmos sp. nov., the predominant ossicles from the mid-body are plates with lateral rounded marginal spines and surface spines and knobs. In the new species *Paracaudina tripoda* O'Loughlin and Barmos the predominant ossicles lack lateral rounded marginal spines, and have surface spines. *Paracaudina australis* specimens show rare slight yellowing, and have rods in the mid-body wall. *Paracaudina cuprea* specimens show strong reddish-yellow colouration with increasing size. *Paracaudina tripoda* specimens show decreasing reddish-yellow colouration with increasing size.

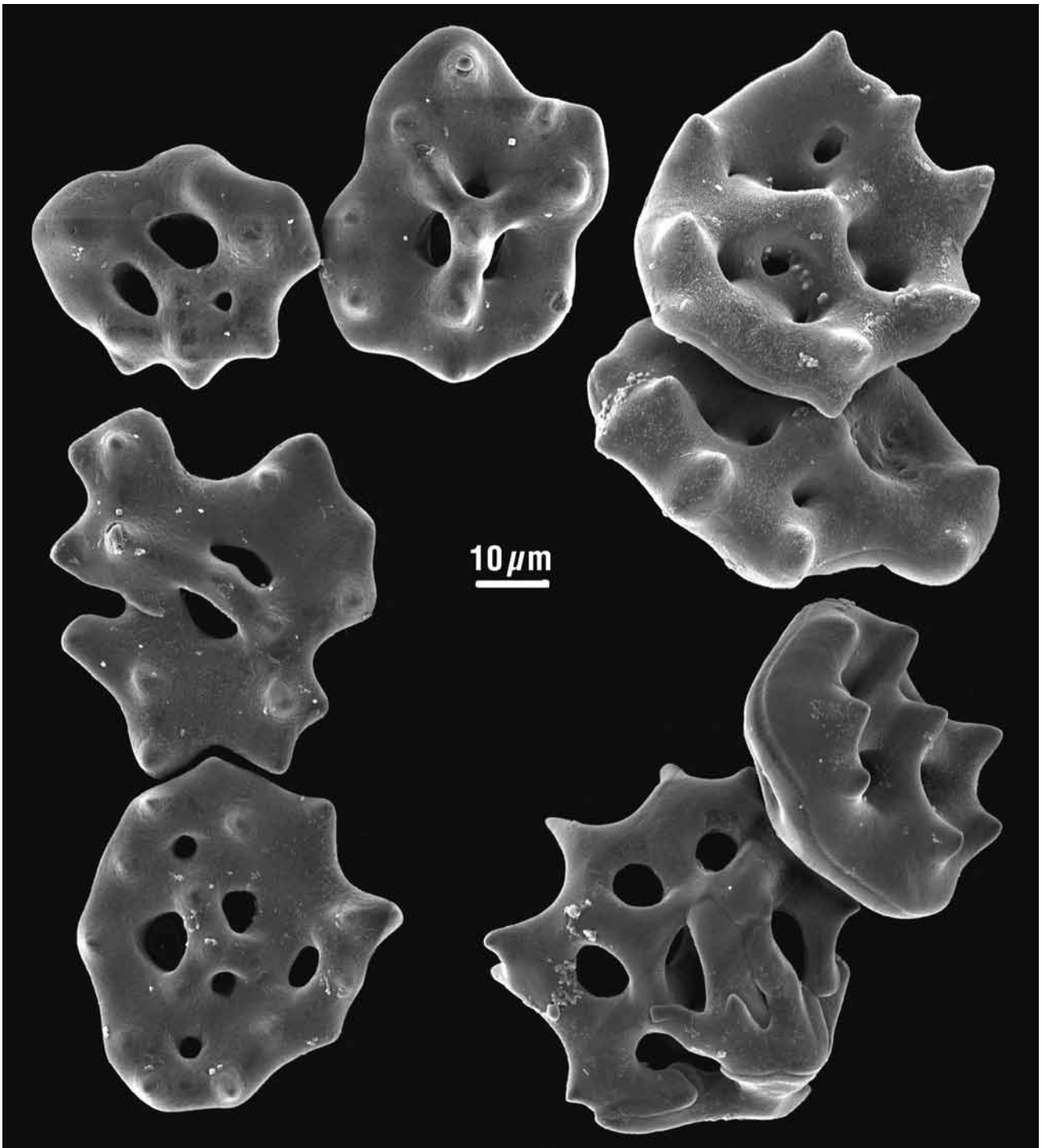


Figure 19. SEM images of ossicles from the mid-body wall of the holotype of *Paracaudina tripoda* O'Loughlin and Barmos sp. nov. (AM J24922).

