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Fossil gorgonocephalid basket stars (Echinodermata: Ophiuroidea: Euryalida) from the Middle Pleistocene of Japan; the first record from the Indo Pacific region

MASANORI OKANISHI[1], YOSHIAKI ISHIDA[2] AND SHOTA MITSUI[3]

[1]*Misaki Marine Biological Station, The University of Tokyo, 1024 Koajiro, Miura, Kanagawa 238-0225 Japan (e-mail: mokanishi@tezuru-mozuru.com)*
[2]*2-20-13 Kamiogi, Suginami-ku, Tokyo 167-0043, Japan*
[3]*Graduate school of Marine Science and Technology, Tokyo University of Marine Science and Technology 4-5-7 Konan, Minato, Tokyo 108-8477, Japan*

Abstract. Disarticulated fossil euryalid ophiuroid vertebrae from the Middle Pleistocene Miyata Formation, Miura, Kanagawa Prefecture, eastern Japan, are described. The vertebrae are assigned to the family Gorgonocephalidae on the basis of arm branching and the presence of an open oral groove along the entire arm. This is the first record of fossil euryalids from Indo-Pacific region.

Key words: Gorgoncephalidae, Kanagawa, Miyata Formation, Ophiuroidea, vertebra

Introduction

The order Euryalida includes the basket stars and snake stars, in the class Ophiuroidea (Echinodermata). Ophiuroid arms are segmentated and each segment has a central arm ossicle, which is referred to as a “vertebra” in ophiuroid systematics (e.g. Okanishi, 2016). The vertebrae have matching articulations on their distal and proximal surfaces, and euryalid ophiuroids have hourglass-shaped articulations, referred to as “streptospondylous”. This form of articulation is also shared by Ophiomyxidae and some species of Ophiacanthidae in the superorder Ophintegrida (e.g. Stöhr, *et al*., 2012; O’Hara *et al*., 2017). The “branching vertebrae” of basket stars have two articulations on the distal surface, confirming the presence of branching arms; therefore, dissociated fossil vertebrae can be regarded as coming from euryalid basket stars (e.g. Kroh, 2002; Kroh and Jagt, 2006). Fossil records of basket stars are very poor, and only four records are currently known; these are from the upper Miocene–Pliocene of Algeria (Pomel, 1885–1887), lower Miocene of Austria (Kroh, 2002), middle Miocene of the Central Mediterranean (Kroh, 2004), and Pliocene strata of eastern Netherlands (Kroh and Jagt, 2006). Apart from these records, other streptospondylous vertebrae have been recorded from the Miocene of Hungary (Vadász, 1915) and of France (Valette, 1928), Oligocene of New Zealand (Spencer & Wright, 1966), upper Pliocene of Jamaica (Donovan & Paul, 1998), Early to Middle Jurassic of Germany (Thuy, 2015) and Middle

Triassic to Lower Jurassic of Germany (Thuy and Stöhr, 2018), but these are not unequivocally assignable to those of basket stars. There is also no record of unquestionable body fossils of basket stars to date (e.g. Kroh, 2002; Thuy, 2015).

Ophiuroid fossils from Japan have been recorded mainly based on associated body fossils, and more than 50 species are currently listed (e.g. Fujita, 1992; Ishida *et al*., 2011; 2015). Although records of disarticulated ossicles are poor in Japan (Ishida, 2004), those ossicles occur from Japanese strata indeed (Ishida, unpublished), and generic or even specific identifications based on vertebrae and oral plates (e.g. Kroh, 2002), and lateral arm plates (e.g. Thuy, 2015), are possible.

Recently, the 5th record of unquestionable fossil basket stars was confirmed in the Pleistocene Miyata Formation in Kanagawa Prefecture, eastern Japan (Okumura *et al*., 2005). This is also the first record of branching vertebra of basket stars from Indo-Pacific region and the first record of euryalid brittle stars from Japan.

Material and methods

Fossil ossicles were collected from the Sha-ana Tuffaceous Sand Member (corresponding to the Kamimiyata Tuffaceous Sand Member in Kanie and Ohkoshi, 1981) of Miyata Formation, exposed at Sha-ana dai, Minami-Shita-ura Town, Miura City, Kanagawa Prefecture, about 1 km northwest of Miura-Kaigan railway station of Keikyu Line on 7 March 2012, 13 October, 2013 and 29 December 2017 (Fig. 1).

