

Selected Echinoid Fossils from the Miyako Group (Lower Cretaceous), Northeast Honshu, Japan

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Introduction

The Lower Cretaceous Miyako Group exposed along the Pacific coast of northeast Honshu (Text-fig. 1) is very famous for its abundant occurrence of well-preserved marine invertebrate fossils of various taxa. Therefore, these fossils have been intensively studied by specialists of respective fields. On the basis of ammonite zonation, among others, the Miyako Group serves as a standard formation for the Aptian to Albian biostratigraphy of Japan (OBATA and MATSUMOTO, 1977).

Some echinoid species were reported by YABE and YEHARA (1913) from the “*Orbitolina* Sandstone”, the upper part of the Miyako Group, without paleontological descriptions. Later, NISIYAMA (1950) described the following four species from the above sandstone: *Pseudocidaris simulans*, *Goniopygus atavus*, *Holectypus* (*Coenholectypus*) *peridoneus*, and *Holaster clypeatulus*. Actually, echinoid fossils have been known to occur commonly at various horizons within the Cretaceous sequence, though they are subordinate constituents among the Miyako fauna. All the echinoid specimens for this study were collected by the present authors, but their specific identification was made by the senior author. Consequently, some of them were identified with or referred to species described by NISIYAMA (1950), but many were assigned to other five species, of which three are new.

The repositories of the specimens described here are the Geological Survey of Japan, Tsukuba (GSJ) and the National Science Museum, Tokyo (NSM).

Before going further, we express our sincere gratitude to Professor Tetsuro HANAI of the Geological Institute, University of Tokyo for his courtesy in carrying out the junior author's field survey, and to Dr. Teruya UYENO of the National Science Museum, Tokyo for reading the manuscript. We are also indebted to Mr. Yoshio MASAI of the Geological Survey of Japan for photographing the specimens.

Biostratigraphic Consideration on the Fossil Localities based on Ammonites

The details of the stratigraphy of the Miyako Group were published by YABE and YEHARA (1913), HANAI, OBATA, and HAYAMI (1968), SHIMAZU, TANAKA, and YOSHIDA (1970), and TANAKA (1978). The Miyako Group consists of about 200 m of littoral to neritic deposits which are rich in conglomerate and calcareous sandstone. It contains calcareous algae, *Orbitolina*, corals, bivalves, gastropods, ammonoids, belemnoids, and echinoids in abundance. This group is correlated with the Upper Aptian to the Lower Albian for its main part.

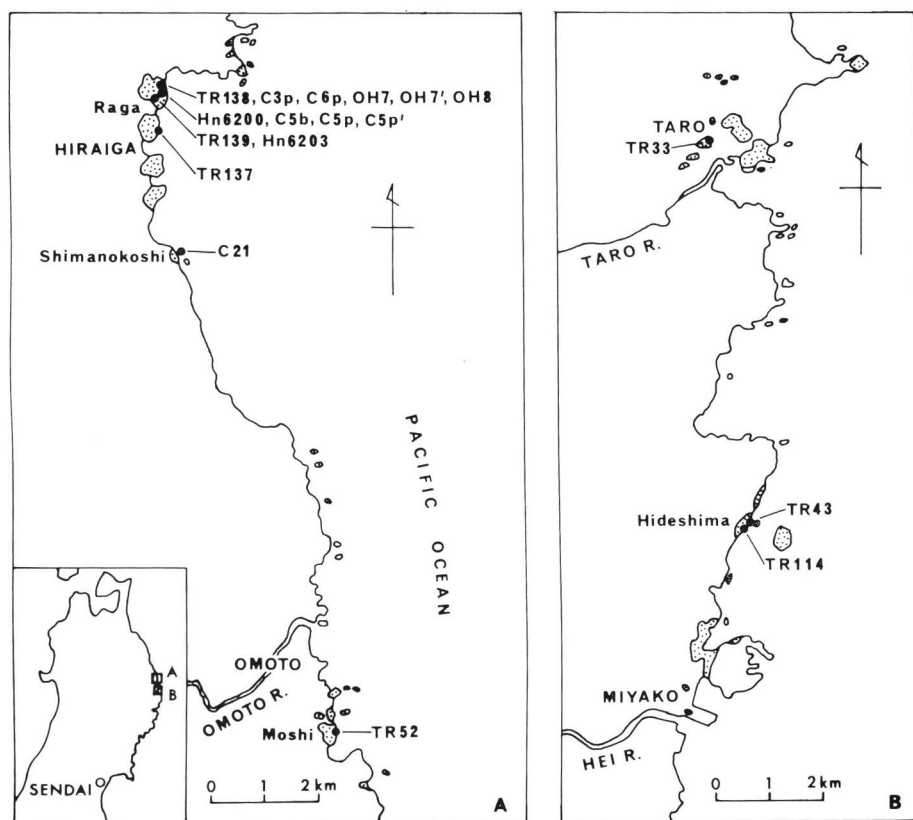
At Raga and Hiraiga, the Miyako Group is the most typically developed and divided into the Raga, Tanohata, Hiraiga, and Aketo Formations in ascending order (YABE and YEHARA, 1913; HANAI, OBATA, and HAYAMI, 1968). The major constituent of the Hiraiga Formation is a calcareous sandstone facies in which a lateral change into coquinal deposits called "*Orbitolina* Sandstone" is noted. The Hiraiga comprises two cycles of upward-fining grain size which are here termed the Lower and Upper Members. At Moshi, Taro, and Hideshima, only a part corresponding to the Lower Member of the Hiraiga Formation at the type locality is dealt with as the Hiraiga Formation and the sequence corresponding to the Upper Member is separately referred to as the Sakiyama Formation (SHIMAZU, TANAKA, and YOSHIDA, 1970; TANAKA, 1978).

The localities of the echinoid specimens available are from north to south as shown in Text-fig. 1, TANAKA's localities being indicated by prefix TR, OBATA's ones by C and OH, and HANAI's ones by Hn.

Locs. TR138 ($\div$ C3p, C6p, OH7, OH7', OH8): road-cut north of Raga, Tanohata-mura, Shimohei-gun, Iwate Prefecture; Aketo Formation (*Douvilleiceras mammillatum* Zone), upper Lower Albian; massive medium- to fine-grained sandstone, either calcareous or muddy, partly abounding in fossils; echinoids common, *Epiaster miyakoanus* TANAKA, sp. nov. sporadic in muddy medium- to fine-grained sandstone or muddy fine-grained sandstone, *Coenholectypus peridoneus* common in muddy medium- to fine-grained sandstone and in fine-grained sandstone; associated fossils dominated by bivalves (trigoniids and *Goniomya* common).

Locs. Hn6200, C5b, C5p, and C5p': road-cut north of Raga; Aketo Formation (*Douvilleiceras mammillatum* Zone), upper Lower Albian; massive medium- to fine-grained sandstone, either calcareous or muddy; echinoids common, *Coenholectypus peridoneus* common in muddy medium- to fine-grained sandstone.

Locs. TR139 and Hn6203: road-cut north of Raga; Upper Member of the Hiraiga Formation (*Douvilleiceras mammillatum* Zone), upper Lower Albian; medium- to fine-grained sandstone, either calcareous or muddy, with frequent sandy siltstone interbeds; fossils other than *Orbitolina* and echinoids not common; echinoids abundant, *Epiaster miyakoanus* TANAKA, sp. nov. abundant in sandy siltstone and also common in muddy fine-grained sandstone and muddy medium- to fine-grained sandstone, *Holaster* sp. aff. *H. laevis* (BRONGNIART) rare in muddy medium- to fine-grained sandstone, *Toxaster* sp. aff. *T. villei* (GAUTHIER) rare in muddy fine-grained sandstone.



Text-fig. 1. Localities of echinoid specimens from the Miyako Group. Outcrops are indicated by stipple pattern. Inset is a map of northeast Honshu, showing location of the study area.

At the seacliff east of this locality is IGPS loc. no. It-5 in NISIYAMA (1950) that is the type locality of *Holaster clypeatus*.

