

A New Species of *Falcidens* (Mollusca: Caudofoveata: Chaetodermatidae) from the Pacific Coast of Japan

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Abstract A new species of the aplacophoran class Caudofoveata, *Falcidens rinkaimaruae* is described from the Pacific coast of central Japan, at a depth from 211 to 590 m. This is the third species of the genus *Falcidens* described from the Northwest Pacific. Its tail-like narrow posterior body has very long, narrow sclerites on the ventral side, which is a unique feature of this species. By this unique sclerite feature, together with the tail-like posterior body, and the pedal shield completely surrounding the mouth, this species is easily separable from all other congeners.

Key words: Caudofoveata, new aplacophoran species, taxonomy, Northwest Pacific.

Introduction

Caudofoveata is a small molluscan class comprising shell-less, worm-like animals, which live in the marine muddy bottom. Currently at least 138 species (Señaris *et al.*, 2016) are known from the world seas, which are assigned into three families: Limifossoridae, Prochaetodermatidae and Chaetodermatidae. The fauna of the Caudofoveata in the Northwest Pacific is poorly known with only eleven species described from this vast area: two *Scutopus* of Limifossoridae, one species of Prochaetodermatidae, two *Falcidens*, and six *Chaetoderma* species of Chaetodermatidae (Heath, 1911; Okuda, 1943; Ivanov, 1984; Ivanov and Scheltema, 2004; Saito and Salvini-Plawen, 2014). Among those eleven species, eight species were described from the Sea of Japan, and the remaining three species were described from the Pacific coast of Japan. This low number of species by no means represents their real species diversity.

As a part of a research project “Geological, biological, and anthropological histories in rela-

tion to the Kuroshio Current” conducted by the National Museum of Nature and Science, which started in 2016, considerable number of bottom samplings were carried out along the areas strongly affected by the Kuroshio warm water current (areas spanning from Ryukyu Islands to the Pacific coast of central Japan), and many specimens of Caudofoveata were collected. This paper describes a new species of *Falcidens* among them.

Materials and Methods

The specimens were collected by a dredge with mouth opening 0.5 m or 1 m, a sledge with mouth opening 0.4 m, or Agassiz-type beam trawl with mouth opening 2 m equipped with a plankton net. Approximate positions of the sampling sites are shown in Fig. 1.

The collected specimens were fixed and preserved in 70–75% ethanol. For the examination of the sclerites, small pieces of skin were cut with a razor blade, soaked in approximately 2% household bleach for 1 minute, rinsed five times by warm water, then sclerites were isolated by needle on a glass slide, air dried, and mounted

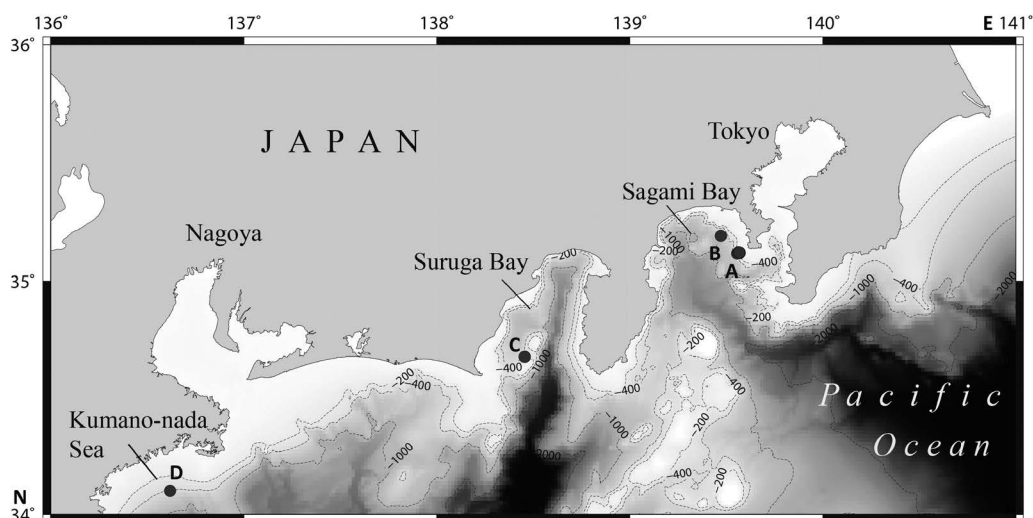


Fig. 1. Sampling sites. Approximate positions of the sampling sites are indicated by circles: A, NSMT-Mo 79128 (Holotype) –79131, 79133–79143; B, NSMT-Mo 79132; C, NSMT-Mo 79144–79145; D, NSMT-Mo 79146.

with Canada balsam (holotype) or Entellan neu[®] Merck (paratypes). The radulae were dissected out with the buccal mass, then isolated by household bleach in the same manner as the sclerites but for a little longer time, 2–3 minutes, then rinsed three times by warm water. The radulae were then put into polyethyleneglycol on a dimpled glass slide, photographed, rinsed, dehydrated with ethanol series and dimethoxypropane, and mounted with Canada balsam.

