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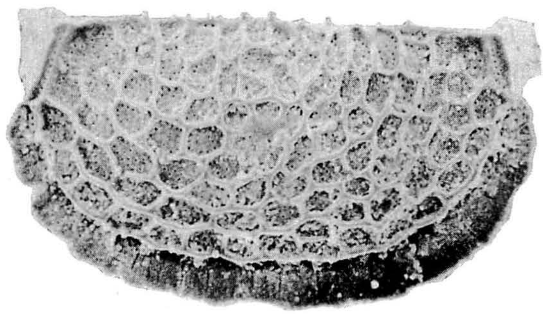

日本古生物学会

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October 15, 1984

The ostracod carapace on the cover is an adult specimen of *Manawa konishii* NOHARA (Suborder Palaeocopina, Family Punciidae) from the East China Sea. (photo by K. ABE, x190)

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782. ONTOGENESIS OF *EHMANIELLA BURGESSENSIS* RASETTI (TRILOBITA) FROM BURGESS SHALE, MIDDLE CAMBRIAN, YOHO PARK, BRITISH COLUMBIA*

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Abstract. The present report describes the ontogenic development of a Middle Cambrian trilobite: *Ehmaniella burgessensis* Rasetti from the Burgess Shale, Yoho Park, British Columbia. The morphogenesis of this trilobite during its early growth stages are similar to those of *Sao hirsuta* Barrande, *Crassifimbra walcotti* (Resser), *Glyphaspis* cf. *parkensis* Rasetti, *Yuknessaspis santaquinensis* Hu, *Trymataspis convexus* Hu, and *Ehmaniella* sp. etc. whereas in the late ontogenic stage the instars are similar to most of its fellow member except for those of *Crassifimbra walcotti* and *Trymataspis convexus*. These phenomena possibly indicate that these trilobites are derived from the same common ancestor but differentiated into different groups in later descendants.

Introduction

In the late summer of 1981, the author has an opportunity to participate in a field trip to the southern Canadian Rocky Mountains, Alberta and British Columbia area. During this field trip a few small pieces of black shale — the Burgess Shale — were collected from the Walcott Quarry, Mount field, Yoho Park, British Columbia. These small piece of black shale yield very abundant larval instars of *Ehmaniella burgessensis* Rasetti. These show very well preserved ontogenetic sequences of this trilobite.

The purpose of this report is to describe the ontogenetic developmental stages of *Ehmaniella burgessensis* and to compare these stages with those of the only known ptychoparioid trilobites from the Middle Cambrian: *Sao hirsuta* Barrande (Whittington, 1959), *Crassifimbra walcotti* (Resser) (Palmer, 1958), *Trymataspis convexus* Hu, *Yuknessaspis santaquinensis* Hu (1972), *Glyphaspis parkensis* Rasetti (Hu, 1971), and *Ehmaniella* sp. (Kopasks-Merkel, 1981), etc. and evaluate their phylogenetic relationships.

The result of this study shows that the morphology of these trilobites during their earlier ontogenic stages are very similar, but are differentiated into two different morphologic groups during their later stages; *i.e.*, *Ehmaniella burgessensis*, *Yuknessaspis santaquinensis*, *Glyphaspis* cf. *parkensis*, *Sao hirsuta*, *Ehmaniella* sp. as one, and *Trymataspis convexus*, *Crassifimbra walcotti* as another. This phenomenon suggests that they are all derived from a common ancestor and had a very close phylogenetic relationship but differentiated into separate phylogenic groups in later descendants.

The author wishes to express his thanks to Dr. J. D. Aitken, Geological Survey of Canada, Calgary, Alberta, for his guidance during the field trip to the Burgess Shale quarry, Yoho Park,

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British Columbia, 1981. Thanks are also go to Dr. K. E. Caster, the University of Cincinnati, for reading over the present manuscript and correcting the English text. The figured specimens are stored in the Geology Museum, University of Cincinnati, Ohio.

Systematic Paleontology

Genus *Ehmaniella* Resser, 1937

Type species: *Crepicephalus* (*Loganellus*) *quadrans* Hall and Whitfield, 1877

Ehmaniella burgessensis Rasetti

Pl. 76, Figs. 1-29; Text-fig. 1

Ptychoparia permulta Walcott, 1918, p. 145, pl. 21, fig. 1 (only).
Elrathia permulta (Walcott), Resser, 1937, p. 10.
Ehmaniella burgessensis Rasetti, 1951, p. 217, pl. 30, figs. 1-16.

Locality and horizon. The Walcott quarry, Mount Field, Yoho Park, British Columbia, Canada; Stephen Formation (Burgess Shale), *Bathyuriscus-Elrathina* Zone, Middle Cambrian (Aitken, 1981).

Ehmaniella burgessensis Rasetti, ontogeny

The present studied materials are all slightly deformed, and, therefore, the early larval instars assigned to a certain growth stage are somewhat arbitrary. Five ontogenic stages are recognized and described as follows:

Anaprotaspid stage (Pl. 76, Fig. 1 and Text-fig. 1A). The shield is round to oval in dorsal view, gently convex, and is about 0.25 to 0.35mm in sagittal length; it is distinctly divided into pleural lobes and axis by dorsal furrows; the forwardly expanded axis is composed of a large frontal lobe, two pairs of incompletely separated knobs, and small terminal portion; a pair of distinct pits is marked at the sides of the frontal lobe tetween the short eyebrow-shaped ridges and the palpebral crests; the pleural lobe is twice as wide as the axis, gently convex, and protruding into a pair of blunt saw-teeth at the posterolateral margin of the shield. The surface of the shield is possibly covered by faint granules; and one or two pairs of very faint cephalic furrows may be present on the pleural lobes.

At this stage some specimens show the axis with a median furrow and two pair knobs, but others are cylindrical without distinct axial segments. These phenomena may indicate different degrees of maturation within the same growth stage, i.e., within the same larval stage, some of individuals may have grown faster than others. The figured specimen is the smallest instar known from the studied material, and it seems reasonable to assign it to the earliest anaprotaspid stage.

This ontogenic stage is correlatable with those of *Yuknessaspis santaquinensis* Hu (1972), *Glyphaspis* cf. *parkensis* Resetti (Hu, 1971), and *Crassifimbra walcotti* (Resser) (Palmer, 1958) for all are of similar morphologic organization.

Metaprotaspid stage (Pl. 76, Figs. 2-4 and Text-fig. 1B). The shield is round to roundly quadrate in outline, moderately convex and measures from 0.35 to 0.50mm in length (sag.); the axis is made of five axial segments, of which the frontal segment is the largest and expanded forwardly, the following three segments are about equal in size, and the last one is a small terminal portion; a pair of short eyebrow-shaped ridges protrude laterally for a short distance from the anterolateral margin of the frontal lobe; the palpebral crest arches anterolaterally from the frontal pits and ends before it reaches the transverse mid-line of the shield; the pleural lobe is more or less twice the width of the axis. The surface of the shield is apparently granulate; there are faintly impressed cephalic grooves on the pleural lobe, and a narrow distinct marginal border present along the posterior half of the shield.

The morphogenesis of the present stage is marked by the absence of the median furrow, five faintly defined axial segments, and the shield has changed from oval to roundly quadrate in outline.

The morphologic features of this stage are comparable to those of *Crassifimbra walcotti* (Palmer, 1958), *Trymataspis convexus* (Hu, 1972), *Yuknessaspis santaquinensis* Hu, 1972, *Glyphaspis* cf. *parkensis* (Hu, 1971), early and late protaspis of *Ehmaniella* sp. (K. -Merkel, 1981). All of their instars possess a cylindrical axial lobe and a somewhat forwardly expanded frontal lobe; the protopygidium is not yet present, but there is a broad posterior shield margin.

