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First Record of the Family Myxasteridae (Asteroidea: Velatida) from Western North Pacific with Description of a New Species of *Asthenactis*

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We describe a new species of the rare and deep-sea family Myxasteridae from Japanese waters. This is the first record of this family in the western North Pacific. The new species, *Asthenactis agni* n. sp., differs from all congeners in having seven arms with an R/r ratio of 7.2, primary radial plates with convex distal edges, and two to three actinolateral spines that are up to 4.7 mm long.

Key Words: Japan, Deep-sea, Taxonomy, Starfish, ROV, Micro-computed tomography.

Introduction

The Myxasteridae is a rarely encountered family of asteroid that has slender flexible arms and an osculum without a nidamental chamber covered by a tent-like supradorsal membrane (Alton 1966; McKnight 2006). This family occurs only at bathyal to abyssal depths (471 to 4877 m in depth), and its members are widely distributed across the Pacific and Atlantic Oceans (Clark 1996; Dilman 2005; Mah et al. 2012). Since the establishment of this family, only nine species in three genera have been discovered: five Pacific species, *Asthenactis australis* McKnight, 2006; *Asthenactis fisheri* Alton, 1966; *Asthenactis papyraceus* Fisher, 1906; *Myxaster medusa* (Fisher, 1913); and *Pythonaster pacificus* Downey, 1979; and four Atlantic species, *Myxaster sol* Perrier, 1885; *Myxaster perrieri* Koehler, 1895; *Pythonaster atlantidis* Clark, 1948; and *Pythonaster murrayi* Sladen, 1889 (Fisher 1906; Alton 1966; Downey 1979; Clark and Downey 1992; Howell et al. 2002; Dilman 2005; McKnight 2006; Mah et al. 2012; Mah 2020; see also Fig. 1).

Within this family, the genus *Asthenactis* Fisher, 1906 is endemic to the Pacific Ocean and is distinguished from the other genera in having seven to eleven arms with actinolateral membranes on the arm base (Fisher 1906; Alton 1966; McKnight 2006). Previous records of this genus are quite limited, and only six specimens of three species have been reported to date (Fisher 1906; Alton 1966; McKnight 2006).

In this study, we found a new species classified into the genus *Asthenactis* from Japanese waters during a deep-sea cruise conducted in October 2021.

Materials and Methods

A specimen of *Asthenactis* was found *KM-ROV* #157 on the muddy bottom, photographed in-situ and collected by a slurp gun during the R/V *Kaimei* Cruise (KM21-E04C) of the Japan Agency for Marine-Earth Science and Technology. The specimen examined in this study is deposited at the National Museum of Nature and Science, Tsukuba (NSMT).

The ethanol-preserved specimen was observed under a dissecting microscope MZ 8 (Leica Microsystems, Wetzlar, Germany). Lengths of major radius (R) and minor radius (r) were measured from the center of the mouth opening to the arm tips and to the connection of each proximal part of two arms, respectively. After photography of the intact preserved specimen, spines and epidermal tissues were partly removed from the abactinal and actinal surfaces of the disc and the arms by applying commercial bleach (about 5% sodium hypochlorite) to observe the shape and arrangement of the underlying plates. Spines removed from on the primary radial plates, abactinal plates at the proximal-most portion of the arms, and adambulacral plates were collected for observation by using a scanning electron microscope (SEM). These spines were immersed in a drop of commercial bleach for a few minutes to remove residual tissues and washed with deionized water. The cleaned spines were then mounted on brass SEM stubs and air-dried. These spines were coated with gold-palladium and observed with a JSM-6380LV SEM (JEOL, Tokyo, Japan). To observe the internal morphology, we scanned the semi-dried specimen with an inspeXio SMX-

