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The Pennatulacean Genus *Protoptilum*, with the Description of a New Deep-Sea Species from the Continental Slope of Central California (Octocorallia, Pennatulacea, Protoptilidae)

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The Farallones Oceanic Research Expedition (FORE) was carried out by the Moss Landing Marine Labortories in the early 1990's under the direction of Dr. James W. Nybakken. The Expedition yielded a wealth of benthic invertebrate material, which was collected by beam trawl on board the R/V *Point Sur* within the U.S. Navy Chemical Munitions Dumping Area. The California Academy of Sciences was the repository for many of the collected invertebrates. The material was subsequently curated and incorporated into the collections of the Department of Invertebrate Zoology and Geology. At present, at least six species of *Protoptilum* are recognized as valid and are distributed in the Indo-West Pacific and North Atlantic Oceans. The new species described herein, *Protoptilum nybakkeni*, sp. nov., is distinguished by possessing 2–4 short calyx teeth and the calyxes are strongly appressed to the sides of the rachis; it also documents the extension of the range of the genus to the Eastern Pacific and increases to seven the number of species in the genus currently recognized as valid.

KEYWORDS: *Protoptilum*, deep-sea pennatulaceans, sea pens, new species, Eastern Pacific, west coast of North America, key to species of the genus.

Protoptilum Kölliker, 1872, is a deep-sea pennatulacean genus of at least six described species currently known from the Atlantic and Indo-Pacific (Table 1; Cordeiro et al. 2019), with a known depth distribution of 250-4000 m (Williams 1995:114; m 2011: 6). Pennatulaceans have been characterized as a morphologically distinct and specialized group octocoral cnidarians (Williams 1990:34, 1995: 3, 2011:2). As a group, pennatulaceans produce a calcitic central axis that has been associated with deep-water habitats as far back in geological time as the Late Cretaceous (Voigt 1958; Murray Roberts et al. 2009). Morphologically, the pennatulacean axis shows a remarkable similarity in structural characteristics with the axis of ellisellid gorgonians (Bayer 1956:224). In addition, a close affinity between ellisellids and pennatulaceans based on molecular evidence was subsequently established as well (McFadden et al. 2006:517–521). The genus *Protoptilum* has previously been reported from the Oregon Province (Vancouver Island, British Columbia to Point Conception, California; 150–3306 m in depth) as *Protoptilum* sp., based on three institutional database records (California Academy of Sciences, NOAA National Database of Deep-Sea Corals and Sponges, and Monterey Bay Aquarium Research Institute) (Whitmire et al. 2017), but further details have not been published up until now.

Since 2012, exploration by remotely operated vehicles of the mesophotic and deep-sea region to the west of the San Francisco Bay Area and in or around three local National Marine Sanctuaries – Cordell Bank, Greater Farallones, and Monterey Bay – has resulted in new biodiversity discoveries. This endeavor has resulted in the acquisition of collected material for the description of new species, as well as the establishment of a new genus name for a previously described binomen that was incorrectly allocated to a different genus (Williams and Breedy 2016, 2019; Williams, 2013).

Historical Assessment of the Type Locality

Chemical Munitions and Radioactive Waste Dumpsites.— In July of 1991, the Farallones Oceanic Research Expedition (FORE) – under the auspices of Moss Landing Marine Laboratories – took place to document benthic invertebrate diversity in an impacted region east of the Farallon Islands. This is an area of overlap between the former Chemical Munitions Dumpsite (Naval Ocean Dump Site) and the Farallon Islands Radioactive Waste Dump (FIRWD). In 1946, the FIRWD was designated by the Atomic Energy Commission as a disposal site for the dumping of numerous canisters containing low-level radioactive wastes (Chin and Ota 2001). The overlap area is the type locality for the new species of *Protoptilum* that was collected by trawling operations during FORE, and is also in close proximity to the southern boundaries of both Cordell Bank NMS and Greater Farallones NMS (Fig. 1).

The National Marine Sanctuary system and the National Marine Sanctuaries of central California.— There has been a history of substantial anthropogenic impacts in the benthic region to the west of the San Francisco Bay Area and the Farallon Islands. Included here are the dumping of dredged sediment from SF Bay due to Gold Rush era hydraulic mining in the foothills of the Sierra Nevada, dumping of chemical and radioactive waste material by the US government, the sinking of the aircraft carrier USS Independence in 1951 after it was serverely damaged during atomic testing at Bikini Atoll, destructive trawling practices, overfishing, industrial pollution and agricultural runoff from nearby urban areas of the Bay Area, etc.

The San Francisco Bay Area and the area around the Farallon Islands have a long history of maritime industry and military history. Maritime trade in the region includes rapidly expanded maritime activity since the beginning of the California Gold Rush in 1849, the subsequent emergence as the center of Pacific Rim trade, commercial fishing in San Francisco Bay for rich resources of fish and shellfish, and the world's largest canning operations from 1899 to 1937, as well as significant military activity. Although fishing activity contributed to the economy and national security, it also has had historic impacts to the ocean environment in the form of shipwrecks, scuttled vessels, munitions and radioactive waste dumps, and fishing gear impacts to the seafloor. Regarding military activity, the Presidio, at the mouth of San Francisco Bay, functioned as a military reservation from 1776–1994, serving colonial Spain, Mexico, and the United States, including the Spanish-American War, and World Wars I and II.