Paraprotaspid stage (Pl. 76, Figs. 5-8 and Text-fig. 1C, D). The shield is made up either of a cephalic region and a transverse protopygidium or of the cranidium without a pygidium; it is subround to trapezoidal in outline, gently convex; the shield is 0.50 to 0.75mm in length (sag.); the axial lobe is strongly expanded from the first glabellar furrow and gently broadens posteriorly to the occipital ring; the paired eyebrow-shaped ridges and the palpebral crests are well demarked at the sides of the frontal lobe; the convex pleural lobe of the fixigenal area is less than twice as wide as the axis; the small protopygidium is lenticular and composed of one to two segments. The surface of the skeleton is covered by faint granules with coarse ones scattered among them.

In the morphogenesis of the present stage the protopygidium appears, the frontal pits have become shallower, the posterior fixigenal border increases in width, and the facial suture appears in the frontal half of the shield; the facial suture is short and convergently convex. The morphological characteristics of the present stage are comparable to those of *Yuknessaspis santaquinensis* Hu, 1972, *Glyphaspis* cf. *parkensis* (Hu, 1971), early meraspid stage of *Crassifimbra walcotti* (Palmer, 1958), and protaspides of *Sao hirsuta* Barrande (Whittington, 1959, fig. 88, A-D), and possibly early and late metaprotaspides of *Ehmaniella* sp. (K. -Merkel, 1981).

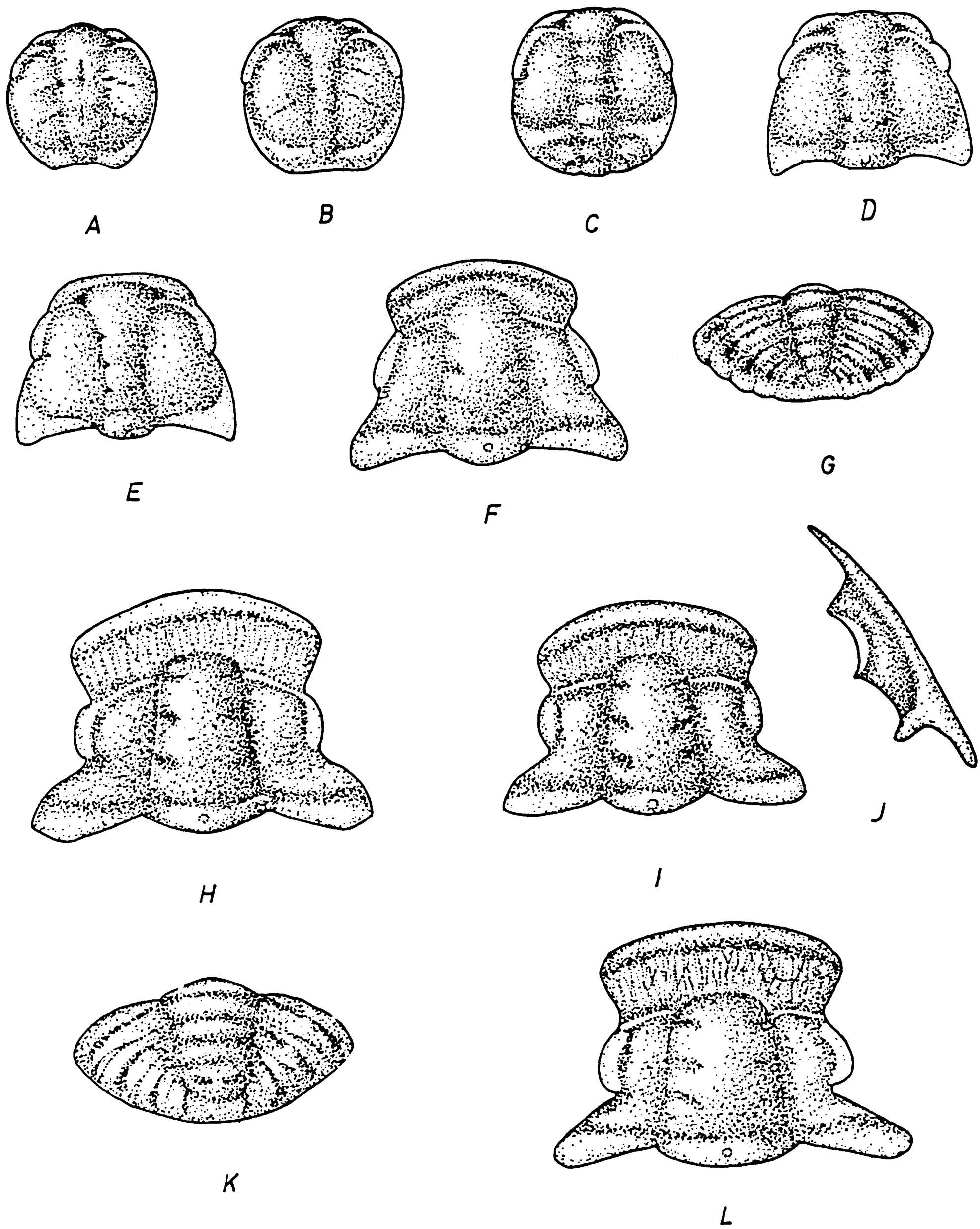
Early meraspid stage (Pl. 76, Fig. 9-11, 15, 19-22 and Text-fig. 1E). The cranidium is trapezoidal in outline with the anterior border slightly arched forwardly; about 0.75mm to 1.00mm in length (sag.); the glabella is oblong and expands both forwardly and posteriorly from the second segment; the glabellar furrows are incomplete and deepen laterally the while being shallow across the central line; the occipital ring is lenticular, convex, and bears a small median tubercle; the forwardly arched anterior border appears; it is narrow and makes contact at the anterior glabellar margin with a faint frontal furrow; the palpebral ridges are distinctly elevated and terminate with small palpebral lobes; the anterior facial suture line is convergently convex and the posterior suture line is divergently convex; the fixigenal area is the same width as the glabella and the posterior fixigenal border is less than twice as wide as that of the occipital ring; the skeletal surface is covered by faint granules and a few coarse ones are scattered among them.

The assigned pygidium is round to semicircular in outline, gently convex, and is made of five or six segments which are not ankylosed as a plate-like structure but freely articulated; the slenderly conical axial lobe tapers posteriorly and ends before reaching the posterior margin; the pleural lobe is approximately twice the width of the axis, and the pleural bands are arched uniformly and each ends into a blunt terminal spine; the intrapleural grooves are distinctly marked.

The special characteristics of this stage are that the anterior border first appears; the glabella becomes short and broader than in the previous stage; the facial suture-line cuts the cranidium into a trapezoidal shape, and the palpebral lobe moves short distance posteriorly from the anterior border.

This stage is equivalent to instars of equivalent age in *Yuknessaspis santaquinensis* Hu, 1972, *Trymataspis convexus* (Hu, 1972), *Glyphaspis* cf. *walcotti* (Hu, 1971), the middle meraspis of *Crassifimbra walcotti* (Palmer, 1958), and the stage E-G of *Sao hirsuta* (Whittington, 1959), and early meraspis of *Ehmaniella* sp. (K. -Merkel, 1981). They all have similar morphologic characteristics at this instar.

Late meraspid stage (Pl. 76, Figs. 12-14, 23, 26 and Text-fig. 1F,J). The cranidium is trapezoidal in outline, moderately convex; about 1.00 to 1.80mm in sagittal length; the glabella is oblong to truncato-conical, tapering slightly anteriorly with a gently expanded frontal margin; the glabellar furrows are complete; a narrow



Text-fig. 1. *Ehmaniella burgessensis* Rasetti.