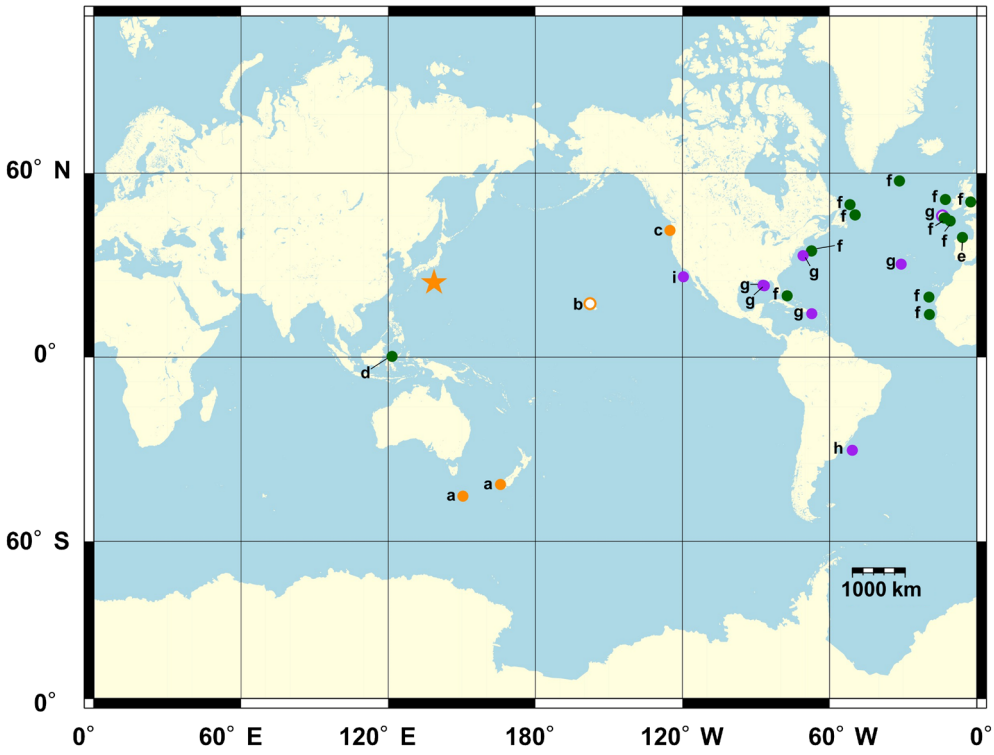

Fig. 1. Sampling site of *Asthenactis agni* n. sp. (indicated by an orange star) and the geographic distribution of nine known species of the family Myxasteridae in the world's oceans. a, *Asthenactis australis*; b, *Asthenactis papyraceus*; c, *Asthenactis fisheri*; d, *Myxaster medusa*; e, *Myxaster perrieri*; f, *Myxaster sol*; g, *Pythonaster atlantidis*; h, *Pythonaster murrayi*; i, *Pythonaster pacificus*. Previous records with information of the sampling sites and/or coordinates are shown herein (Fisher 1906; Alton 1966; Downey 1979; Clark and Downey 1992; Howell et al. 2002; Dilman 2005; McKnight 2006; Mah et al. 2012; Mah 2020). The locality of *A. papyraceus* and one of the localities of *P. atlantidis* are Hawaii and the Porcupine Abyssal Plain, respectively, without data on the coordinates (open circles) (Fisher 1906; Howell et al. 2002). The colors of plots of orange, green, and purple correspond to the genera *Asthenactis*, *Myxaster*, and *Pythonaster*, respectively.

Fig. 2. In-situ image of *Asthenactis agni* n. sp. Holotype, NSMT E-13917, taken at the Anʾei Seamount, Japan (29°17′47.784″N, 138°40′42.714″E), at a depth of 1970 m.

225CT FPD HR micro-computed tomography (micro-CT) scanner (Shimadzu, Kyoto, Japan). The scanning was performed at a tube voltage of 115 kV and a tube current of 70 μA for 30 minutes. Three-dimensional volume rendering images were reconstructed using the software VGSTUDIO Max 3.2 (Volume Graphics, Heidelberg, Germany).

The morphological terms follow the work of McKnight (2006) and Gale (2018). We call the spines on the abradial distal part of adambulacral plates "actinolateral spines", following previous papers on the species belonging to the order Velatida (e.g., Alton 1966; Clark and Downey 1992; McKnight 2006; Gale 2018; Lane and Vimono 2020) to avoid confusion, in spite of the fact that these spines are not on the actinolateral plates.