The environmental movement in the United States in the 1960s and 1970s led to the passage of a several federal environmental protection laws. In 1972, the United States Congress passed legislation that led to the establishment of the National Marine Sanctuary Program (later renamed the Office of National Marine Sanctuaries, ONMS). The National Marine Sanctuary Program was established under the National Oceanic and Atmospheric Administration (NOAA) to protect areas of the marine environment with special national significance due to their conservation, recreational, ecological, historical, scientific, cultural, archeological, educational or esthetic qualities as national marine sanctuaries. In the 1970's, NOAA began a process to study and designate areas as

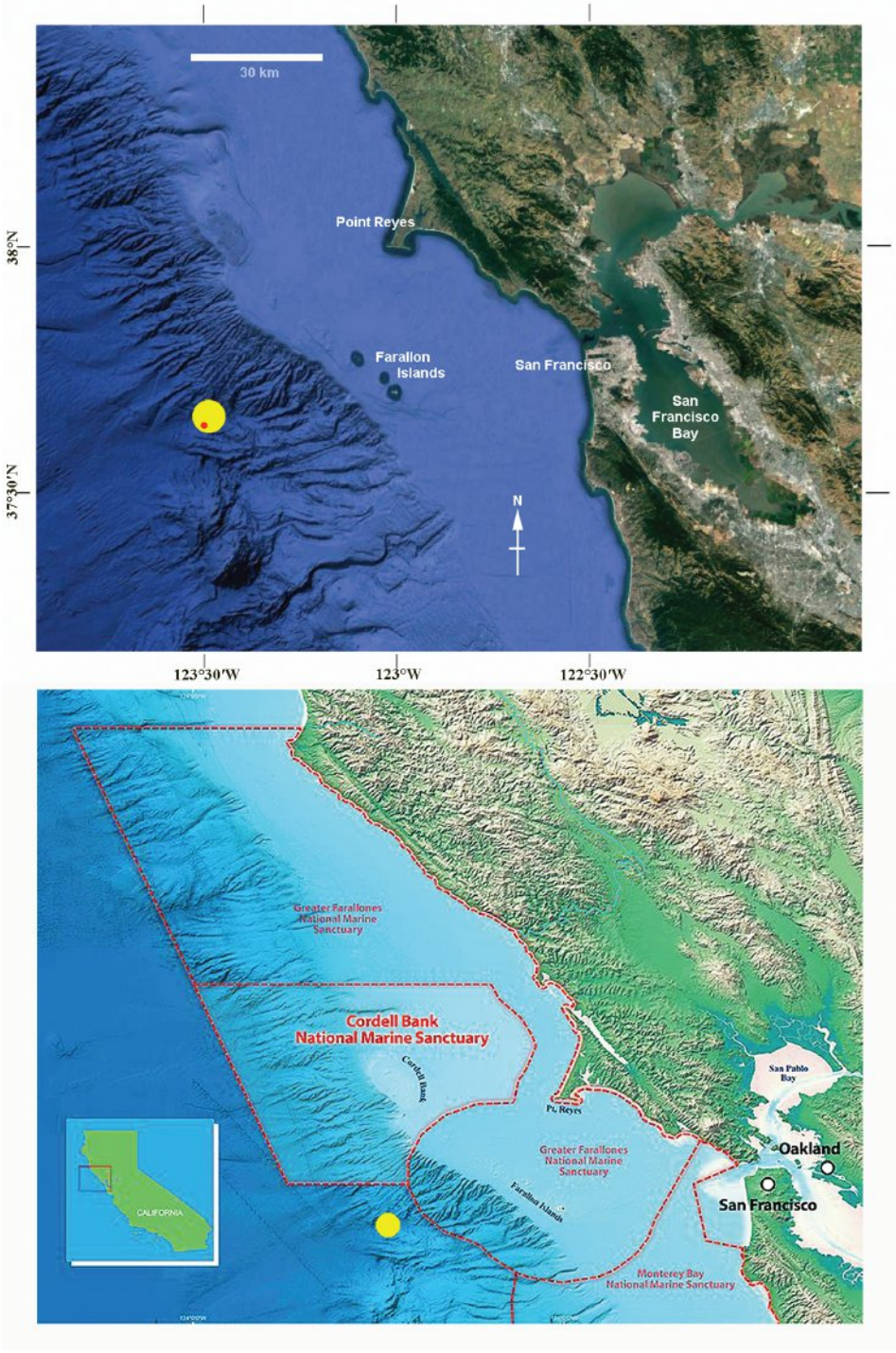

FIGURE 1. Map of the central California region showing a portion of the U.S. Navy Chemical Munitions Dumping Area (yellow circle), in which all material examined in this paper was collected, including the type locality of *Protoptilum nybakkeni* sp. nov. (red dot in yellow circle).

