Author version: *J. Mar. Biol. Assoc. UK, vol.92(5); 2012; 1195-1208*

Brittle stars (Echinodermata: Ophiuroidea) from seamounts in the Andaman Sea (Indian Ocean) - a first account, with descriptions of new species

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Keywords. *Ophiophyllum, Astrophiura, Ophioleuce, taxonomy, systematics, morphology, scanning electron microscopy*

Abstract

For the first time, brittle stars were collected on two seamounts in the Andaman Back-arc Basin. Of the six species, two were new to science and are described herein as *Ophioleuce longispinum* sp. nov. and *Ophiophyllum minimum* sp. nov., in the family Ophiuridae, subfamilies Ophioleucinae and Ophiurinae, respectively. *Ophioleuce longispinum* sp. nov. is particularly interesting, because it combines characters typical for its genus with those otherwise only known from *Ophiophyllum*, such as a limpet-like disk, a fringe of marginal disk papillae or spines, and a paddle-like modified lower arm spine. The remaining species, *Astrophiura* cf. *tiki*, *Ophiactis definita*, *Ophiolimna antarctica* and an unidentified *Ophiura*, are new records for the Andaman Sea.

Introduction

The brittle star fauna of the Indian Ocean is less well known than that of the North Atlantic (Mortensen, 1933; Paterson, 1985; Stöhr & Segonzac, 2005) or eastern Pacific (O'Hara & Stöhr, 2006) and the knowledge on the ophiuroid fauna in Indian waters is limited. Early accounts of Indian echinoderms were published by Bell (1887). Cruises on the Indian vessel "Investigator" contributed some more material in the late 19th century (Koehler, 1899), but progress was slow. James (1970a; 1970b; 1981; 1982a; 1982b) reported on shallow water species in Indian coastal waters, particularly the Andaman and Nicobar Islands, but records of Indian deep water species are scarce. He also provided a review on the status of knowledge on Indian echinoderms (James, 1983) to which not much has been added since.

Recent studies on Indian Ocean ophiuroids have focussed on the area around the Mascarene archipelago in the tropical eastern Indian Ocean (Guille & Ribes, 1981; Guille & Vadon, 1986; Vadon, 1991; Guille & Vadon, 1985; Rowe & Richmond, 2004; Stöhr, Conand & Boissin., 2008). An inventory of shallow water echinoderms of the Indo-West Pacific was compiled by Clark & Rowe (1971) thirty years ago and it is still the standard reference work on the subject. A recent census counted 319 species of ophiuroid for the Indian Ocean (Stöhr, O'Hara & Thuy, in press), about a quarter of them endemic to the region. By comparison, the same study found 831 species for the Indo-Pacific. This numerical difference may however reflect differences in collecting effort rather than actual differences in species richness.

Seamounts are submarine mountains, often of volcanic origin, elevated from the deep sea floor. Initially, they were thought to be centres of endemism and high species richness, due to their isolated position (McClain, 2007). For ophiuroids however, O'Hara (2007) found no elevated levels of endemism or species richness on seamounts in general, although individual seamounts may vary greatly from each other in faunal composition. In general, seamounts reflect the fauna of the surrounding deep sea floor. For the purposes of biological inventories, seamounts are more accessible to observation and collecting than the deep-sea floor. Particularly, rare species of the deep sea with limited geographical distribution and/or low densities may go unnoticed for a long time, despite centuries of ocean exploration. Ophiuroids are a dominant component of the deep-sea benthic fauna (Gage & Tyler, 1991). Yet, until now, none have been recorded from Indian water seamounts, according to the Seamount Online database (http://seamounts.sdsc.edu).

A multidisciplinary research programme has been initiated by Indian researchers to explore the Andaman Back-arc Basin (ABB), including seamounts. The ABB is an active marginal basin and a

part of the major island arc-trench system in the northeastern Indian Ocean. It marks the eastern boundary of the Indian plate where it sub-ducts beneath the Southeast Asian plate. The German research vessel "Sonne" was used to sample and collect geophysical, geological, chemical and biological data from the Andaman seamounts in 2007 (Sautya et al., 2011). Two seamounts were studied during this cruise, the crater seamount (CSM), which is a submarine volcano with conical shape, discovered recently (Kattoju et al., 2010), and a second seamount (SM2), non-volcanic, with flat top.

We report here for the first time on the ophiuroid species collected on these two seamounts. Two species are new to science and will be described below.

Material and methods

Rocks and their attached and associated fauna were collected at various depths on two seamounts (CSM and SM 2) in the Andaman Sea, Indian Ocean, using a TeleVision Gripper (TVG), in October-December 2007 (Fig. 1). A total of four TVG transects were executed, TV9 and TVG10 on the CSM and TVG11 and TVG 12 on SM2, and four samples were collected. Brittle stars were found in the samples from TVG 9, 10 and 11, attached to the rocks. They were carefully picked off and preserved in 70% ethanol. For a more detailed description of methods and general results see Sautya et al. (2011).

The holotypes of each new species were lightly bleached with diluted household bleach (NaOCL:water, 1:1) for about 20 seconds, to clean their surface. They were extremely brittle and easily lost scales and papillae, which prohibited stronger treatment. The specimens were mounted on aluminium stubs with non-permanent spray glue, gold coated and examined with a Hitachi FE-SEM scanning electron microscope (SEM). Then the specimens were removed from the stub by resolving the glue with butyl acetate and brushing with a small artist brush, re-attached with fresh glue, opposite side exposed, and examined in the SEM again. Arm fragments were dissociated in undiluted bleach to isolate the ossicles. These were then washed with tap water and mounted wet on stubs coated with spray glue. Measurements of whole specimens where taken with an ocular micrometer on a dissecting microscope, smaller structures were measured with the SEM scale. All material has been deposited at the Swedish Museum of Natural History.

Abbreviations:

dd – disk diameter

GBIF – Global Biodiversity Information Facility

MNHN – Muséum national d'Histoire naturélle, Paris

SMNH – Swedish Museum of Natural History

UNAM – Colección Nacional de Equinodermos Mexicanos

Taxonomic account

Family Ophiuridae Müller & Troschel, 1840

Subfamily Ophioleucinae Matsumoto, 1915

Genus *Ophioleuce* Koehler, 1904

Type species. *Ophioleuce seminudum* Koehler, 1904

Diagnosis. Based on the type species the following features characterize the genus *Ophioleuce* and consequently the subfamily Ophioleucinae. Disk round, with sharp edge, notched at arm bases, more or less fully covered with granules, sometimes intermingled with slender spines. Arms inserted ventral to the disk. Second tentacle pore inside mouth slit, covered by one or several scales. Arm plates weakly striated; spine articulations u-shaped with pronounced rim. Long adoral shields, separating oral shield from first ventral arm plate.