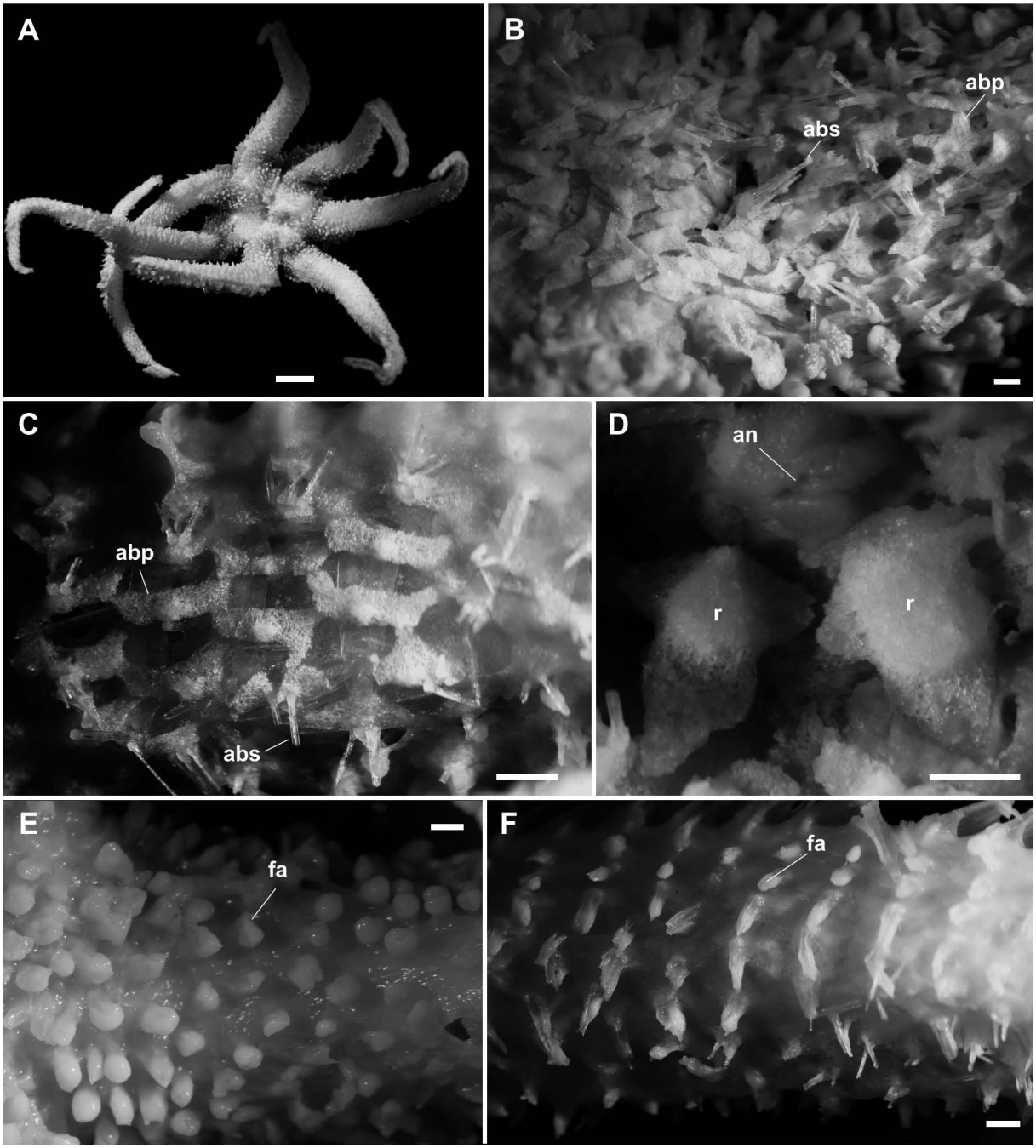

Fig. 3. Abactinal views of *Asthenactis agni* n. sp. Holotype, NSMT E-13917. A, Whole body; B, denuded abactinal surface at proximal part of arm; C, denuded abactinal surface at middle part of arm; D, denuded abactinal surface at the center of the disc; E, abactinal surface at proximal part of arm; F, abactinal surface at middle part of arm. Abbreviations: abp, abactinal plates; abs, abactinal spines; an, anus; fa, fascicles of abactinal spines; r, primary radial plates. Scale bars indicate 10 mm in A and 1 mm in B–F. Proximal is left in B, C, E, and F.

