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An overview of the Australian psolid sea cucumbers (Echinodermata: Holothuroidea: Psolidae) with the description of 5 new species

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Abstract

Four new species of *Psolus* Oken from Australia are described: *Psolus parantarcticus* **sp. nov.** from Macquarie Island, *Psolus salottii* **sp. nov.** from South Australia and Macquarie Island, *Psolus steuarti* **sp. nov.** from Victoria, and *Psolus springthorpei* **sp. nov.** from Queensland. One new species of *Psolidium* Ludwig from Australia is described: *Psolidium oloughlini* **sp. nov.** from King Island. All Australian psolid species are included in the overview: *Ceto cuvieria* (Cuvier), *Psolidium berentsae* O'Loughlin & Maric, *P. granuliferum* H.L. Clark, *P. hutchingsae* O'Loughlin & Maric, *P. karenae* O'Loughlin & Maric, *P. laperousazi* O'Loughlin & Maric, *P. marshae* O'Loughlin & Maric, *P. mccallumae* O'Loughlin & Maric, *P. minutum* (H.L. Clark), *P. nigrescens* H.L. Clark, *P. parmatum* (Sluiter), *P. ravum* Hickman, *P. spinuliferum* (H.L. Clark), and *Psolus antarcticus* (Philippi). A key to the Australian species of Psolidae is provided.

Key words: *Psolus, Psolidium, Ceto*, taxonomy, Dendrochirotida, keys

Introduction

In the order Dendrochirotida, psolid sea cucumbers (Psolidae) differ from other families through the presence of dorsal scales and a clearly demarcated ventral sole, this sole being thin and calcareous in most species. Of the six known genera of Psolidae, *Ceto* Gistel, 1848, *Echinopsolus* Gutt, 1990, *Ekkentropelma* Pawson, 1971, *Lissothuria* Verrill, 1867, *Psolidium* Ludwig, 1886, and *Psolus* Oken, 1815, only three occur in Australian waters: *Ceto, Psolus*, and *Psolidium*. Following the work initiated by O'Loughlin & Maric (2008) on Australian Psolidae we have further studied material from collections at the Smithsonian Institution, Museum Victoria, South Australian Museum, Australian Museum, and Western Australian Museum. To the overview of Australian species of *Psolidium* provided by O'Loughlin & Maric (2008), which included keys to Psolidae genera and *Psolidium* species, we add four new species of *Psolus*, one new species of *Psolidium*, and some minor amendments to their key. We provide a single key for all Australian Psolidae.

Methods

Photographs of specimens were taken using a SLR Canon EOS5D digital camera with 65 and 100 mm lenses, SLR Nikon D70 and 300S digital cameras with 105 mm lens, and a Pentax K10D digital SLR camera using a variety of lenses. Ossicles were cleared for observation using commercial bleach. Photographs of ossicles were taken using a Leica DC500 digital camera and Auto-Montage software. Photographs of specimens were taken by Leon Altoff, Audrey Falconer, Caroline Harding, Chris Rowley and Melanie Mackenzie, with the live specimen photo of *Ceto* provided by Neville Coleman. Photographs of ossicles were taken by Caroline Harding, Melanie Mackenzie and Emily Whitfield. Figures were prepared by Ben Boonan with assistance from Melanie Mackenzie, Emily Whitfield, and Mark O'Loughlin using Adobe Photoshop CS5. Loan material was sourced from a number of Australian museums and the National Museum of Natural History / Smithsonian Institution, in Washington DC, and registration numbers are provided.

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Corrected taxa spellings

The species name *Psolidium spinuliferus* (H.L. Clark, 1938) in O'Loughlin & Maric (2008) is corrected to *Psolidium spinuliferum*, *Psolidium minutus* (H.L. Clark, 1938) is corrected to *Psolidium minutum*, and *Psolidium parmatus* (Sluiter, 1901) is corrected to *Psolidium parmatum*.

Abbreviations

AM	Australian Museum (echinoderm registration numbers are AM with prefix J).
NMV	Museum Victoria (echinoderm registration numbers are NMV with prefix F).
SAM	South Australia Museum (echinoderm registration numbers are SAM with prefix K).
WAM	Western Australian Museum (echinoderm registration numbers are WAM with prefix Z).
USNM	United States National Museum of the Smithsonian Institution in Washington DC (echinoderm registration numbers are USNM, with prefix E for the specimens referred to in this work).

Dendrochirotida Grube, 1840 (restricted Pawson & Fell 1965)

Psolidae Forbes, 1841

Diagnosis (see O'Loughlin & Maric 2008)**.** Body flattened, with well-defined ventral sole. Dorsal surface of body invested by imbricating scales. Ventral sole soft, surrounded by tube feet. Mouth and anus dorsally turned.

Remarks. For synonymy, discussion, and a key to genera of Psolidae see O'Loughlin & Maric (2008), with removal of 'lacking calcareous towers' from point one emended in O'Loughlin & Whitfield (2010). The authors recommend here that 'thin calcareous' also be omitted from the point one description of the sole to allow for the inclusion of *Ceto* which has a thicker, leathery sole. The diagnosis of Psolidae above does not admit *Neopsolidium* Pawson, 1964. There are no Australian species of *Echinopsolus*, *Lissothuria* or *Ekkentropelma*.

Key to Australian species of Psolidae Forbes, 1841

1	Oral valves interradial if present; 10 tentacles 2
-	Oral valves radial; 15 tentacles. . . . . *Ceto cuvieria* (Cuvier, 1817) (southern and western Australia)
2	Mid-body tube feet project through dorsal and lateral scales 3
-	Mid-body tube feet absent dorsally and laterally 15
3	"Thorn" ossicles present in body wall and tentacles. 4
-	Body wall and tentacles lacking "thorn ossicles" 5
4	Mid-ventral radial series of tube feet present; buttons and rosettes present in dorsal and lateral ossicles, lacking spires on dorsal and lateral multi-layered ossicles; live and preserved colour "black" . . . . . *Psolidium nigrescens* H. L. Clark, 1938 (central New South Wales)
-	Lacking mid-ventral radial series of tube feet; buttons and rosettes not present in dorsal and lateral ossicles, calcareous spires present on dorsal and lateral multi-layered ossicles; live and preserved colour not "black" . . . . . *Psolidium parmatum* (Sluiter, 1901) (NW Australia slope)
5	Dorsal and lateral scales with spires/pillars (not lumps). 6
-	Dorsal and lateral scales lacking spires/pillars, some species with surface lumps on the scales 7
6	Dorsal and lateral scales predominantly multi-layered ossicles, each with up to two thick, spinous spires, distally digitiform; lacking mid-ventral radial series of tube feet . . . . . *Psolidium oloughlini* **sp. nov.** (southern Australia)
-	Dorsal and lateral scales lacking multi-layered ossicles, single-layered, thick, perforated plates with predominantly single, marginal, digitiform spires; mid-ventral radial series of tube feet present . . . . . *Psolidium spinuliferum* (H. L. Clark, 1938) (N and W Australia)
7	Body wall with cupped crosses and/or cups 8
-	Body wall lacking cupped crosses and/or cups. 14
8	Cupped crosses and/or cups in sole of 2 size ranges. 9
-	Cupped crosses and/or cups in sole of 1 size 10
9	Rosettes present in dorsal body wall and tentacles; smaller cupped crosses and cups up to 32 μm long; sole with irregular thick perforated plates, knobbed on surface and margin . . . . . *Psolidium marshae* O'Loughlin & Maric, 2008 (SW Australia)
-	Rosettes absent from dorsal body wall and tentacles; smaller cupped crosses and cups up to 24 μm long; sole with smooth per-