national marine sanctuaries. The first national marine sanctuary was designated in 1975 to protect the Civil War shipwreck the USS Monitor off the coast of North Carolina and by 2019 there were 13 national marine sanctuaries and 2 national marine monuments managed by ONMS. In central California, Point Reyes-Farallon Islands National Marine Sanctuary was established in 1981 and renamed the Gulf of the Farallones National Marine Sanctuary in 1997. Cordell Bank National Marine Sanctuary was established in 1989, followed by Monterey Bay National Marine Sanctuary in 1992. In 2015, NOAA expanded Gulf of the Farallones National Marine Sanctuary from 1,282 to 3,295 square miles, extending from Bodega Bay in Sonoma County north to Manchester Beach in Mendocino County (Fig. 1), and renamed it Greater Farallones National Marine Sanctuary. In addition, Cordell Bank National Marine Sanctuary was expanded from 529 to 1,286 square miles, and was extended to the west to include a region of continental slope, as well as slightly to the north (Fig. 1). The three contiguous national marine sanctuaries in central California extend over 450 km (280 mi) of coastline from San Simeon, CA north to Point Arena, CA. Although there is some variation in the regulations at each sanctuary, in general these three sanctuaries protect against disturbance of the seafloor, discharge of material or matter, and oil and gas development. The waste dump that is described in this paper lies outside of sanctuary boundaries, at the edge of both CBNMS and GFNMS. In addition to regulatory protections, national marine sanctuaries are charged with research and monitoring, and education and outreach that may include education of the general public, teachers, students, national marine sanctuary users, and ocean and coastal resource managers. This mandate has resulted in investments in mapping, exploring, characterizing, and monitoring the seafloor. Projects have used various technologies such as submersibles, camera sleds, and remotely operated vehicles to collect imagery of seafloor and biological and geological specimens. California Academy of Sciences is the repository for all biological specimens collected within GFNMS and CBNMS, and CAS and sanctuaries have collaborated since 2012 on targeted surveys and collections. This collaboration has facilitated a distinct focus on the benthic invertebrate taxonomy of the region. Recently, targeted missions to unexplored parts of the sanctuaries have greatly enhanced our understanding of these protected areas and has resulted in several publications on the benthic coral diversity of the region (Williams 2013; Williams & Breedy, 2016, 2019). However, mining the historic archives of CAS has yielded even further discoveries about this region, as evidenced by the recent discovery described in this paper. This collaboration between ONMS and CAS has led to a greater understanding of the habitat, species, and communities in the deep sea and a better appreciation of the value of these "out of sight, out of mind" places. Information about the species and communities in these areas can inform decisions about protecting areas, or allowing commercial and industrial activities to take place.

Materials And Methods

Numerous colonies of the new taxon were collected in July of 1991 by beam trawl in the region of overlap between the US Navy Chemical Weapons Dumping Area and the Farallon Islands Radioactive Waste Dump, adjacent to current boundaries of Cordell Bank National Marine Sanctuary and Greater Farallones National Marine Sanctuary, approximately 70 miles west of San Francisco, California. The protocol for the isolation of sclerites from colonial tissues follows that of Williams & Mattison (2018). Scanning electron micrographs were made using a Hitachi SU3500 scanning electron microscope. Abbreviations used in the text are CASIZ – California Academy of Sciences Invertebrate Zoology and MLML – Moss Landing Marine Laboratories.

Systematic Account

Class Anthozoa Ehrenberg, 1831
Subclass Octocorallia Haeckel. 1866
Order Pennatulacea Verrill, 1865
Family Protoptilidae Kölliker, 1880

Protoptilum Kölliker, 1872

Protoptilum Kölliker, 1872:192. Kölliker, 1880: 28. Jungersen, 1904:51. Balss, 1910:34. Kükenthal & Broch, 1911:256. Kükenthal, 1915:37. Hickson, 1916:97. Williams, 1995:113.

Generic Diagnosis.— Colonies whip-like, elongate, slender. Polyp leaves absent. Rachis bilaterally symmetrical. Polyps often arranged in oblique rows along opposite sides of the rachis, usually two to four polyps per row, sometimes not in rows and arranged singly. Anthocodiae retractile into calyces. Calyces with varying number of terminal teeth, usually 3-8, or teeth absent altogether. Calyces often flattened and closely appressed to sides of rachis. Siphonozooids sparse to numerous between rows and along margins of bare rachis. Sclerites present in most parts of colonies, three-flanged spindles, needles, rods or ovals (Kükenthal 1915:37; Williams 1995:114).

Type Species.— *Protoptilum carpenteri* Kölliker, 1872.

***Protoptilum nybakkeni* Williams and Lipski, sp. nov.**

Figures 2-5.

Holotype.— CASIZ 106702; CALIFORNIA, within U.S. Navy Chemical Munitions Dumping Area, west of the Farallon Islands; 37°37.5'N, 123°30'W – 37°37.8'N, 123°29'W; 2900 m; 30 July 1991; coll. Moss Landing Marine Laboratories aboard R/V *Point Sur*, Farallones Oceanic Research Expedition; one entire colony wet-preserved in 75% ethanol, original fixative 10% formalin.