Taxonomy

Order **Velatida** Perrier, 1893
Family **Myxasteridae** Perrier, 1885
[New Japanese name: Hebi-maku-hitode-ka]
Genus ***Asthenactis*** Fisher, 1906
[New Japanese name: Mizukaki-hitode-zoku]

Asthenactis agni n. sp.
[New Japanese name: Mizukaki-hitode]
(Figs 2–6)

Material examined. Holotype. NSMT E-13917: 20 October 2021, An'ei Seamount, Japan, 29°17′47.784″N, 138°40′42.714″E, at a depth of 1970 m, fixed and preserved in 99.5% ethanol.

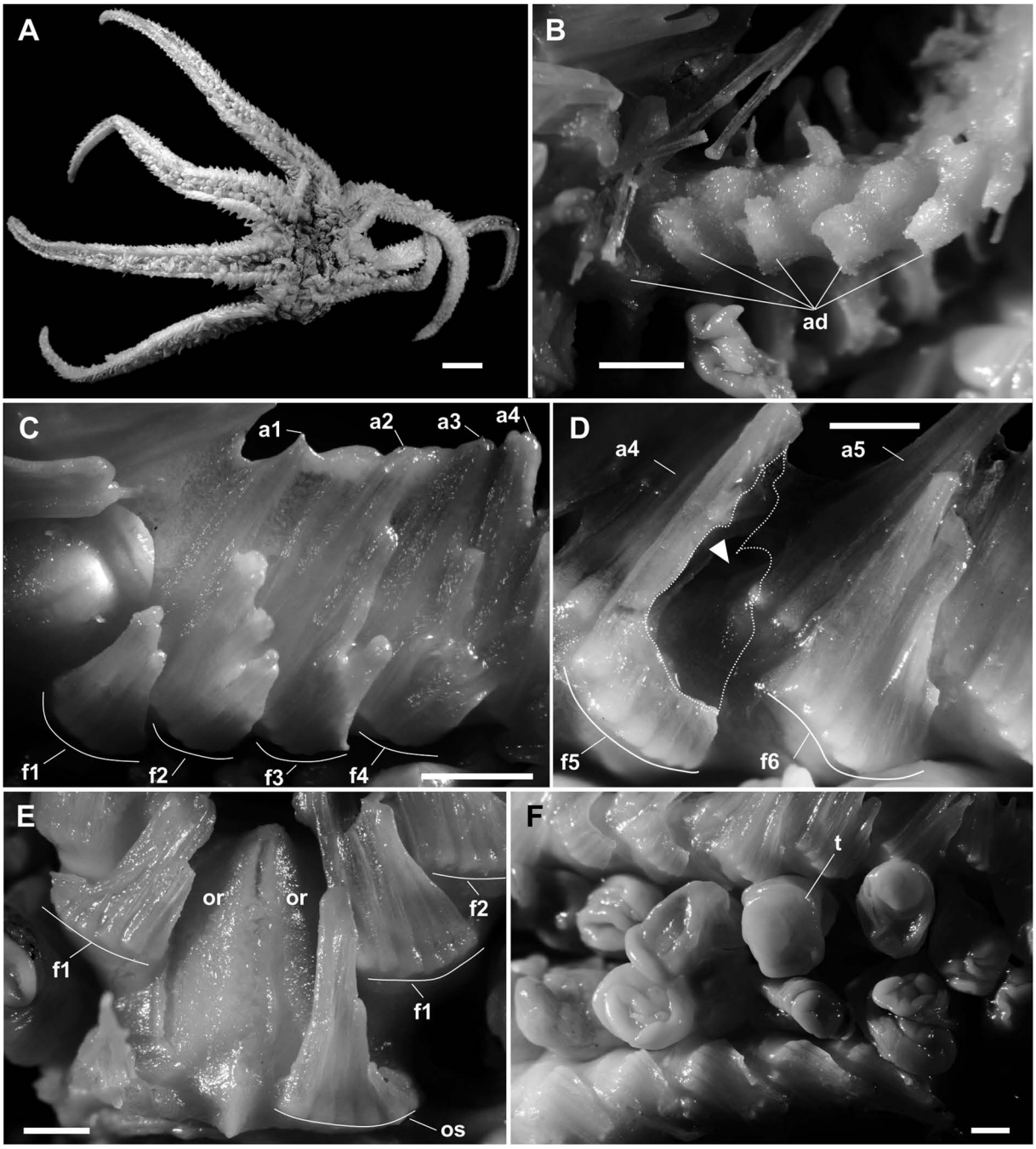

Fig. 4. Actinal views of *Asthenactis agni* n. sp. Holotype, NSMT E-13917. A, Whole body; B, denuded actinal surface at the proximal part of arm; C, actinal surface of the 1st to 4th adambulacral plates; D, actinal surface of the 5th to 6th adambulacral plates, showing an aperture (arrowhead) of an actinolateral membrane. Tips of furrow spines on 5th adambulacal plate shown as the white dotted line were removed; E, actinal surface of oral plates and 1st to 2nd adambulacral plates; F, actinal surface of ambulacral groove. Abbreviations: a, abradial-most actinolateral spine; ad, adambulacral plates; f, furrow spines; or, oral plates; os, oral spines; t, tube feet. Arabic numerals 1 to 6 indicate the spines standing on 1st to 6th adambulacral plates, respctively. Scale bars indicate 10 mm in A and 1 mm in B–F. Proximal is left in B, C, D, and F and bottom in E.

Description. Arms are seven in number, subcylindrical in shape, flexible, slender, and gradually taper to the arm tip (Figs 2, 3A, 4A). R is 103.4 mm, r is 14.4 mm, and R/r ratio is 7.2. Sulci are present at the abactinal interradial area, extending from the periproct to the margin of the disc.

Abactinal skeleton is an irregular close meshwork on the disc (Fig. 3B), and the meshes are larger at the distal portion of arms. Each mesh contains none or one papula which is indistinguishable on undenuded body surfaces. Abactinal plates are papery and various in shape, being trilobate, quadrilobate, stellate, rod-shaped, oblong, and