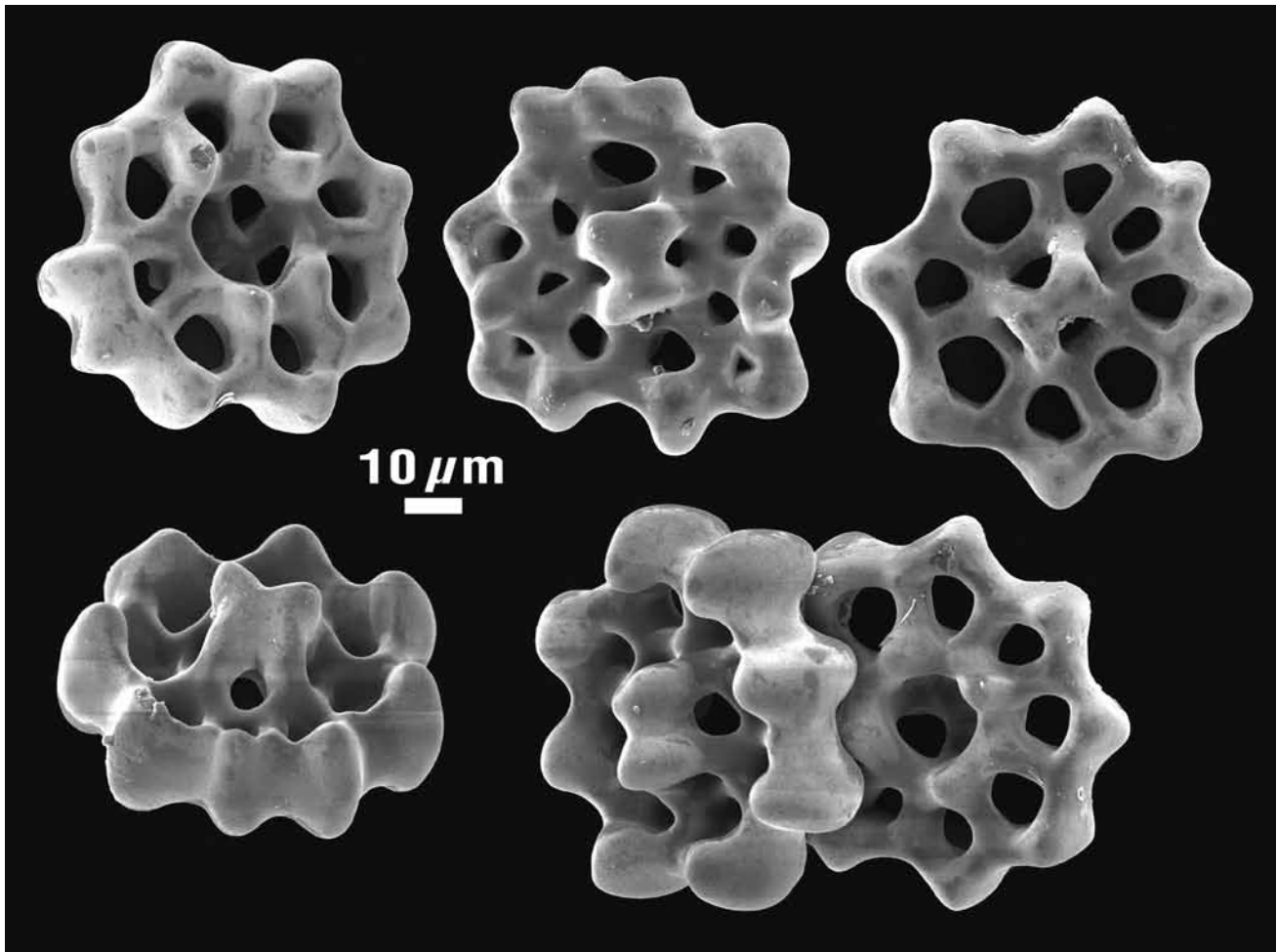


Figure 20. SEM images of ossicles from the mid-body wall of a 35 mm long specimen of a species of *Paracaudina* Heding 1932 from the Chatham Rise (NIWA 70957).

Paracaudina species (not described)

Figure 20

Material examined. East of New Zealand, Chatham Rise, 43.00°S 179.00°W, 546 m, 12 Sep 1989, NIWA 70957 (1); outer east Cook Strait, 41.70°S 175.65°E, 1040–1080 m, 15 Apr 2010, NIWA 63034 (1); 41.51°S 175.72°E, 1076–1104 m, 17 Apr 2010, NIWA 63195 (1); 41.95°S 174.62°E, 964–1005 m, 23 Apr 2010, NIWA 63806 (5).

Remarks. Our colleagues in NIWA (Wellington) inform us of many *Paracaudina* specimens in their collections. We have had the opportunity to examine only eight. Mid-body ossicles from one small specimen (35 mm long; NIWA 70957) are illustrated here. They are not those of *Paracaudina coriacea* (Hutton, 1972) or *Paracaudina chilensis* (Müller, 1850). Nor do the ossicles in the eight specimens appear to be the ossicles of only one species, those from the Chatham Rise specimen differing from those from the outer east Cook Strait specimens. A comprehensive examination of the NIWA *Paracaudina* specimens will be undertaken after this work, presumably in Wellington.

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