Remarks. Over time, several species that deviate somewhat from the above diagnosis have been included in *Ophioleuce*. Madsen (1983) stressed the importance of the position of the second tentacle scale hidden inside the mouth slit and covered by large scales as important for the delimitation of Ophioleucinae from Ophiurinae, in which the pore is somewhat removed from the mouth slit and surrounded by small scales. However, in *O. oxycraspedon* Baranova, 1955, *O. gracilis* Belyaev & Litvinova, 1976 and *O. depressum* (Lyman, 1869) the second pore is slightly superficial, surrounded by several small scales. Also, *O. gracilis* and the Atlantic species identified as *O. oxycraspedon* by Paterson (1985) have a sparse disk granulation, forming a net-like pattern. The type of the Pacific *O. oxycraspedon* had a denser granulation, leaving only the radial shields and some marginal plates bare (Dyakonov, 1954; Baranova, 1955), which suggests that the Atlantic record needs to be re-evaluated. In *O. oxycraspedon* and *O. gracilis*, the disk edge bears a fringe of small papillae that are likely homologous to granules. A revision of the Ophioleucinae is necessary to better understand the phylogenetic value of these characters, but outside the scope of this study.

Ophioleuce longispinum new species

Figures 2, 3

Material. Holotype, on SEM stub; TVG 9, Andaman Sea, Andaman Back-Arc basin, crater seamount (CSM), flank, 07°55.924'N, 94°03.139'E to 07°56.036'N, 94°03.026'E, 517-671 m, 25/11/2007 [SMNH-Type-8199]; arm fragments on SEM stub, unknown from which specimen(s), same sample [SMNH-Type-8200]; skeletal elements on SEM stub from detached arm fragment, same sample [SMNH-Type-8201]; 4 paratypes, same sample, in 80% ethanol [SMNH-Type-8202]; 1 paratype, in 80% ethanol, TVG 10, Andaman Sea, Andaman Back-Arc basin, CSM, summit, 07°56.3330'N, 94°02.638'E to 07°56.255'N, 94°02.693'E, 373-394 m, 26/11/2007 [SMNH-Type-8203].

Etymology. The specific name alludes to the long dorsal spines on the first arm segment.

Diagnosis. Species of *Ophioleuce* with two long, rod-like spines on the dorsal portion of the first lateral arm plates. Up to 18 fringe spines in each interradius. Second tentacle pore slit-shaped, opening into the mouth slit, bordered by several low scales. No other tentacle scales along arm. Large round ventral spine articulation with thickened rim opening ventrally, smaller u-shaped articulation dorsal to the first, opening dorsalwards. Dorsal disk scales with borders of low round granules.

Description of holotype. Disk round, slightly domed, thin, 5.2 mm dd, weakly incised at arm base. Arms broken close to the disk, but fragments in the sample suggest long, carinate, tapered, whip-like arms, at least 5 times dd long. Disk scaling formed by primary rosette of more or less round single central plate and five radial plates in disk centre, a circle of three smaller triangular interradial plates and a larger rhombic radial plate, separating radial shields proximally. Interradially between radial shields, a series of three plates, two rectangular plates, overlapping, wider than long, proximally a large distal one, triangular with obtuse proximal angle, as long as distal width, overlapping second plate. Radial shields about half as long as disk radius, triangular, with wider outer edge, completely separated by a series of plates, a large rhombic proximal plate, a narrower elongated plate, a small round scale, and a short, wide distal scale with depressed distal half. Each radial shield separated from arm by a wide plate, three times as wide as long. These and the last scale separating the radial shields form a trio of plates on the arm base. Disk edge with fringe of 18 elongated scales per interradius. All disk plates with open meshwork stereom, bearing low conical granules along their edges.

Dorsal arm plates contiguous, rectangular, longer than wide, with straight edges, laterally overlapped by convex lateral plates. Lateral and dorsal arm plates striated. Each lateral arm plate with single, flat, triangular spine, standing erect off arm, parallel to disk edge, decreasing in size, becoming increasingly rod-like distalwards along arm; edges finely serrated, stereom multi-layered mesh. Single large, round u-shaped spine articulation with thickened rim of smooth, entire stereom, enlarged smooth distalwards directed lip, opening distalwards, and single central muscle opening, on proximal segments; nerve opening not obvious or reduced. Distalwards a second lateral spine appears, dorsal to the first, rod-like. Dorsal articulation half as large as ventral one, opening dorsalwards. On each first arm segment a long rod-shaped spine on upper part of each lateral plate, laying diagonally across radial shields, most of them broken, but intact spines more than 1 mm long. Long spine articulation strongly reduced, consisting of larger muscle opening and smaller nerve opening with low rim.

Ventral disk formed by large, quadrangular to pentagonal scales. Jaws with pointed triangular apical papilla (presumably first tooth). Oval, bowl-shaped dental plate with long pointed tooth at dorsalmost part, widely separated from apical papilla/tooth. 7 block-like papillae in a series from tip of jaw to distal end of second, slit-shaped, tentacle pore, which opens into mouth slit. Oral plates of each jaw positioned at an angle, v-shaped. Adoral shields narrow, bordering proximal edges of oral shield, extending along first ventral arm plate, bordering proximal part of bursal slit. Oral shields triangular with wide proximal angle, distal edge convex. Madreporite distinguished by distinct hydropore, eccentric at distal edge. Bursal slit does not reach disk each, as long as first two arm segments, edge of long narrow abradial genital scale and lateral plates bordering bursal slit, minutely thorny. Ventral arm plates t-shaped with wavy distal edge, strongly concave lateral edges. First ventral plate bent upwards into mouth slit, distally contiguous with second plate, from 5th segment ventral plates widely separated by lateral plates. Lateral arm plates with sharp angle, separating lateral and ventral surface of plate, ventrally concave. Tentacle pores large, round, lacking scales. On first segment of each arm a pair of smaller holes of unknown function in proximal ventral surface of lateral arm plates. Fringe spines ventrally concave, proximal ends depressed, attached to depressions in disk edge.

Internal characters. Arm skeleton dissociated from arm fragments not assignable to a particular specimen. Vertebrae elongated, with zygospondylous articulation, large wing-like muscle flanges distally and proximally. Ventrally, vertebra with two median flat processes, to which lateral plates attach. Lateral plates with corresponding internal process. Dorsal plates convex, lateral edges slightly concave, stereom with many larger holes and transverse striations. Ventral plates convex, with

upwards bent distal part, stereom with few small holes, smooth.

Paratype variations. In the same sample as the holotype (TVG 9) there were an additional four specimens with disk diameters 2.3, 4.2, 4.5 and 4.6 mm. Another specimen of 5.3 mm dd was found in sample TVG 10. All specimens are more or less covered in a layer of fine sediment or organic matter embedded in slime, which firmly glues the long spines to the disk in preserved animals. All arms are broken, but arm fragments are included in the samples. On all individuals, the disk fringes are damaged, many of the spines lost. Complete interradial fringes consist of 17-18 spines in the larger specimens, 12 in the smallest one. Specimens of 4.5 mm dd and above have seven lateral oral papillae, the 4.2 mm dd specimens has six and the 2.3 mm dd specimen five papillae. The long upper first disk spines are mostly broken or lost, but fragments and single intact spines show that all of these specimens originally possessed these long spines. Large gonads are visible inside the translucent disk, next to the arms, in all but the smallest specimen.