crescent-shaped. The trilobate, quadrilobate, and stellate plates are arranged irregularly at the disc and the abactinal side of the arms (Fig. 3B), and the rod-shaped, oblong, and crescent-shaped plates are arranged in oblique transverse series at the lateral side of the arms (Fig. 3C). They partly imbricate with each other and there are no connecting abactinal plates among them.

Chevron plates are triangle, V-shaped, and eleven to thirteen pair of the plates are arranged in a linear series along the sulci on each interradius (Fig. 5A).

Six primary radial and six primary interradial plates are alternately arranged in a circular series around the anal area (Fig. 5B). This series is partially interrupted by a large and round madreporite. Small abactinal plates are present between the anus and the circular series. The primary radial plates are irregular in shape, but the proximal and distal edges are convex in all plates (Figs 3D, 5B). The primary radial plates imbricate with the adradial proximal part of the primary interradial plates.

Each abactinal plate bears one to five abactinal spines on the central boss, which are united by skin into a fascicle (Fig. 3E). These fascicles are arranged in transverse series at the middle portion of the arms (Fig. 3C), but irregularly on a basal and distal portion of the arms. The abactinal spines are straight, slender, delicate, and have longitudinal sulci running their whole length (Fig. 6A, B). The base of the abactinal spines is inflated and has numerous perforations. The abactinal spines are 1.5 to 3.2 mm in length on primary radial plates (Fig. 6B), and 1.4 to 1.7 mm on the other abactinal plates (Fig. 6A).

Marginal and actinal plates are not recognizable.

The adambulacral plates are longitudinally elongated and transversely constricted at the median part of each plate (Fig. 4B). The adradial distal part of each plate imbricates with the proximal part of the succeeding plate in an actinal