Paratypes.— CASIZ 207521; CALIFORNIA, within U.S. Navy Chemical Munitions Dumping Area, west of the Farallon Islands; 37°37.5'N, 123°30'W – 37°37.8'N, 123°29'W; 2900 m; 30 July 1991; coll. Moss Landing Marine Laboratories aboard R/V *Point Sur*, Farallones Oceanic Research Expedition; one entire colony wet-preserved in 75% ethanol, original fixative 10% formalin. **CASIZ 207522**; CALIFORNIA, within U.S. Navy Chemical Munitions Dumping Area, west of the Farallon Islands; 37°37.5'N, 123°30'W; 37°37.8'N, 123°29'W; 2900 m; 30 July 1991; coll. Moss Landing Marine Laboratories aboard R/V *Point Sur*, Farallones Oceanic Research Expedition; one partial colony wet-preserved in 75% ethanol, original fixative 10% formalin – proximal tip of peduncle missing.

Other Material.— CASIZ 180555; CALIFORNIA: within U.S. Navy Chemical Munitions Dumping Area, west of the Farallon Islands**;** 37°35′N, 123°30.1′W – 37°35′N, 123°28.8′W; 3015-2690 m; 30 July 1991; coll. Moss Landing Marine Laboratories, Farallones Oceanic Research Expedition; one partial colony sorted from CASSIZ 106718 – distal tip of rachis missing; one wet-preserved specimen in 75% ethanol, original fixative 10% formalin. **CASIZ 106703;** CALIFORNIA: within U.S. Navy Chemical Munitions Dumping Area, west of the Farallon Islands**;** 37°37.5′N, 123°30′W – 37°37.8′N, 123°29′W; 2900 m; 30 July 1991; coll. Moss Landing Marine Laboratories aboard R/V *Point Sur*, Farallones Oceanic Research Expedition; one whole colony wet-preserved in 75% ethanol, original fixative 10% formalin. **CASIZ 106722;** CALIFORNIA: within U.S. Navy Chemical Munitions Dumping Area, west of the Farallon Islands; 37°38.4′N, 123°28.6′W – 37°39.1′N, 123°27.5′W; 2910–2850 m; 27 July 1991; coll. Moss Landing Marine

Laboratories aboard R/V *Point Sur*, Farallones Oceanic Research Expedition; two whole colonies wet-preserved in 75% ethanol, original fixative 10% formalin.

Distribution and Habitat.— Central California, approximately 90 km west of San Francisco; 2300–3975 m in depth. Habitat not recorded.

Etymology.— The new species is named in honor of Dr. James W. Nybakken, late Professor of Biological Sciences at Moss Landing Marine Laboratories, Moss Landing, California, and Chief Scientist of the Farallones Oceanic Research Expedition.

Description of the Holotype

External Morphology.— The holotype is an entire colony, extremely slender and delicate, 98 mm in total length. The rachis is 58 mm long and approximately 1.5–1.8 mm in width throughout. The peduncle is 40 mm in length and < 1.5 mm in width. The internal calcareous axis extends throughout the length of the colony. The axis in transverse section shows the radiating pattern of columns of calcareous material (Fig. 2A), that is characteristic of the pennatulaceans as a group as well as the ellisellid gorgonians (Bayer 1956:224).

Polyps.— The anthocodiae are completely retractile within densely spiculated calyces (Fig. 3B–C). The calyces are densely set along the length of the rachis, approximately fifteen rows of authozooids throughout the length of the rachis. In some colonies, the calyces appear to be present in oblique rows of two to three polyps per row. In other colonies with very thin rachis the polyps may be arranged singly and do not appear in oblique rows. The calyces are more-or-less flattened to gently rounded, elliptical or somewhat fan-shaped, with axial sides closely appressed to the sides of the rachis (Figs. 2E–G; 3B–C). An individual calyx has 2–4 discernible teeth (Fig. 3B–C), sometimes exhibiting rounded distal tips (Fig. 2G), or distinguishable teeth are absent altogether. The siphonozoods are minute and inconspicuous. They appear in a sinuous single longitudinal column alongside the calyces. The siphonozooid calyces are similar in shape and appearance to the autozooid calyces, only in miniature (lower left portion of Fig. 2F).

Sclerites.— Scerites of the calyces and rachis are smooth, conspicuously three-flanged needles and spindles, 0.2–0.8 mm in length (Fig. 4). Conspicuous sclerites of the peduncle are not apparent. The surface coenenchyme and interior of the peduncle do contain extremely minute, elliptical to ovoid bodies that often appear in clumps or dense aggregations, and are too small to isolate and successfully prepare for examination under the scanning electron microscope. The individual calcareous bodies differ little in length or diameter, usually 0.003–0.006 mm. A single clump of these minute sclerites may vary from 0.010 mm to 0.040 mm (Fig. 5).

Color.— Overall color of the holotype as well as the paratype colonies is white to pale grey or cream white (Fig. 2).

