Bull. Natn. Sci. Mus., Tokyo, Ser. C, 22(3,4): pp. 63–89, December 22, 1996

Fossil Ophiuroids from the Plio-Pleistocene Hijikata Formation of the Kakegawa Group, Shizuoka, Central Japan

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Abstract Over 500 fossil ophiuroid individuals were collected from a narrow stratigraphic interval of the Hijikata Formation (Plio-Pleistocene, Kakegawa Group) in the Kakegawa area of Shizuoka Prefecture, central Japan. The age of the fossil-bearing beds is close to the Plio-Pleistocene boundary. The species we discriminated include four species definitely referable to modern species, one species most probably referable to a modern species and one indeterminate species of the family Amphiuridae. These identified species are *Ophiura sarsii* LÜTKEN, 1855, *Ophiozonella longispina* (CLARK, 1908), *Stegophiura sterea* (CLARK, 1908) (Ophiuridae); *Ophiochiton fastigatus* LYMAN, 1878 (Ophiochitonidae); *Ophiophthalmus* sp. cf. *O. hylacanthus* (CLARK, 1911) (Ophiacanthidae); an indeterminate species of the family Amphiuridae. The Hijikata specimens of *Ophiura sarsii* are the oldest fossil forms known, and *Ophiozonella longispina*, *Stegophiura sterea* and *Ophiochiton fastigatus* were previously unknown in the fossil record.

Introduction

The Plio-Pleistocene Kakegawa Group is the one of the type sequences of the Neogene series along the Pacific side of Southwest Japan. The Kakegawa Group exposed in the western part of Shizuoka Prefecture, central Japan is rich in fossil molluscs and foraminifera. Fossil molluscs and foraminifera from the Kakegawa Group have been intensively studied because these are useful for correlation and age determination (e.g. TSUCHI, 1961, AOSHIMA, 1978, NOBUHARA, 1993; and references therein). However, paleontological studies of other taxa have remained largely untouched.

We discovered fossil ophiuroids in the Hijikata Formation of the Kakegawa Group (ISHIDA *et al.*, 1995, 1996a, 1996b), and have excavated more than 500 individuals over several years. From detailed morphological observation of these specimens, we have identified five species within five genera and four families,

making it the richest ophiuroid faunule ever found in Japan. The purpose of this paper is to describe these five species systematically.

Locality and Age

The Kakegawa Group is divided into the Dainichi, Ugari, Hijikata and Soga Formations in ascending order (NOBUHARA, 1993; and references therein). The ophiuroid specimens here described come from outcrops in the Ieshiro area, about four kilometers northwest of Kakegawa Station on the Tokaido Line (Fig. 1). The strata that yielded the ophiuroids are composed of alternating bluish-grey siltstones and fine-grained sandstones intercalated with a few lenticular beds of gravel. The ophiuroids occur densely in siltstone and sandstone beds (Fig. 2). Many fragments of sublittoral marine bivalve molluscs such as *Glycymeris rotunda*, *Myadora fluctuosa* and *Saccella gordonis* are also found in the sandstone and gravel layers. In contrast, in the siltstone beds well-preserved and articulated valves of deepwater bivalve *Limopsis tajimae* are found in great numbers. *Ophiura sarsii* and *Ophiozonella longispina* are the dominant ophiuroid species in the siltstone and sandstone beds, respectively. Other fossils associated with the ophiuroids include echinoids, asteroids, comatulids, crustaceans, and trace fossils (e.g. pellets in the siltstone beds are common). Judging from the lithofacies and molluscs, we suggest that *Ophiozonella longispina* was a dweller on a sublittoral

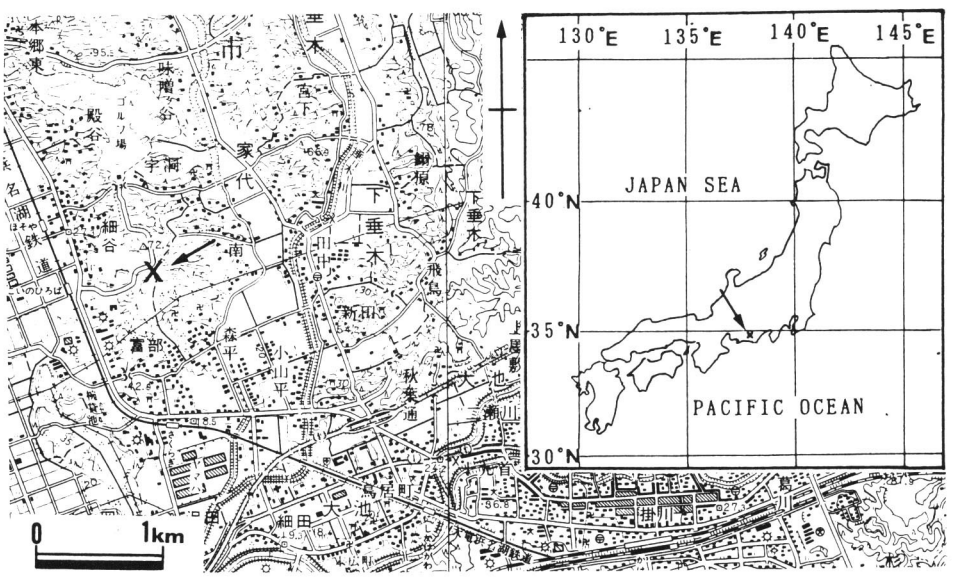

Fig. 1. Locality of fossil ophiuroids. Part of the "Kakegawa" and "Yamanashi" 1:25,000 topographic maps by the Geographical Survey Institute. ×, Fossil locality.

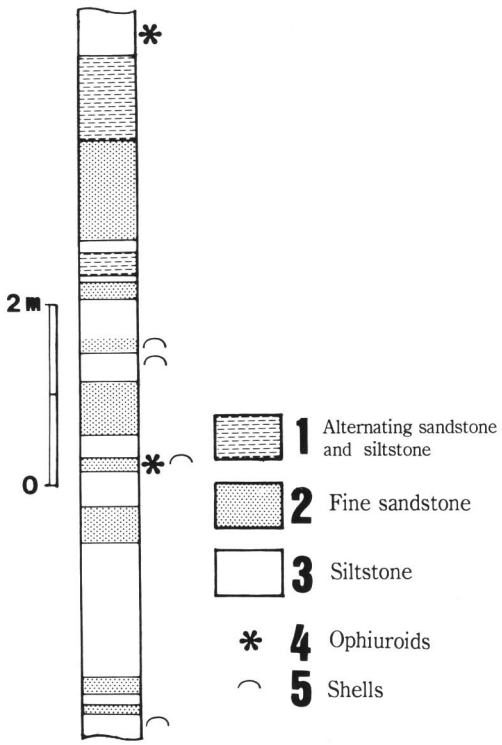

Fig. 2. Columnar section at the fossil locality.

sand bottom and *Ophiura sarsii* was a dweller on an upper bathyal silty bottom. More detailed observations on the mode of occurrence and an interpretation on the habitats of the ophiuroids will be discussed in a separate paper.

The ophiuroid-bearing strata are stratigraphically about 30 meters above the top of the Hosoya Tuff-key chronostratigraphic bed in the Kakegawa Group (TSUCHI, 1961). The Hosoya Tuff has been dated as 1.9 Ma by fission-track dating (NISHIMURA, 1977) and also as N21 or N22 by foraminiferal analysis and occurs at the base of the paleomagnetostratigraphic Olduvai event (IBARAKI, 1986). From the above evidence, the ophiuroid-bearing strata can be assigned to an age somewhere close to the Plio-Pleistocene boundary.

Composition of the Ophiuroid Faunule

The species identified are listed in Table 1. The occurrence of *Ophiozonella longispina* and *Ophiochiton fastigatus* from the Hijikata Formation represents the first fossil record of these species. *Ophiura sarsii* LÜTKEN, 1855 is the only species that is previously recorded in the fossil record: from the late Pleistocene off

Table 1. Composition of the Hijikata ophiuroid faunule and number of specimens obtained.

Species	Siltstone	Sandstone	Total number of specimen
Family Ophiuridae			
Ophiura sarsii LÜTKEN	315	79	394
Stegophiura sterea (CLARK)	—	2	2
Ophiozonella longispina (CLARK)	—	123	123
Family Ophiochitonidae			
Ophiochiton fastigatus LYMAN	—	1	1
Family Ophiacanthidae			
Ophiophthalmus sp. cf. *O. hylacanthus* (CLARK)	17	—	17
Family Amphiuridae gen. et sp. indet.	2	—	2
Total	334	205	539

northern Norway (JENSEN & THOMSEN, 1987), from the Pleistocene of Southern Norway (SIEVERTS-DORECK, 1953) and the Early to Middle Pleistocene Ichijuku Formation (Kazusa Group) of Chiba Prefecture, Japan (ISHIDA & INOUE, 1993, 1995). Therefore the Hijikata specimens represent the oldest fossil record for this species.

We identified two specimens as *Stegophiura sterea* (CLARK), a living species known from Japanese coastal waters and the Korea Strait (IRIMURA, 1990). The Hijikata specimens are the first fossil occurrence, so the fossil record of this species can be extended to somewhere near the Plio-Pleistocene boundary. The genus *Stegophiura* is poorly documented in the fossil record of Japan; some unidentified species have been reported from the Miocene Morozaki Group of Aichi Prefecture, central Japan (ISHIDA, 1993) and from the Miocene Itsukaichi-machi Group of Tokyo, central Japan (PALEONTOLOGICAL SUBGROUP of ITSUKAICHI BASIN RESEARCH GROUP, 1985).

Species of Ophiacanthidae and Amphiuridae are also poorly documented in the fossil record of Japan. Previously recorded species of the Ophiacanthidae are *Ophiacantha* sp. from the Miocene Itsukaichi-machi Group (ITSUKAICHI BASIN RESEARCH GROUP, 1983) and *Ophiocamax* sp. from the Miocene Morozaki Group of Aichi Prefecture (ISHIDA, 1988, 1991). The Amphiuridae is only represented by *Amphioplus uchigoensis* ISHIDA (1992) from the Oligocene Asagai Formation of the Iwaki area (Fukushima Prefecture).