	forated plates . . . . . *Psolidium minutum* (H.L. Clark, 1938) (E Tasman Sea)
10	Dorsal and lateral cups shallow, completely covered by fine spinelets, including the cross; lacking mid-ventral radial series of tube feet . . . . . *Psolidium mccallumae* O'Loughlin & Maric, 2008 (Western Australia slope)
-	Dorsal and lateral cups and cupped crosses not shallow; spinelets on rim of cup or distally on branches of cupped cross, not on cross; mid-ventral radial series of tube feet present 11
11	Body wall with predominantly cups, fewer cupped crosses 12
-	Body wall with predominantly cupped crosses, fewer cups 13
12	Knobbed plates in sole; tentacle rosettes small, up to 40 μm long; body rounded ventrally in transverse section . . . . . *Psolidium berentsae* O'Loughlin & Maric, 2008 (NE Queensland)
-	Perforated plates in sole predominantly smooth; tentacle rosettes large, up to 80 μm long; body flat ventrally . . . . . *Psolidium laperousazi* O'Loughlin & Maric, 2008 (SE Australia)
13	Knobbed perforated plates in sole; irregular perforated plates in tentacles . . . . . *Psolidium hutchingsae* O'Loughlin & Maric, 2008 (N New South Wales)
-	Perforated plates in sole predominantly smooth; tentacles lack irregular perforated plates . . . . . *Psolidium ravum* Hickman, 1962 (SE Australia)
14	Lacking series of mid-ventral radial tube feet; dorsal and lateral tube feet inconspicuous in mid-body; dorsal and lateral scales coarsely granuliform . . . . . *Psolidium granuliferum* H.L. Clark, 1938 (southern to SW Australia)
-	Mid-ventral radial tube feet present as scattered series; dorsal and lateral tube feet conspicuous in mid-body; dorsal and lateral scales finely granuliform . . . . . *Psolidium karenae* O'Loughlin & Maric, 2008 (South Australia)
15	Dorsal and lateral scales microscopically smooth; digitiform oral scales interspersed with larger oral scales; very low, flattened profile . . . . . *Psolus springthorpei* **sp. nov.** (Queensland)
-	Dorsal and lateral scales granuliform; lacking digitiform oral scales interspersed with larger oral scales or valves; low to domed profile 16
16	Dorsal and lateral scales coarsely granuliform; either cups or half-cylinders present in dorsal ossicles 17
-	Dorsal and lateral scales finely granuliform; lacking either cups or half-cylinders in dorsal ossicles 18
17	Macroscopically visible dome-like lumps on dorsal and lateral scales; half-cylinders present but lacking cups in dorsal ossicles . . . . . *Psolus salottii* **sp. nov.** (Great Australian Bight - South Australia to Macquarie Island)
-	Macroscopically visible thick granules (not dome-like lumps) on dorsal and lateral scales; cups present but lacking half-cylinders in dorsal ossicles . . . . . *Psolus steuarti* **sp. nov.** (Victoria)
18	Little to no encroaching on oral valves by body wall scales; multi-layered ossicles and perforated plates present dorso-laterally, lacking bowl ossicles in sole . . . . . *Psolus antarcticus* (Philippi, 1857) (Magellan Strait, Macquarie Island, South Georgia)
-	Encroaching on oral valves by body wall scales; multi-layered ossicles only present dorso-laterally, bowl ossicles present in sole . . . . . *Psolus parantarcticus* **sp. nov.** (Macquarie Island)

Remarks. Pawson (1968) provided a key for "Magellanic, Australasian and Macquarie Island Psolids" that was used in part for this key. The key to *Psolidium* species follows O'Loughlin & Maric (2008).

Material examined. See individual descriptions which follow and O'Loughlin & Maric (2008) for material examined during the testing and revision of this key. The following additional material was also examined: *P. spinuliferum*: Western Australia, Kimberly, Adele Island, 15º27'44.927"S 123º06'11.887"E, stn 08/K09, 6 m, L. Betteridge, 16 Oct 2010, WAM Z26180 (1).

Ceto Gistel, 1848

Diagnosis (see Pawson 1971b)**.** Five conspicuous radial oral valves. Five or more inconspicuous anal valves. Numerous tube feet on sole in all 3 radii and scattered interradially. Dorsal scales large and covered with leathery skin. Dorsal tube feet scattered through and between scales, and visible as pores. 15 tentacles. More than 25 Polian vesicles.

Ceto cuvieria (Cuvier, 1817)

Table 1, Figures 1a–c.

Synonymies. See Pawson (1971b).

Material examined. South Australia, Nuyts Archipelago, Egg Island, 32º28'S 133º19'E, N. Coleman, 1970/1971, NMV F97058 (1); Investigator Strait, 35º29'S 137º18'E, J.E. Watson, Jan 1971, NMV F96709 (4); West Island, 35º36'S 138º35'E, 24 m, J.E. Watson, 12 Jan 1971, NMV F96712 (2).

Diagnosis. As for the genus *Ceto* (see above).

Color (live). Dark brown to black and white.

Distribution. Southeast of Flinders I., South Australia to Shark Bay, Western Australia, from 15–66 m. Distribution taken from Australian Biological Resources Study (2011), where the distribution for *Ceto cuvieria* listed in Rowe & Gates (1995) is corrected based on species records coming from Flinders I., South Australia, not Flinders I., Tasmania.

Remarks. *Ceto* Gistel is a monotypic genus. For synonymy and revised descriptions for *Ceto cuvieria* (Cuvier), see Pawson (1971b) and O'Loughlin & Maric (2008). To the review of *Ceto cuvieria* by Pawson, we add a live specimen photograph. *Ceto cuvieria* is distinguished morphologically from other species of Psolidae by a combination of: radial oral valves; leathery skin covering the body wall scales; 15 tentacles; higher than usual number of Polian vesicles (up to 28 recorded).