A, an anaprotaspid shield, showing the broad axis and a median logitudinal furrow. ×60; B, a metaprotaspid shield, showing the narrow axis and the development of the axial segments. ×62; C, D, two paraprotaspid shields, showing the presence of the protopygidium and the trapezoidal cranidium. ×40; E, an early meraspid cranidium, showing the presence of the anterior border. ×25; F, a late meraspid cranidium, showing the narrow preglabellar field. ×13; G,J, a meraspid and a librigena, showing the freely articulated pygidial segments and the narrow librigenal platform. ×18, ×10; H.I, two "female" cranidia, showing the narrow glabella. ×4.5, ×3.5; K, an holaspid pygidium. ×5.5; L, a "male" cranidium, showing the broad glabella. ×3.5.

preglabellar field appears between the arched anterior border and the anterior glabellar margin; it is slightly depressed medially and gently convex laterally; the anterior suture lines are parenthetic and convex laterally; the posterior suture lines are divergent posterolaterally from the medium-sized sickle-shaped palpebral lobe. The surface of the skeleton is covered by both faint and coarse granules, and faint irregular or subparallel ridges are present on the preglabellar field and the fixigenae.

The assigned pygidium is made up of 3-5 segments, of which at least two or three are not ankylosed with the terminal plate but in freely articulated position; it is semicircular to round in outline, and about 0.5 to 1.0mm in length (sag.); the axial lobe is conical, tapering posteriorly and ends before reaching the posterior margin; the pleural lobe is about the same width as that of the axis, convex, and without a pygidial spines or saw-teeth, except that the anterior freely articulated thoracic segments are terminated by a pair of projections; deep intrapleural grooves and surface granules are distinctly marked along the pleural bands.

The assigned librigena of this stage is narrow crescentic and has the lateral border well defined by a lateral furrow; the anterolateral border is projected into a long sharply pointed spine and at the posterior end is a short genal spine; the ocular platform possesses a large palpebral ring and the surface is covered by both different size granules and faint radial ridges.

The morphogenesis of these late meraspid skeletons are: the narrow preglabellar field appears; the glabella becomes truncato-conical; the anterior facial suture increases in length and changes from convergently convex to parenthetic appearance; and the posterior fixigenal border decreases in width and becomes about the same width as that of the occipital ring.

The ontogenic development of the present stage is equivalent to that of the same aged instars of *Crassifimbra walcotti* (Palmer, 1958), *Trymataspis convexus* (Hu, 1972), *Yuknessaspis santaquinensis* Hu, 1972, "degree" 6-12 of *Sao hirsuta* (Whittington, 1959, fig. 88H, I), and late meraspis of *Ehmaniella* sp. (K. -Merkel, 1981, fig. 1F), but differs in some detailed morphologic structures. It appears that the late meraspid of *Trymataspis convexus* is morphologically very similar to that of *Crassifimbra walcotti*; both possess a conical, rather convex glabella and the same shaped cranidium. They show independent features from their fellow members and form a distinct group: that of *Yuknessaspis santaquinensis*, *Ehmaniella burgessensis*, *Ehmaniella* sp. (K. -Merkel), *Glyphaspis* cf. *parkensis*, and *Sao hirsuta*, all with a low convex cylindrical glabella and trapezoidal cranidium, forms another natural group.

Summary

The ontogenic development of *Ehmaniella burgessensis* Rasetti is described. The result of this study indicates that the morphogenesis during its early larval stages are very similar to that of *Trymataspis convexus* Hu, *Crassifimbra walcotti* (Resser), *Yuknessaspis santaquinensis* Hu, *Glyphaspis* cf. *parkensis* Rasetti, *Sao hirsuta* Barrande, and *Ehmaniella* sp. (K.-Merkel, 1981) but differentiated into two different groups during their late ontogenic period, *i.e.*, *Ehmaniella burgessensis*, *Glyphaspis* cf. *parkensis*, *Sao hirsuta*, and *Ehmaniella* sp. as a natural group, *Trymataspis convexus* and *Crassifimbra walcotti* is another. These phenomena are possibly the indication that these trilobites were derived from the same common ancestor but differentiated into separate groups with the passage of time and evolution.

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ブリティッシュコロンビア州ヨーホー公園の中期カンブリア紀 Burgess 頁岩産三葉虫 *Ehmaniella burgessensis* Rasetti の個体発生：ウォルコット採石場より採集した中期カンブリア紀の三葉虫 *Ehmaniella burgessensis* の個体発生を記載した。*E. burgessensis* の原楯期は *Sao hirsuta, Crassifimbra walcotti, Glyphaspis* cf. *parkensis, Yuknessaspis santaquinensis, Trymataspis convexus* 及び *Ehmaniella* sp. の原楯期と良く似る。しかしその中年期は二組の形態群に分けられる。即ち *E. burgessensis, Sao hirsuta, Glyphaspis* cf. *parkensis, Yuknessaspis santaquinensis, Ehmaniella* sp. が一組，*Crassifimbra walcotti* 及び *Trymataspis convexus* がもう一組である。この現象は，これらの三葉虫が共通の祖先より由来し，その後二つの異なる群に分かれたことを示すものであろう。 胡 忠 恒

Explanation of Plate 76

Figs. 1-29; *Ehmaniella burgessensis* Rasetti.

1. A poorly preserved anaprotaspis, showing the large frontal lobe and the indistinct axis. ×60.

2-4. Three metaprotaspides, showing the well demarked axis and the axial segments. 2, ×62; 3, ×62; 4, ×50.

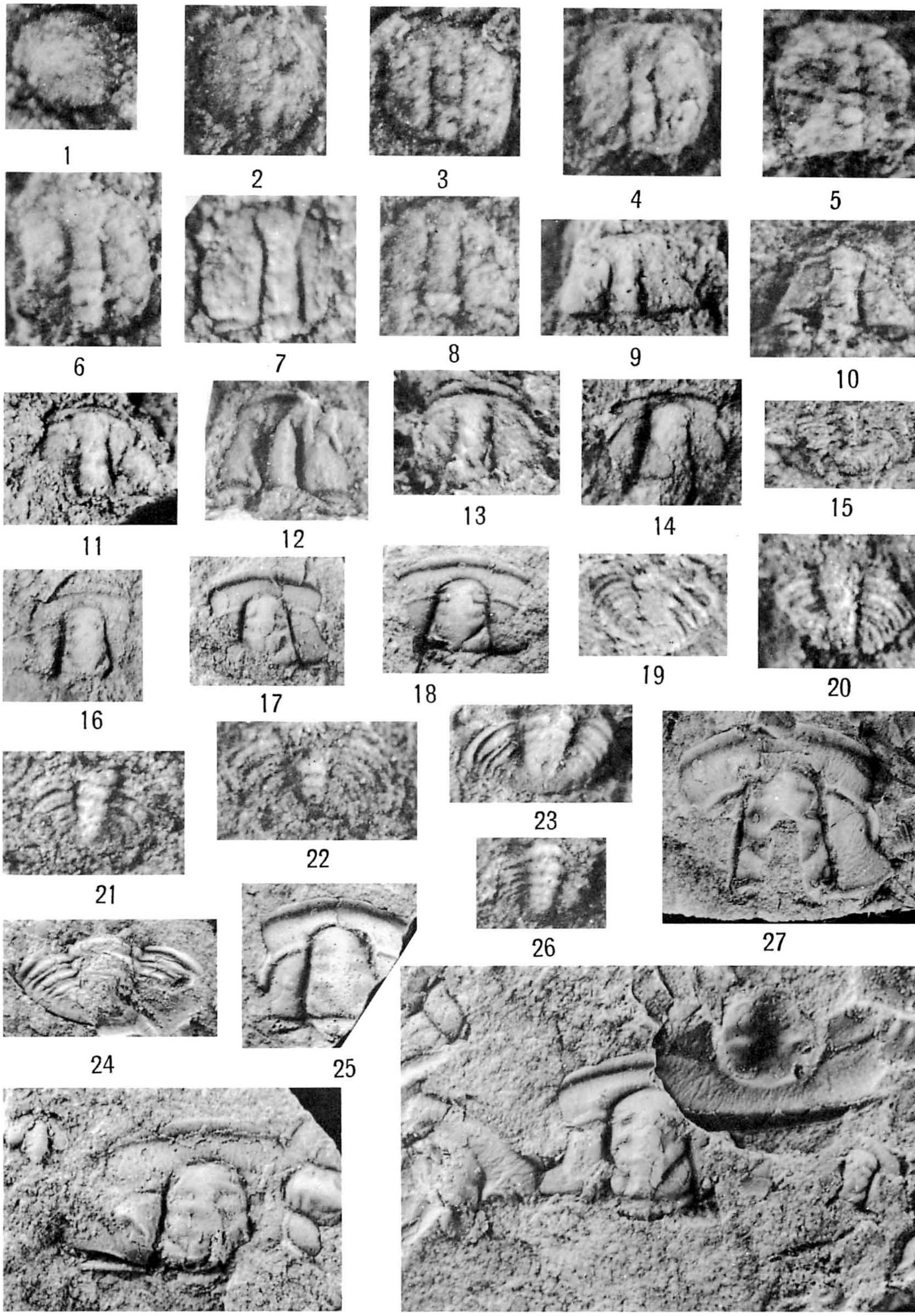
5-8. Paraprotaspides, showing the presence of the protopygidium. 5, ×30; 6, ×42; 7, ×26; 8, ×37.