The Miyata Formation (Cenozoic, Quaternary, Middle Pleistocene), originally described by Aoki (1925), is distributed on Miyada plateau, southern Miura Peninsula, Kanagawa Prefecture, central Japan. The stratigraphy of this formation has been examined historically (e,g, Fujita, 1951; Okumura *et al*., 1977; Kanie and Ohkoshi, 1981). Okumura *et al*. (1977) considered that the Miyata Formation is lithologically subdivided in ascending order into five Members; Sugaruya Sand Member, Tsukui-hama Sandy Gravel Member, Ko-enbo Sand member, Sha-ana Tuffaceous Sand Member and Itchoda Sand Member. Kanie and Ohkoshi (1981) considered that the “Miyata Formation” is subdivided into the Miyata Formation and the Tsukui Formation, the latter of which was previously described as the Tsukuihama Sandy Gravel Member in Okumura *et al*. (1977), and the Miyata Formation could be subdivided into three members (Kamimiyata Sandy Tuffaceous Member, Sugaruya Sand Member and Ohkine Pumiceous Sand Member). Although a consensus has not been reached about the geological structure of this formation, Okumura *et al*. (1977)’s stratigraphy has been supported by recent studies (e.g. Shibata *et al*., 2014; Ishihama *et al*., 2017).

The geological age of the Miyata Formation was estimated to be 0.44 to 1.22 Ma by Yamaguchi *et al.* (1983) based on the calcareous nannofossils, 0.46 to 1.02 Ma by Kanie *et al.* (2000) based also on the calcareous nannofossil, or 0.325 Ma, using the Electron Spin

Resonance-method (Toyota and Okumura, 2000).

Fossil mollusks (Yokoyama, 1920; Arai *et al*., 1971; Horikoshi and Kosuge, 1971; Kanie, 1971; Okumura *et al*., 1977, 1979; Kanie and Ohkoshi, 1981; Yamaguchi *et al*., 1983; Kanie *et al*., 2000; Okumura *et al*., 2005; Shibata *et al*., 2014; Ishihama *et al*., 2017), ahermatypic solitary corals (Omura *et al*., 1991), brachiopods (Kuramochi and Katsuzawa, 1999), barnacles (Yamaguchi, 1971), foraminifers (Higuchi, 1954; Eto, 1971, 1972), elasmobranchs (Taru and Matsushima, 1998) and elephants (Hasegawa and Kanie, 1971) were previously recorded from the Miyata Formation.

The sediment is semi-consolidated, poorly-sorted massive fine-grained tuffaceous sand, which contains scoria and pumice (1 to 3 mm diameter), and fine gravel (2 to 10 mm diameter). Well-preserved fossil mollusks (e.g. *Mizuhopecten tokyoensis*, *Cyclocardia ferruginea*, *Acta* (*Truncacila*) *insignis*), bryozoans, brachiopods, decapods, barnacles, echinoids and foraminifers co-occurred with fossil ophiuroids. Most bivalves occurred as single valves, and were buried horizontally, with their convex sides upward. The other fossils, such as decapods, barnacles or echinoids were represented as disarticulated chelipeds, shells, plates or spines, respectively, suggesting that the fossil assemblages from the outcrop could be allochthonous.

To collect ophiuroid ossicles, sediment samples were air-dried in air and then disintegrated in water. Then samples were washed using a sieve of 0.063 mm mesh. Ossicles were handpicked from the residues under a stereo microscope and cleaned with hydrogen peroxide (30% solution). Photographs of Figures 2 and 3 were focus-stacked using the software CombineZM1 v.1.0.0.

Materials are deposited in the National Museum of Nature and Science (NSMT). Morphological terminology and systematics follow Stöhr *et al.* (2012) and O'Hara *et al.* (2017), respectively.

Systematic description

Superorder Euryophiurida O'Hara *et al*., 2017

Order Euryalida Lamarck, 1816

Family Gorgonocephalidae Ljungman, 1867

Gorgonocephalidae gen. et sp. indet.

Figures 2, 3

Material examined.—Eighty-four vertebrae (NSMT E-***), all originating from bulk samples collected from the Middle Pleistocene Miyata Formation, Miura (Kanagawa, Japan). All materials are preserved in the form of dissociated ossicles. Although it cannot be confirmed, all vertebrae are considered to be conspecific.

