EARLY CRETACEOUS *ISOCRINUS* FROM NORTHEAST JAPAN

by TATSUO OJI

ABSTRACT. Two species of *Isocrinus*, one of which is new (*Isocrinus* (*Chladocrinus*) *hanaii* sp. nov.), are described from the upper Aptian of the Miyako Group, Northeast Japan. The skeletons of *I.* (*C.*) *hanaii* are preserved intact at several localities, so it is presumed that they were rapidly buried either alive or shortly after death, the animals having lived on a sandy bottom in agitated water. In contrast to the relatively deep-water occurrence of modern isocrinids (mostly 200–1000 m), those from Miyako lived in shallow water, indicating that certain stalked crinoids persisted at shallow depths until mid-Cretaceous times. They were among the last isocrinids to have lived in an almost predator-free environment. Soon afterwards, a diversification of predatory teleostean fish was reflected in the contemporaneous appearance of new types of isocrinids.

VARIOUS marine invertebrates are known from the Lower Cretaceous Miyako Group in Northeast Japan; crinoids are among the most common, yet they remain undescribed and have even been ignored in some faunal lists. This study presents systematic descriptions of two species of elegantly preserved isocrinids and discusses the implications of their occurrence with respect to changes in the bathymetric distribution of isocrinids through the Mesozoic and the Cainozoic. They are the first crinoids to be described from the Cretaceous of Japan.

The pioneer work on the stratigraphy of the Miyako Group by Yabe and Yehara (1913) recorded the occurrence of excellently preserved crinoids which were identified as *Pentacrinus*. In the late 1940s, T. Hanai carried out detailed field surveys and excavated fine specimens of crinoids, including nearly complete crowns. R. C. Moore examined these specimens during a visit to Japan and suggested their assignment to *Isocrinus*. Since then, crinoids from the Miyako Group have been cited or listed as a species of *Isocrinus* (e.g. Kobayashi *et al.* 1954; Tamura 1982). Excavations by Hanai and his coworkers in the 1960s led to the discovery of additional material. The present study is based mostly on this material, together with material newly collected by the author.

The Miyako Group ranges from the upper Aptian to the lower Albian. Except for the lowest unit (Raga Formation) the Miyako Group is characterized by rich marine faunas which include a variety of bivalves, gastropods, ammonites, and encrusting organisms such as hermatypic corals and calcareous algae. At present, seventy species of bivalves (Hayami 1975), eighty-seven species of gastropods (Kase 1984), and approximately sixty species of cephalopods (Obata and Matsumoto 1977) have been recorded. These fossils indicate a shallow, open marine environment in a warm climate (Hanai *et al.* 1968). Recently discovered fossil beachrock indicates an ancient strand line and further substantiates the dominance of a tropical or subtropical climate (Hanai and Oji 1981).

Isocrinids occur abundantly in almost all the shallow marine strata of the Miyako Group. They normally occur as disarticulated segments of stem and cirri, as is usually the case with fossil crinoids, either associated with other marine fauna or scattered throughout the sediments. At a few localities, however, unusually well-preserved specimens of *Isocrinus* occur commonly with their arms spread on bedding planes. In addition to their palaeontological significance, such exceptional modes of occurrence also give an indication of the nature of the sedimentary environment.

The crinoid fauna of the Miyako Group is of low diversity despite the abundance of specimens, and contains only a few species of isocrinids and one species of comatulid; only two isocrinid species are represented by sufficient material for description.

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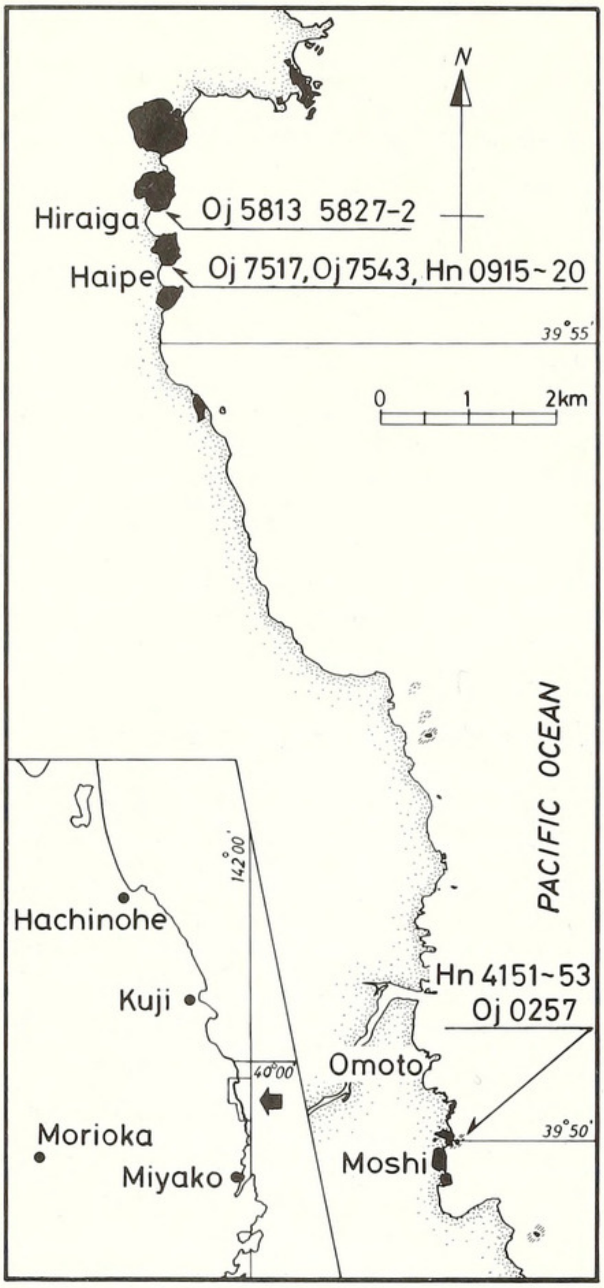
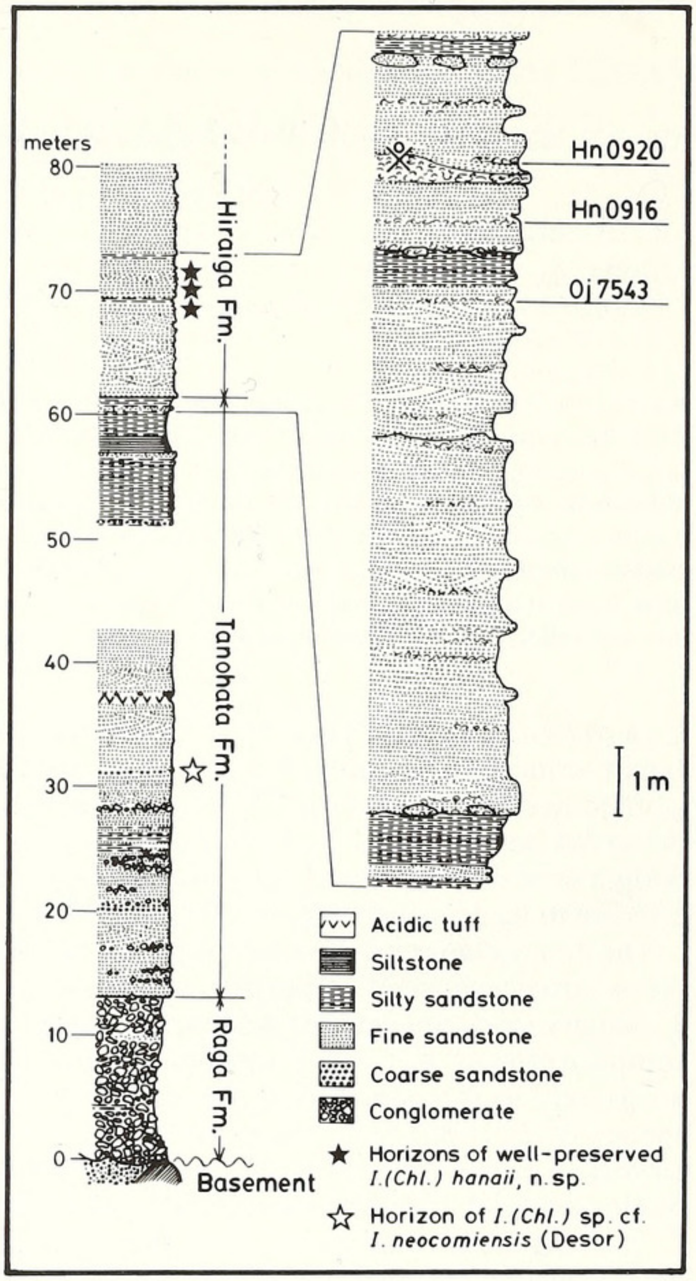