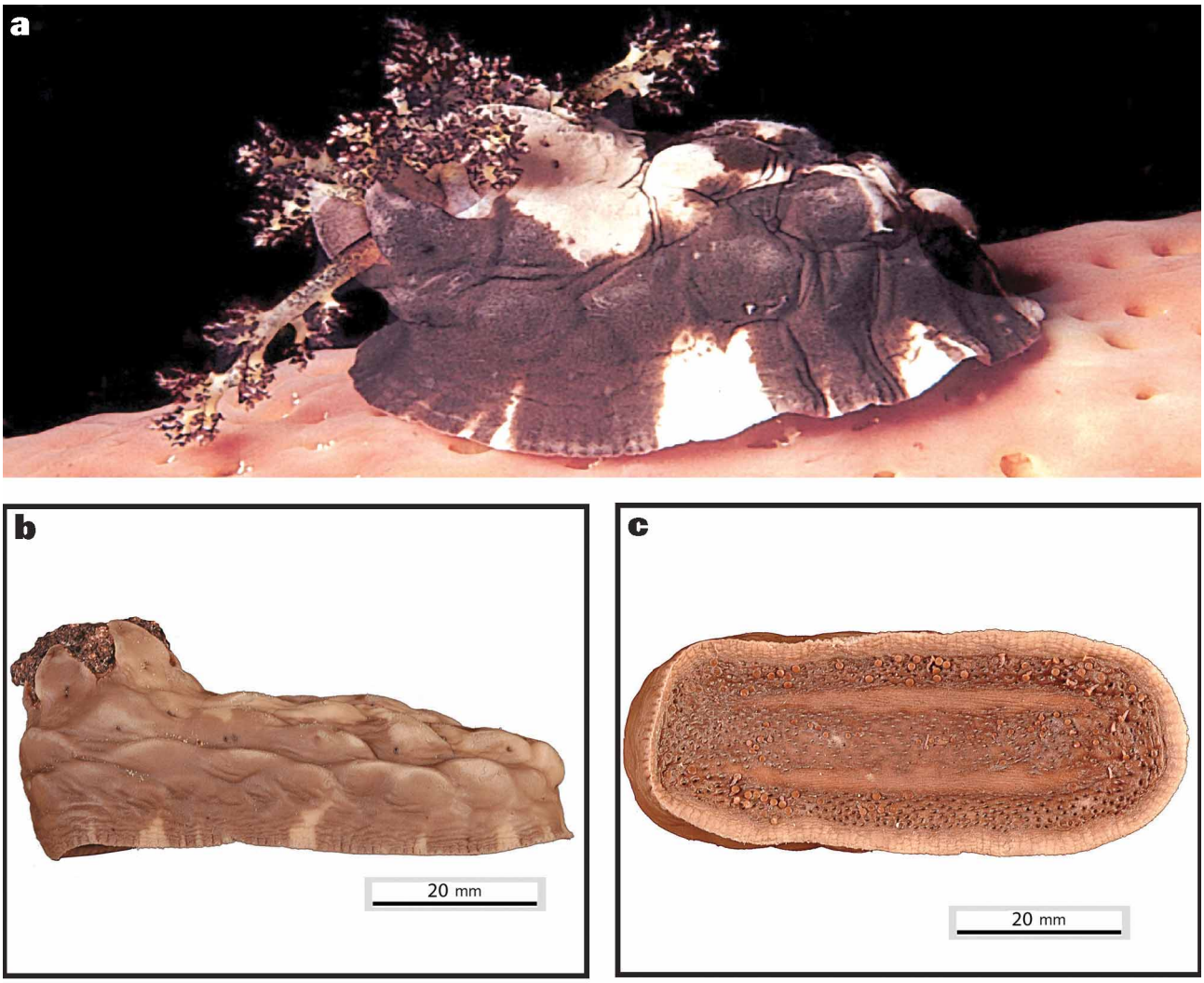

FIGURE 1. *Ceto cuvieria* (Cuvier, 1817). a, live dorso-lateral view (Nuyts Archipelago, South Australia. Photo: Neville Coleman); (b–c, NMV F97058): b, lateral view; c, ventral view.

Psolidium Ludwig, 1886

Diagnosis (O'Loughlin & Maric 2008)**.** Small species of Psolidae, arched dorsally and flattened ventrally with a distinct ventral sole. Ten dendritic tentacles present, eight large and two small ventrally. Imbricating dorsal and lateral scales, decreasing in size ventro-laterally, orally and anally. Oral and anal openings lacking large discrete valves. Tube feet present dorso-laterally though not always macroscopically evident. Ventral tube feet in two sizes with outer peripheral series smaller when present. Mid-ventral series of tube feet variably present. Dorso-lateral and ventral ossicles can include combinations of multi-layered plates, perforated plates, cups, rosettes, crosses,

cupped crosses, thorns (branched rods), and buttons. Always some tube foot canals present in dorso-lateral multi-layered ossicles. Tentacle ossicles commonly include irregular rods and perforated end plates, with rosettes sometimes also present.

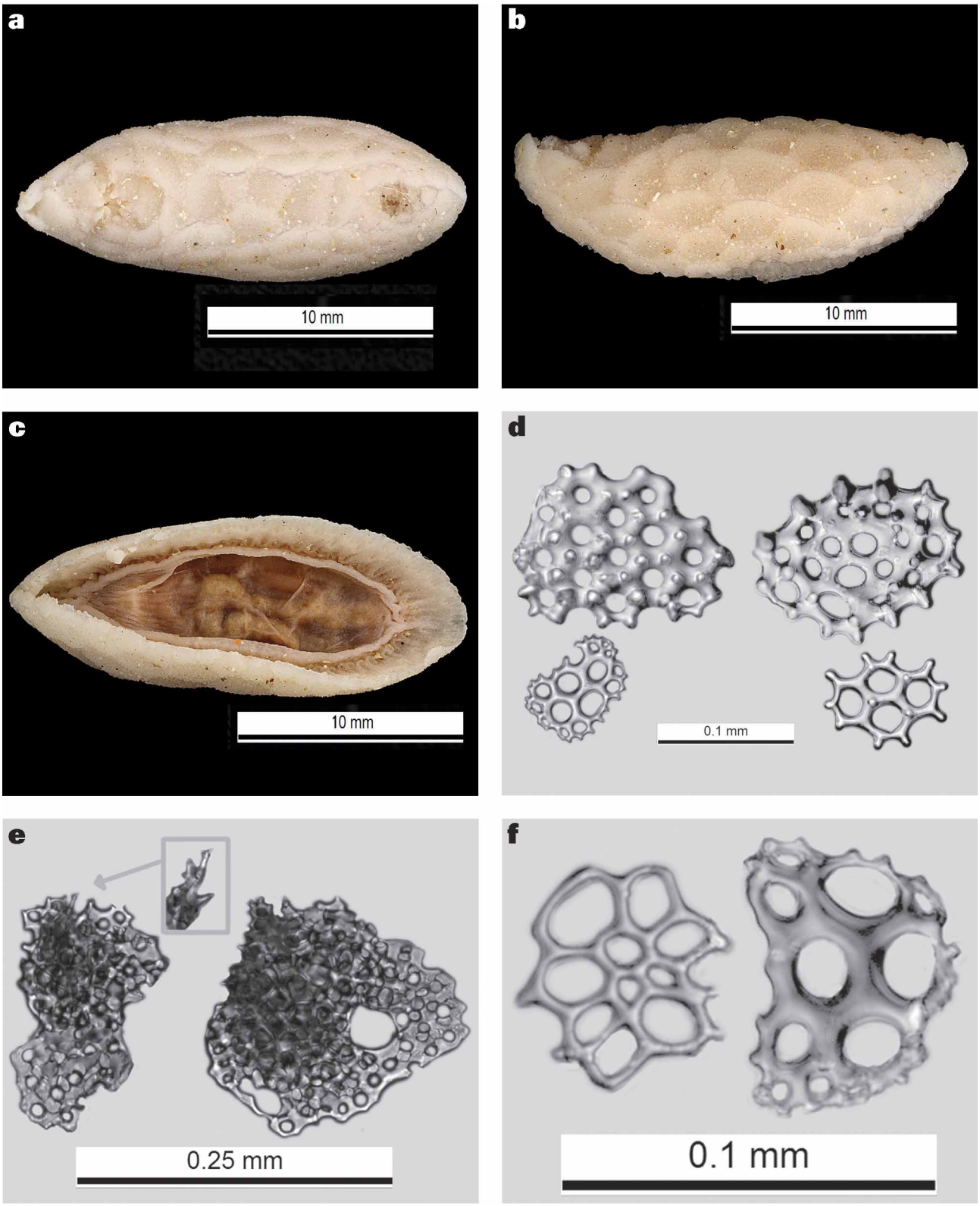

FIGURE 2. *Psolidium oloughlini* **sp. nov.** holotype (a–c, NMV F169347): a, dorsal view; b, lateral view; c, ventral view; paratype (d–f, NMV F169348): d, sole ossicles; e, dorsal scales with spires and perforations for tube feet (insert – tip of spire); f, dorsal tube foot support plates.

***Psolidium oloughlini* sp. nov.**
Table 1, Figures 2a–f.

Material examined. Holotype. Australia, Tasmania, King I., Currie Harbour, below Golf Course, 39º56'S 143º51'E, Marine Study Group, 10 Mar 1980, NMV F169347.

Paratypes. Type locality and collection date, NMV F169348 (2).

Description. *Psolidium* species up to 21 mm long, 8 mm wide, 8 mm high (holotype, preserved); elongate in form and curved ventrally creating a high vertical profile; no discrete oral or anal valves, multiple oral scales in layers, thickened and digitiform with a mostly granular surface except for tip which is smooth and lighter in colour, anal scales are thinner than oral or body wall scales; tentacles 10, 8 large, 2 small ventrally; large, irregular dorso-lateral scales up to 4 mm long with coarsely granuliform surface and macroscopically visible low-pointed spires, ventral margin scales smaller and less conspicuous at 1–2 mm in length, body wall scales strongly imbricated dorsally; dorso-lateral tube feet macroscopically inconspicuous; transparent sole, bare mid-ventrally, surrounded by roll of skin and a single series of large withdrawn tube feet separated from ventral margin by up to 2 mm of ribbed skirting, series of smaller withdrawn tube feet towards the ventral margin.

Large dorso-lateral multi-layered ossicles (scales) up to 1.3 mm long and 0.8 mm wide, or up to 256 μm long and 190 μm wide when tube foot canals are present, and variably with up to two tall (40 μm) spinous spires, distally digitiform; tube foot support plates and end plates also present dorso-laterally. Sole ossicles include single-layered flat perforated plates variably thick or thin, knobbed or smooth up to 168 μm long; flat-bottom bowls up to 176 μm long with perforations, and blunt, spinous edges; smaller tube foot end plates.