The gonads of four specimens were examined histologically. They were decalcified with Bouin's solution, embedded in paraffin, stained with Mayer's hematoxylin and eosin by a standard procedure.

Images of all sclerites, radulae and gonads were taken by AxioImager[®] M1 light microscope with AxioCam[®] HRC image capture equipment controlled by AxioVision[®] ver. 4.8, Carl Zeiss.

A part of the sclerites were also observed by the scanning electron microscope JEOL-LV6380, Jeol, Tokyo. Preparation for the examination by scanning electron microscope followed Correa *et al.* (2014).

The terms for body regions followed Salvini-Plawen (1975) with some modifications, which are shown in Fig. 2. Orientation of the radula followed Schander *et al.* (2006).

Map of the sampling sites was prepared using GMT, with bathymetry data from Japan Oceanographic Data Center (JODC).

Taxonomy

Class Caudofoveata Böttger, 1955

Family Chaetodermatidae Ihering, 1876

Genus *Falcidens* Salvini-Plawen, 1968

Type species: *Falcidens crossotus* Salvini-Plawen, 1968 (original designation)

Falcidens rinkaimaruae new species

(Figs. 1–7)

Type locality. Sagami Bay, off Jyogashima Islet, Pacific coast of Central Japan, 35°07.192'N, 139°34.050'E–35°07.846'N, 139°34.242'E, 250–350 m.

Type depository. Department of Zoology, National Museum of Nature and Science, Tsukuba.

Etymology. This species is named after the training and research vessel *Rinkai-Maru* of the Misaki Marine Biological Station, the University of Tokyo, which collected the present species for the first time.

Material examined. Holotype. NSMT-Mo 79128, ethanol preserved specimen, a part of sclerites and radula are mounted on glass slides,

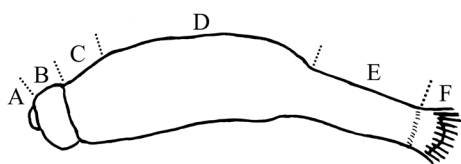


Fig. 2. Terms for the body regions used in the present study. A: peribuccal region; B: foregut region; C: midgut region; D: midgut sac region; E: prepallial region; F: pallial region.

body length 6.2 mm, Sagami Bay, off Jyogashima Islet, Miura Peninsula, TR/V Rinkai-Marui St. 3, 35°07.192'N, 139°34.050'E–35°07.846'N, 139°34.242'E, 250–350 m, 9 Nov. 2018. *Paratypes*. Sagami Bay, off Miura Peninsula: NSMT-Mo 79129–79131, 11 specimens, body length 3.6–7.4 mm, collected with the holotype; NSMT-Mo 79132, 3 specimens, body length 5.2–6.1 mm, TR/V Rinkai-Marui St. 2, 35°11.459'N, 139°28.707'E–35°11.635'N, 139°28.142'E, 432–580 m, 16 Mar. 2001; NSMT-Mo 79133, 4 specimens, body length 3.6–4.0 mm, TR/V Rinkai-Marui St. 1, 35°07.084'N, 139°34.000'E–35°07.112'N, 139°34.146'E, 211–258 m, 23 Jan. 2014; NSMT-Mo 79134, 1 specimen, body length 4.6 mm, TR/V Rinkai-Marui St. 1, 35°07.215'N, 139°34.093'E–35°07.273'N, 139°33.268'E, 250–437 m, 28 May 2015; NSMT-Mo 79135, 5 specimens, body length 4.4–8.7 mm, TR/V Rinkai-Marui St. 2, 35°07.120'N, 139°34.028'E–35°07.507'N, 139°33.275'E, 243–300 m, 28 May 2015; NSMT-Mo 79136, 5 specimens, body length 2.8–7.2 mm, TR/V Rinkai-Marui St. 3, 35°06.928'N, 139°33.852'E–35°06.856'N, 139°33.288'E, 373–475 m, 9 Dec. 2015; NSMT-Mo 79137, 11 specimens, body length 3.2–8.4 mm, TR/V Rinkai-Marui St. 5, 35°07.056'N, 139°33.699'E–35°06.723'N, 139°34.057'E, 230–464 m, 10 Dec. 2015; NSMT-Mo 79138, 1 specimen, body length 4.8 mm, TR/V Rinkai-Marui St. 2, 35°06.994'N, 139°33.317'E–35°07.354'N, 139°33.101'E, 417–590 m, 26 Apr. 2016; NSMT-Mo 79139–79141, 28 specimens, body length 2.0–7.5 mm, TR/V Rinkai-Marui St. 4, 35°07.311'N, 139°33.785'E–35°06.812'N, 139°34.119'E, 253–335 m, 9 May 2017; NSMT-Mo 79142, 3 specimens, body