Variability.— Taking into account the type specimens as well as other material not allocated as types, the total length of the colonies observed varies from approximately 65–235 mm. Rarely, a particular colony can appear a light pinkish red due to the color of the sclerites that comprise the calyces.

Discussion and Conclusion

Key to the species of *Protoptilum* Kölliker, 1872

1a. Distinct calyx teeth absent or indistinguishable. Siphonozoods few and inconspicuous. Colony color red and yellowish white . . . . . *Protoptilum carpenteri*

1b. Distinct calyx teeth present, which can be very short to elongate or needlelike 2

2a. Peduncle equal in length or longer than rachis; colony color white to yellow. 3
2b. Peduncle length shorter than rachis. 4

3a. Two to four short calyx teeth; greyish white overall colony color. . . . . *Protoptilum nybakkeni*
3b. Three to eight calyx teeth 5

4a. Two distinct calyx teeth; colony color dark red . . . . . *Protoptilum celebense*
4b. Three to eight calyx teeth; colony color red or blue-grey. 6

5a. Three to five short calyx teeth; yellowish colony colo . . . . . *Protoptilum smitti*
5b. Six to eight long calyx teeth; whitish colony color . . . . . *Protoptilum denticulatum*

6a. Three small calyx teeth; colony color red . . . . . *Protoptilum thomsoni*
6b. Six to eight long calyx teeth; colony color blue-grey . . . . . *Protoptium cyaneum*

Species comparisons (Table 1).— The two major works that have discussed all ten described species of the genus *Protoptilum* are those of Kükenthal, 1915 and Hickson, 1916. These two authors have reviewed suggestions of synonymies by other authors as well as the assessment of dubious taxa (some of which may belong to other genera), and with the addition of *Protoptilum nybakkeni* sp. nov., is here consolidated to seven species, four of which are distributed in the Atlantic Ocean (Deichmann 1936:263–264). The various species are differentiated mainly by comparative characteristics of the calyx teeth.

Table 1. Principal characters and distribution of *Protoptilum*, deep-sea pennatulacean genus of at least six described species currently known from the Atlantic and Indo-Pacific.

Species	Peduncle Length	Calyx teeth	Color	Geographic Distribution	Source
P. carpenteri	Shorter than rachis	Distinct teeth absent	Red	North Atlantic Ocean	Kükenthal 1915
P. celebense	Shorter than rachis	2 distinct teeth	Dark red	Western Pacific Ocean	Hickson 1916
P. cyaneum	Shorter than rachis	6-8 long teeth	Blue Grey	East Africa	Kükenthal 1915
P. denticulatum	As long or longer than rachis	6-8 long teeth	Colorless	Northern Atlantic Ocean	Kükenthal1915
P. nybakkeni sp. nov.	Roughly as long as rachis	2-4 short teeth or distinct teeth absent	Colorless	California	This work
P. smitti	As long or longer than rachis	3-5 short teeth	Yellow	North Atlantic Ocean	Kükenthal 1915
P. thomsoni	Shorter than rachis	3 small teeth	Red	North Atlantic Ocean	Kükenthal 1915