TEXT-FIG. 1 (*left*). Location of the collecting localities and distribution of the Miyako Group (black), Northeast Japan.

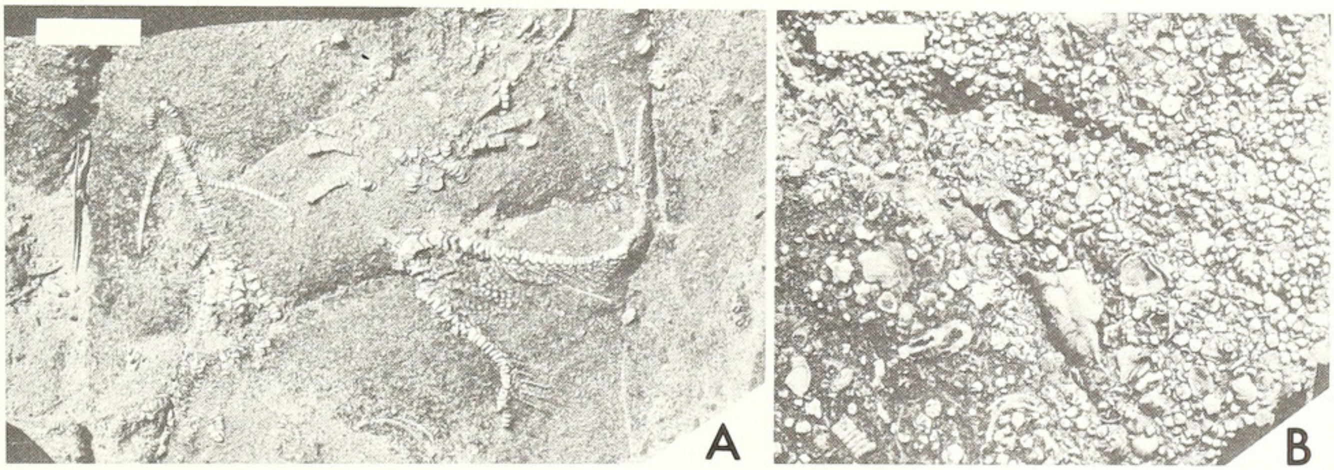
TEXT-FIG. 2 (*right*). Columnar section of the Miyako Group along the northern coast of Haipe, showing horizons of collecting sites (left, whole section; right, partly enlarged).

OCCURRENCE AND SEDIMENTARY ENVIRONMENT

Isocrinus (Chladocrinus) hanaii *sp. nov.*

Specimens are from the lower part of the Hiraiga Formation (uppermost Aptian) in the Tanohata and Moshi areas (text-fig. 1). In the Tanohata area, almost completely preserved specimens occur in several restricted layers approximately 10 m above the base of the Hiraiga Formation (Locs. Oj 7543, Hn 0915, Hn 0916, Hn 0920) along the northern coast of Haipe (text-fig. 2). At these localities a calcareous fine-grained sandstone with large-scale cross-stratification contains abundant bivalves, gastropods, annelid tubes, and fragmented ossicles of *I.* (*C.*) *hanaii* sp. nov. The ossicles are mostly concentrated in the lowermost part of a single cross-stratification, or in continuous thin layers. The highly calcareous, well-washed sandstone, the sedimentary structures, and the mode of occurrence all indicate a high-energy environment in which the disarticulated crinoids were subjected to transport and sorting.

At Loc. Hn 0920 (the type locality for *I.* (*C.*) *hanaii* sp. nov.) well-preserved articulated specimens with cup, arms, and column occur sparsely in a single horizon within a light-grey, fine-grained, and well-sorted calcareous sandstone (text-fig. 3A). The specimens have been brought into relief on the bedding plane by selective natural weathering and etching of the matrix. Other marine fossils are rare at this horizon. In contrast a bed several centimetres lower has produced numerous cirrals of *I.* (*C.*) *hanaii* sp. nov. associated with many small-sized bivalves (text-fig. 3B), identified as *Glycymeris* (*Hanaia*) *densilineata* (Nagao), *Astarte* (*Trautscholdia*) *minor* Nagao, *A.* (*Nicaniella*) *semicostata* Nagao. These two distinct modes of occurence, nearly complete individuals and dissociated cirrals, appear in almost the same lithology and are possibly due to different modes of burial of the skeletons. The former, with well-preserved but fewer specimens, strongly indicates rapid burial of living crinoids, or shortly after their death. Experiments on several species of Recent comatulid crinoids have shown that within two or three days of death they collapse into fragments (Cain 1968; Meyer 1971; Liddel 1975), but there has been no equivalent report on the post-mortem decomposition of Recent isocrinid skeletons. It is unlikely, however, that the well-preserved Cretaceous isocrinids considered here were subjected to much transport. On the other hand the occurrence of *I.* (*C.*) *hanaii* sp. nov. almost exclusively as cirrals may possibly result from the sorting of crinoidal fragments along with sand grains during transport, or during reworking by wave action.



TEXT-FIG. 3. Mode of occurrence of *Isocrinus* (*Chladocrinus*) *hanaii* sp. nov. at Loc. Hn 0920, northern coast of Haipe. A, well-preserved specimens in fine-grained sandstone. B, slightly below the horizon of A, consisting mostly of cirrals. Both figures are views of bedding plane surfaces. Scale bars 2 cm.

In the Moshi area, *I.* (*C.*) *hanaii* sp. nov. is restricted to an interval 24–27 m above the base of the Hiraiga Formation (Locs. Hn 4151, Hn 4153, Oj 0257). The specimens are contained in a calcareous, fine-grained sandstone; while sometimes they retain nearly complete skeletons, they frequently occur as ossicles in calcareous concretions together with wood fragments and small molluscs such as *Mesosaccella insignis* (Nagao), *A.* (*N.*) *semicostata* Nagao, *A.* (*Freiastarte*) *subomalioides* Nagao, and the venerid *Nagaoella corrugata* (Nagao).