length 4.8–5.5 mm, TR/V Rinkai-Marui St. 5, 35°07.226'N, 139°33.971'E–35°06.943'N, 139°33.450'E, 251–480 m, 10 May 2017; NSMT-Mo 79143, 1 specimen, body length 7.6 mm, TR/V Rinkai-Marui St. 6, 35°07.250'N, 139°34.005'E–35°06.900'N, 139°33.513'E, 232–448 m, 10 May 2017; Suruga Bay, Senoumi Bank: NSMT-Mo 79144, 4 specimens, body length 3.3–7.0 mm, R/V Sōyō-Marui St. 2, 34°40.654'N, 138°27.311'E–34°40.497'N, 138°27.003'E, 410–570 m, 5 Aug. 2014; NSMT-Mo 79145, 1 specimen, body length without tail part (missing) 3.0 mm, R/V Sōyō-Marui St. N slope of Senoumi Bank, 34°47.210'N, 138°31.065'E–34°46.888'N, 138°29.215'E, 401–538 m, 9 Aug. 2016; Kumano-nada Sea: NSMT-Mo 79146, 1 specimen, body length 4.2 mm, TR/V Seisui-Marui St. 6, 34°06.100'N, 136°37.100'E, 410 m, 27 Nov. 2019.

Description of holotype. Animal small, 6.2 mm long, anterior body stout, 4.1 mm long, posterior body slender, tail-like, 2.1 mm long, terminating in tassel with long needle-like sclerites (Fig. 3B). Boundary of foregut and midgut regions demarcated by groove. Pedal shield surrounding mouth located dorsally to center (Fig. 3C). Color of living animal light yellowish brown with dark brownish maculation in anterior body, which is the coloration of the internal organs observable through the translucent body wall (Fig. 3A), brown with more or less bluish hue in pedal shield (Fig. 3A).

Dominant sclerites (Fig. 4C–G) covering the surfaces of midgut and midgut sac regions, and dorsal prepallial region adpressed to body wall, arranged parallel to the longitudinal body axis, narrowly oblong, up to 132 μ m long $\times$ 33 μ m wide, curved towards body, bluntly pointed at tip, parallel sided or only slightly widened at base; outer surface (Fig. 5A–B) sharply keeled on midline, weakly concave between median keel and thickened margin, and inner (medial) surface (Fig. 5C) concave along midline. Sclerites of ventral prepallial region (Figs. 4H, 5D–F) similar to dominant sclerites in ornamentation but greatly elongate, up to 220 μ m long $\times$ 22 μ m