To summarise, the Hijikata ophiuroid faunule consists mostly of extant species that are at present living in waters around Japanese Islands. The Hijikata ophiuroid faunule also provides important information on the first occurrences of certain species of ophiuroids in the fossil record.

Systematic Description

Family Ophiuridae LYMAN, 1865
Subfamily Ophiurinae LYMAN, 1865
Genus *Ophiura* LAMARCK, 1816
Ophiura sarsii LÜTKEN, 1855
(Fig. 3; Plate 1)

Ophiura sarsii LÜTKEN, 1855, p. 101: CLARK, 1911, p. 37; MATSUMOTO, 1917, p. 272, fig. 74; MORTENSEN, 1927, p. 238, figs. 128-1, 2; BERRY, 1934, p. 98, Pls. 5, 6; D'YAKONOV, 1954, p. 98, fig. 35; IRIMURA, 1990, p. 98; ISHIDA and INOUE, 1993, p. 104, Pls. 1–3.

Material: 394 specimens were found in siltstones and fine sandstones. The four specimens illustrated are housed at the National Science Museum, Tokyo, Japan (NSM-PA 12938-9, 12945-6).

Measurements: Measurements based on 388 specimens; the smallest disk diameter, 0.6 mm; the largest disk diameter, 20 mm; mean diameter, 8.2 mm.

Description: Disk circular in outline, low and flat, covered with small, flat and imbricated scales (Fig. 3-A-1). Interradial marginal plates elliptical in outline. Radial shields oval in shape, about twice as long as wide, separated from each other, about half length of disk radius. Arm comb plates elliptical in shape. Arm comb papillae conical, short, about one third of basal arm segment (Fig. 3-B). Oral shields pentagonal in shape with rounded distal borders, slightly longer than broad. Teeth and oral papillae long, slender and acute. Adoral plates slender and rectangular in shape, in contact with each other at adoral margin. Oral plates rather long, rectangular in shape, in contact with each other at adoral side. Arms rather wide at base, tapering gently, bent gradually on horizontal plane. Arms flattened, much wider than high. Dorsal arm plates well developed, keeled, rectangular in shape, with straight or slightly convex outer edges, and in contact over their whole breadth. About four dorsal arm plates at base of arm incorporated into disk. First dorsal arm plates triangular in shape. Dorsal arm plates in proximal free arm segments about three times as broad as long. Ventral arm plates triangular in shape with rounded corners, wider than long, about 2.5 times as broad as long, with straight or slightly convex outer edges, separated from each other. First ventral arm plates trapezoidal in shape with curved distal margin. Lateral arm plates separated by dorsal arm plate on dorsal side of arm, but, they in contact on ventral side. Second oral tentacle pores large, outside oral slits. Arm spines long and tapering, twice as long as corresponding arm segment proximally and almost equal to length of corresponding arm segments at mid-arm, three in number. Arm spines appressed or often somewhat detached. Dorsal side of vertebral ossicles tapering at aboral side (Fig. 3-A-2).

Remarks: Although the Hijikata specimens are referable to *Ophiura sarsii*

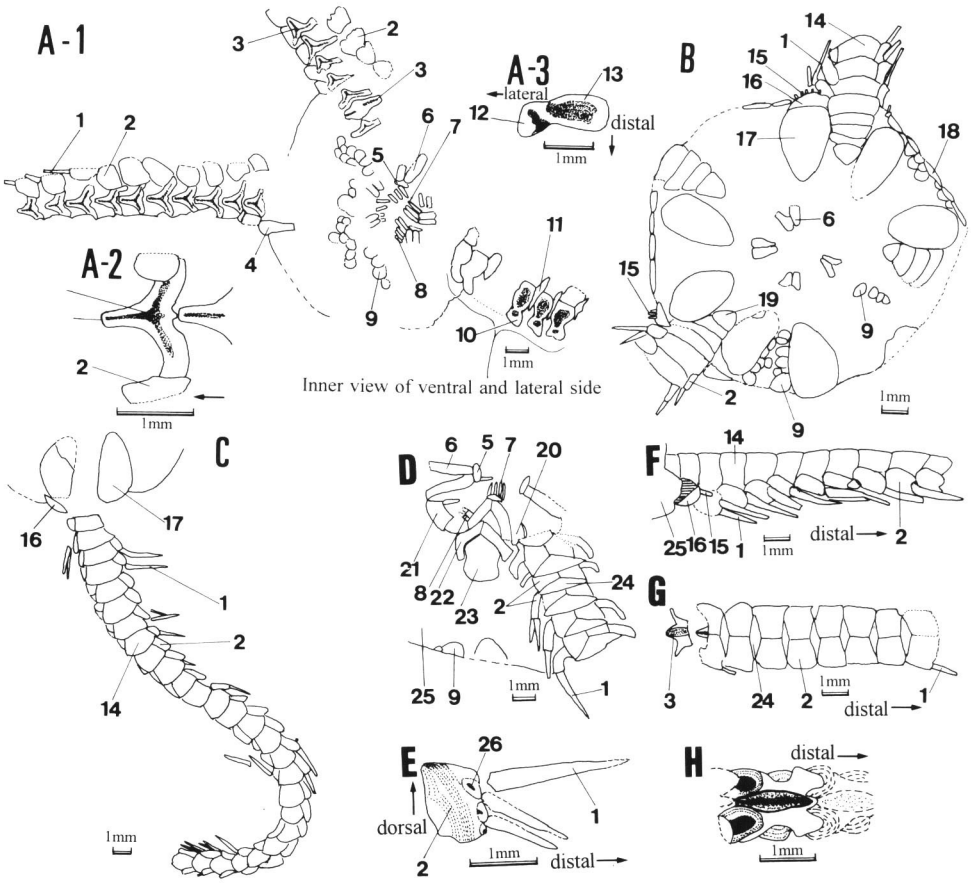

Fig. 3. Drawings of the figured specimens of *Ophiura sarsii* LÜTKEN, 1855 from the Hijikata Formation. A-1, dorsal view of disk and vertebra except for a part of basal arm; A-2, dorsal view of vertebra; A-3, inner view of ventral and lateral side of lateral arm plate; B, dorsal view of disk and basal arm; C, dorsal view of disk edge and arm; D, ventral view of disk; E, lateral view of the lateral arm plate and arm spines; F, lateral view of the arm and disk edge; G, ventral view of the arm; H, ventral view of the vertebral ossicle. Abbreviation: 1, arm spine; 2, lateral arm plate; 3, vertebral ossicle; 4, a part of genital plate; 5, torus angularis; 6, oral plate; 7, tooth; 8, oral papilla; 9, disk scale; 10, inner surface of lateral arm plate; 11, inner surface of ventral arm plate; 12, inner surface of lateral side of lateral arm plate; 13, inner surface of ventral side of lateral arm plate; 14, dorsal arm plate; 15, arm comb papilla; 16, arm comb plate; 17, radial shield; 18, interradial marginal plate; 19, first dorsal arm plate; 20, second oral tentacle pore; 21, first ventral arm plate; 22, adoral plate; 23, oral shield; 24, ventral arm plate; 25, disk; 26, socket of arm spine.

LÜTKEN, 1855, a living species of the northern hemisphere (which forms a typical assemblage on the uppermost continental slope around Japan; FUJITA & OHTA, 1990), there are some differences in morphology among the extant and fossil forms. For example, the Hijikata specimens (mean disk diameter 8.2 mm) are evidently smaller than the fossil specimens (mean disk diameter 9.6 mm) from the Pleistocene Ichijuku Formation of the Kazusa Group, Chiba Prefecture (ISHIDA & INOUE, 1993). The fossil specimens from the Hijikata and Ichijuku Formations possess arm comb papillae shorter and arm spines longer than the known specimens of *Ophiura sarsii vadicola* D'YAKONOV (1954), a living subspecies in shallow waters of the Sea of Japan and the Tatar Strait.

The Hijikata species is somewhat similar to *Ophiura leptoctenia* CLARK (1911), a living species of the northern hemisphere, which coexists with *Ophiura sarsii* around Japan (FUJITA, 1992). *Ophiura leptoctenia* has arms that are slender at the base and arm spines that are as long as the corresponding arm segment near the arm base. In contrast, the Hijikata species has arms that are wide at the base and arm spines that are about twice as long as the corresponding arm segment. The Hijikata species is also similar to *Ophiura kinbergi*, a living species found from the Japanese coast to the Indo-West Pacific area. However, the Hijikata species has arm comb papillae shorter than *Ophiura kinbergi.*

Genus *Stegophiura* MATSUMOTO, 1915

Stegophiura sterea (CLARK, 1908)

(Fig. 4; Plate 2)

Ophioglypha sterea CLARK, 1908, p. 293.
Ophiura sterea; CLARK, 1911, p. 75, fig. 22.
Stegophiura sterea; MATSUMOTO, 1917, p. 177; IRIMURA, 1981, p. 39; IRIMURA, 1982, p. 82, fig. 51, Pl. 15-5; IRIMURA, 1990, p. 100.
Stegophiura liodisca; MURAKAMI, 1942, p. 23, fig. 9.

Material: Two specimens (NSM-PA 12940, 12941) were found in a fine sandstone; one shows the ventral side of the disk, and the other shows a part of the arm.

Measurements: Disk diameter, 8.0 mm; basal arm width, 2.0 mm.