Colour (preserved). Off-white

Distribution. Australia, Tasmania, King I., Bass Strait; shallow sub-littoral zone.

Etymology. Named for P. Mark O'Loughlin (NMV Honorary Associate) in recognition of his initial research into the Australian Psolidae, which was of great assistance in this paper, and his significant ongoing contribution to holothuroid taxonomy and research.

Remarks. *Psolidium oloughlini* **sp. nov.** appeared initially to be a species of *Psolus* as the dorsal and lateral tube feet were not evident. Microscopic examination of ossicles revealed the tube foot canals and end plates of a *Psolidium*. It is distinguished from other Australian *Psolidium* species by a combination of: a greater number of oral scales; wide, ridged skirting surrounding the sole; the presence of spinous spires on many of the multi-layered dorso-lateral ossicles; the presence of flat-bottom bowls with blunt, spinous edges in the sole.

***Psolus* Oken, 1815**

Diagnosis. (from O'Loughlin & Whitfield 2010)**.** Species of Psolidae with large imbricating or contiguous dorsal and lateral scales; ventro-lateral scales at margin clearly demarcated from thin sole that lacks conspicuous scales; tube feet absent dorsally and laterally, except sometimes present orally and anally. Ten dendritic tentacles present, eight large and two small ventrally.

***Psolus antarcticus* (Philippi,1857)**
Table 1, Figures 3a–f.

Synonymies. See Pawson (1969).

Material examined. Chile, Tierra del Fuego, Isla Dawson, 53°58'S 70°34'W, Gallardo, A. & Castillo, J., 26 Sep 1965, USNM E31749 (1); Strait of Magellan, 1500–1666 m, USNS *Eltanin*, 1966, USNM E33617 (2); South Georgia, 659–686 m, USNS *Eltanin*, 1966, USNM E33616 (4); Australia, Macquarie I., off Lusitania Bay, 54°43'30"S 158°53'06"E, 100–105 m, ANARE, MV *Nella Dan*, Cochrane, T., 6 Dec 1986, NMV F76117 (1).

Description. *Psolus* species up to 51 mm long, 35 mm wide, 12 mm high (damaged specimen, USNM E31749, preserved); oval to round in form with low profile, slightly raised oral and anal cones; clear demarcation between the body wall scales and oral and anal openings, 5 large oral valves and 5 smaller anal valves, sometimes composite, with little to no encroaching by nearby body wall scales; tentacles 10, 8 large, 2 small ventrally; large,

irregular dorso-lateral scales up to 10 mm long with finely granuliform 'beaded' surface, 2 to 3 rows of significantly smaller ventro-lateral margin scales, 1–3 mm long; sole with inner paired to zig-zag rows of larger tube feet and scattered smaller peripheral tube feet, bare mid-ventrally though tube feet extend variably at oral and anal ends onto the mid-ventral line.

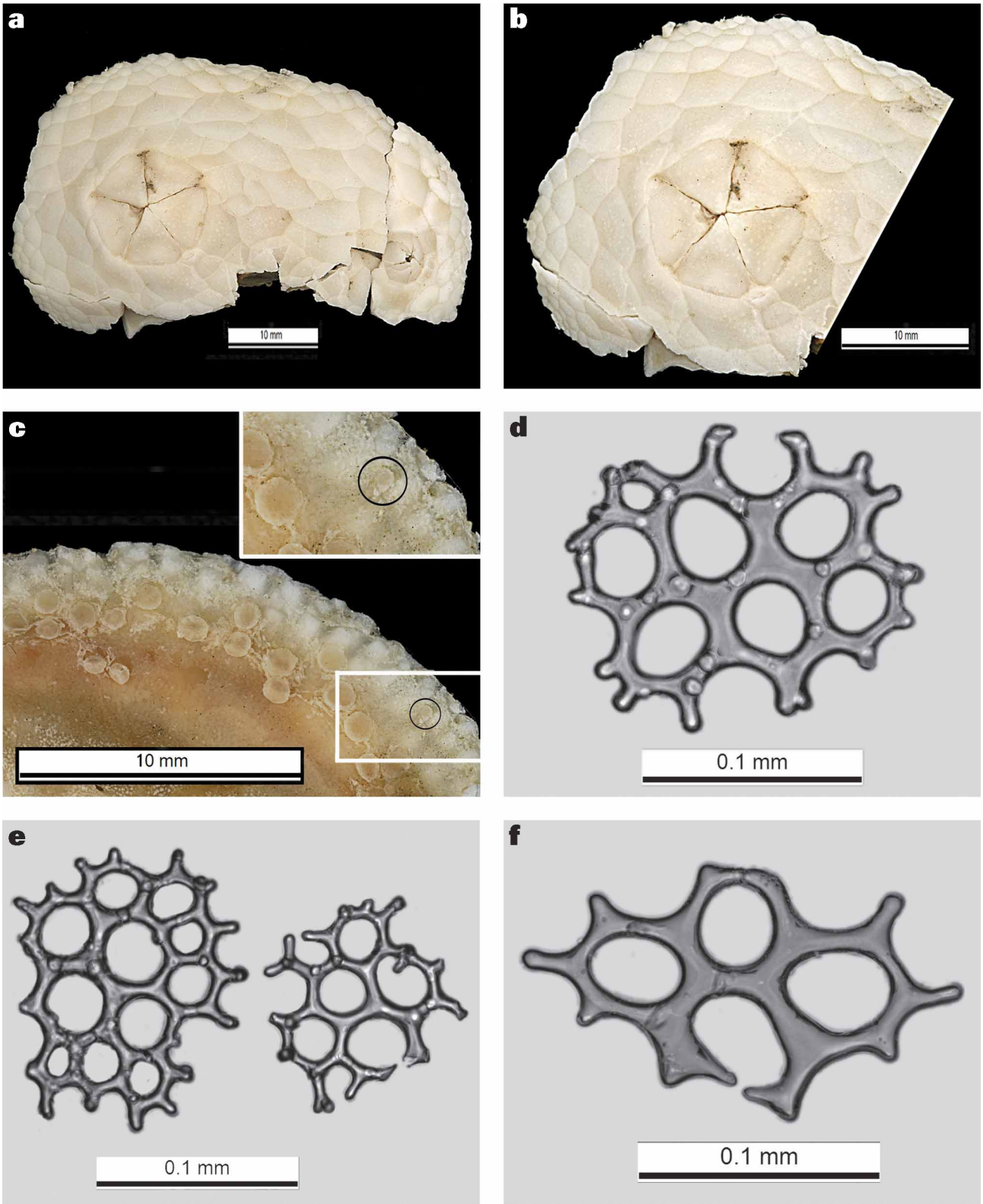

FIGURE 3. *Psolus antarcticus* (Philippi, 1857) (a–f, USNM E31749): a, dorsal view; b, dorsal view (oral end); c, ventral view; d, sole ossicle (insert, smaller scattered tube feet); e–f, dorsal ossicles.

Dorsal and lateral ossicles consist of multi-layered plates up to 1.2 mm long and perforated plates up to 0.2 mm long, variably knobbed with digitiform margins. Sole ossicles consist of irregular, heavily knobbed, perforated plates with raised margins either bluntly spinous, forked or knobbed, irregular in shape and up to 200 μm long by 160 μm wide with rounded perforations up to 40 μm in diameter. Tentacle ossicles irregular perforated plates, variably smooth to knobbed, thick to thin, often with bluntly spinous edges; largest tentacle ossicles up to 208 μm long by 184 μm wide.

Colour (preserved). White.

Distribution. South America (Magellanic region), South Georgia, Australia (Macquarie I.); 100–1666 m.