Locs. TR137: seacliff north of Hiraiga, Tanohata-mura; Upper Member of the Hiraiga Formation (*Douvilleiceras mammillatum* Zone), upper Lower Albian; *Orbitolina*-bearing coarse-grained sandstone with frequent sandy siltstone interbeds abounding in bivalves; echinoid rare, *Holaster* sp. cf. *H. clypeatus* in fine-grained sandstone; associated fossils dominated by bivalves (trigoniids and *Goniomya* abundant). Nearly the same as this locality is IGPS loc. no. It-4 in NISIYAMA (1950), where the respective holotypes of *Pseudocidaris simulans*, *Goniopygus atavus*, and *Coenholectypus peridoneus* were collected.

Loc. C21: block dredged from the sea bottom of the fishing port of Shimanokoshi, Tanohata-mura; derived from the upper part of the Tanohata Formation containing *Parahoplites* sp. aff. *P. vectensis* CASEY, middle (?) Upper Aptian; muddy fine-grained sandstone to sandy siltstone; echinoids rare, *Epiaster miyakoanus* TANAKA, sp. nov. in

muddy fine-grained sandstone to sandy siltstone.

Loc. TR52: coast of Moshi, Iwaizumi-cho, Shimohei-gun; lower part of the Tano-hata Formation, probably middle Upper Aptian; alternating coarse-grained sandstone and conglomerate, rich in fossil fragments; echinoid spine rare in shelly calcareous coarse-grained sandstone.

Loc. TR33: Taro, Taro-cho, Shimohei-gun; upper equivalent of the Lower Member of the Hiraiga Formation; massive, partly laminated, fine sandy siltstone with some fine-grained sandstone interbeds, containing a number of molluscan fossils; echinoid rare, *Epiaster miyakoanus* TANAKA, sp. nov. in fine sandy siltstone. Near loc. TR33 *Valdedorsella* sp. cf. *V. getulina* (COQUAND) probably indicating latest Aptian to early Albian was obtained.

Loc. TR114: coast of Hideshima, Miyako City, Iwate Prefecture; upper equivalent of the Lower Member of the Hiraiga Formation (*Diadochoceras nodosocostati-forme* Zone), upper Upper Aptian; siltstone with numerous calcareous concretions, abounding in fossils; echinoids abundant, *Epiaster zonarius* TANAKA, sp. nov. abundant in siltstone; associated fossils dominated by bivalves, with common ammonites.

Loc. TR43: coast of Hideshima; lower equivalent of the Lower Member of the Hiraiga Formation; muddy fine-grained sandstone with some shell beds; echinoids uncommon, *Coenholectypus hideshimensis* TANAKA, sp. nov. rare in muddy medium-to fine-grained sandstone; echinoid spines sporadic in shelly coarse- to fine-grained sandstone; associated fossils dominated by bivalves and crinoid stems. Near loc. TR43 the holotype of *Hypacanthoplites subcornuerianus* (SHIMIZU) indicating late Late Aptian was found.

Systematic Descriptions

Subclass EUECHINOIDEA BRONN, 1860

Superorder GNATHOSTOMATA ZITTEL, 1879

Order HOLECTYPOIDA DUNCAN, 1889

Suborder Holectypina DUNCAN, 1889

Family Holectypidae LAMBERT, 1899

Genus *Coenholectypus* POMEL, 1883

Coenholectypus peridoneus (NISIYAMA)

Pl. 1, figs. 1a–b, 2a–b; Text-fig. 2a

Holectypus (*Coenholectypus*) *peridoneus* NISIYAMA, 1950, *Inst. Geol. Palaeont. Tohoku Univ., Short Papers*, no. 2, p. 32, pl. 4, figs. 5–7.

Caenholectypus peridoneus, NISIYAMA, 1966, *Palaeont. Soc. Japan, Special Papers*, no. 11, p. 274.

Material. Nine specimens, GSJ-F6176–1, 2 from loc. TR138, Aketo Formation, upper Lower Albian (Coll. TANAKA), NSM-PA12124a from loc. C3p, NSM-PA12125a from loc. OH8, and NSM-PA12127 from loc. C6p, Aketo Formation, upper Lower Albian (Coll. OBATA), and NSM-PA12126a from loc. C5b, and NSM-PA12161 from loc. C5p, Aketo Formation, upper Lower Albian (Coll. OBATA), represented by

an external cast respectively, are available for this study. Two comparable specimens, NSM-PA 12124b from loc. C5p' and NSM-PA 12126b from loc. C5b (Coll. OBATA) were also examined.

Diagnosis. Test small to medium-sized, subpentagonal to circular in outline, subconical to dome-shaped. Aboral surface inflated; oral surface flattish, concave around the peristome; margin rather narrowly rounded. Apical system central, small, having five gonopores; madreporite large.

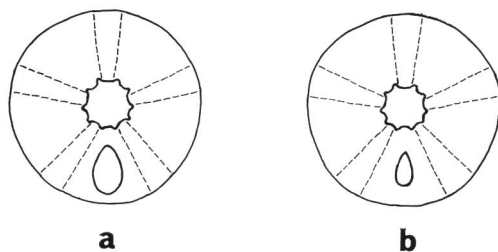
Ambulacra straight, narrow, about one-third as wide as the interambulacra; poriferous zones very narrow, straight, continuous; pore pairs in a single series, oblique; ambulacral plates simple on the aboral surface, in groups of three on the oral surface; a primary tubercle on every third plate. Interambulacra broad; interambulacral plates rather low, as high as one-sixth to one-tenth the width above the ambitus.

Peristome central, depressed, rather small, about one-sixth the length of the test; gill slits deep, wide. Periproct large, elongate-pyriform in outline, much longer than the diameter of the peristome, about one-fourth the length of the test, closer to the posterior margin than to the peristome. Tuberculation rather close; tubercles small and perforate on the aboral surface, and larger, perforate, crenulate, and scrobiculate on the oral surface.

Measurements. Most of the specimens available are secondarily deformed. The least depressed specimen, GSJ-F6176-1, is 25.0 mm long, 23.6 mm wide, and 14.0 mm high. The largest of the other specimens, though secondarily somewhat depressed, measures about 37.5 mm long.

Remarks. The original specific diagnosis (NISIYAMA, 1950) is mostly available, but some remarks are given in the lines to follow, on the basis of observations of the material available. Most of the specimens together with the holotype designated by NISIYAMA (1950) are to varying degrees deformed by the subsequent disfigurement. The more depressed specimens have a test of height/length ratio of 0.33 to 0.40 and of rounded horizontal outline (see Pl. 1, fig. 2a-b). In the less depressed specimens, on the other hand, the test shows a higher ratio of 0.41 to 0.50 and a rather rounded subpentagonal outline. The rocks containing all the depressed specimens mentioned above are muddy medium- to fine-grained or muddy fine-grained sandstone. The specimens that are not or hardly depressed have a higher, subconical test of height/length ratio of 0.50 to 0.56, which is subpentagonal in ambital outline (see Pl. 1, fig. 1a-b; the figured specimen is transversely somewhat compressed). They were obtained from compact, calcareous, fine-grained sandstone. To sum up, the above difference in shape and height of the test may have been caused by the secondary deformation, the degree of which was affected by the features of the rocks containing the specimens, combined with the original intraspecific variation.

The apical system has five gonopores, but its detailed structure as indicated in the original specific diagnosis is not known in the material available because of the poor preservation. The interambulacra possess 25 or a little more plates in each column, and below the ambitus each ambulacral plate has two large tubercles, each inter-



Text-fig. 2. Diagrammatic figures of the oral surface of the two species of *Coenholectypus* from the Miyako Group.

- a. *Coenholectypus peridoneus* (NISIYAMA), from loc. C5p, Aketo Formation. $\times$ ca. 1.1 (NSM-PA12161).
- b. *Coenholectypus hideshowensis* TANAKA, sp. nov., from loc. TR43, lower equivalent of the Lower Member of the Hiraiga Formation. $\times$ ca. 1.8 (Holotype, GSJ-F6165).

ambulacral plate having a row of eight or nine large tubercles.

Comparison. This species distinctly differs from *Coenholectypus hideshowensis* TANAKA, sp. nov. to be described below, especially in that the periproct is larger and nearer the posterior margin, the oral surface is less concave around the peristome, and in that the miliary tubercles on the aboral surface show no appreciable serial arrangement. *Coenholectypus peridoneus* (NISIYAMA) is fairly close to *C. neocomiensis* (A. GRAS) (COTTEAU, 1861, p. 49, pl. 1015, figs. 5–10) from the Aptian of France, but has a periproct which is farther from the posterior margin and a greater number of coronal plates in each column. Moreover, *Coenholectypus neocomiensis* shows more or less serial arrangement of miliary tubercles on the aboral surface, as seen in COTTEAU's figures (1861, pl. 1015, figs. 8–10). The present species also resembles *Coenholectypus planatus* (ROEMER) (COOKE, 1955, p. 94, pl. 21, figs. 1–3) from the Lower and Middle Albian of Texas, but is clearly distinguished from that species by its narrower ambulacra, smaller peristome, and a smaller number of coronal plates in each column.