Isocrinus (Chladocrinus) *sp. cf.* Isocrinus? neocomiensis (*Desor*)

Specimens occur in the middle and upper part of the Tanohata Formation (upper Aptian) of the Tanohata area. Those from the middle part of the formation are scattered through calcareous sandstone at the following localities: Loc. Oj 5813, cross-stratified, calcareous, fine-grained sandstone on the northern coast of Hiraiga; Loc. Oj 7517, pebble conglomeratic, calcareous, coarse-grained sandstone, with fragmented ostreids and other bivalves, on the northern coast of Haipe. Specimens from the upper part of the formation are in sandy siltstone at the following localities on the northern coast of Hiraiga: Loc. Oj 5827-2, just below the base of the overlying Hiraiga Formation; Loc. Oj 5825-2, 4 m below the base of the Hiraiga Formation. The siltstones are extensively bioturbated; disarticulated columns and brachials occur scattered throughout the sediment. Specimens from the siltstone are better preserved than those from the sandstone. This species probably lived in relatively calm water.

DISCUSSION

Direct information on the bathymetry of the sediments within which the specimens occur is not available. However, the two species described herein are considered to have been shallow-water isocrinids. Nearly complete specimens of *I.* (*C.*) *hanaii* sp. nov. occur associated with transported blocks of hermatypic corals and coralline algae at Haipe. Columnals and a series of brachials of *I.* sp. cf. *I.*? *neocomiensis* are found in siltstone just above fossil beachrock at Hiraiga. Consequently both species are considered to have been shallow-water dwellers, probably living in depths less than several tens of metres.

Living stalked crinoids are mainly distributed in relatively deep water, mostly 200–1000 m (isocrinids), deeper than 200 m (bourgueticrinids), and 500–5000 m (cyrtocrinids) (Breimer 1978*b*, p. T329). However, a few examples of Mesozoic stalked crinoids (including the species of *Isocrinus* described here) are found in apparently shallow-water lithofacies. Because of this, it has been proposed that the living stalked crinoids are 'living fossils' which disappeared from shallow water to take refuge in deep water. According to Breimer (1978*a*, p. T10) they are approaching extinction.

Fossil stalked crinoids for which bathymetric information may be inferred are few. *Seirocrinus subangularis* (Miller), an early Jurassic pentacrinitid from Holzmaden, was once regarded as pseudoplanktonic (Seilacher *et al.* 1968), but has subsequently been reinterpreted as benthonic by Rasmussen (1977) who estimated that the crinoid lived at depths of 100–600 m. If Rasmussen is right this pentacrinitid was present in relatively deep water during the early Jurassic. Nearly complete specimens of *Chariocrinus andreae* (Desor) from the Bajocian of Switzerland occur in apparently shallow-water oolitic sediments (Hess 1972). Other than this occurrence, records of shallow-water isocrinids are scarce, and the two species of *Isocrinus* from the Miyako Group described herein represent the youngest such shallow-water isocrinids so far reported. Apart from the Isocrinidae, a rather different stalked crinoid, the bathycrinid *Dunnicrinus mississippiensis* R. C. Moore, is known from apparently shallow-water facies of Maastrichtian age (Moore 1967). This may suggest that some bathycrinids persisted in shallow seas after the isocrinids had disappeared from such depths.

Despite differing opinions on their taxonomy, it is possible to split the isocrinids into two groups on the basis of the kind of articulation in the primibrachials. One group has synarthrial articulation and the other has cryptosyzygial articulation (including the 'synostosis' of several authors). This subdivision of isocrinids was first proposed by Carpenter as early as 1882. Synarthry is characterized by a prominent transverse ridge in the centre of each opposing articular facet, and the ligamentary bundles are distributed in two fossae on either side of the ridge. Synarthrial articulation allows slight movement between two connected ossicles. On the other hand, cryptosyzygy is a weak form of articulation; joint facets are almost flat so that each ossicle is tightly connected. Cryptosyzygy also occurs in more distal brachitaxes than IBr, and frequently in the proximal part within each brachitaxis.

Observations of living crinoids show that isocrinid arms are easily disarticulated at the cryptosyzygy just after specimens have been dredged, and that regeneration of the arms is usually found at the distal facet of a hypozygal. I have frequently observed this in specimens of the isocrinid *Metacrinus rotundus* Carpenter dredged off the southern coast of Japan. Such regeneration indicates that disarticulation at the cryptosyzygy occurs while the crinoids are living. Consequently the cryptosyzygy of isocrinids may be a specialized articulation for autotomy (as is the case for comatulids) as suggested by Roux (1974). Arms are easily disarticulated at the cryptosyzygy in both living and dead specimens of Recent isocrinids. There has been no report of regenerated arms growing from the distal facet of a synarthry.

The group which has synarthrial articulation (named here the 'old group') lived from the Triassic to the Recent, while those which have cryptosyzygy in IBr (named here the 'new group') appeared in the early Cretaceous and diversified after the mid-Cretaceous (Table 1). In the present-day Pacific the 'new group' is characterized by many species of *Metacrinus* and *Saracrinus* living mostly between 100–600 m water depth, while a member of the 'old group', *Hypalocrinus naresianus* (Carpenter),

	GENERA	IBr	IIBr~
OLD GROUP	*Isocrinus*	SYN	SYN+CZ
	Hypalocrinus	SYN	SYN+CZ
	Chariocrinus	SYN	SYN+CZ
	Balanocrinus	SYN	SYN+CZ
NEW GROUP	*Nielsenicrinus*	CZ	SYN+CZ
	Austinocrinus	CZ	unknown
	Isselicrinus	CZ	CZ
	Doreckicrinus	CZ	CZ
	Cainocrinus	CZ	SYN+CZ
	Teliocrinus	CZ	CZ(+SYN)
	Endoxocrinus	CZ	CZ
	Diplocrinus	CZ	CZ
	Cenocrinus	CZ	CZ
	Metacrinus	CZ	CZ
	Saracrinus	CZ	CZ

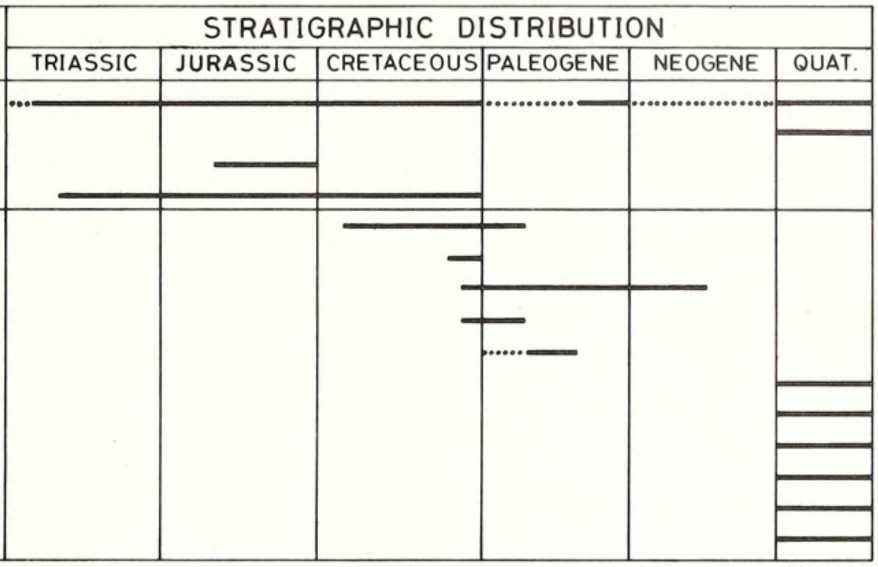


TABLE 1. Stratigraphic distribution of ligamentary articulation type within 'old' and 'new' groups of Isocrinidae (see text); genera and stratigraphic information modified after Rasmussen (1978). IBr, type of ligamentary articulation in primibrachials; IIBr, type of ligamentary articulation in more distal brachitaxes than secundibrachials; SYN, synarthry; CZ, cryptosyzygy (including synostosis and symmorphy).

is restricted to depths greater than 600 m. Data on distribution are still insufficient, especially for the 'old group', but I conclude that the 'new group' lives at shallower depths than the 'old group'.