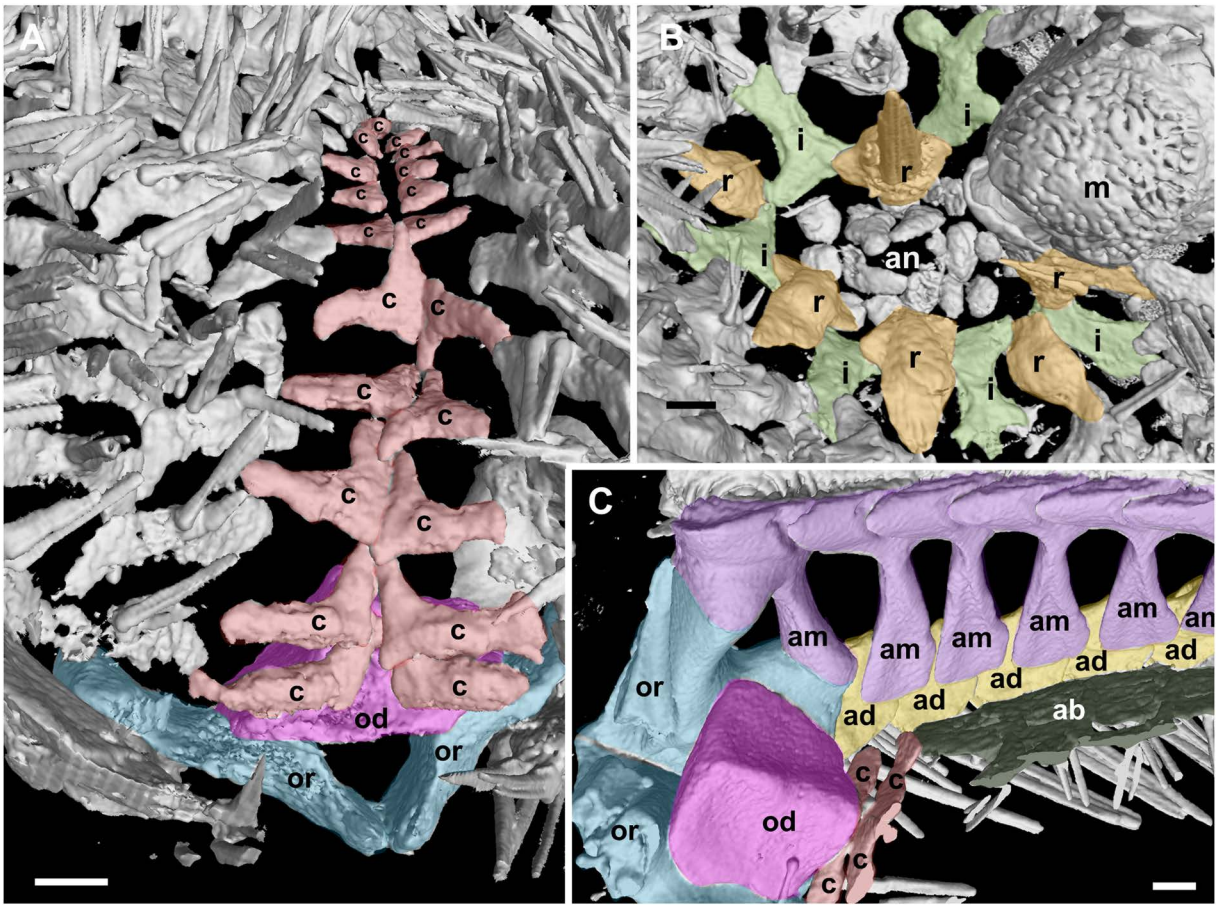

Fig. 5. Volume rendering images of *Asthenactis agni* n. sp. Holotype, NSMT E-13917. A, Lateral surface of the interradial area; B, abactinal surface at the center of the disc; C, abactinal view of the internal surface of the proximal part of the arm and the disc. Abbreviations: ab, abactinal plates; ad, adambulacral plates; am, ambulacral plates; an, anus; c, chevron plates; i, primary interradial plates; m, madreporite; od, odontophore; or, oral plates; r, primary radial plates. All scale bars indicate 1 mm. Proximal is left in B.