9-11,15,19-22. A few early meraspid cranidia and pygidia, showing the narrow anterior border and the pygidium with freely articulated segments and without a pygidial plate. 9, ×23; 10, ×18; 11, ×21; 15, ×34; 20, ×30, 21, ×26; 22, ×18.

12-14,23,26. Late meraspid cranidia and pygidia, showing the preglabellar field and well ankylosed pygidial plate lying behind the freely articulated thoracic segments. 12, ×20; 13, ×22.5; 14, ×13.5; 23, ×15; 26, ×20.

16-18,25,27-29. Several small and large-sized cranidia, showing the morphologic varieties, *i.e.*, the subquadrate and quadrate cranidia, and truncato-conical and short oblong glabellae. 16, ×9; 17, ×5.5; 18, ×6.5; 25, ×4.5; 27, ×3.6; 28, ×3.5; 29, ×6.5.

24. A partly broken pygidium, showing the complete left margin. ×5.5.



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783. MIDDLE-LATE EOCENE PLANKTONIC FORAMINIFERAL FAUNAS FROM LIMESTONES OF THE SETOGAWA GROUP, CENTRAL JAPAN*

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Abstract. Several thick limestone layers are exposed in the Setogawa terrain. Well-preserved planktonic foraminifers were recovered from most of these limestone layers. Planktonic foraminifers consisting of a total of 23 species were discovered at seven limestone localities and in one mollusca-bearing sandstone of the Setogawa Group. These limestones of the Setogawa Group are assignable to three different horizons corresponding to Blow's zones of P. 12 to P. 13, P. 14 and P. 16, and are dated to range from the Middle to Late Eocene.

Introduction

The Setogawa Group, which is extensively exposed in the central part of Shizuoka Prefecture, Central Japan, has been regarded to be of Paleogene age based on such sporadically occurring fossils as *Discocylina* (Ishii and Makino, 1946), molluscs (Mizuno, 1956; Iwasaki and Ono, 1977; Matsumoto, 1966, 1971), a Paleogene-type globorotaliid (Asano, 1962a), Eocene nannoplankton (Honjo and Minoura, 1968; Iijima et al., 1981), and Late Oligocene radiolarians (Iijima et al., 1981). However, some Early to Middle Miocene radiolarians, have also been reported from southern exposures of this group (Iijima et al., 1981). There have been few studies on planktonic foraminifers from this group mainly because of its strongly deformed geologic structure and strongly indurated lithofacies.

Recently, the present author discovered Middle Eocene planktonic foraminifers from a mollusca-bearing calcareous sandstone and limestone bed slightly above the sandstone in the Setogawa Group at Ashikubo (Ibaraki, 1983). Several thick limestone layers in the Setogawa terrain have been found to yield well-preserved planktonic foraminifers after subjecting them to some kind of treatments of acid. This is a report on these planktonic foraminiferal faunas with which assignment of geologic age is attempted to the limestones.