Description: Arms more than twice as long as disk diameter. Disk pentagonal in outline. Dorsal and ventral surface of disk covered with comparatively large scales. Radial shields small, in contact proximally but separated distally by first dorsal arm plate. Arm comb papillae numerous, covering lateral sides of first to third dorsal arm plates. Arm comb plates large. Oral shields large, oval and narrower proximally than distally. Adoral plates long and narrow. Oral plates (ventral side of jaws): general outline of the plate wedge-shaped, wider than adoral plate, smallest at adoral end, in contact at adoral side, making an acute

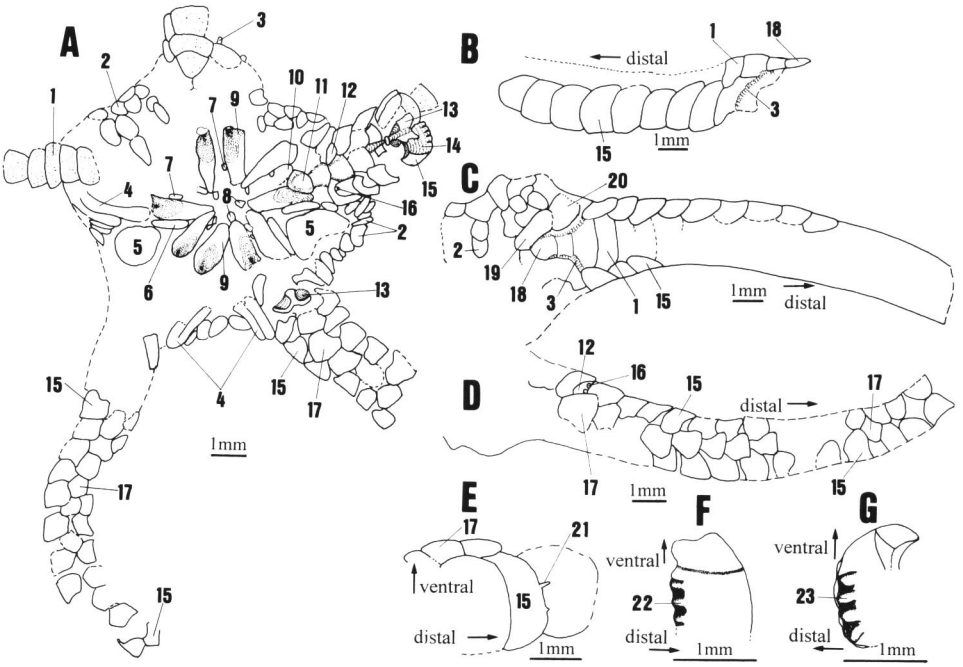

Fig. 4. Drawings of the figured specimens of *Stegophiura sterea* (CLARK, 1908) from the Hijikata Formation. A, ventral view. Dot marks show inside of dorsal arm plates; B, lateral view of arm; C, dorsal view; D, ventral view of arm; E, lateral view of arm; F, outside view of lateral arm plates at the free basal arm; G, inside view of lateral arm plates at the free basal arm. Abbreviation: 1, dorsal arm plate; 2, disk scale; 3, arm comb papilla; 4, a part of genital plate; 5, oral shield; 6, adoral plate; 7, oral papilla; 8, tooth; 9, oral plate; 10, second oral tentacle pore; 11, first ventral arm plate; 12, tentacle pore; 13, vertebral ossicle; 14, inside view of lateral arm plate; 15, lateral arm plate; 16, tentacle scale; 17, ventral arm plate; 18, first dorsal arm plate; 19, radial shield; 20, arm comb plate; 21, arm spine; 22, tubercle situated on adoral outer surface of lateral arm plate; 23, tubercle situated on aboral inner surface of lateral arm plate.

angle, 0.4 times as long as disk radius. Adoral area of plate has a round ridge while aboral area of plate has a deep pit, which is deepest at its aboral end. Pits occupy a bit more area than ridges on plates (Fig. 4-A). Oral slits narrow and rectangular in shape. Teeth pointed, larger than oral papillae. Oral papillae short; outer papillae wide and flat, inner ones pointed. Arms stout. Basal arms slightly higher than wide. First ventral arm plates triangular with rounded edges, swollen on median longitudinal line; second and following ventral arm plates in disk trapezoidal or rectangular with round distal border, widely in contact, slightly swollen longitudinally; following plates of free basal arm fan-shaped, narrowly in contact, then becoming rhombic, longer than wide, separated from each other. First dorsal arm plates nearly pentagonal with an angle between radial shields;

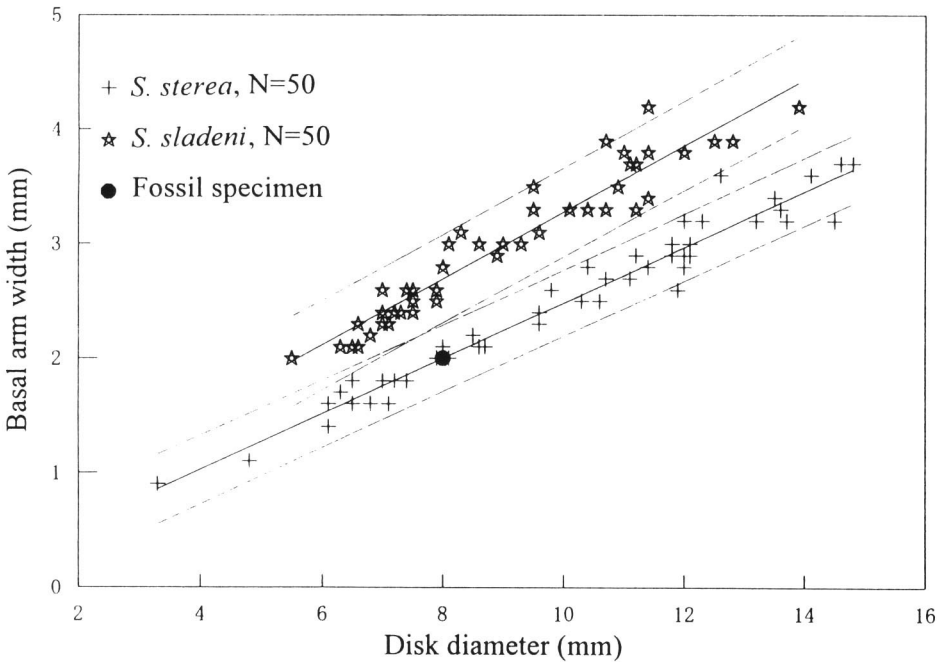

Fig. 5. Scattered diagram showing the relationship between the basal arm width and the disk diameter of *Stegophiura sterea* (CLARK, 1908), *Stegophiura sladeni* (DUNCAN, 1879), and the fossil specimen *Stegophiura sterea* from the Hijikata Formation. Solid lines show linear regression and broken lines show 95% confidence limits. Each regression line shows statistically significant ($r=0.98$, $p<0.05$ for *Stegophiura sterea* and $r=0.95$, $p<0.05$ for *Stegophiura sladeni*). There is a statistically significant difference on intercept ($p<0.05$) and regression coefficient ($p<0.05$) between the two regression lines. The fossil specimen falls in the confidence interval of Recent specimens of *Stegophiura sterea*. Data for living specimens of *Stegophiura sterea* and *S. sladeni* are from the specimens stored at the National Science Museum, Tokyo (*Stegophiura sterea* NSMT-E 555, 1076, *S. sladeni* NSMT-E 2094).

second plates quadrilateral, slightly wider than long; third plates quadrilateral with round corners, about three times as wide as long; following plates more or less hexagonal, wider than long and broadly in contact with each other. Lateral arm plates large, high, broad, and flat proximally where they meet neither above nor below: they meet ventrally at mid-arm length or farther distally. Three or four tubercles aborally on inside of lateral arm plates at free basal arm (Fig. 4-G). Three tubercles adorally on outside of lateral arm plates at free basal arm (Fig. 4-F). Second oral tentacle pores situated beside first ventral arm plate. Tentacle pores large at basal arm, but reduced to narrow slits in middle and distal arm seg-

ments. Primary arm spines short and acute, appressed. Sockets of arm spines small.

Remarks: The Hijikata specimens have morphological characteristics much in common with *Stegophiura sterea* (CLARK, 1908), a living species off all the Japanese coasts and also in the Korea Strait at a depth of 70–350 m, and *Stegophiura sladeni* (DUNCAN, 1879), a living species (also with the same distribution as *Stegophiura sterea*) which lives mostly 50–150 m in depth (IRIMURA, 1990). IRIMURA (1990) distinguished the two living species from each other mainly on the basis of the number of arm spines. In addition to this difference, we suggest that *Stegophiura sterea* has less convex ventral arm plates in the disk (Pl. 2-F, G) and a smaller ratio of basal arm width to disk diameter than those of *Stegophiura sladeni* (the ratio is 0.24 for *S. sterea* and 0.29 for *S. sladeni*; see Fig. 5). Taking these differences into consideration, we conclude that the Hijikata specimens are referable to *Stegophiura sterea* rather than *Stegophiura sladeni*, although the number of arm spines is not known.

The Hijikata species is comparable to *Stegophiura* sp. from the Miocene Morozaki Group. The Morozaki species has a disk diameter of 22.0 mm and a proximal arm width of 6.3 mm (ISHIDA, 1993), so that the ratio of basal arm width to disk diameter (0.29) is larger than the Hijikata species. The Hijikata species evidently differs from *Stegophiura* sp. from the Miocene Itsukaichi-machi Group (PALEONTOLOGICAL SUBGROUP of ITSUKAICHI BASIN RESEARCH GROUP, 1985) in having a much smaller ratio of basal arm width to disk diameter (the ratio is 0.13 for the Itsukaichi species).

Subfamily Ophiolepidinae MATSUMOTO, 1915

Genus *Ophiozonella* MATSUMOTO, 1915

Ophiozonella longispina (CLARK, 1908)

(Fig. 6; Plates 3, 4)

Ophiozona longispina CLARK, 1908, p. 290; CLARK, 1911, p. 33.