Remarks. In *O. longispinum* sp. nov. the second tentacle pore is close to the mouth angle, slit-like narrow and opens into the mouth slit. It is also bordered by low scales and overall resembles the condition found in *Ophiura*, thus suggesting a placement in Ophiuridae. Although this character suggests a placement in the subfamily Ophiurinae, I propose to place it in Ophioleucinae, because all other characters agree with that subfamily. In addition, the superficial placement of the second pore is a juvenile character (Sumida et al., 1998; Stöhr, 2005) and its value for classification above genus level is questionable. At first glance, this new species is similar to *Ophiophyllum*, with its limpet-like, fringed disk, paddle-like modified lower arm spine, carinate, ventrally concave arms, lateral arm plates with a sharp lower edge and broad ventral surface, and the large tentacle pores. However, the granulated dorsal disk, block-like oral papillae, striated arm plates, slit-like second tentacle pore surrounded by scales, and the rectangular dorsal arm plates are characters shared with *Ophioleuce*. The critical clue revealing the close affinity of *O. longispinum* sp. nov. with *Ophioleuce* is found in the arm spine articulation. Martynov (2010) argued that the spine articulation reflects phylogenetic relationships between ophiuroid families. The articulation of *O. longispinum* sp. nov. is similar to that shown for several Ophioleucinae (Martynov 2010) and to that of *Ophioleuce seminudum* (personal observation), the generic type, and *O. gracilis* Belyaev & Litvinova, 1976 (Martynov, personal communication). Although some similarity between the articulations of *Ophioleuce* and some species of *Ophiophyllum* can be observed (see below), they are clearly different and *O. longispinum* has a typical ophioleucin articulation. Another strikingly conservative feature appears to be the rectangular shape of the dorsal arm plates in all species of *Ophioleuce*, but no species of *Ophiophyllum*.

The large open tentacle pores lacking scales, the more developed but still superficial first pore, the sparse granulation of the disk, the bowl-shaped dental plate bearing few teeth, the along most of the arm widely separated ventral arm plates and the low number of spines are all indications of a juvenile, paedomorphic state that may have evolved independently in both genera. The limpet-like shape of the disk, the disk fringe and the modified lower spine may be ecological adaptations, or they may indicate phylogenetic relationships. It is possible that the genus *Ophiophyllum* evolved from the paedomorphic branch of *Ophioleuce*, but a thorough evaluation of all species of both genera is needed to answer this question. A phylogenetic analysis of these genera is beyond the scope of this paper, but will be explored in a future study.

Ophioleuce longispinum sp. nov. differs from all known congeners in the presence of long dorsal arm spines on the first segment and in the shape of the lower arm spine. It is closest to *O. oxycraspedon* and *O. gracilis*, both of which share the flat, sparsely granulated disk and edge fringe, but they do not have the strongly modified lower arm spine and their fringe consists of shorter papillae.

Distribution. According to type localities and GBIF records, of the seven species of *Ophioleuce*, *O. depressum* is restricted to the Atlantic Ocean, where also *O. oxycraspedon* has been found, although records of the latter need to be verified. *Ophioleuce longispinum* sp. nov. and *O. seminudum* are known from the Indian Ocean, while *O. regulare* (Koehler, 1900) is a species of the Southern Ocean and *O. oxycraspedon* has been described from the Bering Sea. *Ophioleuce gracilis*, *O. brevispinum* (H.L. Clark, 1911) and *O. seminudum* occur in the Pacific Ocean. Most of the species, including *O. longispinum* sp. nov., have been found at depths of few hundred to about 1000 m, whereas *O. oxycraspedon* and *O. gracilis* are bathyal species at 2000-3000 m.

Subfamily Ophiurinae Lyman, 1865

Genus *Ophiophyllum* Lyman, 1878

Type species. *Ophiophyllum petilum* Lyman, 1878: 130, pl. VII figs 179-181.

Diagnosis. A genus of Ophiurinae with round, flat, thin disk, slightly limpet-like domed; long, carinate, ventrally concave arms. A fringe of short, flat spines along interradial disk edge. Three arm segments included in the disk (in adult specimens). Two arm spines, ventral spine more or less transformed, scale or paddle-like, dorsal spine small, pointed.

Ophiophyllum minimum new species

Figures 4, 5

Material. Holotype, on SEM stub, TVG 9, Andaman Sea, Andaman Back-Arc basin, crater seamount (CSM), flank, 07°55.924'N, 94°03.139'E to 07°56.036'N, 94°03.026'E, 517-671 m, 25/11/2007 [SMNH-Type-8204]; 2 paratypes from same sample, in 80% ethanol [SMNH-Type-8205].

Comparative material. *Ophiophyllum novaecaledoniae* Vadon, 1991, holotype, New Caledonia, sta. CP 72, 2100 m [MNHN Ec Os 22134]. *Ophiophyllum borbonicum* Vadon & Guille, 1984, holotype, Réunion Island, MD 32, stn DC64, 21°12'S, 55°05'E, 1150-1180 m [MNHN Ec Os 22064].

Etymology. The specific name alludes to the small size of this species, the smallest of the genus.

Diagnosis. Species of *Ophiophyllum* with large, flat disk scales, 14-15 fringe spines in each interradius, large rectangular ventral disk plates, lacking tentacle scales. Largest known size 2.5 mm dd.

Description of holotype. Disk round, slightly domed, 2.5 mm dd. Arms carinated, all broken. Dorsal disk with large round central plate, surrounded by a circle of smaller overlapping scales, then a circle of five larger plates (presumably the radial primaries), separated by smaller scales. Radial shields triangular, half the disk radius long, completely separated by a distal wedge-shaped plate and smaller proximal scales. In each interradius a rectangular distal plate, twice as along as wide and a short quadrangular plate, proximally overlapped by other scales. All scales and plates with finely porous stereom. In each interradius a fringe of 13-14 rectangular spines with straight distal edge and porous stereom, inserted under the dorsal disk plates in a groove running along the edge, hiding about half their length. Fringe spines closest to arms triangular, larger than remaining, block-like rectangular spines. Dorsal arm plates triangular, slightly longer than wide, contiguous, bordered by the larger lateral plates. A tiny first dorsal arm plate inserted between radial shields distally. A large leaf-shaped ventral spine and a much smaller conically pointed spine dorsal of it on each lateral arm plate. Lateral plates and leaf-spines strongly striated.

Ventral disk formed by 3 rectangular, slightly flaring distal plates, 2 narrow abradial genital plates and up to 3 round proximal scales, variable between interradii. Oral shields wider than long with obtuse proximal angle and strongly convex distal edge. Madreporite not distinguishable. Jaws with large round distal scale, middle low wide buccal scale, on some jaws fragmented into smaller papillae, apical papilla and tooth fallen off, conical, sharply pointed. Round, bowl-shaped dental plate with two tooth articulations. Oral plates curved. Adoral shields long and narrow, bordering

proximal angle of oral shield, extending past second tentacle scale to bursal slit. Bursal slit as long as first two segments, edges smooth. Second tentacle pore large, round, lacking scales, separated from mouth slit by first ventral arm plate.