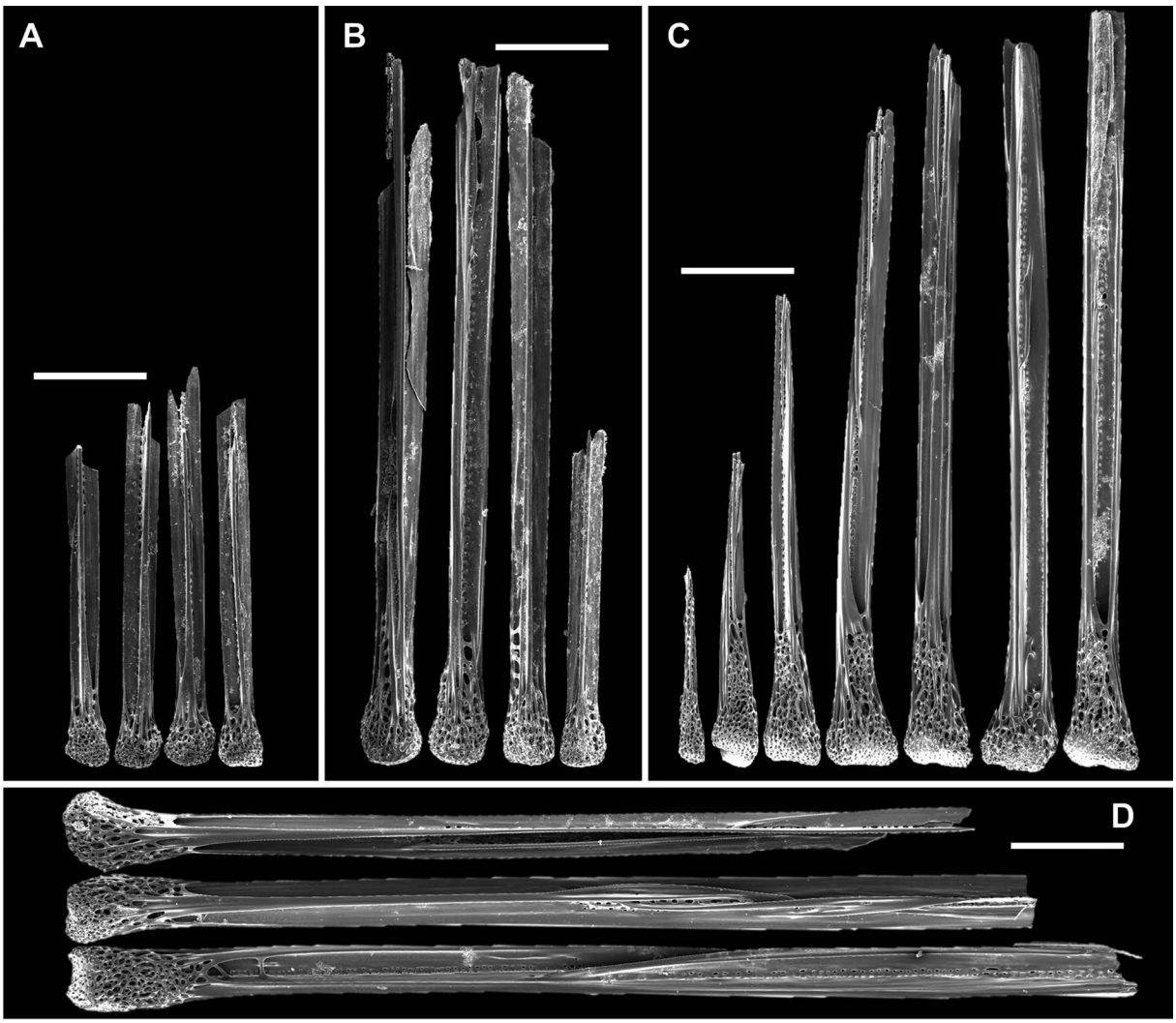

Fig. 6. SEM images of spines of *Asthenactis agni* n. sp. A, Abactinal spines on the proximal portion of the arms; B, abactinal spines from one of the primary radial plates; C, furrow spines from 3rd adambulacral plate; D, actinolateral spines from 3rd adambulacral plate.

Table 1. Tabular key to the species of the genus *Asthenactis*.

	A. agni n. sp.	*A. papyraceus*	*A. fisheri*	*A. australis*
R/r ratio	7.2	7.0	**2.9–3.5**	**2.8**
Arm number	7	7	**9–10**	**11**
Distal edge of primary radial plates	convex	**concave**	**concave**	convex
Number of actinolateral spines	2–3	2–3	**1–2**	**1**
Length of the longest actinolateral spine (mm)	up to 4.7	**up to 6**	ND	ND
Distribution	western North Pacific	eastern North Pacific	eastern North Pacific	western South Pacific
Number of known individuals	1	1	3	2
References	This study	Fisher (1906); Alton (1966)	Alton (1966)	McKnight (2006)