Fig. 6. Drawings of the figured specimens of fossil *Ophiozonella longispina* (CLARK, 1908) from the Hijikata Formation. A, dorsal view; B, ventral view; C, dorsal view of the vertebrae; D, dorsal view of the vertebrae in the disk; E, ventral view of the vertebrae; F, jaw apparatus including the oral papillae; G, ventral view of the mouth angle; H, teeth; I, lateral and dorsal view including the arm spines. Abbreviation: 1, dorsal arm plate; 2, lateral arm plate; 3, arm spine; 4, radial shield; 5, disk scale; 6, dorsal side of the vertebra; 7, a part of oral plate; 8, oral plate; 9, ventral arm plate; 10, tentacle pore; 11, oral shield; 12, oral frame; 13, a part of genital plate; 14, first vertebral ossicle; 15, upper ara ridge; 16, upper parapophysis ridge; 17, zygapophysis; 18, zygocondyle; 19, lower ara; 20, lower canal furrow; 21, anterior hypapophysis; 22, canal for tentacle; 23, oral papillae; 24, tooth; 25, first ventral arm plate; 26, upper canal furrow; 27, disk edge.

Ophiozonella longispina; MATSUMOTO, 1915, p. 82; CLARK, 1915, p. 338, pl. 20, figs. 5, 6; MATSUMOTO, 1917, p. 297, fig. 80, pl. 5, fig. 9; MURAKAMI, 1942, p. 29; MURAKAMI, 1963, p. 179; IRIMURA, 1981, p. 41; IRIMURA, 1982, p. 78, fig. 48, Pl. 14, figs. 5, 6; IRIMURA, 1990, p. 91.

Material: 123 specimens were found in fine sandstone. Two specimens illustrated are stored at the National Science Museum, Tokyo, Japan (NSM-PA

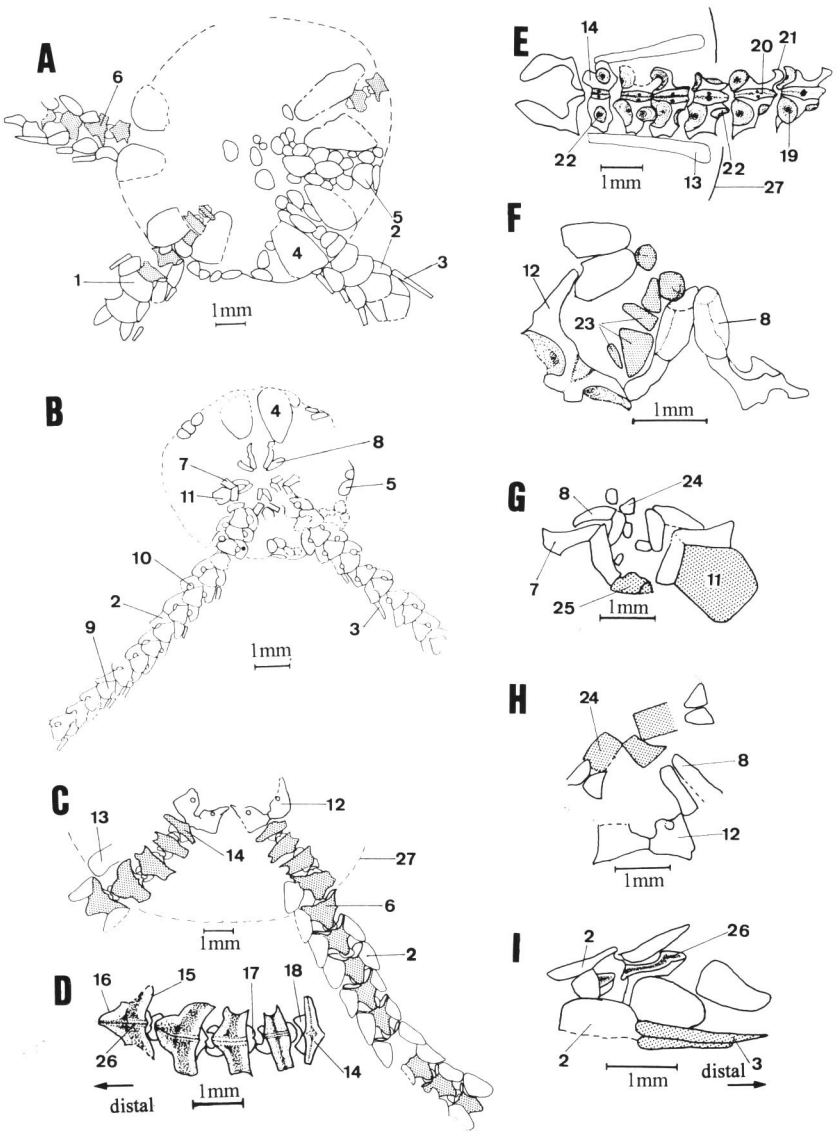

Fig. 6

12942, 12943).

Measurements: Measurements based on 120 specimens; the smallest disk diameter, 3.7 mm; the largest disk diameter, 13.6 mm; mean disk diameter, 8.8 mm.

Description: Disk low and flat, circular in outline and covered with large scales. First four or five arm segments inserted laterally into disk. Arms robust, becoming almost straight on horizontal plane. Radial shields large, oval in shape, about twice as long as wide, half to two thirds of length of disk radius, separated from each other. Oral shields large, pentagonal, with an inner angle, slightly longer than wide. Oral plates rectangular in shape, in contact at base. Oral papillae five in number on one side of jaw; second one from distal largest of all, triangular in shape, pointed inwards (Fig. 6-F). Other ones blunt at top. Teeth rectangular in shape (Fig. 6-H). Arms about three times as long as disk diameter. Dorsal arm plates of proximal arm segments trapezoidal in shape, wider than long, in contact; first four or five distinctly in contact. However they become fan-shaped or rhombic, longer than wide, and separated from each other beyond proximal arm segments. Ventral arm plates trapezoidal in shape at basal arm, and subsequently pentagonal, further fan-shaped with a convex distal border; first five to eight wider than long, six to eleven as long as wide, remainder longer than wide; first four to five widely in contact, remainder not too widely in contact or mostly separated from one another. First ventral arm plates small, wider than long. Lateral arm plates not in contact dorsally and ventrally at proximal arm segments, but in contact from fifth or sixth arm segments onwards. Proximalmost arm segments have some small scales laterally. Tentacle pores large, very well-developed along entire arms. Arm spines long, acute, conical, two in number; dorsal spines longer than ventral ones, and 1.2–2.0 times longer than corresponding arm segments. Lower canal furrows of vertebral ossicles deep, with a large pore at center of lower canal furrow but two small pores at a right angle to canal furrow at first to fifth vertebral ossicles (Fig. 6-E). On dorsal surface of vertebral ossicles, they wide and raised at aboral side (Fig. 6-D, I).

Remarks: We identified more than 100 specimens as *Ophiozonella longispina* (CLARK, 1908), a living species of the Pacific coast of Japan, mostly living at 80–120 m in depth (IRIMURA, 1990). This species is similar to *Ophiozonella projecta* (KOEHLER, 1905), a living species in the Indian Ocean. However, *O. longispina* is easily distinguished from *O. projecta* as the former species has arm spines longer than the latter species.

The Hijikata species is also similar to *Ophiozona*? *eocaena* (LERICHE, 1931) (JAGT, 1990) from the Eocene of Northwest Belgium. However, in *Ophiozona*? *eocaena* the ventral arm plates are almost square in shape and are being contact with the entire length of arm, while in the Hijikata species the ventral arm plates are fan-shaped rhombic and are separated from the middle portion onwards.

Family Ophiochitonidae MATSUMOTO, 1915
Subfamily Ophiochitoninae MATSUMOTO, 1915
Genus *Ophiochiton* LYMAN, 1878
Ophiochiton fastigatus LYMAN, 1878

(Fig. 7; Plate 5)

Ophiochiton fastigatus LYMAN, 1878, p. 132, pl. 7, figs. 182, 183; LYMAN, 1882, p. 176, pl, 24, figs. 13–15; CLARK, 1911, p. 133; MATSUMOTO, 1917, p. 328, fig. 91; IRIMURA, 1981, p. 69, figs. 41, 42; IRIMURA, 1990, p. 89.

Ophiochiton carinatus LÜTKEN and MORTENSEN, 1899, p. 164, pl. 14, figs. 1–3.

