

New abyssal Primnoidae (Anthozoa: Octocorallia) from the Clarion-Clipperton Fracture Zone, equatorial northeastern Pacific

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Abstract Three new species, including a new genus, *Abyssoprímnoa*, are described from abyssal depths from the easternmost Clarion-Clipperton Fracture Zone in the equatorial northeastern Pacific. This prompted the listing of all 39 octocorallian taxa collected deeper than 3000 m, which constitutes only about 1.2 % of the octocoral species. To place this in perspective, the depth records for other benthic cnidarian orders are compared.

Keywords Primnoidae · Clarion-clipperton fracture zone · New species · New genus · Octocorallia · Abyssal fauna · Depth records

Introduction

The vast abyssal region between the Clarion and Clipperton Fracture Zones, known as the Clarion-Clipperton Fracture Zone (CCFZ), is approximately 7200 km in width and 6×10^6 km² area situated in the equatorial northeastern Pacific. Because no single land mass has an equivalent area, it can be compared to a region roughly twice the size of India. The water depth ranges from 3900 to 4400 m and the bottom temperature is approximately 1.5 °C. Large regions of this area are covered with small (potato-sized) polymetallic

nodules that contain iron, manganese, copper, nickel, cobalt, zinc, silver, and other metals (Bluhm 1994), and thus have been of interest to deep-sea mining companies for several decades since the region was discovered in the 1950s. Currently, at least 12 claim sites have been awarded to various mining companies, each associated with one or more countries. The hard substrate afforded by the nodules allows the settlement of various benthic invertebrates that require a hard surface for attachment and subsequent anchoring, one of these groups being the octocorals. Because of the extreme depth and logistic difficulty of collecting organisms from such depths, our knowledge of the megafauna that inhabits this region is based primarily on photographs (Pawson and Foell 1983, Bluhm 1994). Indeed, in 2013 a workshop was convened to construct an “Atlas of Abyssal Megafauna Morphotypes of the Clipperton-Clarion Fracture Zone” based on in situ images, and can be found on this link: http://ccfzatlas.com/wiki/index.php?title=Main_Page (International Seabed Authority 2014). This resource also has a map of the various claim zones. Most of these morphotypes are unidentified because associated specimens were not collected, but recently some specimens of primnoid octocorals were collected from the British (UKSRL) and German (BGR) claim zones, which are in the easternmost part of the CCFZ at depths of 4111–4244 m. This material has allowed the description of three new species, including one new genus, of octocoral, and consist of some of the deeper octocorals ever recorded. Other unidentified octocorals figured in the Atlas include species of the taxa: *Keratoisis*, *Lepidisis*, Chrysogorgiidae, and *Umbellula*.

The collection of these deep water primnoids prompted a listing of all (39 taxa) octocorals that have been collected deeper than 3000 m (Table 1). The three primnoids reported herein are not the deepest octocorals ever collected, but among the deepest 16 out of approximately 3200 octocoral species

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Table 1 Octocorallia known from deeper than 3000 m (bold face taxa treated herein)

	Primnoidae	Pennatulacea	Chryso-gorgiidae	Isididae	Greatest Depth (m)
<i>Thouarella vitjaz</i> Zapata & López-González, 2012	X				6400
<i>Umbellula</i>		X			6100
<i>Convexella krampi</i> (Madsen, 1956)	X				5850
<i>Porcupinella profunda</i> López-González & Williams, 2011		X			5300
<i>Dasystenella acanthina</i> (Wright & Studer, 1889)	X				5087
<i>Echinisis persephone</i> Bayer & Stefani, 1987				X	4851
<i>Narella abyssalis</i> Cairns & Baco, 2007	X				4594
<i>Convexella murrayi</i> (Wright & Studer, 1889)	X				4851
<i>Chrysogorgia</i> sp. sensu Pante & Watling, 2011			X		4492
<i>Kophobelemnon</i>		X			4400
<i>Distichoptilon</i>		X			4300
<i>Calyptrophora persephone</i> n. sp.	X				4244
<i>Callozostrom bayeri</i> n. sp.	X				4235
<i>Keratoisis profunda</i> (Wright, 1885)				X	4206
<i>Scleroptilon</i>		X			4200
<i>Abyssoprinoa gemina</i> n. sp.	X				4168
<i>Narella bayeri</i> Cairns & Baco, 2007	X				4091
<i>Protoptilon</i>		X			4000
<i>Chrysogorgia tricaulis</i> Pante & Watling, 2011			X		3860
<i>Paranarella watlingi</i> Cairns, 2007	X				3855
<i>Callozostrom mirabile</i> Wright, 1885	X				3819
<i>Plumarella diadema</i> (Cairns, 2006)	X				3693
<i>Calyptrophora laevispinosa</i> Cairns, 2007	X				3531
<i>Narella parva</i> (Versluys, 1906)	X				3500
<i>Narella arbuscula</i> Cairns & Baco, 2007	X				3465
<i>Parastenella doederleini</i> (Wright & Studer, 1889)	X				3423
<i>Narella alvinae</i> Cairns & Bayer, 2003	X				3419
<i>Narella cristata</i> Cairns & Baco, 2007	X				3385
<i>Chrysogorgia japonica</i> (Wright & Studer, 1889)			X		3375
<i>Keratoisis siemensii</i> Studer, 1878				X	3259
<i>Narella laxa</i> Deichmann, 1936	X				3186
<i>Plumarella (F.) abietina</i> (Studer, 1894)	X				3182
<i>Lepidisis cyanae</i> Grasshoff, 1986				X	3150
<i>Anthoptilum</i>		X			3150
<i>Radicipes gracilis</i> (Verrill, 1884)			X		3120
<i>Chrysogorgia pinnata</i> Cairns, 2007			X		3114
<i>Narella versluysi</i> (Hickson, 1909)	X				3100
<i>Lepidisis</i> sp. sensu Pasternak, 1981				X	3040
<i>Callozostrom diplodiadema</i> Bayer, 1996	X				3040
Family Totals	22	7	5	5	