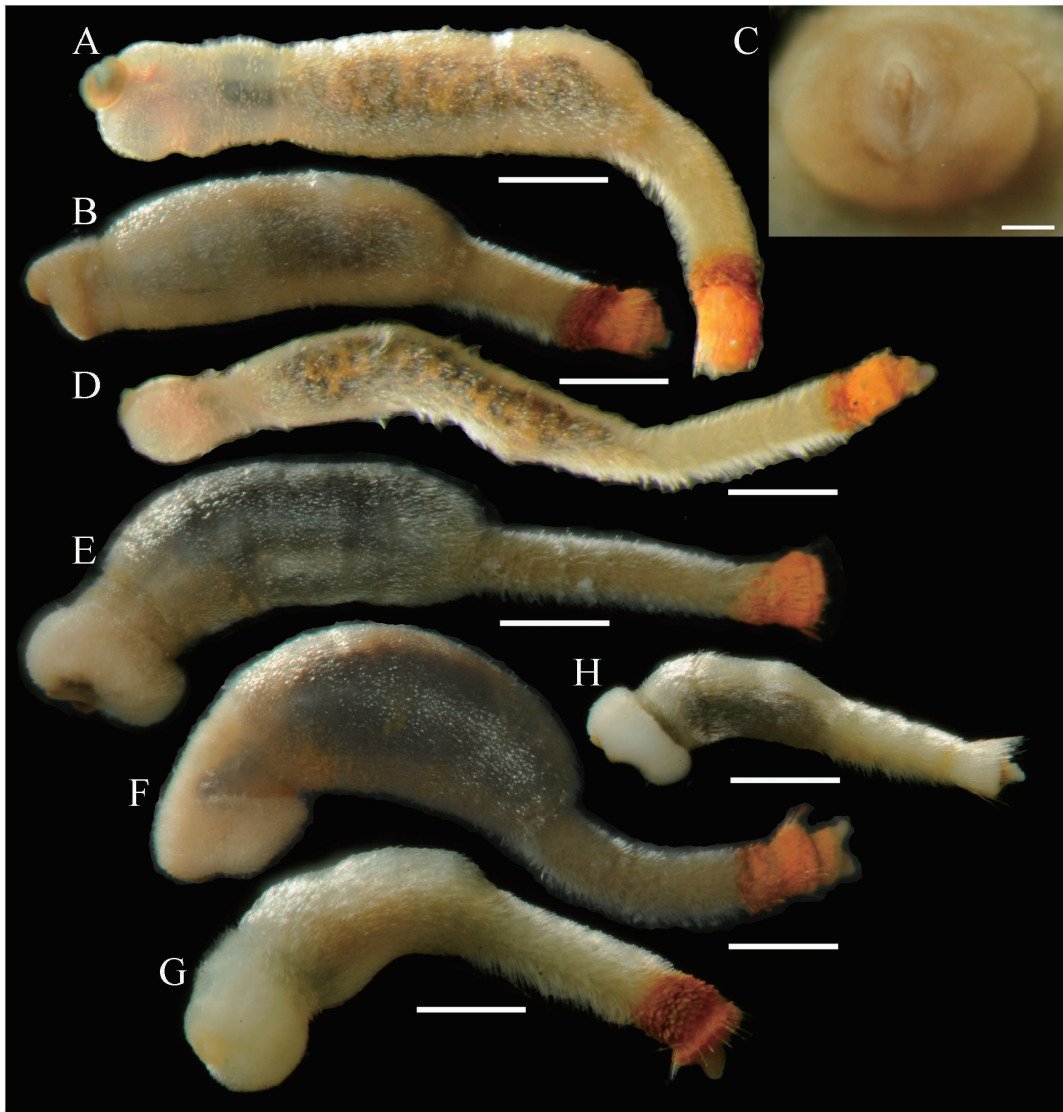


Fig. 3. *Falcidens rinkaimaruae* n. sp. A–C, holotype, D–H, paratypes. A. specimen in life; B, preserved condition; C, pedal shield; D, NSMT-Mo 79129, specimen in life; E, F, NSMT-Mo 79140, specimens from which gonads were examined (E, specimen “B”; F, specimen “A”, see Fig. 7); G, NSMT-Mo 79144, preserved condition; H, NSMT-Mo 79146, preserved condition. Scale bars: 1 mm for A–B, D–H; 0.5 mm for C.

wide, erected, which gives a brush-like appearance to the posterior body; keel on outer surface with flat or round top near base. Sclerites of peribuccal region (Fig. 4A) minute, elongate oval, flat, up to $32\ \mu\text{m}$ long $\times$ $14\ \mu\text{m}$ wide. Sclerites in foregut region (Fig. 4B) elongate triangular, flat, up to $74\ \mu\text{m}$ long $\times$ $44\ \mu\text{m}$ wide; their base apparently wider than that of other sclerites. Posterior

margin of pallial region (Fig. 4J) with long, sharply pointed needles, up to $526\ \mu\text{m}$ long $\times$ $16\ \mu\text{m}$ wide. Sclerites around dorso-terminal sense organ (Fig. 4I) small, narrowly elliptic to acicular, flat, up to $82\ \mu\text{m}$ long $\times$ $5\ \mu\text{m}$ (acicular) to $16\ \mu\text{m}$ (narrowly elliptic) wide.