Material: One specimen (NSM-PA 12944) was found in sandstone, expos-

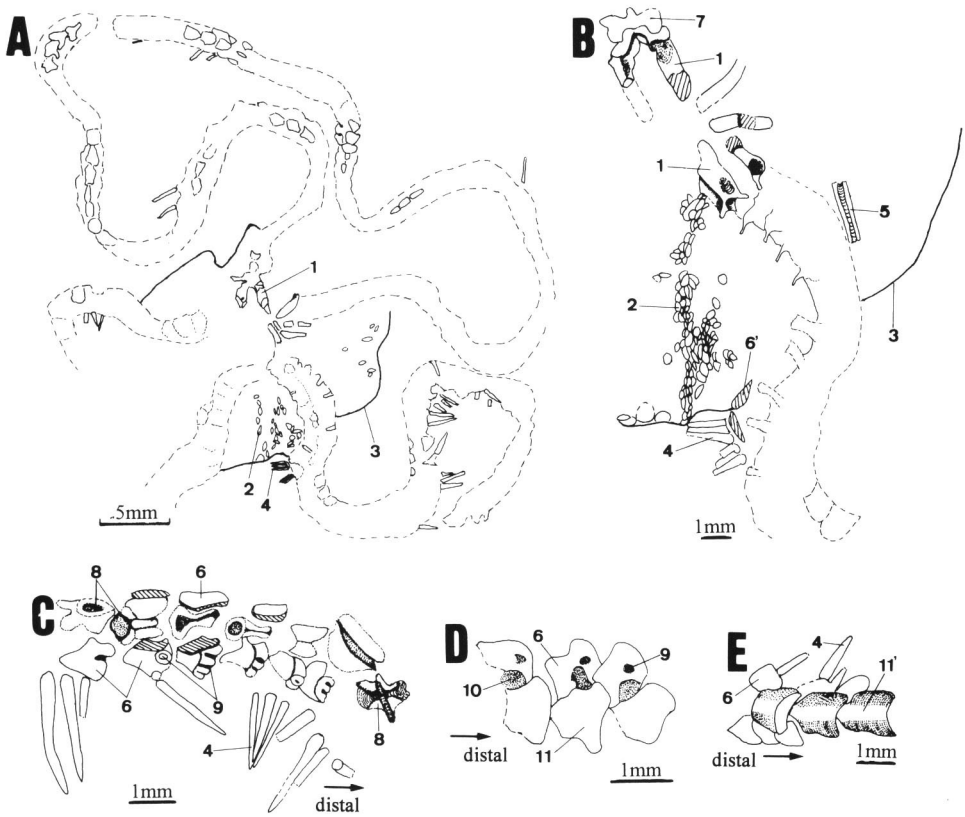

Fig. 7. Drawings of the figured specimen of *Ophiochiton fastigatus* LYMAN, 1878 from the Hijikata Formation. Ventral view. A, whole view; B, jaws, disk and basal arm; C–E, middle part of arms. Abbreviation: 1, a part of oral plate; 2, disk scale; 3, disk edge; 4, arm spine; 5, a part of genital plate; 6, lateral arm plate; 7, first vertebral ossicle; 8, vertebral ossicle; 9, socket of arm spine; 10, tentacle pore; 11, ventral arm plate; 11′, keeled ventral arm plate.

ing the ventral side.

Measurement: Disk diameter, 16.8 mm.

Description: Disk with notched interradial borders, covered with very fine imbricated scales. Oral frames without well developed lateral wings. Arms more than three times as long as disk diameter, horizontally flexible. Width of basal arms, without spines; 2.9 mm. Ratio of basal arm width to disk diameter; 0.17 (Fig. 8). Ventral arm plates keeled at a median longitudinal line, wider than long, trapezoid with concave lateral border, broader distally than proximally (Fig. 7-E). Lateral arm plates small, not in contact with ventral side. Tentacle pores large. Arm spines thick, cylindrical, smooth, about twice length of corresponding arm segments, three or four in number at basal arm segments, placed in sockets on externally distal side of lateral arm plate.

Remarks: We identified one specimen as *Ophiochiton fastigatus* LYMAN, 1878, a living species habiting waters Japanese coast to around the East China Sea (in waters 128–860 m in depth; IRIMURA, 1990). This identification is mainly based on the fact that the Hijikata specimen has the ratio of basal arm width to disk diameter almost same with that of living *O. fastigatus* (Fig. 8).

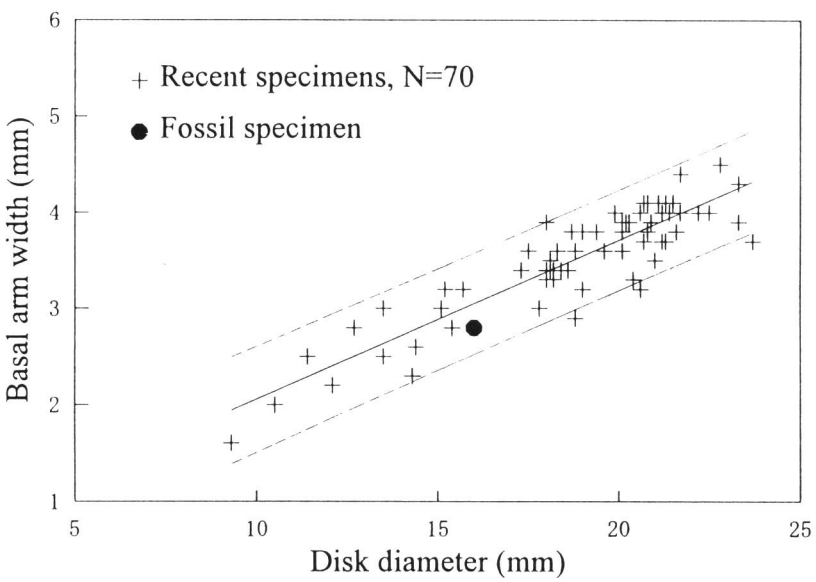

Fig. 8. Scattered diagram showing the relationship between the basal arm width and the disk diameter of *Ophiochiton fastigatus* LYMAN, 1878 and the fossil specimen from the Hijikata Formation. Solid line shows linear regression and broken lines show 95% confidence limits. The regression line shows statistically significant ($r=0.90$, $p<0.05$). The fossil specimen falls in the confidence interval of Recent specimens of *Ophiochiton fastigatus*. Data for living specimens are from the specimens collected in Suruga Bay, October 1995 (FUJITA *et al.*, unpublished data).

There are three living species (all with an Indian ocean distribution) comparable to the Hijikata specimens. The Hijikata species is easily distinguished from *Ophiochiton lentus* LYMAN, 1879, in that the former species has a ridge in the ventral arm plates while the latter has no ridge. The Hijikata species differs from *Ophiochiton ambulator* KOEHLER (1898), in that the former has trapezoidal ventral arm plates while the latter has rhombic ventral arm plates. The Hijikata species is distinct from *Ophiochiton modestus* KOEHLER (1898) as the former species has arm spines shorter than the latter.

Ophiochiton? pratti (FORBES, 1844) (HESS, 1964) from the Jurassic of England is comparable to the Hijikata species, but differs in having shorter arm spines.

Family Ophiacanthidae PERRIER, 1891

Genus *Ophiophthalmus* MATSUMOTO, 1917

Ophiophthalmus sp. cf. ***O. hylacanthus*** (CLARK, 1911)

(Fig. 9; Plate 6)

Material: 17 specimens were found in siltstone. The inner molds of the ventral and dorsal side are observed and outer molds of the disk are partly observed. One specimen illustrated is stored at the National Science Museum, Tokyo, Japan (NSM-PA 12947).

Measurement: Disk diameter, 14 mm.

Description: Arms robust, wide, not much constriction at nodes and about four times as long as disk diameter. Dorsal arm plates triangular in shape, as long as wide; basal ones in contact, but further out they separated. On disk and first dorsal arm segment, there are many pores possibly made by spines, tapering at end. Arm spines very long, 3–4 times length of corresponding arm segments, very slender and erect, not approximating dorsally. Sockets of arm spine 7–8 in number at proximal arm segments.

Remarks: Morphological details of the Hijikata specimens are poorly known. However, they appear to be identical to *Ophiophthalmus hylacanthus* (CLARK, 1911) which is known from Japanese waters. They possess very long, 7 or 8 arm spines, a disk that is covered with spines, and robust arms that lack constriction at the nodes.

The Hijikata species is distinguished from *Ophiophthalmus codonomorpha* (CLARK, 1911) living around Japan by having longer arm spines. The Hijikata species differs from *Ophiophthalmus cataleimmoidus* (CLARK, 1911), a living species off the coast of Alaska to Japan, the former species has 7 or 8 arm spines and a disk that is covered with spines, while the latter has 6 arm spines and a disk that is covered with granules.

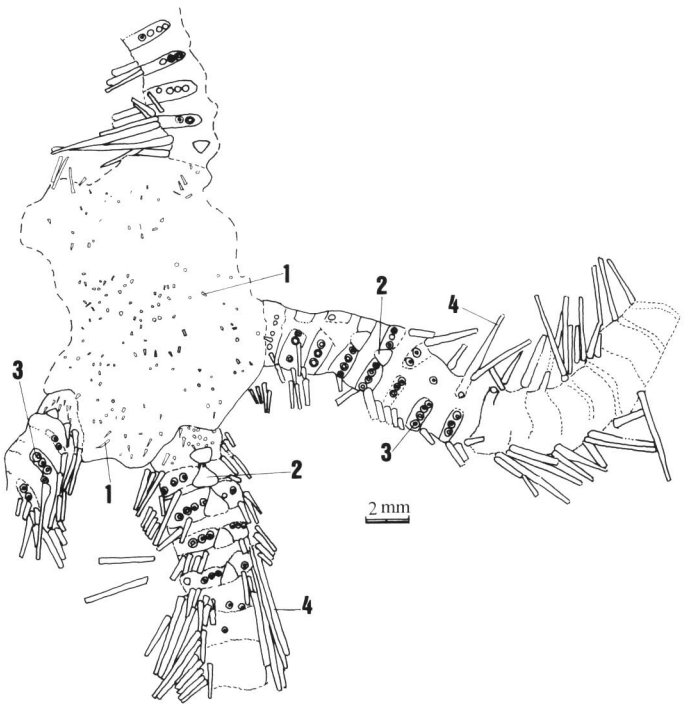

Fig. 9. Sketch showing *Ophiophthalmus* sp. cf. *O. hylacanthus* (CLARK, 1911) from the Hijikata Formation. Dorsal view. Abbreviation: 1, disk spine; 2, dorsal arm plate; 3, socket of arm spine; 4, arm spine.

Family Amphiuridae LJUNGMAN, 1867
Genus and species indeterminate
(Figs. 10, 11)

Material: Two specimens were found in siltstone. One specimen illustrated is stored at the National Science Museum, Tokyo, Japan (NSM-PA 12948).

Measurement: Disk diameter, 5.7 mm.

Description: Arms very slender and flexible on horizontal plane. Arm width of basal arm segment 0.7 mm. Arm length three times greater than disk diameter. Disk scales fine. Arm spines as long as corresponding each arm segments, slender, and erect.

Remarks: The present species is evidently referable to the family Amphiuridae as it has slender and long arms. However, the generic determination and specific comparison are impossible due to poor preservation of the material.

Amphioplus uchigoensis ISHIDA (1992) from the Oligocene Asagai Formation appears to be a species comparable to the present species. However, the Hijikata species has an arm much shorter than *A. uchigoensis*.