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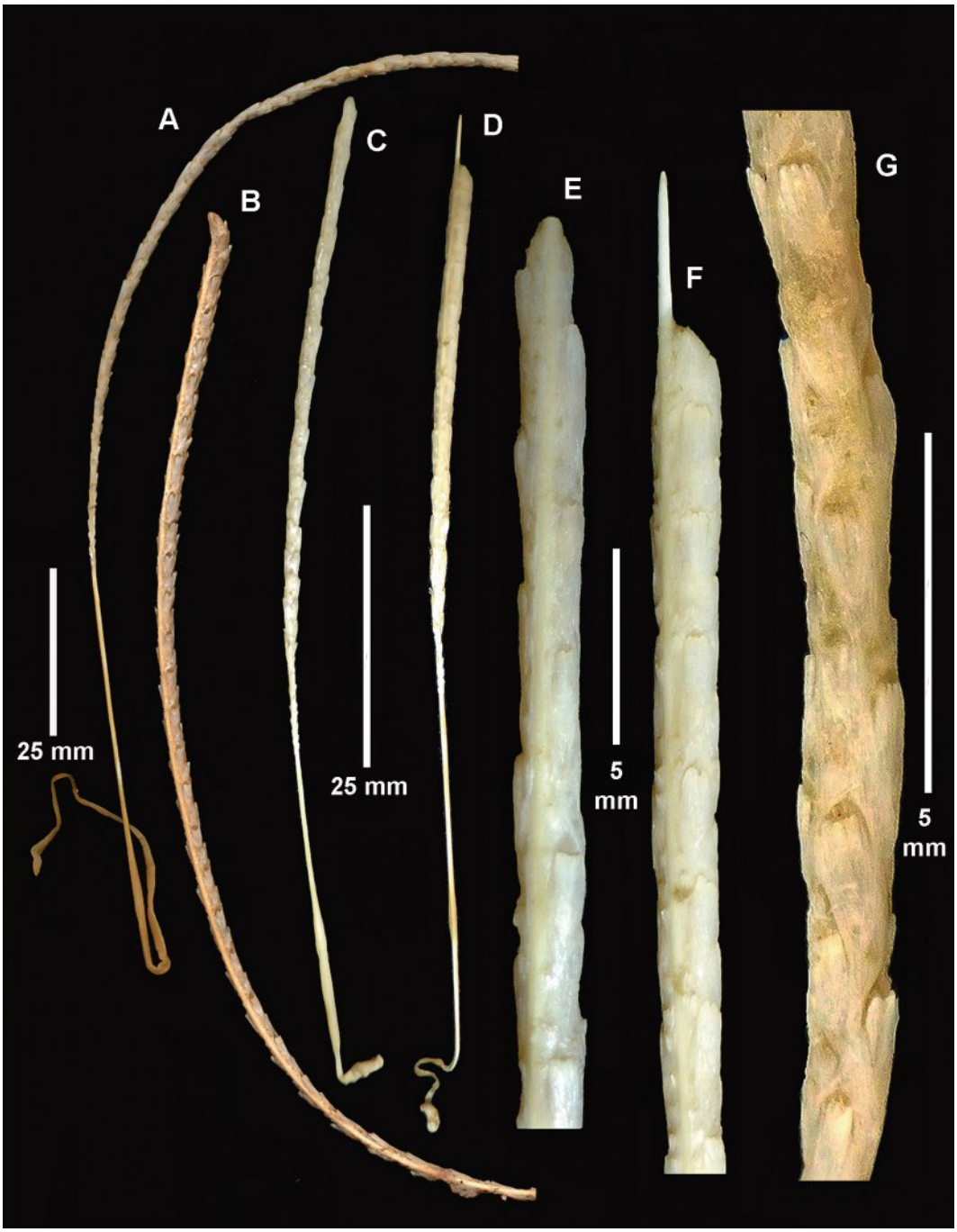

FIGURE 2. *Protoptilum nybakkeni* sp. nov. External morphology. A. Partial colony with distal tip missing (CASIZ 180555); far left scale bar = 25 mm. B. Partial colony with proximal portion missing (CASIZ 106722); center left scale bar = 25 mm. C. Holotype, entire colony (106702); center left scale bar = 25 mm. D. Paratype, entire colony (207521); center left scale bar = 25mm. E. Detail of partial holotype colony, distal portion (106702); center right scale bar = 5 mm. F. Paratype, detail of distal portion of colony (207521); center right scale bar = 5 mm. G. Detail of colony and calyces (CASIZ 180555); far right scale bar = 5 mm.