Lateral arm plates with sharp lateral edge, forming an angle between lateral and ventral surface, outwards flaring, giving ventral arm wing-like appearance. Ventral stereom of lateral plate smooth and entire, with series of holes that demarcates outer wing-like part. Ventral arm plates contiguous, elongated pentagonal with truncated proximal angle, strongly excavated lateral edges in lower half of plate. All tentacle scales similar to first, large, round, lacking scales. Spine articulations vertical at distal edge of lateral plate, inserted under the lamellar stereom of the plate, opening distalwards.

Internal characters. Arm skeleton dissociated from fragment not assignable to a particular specimen. Vertebrae with zygospondylous articulation, elongated, in proximal arm shorter and wider, in distal arm longer and incompletely fused; with two processes in middle of ventral side to which corresponding processes of lateral plates attach. Inside of lateral arm plate with process, stereom on lateral surface lamellar striated; proximal edge concave, distal dorsal edge convex. Spine articulations restricted to ventral part of lateral surface of plate, inserted at the edge of the plate, partly overlaid by the plate edge, round openings with lower lip. Ventral arm plate stereom dense, with small pores. Dorsal arm plates ventrally concave, dorsally convex, stereom with larger pores, dorsal side with short thorns, rough.

Paratype variations. A paratype of 2.1 mm dd has 15 fringe spines. A second paratype of 1.3 mm dd, with a hole in the centre of its dorsal disk, has 12 fringe spines and shorter arms; its jaws are damaged. Several arm fragments are also included in the sample, but cannot with certainty be matched to a specimen.

Remarks. Until now, the genus *Ophiophyllum* included eight species (Stöhr & O'Hara, 2007). Originally, the genus was placed in the family Ophiolepididae, but Vadon & Guille (1984) transferred it to Ophiuridae after examining the holotype of the generic type species *O. petilum* Lyman, 1878, on the grounds of its second tentacle pore being outside the mouth slit, contrary to Lyman's (1878) original illustration. Stöhr & Segonzac (2005) followed this decision, but McKnight (2003) considered his *O. teplium* McKnight, 2003 within Ophiolepididae, as did Martynov & Litvinova (2008) with their new species *O. nesisi* Martynov & Litvinova, 2008, but neither of these authors gave an explanation. This question needs to be revisited here to eliminate the resulting confusion. In Ophiolepididae, the second tentacle pore is completely hidden inside the mouth slit,

covered by the distal oral papilla, whereas species with the second pore placed outside the mouth slit, bordered by several scales or papillae, are usually assigned to Ophiuridae, mainly the subfamily Ophiurinae (but for exceptions see above). *Ophiophyllum* is characterized by a large round second tentacle pore, placed at a distance from the mouth angle, thus not in accordance with Ophiolepididae. The position of the second tentacle pore outside the mouth slit is a juvenile character (Sumida et al., 1998; Stöhr, 2005) and thus doubtful for family delimitation, but pending a revision of Ophiuridae and Ophiolepididae, it seems best not to cause confusion by deviating from this principle. Also, the possible close affinity of *Ophiophyllum* with *Ophioleuce* (see above) suggests that both should be included in the same family.

A single species of *Ophiophyllum* was previously known from the Indian Ocean, at La Réunion, *O. borbonicum* Vadon & Guille, 1984 (erroneously named *O. borbonica*, neglecting that *phyllum* is neuter). *Ophiophyllum minimum* sp. nov. somewhat resembles *O. borbonicum* with regard to the pattern of the dorsal disk scalation, but differs in having more fringe scales (*O. borbonicum* has 9 square spines), different ventral scalation and in lacking tentacle scales (*O. borbonicum* has two). The number of fringe spines in each interradius has been used to distinguish the species (Vadon and Guille 1984; McKnight 2003). For *O. atlanticum* this was not included in the description, but re-examination of the type images resulted in a maximum of 14 fringe spines and its spine articulations are somewhat similar to the new species. It differs from *O. minimum* sp. nov. in the dorsal and ventral disk scalation, oral papillae, shape of fringe spines, and shape of ventral arm plates. The other Atlantic species *O. nesisi* has 12-15 (holotype) and 11-15 (paratype) fringe spines (Martynov, personal communication), but differs in having many small tumid dorsal disk scales, a different spine articulation and spines, and rounded fringe spines with entire, smooth stereom. *Ophiophyllum novaecaledoniae* Vadon, 1991 from New Caledonia differs from *O. minimum* sp. nov. in having small domed dorsal disk scales among which the primaries are larger, 10 short fringe spines, tumid dorsal arm plates, more and smaller ventral disc scales and a reduced bursal slit. The new species differs from the South Pacific *O. petilum* in having fewer and larger dorsal disk scales, two dorsal interradial plates, more fringe spines at a smaller disk diameter, fewer ventral interradial plates and different oral papillae. The North Pacific *O. concinnus* Litvinova, 1981 has more and smaller dorsal disk scales, 7-9 fringe spines, more oral papillae, a longer than wide oral shield and a higher number of ventral disk scales (Litvinova, 1981). *Ophiophyllum teplium* from New Zealand also has more disk scales that are tumid, many more oral papillae and a different ventral disk. *Ophiophyllum marginatum* A.H. Clark, 1916 from Galapagos has up to 10 fringe spines, up to a dozen ventral interradial scales, longer bursal slits, two tentacle scales and more oral papillae (A.H. Clark, 1916).

This is the smallest species of the genus, although its maximum size may not be known. It shows several juvenile characters (Sumida et al., 1998; Stöhr, 2005): the curved jaws, few oral papillae and teeth, cupped dental plate, long vertebrae, large tentacle pores lacking scales, second tentacle pore far from mouth slit, but also adult characters such as contiguous dorsal and ventral arm plates throughout the arm, large radial shields, wider than long oral shields, primary dorsal plates separated by scales. The possible affinities of *Ophiophyllum* with *Ophioleuce* are discussed above under *O. longispinum*. *Ophiophyllum minimum* sp. nov. appears to be less paedomorphic than *Ophioleuce longispinum* sp. nov., with contiguous arm plates and comparatively less elongated arm segments. The homologies of the fringe spines are not easily deduced in O*phiophyllum*, but it is possible that they originated from granules, although no known species has disk granules. They are more specialised than in *Ophioleuce*, varying in size and shape between larger triangular spines close to the arm and rectangular ones in between. They are also placed in a groove at the disk edge, supported by a ledge formed by the ventral disk plates, whereas the shorter fringe spines/papillae in *Ophioleuce longispinum* sp. nov. are articulated to small depressions, similar to those found under the disk granules.