Radula (Fig. 6) of single pair of sclerotized sickle-shaped teeth, $46\ \mu\text{m}$ long, obtusely pointed

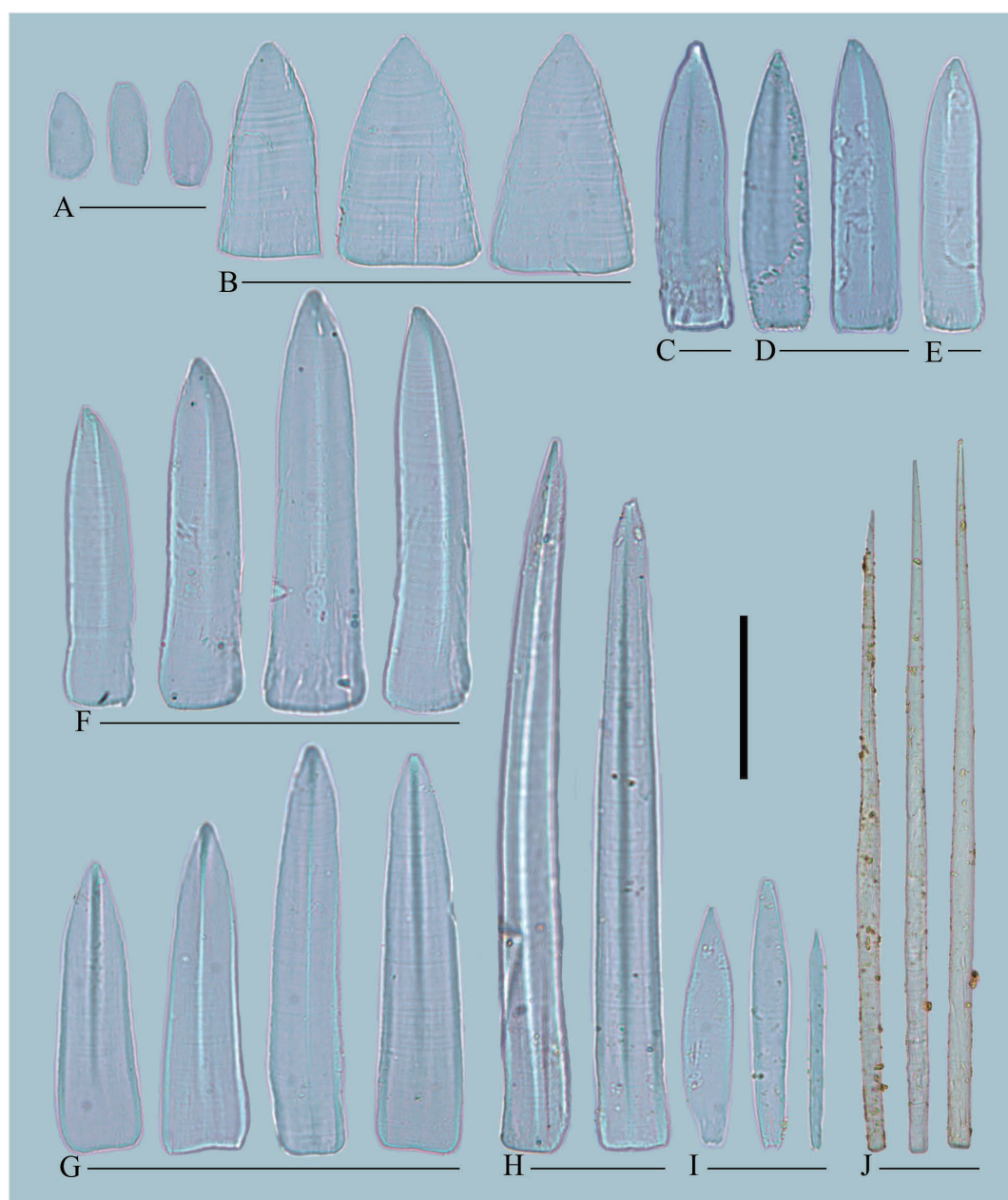


Fig. 4. *Falcidens rinkaimaruae* n. sp. Sclerites of holotype. A, in peribuccal region; B, in foregut region; C, in midgut region; D in anterior midgut sac region; E, in ventral midgut sac region, F, in posterior midgut sac region; G, in dorsal and lateral prepallial region; H, ventral prepallial region, I, around dorso-terminal organ; J, in pallial region. Scale bar: 50 μm for A–I, 100 μm for J.