(Cairns 2007a). Cairns and Bayer (2009: 1) described the Primnoidae as the “quintessential deepwater octocoral family”, and it is clear from Table 1 that this family has the most species represented in deep water, followed by the order Pennatulacea (sea pens), and the families Chrysogorgiidae (golden corals), and Isididae (bamboo corals), all of which

are figured in the CCFZ Atlas. To place the deep-living octocorals in perspective within the phylum Cnidaria, the deepest known scleractinian is *Fungiacyathus marenzelleri* at 6328 m (Keller 1976), the deepest hydrozoan *Halisiphonia galatheae* at 8300 m (Kramp 1956), the deepest antipatharian *Bathypathes patula* at 8600 m (Pasternak

1958), and the deepest sea anemone *Galatheanthemum profundale* at 10,710 m (Belyaev and Sokolova 1960, see also Cairns et al. 2007). Thus, the two cnidarian orders having calcareous structural elements, the Scleractinia and Octocorallia, both attenuate at about 6400 m; the deepest calcified hydrozoan, the stylasterid *Crypthelia affinis* Moseley, 1879, occurs at only 2789 m (Zibrowius & Cairns 1992).

Material and methods

The specimens used in this study were collected from the easternmost sectors of the CCFZ. Their locations are given in Table 2.

The following abbreviations are used in the text:

AB	ABYSSLINE project of the UKSRL
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe
CCFZ	Clarion-Clipperton Fracture Zone
DZMB	Senckenberg Gesellschaft für Naturforschung
L:W	Ratio of length to width of an octocoral sclerite
NMNH	National Museum of Natural History, Smithsonian, Washington, DC
SEM	Scanning Electron Microscope
UKSRL	UK Seabed Resources Ltd
USNM	United States National Museum, now the National Museum of Natural History, Smithsonian, Washington, DC

The classification and terminology for primnoid taxa are those used in Cairns and Bayer (2009).

Results

Order Alcyonacea

Family Primnoidae Milne Edwards, 1857

Genus *Calyptrophora* Gray, 1866

Calyptrophora Gray, 1866: 25.—Bayer, 2001: 367–368.—Cairns & Bayer, 2009: 44–45.—Cairns, 2007b: 527.—Cairns, 2009a: 420–426 (key to species).—Cairns, 2011: 22–23.

Diagnosis

Colonies uniplanar to slightly bushy; branching lyrate, dichotomous, polychotomous, biplanar, or unbranched. Polyps arranged in whorls, pointing either distally or proximally. Body wall of polyps covered with two annular sclerite rings (basal and buccal), each composed of two inseparably fused scales; infrabasals may also be present. Distal margins of body wall scales often spinose, toothed, or lobate. Inner surface of opercular scales usually keeled. Outer surface of coenenchymal scales granular or longitudinally ridged. Small curved flattened tentacular platelets usually present.

Type species

Calyptrophora japonica Gray, 1866, by monotypy.

Discussion

Including the new species described herein, there are 22 species in the genus (see Cairns 2009a, 2012). A key to the species and phylogenetic analysis were given by Cairns (2009a).

Distribution

Tropical and temperate regions of Atlantic, Pacific, and Indian Oceans, 227–4244 m.

Calyptrophora persephone sp. nov.

Material examined

Holotype: KG-61, 1 colony and SEM stubs 2070–2072, 2210, USNM 1268844. Paratypes: KG30, 1 colony, DZMB; AB01-CRS1545-CS16, 1 colony, USNM 1268754.