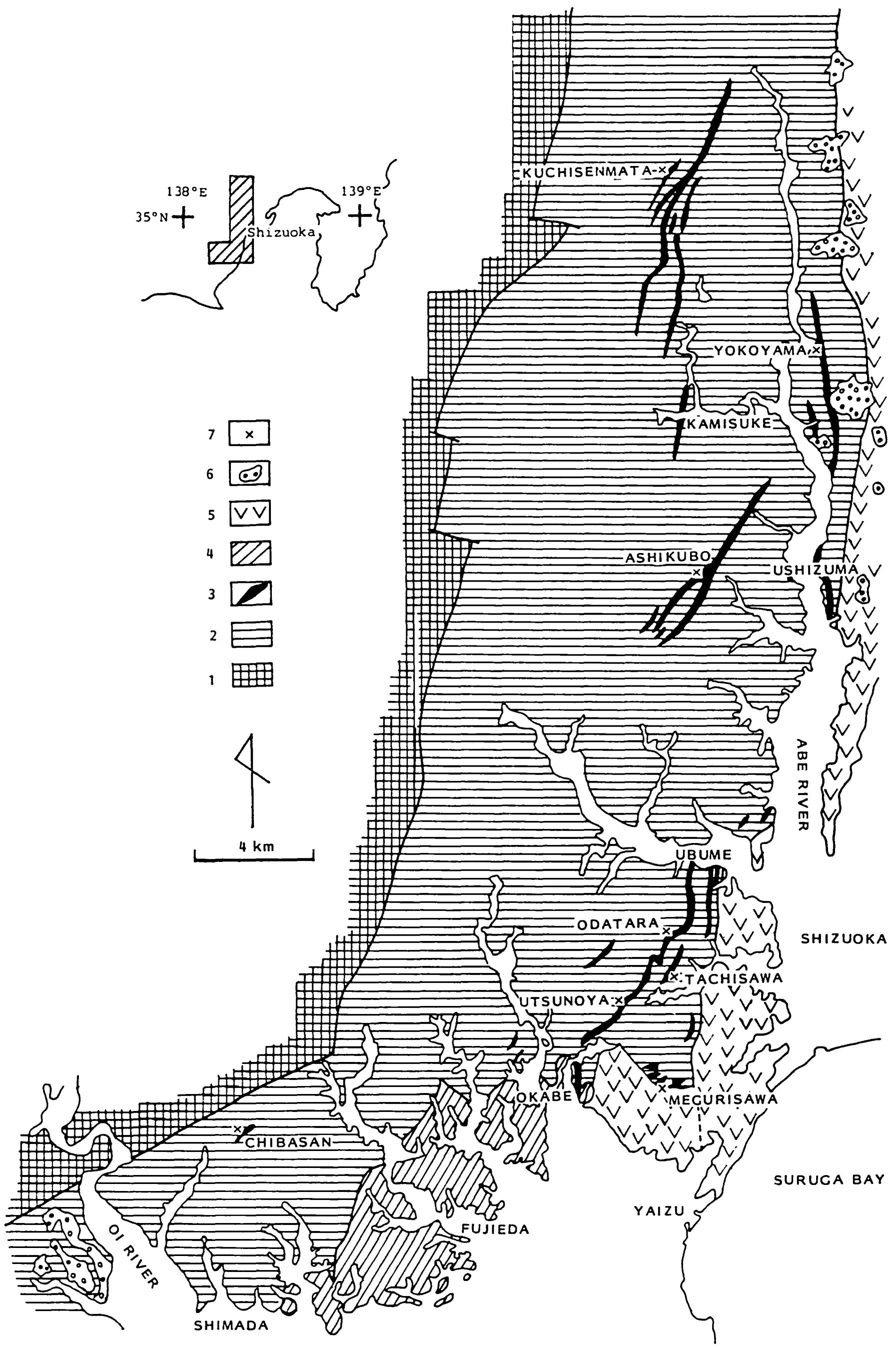
Acknowledgements

I am grateful to Professor Ryuichi Tsuchi of our university for his kind advice about the geology of the Setogawa Group and reviewing the manuscript. Deepest appreciation is also due to Professor Tsunemasa Saito of Yamagata University who gave helpful suggestion about the identification of planktonic foraminifers and read the manuscript.

Notes on the Stratigraphy of the Setogawa Group with Special Reference to Limestone Layers

The Setogawa Group consists mainly of alternating beds of sandstone and shale, which

* Received June 17, 1983.



Text-fig. 1. Index and location map of limestone layers in the Setogawa Group. (mainly after Sameshima (1960) and Tsuchi et al. (1973))
1. Mikura Group (or Shimanto Group), 2. Setogawa Group, 3. limestone, 4. Oigawa Group, 5. Ryuso Group, 6. terrace deposit, 7. sampling locality.

are more than 1000m in thickness, and is frequently intercalated with chert, limestone, basaltic lavas, and pyroclastic and ultrabasic rocks. This group exhibits strongly folded structure with a general NE-SW structural trend.

The group has been classified stratigraphically into three formations; namely, Ichinose, Takisawa and Tentokuji in upward sequence by Chitani (1931), Makiyama (1963) and Tokuoka (1964). However, Ono (1973), Tokuyama (1974), and Sugiyama and Shimokawa (1981) divided it into three formations, Sakasagawa, Takisawa and Tentokuji (or Yoshizu).

Several thick limestone layers, which are exposed in various localities, have been included in the Takisawa Formation by most of these authors, though some limestones were considered by Wada (1976) to belong to the lower part of the group, and by Iijima et al. (1981) to be intercalations at various horizons within the group.

The distribution of these limestone layers is shown in Fig. 1, largely on the basis of geological maps of Shizuoka Prefecture (Sameshima (1960) and Tsuchi et al. (1973)). Typical exposures of these limestone layers occur from north to south at Kuchisenmata, Kamisuke, Yokoyama, Ushizuma, Ashikubo, Ubume, Odatara, Utsunoya, Okabe, Tachisawa, and Chibasan.

Sampling and Treatment of Materials

Samples of limestone were collected from the above-mentioned typical outcropping areas, and at each locality about ten samples representing slightly different limestone lithologies were collected for the examination of planktonic foraminifers.

Rocks were crushed into a small pebble size and soaked in a 3% solution of either hydrochloric acid, or formic acid for several hours. Materials separated from the rock surface were then washed through a 200 mesh screen. In this way, a few identifiable specimens of planktonic foraminifers can be obtained from some of these limestones. During the course of acid treatment, solution was refreshed several times until a considerable amount of foraminiferal specimens were recovered. Planktonic foraminifers of about 30—200 individuals thus obtained were picked up from the residue and were examined with binocular microscope. It is interesting to note that planktonic foraminifers from these limestone are hardly deformed.

The present author was able to obtain planktonic foraminifers from most of the above-mentioned limestones and discussion of these foraminifers are given, for the sake of convenience, under the locality name of typical exposures of the limestones. These are: Kuchisenmata, Yokoyama, Ashikubo, Utsunoya, Megurisawa, Tachisawa and Chibasan.

Planktonic Foraminifers and their Geologic Ages

Planktonic foraminifers from seven limestones and one mollusca-bearing sandstone of the Setogawa Group consist of 23 species in total and their frequencies are shown in Table 1. Stratigraphic ranges to each species are based mainly on Blow (1969, 1979).

Ashikubo Limestone: As previously stated (Ibaraki, 1983), a mollusca-bearing calcareous sandstone at Ashikubo yielded such planktonic foraminifers as *Acarinina punctocarinata* and *Subbotina frontosa boweri*, which range from Zone P. 10 to P. 11 of Blow's zonal scheme, and *Subbotina pseudoeocaena* whose range spans from Zone P. 11 to P. 13. The mollusca-bearing horizon is, therefore, assigned to Zone P. 11 of an early Middle Eocene age. A limestone occurring a little above the mollusca-bearing horizon at Ashikubo was reexamined for planktonic foraminiferal content by taking additional samples. As a result, *Subbotina bakeri* and *Subbotina inaequispira* both of which range from Zone P. 8 to P. 13 and *Subbotina pseudoeocaena*, as mentioned above, were commonly recovered. No specimen of such species as *Subbotina frontosa boweri* and *Acarinina punctocarinata*, whose ranges are limited to Zone P. 10 to P. 11, could be found. Therefore, this limestone is most probably assignable to the Middle Eocene Zone P. 12 to P. 13, slightly younger than the mol-

Table 1. Occurrences of planktonic foraminifers from limestones and mollusca-bearing sandstone of the Setogawa Group.
1. Kuchisenmata, 2. Ashikubo, 3. Yokoyama, 4. Odatara, 5. Utsunoya, 6. Megurisawa, 7. Chibasan, 8. Tachisawa, 9. mollusca-bearing sandstone at Ashikubo.

Specific name Loc.	1	2	3	4	5	6	7	8	9
Acarinina boudreauxi Fleisher									R
Acarinina coalingensis (Cushman & Hanna)		R							R
Acarinina pseudotopilensis Subbotina									R
Acarinina punctocarinata Fleisher									A
Chiloguembelina cubensis (Palmer)				R		C		C	
Globigerina garavisi Bermudez								C	
Globigerina officinalis Subbotina			A	C	A	C		A	
Globigerina praebulloides praebulloides Blow								A	
Globigerina pera Todd			C		R		C	C	
Globigerinatheka index index (Finlay)		A	R					C	
Globigerinita echinata echinata (Bolli)		R				C			R
Globigerinita globiformis Blow & Banner								C	
Globorotalia insolita Jenkins			C		R		C		
Globorotalia spinulosa Cushman									C
Globorotaloides suteri Bolli			C						
Muricoglobigerina senni (Beckmann)			C				R		
Pseudohastigerina micra (Cole)	R	R	C	C	C	C	R		A
Subbotina bakeri (Cole)		C							
Subbotina frontosa boweri (Bolli)									A
Subbotina inaequispira (Subbotina)	R	C							C
Subbotina linaperta (Finlay)	C	A	A		C		C	A	C
Subbotina pseudoeocaena (Subbotina)	C	C							A
Truncorotaloides collactea (Finlay)		R	C		R	C			C

Frequency of occurrence: R. 1—2; C. 3—9; A. over 10 specimens.

lusca-bearing horizon.

Kuchisenmata Limestone: This limestone is located at the northernmost locality among the studied limestones of the Setogawa Group. It is a bedded limestone of about 30m in thickness. Although planktonic foraminifers are scarce, *Subbotina inaequispira* and *Subbotina pseudoeocaena* were recovered from this locality. Since this species composition resembles that of the Ashikubo Limestone, these limestones are likely to be of a comparable age.