Distribution. The genus *Ophiophyllum* with now nine species has a worldwide distribution, but each species seems to have a narrow range, rarely found outside their type locality. *Ophiophyllum petilum* was described from the Kermadec Islands (New Zealand) from a sample taken at 390-1119 m, and found later in the North Pacific (GBIF record: SDSC SeamountsOnline 14134). The identity of another specimen from the Caribbean tentatively assigned to that species by Lyman (1883) is doubtful considering the great geographic distance, and its presence there has never been confirmed. The other Atlantic species are so far known only from their type localities, *O. nesisi* from the Reykjanes Ridge near Iceland at 1670-1895 m depth, *O. atlanticum* from the axial valley of the mid-Atlantic Ridge at 4078 m, which is the deepest distribution of any of these species. *Ophiophyllum borbonicum* is known from its type locality at Reunion Island at 1150-1180 m. Among the Pacific species, *O. marginatum* is known only from Galapagos, found at 717 m depth, *O. concinnus* from NE of the Mariana Islands was found at 1900 m, and *O. novaecaledoniae* has the widest depth distribution range with 410-2100 m. Like *O. minimum* sp. nov., *O. teplium* was found on a seamount, north of the Chatham Rise (New Zealand), at 1040-1035 m. Most of these species are known from few or single specimens, only the type series of *O. novaecaledoniae* consists of 29 specimens of different sizes, including juveniles. *Ophiophyllum minimum* sp. nov. is the first record of the genus from Indian waters and the Andaman Sea.

Genus *Astrophiura* Sladen, 1879

Type species. *Astrophiura permira* Sladen, 1879: 11.

Diagnosis. Genus of Ophiurinae with large, thin, pentagonal disk, limpet-like arched, dorsally convex, ventrally concave; thin, short, ventrally concave arms. Six or more arm segments included in the disk (in adult specimens), their lateral plates fused to form most of the distal disk portion beyond the radial shields. Interradial disk edge with fringe of short flat spines. Oral shields reduced except madreporite. Tentacle pores disproportionately large.

Astrophiura cf. *tiki* Litvinova & Smirnov, 1981

Figure 4

Material. 1 specimen, TVG 9, Andaman Sea, Andaman Back-Arc basin, crater seamount (CSM), flank, 07°55.924'N, 94°03.139'E to 07°56.036'N, 94°03.026'E, 517-671 m, 25/11/2007.

Description. 7 mm dd, disk pentagonal, arched, dorsally convex, ventrally concave, translucent, arms broken off close to disk, lost. Particles of sediment and/or debris embedded in dorsal integument. Dorsal disk with five-pointed star-shaped central plate with concave edges, bordered by five quadrangular radial infrabasals and five larger, elongated pentagonal interradial basals. Five large pentagonal radial primary plates, with acute distal point and straight proximal and lateral edges separating the radial shields proximally. Interradially a rectangular plate (ir1), twice as long as wide, in series with a large pentagonal plate (ir2) with acute distal point, separating the lateral plates of the first segment. Radial shields pentagonal with proximal angle. First dorsal arm plate (d2, associated with second pair of lateral plates) triangular, with proximal angle, separating distal ends of radial shields. Following four dorsal arm plates (d3-d6) rectangular, wider than long, contiguous, decreasing in size along the arm. Last dorsal arm plate (d7) triangular, with proximal angle, straight distal edge, widely separated from previous plate (d6). Lateral arm plates (l1-7) elongated, flat, thin, standing erect off the arm at an angle, fused to form an extension of the disk. First lateral plates of one arm fused to the next by their distal ends. In each interradius a fringe of 35 rectangular spines, two to three at each lateral plate, aligned with grooves on the lateral plates. Two short conical spines at arm base at disk edge.

Ventral disk in proximal part with scattered, small translucent scales, distal part formed by the lateral arm plates. Seven arm segments included in disk. Oral shields absent, few scales instead. Madreporite small, oval, with distal, eccentric hydropore. Jaws strongly curved, proximally concave distally convex, diverging. Small pointed apical papilla or tooth, flanked by two similar, small, pointed papillae laterally at dental plate, a small pointed papillae at intersection of dental and oral

plate, a wide lateral papilla with jagged edge at oral plate. Adoral shields narrow, bar-like, proximally widely separated, abutting first arm segment. Tentacle pores extremely large, round, lacking scales, second one some distance from mouth slit; decreasing in size distalwards from fourth segment, from seventh pore hardly visible. Ventral arm plates within disk saddle-shaped, rectangular, with strongly concave lateral edges, almost straight distal and proximal edges, contiguous. First ventral arm plate longer than others, distal edge widened with three excavations, proximally with rounded lobe. Large round gonads visible in proximal part of disk. No bursal slits.

Remarks. According to the latest revision, the genus *Astrophiura* contains eight species (Fujita & Hendler, 2001), which are distinguished by few diagnostic characters due to a lack of sufficient sample sizes for the assessment of intraspecific variability and loss of type material. The specimen presented here differs from *A. permira*, *A. chariplax* Baranova, 1955 and *A. wanikawa* Fujita & Hendler, 2001 in the lack of tubercles and sculpturing of the dorsal disk plates, and from *A. chariplax*, *A. kohurangi* McKnight, 1975 and *A. wanikawa* in the reduced and widely separated adoral shields. *Astrophiura marionae* Ziesenhenne, 1951 has four plates in the interradial series and a single oval tentacle scale. The type of *A. kawamurai* Matsumoto, 1912 has been lost (Fujita & Hendler, 2001), but according to the original description it differs from our specimen in the presence of a tentacle scale, a greater number of oral papillae and almost fully separated radial shields. Apart from their larger size with 12 mm and 12.5 mm dd, respectively, *A. levii* Vadon, 1991 and *A. tiki* differ from our specimen only in the presence of a minute tentacle scale, which may not have developed yet in our smaller specimen. These two species may also be conspecific. Vadon (1991) omitted *A. tiki* in her work and possibly did not know about its existence. Given these subtle differences it is possible that the actual number of species in the genus is less than eight and describing another one based mainly on the absence of tentacle scales in a single specimen seems not advisable.

Distribution. The genus *Astrophiura* has a wide Indian Ocean-Indo-Pacific distribution, extending into polar regions. *Astrophiura permira* was described from Madagascar, but has been found numerous times in South Africa (Litvinova & Smirnov, 1981), where the conspecific *A. cavallae* Koehler, 1915 had been described, and in the Kerguelen (GBIF, record from Russian Academy of Sciences). It is the only species of the genus reported from the Atlantic, off Mexico (GBIF, records from MNHN and UNAM), an extraordinary distance from its type locality and given the great similarity between the species of *Astrophiura*, these records should be verified. *Astrophiura kohurangi* was described from the Northern Tasman Sea and has also been found in the Solomon Islands (GBIF, records from MNHN), *A. marionae* was described from California and has since been

found there again (GBIF, records from MNHN and UNAM), *A. levii* is so far known only from New Caledonia, *A. chariplax* from the Bering Sea and Sakhalin, *A. kawamurai* and *A. wanikawa* from Japan and *A. tiki* from off Chile. Most of the species have been found at medium depths above 1000 m, only *A. chariplax* is a bathyal species from 2440 m.