Occurrence. Loc. TR138 ($\div$ C3p, C6p, OH8), common; locs. C5b, C5p, and C5p', common; upper Lower Albian.

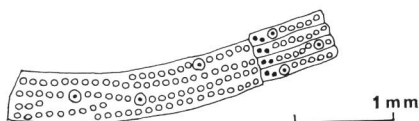
Coenholectypus hideshowensis TANAKA, sp. nov.

Pl. 1, fig. 3a–c; Text-figs. 2b, 3

Material. Holotype, GSJ-F6165 (NSM-PA 12156 for the plastotype), represented by an external cast, from loc. TR43, coast of Hideshima, Miyako City, Iwate Prefecture, lower equivalent of the Lower Member of the Hiraiga Formation, probably upper Upper Aptian (Coll. TANAKA).

Diagnosis. Test small, subpentagonal in outline, dome-shaped. Aboral surface evenly and smoothly convex; oral surface considerably concave around the peristome; margin broadly rounded. Apical system central, small, with five gonopores.

Ambulacra straight, narrow, about one-third as wide as the interambulacra;



Text-fig. 3. Ambulacral and interambulacral plates of *Coenholectypus hideshowensis* TANAKA, sp. nov., from loc. TR43, lower equivalent of the Lower Member of the Hiraiga Formation (Holotype, GSJ-F6165).

poriferous zones very narrow, straight, continuous; pore pairs uniserial, oblique; ambulacral plates simple on the aboral surface, in groups of three on the oral surface; a primary tubercle on every third plate. Interambulacra broad; interambulacral plates nearly as high as one-fifth the width above the ambitus.

Peristome central, depressed, rather small, about one-sixth the length of the test; gill slits deep, wide. Periproct rather small, elongate-pyriform in outline, pointed at the inner end, about as long as the diameter of the peristome, midway between the peristome and the posterior margin. Tubercles small and perforate on the aboral surface, and much larger, perforate, and scrobiculate on the oral surface; on the aboral surface miliary tubercles arranged in more or less regular horizontal series.

Measurements. Length 14.7 mm; width 14.3 mm; height 7.3 mm.

Remarks. The interambulacra have about 22 plates in each column. Below the ambitus, each ambulacral plate possesses two large tubercles and each interambulacral plate a row of four large tubercles. It is one of the prominent features of this new species that on the aboral surface the miliary tubercles are arranged in more or less regular horizontal series in such a manner as illustrated by MORTENSEN (1948, p. 28, text-fig. 12a).

Comparison. This new species is distinctly separated from *Coenholectypus peridoneus* (NISIYAMA), described above, by its much smaller periproct which is farther from the posterior margin and its oral surface which is more concave around the peristome. The former species has a much smaller test than does the latter. The tuberculation on the aboral surface is also different between the two species; in *Coenholectypus hideshowensis* sp. nov. the miliary tubercles are arranged in more or less regular horizontal series, whereas in *C. peridoneus* they are irregularly or more widely disseminated so that they do show no appreciable serial arrangement. Moreover, the tubercles on the oral surface are much larger than those on the aboral surface in the new species, whereas in *Coenholectypus peridoneus* they are somewhat larger. The present species closely resembles *Coenholectypus neocomiensis* (A. GRAS) (COTTEAU, 1861, p. 49, pl. 1015, figs. 5–10) from the Aptian of France, in the outline of test, the number of coronal plates in each column, the width of ambulacra, and in the mode of arrangement of miliary tubercles on the aboral surface. But it is distinguished from that species by its smaller size of the test and much smaller periproct which is much farther from the posterior margin. The species described here is also akin to *Coenholectypus planatus* (ROEMER) (COOKE, 1955, p. 94, pl. 21, figs. 1–3) from the Lower and Middle Albian of

Texas, but has narrower ambulacra, a smaller peristome, and a smaller periproct which is farther from the posterior margin. *Coenholectypus hideshowensis* is also similar to *C. transpecoensis* (CRAGIN) (COOKE, 1955, p. 95, pl. 21, figs. 4–6) from the Upper Albian of Texas, but the test is much smaller and the peristome has more distinct gill slits.

Occurrence. Loc. TR43, rare; probably upper Upper Albian.

Superorder ATELOSTOMATA ZITTEL, 1879
Order HOLASTEROIDA DURHAM and MELVILLE, 1957
Family Holasteridae PICTET, 1857
Genus *Holaster* AGASSIZ, 1836

Holaster sp. cf. *H. clypeatulus* NISIYAMA

Pl. 1, fig. 4

Compare.

Holaster clypeatulus NISIYAMA, 1950, *Inst. Geol. Palaeont. Tohoku Univ., Short Papers*, no. 2, p. 35, pl. 4, figs. 8–9, text-figs. 1–3.

Holaster clypeatulus, NISIYAMA, 1968, *Palaeont. Soc. Japan, Special Papers*, no. 13, p. 150.

Remarks. Only a specimen, GSJ-F6061 (NSM-PA12157 for the plaster cast) (Coll. TANAKA), represented by an external cast, is available for this study. The present form, though poorly preserved, is probably identifiable with *Holaster clypeatulus* in the general features of the test. The specimen, though secondarily deformed, roughly measures a little more than 30 mm long.

Occurrence. Loc. TR137, rare; upper Lower Albian.

Holaster sp. aff. *H. laevis* (BRONGNIART)

Pl. 1, figs. 5a–b, 6a–e; Text-fig. 4

Compare.

Holaster laevis, D'ORBIGNY, 1853, *Paléont. Franç., Terr. Crét., Échin.*, vol. 6, p. 83, pl. 812.

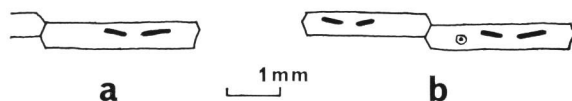
Holaster laevis, DESOR, 1858, *Synopsis*, p. 339.

Holaster laevis, DE LORIO, 1873, *Matér. Paléont. Suisse*, ser. 6, p. 319, pl. 27, figs. 1–5.

Holaster laevis, WRIGHT, 1881, *Palaeontogr. Soc. London*, p. 310, pl. 72, fig. 1.

Material. GSJ-F6057 (NSM-PA 12158 for the plaster cast), and GSJ-F6058, both represented by an external cast (test partly stripped off), from loc. TR139, Upper Member of the Hiraiga Formation, upper Lower Albian (Coll. TANAKA).

Description. Test medium-sized, ovate in outline, somewhat heart-shaped, slightly emarginate in front, slightly contracted behind, somewhat longer than wide, widest near the middle of the posterior lateral interambulacra, relatively high; frontal sinus shallow, broad, disappearing near the apical system, expanding distinctly toward the ambitus with more or less distinct keellike elevations on both sides, extending to the peristome as a shallow groove on the oral surface; anterior notch wide, shallow. Aboral surface inflated with nearly vertical sides, highest at or slightly behind the apical system, sloping more gently forward than backward then sloping abruptly in front, rather



Text-fig. 4. *Holaster* sp. aff. *H. laevis* (BRONGNIART), from loc. TR139, Upper Member of the Hiraiga Formation (GSJ-F6058). a, Right anterior paired ambulacra. b, Right posterior paired ambulacra.

abruptly truncated behind, with a prominent median carina extending posteriorly in the posterior interambulacral area and terminating above the periproct; posterior truncated surface slightly concave; posterior margin very shallowly emarginate; oral surface raised on the plastronal area, depressed around the peristome; margin acutely rounded. Apical system fairly anterior, compact, elongate, with four gonopores.