at distal end, shortly curved outward at proximal end, and connected to each other by symphysis: thus, the connected part looks circular viewed from the front. Symphysis connected to apical

notch of basal plate via “spring-like attachment” (Schander *et al.*, 2009) (Fig. 6B, sa), measuring 11–14 μm . Basal plate wedge-shaped, 250 μm long, 102 μm high (front to back at widest point

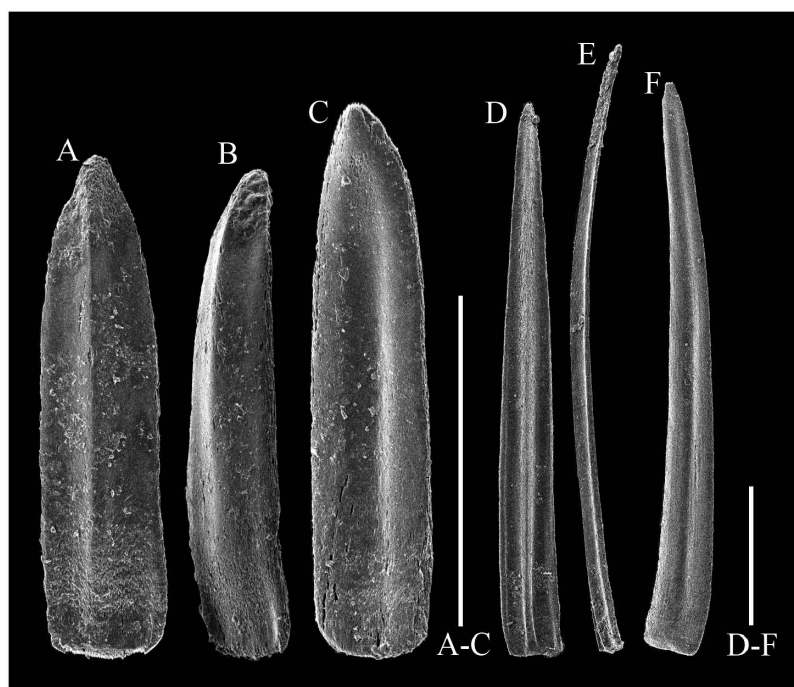


Fig. 5. *Falcidens rinkaimaruae* n. sp. SEM images of sclerites of a paratype, NSMT-Mo 79129. A–C, in dorsal midgut region, from left to right, dorsal, oblique lateral and ventral views; D–F, in ventral prepallial region, from left to right, dorsal, lateral and ventral views. Scale bar 50 μm .

near proximal end), 57 μm wide, sclerotized except for both ends. Cuticular lateral supports about half length of entire radula apparatus, substructured into three lobes at each side. Slightly sclerotized cuticular lining: central plate (Mikkelsen and Todt, 2018) [= plate with its apophyses (Scheltema, 1972); “transverse bar”: as shown in Salvini-Plawen, 1975, Fig. 7A, hatched portion between tips of lateral supports] in distal radular pit (Fig. 6A, cp).

Additional description from paratypes. Among four paratypes examined gonad (NSMT-Mo 79140 specimens “A”–“D”), specimen “B”, body length 7.7 μm (Fig. 3E) with developing ovary (Fig. 7A, C) which contains oocytes with maximum diameter ca. 70 μm , and other three specimens, body length from 5.8–7.5 mm with developing testis (Figs. 3F, 7B, D: specimen “A”, 7.5 mm) which contains spermatids.

Contents from the foregut of the paratype (NSMT-Mo 79140 specimen “A”, body length 7.5 μm) included five foraminiferan shells

(mounted on one glass slide), 140 $\times$ 100 μm –200 $\times$ 160 μm .

Remarks. The family Chaetodermatidae, to which the genus *Falcidens* belongs, is one of the three families of the class Caudofoveata, which is defined mainly by the radula characters, namely, possession of a single pair of denticles attached to a large chitinous plate, and also chitinous membrane surrounding the denticles. Other two families, Limifossoridae and Prochaetodermatidae have several transverse rows of radula denticles, and lack such a large chitinous plate. In the family Chaetodermatidae, currently three genera are recognized: *Falcidens*, *Chaetoderma*, and *Furcillidens*, which are also defined by radula characters. In *Falcidens*, the paired denticles are connected to each other in the proximal portion, whereas in *Chaetoderma*, denticles themselves are never connected, and in *Furcillidens*, denticles are completely lacking. Recently, Mikkelsen and Todt (2018) reviewed the species identity of *Chaetoderma nitidulum* with morpho-