Type Locality

11°45.634'N, 116°44.266'W (eastern Clarion-Clipperton Fracture Zone, German claim zone), 4244 m.

Distribution

Eastern Clarion-Clipperton Fracture Zone (German and British claim zones), 4123–4244 m.

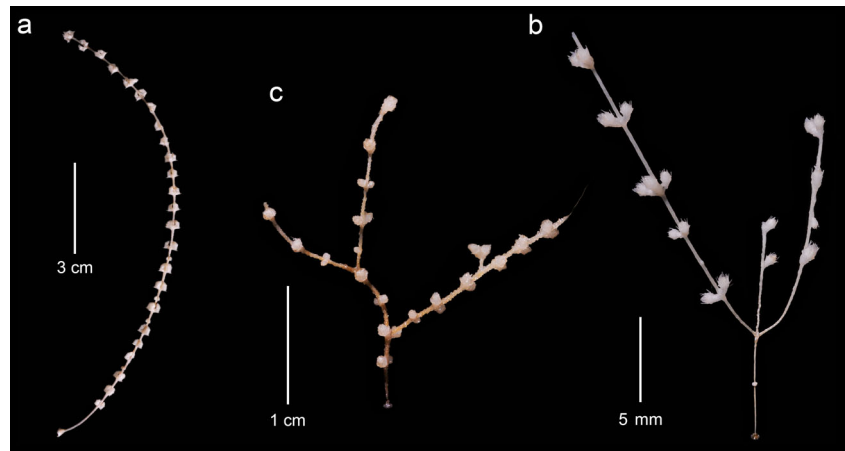
Description

Colonies are unbranched, consisting of an upright monopodial stem that in the largest specimen (the holotype, Fig. 1a)

Table 2 Station data

Station number	Latitude (N)	Longitude (W)	Depth (m)	Date (2013)
German Sector (BGR)				
KG25	11°50.299'	117°02.123'	4133	15 April
KG28	11°53.270'	117°02.853'	4134	16 April
KG30	11°52.015'	117°03.722'	4123	16 April
KG58	11°46.981'	116°48.801'	4168	28 April
KG61	11°45.634'	116°44.266'	4244	28 April
KG64	11°44.176'	116°50.288'	4158	29 April
KG68	11°43.275'	116°43.679'	4235	29 April
ABYSSLINE, cruise AB01, British Sector (UKSRL)				
CRS1533-CS09	13°45.700'	116°27.620'	4111	18 October
CRS1545-CS16	13°43.597'	116°40.200'	4160	22 October

Fig. 1 **a**, holotype of *Calyptrophora persephone*; **b**, holotype of *Callozostron bayeri*; **c**, holotype of *Abyssoprinoa gemina*



measures 11.5 cm in length and 0.35 mm in basal branch diameter. Colonies are attached to manganese nodules by a dome-shaped holdfast up to 2.1 mm in diameter. The axis is golden-yellow and easily seen through the single layer of translucent coenenchymal scales. Polyps occur in whorls of three or four, face upward, and are easily detached from the branch, perhaps because there are no locking infrabasal scales; whorls are widely spaced, only about 2.5 occurring per centimeter branch length, the holotype having 24 whorls, and an additional four juvenile whorls composed of polyps only 0.8 mm in length. The basalmost 5–9 mm of the branch is devoid of polyps. The polyps are 2.1–2.4 mm in length, the operculum contributing to half of this length.

The fused basal scale (Fig. 2a, b, and f) stands perpendicular to the branch and reaches up to 1.4 mm in height, the distal 0.40–0.55 mm consisting of two pointed, elongate, but flattened spines, one on each of the distal anterolateral margins, which bear serrate ridges on their outer and inner surfaces (Fig. 2g). The basal scales bear a low ridge on the right-angle anterolateral edges, which are continuous with the distal buccal spines (Fig. 2f). The fused buccal scale (Figs. 2c–d) is approximately of the same length, forming a right angle articulation with the basal scale. It also bears a low ridge on its anterolateral edges as well as a low sagittal ridge (Fig. 2c). Each distal anterolateral margin consists of a short (0.20–0.35 mm) lateral flattened blunt spine (Fig. 2e), which flank two medial lobes of approximately the same height. The spines are ridged, the lobes are not. The outer surfaces of the basals and buccals are covered with a low granulation.

The operculum is elongate (Fig. 2a), consisting of narrow (L:W=2.3–3.4), triangular scales ranging from 0.75–1.25 mm in length, decreasing in length from the ab- to the adaxial side of the polyp (Fig. 2h). The outer face of the operculars is concave and often bears a low medial ridge, but is otherwise covered with low granules. The proximal inner surface is tuberculate, whereas the distal inner surface is prominently

keeled; the edges are finely serrate. Tentacular platelets (Fig. 2j) are 0.11–0.13 mm in length and about 0.03–0.035 mm in width, flat, and curved along their longer axis, typical for the genus.