Yokoyama Limestone: *Discocyclina* sp. was reported from this limestone (Ishii and Makino, 1946). The limestone is about 30m thick and contains abundant planktonic foraminifers. As specimens of *Truncorotaloides collactea* (Zone P. 10 to P. 14), *Muricoglobigerina senni* (Zone P. 8 to P. 14) and *Globigerina pera* (Zone P. 14 to P. 21) were commonly found, this limestone can be assigned to Zone P. 14 of the latest Middle Eocene age. The extinction of *Muricoglobigerina senni*, which is known in Zone P. 15 after Blow (1979), has been examined by Toumarkine (1978) and Keller (1983) at the top of Zone P. 14.

Utsunoya Limestone at Odatara and at Utsunoya: The distribution of this limestone extends in the area west of Shizuoka City from Ubume via Odatara to Utsunoya and Okabe. It is siliceous one, 40—80m thick and exhibits a dark gray color. At Odatara only three species were recovered. They are *Chiloguembelina cubensis* (Zone P. 13 to P. 22) and *Globigerina officinalis* (Zone P. 14 to P. 21). The locality of Utsunoya yielded specimens of *Truncorotaloides collactea* (Zone P. 10 to P. 14) and *Globigerina pera* (Zone P. 14 to P. 21). The limestone is thus correlated with Zone P. 14 of the latest Middle Eocene age.

Megurisawa Limestone: Some small limestone lenses occur scatteringly near Megurisawa north of Yaizu. They are dark gray silty limestones of about 5m in thickness. From one of the lenses, *Truncorotaloides collactea* and *Globigerina officinalis*, were obtained, suggesting the latest Middle Eocene Zone P. 14 age for this limestone lens.

Chibasan Limestone: This limestone is exposed to the northwest of Chibasan and this is the westernmost outcrop of the limestones studied from the Setogawa Group. It is a dark gray silty limestone of about 10m in thickness. As the limestone yields *Globigerina pera* and *Muricoglobigerina senni*, it is also assigned to Zone P. 14 of the latest Middle Eocene age.

Tachisawa Limestone: This limestone crops out at a locality a little east of the Utsunoya Limestone. Planktonic foraminifers recovered include *Globigerina praebulloides praebulloides* (Zone P. 16 to P. 17), *Globigerinatheka index index* (Zone P. 11 to P. 16) and *Subbotina linaperta* (Zone P. 4 to P. 16). This limestone is, therefore, assigned to Zone P. 16 of a Late Eocene age.

In summary, planktonic foraminifers from the limestones of the Setogawa Group establish three different age assignment covering a Middle to Late Eocene interval (Fig. 2); the Ashikubo and Kuchisenmata Limestones belonging to Zone P. 12 to P. 13, the Yokoyama, Utsunoya, Megurisawa and Chibasan Limestones belonging to Zone P. 14, and the Tachisawa Limestone belonging to Zone P. 16. It seems, therefore, that geologic ages of the limestones of the Setogawa Group, except for the southeasternmost one, become younger in a general northwest-to-southeast direction.

The Middle Eocene planktonic foraminiferal faunas in Japan have been reported by Asano (1962b) from the Kyoragi Formation and other beds in Amakusa Island, and by Saito (1962) from the *Nummulites*-bearing Tuff and some other rocks in Hahajima Island. These faunas bear some resemblance to those of the Setogawa Group. The fauna of the Kyoragi Formation includes *Subbotina frontosa boweri* (reported as *Globigerina boweri*), which is one of age diagnostic species of the mollusca-bearing sandstone at Ashikubo assigned to Zone P. 11. The Hahajima Island fauna contains such species as *Truncorotaloides collactea* (reported as *Globigerina collactea*) and *Muricoglobigrina senni* (reported as *Sphaeroidinellopsis senni*), both of which are found in the Yokoyama Limestone assigned to Zone P. 14.

Recently, Keller (1983) has pointed out three major faunal changes of planktonic foraminifers during Middle to Late Eocene, which indicate cooling episodes, respectively. The ages of the limestones of the Setogawa Group are, however, corresponding just to warmer intervals prior to those cooling episodes.

Systematic Description of Diagnostic Species

Family Globorotaliidae

Genus *Acarinina* Subbotina, 1953

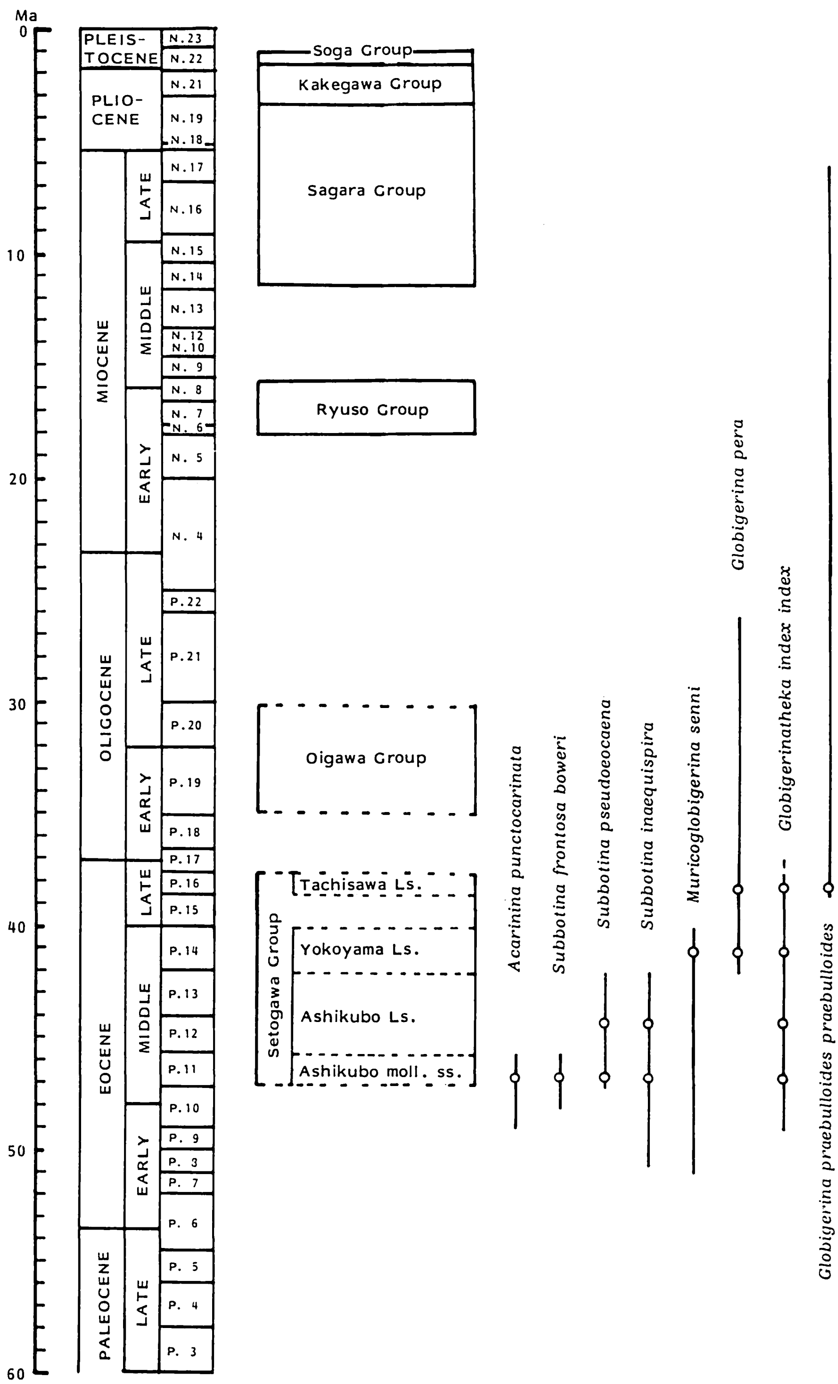
Acarinina punctocarinata Fleisher, 1974

Pl. 77, Figs. 1a—c, 2b

Acarinina punctocarinata Fleisher, 1974, p. 1014, pl. 3, figs. 4—8.