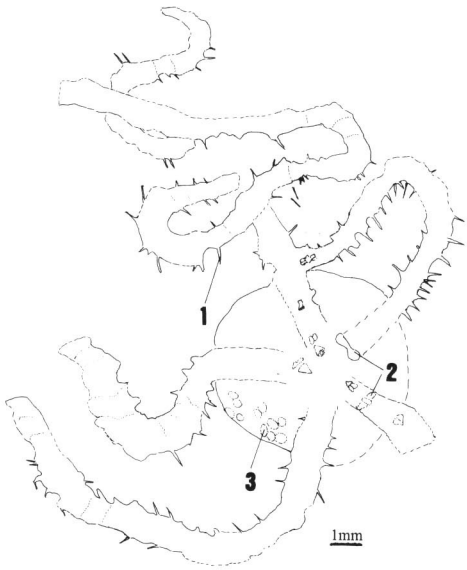

Fig. 10. Sketch showing Amphiuridae genus and species indeterminate from the Hijikata Formation. Abbreviation: 1, arm spine; 2, vertebral ossicle; 3, disk scale.

Fig. 11. Amphiuridae genus and species indeterminate from the Hijikata Formation.

Acknowledgments

The writers would like to thank Dr. Seiichi IRIMURA, Dr. Toshihiko FUJITA of the National Science Museum, Tokyo, Dr. John W. M. JAGT of Natuurhisto-

risch Museum, Naastricht, Netherlands, Dr. Frederick H.C. HOTCHKISS of the Panametrics Company, U.S.A. and Dr. Masae OMORI, Prof. Emeritus of Azabu University for their critical reading of the manuscript and supplying useful information. Our deep gratitude is due to Dr. Takami NOBUHARA of Nagoya University for identification of the molluscan fossils and valuable comments. Our special thanks are due to Drs. Tomoki KASE and Paul G. DAVIS of the National Science Museum, Tokyo for giving the useful comments to the manuscript. Thanks are due to the following persons for their kind help in various ways: Dr. Tsunemi KUBODERA and Dr. Kazumi YOKOYAMA of the National Science Museum, Tokyo, Mr. Atsushi MIYASHITA of Seikei High School, Mr. Masaki KAJIHARA and Mr. Matthew WILLEMSEN of Hitotsubashi High School.

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Explanation of Plates

Plate 1. *Ophiura sarsii* LÜTKEN, 1855 from the Hijikata Formation. Fig. A. Dense occurrence of fossil *Ophiura sarsii* in siltstone matrix. Fig. B. Dorsal view, but the middle to tip of the arms shows the mould of the ventral side. Figs. C–E. Dorsal view. Fig. F. Lateral view. Figs. G–I. Ventral view. Fig. J. Ventral view, showing part of the jaw. Abbreviation: 1, ventral arm plate; 2, dorsal arm plate; 3, external view of lateral arm plate; 3′, internal view of lateral arm plate; 4, arm spine; 5, first dorsal arm plate; 6, disk scale; 7, radial shield; 8, oral papilla; 9, dorsal view of vertebral ossicle; 9′, ventral view of vertebral ossicle; 10, first ventral arm plate; 11, marginal disk scale; 12, ventral view of first vertebral ossicle; 13, oral plate; 14, tooth; 15, oral shield; 16, arm comb papilla.

Plate 2. *Stegophiura sterea* (CLARK, 1908) and *Stegophiura sladeni* (DUNCAN,1879). Figs. A–D. Fossil specimens of *Stegophiura sterea* from the Hijikata Formation. Figs. E, F, H, I. Living specimens of *Stegophiura sterea.* Fig. G. Living specimen of *Stegophiura sladeni.* Figs. A, B, D, F, G. Ventral view. Fig. D. Basal arm segments. Figs. C, E. Dorsal view. Fig. H. Internal view of lateral arm plate. Fig. I. External view of lateral arm plate. Figs. H, I. SEM. Abbreviation: 1, oral shield; 2, oral plate; 3, internal view of dorsal arm plate; 4, genital plate; 5, first ventral arm plate; 6, vertebral ossicle; 7, disk scale; 8, tentacle pore; 9, ventral arm plate; 10, lateral arm plate; 11, radial shield; 12, arm comb papilla; 13, first dorsal arm plate; 14, external view of dorsal arm plate; 15, internal view of lateral arm plate; 16, tubercle situated on aboral inner surface of lateral arm plate; 17, tubercle situated on adoral outer surface of lateral arm plate.

Plate 3. *Ophiozonella longispina* (CLARK, 1908) from the Hijikata Formation. Fig. A. Dense occurrence of fossil *Ophiozonella longispina* in fine sandstone matrix. Figs. B–E. Dorsal view. Fig. F. Ventral view. Abbreviation: 1, external view of radial shield; 1′, internal view of radial shield; 2, dorsal arm plate; 3, dorsal view of vertebral ossicle; 4, arm spine; 5, oral frame; 6, disk scale; 7, lateral arm plate; 8, genital plate; 9, dorsal view of first vertebral ossicle; 10, disk edge; 11, tentacle pore; 12, ventral arm plate.

Plate 4. *Ophiozonella longispina* (CLARK, 1908). Figs. A–E. Fossil specimens from the Hijikata Formation. Figs. F, G. Living specimen. Figs. A–E, G. Ventral view. Figs. C, D. Jaw apparatus. Fig. F. Dorsal view. Abbreviation: 1, lateral arm plate; 2, tentacle pore; 3, ventral arm plate; 4, oral plate; 5, aboral plate; 6, oral shield; 7, first vertebral ossicle; 8, oral frame; 9, genital plate; 10, arm spine; 11, disk scale; 12, oral papillae; 13, tooth; 14, ventral view of vertebral ossicle; 15, first ventral arm plate.

Plate 5. *Ophiochiton fastigatus* LYMAN, 1878. Figs. A–E. Ventral view of fossil specimen from the Hijikata Formation. Figs. F, G. Living specimens. Fig. A. Whole view. Figs. B, C. Arm. Fig. D. Jaw. Fig. E. Disk margin. Fig. F. External view of lateral arm plate by SEM. Fig. G. Ventral view of whole specimen. Abbreviation: 1, disk; 2, ventral arm plate; 3, arm spine; 4, vertebral ossicle; 5, tentacle pore; 6, lateral arm plate; 7, oral frame; 8, oral tentacle pore; 9, disk scale; 10, marginal disk scale; 11, socket of arm spine.

Plate 6. *Ophiophthalmus* sp. cf. *O. hylacanthus* (CLARK, 1911) from the Hijikata Formation and living species *O. hylacanthus.* Figs. A–E. Fossil specimens. Fig. A. Whole view of two specimens. Fig. B. Inner mould of several arms. Fig. C. Inner mould of dorsal side of disk and arms. Fig. D. Disk edge and basal arm (enlarged Fig. C). Fig. E. Arm segments and arm spines (enlarged Fig. D). Fig. F. Dorsal view of living specimen. Abbreviation: 1, disk; 2, arm spine; 3, jaw; 4, socket of arm spine; 5, disk spine.