Frontal ambulacrum short, rather narrow, shallowly sunken, nonpetaloid; poriferous zones much narrower than half the width of the interporiferous zones; pores similar, small, round to oval, close together. Paired ambulacra rather long, wider than the frontal ambulacrum, widely open distally, superficial, subpetaloid, somewhat distant from each other at the apical system; anterior ambulacra shorter, somewhat wider, more divergent than the posterior ambulacra; poriferous zones diverging, much narrower than the interporiferous zones; anterior zones narrower than the posterior zones which are much narrower than the interporiferous zones. Pores of the anterior and posterior paired ambulacra of slit shape, longer in the posterior poriferous zones than in the anterior, somewhat longer in the outer row than in the inner row in each poriferous zone; pores of each pair slightly in circumflex, rather widely set, not conjugate.

Peristome anterior, transversely oblong, rather shallow. Plastron meridosternous. Periproct oval, vertically elongate, pointed above, high up on the posterior truncated surface, partly visible from above. Tubercles small, perforate, crenulate, larger on the oral surface than on the aboral, rather closely spaced on the plastron and near the ambitus, homogeneously and widely scattered elsewhere; interporiferous zones dotted with tubercles; numerous granules between tubercles. No fasciole.

Measurements. The specimens available are secondarily deformed, and the original size of the test is difficult to estimate. Nevertheless, they roughly measure about 46 mm long and about 27 mm high.

Remarks. The specimens available are characterized by, among other features, that the pores of the paired ambulacra are transversely elongate, especially the outer pores of the posterior poriferous zones being of long slit shape. This feature is unusual for *Holaster* and recalls *Pseudholaster*. However, in the present form the frontal sinus is shallow with a slight anterior notch, whereas in *Pseudholaster* it is deep with a distinct anterior notch. The above feature makes it impossible to identify the specimens described here with *Pseudholaster*. Anyhow, we had better refer the present form to *Holaster* on the basis of the general features of the test.

Comparison. The present specimens are easily distinguishable from *Holaster*

clypeatulus NISIYAMA (1950, p. 35, pl. 4, figs. 8–9, text-figs. 1–3) from the Upper Member of the Hiraiga Formation of the Miyako Group by the higher, more strongly inflated test and the more anterior position of the apical system. Moreover, they differ from that species in having a shorter, broader frontal sinus and a more distinct carina in the posterior interambulacral area.

The present form more closely resembles *Holaster laevis* (BRONGNIART) from the Albien of France and Switzerland than many other hitherto described foreign species of the genus in the general features of the test. But it differs from that species in that the median carina in the posterior interambulacral area is more distinct, the paired ambulacra have wider poriferous zones and more elongated pores (especially outer pores of the posterior poriferous zones being of long slit shape), and the periproct is placed higher up on a larger posterior truncated surface. Thus, the present form probably represents a new species of *Holaster* which is allied to but distinct from *H. laevis*. We refrain, however, from the establishment of a new species until more and better material is obtained.

Occurrence. Loc. TR139, rare; upper Lower Albien.

Order SPATANGOIDA CLAUS, 1876

Suborder Toxasterina FISCHER, 1966

Family Toxasteridae LAMBERT, 1920

Genus *Toxaster* L. AGASSIZ, 1840

Toxaster sp. aff. *T. villei* (GAUTHIER)

Pl. 1, figs. 7a–c; Text-fig. 5

Compare.

Echinospatagus villei, COTTEAU, PERON, and GAUTHIER, 1884, *Échinides fossiles de l'Algérie*, vol. 1, pt. 2, p. 71.

Toxaster villei, LAMBERT, 1931, *Mém. Soc. Géol. France* (Nouv. série), vol. 7, pt. 2, mém. no. 16, p. 41, pl. 2, figs. 6, 25.

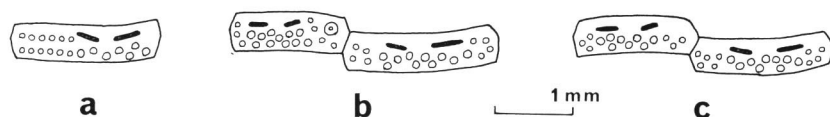
Toxaster villei, LAMBERT, 1938, *Bull. Soc. Géol. France*, ser. 5, vol. 8, p. 273, pl. 19, figs. 6–8.

Toxaster villei, DEVRIÈS, 1954, *Publ. Sér. Carte Géol. Algérie* (Nouv. série), bull. no. 5, p. 127, pls. 1–2.

Toxaster villei, DEVRIÈS, 1960, *Publ. Sér. Carte Géol. Algérie* (Nouv. série), mém. no. 3, p. 20, pl. 4, figs. 18–25.

Material. GSJ-F6140 (NSM-PA12159 for the plaster cast) and GSJ-F6177, both represented by an external cast, from loc. TR139, Upper Member of the Hiraiga Formation, upper Lower Albien (Coll. TANAKA).

Description. Test medium-sized, ovate in outline, somewhat heart-shaped, slightly emarginate in front, longer than wide, widest somewhat in front of the midpoint, more or less contracted behind, relatively low; frontal sinus rather narrow, shallow, not sharply limited, widening toward the ambitus, extending to the peristome; anterior notch shallow. Aboral surface uniformly convex, highest somewhat behind the apical system, gradually sloping anteriorly, abruptly truncated posteriorly, with a slight



Text-fig. 5. *Toxaster* sp. aff. *T. villei* (GAUTHIER), from loc. TR139, Upper Member of the Hiraiga Formation (GSJ-F6140). a, Frontal ambulacrum. b, Right anterior paired ambulacra. c, Right posterior paired ambulacra.

carina in the posterior interambulacral area; oral surface slightly convex on the whole, depressed around the peristome. Apical system small, somewhat posterior, ethmophract, with four gonopores.

Frontal ambulacrum shallowly sunken throughout its length, longer, somewhat wider than the paired ambulacra, subpetaloid. At the middle of the petaliferous part the poriferous zones about half as wide as the interporiferous zones, with slit-shaped pores rather widely set. In the proximal part the poriferous zones much narrower than the interporiferous, consisting of smaller, oval to elongate oval pores near together. Pores of each pair more or less longer in the outer row than in the inner row, arranged in chevrons, not separated by a granule; successive pore pairs in each poriferous zone separated by a band of irregularly arranged granules. Paired ambulacra unequal in length, somewhat flexuous, slightly sunken, subpetaloid. Anterior paired ambulacra longer, much more divergent than the posterior; petaliferous parts long, open distally; poriferous zones very unequal in width, widest near the middle, tapering toward the ambitus and the apical system; anterior zones much narrower than the posterior zones which are about as wide as the interporiferous zones at the middle. Pores slit-shaped, longer in the posterior poriferous zones than in the anterior; pores of each pair somewhat longer in the outer row than in the inner row, rather widely spaced in the anterior poriferous zones, widely set in the posterior, not conjugate; outer pore transverse, inner pore somewhat oblique; successive pore pairs in each poriferous zone separated by a band of irregularly arranged granules. Posterior paired ambulacra shortest; petaliferous parts shorter than those of the anterior ambulacra, slightly closed distally; poriferous zones about equal in width, nearly as wide as the interporiferous zones. Pores slit-shaped; pores of each pair slightly longer in the outer row than in the inner, widely set, not conjugate; outer pore transverse, inner pore more or less oblique; successive pore pairs in each poriferous zone separated by a band of irregularly arranged granules.

Peristome very eccentric in front, small, shallow, subpentagonal. Plastron amphisternous. Periproct oval, vertically elongate, high up on the posterior truncated surface, visible from above. Tubercles small, perforate, crenulate, scrobiculate, closer and somewhat larger on the oral surface than on the aboral, fairly crowded on the plastron, more or less closely spaced near the ambitus, widely scattered elsewhere; interporiferous zones of the paired ambulacra dotted with smaller tubercles; numerous granules between tubercles. No fascioles.

Measurements. The better preserved one (GSJ-F6140) of the two specimens availa-

ble, though somewhat deformed by the subsequent disfigurement, measures about 43 mm long, about 33 mm wide, and about 18 mm high. Its test has a thickness of about 0.8–1.0 mm, thickening up to about 1.2 mm near the apical system.

Remarks. The two specimens are secondarily deformed. In one of the specimens (GSJ-F6140) the posterior truncated surface is overhung, as a result of the secondary deformation that the posterior part of the test is compressed backward from the front. Furthermore, it should be noticed that in the above specimen granules covering the aboral surface of the test are regularly arranged forming a broad, ill-defined band near the distal end of the paired petals, as in the case of *Toxaster villei* (GAUTHIER) and *T. radula* (GAUTHIER) which was noted by DEVRIÈS (1960). However, such a band is untraceable between the petals, and is distinctly different from the peripetalous granular band of one *Epiaster* species to be described below or from the peripetalous pseudo-fasciole of the other *Epiaster* species, which is represented by an ill-defined band densely covered with streaks of granules smaller than those covering the rest of the aboral surface.