This species was originally described by Fleisher, based on materials obtained from Hole 220, core 12, section 5, 70—72cm, DSDP, Leg. 23.

Fleisher (1974) placed this species under the genus *Acarinina*, on the basis of its external form and coarsely punctate character of the pseudocarina. The most characteristic feature of the species is its distinct and thickened pseudocarina consisting of coalesced pseudospines along the peripheral margin and extending over a short



Text-fig 2. Chronologic positions of limestones of the Setogawa Group. Vertical ranges and occurrences of age diagnostic planktonic foraminifers are also indicated.
The Paleogene time scale is that given by Hardenbol and Berggren (1978) and that of the Neogene is given by Tsuchi et al. (1981)

distance along dorsal intercameral sutures; test typically subquadrate, a low trochospire, with four or five chambers in the final whorl; chambers broadly wedge-shaped in ventral side view.

The genus *Acarinina* was first recognized by Subbotina (1953) as that was distinguishable from *Globigerina* and *Globorotalia* in having an inflated *Globigerina*-like chamber without a peripheral keel. Recent authors accept this genus to represent those species ranging in age from Paleocene to Middle Eocene. Most of the species possess a broadly planoconvex test with pseudo carina.

According to Fleisher (1974), this species has a limited stratigraphic range from Zone P. 10 to P. 11 in the lower Middle Eocene. The species occurs commonly in the mollusca-bearing sandstone at Ashikubo.

Genus *Truncorotaloides* Bronnimann and Bermudez, 1953

Truncorotaloides collactea (Finlay, 1939)

Pl. 78, Fig. 6a

Globorotalia collactea Finlay, 1939, p. 327, pl. 29, figs. 164—165.
Globigerina collactea (Finlay). Bronnimann, 1952, p. 13—14, pl. 1, figs. 13—15; Bolli, 1957, p. 72, pl. 15, figs. 21—23; Saito, 1962, p. 216, pl. 32, figs. 12a—c.
Acarinina rotundimarginata Subbotina, 1953, p. 234, pl. 25, figs. 1—3.
Truncorotaloides collactea (Finlay). Jenkins, 1971, p. 134, pl. 14, figs. 402—407.

This species was first described as belonging to the genus *Globorotalia*. Afterward, it was placed in the genus *Globigerina* or sometimes in the genus *Truncorotaloides*. Recent authors place this species in the genus *Truncorotaloides* (Jenkins, 1971; Fleisher, 1974; Berggren, 1976).

The species is characterized by having five hispid to weakly spinose chambers in the final whorl, which are almost equal in size. The species has been reported from the *Nummulites*-bearing Tuff in Hahajima (Saito, 1962).

Family Globigerinidae

Genus *Globigerina* d'Orbigny, 1826

Globigerina officinalis Subbotina, 1953

Pl. 77, Figs. 4a, c

Globigerina officinalis Subbotina, 1953, p. 87, pl. 11, figs. 1—7.

According to Subbotina (1953), one of the characteristic features of this species is the shape and size of the last hemispherical chamber which may occupy as much as one half of the total volume of the test. Test small, a low trochospire being composed of three tightly coiled whorls. The last whorl has four chambers which increase rapidly in size as added and are clearly delimited from each other by a deep suture. The species occurs commonly in most of the studied limestones of the Setogawa Group.

Globigerina praebulloides praebulloides Blow, 1959

Pl. 77, Figs. 5a, b

Globigerina praebulloides Blow, 1959, p. 180—181, pl. 8, figs. 47a—c, pl. 9, fig. 48.
Globigerina praebulloides praebulloides Blow. Blow and Banner, 1962, p. 92, figs. O-Q.

This species is the ancestral form of *Globigerina bulloides* d'Orbigny (Banner and Blow, 1959), being characterized by its four chambers in the last whorl; test subtrapezoidal in outline, and bears a low-arched aperture with a thin rim-like lip, being different from *Globigerina bulloides* d'Orbigny.

The species has a long stratigraphic range from the upper Eocene to Middle Miocene and has been reported from many other localities in Japan.

Globigerina pera Todd, 1957

Pl. 78, Figs. 1a, c

Globigerina pera Todd, 1957, p. 301, pl. 70, figs. 10—11.

This species is characterized by having three chambers in the last whorl, being triangular in the outline of test, and having a supplementary chamber which extends from the periphery onto the umbilicus. The species resembles *Catapsydrax dissimilis*. However, the distinction between these two species lies in the shape of supplementary chamber. In *Catapsydrax dissimilis*, it is like a bridge over the umbilicus and has an opening on both sides. In the present species, it is like a pocket which has only one opening.

Genus *Globigerinatheka* Bronnimann, 1952

Globigerinatheka index index (Finlay, 1939)

Pl. 78, Fig. 2a

Globigerinoides index Finlay, 1939. p. 125, pl. 14, figs. 85—88.
Globigerapsis index (Finlay). Bolli, 1957, p. 165, pl. 36, figs. 14—18; Blow and Banner, 1962, p. 124—125, pl. 15, figs. g—h; Saito, 1962, p. 221, pl. 32, figs. 9—10.
Globigerinatheka (*Globigerapsis*) *index index* (Finlay). Jenkins, 1971, p. 187—188, pl. 22, figs. 641—645.
Globigerinatheka index index (Finlay). Bolli, 1972, p. 124, figs. 51—57, 63—64, pl. 1, figs. 1—4, 6—7.

This species was first described under the genus *Globigerinoides* from the Middle Eocene of New Zealand. In 1957, Bolli, Loeblich and Tappan discriminated a new genus *Globigerapsis* from *Globigerinatheka* Bronnimann on account of the lack of a small angular bullae covering the secondary apertures in the latter genus. In 1970, Proto Decima and Bolli included *Globigerapsis* in the genus *Globigerinatheka*. This species is characterised by having three spherical chambers in final whorl and more deeply incised sutures. It has also been reported from the Eocene of Hahajima (Saito, 1962).

Genus *Globigerinita* Bronnimann, 1951

Globigerinita globiformis Blow and Banner, 1962

Pl. 78, Figs. 3a, c

Globigerinita globiformis Blow and Banner, 1962. p. 108—109, pl. 14, figs. S—U.

Test globose, tightly coiled a low trochospire, having four chambers in the last whorl. This species is characterized by its umbilicus and primary aperture which are completely covered by a broad inflated bulla. The bulla is strongly vaulted on the ventral side.