Remarks. Pawson (1968) extended the geographical distribution of *Psolus antarcticus* to Australia. With no type specimen our description is based on a damaged specimen from what we understand to be the type locality (Tierra del Fuego). Specimens of *P. antarcticus* from Macquarie Island were also examined and compared with those from the type locality, Strait of Magellan, and South Georgia. Some Macquarie Island specimens were found to be morphologically conspecific with those from the type locality, with uniformly white scales, no encroaching of body wall scales on the oral valves, and knobbed plates rather than bowls in the sole ossicles. These have been treated as the same species for this key, as we await confirmation from molecular data. Others were designated as *P. parantarcticus* **sp. nov.** and are described below. *P. antarcticus* from both the type locality and Macquarie Island is similar to *P. neozelanicus* Mortensen, 1925 but is distinguished in the literature by having sole ossicles with marginal knobs and fewer perforations. *P. neozelanicus* is a small (up to 10 mm), rare species which has been found only off the northern tip of New Zealand.

Psolus parantarcticus sp. nov.

Table 1, Figures 4a–f.

Material examined. Holotype. Australia, Macquarie I., off Nuggets Point, 54°33.4'S 158°56.9'E, 108–135 m, ANARE, MV *Nella Dan*, Cochrane, T., 8 Dec 1986, NMV F60306.

Paratypes. Type locality and date, NMV F176181 (1), NMV F160012 (4).

Other material. Australia, Macquarie I., 54°S 159°E, USNS *Eltanin*, 1968, USNM E33625 (1); Australia, Macquarie I., 112–124 m, USNS *Eltanin*, 1974, USNM E33647 (2).

Description. *Psolus* species up to 45 mm long, 31 mm wide, 12 mm high (damaged paratype NMV F176181, preserved); oval to round in form with low profile, slightly raised anteriorly; clear demarcation between the body wall scales and oral and anal openings which are both concave when tentacles are retracted; tentacles 10, 8 large, 2 small ventrally; 5 medium-sized oral valves, sometimes composite, with small body wall scales encroaching up to half the length, both scales and valves are granuliform; large, irregular dorso-lateral scales up to 9 mm long with finely granuliform 'beaded' surface and typically grey to pale brown colouring with distinct white margins (preserved); 4 to 5 clearly defined rows of significantly smaller scales on the ventral margin, less than 1 mm in length, often conspicuous due to their central darker brown colouring; sole with inner paired to single or zig-zag rows of larger tube feet and a peripheral band of closely placed, smaller tube feet, bare mid-ventrally but tube feet extend variably at oral and anal ends onto the mid-ventral line.

Dorsal and lateral ossicles consist of multi-layered plates only, up to 1.68 mm long. Sole ossicles consist of oval to rounded bowls up to 160 μm long and 128 μm wide with heavily knobbed raised margins and rarer central knobs, rounded perforations are typically smaller towards the edges with 2–3 larger central perforations up to 48 μm wide; knobbed perforated plates up to 160 μm long and 120 μm wide sometimes present. Majority of tentacle ossicles are thin, curved, irregular perforated plates with bluntly spinous edges; largest tentacle ossicles are thick and triangular, slightly curved with surface knobs and up to 424 μm long and 256 μm wide.

Colour (preserved). Pale to dark brown or grey dorso-lateral scales with distinct white margins.

Distribution. Australia, Macquarie I.; 108–135 m.

Etymology. From the Latin *par* (like), with reference to its superficial similarity to *P. antarcticus*.

Remarks. *Psolus parantarcticus* **sp. nov.** was initially assumed to be *P. antarcticus*, which is also present on Macquarie Island at similar depths. Closer examination of preserved specimens revealed significant differences including encroaching body wall scales on oral valves for *P. parantarcticus*, along with bowl-like ossicles in the sole and multi-layered ossicles only dorso-laterally. *P. parantarcticus* is distinguished from other Australian *Psolus*

species by a combination of: close peripheral series of distinctly smaller ventral tube feet; finely granuliform 'beaded' body wall scales; bowl-shaped sole ossicles; multi-layered ossicles only dorso-laterally.

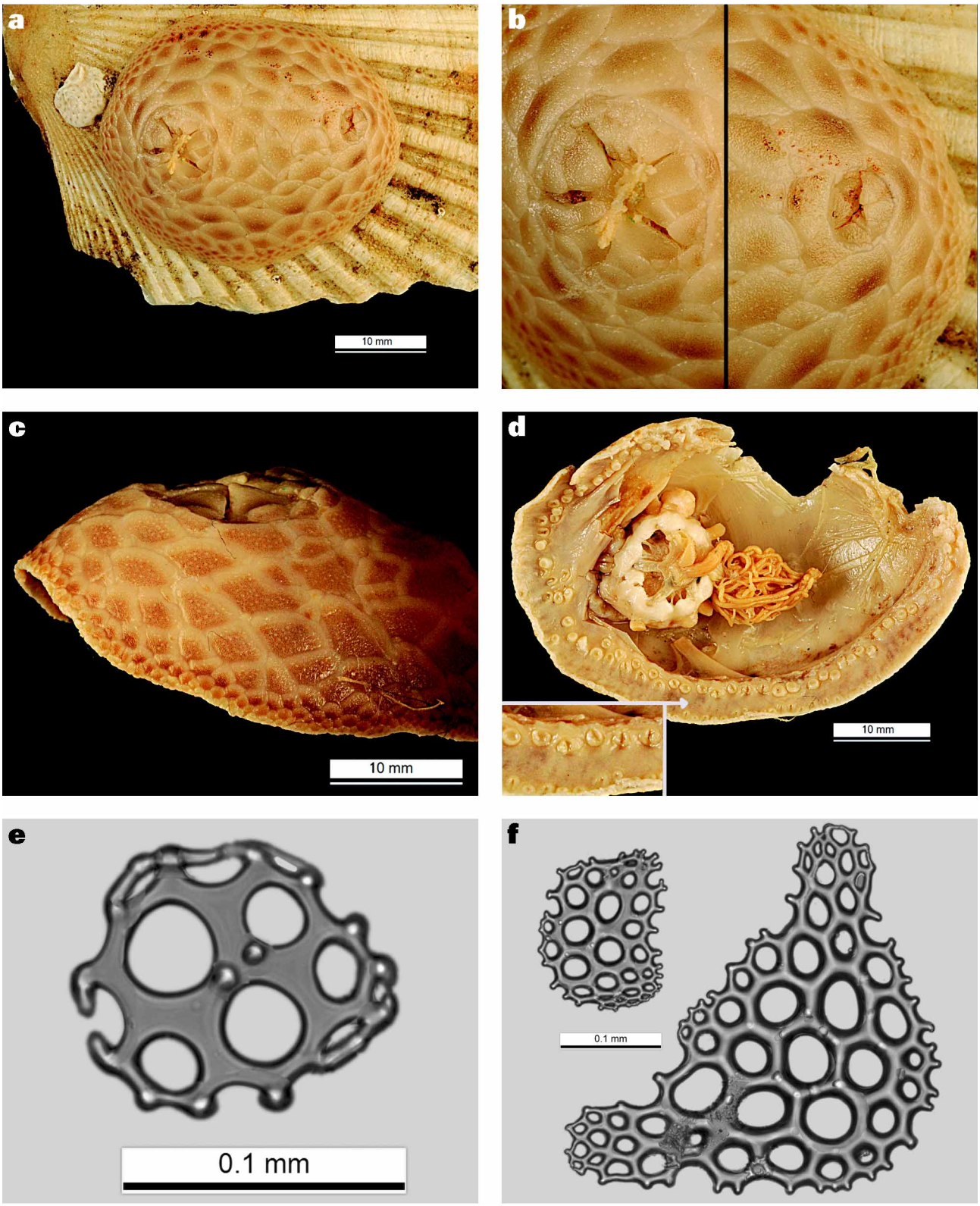

FIGURE 4. *Psolus parantarcticus* **sp. nov.** holotype (a–b, NMV F60306): a, dorsal view; b, dorsal view (oral end, anal end); paratype (c–f, NMV F176181): c, lateral view; d, ventral view (insert, smaller close series of marginal tube feet); e, bowl-like sole ossicle; f, tentacle ossicles.