Comparison. The present form is distinctly separated from *Toxaster sanchuensis* TANAKA (1965, p. 131, pl. 15, figs. 5–6, pl. 16, figs. 1–2, text-fig. 3) from the Upper Neocomian Ishido Formation of the Sanchu Graben, central Japan, by its somewhat posterior position of the apical system, slit-shaped pores at the middle of the petaliferous part of the frontal ambulacrum, and by its pores of the posterior poriferous zones of the anterior paired ambulacra being not acuminate inward. Moreover, in the present form granules are regularly arranged near the distal end of the paired petals; such is not the case with *Toxaster sanchuensis*.

The present specimens closely resemble *Toxaster villei* (GAUTHIER) from the Aptian and the Albian of northern Africa, especially in the general outline of the test, somewhat posteriorly placed apical system, relatively shallow frontal sinus and anterior notch, slightly depressed paired petals, of which the posterior are more or less closed distally, and in the regular arrangement of granules near the distal end of the paired petals. But they differ from that species in that the pore pairs of the frontal ambulacrum are not separated by a granule and those of the paired ambulacra are composed of transverse outer pore and oblique inner pore, pores being not acuminate inward. The present material is also to some extent similar to *Toxaster radula* (GAUTHIER) (DEVRIÈS, 1960, p. 18, pl. 4, figs. 1–2) from the Aptian and the Albian of northern Africa. However, it is clearly distinguished from that species by its posteriorly placed apical system and slit-shaped pores of the frontal ambulacrum. To sum up, this probably represents a new species of *Toxaster* which is distinctly separated from many other hitherto known species. However, I postpone proposing a new specific name until more and better specimens are obtained.

Occurrence. Loc. TR139, rare; upper Lower Albian.

Genus *Epiaster* D'ORBIGNY, 1853

Remarks. The genus *Epiaster* established by D'ORBIGNY (1853) has for long been

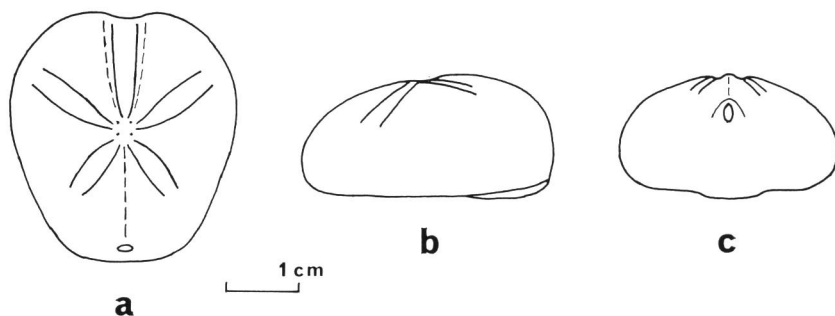
regarded as a distinct genus by various authors (e. g. DE LORIO, 1873; STOLICZKA, 1873; DUNCAN, 1889; LAMBERT and THIÉRY, 1924; ADKINS, 1928; MORTENSEN, 1950; COOKE, 1955). However, this genus was recently placed in the genus *Heteraster* as its synonym by FISCHER (in MOORE, ed., 1966), without full discussion. Nevertheless, following the traditionally adopted classification of the Echinoidea, I regard *Epiaster* as being generically distinguishable from *Heteraster*, on the basis of the following significant differences between the two genera. Actually, *Epiaster* is characterized by, among other features, the frontal ambulacrum having rounded or comma-shaped pore pairs separated by a granule, and by the paired ambulacra which are petaloid, generally depressed, and more or less closed distally, with nearly equal poriferous zones. On the other hand, in *Heteraster* the frontal ambulacrum has regularly or irregularly alternating larger and smaller pores and the anterior paired ambulacra are composed of unequal poriferous zones. In some species of *Heteraster* a broad, ill-defined granular band or pseudo-fasciole decorated with tubercles surrounds the petals (COOKE, 1955; DEVRIÈS, 1960; TANAKA, 1965; TANAKA and KOZAI, 1982). Such is the case with some *Epiaster* species (LAMBERT, 1902; COOKE, 1955; DEVRIÈS, 1960) and also with the Japanese species of the genus to be described below. However, no genuine fasciole is present in any species of the above two genera.

Epiaster miyakoanus TANAKA, sp. nov.

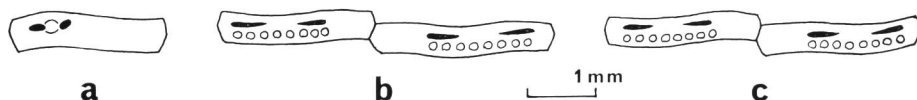
Pl. 2, figs. 1a-e, 2a-c, 3a-e, 4a-b; Text-figs. 6, 7

Material. Holotype, NSM-PA12129, represented by an external cast (test partly stripped off on the oral surface), from loc. OH7', road-cut north of Raga, Tanohata-mura, Shimohei-gun, Iwate Prefecture, Aketo Formation, upper Lower Albian (Coll. OBATA); paratypes, GSJ-F6142, represented by an external cast, from loc. TR139, road-cut north of Raga, Upper Member of the Hiraiga Formation, upper Lower Albian (Coll. TANAKA), and NSM-PA12130a, represented by an external cast, from loc. C21, Shimanokoshi, Tanohata-mura, block derived from the upper part of the Tanohata Formation, middle (?) Upper Aptian (Coll. OBATA). In addition to the holotype and paratypes, comparatively well-preserved specimens are as follows: NSM-PA12128 from loc. OH7' (Coll. OBATA); GSJ-F6137 from loc. TR138 (Coll. TANAKA); GSJ-F6141 and 6149 (Coll. TANAKA) and NSM-PA12131 (Coll. OBATA) from loc. TR139; GSJ-F6175 from loc. TR33 (Coll. TANAKA). Other numerous ill-preserved specimens from loc. TR139 (Coll. TANAKA) are available.

Diagnosis. Test medium-sized, subovate in outline, somewhat subpolygonal, longer than wide, widest at the anterior third, constricted behind, relatively low; frontal sinus rather narrow, shallow, with constant depth, somewhat open distally, forming a broad and shallow notch in the anterior edge of the test, extending to the peristome. Aboral surface rather evenly inflated, highest somewhat behind the center, gradually sloping anteriorly, abruptly truncated posteriorly, with a somewhat distinct carina in the posterior interambulacral area; oral surface rather flat on the whole, slightly in-



Text-fig. 6. *Epiaster miyakoanus* TANAKA, sp. nov., from loc. OH7', Aketo Formation (Holotype, NSM-PA12129). a, Aboral view. b, Left lateral view. c, Posterior view. (All restored.)



Text-fig. 7. *Epiaster miyakoanus* TANAKA, sp. nov., from loc. TR139, Upper Member of the Hiraiga Formation (Paratype, GSJ-F6142). a, Frontal ambulacrum. b, Right anterior paired ambulacra. c, Right posterior paired ambulacra.

flated in the plastral region. Apical system nearly central, ethmophract, with four gonopores.

Frontal ambulacrum rather narrow, shallowly sunken throughout its length, subpetaloid; poriferous zones much narrower than the interporiferous zones, nearly a quarter as wide as the latter at the middle of the petaliferous part. Pores of the petaliferous part small; outer pores elongate oval, somewhat longer than the inner ones, transverse; inner pores oval, oblique; pores of each pair close together, separated by a granule. Paired ambulacra about as wide as the frontal ambulacrum, shallowly sunken, petaloid. Anterior paired petals considerably longer, somewhat wider, much more divergent than the posterior, slightly flexuous, rather open distally, extending about two-thirds the way to the ambitus; poriferous zones about as wide as the interporiferous; anterior zones more or less narrower than the posterior. Pores slit-shaped, acuminate inward, somewhat longer in the posterior poriferous zones than in the anterior; pores of each pair somewhat longer in the outer row than in the inner row, opposite, widely set, not conjugate; successive pore pairs in each poriferous zone separated by a row of eight granules. Posterior paired petals much shorter than, and about two-thirds as long as the anterior ones, nearly straight, more or less closed distally, extending about halfway to the margin; poriferous zones equalling the interporiferous in width; anterior poriferous zones slightly narrower than the posterior; pores about equal in size, of slit shape, acuminate inward; pores of each pair opposite, widely spaced, not conjugate; successive pore pairs in each poriferous zone separated by a row of eight granules.