Description of "normal" vertebrae. —In total 69 vertebrae range in size from 0.6 to 5.2 mm in width, having a hourglass-shaped, streptospondylous articulation. In lateral view, they are approximately two-thirds wider than high. Most vertebrae lack any ornament in lateral view, probably due to abrasion (e.g. Fig. 2A-3, B-3), but some well-preserved specimens show some remaining ornament (Fig. 2C-3). In these well-preserved vertebrae, vertical furrows are visible on the oral-lateral side (Fig. 2C-3). The aboral (Fig. 2A-1, A-2, B-1) and oral (Fig. 2C-1) grooves are shallow, U-shaped. No oral grooves covered (Fig. 2A-1, A-2, A-5, B-1, B-2, B-5, C-1, C-2, C-5). A pair of probably radial water canals open on the oral groove and can be observed in well-preserved specimens (Fig 2C-5).

Description of branching vertebrae. —Fifteen branching vertebrae were picked from bulk samples. These are slightly wider than "normal" vertebrae but of the same height, approximately 1.1 to 2.6 mm in width, having two inclined articulation surfaces on the distal face (Fig. 3A-2, B-2, C-2, D-2, E-2). Both symmetrical (Fig. 3B-2, C-2, D-2) and asymmetrical (A-2, E-2) branching angles were found in examined materials. No ornamentation was observed in examined materials due to the abrasion. Aboral and oral furrows branching on center, and two furrows extend to distal portion (Fig. 3A-4, A-5, B-4, B-5, C-4, C-5, D-4, D-5, E-4, E-5). A pair of probably radial water canals lie on the proximal portion of oral furrow and another pair of radial canals lie on one of two branched distal furrows (Fig. 3A-5).

Discussion

The examined vertebrae fall within Gorgonocephalidae, for they possess: open oral furrows throughout the arms; streptospondylous type articulations; no projecting area in distal side; and branching arms. Distal side of vertebrae in the middle to distal portion of the arms of Euryalidae are projecting, (e.g. see Mortensen, 1933, P4, fig. 2), but these projections are not observed in the present materials. Branching vertebrae are also found in the family Euryalidae, but their oral furrow is closed by an "oral bridge" in the middle to distal portion of the arms (e.g. Kroh, 2004; Okanishi *et al*., 2013). There is possibility that these oral bridges are heavily abraded. However, the oral bridges of Euryalidae, especially in arm tips, are very thick (e.g. see Mortensen, 1933, P4, fig. 2) and it is unlikely that they are all abraded in our examined materials.

The paleoenvironment of the Sha-ana Tuffaceous Sand Member was reconstructed as shallow water or continental shelf in depth, under the influence of cold currents (Kuramochi and Katsuzawa, 1999; Kanie *et al*., 2000). Additionally, Higuchi (1954) estimated the paleo-temperature of Miyata Formation to be similar to, or somewhat colder than, the current water temperature of the adjacent waters of the Miura Peninsula, based upon the fossil foraminifer fauna. The gorgonocephalid basket stars are highly specialized suspension feeders, trapping plankton in their network of branching arms, which extend into water currents. In general, they are found at depths of 40 to 2000 m, with strong currents, attached primarily to rocks, hard corals, soft octocorals, and black corals (Okanishi, 2016). Therefore, although the fossils possibly show allochthonous occurrence because of abrasion and dispersion of dissociated ossicles, the discovery of many ossicles probably supports the known paleoenvironment of the Miyata Formation and, as well, indicates the possible existence of a paleoenvironment characterized by strong current and hard substrates near the formation.

This 5th undoubted record of fossil basket stars of the family Gorgonocephalidae is the youngest in the previously known records of basket stars (Pomery, 1885–1887; Kroh, 2002, 2004; Kroh and Jagt, 2006). The previous undoubted records of basket stars are known from Europe (Kroh, 2002, 2004; Kroh and Jagt, 2006) and north Africa (Pomery, 1885–1887). Therefore, this is the first record of basket stars from Indo-Pacific region. Kroh (2002) suggested that the lack of previous euryalid fossil records from modern diversity hotspots (the Indo-Malayan region) may be the result of sampling bias. The present discovery from the Japanese area indicates that the scarce fossil records of euryalid vertebrae may indeed be due to sampling bias. Further investigations focusing on these ossicles in the Indo-Malayan region as well as Japan, will surely increase the discoveries of euryalid vertebrae.