***Psolus salottii* sp. nov.**
Table 1, Figures 5a–f.

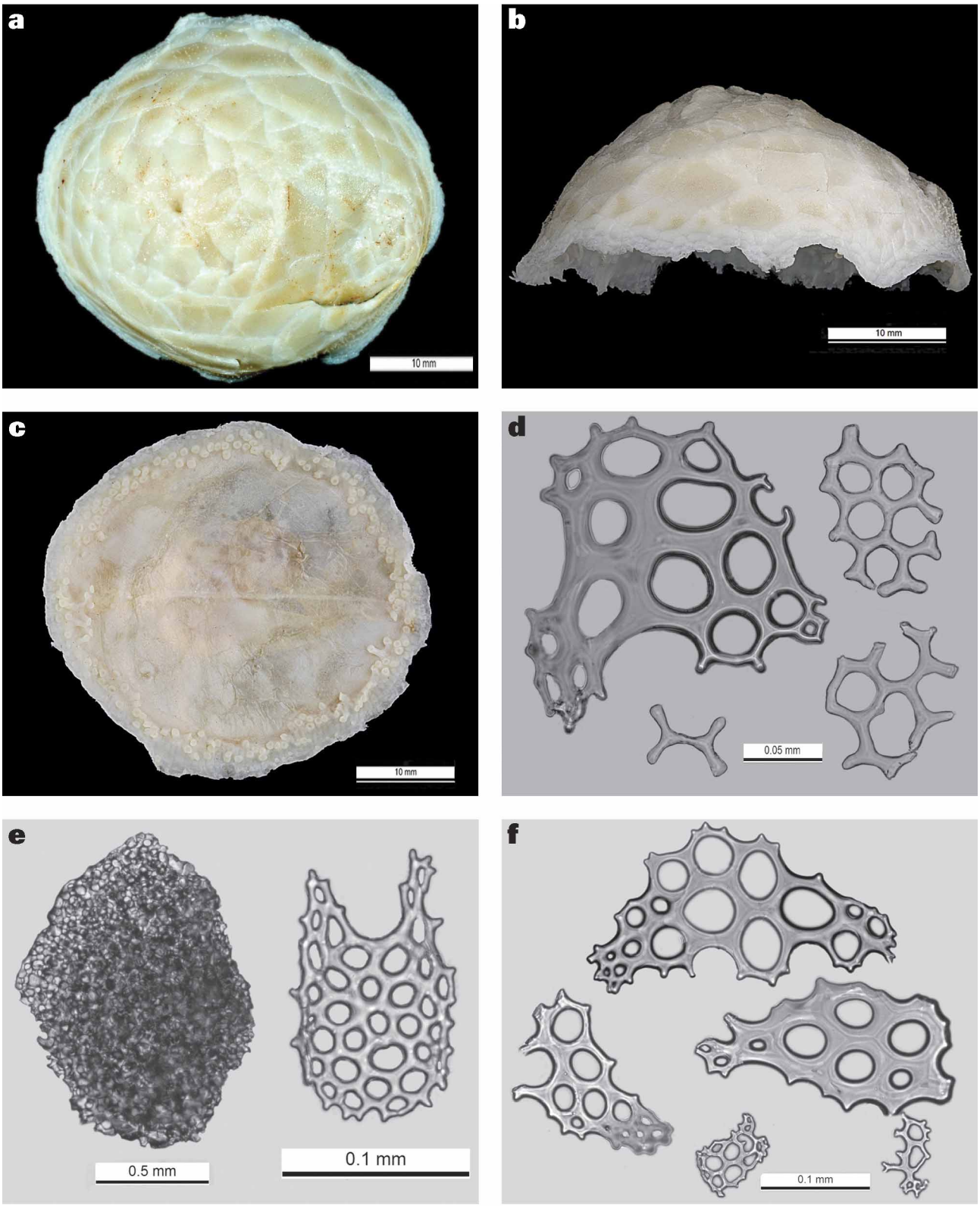

FIGURE 5. *Psolus salottii* **sp. nov.** holotype (a, b, c, d in part, e, SAM K2175): a, dorsal view; b, lateral view; c, ventral view; d, sole ossicle (larger curved plate from holotype, others from paratype); e, dorsal ossicles (multi-layered scales and perforated cylinders); paratype (d in part, f, NMV F157397): d, sole ossicles (3 smaller ossicles from paratype); f, tentacle ossicles, including end plates.

Material examined. Holotype. South Australia, Great Australian Bight, approximately 120 nautical miles due West of Cape Wiles, 34º56'S 133º19'E, trawled 772–820 m, FW *Longva III*, K. Gowlett-Holmes, 8 Nov 1989, SAM K2175.

Paratypes. Australia, North of Macquarie I., 52º59'36"–53º00'30"S 159º59'48"–160º00'36"E, epibenthic sled, 400–600 m, RV *Southern Surveyor* SS01/99, stn 129, CSIRO Fisheries Research Cruise, 31 Jan 1999, NMV F157397 (4).

Description. *Psolus* species up to 60 mm long, 40 mm wide and 20 mm high (damaged paratype, preserved); oval to circular form with domed profile, no oral or anal cone, lacking distinct oral or anal valves though 5 or more irregular, bluntly pointed oral scales present, with encroaching body wall scales; tentacles 10, 8 large, 2 small ventrally; thin, calcareous, coarsely granuliform body wall scales irregular in shape and arrangement, up to 10 mm long but variable in size and smaller on ventral margin; scales with macroscopically visible, low, dome-like lumps, slightly constricted at base, more evident laterally; non-calcareous parchment-like sole, bare mid-ventrally though tube feet extend variably at oral and anal ends onto the mid-ventral line; inner paired to zig-zag rows of larger tube feet and a peripheral band of sparsely placed and embedded, smaller tube feet.

Dorsal and lateral ossicles consist of large multi-layered ossicles (scales) up to 1.4 mm long, less common perforated plates with anastomosing secondary developments and multi-layering up to 0.9 mm long, and rare half cylinder perforated plates up to 144 μm long and 72 μm wide. Sole ossicles, rare, small, irregular single-layered plates with large round perforations often forming from cross-like initial plate of ~ 40 μm; larger single-layered perforated plates up to 160 μm long and 120 μm wide, flat to curved with up to 13 irregular perforations and some blunt spines on margins. Largest tentacle ossicles up to 280 μm long and variable in shape, thick to thin plates with multiple irregular perforations, some curved; some smaller dendritic branch endplates ~56 μm long.

Colour (preserved). Off-white.

Distribution. South Australia, 34º56'S 133º19'E, 772–820 m (holotype only); southern ocean north of Macquarie I. 400–600 m (paratypes only).

Etymology. Named for Mark Salotti (Marine Invertebrates Section, Department of Aquatic Zoology, Western Australian Museum), in appreciation of his gracious assistance with echinoderm data and loan material from the Western Australian Museum.

Remarks. *Psolus salottii* **sp. nov.** is distinguished morphologically from other Australian *Psolus* species by a combination of: multiple irregular, bluntly pointed oral scales; large, conspicuous body wall scales with dome-like lumps; and the presence of perforated half-cylindrical ossicles dorso-laterally.

***Psolus springthorpei* sp. nov.**

Table 1, Figures 6a–f.

Material examined. Holotype. Queensland, North East of Sandy Cape, 24º28'12"S 153º31'12"E, rock, coarse sand and shell, 1330–1380 m, HMAS *Kimbla* stn 17, P.H. Colman, G. Hangay and S.J. Keable, 8 Jul 1984, AM J23014. Paratype. Type locality, depth and collection date, AM J24095 (1).

Description. *Psolus* species up to 28 mm long, 17 mm wide and 5 mm high (holotype, preserved); elongate, oval form with very low profile, slightly elevated oral and anal cones; 5 large oral scales interspersed with smaller digitiform scales, all pointed apically, and smaller encroaching scales at base, no clear demarcation between body wall scales and oral scales, discrete anal cone with very small scales up to 1 mm long; tentacles 10, 8 large, 2 small ventrally; dorso-lateral scales up to 5 mm long and smooth microscopically, ventral margin scales small, 1–3 mm long, sole bare mid-ventrally, surrounded by an inner series (zig-zag to double-row) of larger tube feet separated by ribbed skirting from a peripheral single series of distinctly smaller tube feet.