Peristome near the anterior fourth, small, shallow, transversely oval. Plastron

protamphisternous, with a more or less prominent, considerably emarginate labrum. Periproct small, oval, vertically elongate, pointed at both ends, high up on the posterior truncated surface, visible from above. Tubercles small, of varying sizes, perforate, crenulate, scrobiculate, somewhat larger on the oral surface than on the aboral, much crowded on both sides of the frontal sinus, relatively small and fairly crowded near the ambitus, more or less closely spaced on the plastron, widely spaced elsewhere; numerous granules between tubercles. A granular band decorated with tubercles developed between the paired petals and also somewhat anteriorly beyond the anterior petals, somewhat distinct, broad, fairly ill-defined, nearly as wide as the paired petals.

Measurements. The holotype, though more or less transversely compressed, is about 36 mm long, about 29 mm wide, and about 17 mm high, its test being about 0.5 mm thick. In this specimen the granular band, though ill-defined, is some 3 mm in width on an average. The specimens available measure between about 24 mm and about 52 mm in length.

Remarks. The material available is somewhat deformed by the subsequent disfigurement. The holotype is somewhat transversely compressed so as to become more elongated in horizontal outline than the normal form. It is clear that the apical system of the present species is ethmophract. It is not known, however, whether the posterior genital plates are in contact or separated by the madreporite, because of the poor preservation. Numerous poorly preserved specimens with a peripetalous granular band were collected from loc. TR139 in association with the present species. They are probably identical with *Epiaster miyakoanus* sp. nov., on the basis of the general features of the test.

Comparison. This new species, together with *Epiaster zonarius* TANAKA, sp. nov. to be described below, is easily distinguished from a hitherto described Japanese species, *Epiaster* sp. aff. *E. nobilis* STOLICZKA (TANAKA and KOZAI, 1982, p. 343, pl. 55, fig. 1) from the Upper Santonian part of the Kajisako Formation of central Shikoku, by having a more distinct frontal sinus, paired petals that are narrower, more sunken, more flexuous, and less closed distally, and a peripetalous granular band or pseudo-fasciole. Moreover, the paired petals are very unequal in length in *Epiaster miyakoanus* sp. nov., whereas in *Epiaster* sp. aff. *E. nobilis* they are nearly equal. The distinction between *Epiaster miyakoanus* and another *Epiaster* species from the Miyako Cretaceous will be described in the succeeding article.

The present species resembles *Epiaster trigonalis* D'ORBIGNY (1853, p. 189, pl. 855, figs. 1–8), the type species of the genus, from the Albian of France and Switzerland, in some respects. But it differs from that species in that the apical system is situated more posteriorly, the paired petals are more depressed, the posterior petals are much shorter than the anterior, the pore pairs of the paired petals are widely set, and in that relatively small tubercles are crowded on both sides of the frontal sinus and near the ambitus. It, furthermore, should be noted that this new species has a peripetalous granular band. However, no mention was made of the presence of granular band or the like in *Epiaster trigonalis*, by the original author. *Epiaster miyakoanus* is to some

extent similar to *Epiaster prior* LAMBERT (1902, p. 20, pl. 4, figs. 17–19) having a diffuse pseudo-fasciole, from the Aptian of Spain, but can be distinctly separated from that species by its elongated outline of the test, narrower and shallower frontal sinus, and shallower anterior notch.

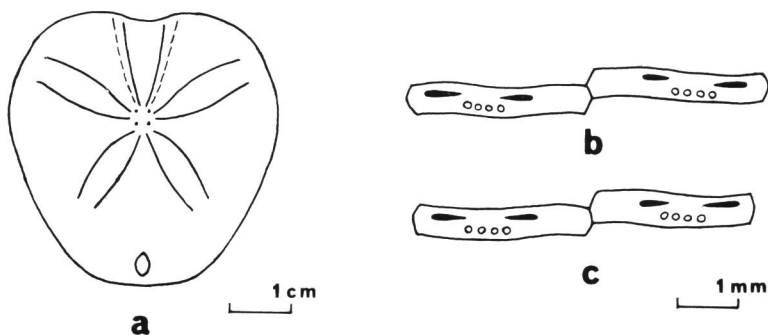
Occurrence. Loc. TR138 ($\div$ OH7'), sporadic; locs. TR139 and Hn6203, abundant; loc. C21, rare; loc. TR33, rare; middle (?) Upper Aptian to upper Lower Albian.

Epiaster zonarius TANAKA, sp. nov.

Pl. 2, fig. 5; Pl. 3, figs. 1a–e, 2a–b, 3; Text-figs. 8, 9

Material. Holotype, GSJ-F6138 (NSM-PA12177 for the plastotype), represented by an external cast (test partly stripped off on the aboral surface, partly preserved on the oral surface), from loc. TR114, coast of Hideshima, Miyako City, Iwate Prefecture, upper equivalent of the Lower Member of the Hiraiga Formation, upper Upper Aptian (Coll. TANAKA); paratype, GSJ-F6139 (NSM-PA12178 for the plastotype), represented by an external cast (test partly preserved on the aboral surface, partly stripped off on the oral surface), from the same locality (Coll. TANAKA). In addition to the holotype and paratype, GSJ-F6056 and 6146, and numerous other ill-preserved specimens (Coll. TANAKA) from the same locality are available.

Diagnosis. Test rather large, heart-shaped in outline, more or less rounded polygonal, about as long as wide, evenly rounded at the anterolateral margins, nearly straight at the posterolateral margins, widest at the anterior third, contracted behind, relatively low; posterior truncation rather gently sloping. Frontal sinus wide, more or less deep, with constant depth, expanding distinctly toward the ambitus with divergent edges, extending to the peristome; anterior notch broad, shallow. Aboral surface inflated, highest near the apical system, with a slight carina in the posterior inter-ambulacral area; oral surface flattish. Apical system eccentric in front, with four



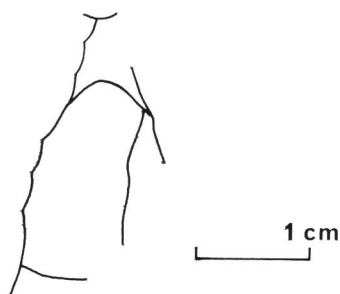
Text-fig. 8. *Epiaster zonarius* TANAKA, sp. nov., from loc. TR114, upper equivalent of the Lower Member of the Hiraiga Formation (Holotype, GSJ-F6138). a, Aboral view (restored). b, Left anterior paired ambulacra. c, Left posterior paired ambulacra.

gonopores.

Frontal ambulacrum wide, moderately sunken throughout its length, subpetaloid; poriferous zones much narrower than the interporiferous, considerably narrower than half the width of the latter; pores of the petaliferous part small, oval; pores of each pair close together, arranged in chevrons, separated by a granule. Paired ambulacra about as wide as the frontal ambulacrum, moderately sunken, petaloid. Anterior paired petals somewhat longer, more or less broader, much more divergent than the posterior, somewhat flexuous, rather open distally, extending about two-thirds the way to the margin; poriferous zones nearly equal in width, about as wide as the interporiferous zones; pores slit-shaped, acuminate inward, somewhat longer in the outer row than in the inner row; pores of each pair opposite, widely spaced, not conjugate; successive pore pairs in each poriferous zone separated by a row of four granules. Posterior paired petals shorter than, and 0.75–0.8 the length of the anterior ones, nearly straight, somewhat closed distally, extending halfway; poriferous zones about equal in width, nearly as wide as the interporiferous zones; pores of slit shape, acuminate inward, somewhat longer in the outer row than in the inner row; pores of each pair opposite, widely set, not conjugate; successive pore pairs in each poriferous zone separated by a row of four granules.

Peristome anterior, small, shallow, subpentagonal. Plastron protamphisternous, with a more or less prominent, considerably emarginate labrum. Periproct rather large, oval, vertically elongate, pointed at both ends, high up on the posterior truncated surface. Tubercles small, of varying sizes, perforate, crenulate, scrobiculate, more or less larger on the oral surface than on the aboral, somewhat smaller and more or less closely spaced near the ambitus, crowded on the plastron, widely spaced elsewhere; numerous granules between tubercles. A pseudo-fasciole, which is densely covered with streaks of somewhat smaller granules and decorated with tubercles, developed between the paired petals, fairly distinct, broad, ill-defined, about as wide as the paired petals.