The coenenchymal scales (Fig. 2i) are elongate (L:W=6–9) and pointed, up to 2.0 mm in length. On their outer surface, most coenenchymal scales have a medial ridge (sail-scale) up to 0.3 mm in height, which occurs on most of the outer surface.

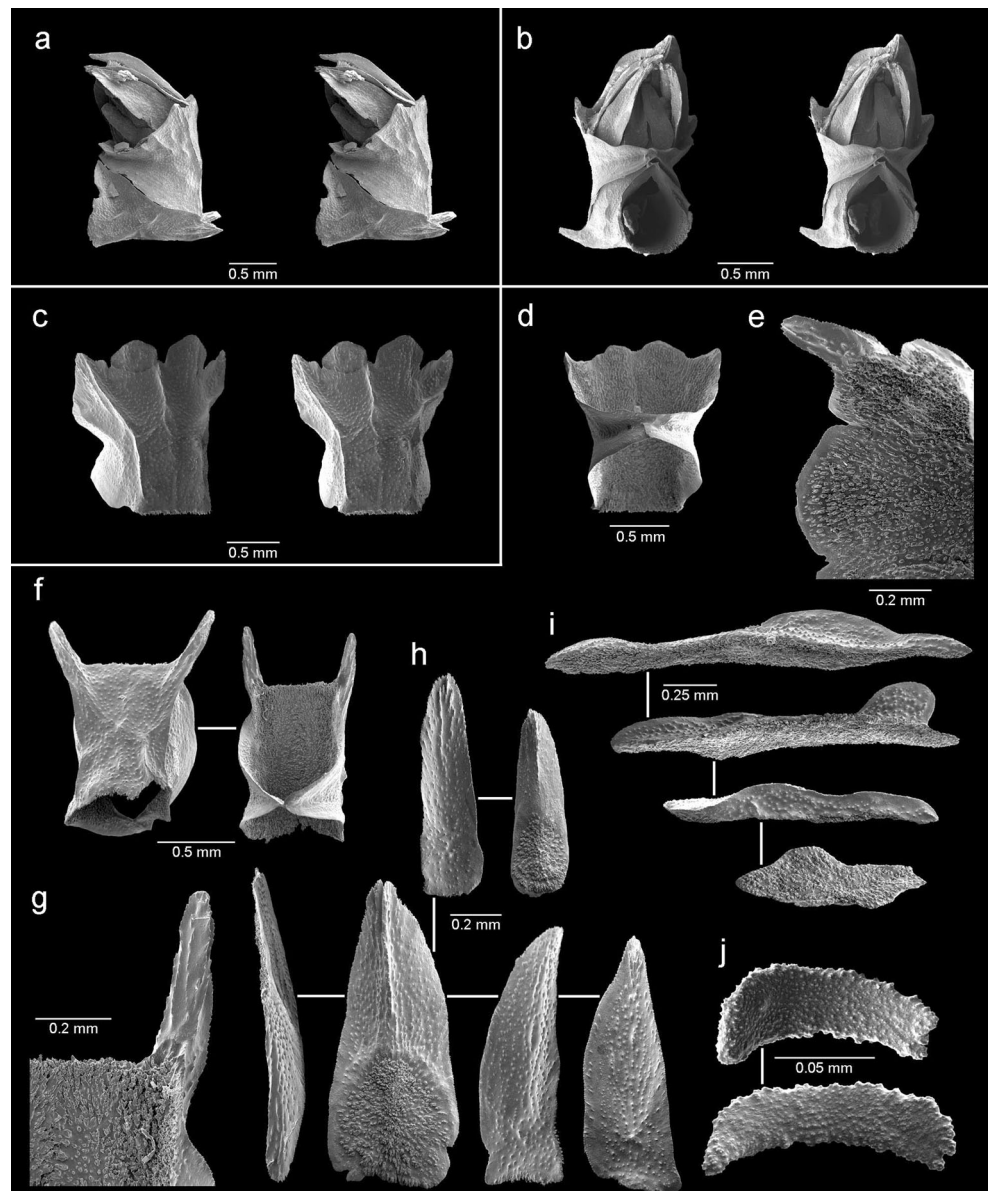
Comparisons

Bayer (2001) conveniently divided *Calyptrophora* into those species having upward oriented polyps (*japonica*-complex) and downward oriented polyps (*wyvillei*-complex). He further divided the *japonica*-complex into those species having marginal spines and/or lobes on their body wall scales (Group 1) or not (Group 2). *Calyptrophora persephone* is part of Group 1 of the *japonica*-complex, which is the largest group that includes another 15 species, but only one of these species has an unbranched colony structure: *C. juliae* Bayer, 1952 (Philippines, 729 m). *C. juliae* is a very distinctive species, differing in having much more robust basal spines, a non-lobate buccal margin, and much shorter opercular scales. Indeed, *C. persephone* is unique in the genus for having such elongate opercular scales. Bayer (2001: 374) alluded to another undescribed, unbranched *Calyptrophora* from New Caledonia (570–610 m), one specimen of which is deposited at the USNM (1016380). It differs from *C. persephone* in having much larger basal spines, smaller buccal spines, and no anterolateral ridges.