Genus *Ophiura* Lamarck, 1801

Ophiura sp.

Material. 1 specimen, 4.5 mm dd, TVG-11, Andaman Sea, Back-Arc basin, Seamount 2 (SM2), flank, 09°59.500'N, 93°57.137'E to 09°59.526'N, 93°57.260'E, 1290-1424 m, 27/11/2007.

Remarks. This specimen has the appearance of a juvenile *Ophiura*, with three pointed proximal oral papillae and a wide distal papilla (buccal scale). The genital papillae are low, block-like, in a continuous row along the bursal slit, continuing onto the dorsal arm, forming a low comb. There are two short pointed arm spines. Juvenile brittle stars are notoriously difficult to identify (Stöhr, 2005) and since the genus *Ophiura* is one of the largest (Stöhr et al., In press) of the genus, we prefer not to attach a name to this single specimen.

Family Ophiactidae Matsumoto, 1915

Genus *Ophiactis* Lütken, 1856

Ophiactis definita Koehler, 1922

Figure 6C-E

Material. 1 specimen, 4.5 mm dd, TVG 11, Andaman Sea, Back-Arc basin, Seamount 2 (SM2), flank, 09°59.500'N, 93°57.137'E to 09°59.526'N, 93°57.260'E, 1290-1424 m, 27/11/2007.

Diagnosis. Five-armed *Ophiactis*. Dorsal disk covered by medium sized, round, overlapping scales, among which only the centrodorsal is larger and conspicuous, no spines. Radial shields 1/4 as long as dd, completely separated by scales. Dorsal arm plates triangular, twice as wide as long, contiguous. Three conical, blunt arm spines, slightly longer than a segment. Single distal oral papilla, large, triangular. Apical papilla and teeth tricuspid with pronounced median point. Oral shields (except madreporite) small, triangular with distal lobe, as wide as long. Adoral shields narrow, crescent-shaped. Ventral arm plates quadrangular to trapezoid, at distal edge slightly wider than long, contiguous. Single large, oval tentacle scale.

Remarks. Although this specimen measures about half the size of the type specimens (Koehler, 1922), it presents all the characteristics of its species. The large pointed oral papilla is a distinctive

character and the separated radial shields, contiguous wide dorsal and contiguous ventral arm plates distinguish the species from others. This is an Indo-Pacific species according to the 160 records found in GBIF, most of them from the area around New Caledonia, Vanuatu and Fiji (MNHN, accessed through GBIF data portal, http://data.gbif.org/datasets/resource/12030, 2011-07-04). It is a new record for the Andaman Sea.

Family Ophiacanthidae Ljungman, 1867

Genus *Ophiolimna* Verrill, 1899

Ophiolimna antarctica (Lyman, 1879)

Material. 3 specimens, 1.3 mm dd and 1.7 mm dd, TVG 9, Andaman Sea, Andaman Back-Arc basin, crater seamount (CSM), flank, 07°55.924'N, 94°03.139'E to 07°56.036'N, 94°03.026'E, 517-671 m, 25/11/200. 1 specimen, 4.4 mm dd, TVG 11, Andaman Sea, Back-Arc basin, Seamount 2 (SM2), flank, 09°59.500'N, 93°57.137'E to 09°59.526'N, 93°57.260'E, 1290-1424 m, 27/11/2007.

Diagnosis. Both sides of disk densely covered with round granules. In large specimen oral frame naked, in smaller specimens completely covered with granules. Lateral arm plates strongly striated; longest arm spines almost two segments long. Dorsal arm plates triangular, ventral plates pentagonal. Single apical papilla at each jaw tip, three conical lateral oral papillae and a larger, operculiform distal papilla. Oral shield twice as wide as long.

Remarks. *Ophiolimna antarctica* is a deep-sea species with wide distribution in the Indo-West Pacific, Arctic and Antarctic (O'Hara & Stöhr, 2006). Its occurrence on the Andaman seamounts is therefore not unexpected, but previously not documented.

Discussion

The discovery of two unknown species in a small collection of six species from seamounts could be taken as evidence of endemism as has long been speculated (McClain, 2007). Considering that the Andaman Sea and the Indian Ocean are undersampled with regard to deep-sea ophiuroids, and taking into account the contrary results by O'Hara (2007), we suspect instead that these species occur on the deep-sea floor, but had not been collected before. The elevated position of the seamount provided access to this elusive fauna. *Ophiophyllum*, *Astrophiura* and bathyal species of *Ophioleuce* are rarely collected and largely unknown, which makes these additional finds particularly valuable. We suspect that more unknown species will be discovered with further collecting. The known geographic range of all species found by this study was extended.

The systematics of Ophiuroidea is problematic, in need of revision, due to many inconsistencies between higher taxa and species with difficult to understand combinations of characters (A. Martynov, 2010). *Ophioleuce longispinum* sp. nov. is another such species with characters otherwise found in different genera. Further study should reveal whether this is an interesting case of convergent evolution or evidence of phylogenetic relationships.

Acknowledgements

The authors wish to express their gratitude to the CSIR for financial support to the Net-Work project 'Indian Ridge studies'. We also thank the director of NIO (Goa) for use of the facilities. We wish to acknowledge the project leader Dr. Kamesh Raju and the entire 'ridge group' especially for excellent team work during the deep-sea cruises. We are also thankful to the captain of the 'RV Sonne' and his crew for help in collecting the priceless samples from the deep-sea. Sabyasachi Sautya gratefully acknowledges support by a grant from the CenSeam (Global Census of Marine Life on Seamounts) as part of the CoML project for a visit to the Natural History Museum, Stockholm, Sweden. Many thanks to A. Martynov for providing data on *Ophiophyllum* and for inspiring discussions, and to M. Eleaume for the loan of type material. This is contribution No……of NIO (CSIR) Goa.