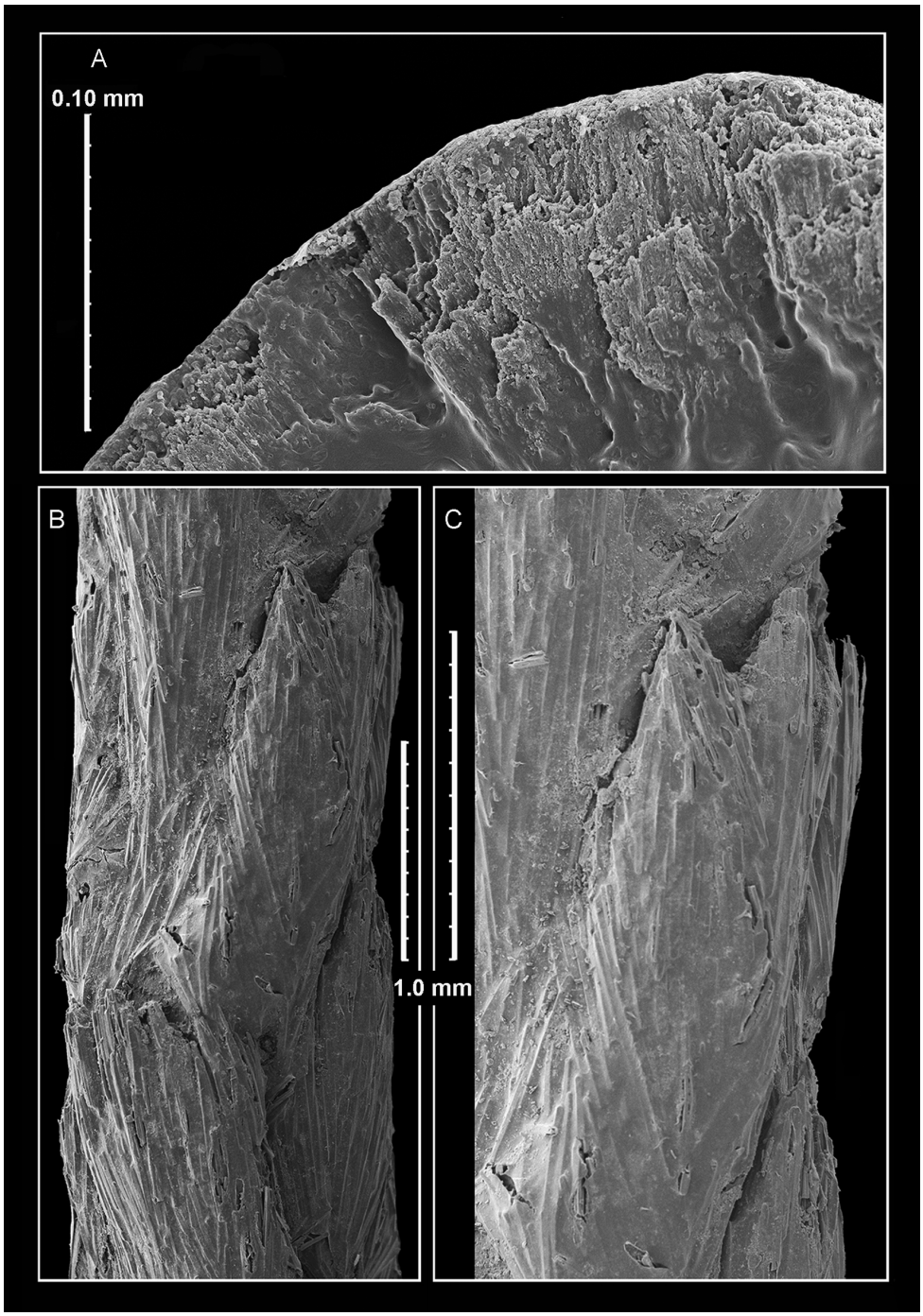

FIGURE 3. *Protoptilum nybakkeni* sp. nov. (CASIZG 180555). Scanning electron micrographs of morphological details. A. Outer edge of a portion of the axis in cross section, showing the radiating pattern of calcareous material; scale bar = 0.10 mm. B. Detail of the rachis showing three polyps closely appressed to the rachis, as well as a varying number of terminal teeth per polyp. Outlines of the longitudinally placed needle-like sclerites are seen under the epidermis; scale bar = 1.0 mm. C. Detail of a single polyp from B; scale bar = 1.0 mm.