Remarks

This species extends the known depth range of the genus and represents one of the deepest known species of octocoral; one other species in the genus, *C. laevispinosa*, is also known from deeper than 3000 m (Table 1). Several in situ photographs of this species are found in the Atlas of Abyssal Megafauna Morphotypes.

Fig. 2 Holotype of *Calyptrophora persephone*: **a**, lateral stereo view of a polyp; **b**, adaxial stereo view of a polyp; **c**, abaxial stereo view of fused buccal scale; **d**, adaxial view of buccal scale; **e**, anterolateral spine on buccal scale (inner face); **f**, basal scales; **g**, anterolateral spine of basal scale (inner face); **h**, six opercular scales; **i**, four coenenchymal sail scales; **j**, pinnular scales



Etymology

Persephone (Greek) was the mythological daughter of Zeus and wife of Hades, and thus queen of the lower world.

Genus *Callozostrom* Wright, 1885

Callozostrom Wright, 1885: 690–691.—Wright and Studer, 1889: 48.—Bayer, 1996: 151–152 (key to species).—Cairns and Bayer, 2009: 32–33 (complete synonymy and discussion).—Cairns, in prep.: key to species.

Diagnosis

Colonies unbranched (flagelliform), sparsely dichotomously branched, or pinnately branched. Polyps cylindrical and stand perpendicular to branch, arranged in whorls of 3–14, the bases of adjacent polyps sometimes fused. Opercular scales blunt or have elongate apical spines. At least four, and in some species up to 24 (the three distal transverse rows of body wall

scales), marginal/submarginal scales bear elongate apical spines; marginals do not fold over operculum. Polyp covered by eight longitudinal rows of body wall scales, which completely cover the polyp body. Coenenchymal scales similar to those of body wall, but smaller, and arranged in one thin layer, but basal region of at least one species is covered with a thick layer of tuberculate spheroids. All scales thin, with a smooth outer face and sparsely tuberculate inner face.

Type species

Callozostrom mirabile Wight & Studer, 1885.

Discussion

Callozostrom is a characteristically deep-water (bathyal-abyssal) genus. Bayer (1996) described and keyed the four species of *Callozostrom* known at that time, and Cairns

(in prep.) describes a fifth species and also provides an updated key. The species described herein is thus the sixth species known in the genus.

Distribution

Antarctic, Subantarctic (Scotia Sea, South Sandwich Islands, South Orkney Islands, South Georgia), Antipodes Islands, off North Island of New Zealand, Clarion-Clipperton Fracture Zone, 744–4235 m.

Callozostron bayeri sp. nov.

Material examined

Holotype: KG-68, 1 colony and SEM stubs 2140–2141, USNM 1268849.

Type Locality

11°43.275 N, 116°43.679 W (eastern Clarion-Clipperton Fracture Zone, German claim zone), 4235 m.

Distribution

Known only from the type locality.

Description

The holotype (Fig. 1b) is a small intact (attached) colony 25 mm in height, showing only two short branches originating on opposite sides of the main branch at the same level, interpreted as opposite pinnate branching. The colony is quite fragile, the colony considered to be a juvenile, its axis only 0.1 mm in diameter and the branch diameter being 0.14 mm in diameter. The polyps are arranged in pairs or more commonly whorls of three, approximately 3.5 whorls occurring per cm branch length; only 10 whorls or pairs of polyps are present on the holotype. The polyps are 1.2–1.3 mm in height and slightly flared distally (Fig. 3a and b), the distal polyp diameter being about 0.65 mm.

The body wall scales are arranged in eight longitudinal rows, the abaxial row having five or six scales, the outer lateral row having four or five scales, but the number in the inner lateral and adaxial rows are unknown due to the paucity of material to examine. The body wall scales (exclusive of the marginals) are elliptical to rectangular in shape, 0.23–0.31 mm in width and length, slightly curved molding to the cylindrical polyp, and have slightly serrate distal edges (Fig. 3f). They have a smooth outer face and only sparsely tuberculate inner face. The eight marginals (Fig. 3e) are similar in shape, but have an elongate, slender (0.02 mm in diameter), cylindrical distal spine that comprises half of the length of the scale, these scales ranging from 0.37 to 0.55 mm in length. Like the other body wall scales, they have a smooth outer surface and a sparsely tuberculate inner surface. The eight opercular scales (Fig. 3c) are the same length as the marginal scales, but have a blunt distal edge and a longitudinally concave outer face. Like all the other scales, they are smooth exteriorly and sparsely tuberculate interiorly. The coenenchymal scales (Fig. 3g), which occur in one thin layer, are elliptical to irregular in shape, flat, and about 0.20–0.25 mm in diameter.