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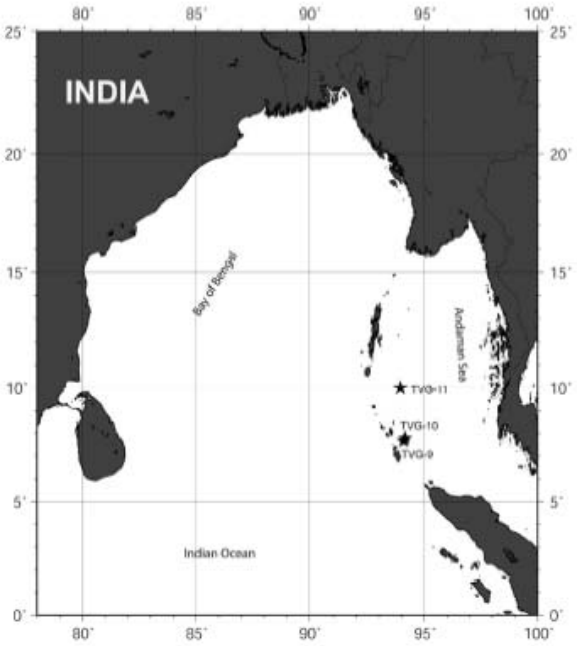

Fig 1. Location map of the sampling area in the Andaman Sea, with stations at which ophiuroids were collected. TVG - TelevisionGripper.
85x85mm (300 x 300 DPI)

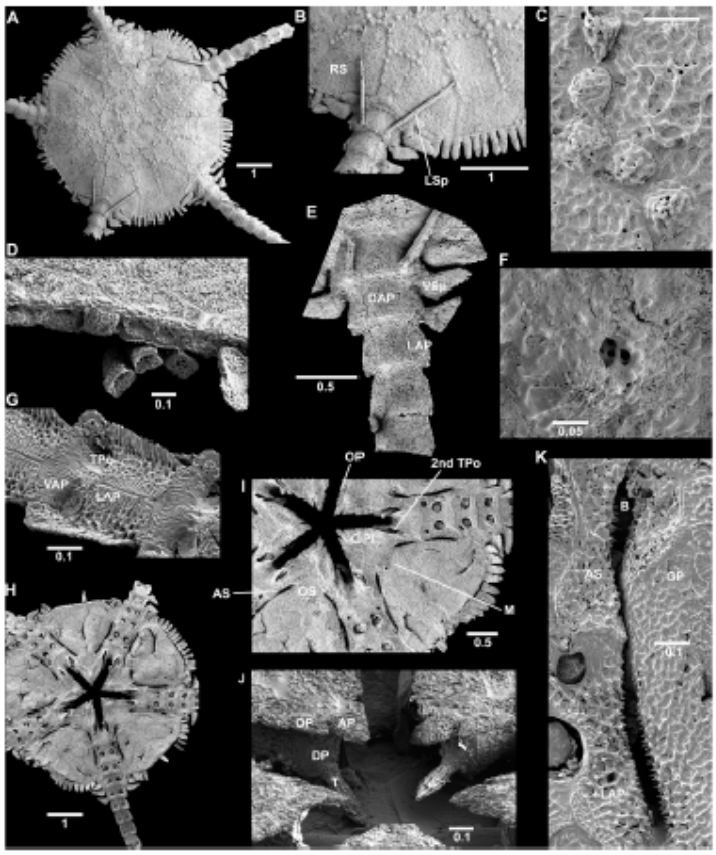

Fig 2. Ophioleuce longispinum sp. nov., holotype, SEM images. A, dorsal aspect; B, long spines on arm base; C, disk granules; D, disk edge with dislocated spines; E, dorsal arm; F, articulation of long arm spine; G, ventral arm; H, ventral aspect; I, ventral disk; J, proximal aspect of jaws; K, bursal slit. AP, apical papilla; AS, adoral shield; B, bursal slit; DAP, dorsal arm plate; DP, dental plate; GP, genital plate; LAP, lateral arm plate; LSp, long spine; M, madreporite; OP, oral papilla; OS, oral shield; RS, radial shield; T, tooth; TPo, tentacle pore; VAP, ventral arm plate; VSp, ventral spine. Scale bars in millimetre.
175x208mm (300 x 300 DPI)

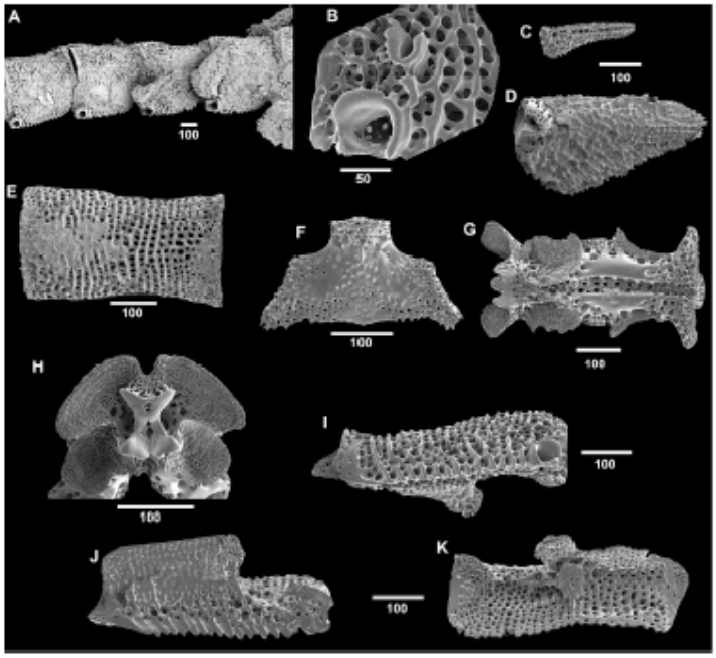

Fig 3. Ophioleuce longispinum sp. nov., arm skeleton, SEM images, A, holotype, B-K, holotype or paratype. A, proximal arm laterally, note the large ventral spine articulations; B, articulations of lateral spines, lower for ventral spine, above for upper, distal edge to left; C, small upper spine, articulation aspect; D, flat ventral spine, articulation aspect; E, dorsal arm plate, external, distal edge left; F, ventral arm plate, middle of arm, external; G, vertebra, proximal arm, dorsal aspect, distal end at left; H, vertebra, proximal aspect; I, lateral plate, ventrolateral aspect, distal to the right; J, lateral plate, ventral aspect, distal to the right; K, lateral plate, internal, distal to the left. Scale bars in micrometre.
175x160mm (300 x 300 DPI)