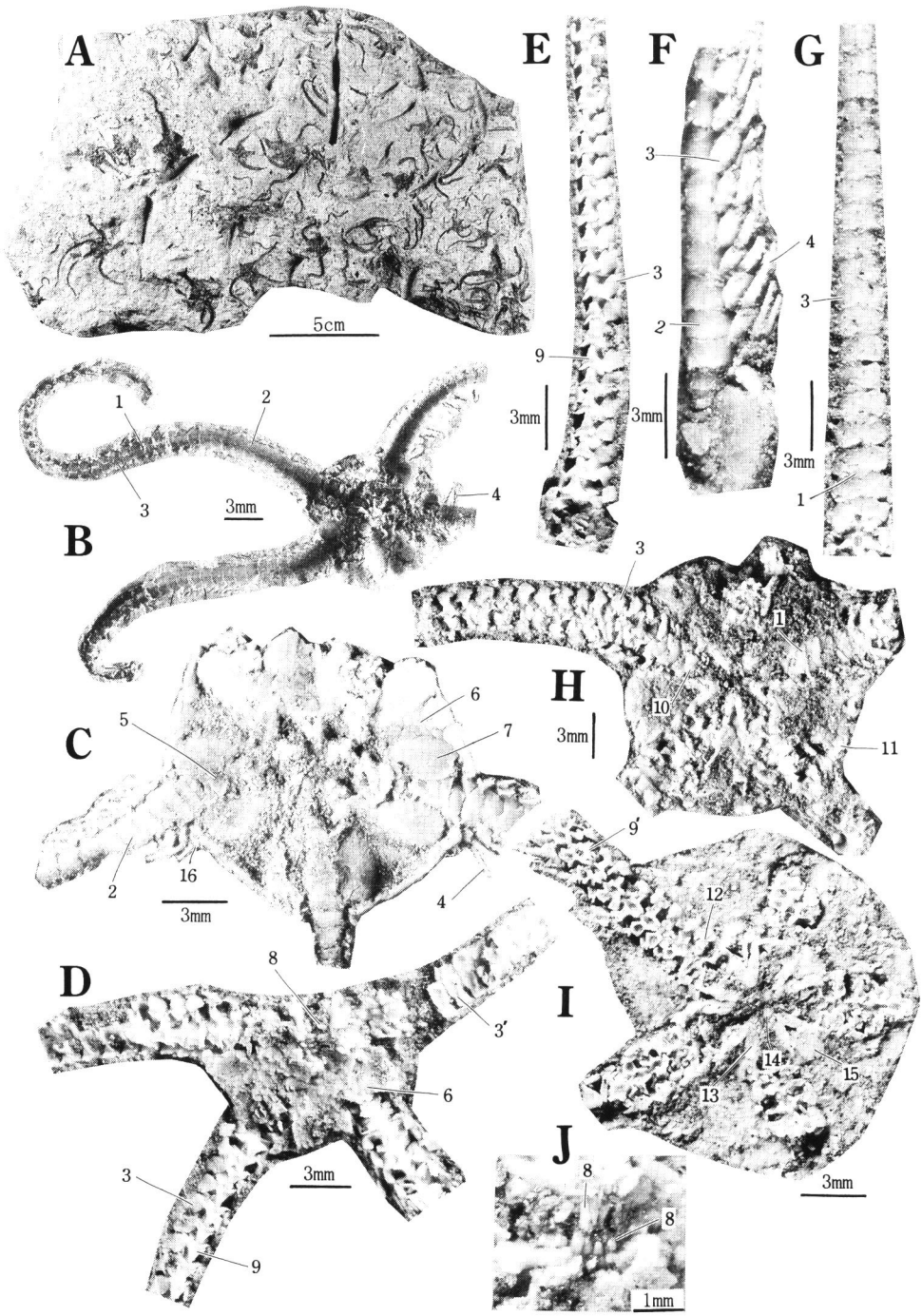
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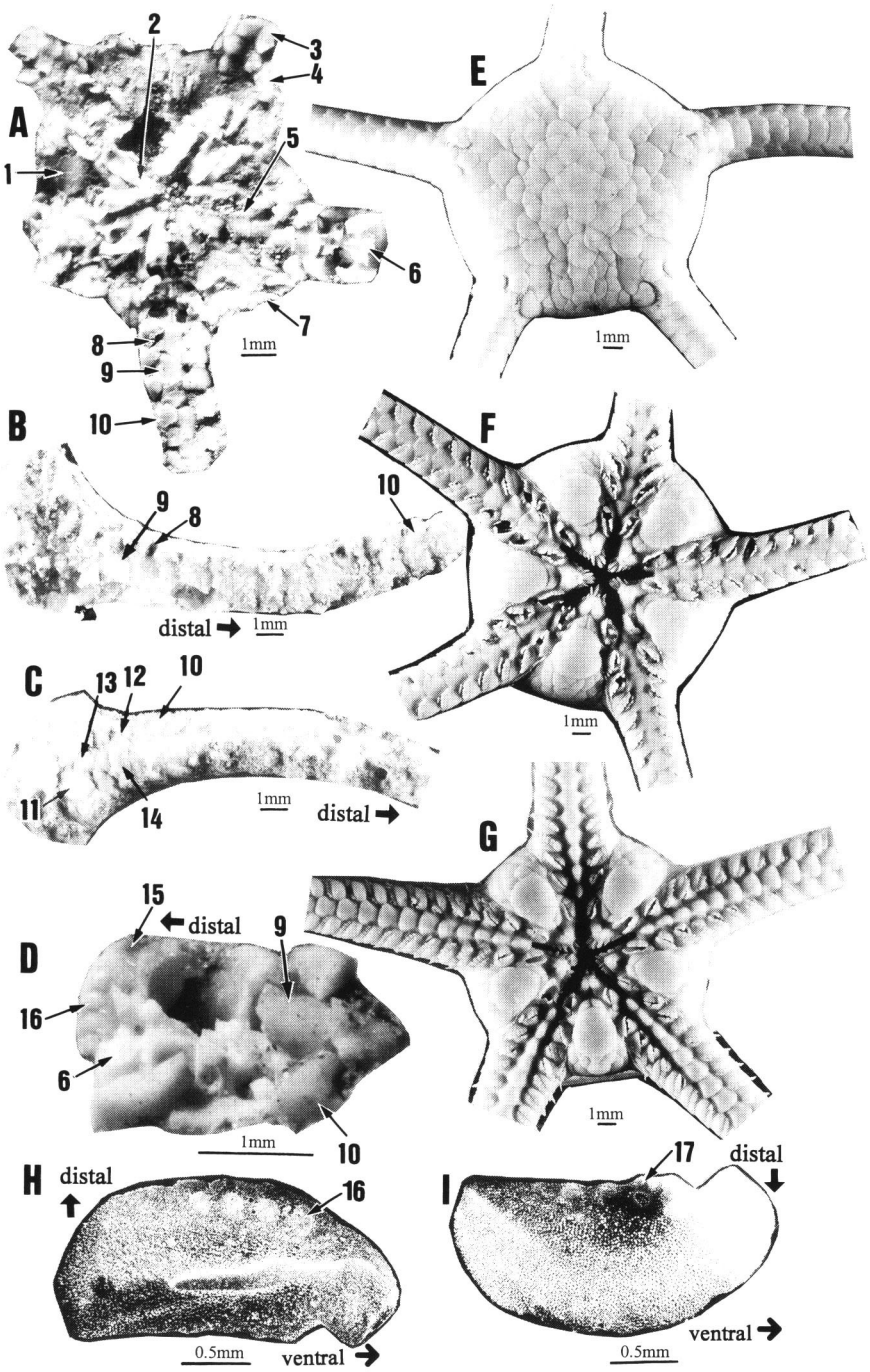
Plate 1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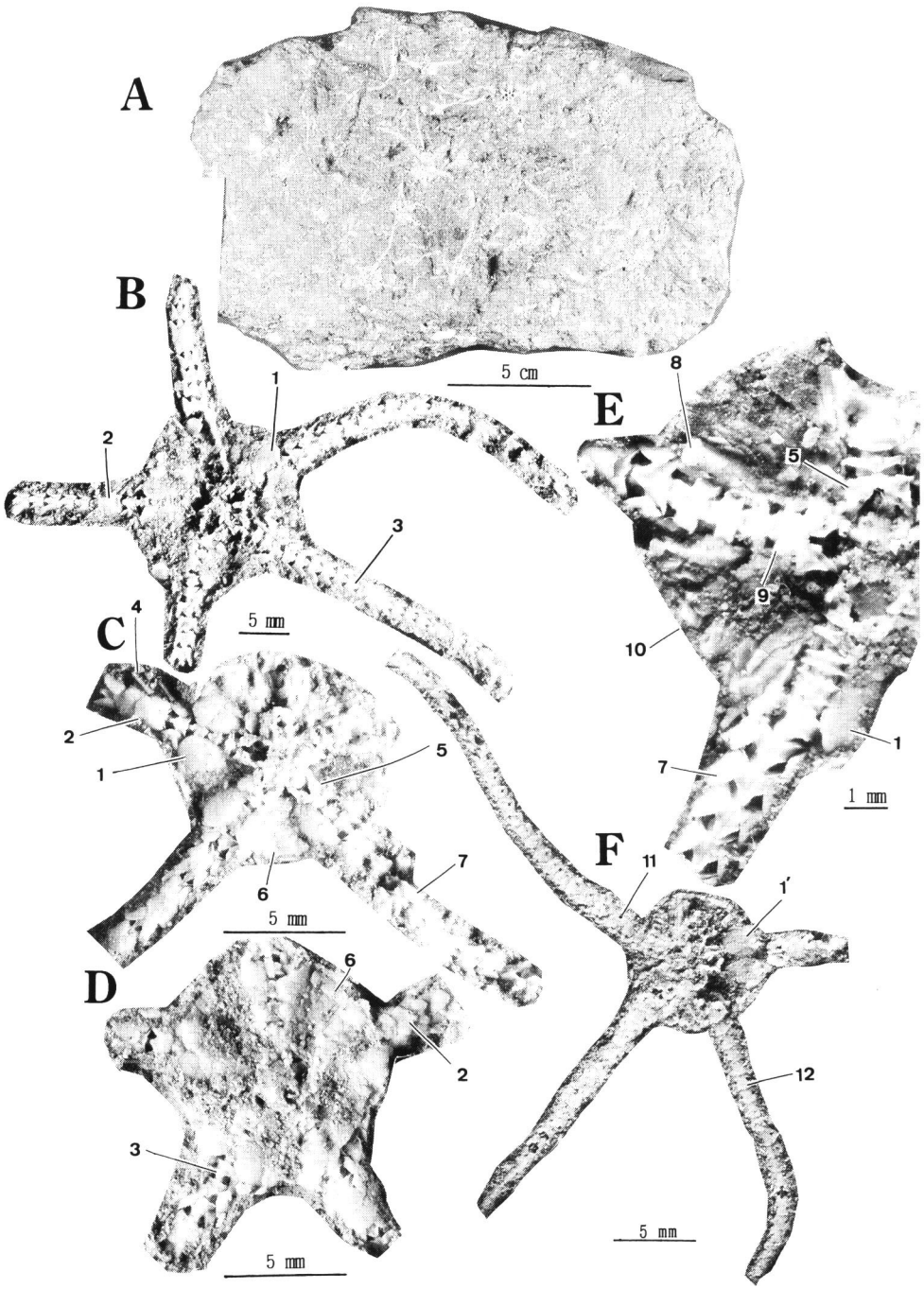