Morphological characters differing from the new species are shown in bold. ND: no data.

view. Each adambulacral plate bears two kinds of spines on different parts: the proximal part of the plate bears five to eight webbed furrow spines arranged in a curved transverse row, and the abradial distal part of the plate bears two to three actinolateral spines arranged in an oblique transverse row (Fig. 4C, D). These spines show almost the same shape as in the abactinal spines (Fig. 6). Furrow spines are 0.8 to 3.4 mm in length (Fig. 6C), and the actinolateral spines are 4.0 to 4.7 mm in length (Fig. 6D). The lengths of both spines decrease toward the ambulacral furrow.

The actinolateral membrane that envelops actinolateral spines and unites them longitudinally is present within one-third of the arm's length (Fig. 4C). The membranes have slit-like apertures between two consecutive rows of actinolateral

spines (Fig. 4D). The actinolateral membranes of two adjacent arms are connected to form a web between the adradial-most actinolateral spines on the first adambulacral plates (Fig. 4C).

The ambulacral plates are transversely elongated and longitudinally constricted at the median part of each plate (Fig. 5C). The adradial narrow triangle part projects proximally, and this projection overlaps with the preceding plate from the abactinal view. The abradial part is flared toward the abradial end and contacts the adambulacral plate. The adradial part of the first ambulacral plates has a proximally widened projection that connects with an abactinal adradial projection of the oral plate. The abradial part of the first ambulacral plates is flared toward the abradial end and contacts the distal adradial end of the oral plate.

The oral plates are triangular in the actinal surface and bear seven to eight spines per plate along the furrow (Fig. 4E). The innermost oral spine is the longest, and the length decreases toward the outer spines. These spines are enveloped within a membrane, leaving two to three outer spines isolated. There are no suboral spines on the actinal surface of the oral plates.

The odontophore is a rounded triangle in shape and has a keel on the median part of the abactinal surface (Fig. 5C). The plate contacts the abactinal surface of a pair of oral plates and completely concealed by them from the outside of the body.

Tube feet are biserial, and each tube foot terminates in a suckered disc (Fig. 4F).

The color when alive is pale orange (Fig. 2).

Distribution. *Asthenactis agni* n. sp. is only known from the type locality, An'ei Seamount on the Nishi-Shichito Ridge, south of central Honshu, Japan, at a depth of 1970 m.

Etymology. The specific name comes from the fire god "Agni" that has seven arms in Indian mythology (Harle 1962). *Asthenactis agni* n. sp. also has seven arms. Therefore, the specific name "*agni*" is a noun in apposition.

In the Japanese name of the family Myxasteridae, "hebi" means snake alluding to the nature of the flexible, long, and slender arms, and "maku-hitode-ka" is the Japanese name of the related family Pterasteridae. "Hitode" is the common Japanese name for starfish. "Mizukaki" of the Japanese name of this new species means a web, which comes from the membranes uniting the actinolateral spines. The Japanese name of the genus also follows the specific name.

Remarks. Of three known species of the genus, *Asthenactis agni* n. sp. is most closely related to the Hawaiian species, *A. papyraceus*, sharing an R/r ratio of 7 or more, seven arms, and two to three actinolateral spines (Fisher 1906; Alton 1966), unlike the other two species that have an R/r ratio of 3.5 or less, nine to eleven arms, and only one or two actinolateral spines (Alton 1966; McKnight 2006; see also Table 1).

However, our specimen is distinguished from *A. papyraceus* by the following two morphological characters (Table 1). The primary radial plates of the new species have a distal extension ending with a convex edge (Figs 3D, 5B), while those of *A. papyraceus* have a concave edge (Alton 1966). Moreover, the length of actinolateral spines is slightly shorter in the new species; the longest spine is up to 4.7 mm in *A. agni* n. sp. (Fig. 6D), whereas it reaches 6.0 mm in *A. papyraceus* (Fisher 1906).

The family Myxasteridae has not been recorded in the western North Pacific (Fig. 1). This is the first record of this family from Japanese waters. In contrast to the scarce occurrence records, this family shows wide-range distribution across the Pacific and Atlantic Oceans. Further deep-sea surveys may discover unknown habitats or undescribed species.

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