Large multi-layered dorso-lateral ossicles (scales) up to 2.24 mm long, with rare thick, smooth, perforated plates (broken, up to 256 μm). Sole ossicles irregular smooth plates with occasional knobbed margins, typically 130–180 μm long, with 2 or more round to oval perforations.

Colour (preserved). Uneven brown to dark brown dorsally, white translucent sole.

Distribution. Australia, Queensland, NE of Sandy Cape; 1330–1380 m.

Etymology. Named for Roger Springthorpe (Marine Invertebrate Section, Division of Invertebrate Zoology, Australian Museum), with appreciation of his gracious assistance with loan material and data for this research.

Remarks. *Psolus springthorpei* **sp. nov.** is distinguished morphologically from other Australian *Psolus* species by a combination of: microscopically smooth dorso-lateral scales, flattened profile with slightly elevated oral and anal cones, smaller digitiform oral scales between the 5 larger and more regular scales, and uneven brown colouration on dorsal scales.

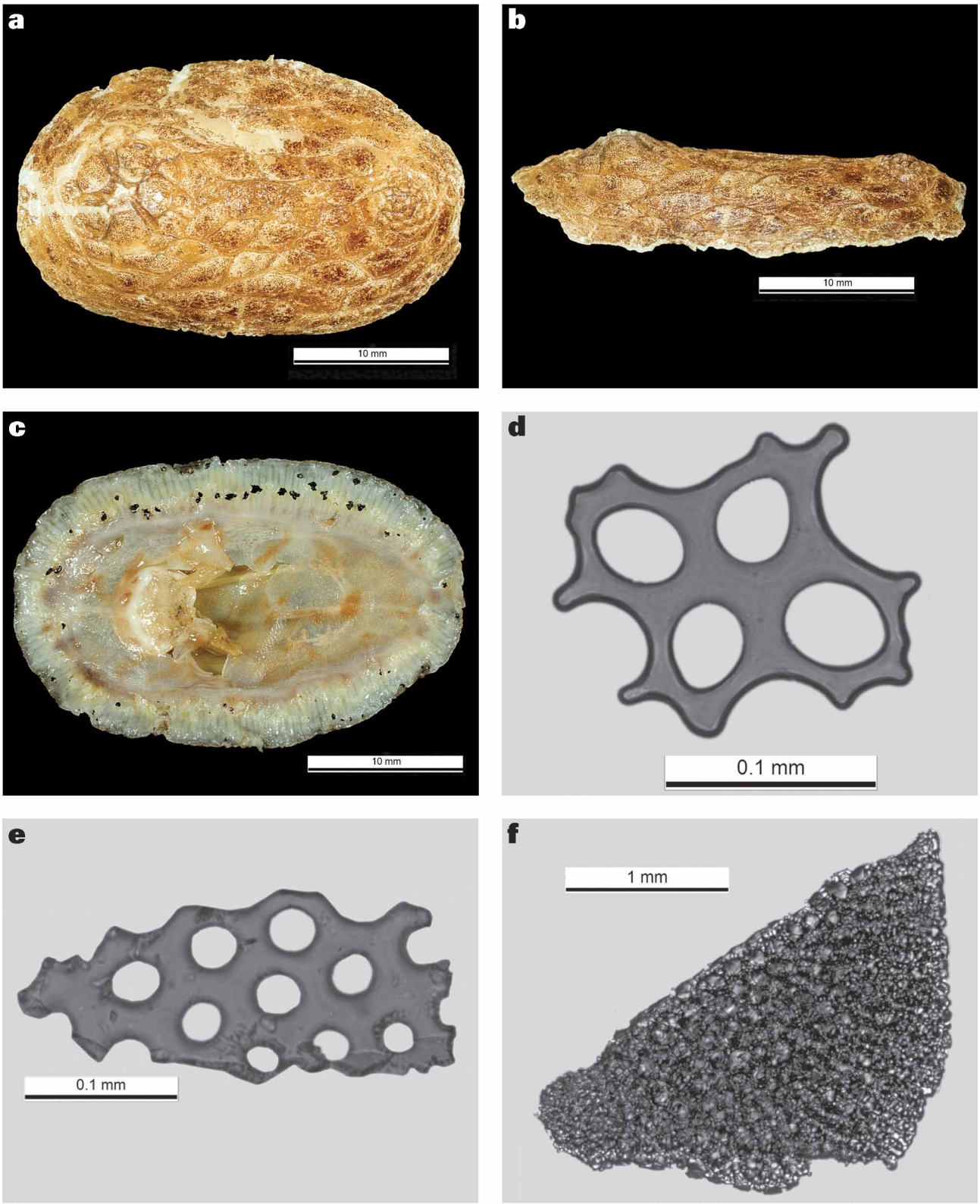

FIGURE 6. *Psolus springthorpei* **sp. nov.** holotype (a–f, AM J23014): a, dorsal view; b, lateral view; c, ventral view; d, sole ossicle; e, dorsal ossicle, fragment of perforated plate; f, dorsal ossicle, fragment of multi-layered ossicle (scale).

***Psolus steuarti* sp. nov.**
Table 1, Figures 7a–f.

Material examined. Holotype. Australia, Victoria, 38º28'41"S–38º28'40"S, 149º34'48"E–149º35'13"E, RV *Southern Surveyor* SS01/2000 stn 158, epibenthic sled 1426–1509 m, 17 Apr 2000, NMV F157398.