Comparisons

Only one other species of *Callozostron* has pinnate branching, an undescribed species (Cairns in prep.), known from off New Zealand at 878–911 m. *C. bayeri* differs from that species in having opposite pinnate branching (vs. alternate pinnate), whorls consisting of fewer polyps, and smaller and fewer spinose marginal/submarginal scales (only 8 up to 0.55 mm in length vs. 24 up to 1 mm long).

Remarks

This species extends the known depth range of the genus and represents one of the deepest known species of octocoral; two other species in the genus, *C. mirabile* and *C. diplodiadema*, are also known from deeper than 3000 m (Table 1).

Several in situ photographs of this species are found in the Atlas of Abyssal Megafauna Morphotypes.

Etymology

Named in honor of Frederick M. Bayer, who has named many species of deep-water octocorals (see Cairns 2009b), including two species of *Callozostron*.

Genus *Abyssoprímnoa*, gen. nov.

Diagnosis

Colonies small and dichotomously branched. Polyps globose, short, and occur in pairs. Operculars non-spinose and prominently keeled. Body wall covered with only four marginal scales. Coenenchymal scales elongate and bear tall medial ridges (sail scales). Small, curved pinnular scales present.

Type species

Abyssoprímnoa gemina, here designated.

Discussion

Because polyps in this genus do not have body wall scales, except for four marginals, the genus key of Cairns and Bayer (2009) cannot be applied. It does, however, have some similarities to *Candidella*, especially the presence of four marginal scales per polyp (two of which are larger than the other two), keeled operculars, and dichotomous branching. *Abyssoprímnoa* differs from *Candidella* in lacking body wall scales proximal to the marginals, having exclusively paired polyps, ridged coenenchymals and marginal scales, and in having pinnular scales.

Distribution

Eastern Clarion-Clipperton Fracture Zone (German and British claim zones), equatorial northeastern Pacific, 4111–4168 m.