Teleostean fish are considered to be the main predators of crinoids (Meyer and Macurda 1977) and this may well apply to isocrinids. There is some evidence from a deep-sea photograph of Conan *et al.* (1981, fig. 4) which shows predation by a fish on *Diplocrinus wyvillethomsoni* (Carpenter). An adaptive radiation of teleostean fish took place in shallow water after the mid-Cretaceous (Thomson 1977); if teleosts were the predators of isocrinids, this radiation would have led to some selection pressure on these shallow-water stalked crinoids.

I consider that isocrinids of the 'new group' probably had an advantage over the 'old group' with regard to predation by bony fish because of their greater ability to shed arms in times of emergency. It is not apparent whether they shed their arms deliberately or passively, but it is presumed that they underwent autotomy just as comatulids do. Autotomy or disarticulation of the arms probably guarded the central soft body of isocrinids from predation. Crinoids of the 'new group' have a greater number of cryptosyzygies near the central soft body mass and therefore are presumably better protected from predation and better adapted for regeneration. Consequently, some of the 'new group' have overcome the selection pressure and revived in relatively shallow depth (sometimes less than 100 m) in the present-day Pacific.

Apparent regeneration is absent in *Isocrinus* from Miyako, strongly suggesting that it seldom if ever suffered from predation; the late Aptian shallow sea of Miyako was still then a favourable environment for the 'old group'.

It has not yet been documented whether the isocrinids shed arms by autotomy, and the above discussion is based only on the fact that the arms of living or dead specimens of isocrinids are easily disarticulated at the cryptosyzygy. Further investigation, and particularly experiments on living specimens, are needed to resolve this matter.

SYSTEMATIC PALAEONTOLOGY

Family ISOCRINIDAE Gislén, 1924
Genus ISOCRINUS von Meyer, 1936
Subgenus CHLADOCRINUS Agassiz, 1836 emend. Sieverts-Doreck, 1971

Remarks. *Chladocrinus* was first introduced by Agassiz, and loosely defined for fossil species of '*Pentacrinus*' with relatively numerous internodal plates. Owing to his brief diagnosis and failure to designate a type species, this genus has long been ignored. Recently, Sieverts-Doreck (1971) discussed the validity of the genus, designated as type species *P. basaltiformis* Miller, and emended the diagnosis. She included five early Jurassic species in the genus and treated the two closely related forms *Isocrinus* von Meyer, 1936 (type species *I. pendulus* von Meyer) and *Neocrinus* Thomson, 1864 (type species *P.* (*Neocrinus*) *decorus* Thomson) as distinct genera. According to Sieverts-Doreck, *Chladocrinus* is easily distinguished from *Isocrinus* by its lack of symmorphial articulation, and from *Neocrinus* by its more ramified arms. On the other hand, Hess (1972) regarded *Chladocrinus* as a subgenus of *Isocrinus* because the two are differentiated only by the types of ligamentary articulation between $IIBr_{3-4}$ (cryptosyzygy versus symmorphy). Hess (1972) also treated *Neocrinus* as a distinct genus. Rasmussen (1978) accepted the emended diagnosis of Sieverts-Doreck (1971) and considered *Chladocrinus* a distinct genus. He did not restrict *Chladocrinus* to the early Jurassic species but included within it those early Cretaceous to Recent species of *Neocrinus* whose ligamentary articulation fitted the diagnosis given by Sieverts-Doreck, i.e. IBr_{1-2} (synarthry), $IIBr_{1-2}$ (synarthry), and $IIBr_{3-4}$ (cryptosyzygy).

If *Chladocrinus* in the sense of Rasmussen (1978) is adopted, what is the essential difference between *Chladocrinus* and *Isocrinus*? *Isocrinus* possesses symmorphial articulation, generally at $IIBr_{3-4}$, which is replaced by cryptosyzygial articulation in *Chladocrinus*. Consequently, the two genera are separated only by differences in the types of ligamentary articulation.

Both cryptosyzygy and symmorphy are considered to be modified forms of syzygy (Breimer 1978*a*), differentiated as follows: in cryptosyzygy the joint facets are almost flat; in symmorphy they are not flat, and instead a prominent transverse culmination of the epizygal brachial fits into a corresponding depression of the hypozygal to form an interlocked structure. *Isocrinus* is characterized by symmorphy, but the degree of prominence and depression varies between species. For example, the articular facet of *I. cingulatus* (Münster) drawn by Hess (1972, fig. 3) has a hypozygal which is almost flat, the depression being conspicuous only near the margin. *I.* (*C.*) *hanaii* sp. nov. shows an almost flat suture between $IIBr_{3-4}$ (Pl. 77, fig. 2), but the articular facets are somewhat undulating; the distal facet of the hypozygal is more or less concave and the adoral part is slightly elevated (Pl. 78, figs. 7, 8). Similar articulation is also present in an epizygal of *I.* (*C.*) sp. cf. *I.*? *neocomiensis* (Desor) (Pl. 78, fig. 6). Considering the various degrees of prominence and depression observed in symmorphy and cryptosyzygy, it seems difficult to draw a line between the two forms of articulation. I follow Hess (1972) in treating *Chladocrinus* as a subgenus of *Isocrinus*, and regard the Miyako examples as a species of the subgenus *Chladocrinus* because of their slightly depressed, almost flat cryptosyzygy.