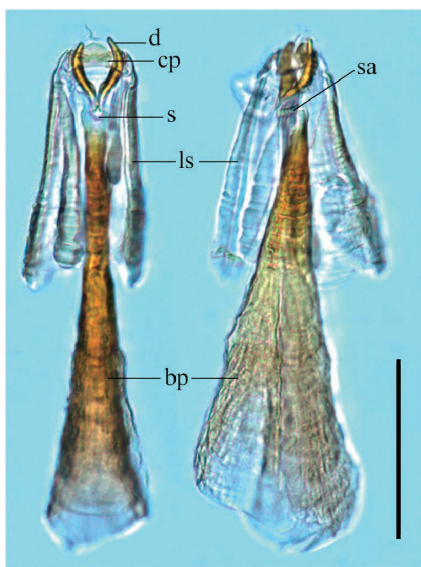


Fig. 6. *Falcidens rinkaimaruae* n. sp. Radula of holotype. A, frontal view; B, lateral view. Scale bar 100 μ m. bp: basal plate, cp: central plate, d: denticles, ls: lateral support, s: symphysis, sa: "spring-like attachment" between denticles and basal plate.

logical and molecular analysis, and revealed that *Falcidens sterreri* (Salvini-Plawen, 1967) was described based on juvenile of *Chaetoderma niti-dulum* Lovén, 1846. That is, juvenile or young *Chaetoderma* species may have *Falcidens*-type radula. Based on the fact, they suggested as "some caution has to be employed when describing *Falcidens* species from few and small individuals". The assignment of the present species to the genus *Falcidens* can be warranted by the following reasons: 1) having tail-like posterior body which is not shared by *Chaetoderma* species. 2) attaining mature stage: the maximum body length of the present species can be approximately 8 mm in contracted, preserved condition, based on 80 specimens examined, which were collected in different seasons, and no larger specimen was collected; developing gonads which contains oocytes and spermatids were observed in four examined specimens of body length 5.8–7.7 mm; all the four specimens have *Falcidens*-type radula, basically identical with that of the holotype. 3) presence of the central plate which

is considered to be one of the diagnostic characters separating *Falcidens* and *Chaetoderma*: In *Chaetoderma*, it is present only in juveniles stage (Mikkelsen and Todt, 2018).

Among 35 described species belonging to the genus *Falcidens* (Señaris *et al.*, 2016), six species are easily recognizable by the characteristic sclerites with criss-cross sculpture, by which some researchers group them as a subgenus *Chia-stofalcidens* (new name for *Lepoderma* Salvini-Plawen, 1992, preoccupied by *Lepoderma* Loose, 1899), which is not shared by the present species. The present species shares with eight out of the remaining 29 species a slender, tail-like posterior body which is contrasted to stout anterior body; those species are: *F. australocaudatus* Passos *et al.*, 2016, *F. caudatus* (Heath, 1911), *F. crossotus* Salvini-Plawen, 1968, *F. gutturosus* (Kowalevsky, 1901), *F. hartmanae* (Schwabl, 1961), *F. procerus* Salvini-Plawen, 1986, *F. ryokuyomaru-ae* Saito and Salvini-Plawen, 2014, and *F. vasconiensis* Salvini-Plawen, 1996) (Saito and Salvini-Plawen, 2014; Passos *et al.*, 2016). For their provenances, only *F. ryokuyomaru-ae* from the Sea of Japan, *F. hartmanae* from off Southern California and *F. procerus* from the Peru-Chile trench inhabit Pacific waters, whereas the type species *F. crossotus* and the other representatives belong to the Atlantic fauna. The present species differs from all these species by having very long, narrow sclerites in the ventral side of the tail-like posterior body (prepallial region), which are easily recognizable as they give brush-like appearance to the posterior body. Apart from the ventral prepallial sclerites, the present species is distinguishable from the other species as follows: the pedal shield is totally surrounding the mouth opening in the present species, *F. caudatus*, and *F. ryokuyomaru-ae* whereas it is preorally divided in other species; the dominant sclerites of the present species and *F. australocaudatus* have only a single median keel, but other species have additional ridges or riblets on each side of the keel. For the features of sclerites, the present species most resembles *F. australocaudatus*, but differs in the absence of keel in the sclerites of the