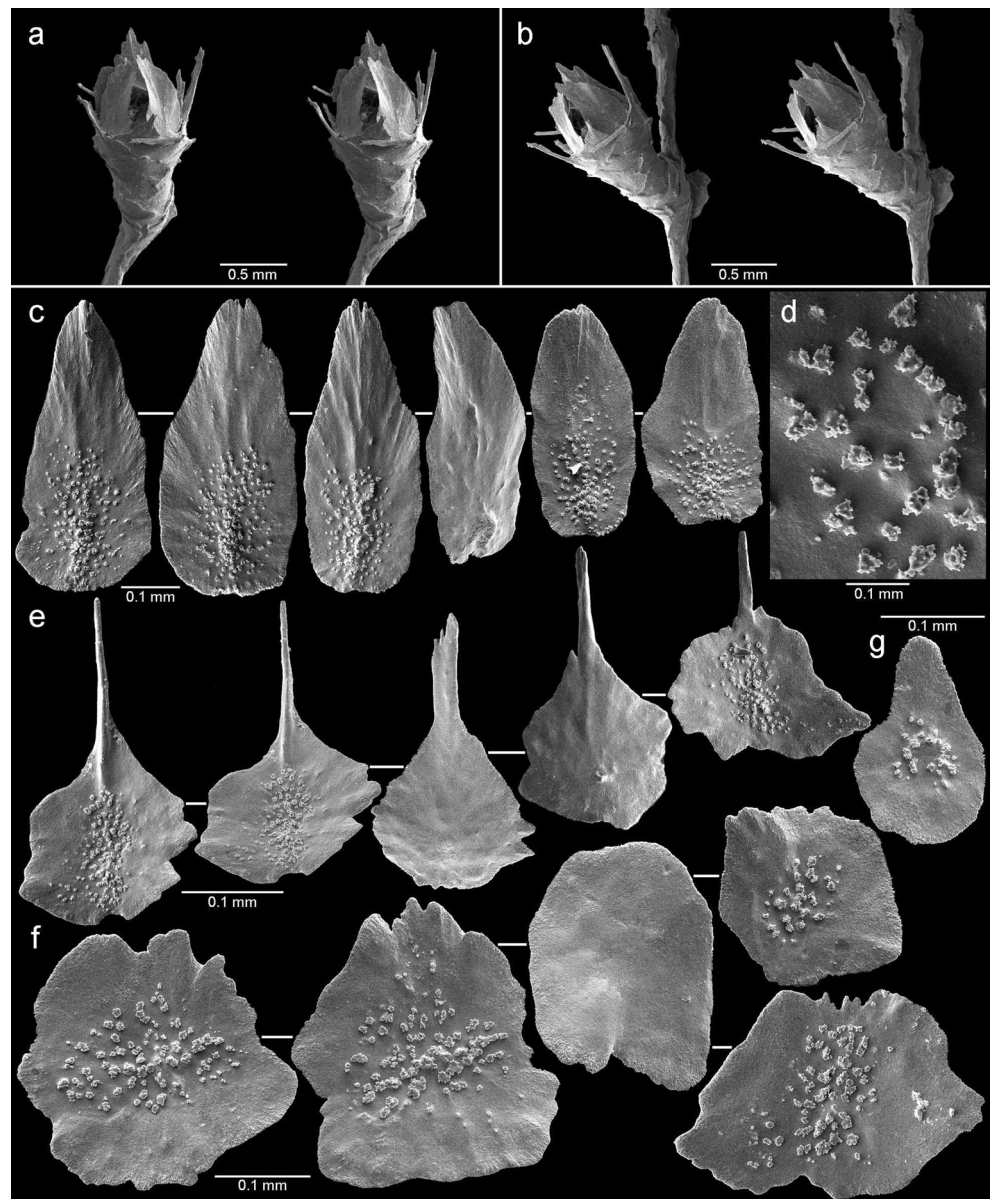
Etymology

Named *Abyssoprímnoa* (from the Latin *abyssus*, meaning bottomless pit, but in conventional oceanographic terminology between 3500 and 6500 m+*primnoa*, suffix common to the family), in allusion to the great depth of occurrence of the taxon. Gender: feminine.

Abyssoprímnoa gemina sp. nov.

Material examined

Fig. 3 Holotype of *Callozostron bayeri*: **a–b**, stereo views of polyps; **c**, six opercular scales; **d**, tubercles on inner face of opercular scale; **e**, five spinose marginal scales; **f**, five body wall scales; **g**, coenenchymal scale



Holotype: KG58, 1 colony and SEM stubs 2165, 2165, USNM 1268847. Paratypes: KG25, 1 colony, DZMB; stn KG28, 1 colony, USNM 1268846; stn KG64, 1 colony, USNM 1268845; AB1-CRS-1533- CS09, 1 colony, USNM 1268848.

Type Locality

KG-58, 11°46.981'N, 116°48.801'W (eastern Clarion-Clipperton Fracture Zone, German claim zone), 4168 m.

Distribution

As for the genus.