Another classification of the Isocrinidae is that of Roux (1977). Based on columnal morphology, Roux emphasized a strong similarity between the fossil *Balanocrinus* and Recent *N. blakei* and *N. decorus*. Later Roux (1981) placed the two living species in his Balanocrininae; he included fossil *Isocrinus* in his Isocrininae. His subdivisions were based mostly on columnal microstructure, and

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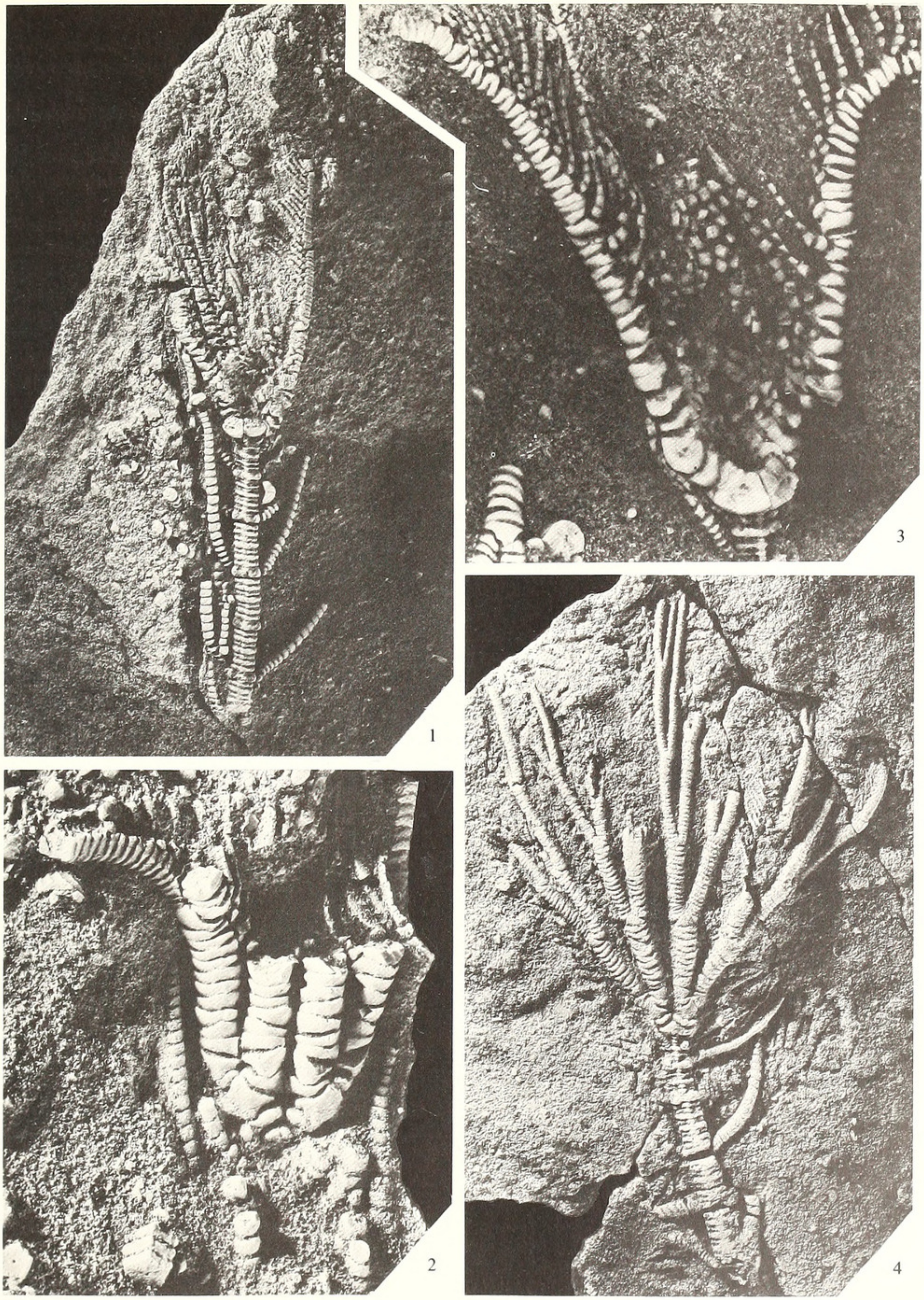
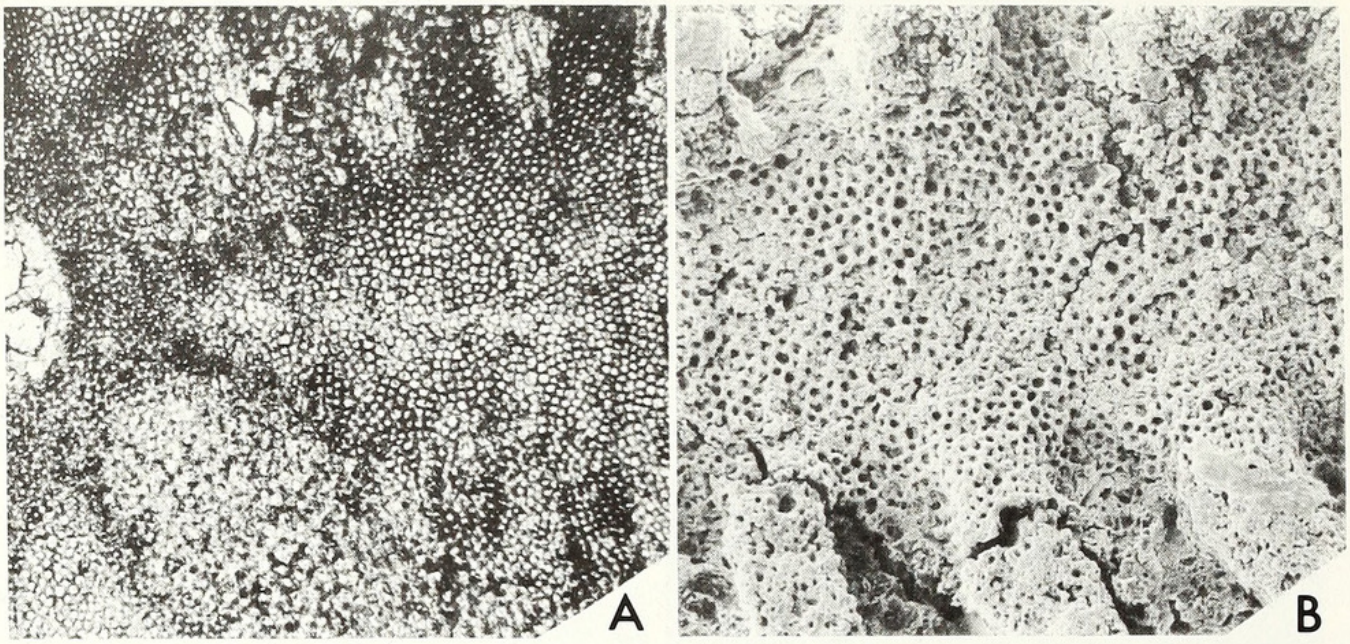
EXPLANATION OF PLATE 77

Figs. 1–4. *Isocrinus* (*Chladocrinus*) *hanaii* sp. nov., lower part of Hiraiga Formation, northern coast of Haipe. 1, ME6945, Loc. Hn 0916, paratype, × 1. 2, ME6936, Loc. Hn 0920, holotype, × 2. 3, ME6943, Loc Hn 0920, paratype, × 2. 4, ME6950, Loc. Hn 0916 or Hn 0920 (precise locality unknown), paratype, × 1.

Figs. 1, 2, and 4 whitened; Fig. 3 submerged in water.



OJI, *Isocrinus* (*Chladocrinus*)



TEXT-FIG. 4. Stereom in columnal; note rounded meshes of α-stereom. A, *Isocrinus* (*Chladocrinus*) *hanaii* sp. nov. from Loc. Hn 0920, light micrograph of thin section of columnal, cut transversely near surface, × 57. B, *I.* (*C.*) sp. cf. *I.*? *neocomiensis* (Desor), ME6962 from Loc. Oj 5825-2, SEM micrograph, × 95 (treated in HF following the method of Sevastopulo and Keegan 1980).

especially on the shape of the meshes of the α-stereom. The two species of *Isocrinus* (*Chladocrinus*) from the Miyako Group are characterized by rounded-polygonal to rounded meshes, and fall into his Isocrininae (text-fig. 4). The controversy surrounding the classification of the Isocrinidae, especially regarding the recognition of reliable taxonomic criteria, remains unsolved.