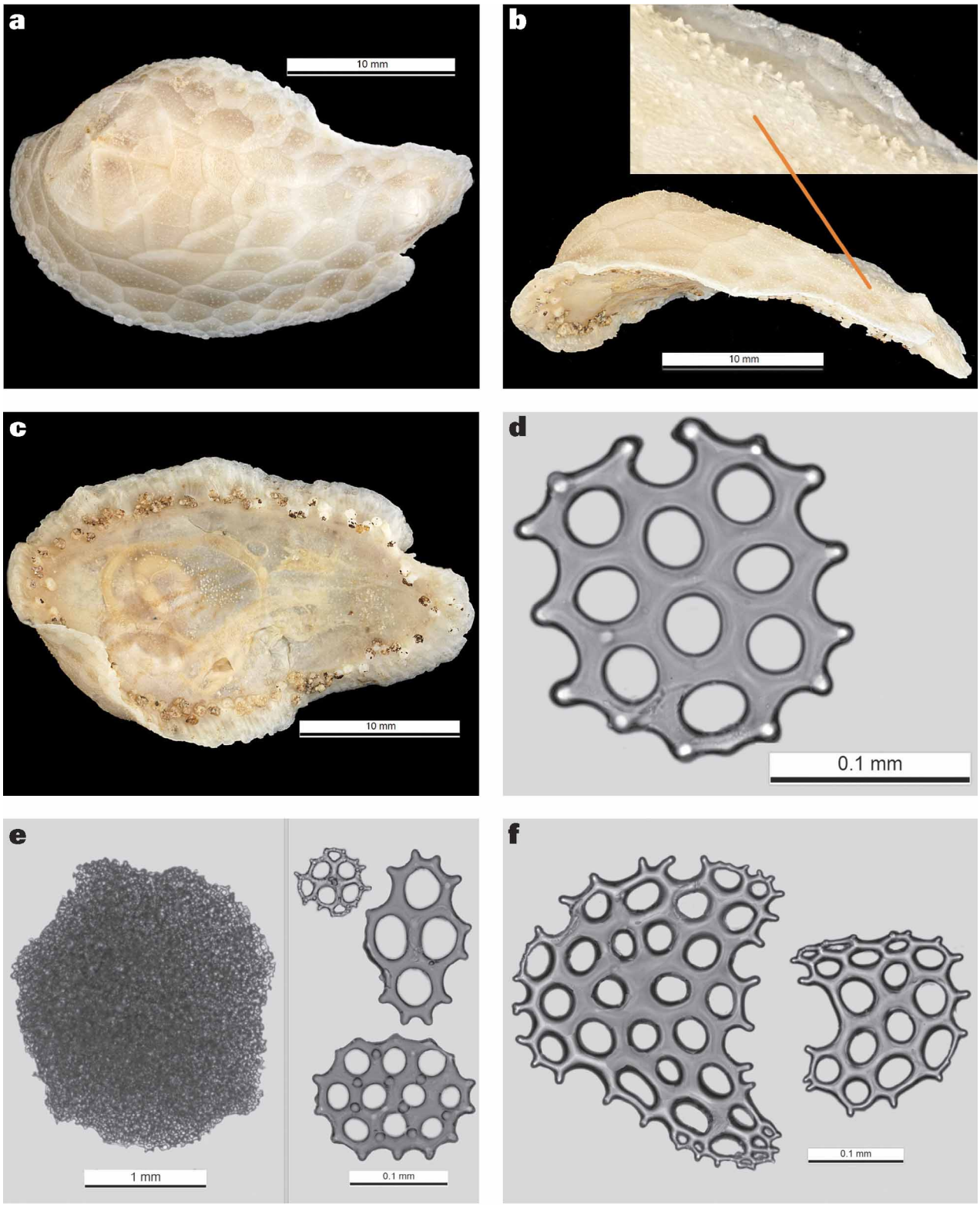

FIGURE 7. *Psolus steuarti* **sp. nov.** holotype (a–c, NMV F157398): a, dorsal view; b, lateral view (insert, thick granules); c, ventral view; paratype (d–f, NMV F157399): d, sole ossicle; e, dorsal ossicles (multi-layered scales, perforated plates and cups); f, tentacle ossicles.

TABLE 1. Distribution of Australian species of Psolidae Forbes, 1841.

Species	Distribution	Depth range	Habitat
***Ceto* species**			
Ceto cuvieria (Cuvier, 1817)	Southeast of Flinders I., South Australia to Shark Bay, Western Australia	15–66 m	On sponge
***Psolidium* species**			
P. berentsae O'Loughlin & Maric, 2008	Queensland, Lizard I.	6–18 m	Under or among coral rocks and rubble
P. granuliferum H. L. Clark, 1938	SW Western Australia to SE Tasmania	4–37 m	On coralline foliose algae, under rocks
P. hutchingsae O'Loughlin & Maric, 2008	Northern New South Wales	12–15 m	On rock, sponge, ascidians
P. karenae O'Loughlin & Maric, 2008	South Australia	3–12 m	Under or among rocks
P. laperousazi O'Loughlin & Maric, 2008	SE Tasmania to South Australia	1–10 m	
P. marshae O'Loughlin & Maric, 2008	Western Australia to South Australia	5–14 m	On granite reef, under rocks, on coralline red algae, brown algae or sponge
P. mccallumae O'Loughlin & Maric, 2008	Western Australia, off Point Cloates	100 m	On hard substrate
P. minutum (H. L. Clark, 1938)	Eastern Tasman Sea	1–10 m	Under rocks, sandy bottom
P. nigrescens H. L. Clark, 1938	New South Wales, Broken Bay to Batemans Bay	0–11 m	Estuarine, mud sediment, on live and dead mussels
P. oloughlini **sp. nov.**	Tasmania, King I., Bass Strait,		Shallow sub-littoral zone
P. parmatum (Sluiter, 1901)	Indonesia to NW Western Australia,	95–487 m	On coral sand, hard substrate and rubble
P. ravum Hickman, 1962	SE Tasmania to W South Australia	0–15 m	Under rocks, littoral
P. spinuliferum (H. L. Clark, 1938)	NW Australia, Darwin to Perth	0–22 m	On coral rubble covered with sponges and algae, on mixed algal zone and reef flat under thin layer of sand
***Psolus* species**			
P. antarcticus (Philippi,1857)	Magellanic region of South America, South Georgia, Macquarie I.	100–1666 m	
P. parantarcticus **sp. nov.**	Macquarie I.	108–135 m	Often attached to shells
P. salottii **sp. nov.**	South Australia and Southern Ocean north of Macquarie I. (single occurrences)	772–820 m and 400–600 m respectively	
P. springthorpei **sp. nov.**	Queensland (single occurrence)	1330–1380 m	On rock, coarse sand and shell
P. steuarti **sp. nov.**	Victoria (single occurrence)	1426–1509 m	

Remarks. Distribution for *Ceto cuvieria* taken from Australian Biological Resources Study (2011). Distribution ranges for *Psolidium* species follow O'Loughlin & Maric (2008). Distributions for *Psolus salottii*, *Psolus springthorpei* and *Psolus steuarti* are limited to single occurrences recorded for the type specimens so are not a true reflection of range at this stage. Habitats where recorded are a generalization only, based on collection data from material examined by O'Loughlin & Maric (2008), and by the authors for this paper.

Paratype. Type locality, depth and collection date, NMV F157399 (1) (damaged).

Description. *Psolus* species up to 27 mm long, 17 mm wide and 6 mm high (holotype, preserved); low profile

raised and rounded orally with flattened oral opening rather than cone, tapered anally with slightly apical anal opening; tentacles 10, 8 large, 2 small ventrally; clear demarcation between body wall scales and 5 very distinct oral/anal valves, irregular sizes; coarsely granuliform dorso-lateral scales, typically off-white colouring with distinct white margins (preserved), up to 7 mm long covered with thick granules, ventral margin scales significantly smaller; sole with single outer peripheral series of distinctly small tube feet and larger inner series of zig-zag to irregular double rows of tube feet, bare mid-ventrally.

Large multi-layered ossicles (scales), up to 2.5 mm long dorso-laterally, also irregular shallow cups up to 64 μm wide, rim finely knobbed with digitiform spines, and single-layered perforated plates up to 240 μm long with surface and marginal knobs. Sole with thin, flat, perforated plates, irregularly curved at edges with fine knobs on margin and variably on surface, up to 272 μm long by 240 μm wide with up to 30 perforations. Tentacle ossicles consist of thick, curved, large and small perforated plates up to 360 μm long with digitiform margins; curved, perforated support plates and smaller dendritic branch endplates ~72 μm long also present.

Colour (preserved). Off-white.

Distribution. Australia, Victoria, 38º28'41"S–38º28'40"S, 149º34'48"E–149º35'13"E 1426–1509 m (type material only).

Etymology. Named for Frank Steuart in appreciation of his contribution to marine invertebrate research over three decades through fieldwork and leadership, as occasional president, with the Marine Research Group of The Field Naturalists Club of Victoria, and for his curatorial work on the molluscan collection in Museum Victoria.

Remarks. *Psolus steuarti* **sp. nov.** is distinguished morphologically from other Australian *Psolus* species by a combination of: thick granules on dorso-lateral scales; shallow, finely knobbed cups with digitiform margins present dorsally; and perforated knobbed plates in the sole.

Concluding Comments

Holothuroids from the family Psolidae were considered to be relatively rare in Australian waters (Pawson, 1971b), however while genera diversity remains low, recent studies by O'Loughlin & Maric (2008), along with the 5 new species described here extend the number of known species found in Australia to 19. From data examined in this study, most species seemed to favour protective habitats, being found attached to shells, corals, sponge, or under rocks when in areas of higher wave action. To date none of the Australian continental species of psolids have been seen to brood protect, though this is a common strategy amongst Antarctic holothuroids, particularly smaller and more vulnerable species (O'Loughlin, personal communication). Our current knowledge indicates that species diversity of psolids is greater in southern Australia than northern Australia, though as discussed this is limited to only three genera. It is likely that the group is even more diverse in the Southern Ocean, with new species being discovered from Antarctic waters on a regular basis (personal observation of authors, unpublished). Future phylogenetic work is needed to give us a better understanding of the origins of the Australian psolid fauna including any affinities to Antarctic and sub-Antarctic fauna, and to decide whether diversity in Australia is the result of local radiation or due to other complex biogeographical patterns.

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