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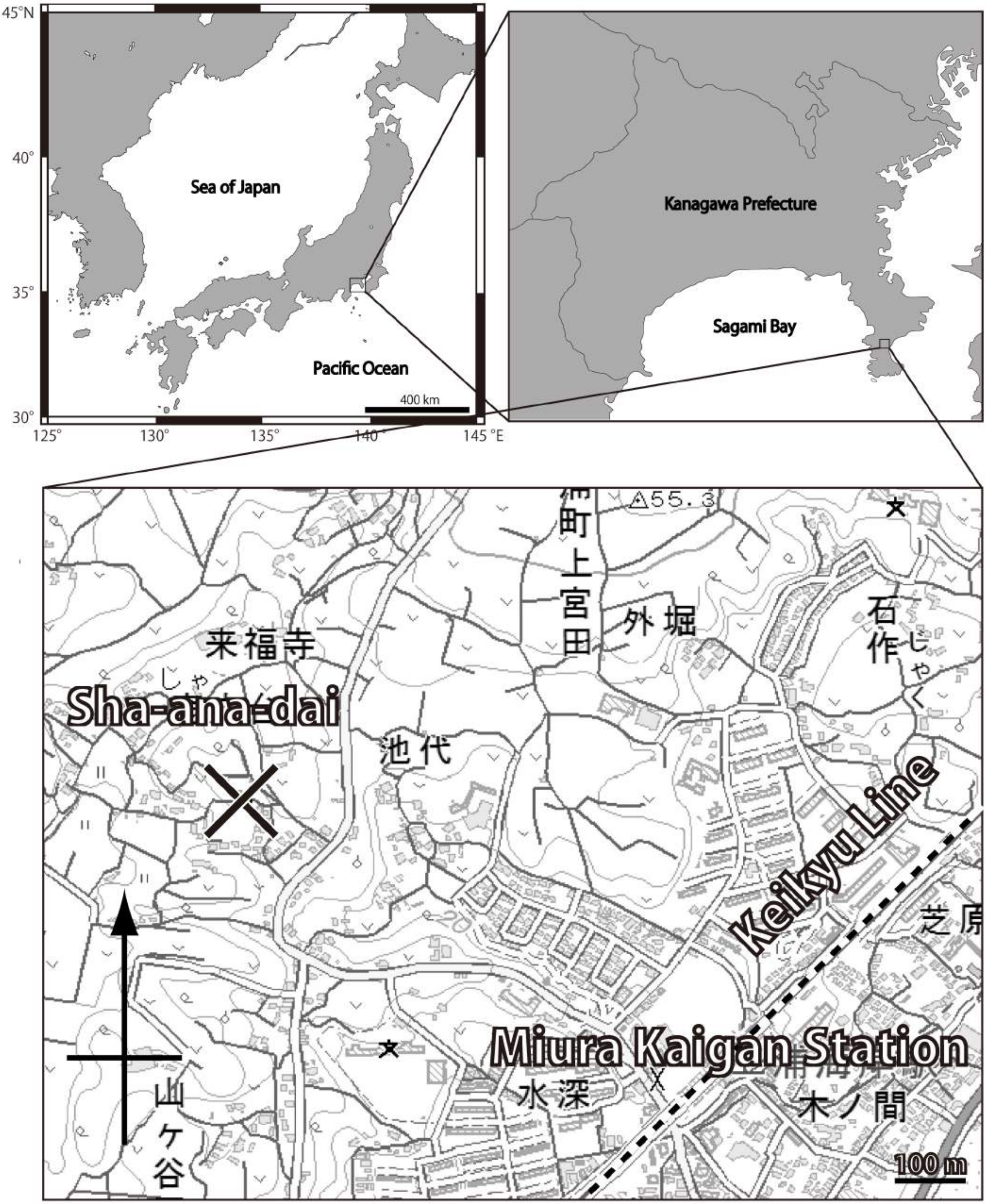
Figure legends

Figure 1. Position of the sampling locality (marked by ×) of euryalid vertebrae from the Miyata Formation, Miura City, Kanagawa Prefecture. 1:50000 topographic maps by the Geographical Survey Institute.

Figure 2. Gorgonocephalidae from the Miyata Formation, unbranching “normal” vertebrae. **A,** proximal vertebra (MO-2018-F-10); **B,** distal vertebra (MO-2018-F-11), **C,** middle vertebra (MO-2018-F-12). Numbers show orientations, proximal (1), distal (2), lateral (proximal to left) (3), aboral (4) and oral (5). Scale bars, 1 mm. Arrows indicate oral furrows. Arrowheads indicate lateral furrows. Abbreviation: rwc, radial water canal.