Isocrinus (*Chladocrinus*) *hanaii* sp. nov.

Plate 77; Plate 78, figs. 1–5, 7, 8; Plate 79, figs. 1–7; text-fig. 4A

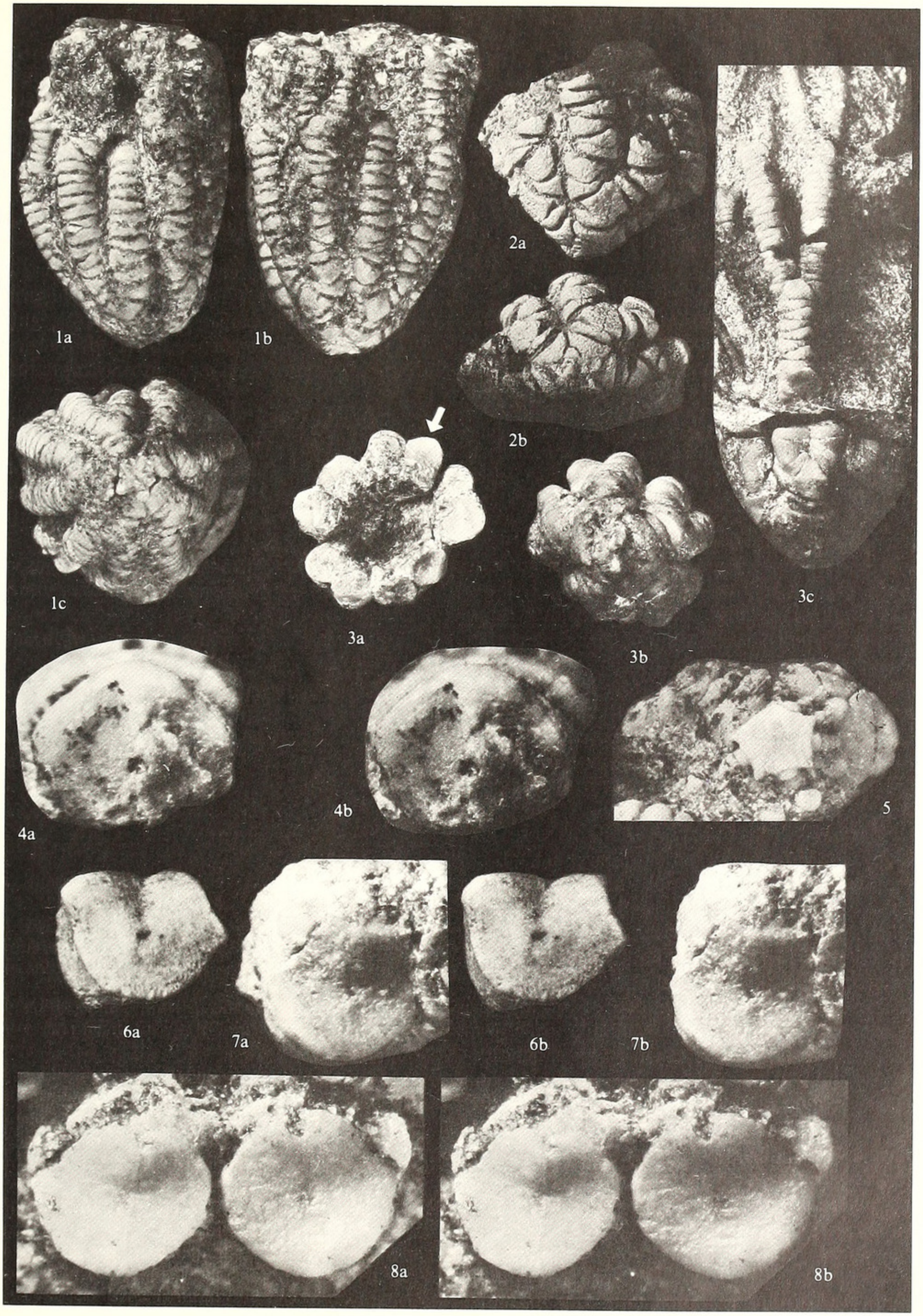
1913 *Pentacrinus*, Yabe and Yehara, pp. 12, 13.
1913 *Pentacrinus*(?), Yabe and Yehara, p. 17.
1954 *Isocrinus*, Kobayashi *et al.*, p. 309.
1966 *Isocrinus* sp., Masutomi and Hamada, p. 143, pl. 72, fig. 3.
1982 *Isocrinus* sp., Tamura, p. 20, table 1.

Diagnosis. Medium- to small-sized species of *Isocrinus* (*Chladocrinus*) characterized by very low and tumid columnals, and by regular distribution of slightly embayed cryptosyzygy between the third and fourth brachials in each brachitaxis.

EXPLANATION OF PLATE 78

Figs. 1–5, 7, 8. *Isocrinus* (*Chladocrinus*) *hanaii* sp. nov., lower part of Hiraiga Formation, Matsushima islet in Moshi (Locs. Hn 4151, Hn 4153), and on northern coast of Haipe (Oj 7543). 1, ME6962, Loc. Hn 4153, paratype in lateral (*a*, *b*) and dorsal (*c*) views, × 2. 2, ME6964, Loc. Hn 4151, paratype in lateral (*a*) and dorsal (*b*) views, × 2. 3, ME6949, Loc. Oj 7543, in ventral (*a*), dorsal (*b*), and lateral (*c*) views, × 2; arrow indicates one of distal facets of $IIBr_3$ (also shown in Fig. 7). 4*a*, *b*, ME6955, Loc. Oj 7543, paratype, stereo pair of distal facet of IBr_1, synarthry, × 8·5. 5, ME6955, Loc. Oj 7543, paratype in ventral view, × 4. 7*a*, *b*, ME6949, Loc. Oj 7543, paratype, stereo pair of distal facet of $IIBr_3$, × 8·2. 8*a*, *b*, ME6954, Loc. Oj 7543, paratype, stereo pair of distal facet of $IIBr_3$, × 10.

Fig. 6. *Isocrinus* (*Chladocrinus*) sp. cf. *Isocrinus*? *neocomiensis* (Desor), ME6974, Loc. Oj 5825-2, proximal facet of brachial, × 8·3.



OJI, *Isocrinus* (*Chladocrinus*)

Types. ME6936, holotype, well-preserved crown and column from Loc. Hn 0920 (Pl. 77, fig. 2). ME6937–6959, paratypes from Locs. Hn 0915, Hn 0916, Hn 0920, and Oj 7543, northern coast of Haipe. ME6960–6964, paratypes from Locs. Hn 4151, Hn 4153, and Oj 0257, Moshi. All the types are housed in the University Museum, University of Tokyo.

Description. Cup bowl-shaped, low, and wide. Basals small, triangular, and separated on surface. Radials low and broad, with smooth and evenly curved dorsal surface. Articular facet for IBr inclined 50–60°. Dorsal ligament fossa relatively large, approximately one half as large as the articular facet.