Measurements. The holotype is secondarily deformed, and the original size of the test is difficult to estimate. Nevertheless, it roughly measures about 46 mm long,



Text-fig. 9. Plastron of *Epiaster zonarius* TANAKA, sp. nov., from loc. TR114, upper equivalent of the Lower Member of the Hiraiga Formation (Paratype, GSJ-F6139).

about 45 mm wide, and about 19 mm high. Its test is about 0.5 mm thick, up to about 0.7 mm around and near the apical system. In this specimen the pseudo-fasciole, though ill-defined, is about 4 mm in width on an average. The largest of the other specimens attains about 58 mm in length.

Remarks. The holotype is secondarily depressed on the whole, and appears more or less compressed forward from the back. It is not confirmed that the apical system of the present species is ethmophract, because of the poor preservation. Nevertheless, the present new species is safely referable to *Epiaster* on the basis of the general features of the test. The presence of a broad, ill-defined pseudo-fasciole surrounding the petals is one of the most prominent characters of the new species. The pseudo-fasciole is very similar to that of *Epiaster restrictus* GAUTHIER figured by DEVRIÈS (1960, pl. 16, fig. 6), in mode of arrangement of granules and breadth relative to the height of inter-ambulacral plates.

Comparison. This species is clearly distinguished from *Epiaster miyakoanus* TANAKA, sp. nov. described above, in many respects. One of the most distinct differences between the two species is that in *Epiaster zonarius* sp. nov. the test is heart-shaped, somewhat rounded polygonal in outline with rather gently sloping posterior truncation, and in *E. miyakoanus* it is subovate with vertical posterior truncation. *Epiaster zonarius* has a wider and deeper frontal sinus widening more distinctly toward the ambitus, a more anteriorly placed apical system, and more deeply sunken paired petals, of which the anterior are more divergent and the posterior are longer. This species has a peripetalous pseudo-fasciole, whereas *Epiaster miyakoanus* has no more than a worse-defined granular band where serial arrangement of minute granules is very obscure and scattered tubercles are more numerous. In *Epiaster miyakoanus* tubercles are very closely spaced on both sides of the frontal sinus. But such is not the case with *Epiaster zonarius*. Moreover, *Epiaster zonarius* has a subpentagonal peristome as against transversely oval in *E. miyakoanus*. There is also a minor but distinct difference in number of granules separating successive pore pairs in each poriferous zone of the paired petals between the two species.

In addition to the two *Epiaster* species from the Miyako Group and *Epiaster* sp. aff. *E. nobilis* STOLICZKA (TANAKA and KOZAI, 1982, p. 343, pl. 55, fig. 1) from the Upper Santonian of central Shikoku, several specimens referable to this genus (GSJ-F6051, 6052, 6053, 6054; Pl. 3, figs. 4, 5) are known to occur in the middle part (Lower Aptian) of the Hinagu Formation of western middle Kyushu (TANAKA and KOZAI, 1982). These specimens, though fragmentary and secondarily depressed, are characterized by the frontal sinus becoming much shallower near the ambitus with an indistinct anterior notch, the pore pairs of the frontal ambulacrum that consist of transverse outer pores and oblique inner pores, each pair being separated by a granule, the depressed paired petals, of which the somewhat flexuous anterior petals are considerably longer and less closed distally than the nearly straight posterior, and by the broad, ill-defined peripetalous granular band decorated with tubercles. In these specimens, tubercles are not crowded on both sides of the frontal sinus. Furthermore, one of

these specimens (GSJ-F6053) clearly indicates the apical system to be of ethmophract type with four gonopores, the posterior genital plates being in contact behind the madreporite. The Hinagu specimens differ from the above Japanese three species especially in frontal sinus plus anterior notch and/or paired petals, and/or tuberculation, thus representing a distinct species separated from those species; this will be described in more details on another occasion.

The present new species closely resembles *Epiaster jeanneti* COLLIGNON (1950, p. 13, pl. 2, fig. 4) from the Albian of Madagascar. However, it has narrower paired petals and a more completely developed peripetalous pseudo-fasciole than does the Malagasy species. Moreover, number of granules separating successive pore pairs in each poriferous zone of the paired petals distinctly differs between the two species. The species described here is also similar to *Epiaster dartoni* COOKE (1955, p. 108, pl. 28, figs. 1–10) from the Lower Cretaceous (Aptian ?) of the United States and Mexico in many respects. However, it is not confused with that species by its more anteriorly displaced apical system and more widely spaced tubercles.

Occurrence. Loc. TR114, abundant; upper Upper Aptian.

Concluding Remarks

Many of the echinoid specimens examined came from the Upper Member of the Hiraiga Formation (“*Orbitolina* Sandstone”) in the northern part of the studied area and the upper equivalent of the Lower Member of the Hiraiga Formation in the southern part, and some others from the Tanohata Formation, the lower equivalent of the Lower Member of the Hiraiga Formation in the southern part and the Aketo Formation in the northern part. Among them the following four genera and seven species, of which three are new, are identified, indicating their stratigraphic occurrence in parentheses.

Coenholectypus peridoneus NISIYAMA (Lower Albian)

Coenholectypus hideshowensis TANAKA, sp. nov. (Upper Aptian)

Holaster sp. cf. *H. clypeatulus* NISIYAMA (Lower Albian)

Holaster sp. aff. *H. laevis* (BRONGNIART) (Lower Albian)

Toxaster sp. aff. *T. villei* (GAUTHIER) (Lower Albian)

Epiaster miyakoanus TANAKA, sp. nov. (Upper Aptian–Lower Albian)

Epiaster zonarius TANAKA, sp. nov. (Upper Aptian)

Of the above species, the two species of *Epiaster* are of abundant occurrence; *Epiaster miyakoanus* is dominant over *E. zonarius*. *Coenholectypus peridoneus* is also common. In addition to the species mentioned above, *Pseudocidaritis simulans* NISIYAMA (represented by a single primary spine) and *Goniopygus atavus* NISIYAMA are known to occur in the Lower Albian (NISIYAMA, 1950), and some poorly preserved primary spines of regular echinoids of unknown taxonomic position were also obtained from the Upper Aptian. Moreover, there are many other undeterminable irregular echinoids from the Upper Member of the Hiraiga Formation (“*Orbitolina*

Sandstone"). By far the majority of the echinoids from the Miyako Group are Spatangoida, and some others are Holecypoida and Holasteroida, with subsidiary regular echinoids.

The clublike primary spines probably of cidaroid type of the unidentified regular forms are occasionally found in the shelly calcareous coarse- to fine-grained sandstone which is referred to as conglomerate or conglomeratic sandstone in terms of grain size and contains numerous waterworn stocks of reef-building corals. These regular forms, together with *Pseudocidaris simulans* NISIYAMA, a regular form with ovoid-clavate primary spines, may have been littoral forms which lived free on the sea floor. They probably inhabited wave-washed hard bottoms floored, for example, by coral reefs, in agitated shallow sea. Another regular form, *Goniopygus atavus* NISIYAMA, is presumed to have lived free upon the sea floor at moderate depths.

Coenholectypus peridoneus NISIYAMA, an irregular form having a large peristome and a large anus on the oral surface, is restricted to the muddy medium- to fine-grained sandstone and clean fine-grained sandstone, being commoner in the former. *Coenholectypus hideshowensis* sp. nov. was also obtained from the muddy medium- to fine-grained sandstone. It is very likely that these species inhabited a muddy sand or sand bottom of shallow sea. The rock from which *Holaster* sp. cf. *H. clypeatulus* NISIYAMA, an irregular form, came is fine-grained sandstone, and that containing *Holaster* sp. aff. *H. laevis* (BRONGNIART) is muddy medium- to fine-grained sandstone. These species as well as the two species of *Coenholectypus* are found more commonly in the finer grained sediments than are the unnamed regular echinoids mentioned above. Hence, it is suggested that *Holaster* sp. cf. *H. clypeatulus* and *Holaster* sp. aff. *H. laevis* generally preferred a sandy bottom of shallow sea. *Toxaster* sp. aff. *T. villei* (GAUTHIER) was obtained from the muddy fine-grained sandstone. This lithology is finer grained or muddier than that containing the two species of *Coenholectypus* or the two species of *Holaster*. Thus, the above difference in mode of occurrence is presumed to have been related to that *Toxaster* sp. aff. *T. villei* has depressed paired ambulacra as against superficial in the two *Coenholectypus* species whose frontal ambulacrum also is superficial and in the two *Holaster* species.