Figure 3. Gorgonocephalidae from the Miyata Formation, “branching” vertebrae. **A,** proximal “asymmetrical” vertebra (MO-2018-F-5); **B,** middle “asymmetrical” vertebra (MO-2018-F-6), **C,** middle “symmetrical” vertebra (MO-2018-F-7), **D,** distal “symmetrical” vertebra (MO-2018-F-8); **E,** distal “asymmetrical” vertebra (MO-2018-F-9). Numbers show orientations, proximal (1), distal (2), lateral (proximal to left) (3), aboral (4) and oral (5). Scale bars, 1 mm. Arrows indicate oral furrows. Abbreviations: drwc, distal radial water canal; daf, distal aboral furrow; dof, distal oral furrow; paf, proximal aboral furrow; drwc, distal radial water canal; prwc, proximal radial water canal.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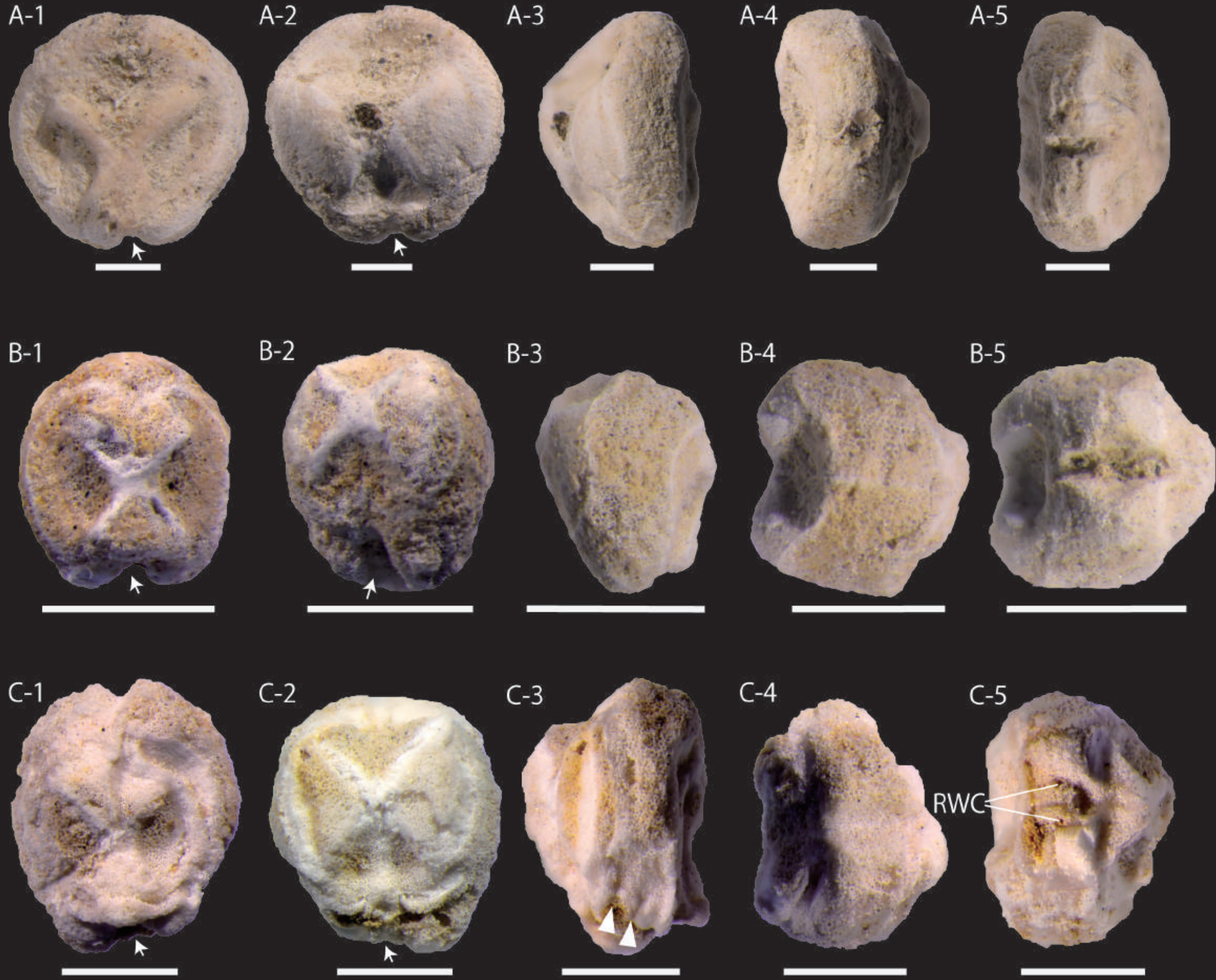