Arms more slender towards distal ends, but almost uniform in diameter within each brachitaxis. Nearly isotomous branching until fourth axillary (IVAx). In paratype ME6950, after IVAx, one of two VBrr forks to form VIBrr, and the other remains undivided (Pl. 77, fig. 4). If there is no further division of arms distally and every brachitaxis follows such a pattern of ramification, the finials can number 120. Brachial plates generally thin and smooth on surface. IBr_1 very thin. Articulation IBr_{1-2} embayed synarthrial (Pl. 78, fig. 4). On dorsal surface, distal facet of IBr_1 slightly concave and in contact with strongly convex proximal facet of IBr_2. IBr_2 axillary. Dorsal surface of IBr_2 nearly rhombic in outline, a little wider than high. Secundibrachials twelve or thirteen, rarely eleven or fourteen in number. $IIBr_1$ strongly wedge-shaped. Articulation $IIBr_{1-2}$ embayed synarthrial as between IBr_{1-2}. $IIBr_2$ a little higher than the other secundibrachials. First pinnules on $IIBr_2$. $IIBr_{2-3}$ oblique muscular. $IIBr_3$ and $IIBr_4$ wedge-shaped, a little thinner than the other secundibrachials. Articulation $IIBr_{3-4}$ slightly embayed cryptosyzygial, showing nearly straight suture on dorsal surface. Distal facet of $IIBr_3$ smooth and marginal crenulation invisible (Pl. 78, figs. 7, 8). Ligamentary articulation of this kind developed between third and fourth brachials of every brachitaxis, with only one exception (one secundibrach of ME6962). Tertibrachials seventeen, nineteen, or twenty-one in number. Quartibrachials twenty-one or twenty-five, rarely thirty-seven. Proximal pinnules composed of approximately ten pinnulars, which are rectangular in lateral view.

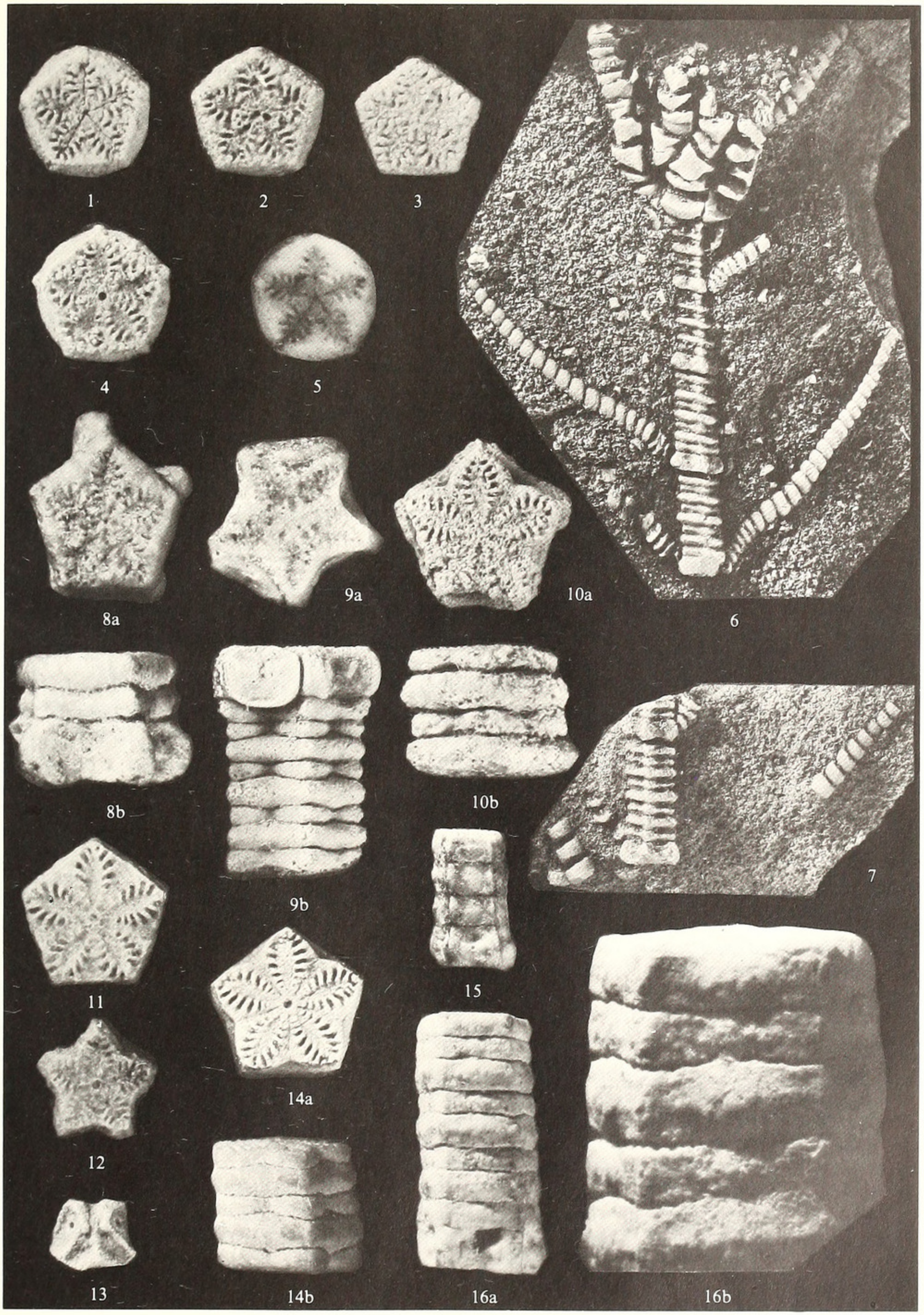
Column short and slender; proximal part highly variable in diameter but gradually modified distally to uniform diameter. Distal part slightly larger than the proximal part. Internodal plates low and tumid, with pentagonal to rounded subpentagonal outline in transverse section. Suture almost straight on surface. Articular facet of columnals petaloid; floors subguttiform, outwardly a little broad, surrounded by culmina and crenellae. Crenulae vary in size from the adradial to the marginal position, with the greatest length between radial and marginal areas. Culmina small in number for the diameter; two or three along margin, three or four along radius in columnals of diameter 4·1 mm. Canal narrow and rounded. Number of internodal plates seven or eight, rarely nine in the distal part. Radial pore developed in the proximal part of paratype ME6947, but otherwise absent. Nodal plates higher (approximately twice as high as internodal), wider, and more stellate in outline than internodal. Interradial edge sharp and arched. Articulation between nodal and infranodal synostosial. Periphery of the distal facet of nodal slightly raised. Cirrus sockets always five in number, large and wide, occupying almost entire height and width of lateral side of nodal, but not interfering with adjacent columnals. Articular ridge of cirrus socket weakly protruding with slightly tuberculated triangular ends. Proximal cirral plates thin and disc-shaped, with circular to slightly ovate outline in transverse section. Height of cirral plates suddenly increases distally in several plates, becoming almost as high as wide. Articular ridge slightly raised, canal passing a little above the centre.

EXPLANATION OF PLATE 79

Figs. 1–7. *Isocrinus* (*Chladocrinus*) *hanaii* sp. nov., lower part of Hiraiga Formation, northern coast of Haipe. 1–5, Loc. Hn 0920, articular facets of columnals, all ×5; 1 and 5, ME6956, paratype; 2, ME6957, paratype; 3, ME6958, paratype; 4, ME6959, paratype. 6, ME6942, Loc. Hn 0920, paratype, lateral view of column, cirri, and crown, ×2. 7, ME6947, Loc. Hn 0916, paratype, proximal column and cirri, ×2.