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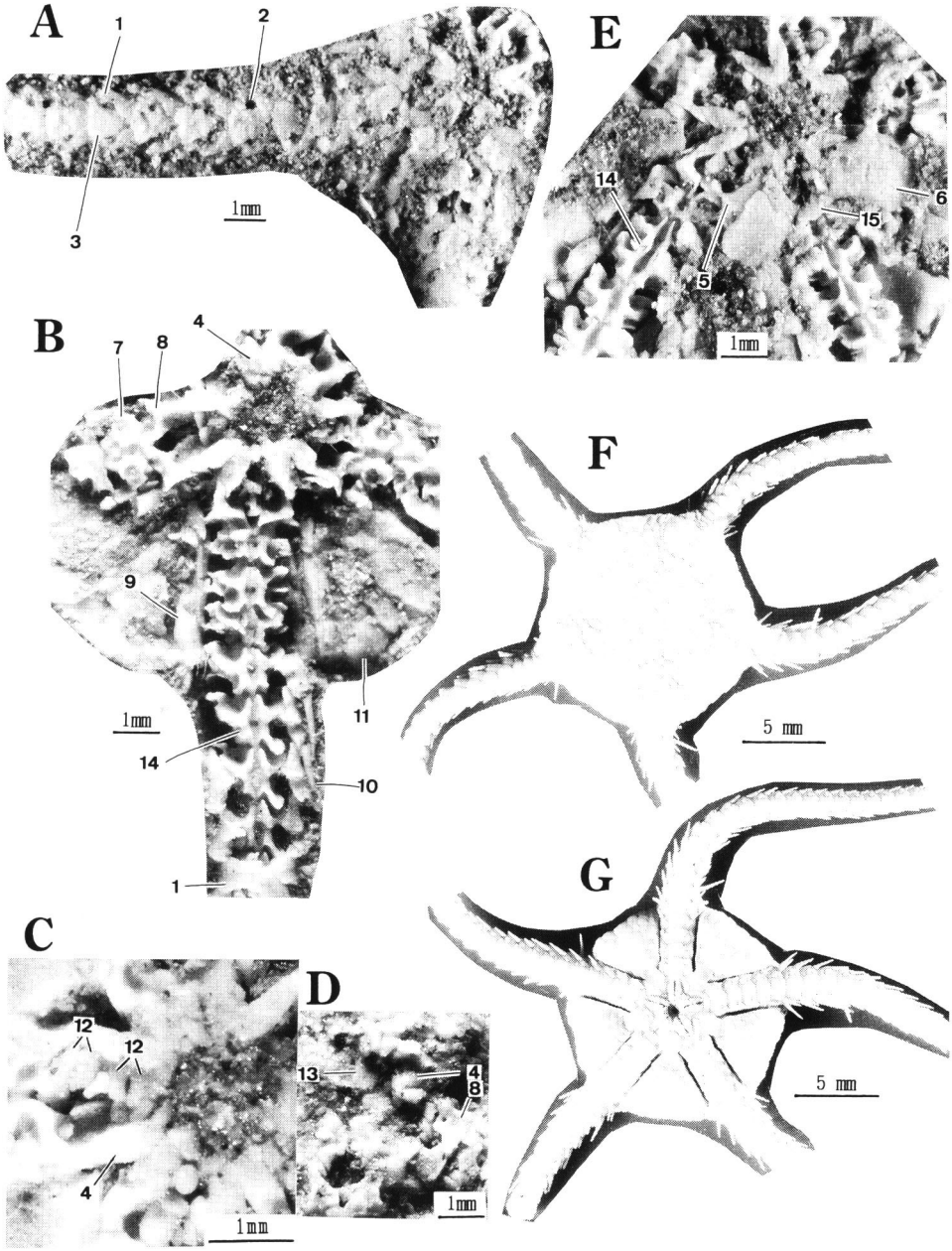
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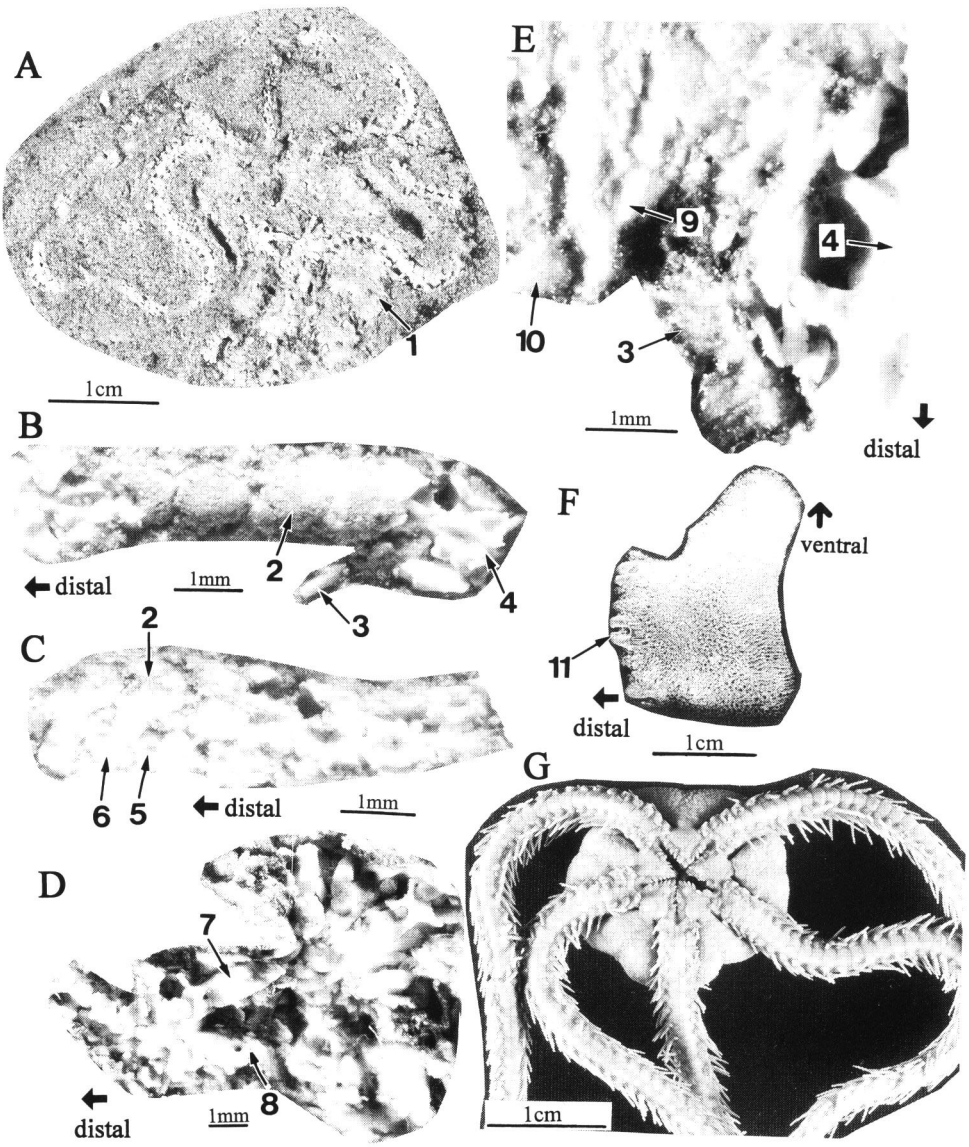
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Plate 5

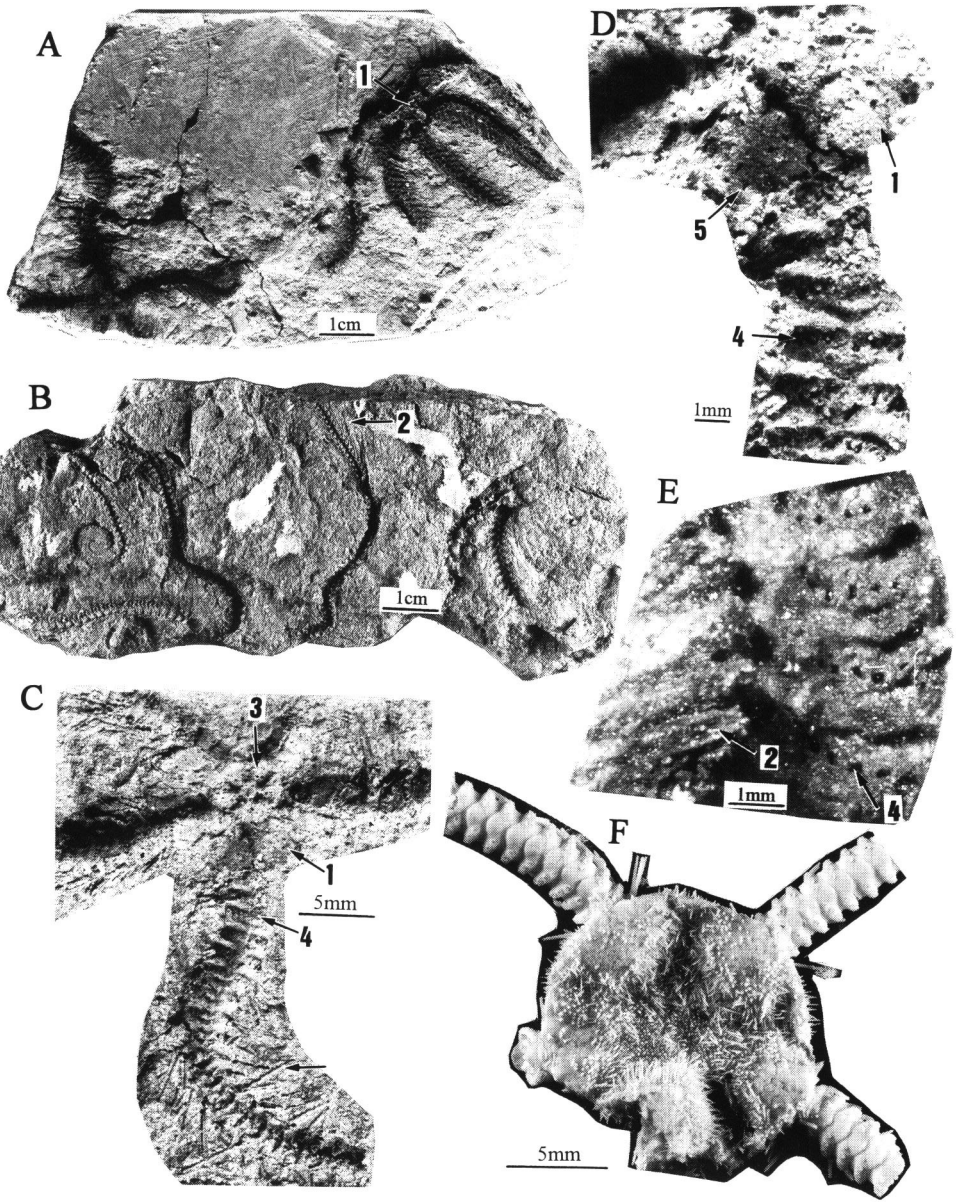

Plate 6