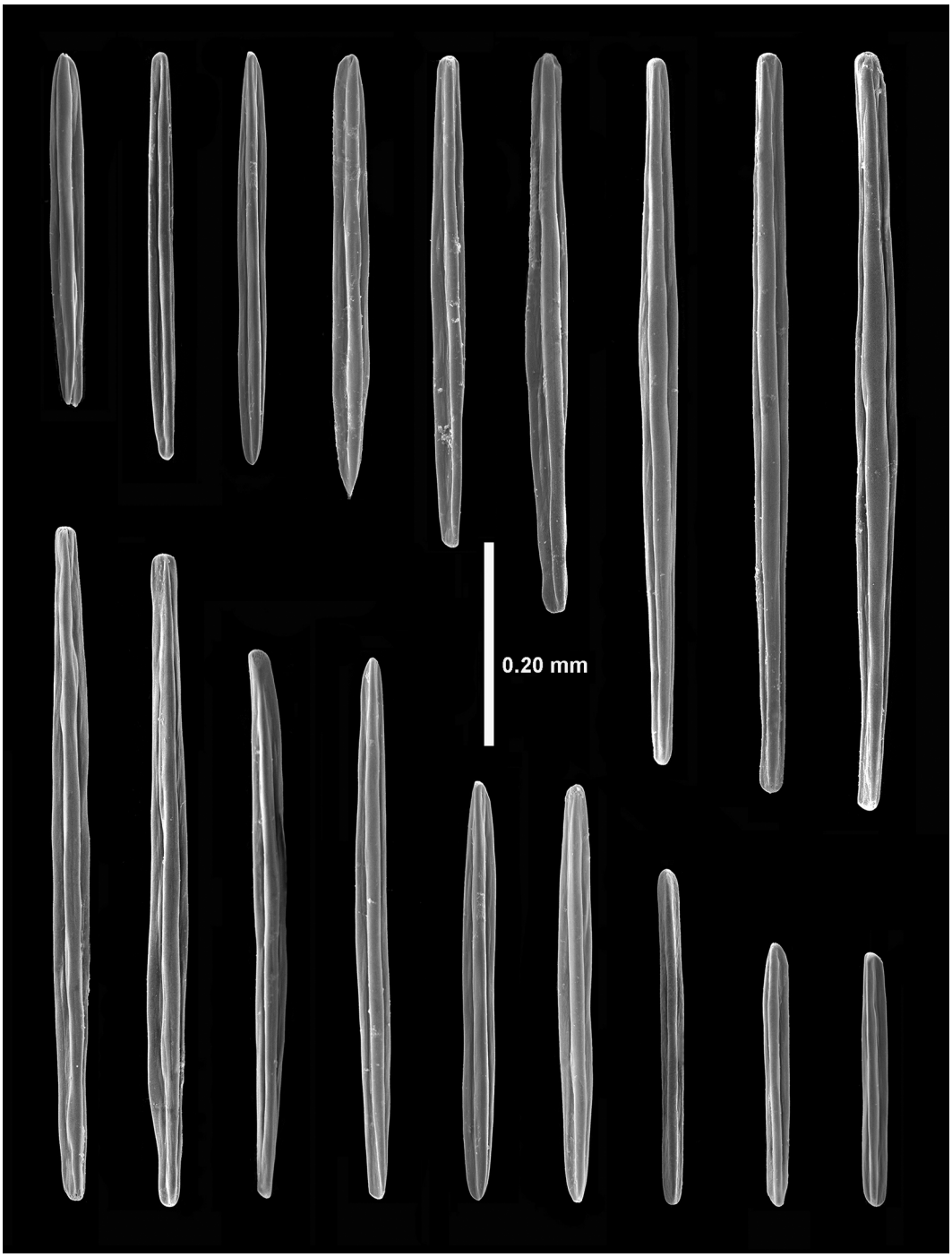

FIGURE 4. *Protoptilum nybakkeni* sp. nov. (CASIZG 106702). Scanning electron micrographs of sclerites from the calyx and rachis; scale bar = 0.20 mm.

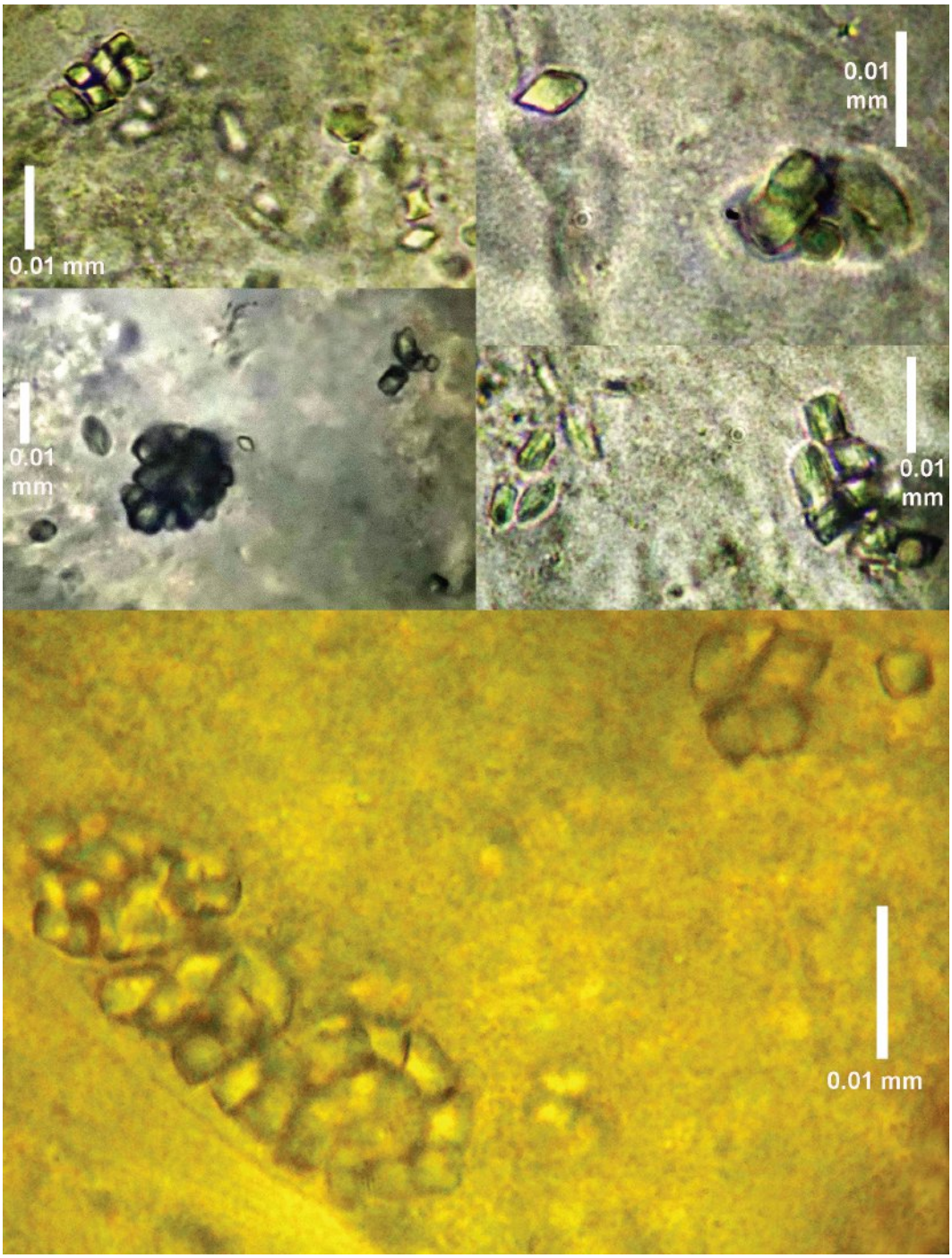

FIGURE 5. *Protoptilum nybakkeni* sp. nov. (CASIZG 106703). Light Microscope photographs of minute sclerites from the peduncle; scale bars = 0.01 mm.