Figs. 8–16. *Isocrinus* (*Chladocrinus*) sp. cf. *Isocrinus*? *neocomiensis* (Desor), Tanohata Formation. 8, ME6965, Loc. Oj 5813, northern coast of Hiraiga, articular facet (*a*) and lateral view (*b*) of columnals, ×4. 9, ME6966, Loc. Oj 5813, northern coast of Hiraiga, articular facet (*a*) and lateral view (*b*) of columnals, ×4. 10, ME6967, Loc. Oj 7517, northern coast of Haipe, articular facet (*a*) and lateral view (*b*) of columnals, ×4 11, ME6968, Loc. Oj 5827-2, northern coast of Hiraiga, articular facet of internodal plate, ×5. 12, ME6969, Loc. Oj 5827-2, northern coast of Hiraiga, articular facet of nodal plate, ×5. 13, ME6970, Loc. Oj 5827-2, northern coast of Hiraiga, underside view of radial plate, ×4. 14, ME6971, Loc. Oj 5825-2, northern coast of Hiraiga, articular facet (*a*) and lateral view (*b*) of columnals, ×4. 15, ME6972, Loc. Oj 5825-2, lateral view of column, ×5·9. 16, ME6973, Loc. Oj 5825-2, lateral views of column, (*a*) ×4, (*b*) ×9·9.

Figs. 1–4, 9*b*, 10*a*, 13, and 14*a* whitened; Fig. 5 submerged in water.



OJI, *Isocrinus* (*Chladocrinus*)

Discussion. The description above is based on material from Haipe and Moshi. Specimens from the two areas are considered conspecific because of the agreement (or strong similarity) in form of the dorsal cup and brachials, the arrangement of ligamentary articulation, and the pattern of ramification. Relatively complete specimens from Haipe are almost uniform in size, and may represent an adult stage. On the other hand, those from Moshi include relatively small columns which may represent a younger stage; these columns show a more pronounced alternating variation in diameter and columnals are higher with respect to the diameter. Columns of *I.* (*C.*) *hanaii* sp. nov. almost lack radial pores and crenulated sutures between columnals, suggesting that their rate of the accretionary growth was high.

I. (*C.*) *hanaii* sp. nov. is similar to *N. australis australis* (C. Moore) and *N. a. albascopularis* (Etheridge) from the lower Cretaceous of Australia in the form of the crown (Moore 1870, pl. 3, figs. 1–3; Etheridge 1901, pl. 1, fig. 4, pl. 3, figs. 1–3; Etheridge 1902, pl. 4, figs. 7–10) but the surface of the radials and brachials of *I.* (*C.*) *hanaii* sp. nov. is smooth in contrast to the rugose surface of theca and brachials of *N. australis* (which has, in addition, higher IBr_2 and more strongly wedge-shaped $IIBr_1$).

I. (*C.*) *hanaii* sp. nov. is distinguished from *Percevalicrinus aldingeri* Klikushin (Rasmussen 1961, pl. 10, figs. 1–11 as *N. tenellus* (Eichwald); Klikushin 1981, pl. 9, figs. 1, 2) by the more tumid columnals of the former which show an alternating variation in diameter in the proximal part of the column. The present species is also distinguished from *P. tenellus* (Eichwald) from the lower Cretaceous of the USSR (Klikushin 1979, pl. 11, fig. 5; text-fig. 1*d*) by the latter's regular arrangement of meshes in the α-stereom.

There are many species of isocrinids which are tentatively assigned to *Isocrinus* only on the basis of stem elements (e.g. Rasmussen 1961). *I.* (*C.*) *hanaii* sp. nov. differs from all of these Cretaceous species in having strongly tumid columnals with a smooth lateral surface.

Although the Miyako examples from calcareous sandstone have been subjected to secondary precipitation of calcite around the ossicles, and the details of the articular facets are more or less obscured, they often retain an almost complete crown and most of the original pattern of ramification. In paratype ME6962 the number of secundibrachials is exceptionally small, eleven in one brachitaxis; this is probably related to the absence of ligamentary articulation at $IIBr_{3-4}$ in the brachitaxis. No apparent regeneration has been observed in any of the material.

Isocrinus (*Chladocrinus*) sp. cf. *Isocrinus*? *neocomiensis* (Desor)

Plate 78, fig. 6; Plate 79, figs. 8–16

1961 *Isocrinus*? *neocomiensis* (Desor); Rasmussen, p. 143, pl. 18, figs. 4, 5.

Material. ME6965 and 6966, columns from Loc. Oj 5813, northern coast of Hiraiga. ME6967, column from Loc. Oj 7517, northern coast of Haipe. ME6968–6970, columnals and a radial plate from Loc. Oj 5827-2, northern coast of Hiraiga. ME6971–6974, columns and brachials from Loc. Oj 5825-2, northern coast of Hiraiga.

Description. Brachials smooth on dorsal surface. A brachial (epizygal) with slightly convex and almost smooth proximal facet of cryptosyzygial articulation, as in $IIBr_{3-4}$ of *I.* (*C.*) *hanaii* sp. nov. (ME6974; Pl. 78, fig. 6). Marginal crenulation inconspicuous.

Column fairly constant in diameter in the small- and medium-sized specimens ME6972 and 6973, slightly variable in diameter in the larger specimens ME6965–6967 and 6971). In the small specimen ME6972, column pentagonal in section, with columnals almost uniform in height and diameter. In the larger column ME6973, a row of a few tubercles is aligned horizontally on the side of a large columnal, and also along the suture. In still larger columns, the kind most commonly represented, internodals are a little tumid and slightly variable in diameter; larger columnals are almost pentagonal and higher compared with smaller ones, which are slightly stellate to pentalobate and less high (ME6965–6967 and 6971). Internodals eight in number. Articular facet of columnals with subguttiform floors surrounded by culmina and crenellae. Crenulae with gradual transition in size from adradial to marginal position, attaining greatest length between radial and marginal areas. Culmina seven or eight in number in a column of diameter 5·7 mm. Canal narrow and rounded. Nodal plate higher, wider, and more stellate in outline than internodal plates, especially in large specimens. Cirrus sockets five in number, large and wide, occupying almost the entire height and width of lateral side of nodal. Articular ridge weakly protruding with slightly tuberculated triangular ends. Articular ridge of cirral plate weakly raised, with canal passing a little above centre.

Remarks. This species is assigned to the subgenus *Chladocrinus* because of the slightly convex cryptosyzygial articular facet of the epizygal. Small- and medium-sized columns with longitudinal ridge and tubercles are strongly reminiscent of *I.*? *neocomiensis* (Desor) from the Hauterivian of France (Rasmussen 1961, pl. 18, figs. 4, 5), which is represented only by columns. The present species, however, occurs in younger strata (upper Aptian). Because the brachial plates of *I.*? *neocomiensis* from Europe are unknown, strict specific identification is difficult.

The present species resembles *I.* (*C.*) *hanaii* sp. nov. in the form of its brachial plates (especially in the facet of ligamentary articulation) but differs in that its succeeding columnals show little or no variation in diameter and tubercles are present on the lateral side of small- to medium-sized columns.

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