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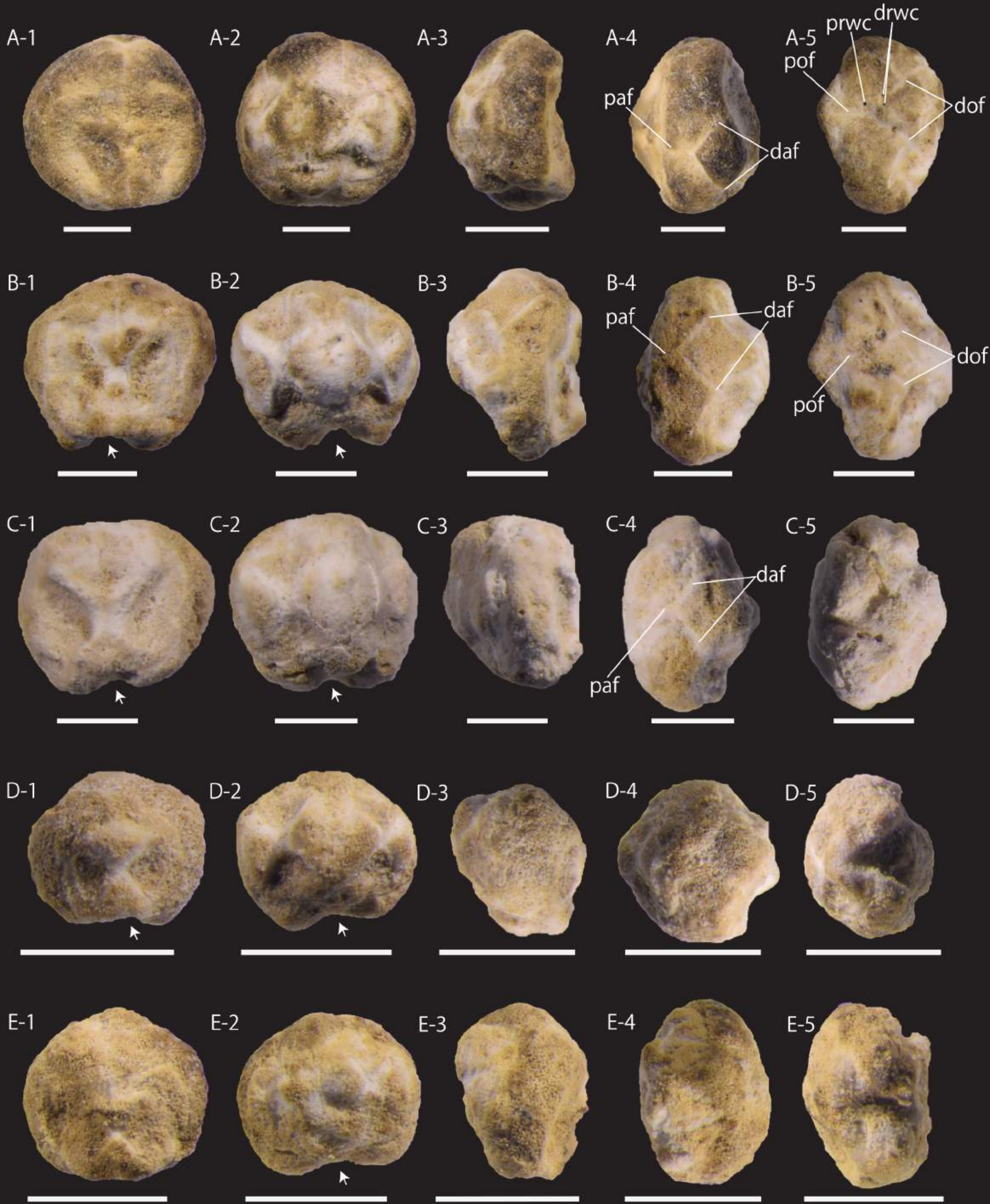
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