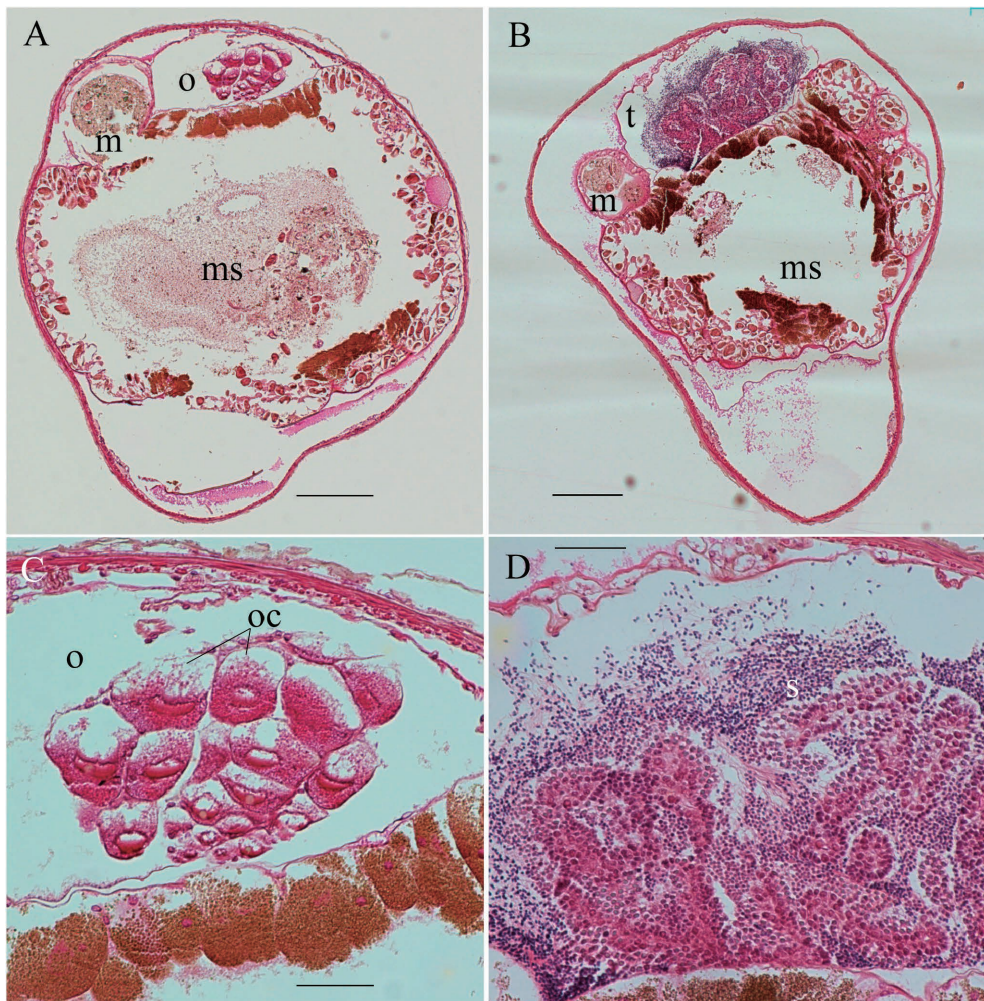


Fig. 7. *Falcidens rinkaimaruae* n. sp. Gonad of paratypes, NSMT-Mo 79140. A, C, specimen "B"; B, D, specimen "A" (specimens "A" and "B" are indicated on slides of sections, and labels in specimen jars contain remaining bodies). A, B, cross sections through midgut sac region; C, close up of ovary in Fig. A; D, close up of testis in Fig. B. Scale bar 200 μ m for A, B, 50 μ m for C, D. m: midgut, ms: midgut sac, o: ovary, oc: oocytes, s: spermatids, t: testis.

foregut region, and the presence of the narrow long sclerites in the ventral prepallial region. The larger body size and longer pallial sclerites in the present species appears to be other distinguishing features between them.

In the Northwest Pacific, only two species have been known: *F. ryokuyomaruae* from Wakasa Bay, compared as above and *Falcidens salviniplaweni* (Ivanov, 1984) from Peter the Great Bay, both in the Sea of Japan. The present species is distinguishable from the latter by hav-

ing the tail-like narrowed posterior body, the pedal shield totally surrounding the mouth opening, and the nearly parallel sided mid portion of the dominant sclerites (elongate triangular in the latter).

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