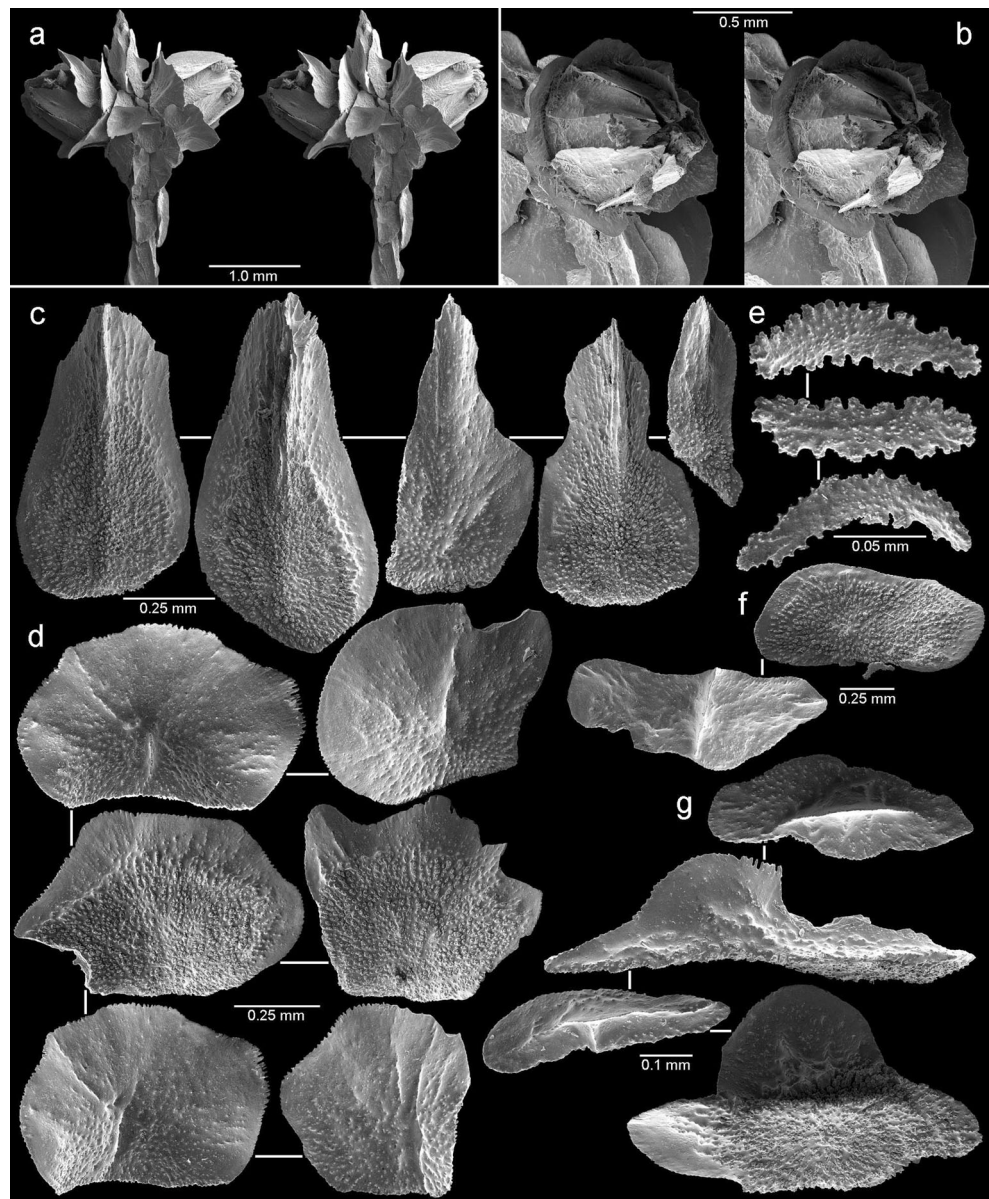
Description

Colonies are uniplanar, fragile, and quite small, the holotype (Fig. 1c) complete with holdfast, measuring only 26 mm in height, with a branch diameter of about 0.38 mm. The largest specimen (USNM 1268848) is 4 cm in height.

Branching is equal and dichotomous but sparse. The polyps are globose in shape (Fig. 4a and b), about 1.1 mm in height, and occur in pairs (Fig. 4a), about five pairs along 1 cm branch length. The holotype bears 19 polyp pairs.

The only body wall scales are four large marginals, which, along with the eight operculars, cover the entire stout polyp. The marginal scales (Fig. 4d) are oval to rectangular in shape (only slightly wider than tall), and sometimes have a multi-lobate distal edge. The two abaxial marginals are slightly wider than the two adaxial marginals: the abaxial marginals are 0.72–0.85 mm wide, each bordering about 100° of the opercular circumference, whereas the adaxial marginals are 0.57–0.62 mm in width, each bordering about 80° of the circumference. The marginals are slightly concave, bending away from the operculum, and have finely serrate distal and

Fig. 4 Holotype of *Abyssoprímnoa gemina*: **a**, stereo view of a pair of polyps; **b**, stereo opercular view of a polyp; **c**, five opercular scales; **d**, six marginal (body wall) scales; **e**, pinnular scales; **f**, two modified coenenchymal scales; **g**, four coenenchymal sail scales



lateral edges, as well as bearing a low medial longitudinal ridge. Their outer surface is faintly granular, their inner surface tuberculate, except near the distal edge, which is smooth. The opercular scales (Fig. 4c) are 0.58–0.97 mm in length and roughly twice as tall as wide, their tip being blunt or only slightly pointed. Like the marginals, their lateral edges are finely serrate and their granulation is the same. Each opercular bears a prominent medial keel on its inner face and is concave on its outer surface.

The coenenchymal scales are elongate, 0.50–0.85 mm in length ($L:W=2.6\text{--}4.2$), and arranged in one layer on the axis. Each coenenchymal bears a tall (up to 0.25 mm) thin, medial (longitudinal) ridge for half to three-quarters of its length, this morphology herein termed a “sail scale” (Fig. 4g). In some polyps, two

coenenchymal scales flank the lateral base, reinforcing the juncture of the ab- and adaxial marginal scales. These modified coenenchymals (Fig. 4f) are up to 0.77 mm in length and slightly bent around the curvature of the polyp, and its ridge is transverse, not longitudinal, and thus short. One might interpret these scales to be submarginals or even infrabasals, but because they are inconsistent in occurrence and occur only two to a polyp, they are classed as coenenchymal herein. Small (0.10–0.13 mm in length), curved (about 90°), flat pinnular scales (Fig. 4e) are also present in each polyp, judging from their frequency probably present as no more than two per tentacle. As is typical for pinnular scales, they are granular on both sides and have coarsely serrate edges.

Remarks

This genus and species is among the deepest known octocorals (Table 1). Several in situ photographs of this species are found in the Atlas of Abyssal Megafauna Morphotypes.

Etymology

Named *gemina* (from Latin *geminus*, meaning twin-born), in allusion to its paired polyps.

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