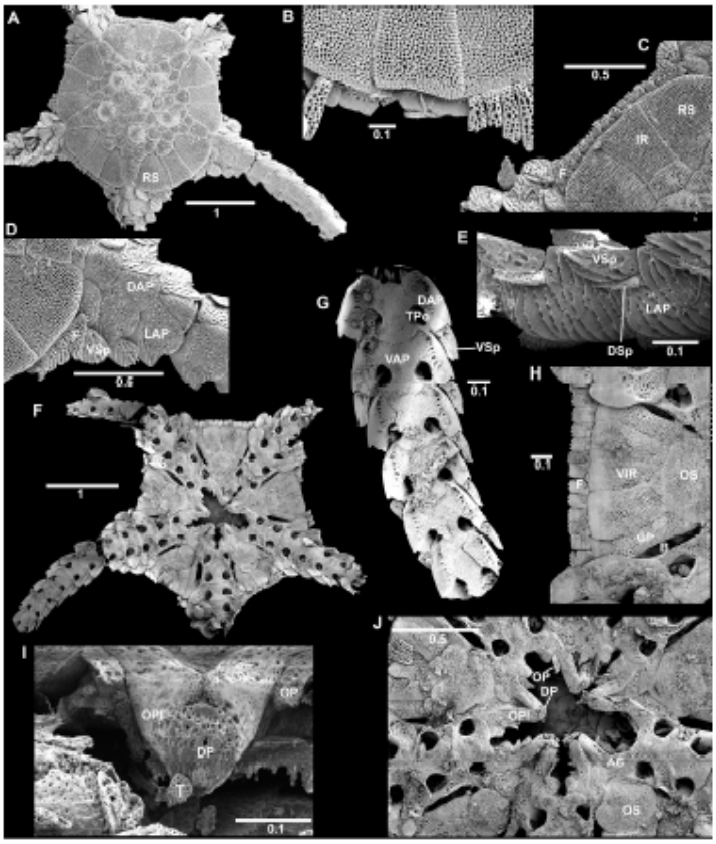

Fig 4. Ophiophyllum minimum sp. nov., holotype, SEM images. A, dorsal aspect; B, disk edge dorsolaterally, with spines; C, interradial disk with fringe; E, dorsolateral arm base; G, lateral arm; H, ventral arm; I, ventral aspect; J, ventral disk interradius with fringe; K, proximal jaw aspect; L, oral frame. Abbreviations as in Figure 2, and DSp, dorsal spine; IR, interradial plate; OPl, oral plate (half-jaw); VIR, ventral interradial plate. Scale bars in millimetre.
175×206mm (300 × 300 DPI)

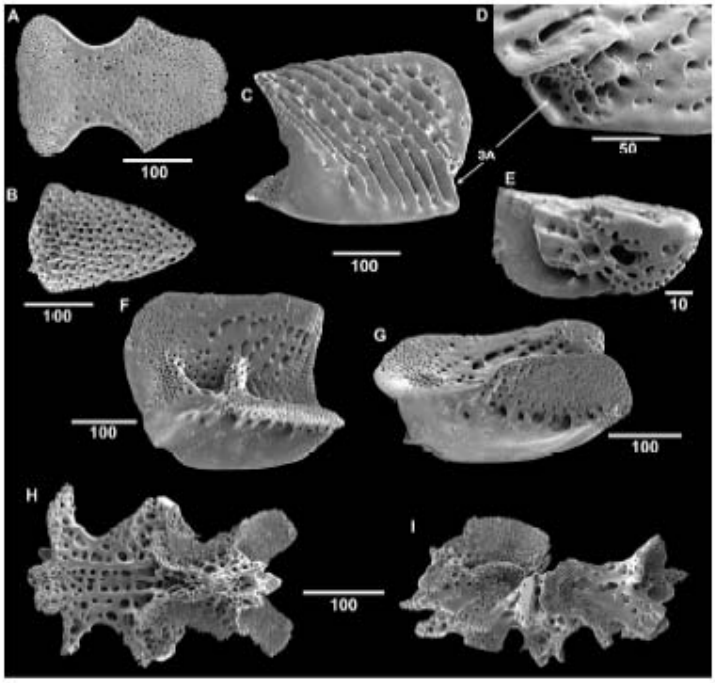

Fig 5. Ophiophyllum minimum sp. nov. arm skeleton, SEM images. A, ventral plate, external; B, dorsal plate, external; C, lateral plate, laterally, distal to right; D, lateral plate, spine articulations; E, large ventral spine; F, lateral plate, internal; G, lateral plate, ventral aspect; H, vertebra, dorsal aspect, distal at right; I, vertebra, lateral. SA, spine articulation. Scale bars in micrometre.
175×166mm (300 × 300 DPI)

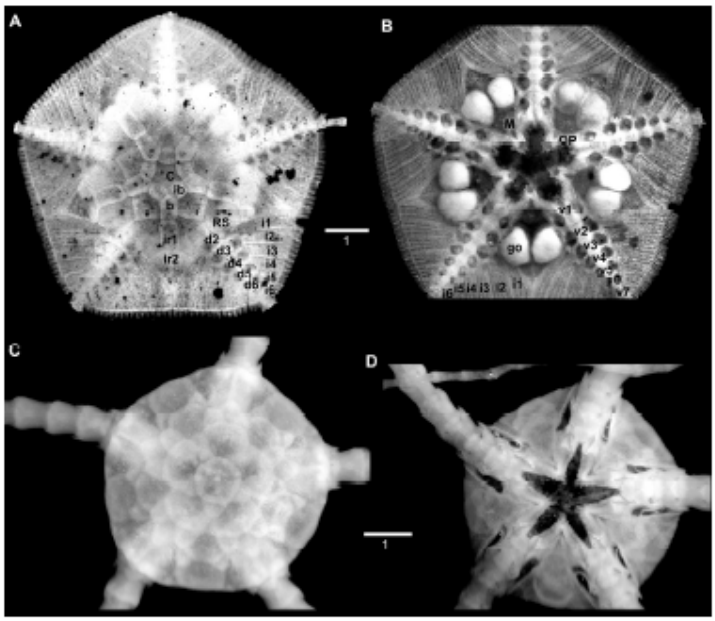

Fig 6. Astrophiura cf. tiki. A, dorsal aspect; B, ventral aspect. Ophiura sp., C, dorsal aspect; D, ventral aspect. Labelling for Astrophiura follows the tradition for this genus, c, centrodorsal plate; b, basal plate; d, dorsal arm plate; ir, interradial plate; r, radial plate; v, ventral arm plate. remaining abbreviations as in Figure 2. Scale bars in millimetre.
175×151mm (300 × 300 DPI)

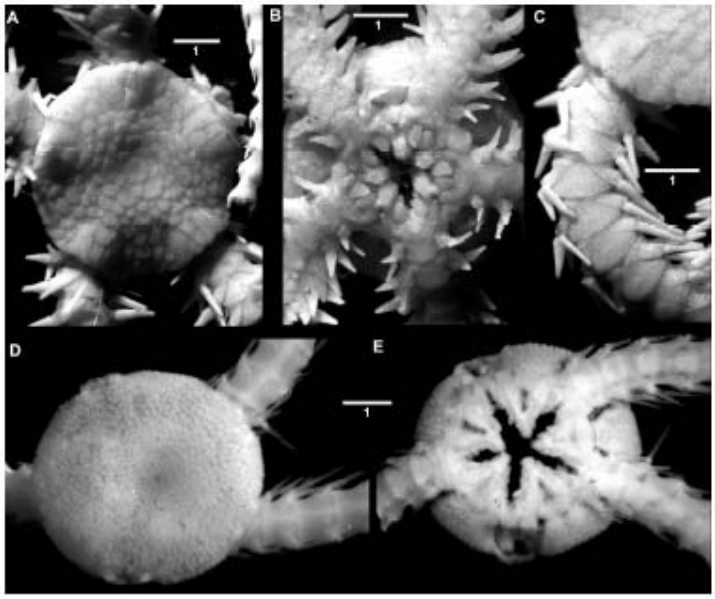

Fig 7. Ophiactis definita. A, dorsal aspect; B, ventral aspect; C, arm dorsally. Ophiolimna antarctica. D, dorsal aspect; E, ventral aspect. Scale bars in millimetre.
175×145mm (300 × 300 DPI)