The two species of *Epiaster*, irregular forms, which are the most dominant constituents of the Miyako echinoid fauna, occur abundantly mainly in finer grained sediments than do the other species. These echinoids are very abundant in the sandy siltstone and siltstone, occurring commonly also in the muddy fine-grained sandstone, but they have not yet been discovered in the clean sandstone. In this connection, it should be noted that each of the two *Epiaster* species has a thinner test than *Toxaster* sp. aff. *T. villei* when compared with each other in terms of similar test-size. The *Epiaster* species are characterized by having depressed paired petals and a peripetalous pseudo-fasciole or granular band. This combined with the mode of occurrence suggest that the *Epiaster* species were generally mud-dwellers living at moderate depths (sublittoral to bathyal zone) which were of deeper water than the places inhabited by the other species. They were probably burrowers. As regards the occurrence of the

Epiaster species, going into details, *E. miyakoanus* sp. nov. occurs abundantly in the sandy siltstone and less commonly in the muddy fine-grained sandstone, whereas *E. zonarius* sp. nov. has been hitherto found abundantly only in the siltstone. And, these two species do not coexist with each other at one and the same locality. Therefore, it is concluded that *Epiaster miyakoanus* occurs in the worse sorted, coarser grained sediments, which were probably deposited in a shallower water, current-agitated environment, than does *E. zonarius*. *Epiaster zonarius* has a wider, deeper, and more forward-expanding frontal sinus, more deeply sunken paired petals, and a better defined peripetalous pseudo-fasciole. It follows from this that presumably, *Epiaster zonarius* burrowed into muddy bottom sediments more actively or more deeply than did *E. miyakoanus*.

As can be seen from the above, the deposits in which the Miyako echinoid fauna is mainly found, differ in grain size with different taxa. That is to say, roughly speaking, the substrates inhabited were finer grained or muddier in the order of *Epiaster zonarius*, *E. miyakoanus*, *Toxaster* sp. aff. *T. villei*, *Holaster* spp.-*Coenholectypus* spp., and certain regular forms with primary spines of cidaroid type. From this we conclude that the occurrence of echinoids in the Miyako Group, though allochthonous in some cases, is closely related to the lithofacies.

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Explanation of Plates

Plate 1

- Fig. 1. *Coenholectypus peridoneus* (NISIYAMA). 1a, Aboral view, $\times 1$. 1b, Left lateral view, $\times 1$. GSJ-F6176-1. Loc. TR138, north of Raga, Aketo Formation, upper Lower Albian.
- Fig. 2. *Coenholectypus peridoneus* (NISIYAMA). 2a, Aboral view, $\times 1$. 2b, Left lateral view, $\times 1.1$. NSM-PA12124a. Loc. C3p, north of Raga, Aketo Formation, upper Lower Albian.
- Fig. 3. *Coenholectypus hideshimensis* TANAKA, sp. nov. 3a, Aboral view, $\times 1.5$. 3b, Oral view, $\times 1.5$. 3c, Left lateral view, $\times 1.5$. Holotype, GSJ-F6165. Loc. TR43, Hideshima, lower equivalent of the Lower Member of the Hiraiga Formation, probably upper Upper Aptian.
- Fig. 4. *Holaster* sp. cf. *H. clypeatulus* NISIYAMA. Aboral view, $\times 1$. GSJ-F6061. Loc. TR137, north of Raga, Upper Member of the Hiraiga Formation, upper Lower Albian.
- Fig. 5. *Holaster* sp. aff. *H. laevis* (BRONGNIART). 5a, Aboral view, $\times 0.8$. 5b, Oral view, $\times 0.8$. GSJ-F6058. Loc. TR139, north of Raga, Upper Member of the Hiraiga Formation, upper Lower Albian.
- Fig. 6. *Holaster* sp. aff. *H. laevis* (BRONGNIART). 6a, Aboral view, $\times 0.8$. 6b, Oral view, $\times 0.8$. 6c, Left lateral view, $\times 0.8$. 6d, Anterior view, $\times 0.8$. 6e, Posterior view, $\times 0.8$. GSJ-F6057. Loc. TR139, north of Raga, Upper Member of the Hiraiga Formation, upper Lower Albian.
- Fig. 7. *Toxaster* sp. nov. aff. *T. villei* (GAUTHIER). 7a, Aboral view, $\times 1$. 7b, Oral view, $\times 1$. 7c, Left lateral view, $\times 1$. GSJ-F6140. Loc. TR139, north of Raga, Upper Member of the Hiraiga Formation, upper Lower Albian.

Plate 2

- Fig. 1. *Epiaster miyakoanus* TANAKA, sp. nov. 1a, Aboral view, $\times 1.1$. 1b, Oral view, $\times 1.1$. 1c, Left lateral view, $\times 1.1$. 1d, Anterior view, $\times 1.1$. 1e, Posterior view, $\times 1.1$. Holotype, NSM-PA12129. Loc. OH7', north of Raga, Aketo Formation, upper Lower Albian.
- Fig. 2. *Epiaster miyakoanus* TANAKA, sp. nov. 2a, Aboral view, $\times 1.5$. 2b, Oral view, $\times 1.5$. 2c, Left lateral view, $\times 1.5$. Paratype, NSM-PA12130a. Loc. C21, Shimanokoshi, upper part of the Tanohata Formation, middle (?) Upper Aptian.
- Fig. 3. *Epiaster miyakoanus* TANAKA, sp. nov. 3a, Aboral view, $\times 1$. 3b, Oral view, $\times 1$. 3c, Left lateral view, $\times 1$. 3d, Anterior view, $\times 1$. 3e, Posterior view, $\times 1$. GSJ-F6141. Loc. TR139, north of Raga, Upper Member of the Hiraiga Formation, upper Lower Albian.
- Fig. 4. *Epiaster miyakoanus* TANAKA, sp. nov. 4a, Aboral view, $\times 1$. 4b, Oral view, $\times 1$. Paratype, GSJ-F6142. Loc. TR139, north of Raga, Upper Member of the Hiraiga Formation, upper Lower Albian.
- Fig. 5. *Epiaster zonarius* TANAKA, sp. nov. Aboral view, $\times 0.8$. GSJ-F6056, internal mold. Loc. TR114, Hideshima, upper equivalent of the Lower Member of the Hiraiga Formation, upper Upper Aptian.

Plate 3

- Fig. 1. *Epiaster zonarius* TANAKA, sp. nov. 1a, Aboral view, $\times 1$. 1b, Oral view, $\times 1$. 1c, Left lateral view, $\times 1$. 1d, Anterior view, $\times 1$. 1e, Posterior view, $\times 1$. Holotype, GSJ-F6138. Loc. TR114, Hideshima, upper equivalent of the Lower Member of the Hiraiga Formation, upper Upper Aptian.
- Fig. 2. *Epiaster zonarius* TANAKA, sp. nov. 2a, Aboral view, $\times 1$. 2b, Oral view, $\times 1$. Paratype, GSJ-F6139. Loc. TR114, Hideshima, upper equivalent of the Lower Member of the

Hiraiga Formation, upper Upper Aptian.

- Fig. 3. *Epiaster zonarius* TANAKA, sp. nov. Aboral view, $\times 4$. Holotype, GSJ-F6138. Loc. TR114, Hideshima, upper equivalent of the Lower Member of the Hiraiga Formation, upper Upper Aptian. A peripetalous pseudo-fasciole is seen between two arrows. Front to the left.
- Fig. 4. *Epiaster* sp. Aboral view, $\times 1.5$. GSJ-F6051, internal mold. Yatsushiro district, Kumamoto Prefecture, middle part of the Hinagu Formation, Lower Aptian.
- Fig. 5. *Epiaster* sp. Aboral view, $\times 1.5$. GSJ-F6054, external mold. Yatsushiro district, Kumamoto Prefecture, middle part of the Hinagu Formation, Lower Aptian.

All specimens illustrated here are external casts, unless otherwise stated.