Genus *Muricoglobigerina* Blow, 1979

Muricoglobigerina senni (Beckmann, 1953)

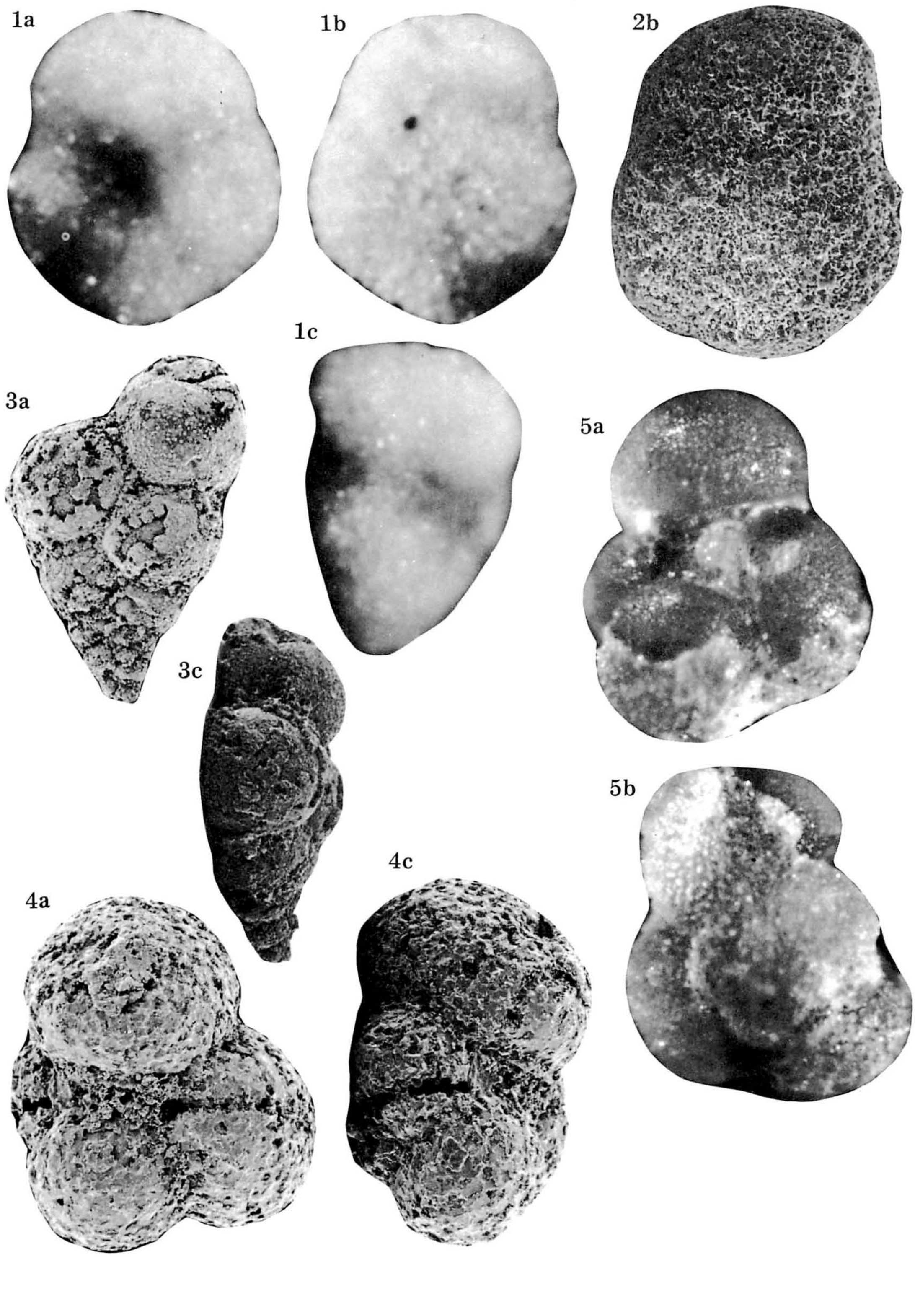
Pl. 78, Figs. 4a, b

Sphaeroidinella senni Beckmann, 1953, p. 394—395, pl. 26, figs. 2—4.
Globigerina senni (Beckmann). Bolli, 1957, p. 163, pl. 35, figs. 10—12.
Sphaeroidinellopsis senni (Beckmann). Saito, 1962, p. 218, pl. 34, figs. 3—5.
Muricoglobigerina senni (Beckmann). Blow, 1979, p. 1131, pl. 131, figs. 7—9; pl. 142, figs. 7—9, pl. 146, figs. 9—10, pl. 165, fig. 8, pl. 236, figs. 1—4.

Explanation of Plate 77

a: umbilical view, b: dorsal view, c: side view

Figs. 1a, b, c; 2b. *Acarinina punctocarinata* Fleisher
Loc. mollusca-bearing sandstone at Ashikubo. 1a, b, c, x270; 2b x 200
Figs. 3a, c. *Chiloguembelina cubensis* (Palmer)
Loc. Tachisawa L.s. 3a, c. x 300
Figs. 4a, c. *Globigerina officinalis* Subbotina
Loc. Yokoyama L.s. 4a, c x 180
Figs. 5a, b. *Globigerina praebulloides praebulloides* Blow
Loc. Tachisawa L.s. 5a, b x 115


1a
1b
2b
1c
3a
5a
3c
5b
4c
4a

This species was originally described under the genus *Sphaeroidinella*. In 1957, Bolli placed it in *Globigerina* because of the absence of sutural supplementary apertures and chamber flange. Saito (1962) placed it in the genus *Sphaeroidinellopsis*, because it has a well developed crenulate flange along apertural margins and because Banner and Blow (1959) established a new genus *Sphaeroidinellopsis* which is distinct from *Sphaeroidinella* by the absence of supplementary sutural apertures. Afterwards, Blow (1979) placed it in the new genus *Muricoglobigerina* by its characteristic muricate wall. Here present author adopts Blow's concept of the genus *Muricoglobigerina*.

This species has a very tightly-coiled test showing an almost globular to elongated globular globigerine appearance. The last whorl has four chambers which increase rapidly in size as added. Under the microscope, the surface of the test has a coated appearance reminiscent of *Sphaeroidinella* or *Sphaeroidinellopsis*. The species has been reported from the Eocene of Hahajima (Saito, 1962).

Genus *Pseudohastigerina* Banner and Blow, 1959

Pseudohastigerina micra (Cole, 1927)

Pl. 78, Figs. 5a, c

Nonion micrus Cole, 1927, p. 22, pl. 5, fig. 12.
Globigerinella micra (Cole). Subbotina, 1953, p. 122, pl. 8, figs. 16a—b, 17.
Hastigerina micra (Cole). Bolli, 1957, p. 161, pl. 35, figs. 1—2.
Pseudohastigerina micra (Cole). Banner and Blow, 1959, p. 19—20, figs. 4g—i, Saito and Be, 1964, p. 704, fig. 2; Berggren et al., 1967, p. 271, fig. 9.
Globanomariina micra (Cole). Loeblich and Tappan, 1964, p. C655, fig. 531, nos. 5—8.

This species was originally described as *Nonion micrus*. Planispirally coiled planktonic foraminifers are known in the Cretaceous, Tertiary and also Recent. Early authors have assigned planispiral species to such genera as *Globigerinella* Cushman, 1927 and *Hastigerina* Thomson, 1876. The genus *Pseudohastigerina* was erected by Banner and Blow (1959), and was placed in the subfamily Planomalinae. Loeblich and Tappan (1964) considered *Pseudohastigerina* to be a junior synonym of *Globanomalina* Haque, 1956, and placed it in the subfamily Hastigerinae. Berggren et al. (1967) discussed the evolution of early members of the genus *Pseudohastigerina* from the ancestral *Globorotalia champmani* and placed it in the subfamily Hastigerinae. Planispirally coiled Paleogene planktonic foraminifers have mostly been included in the genus *Pseudohastigerina*. Recent authors accept *Pseudohastigerina* as the valid genus for this species.

Test involute, bilaterally symmetrical; with six or seven chambers in the last whorl which rapidly increase in as added; sutures depressed, initially almost radial, and it becomes increasingly curved in the younger part of test; aperture, a low interiomarginal equatorial arch, extending along the base of apertural face and embracing an earlier whorl, with lip and partial flanges. The species occurs commonly in most of the limestones of the Setogawa Group.

According to Stainforth et al. (1975), *Pseudohastigerina micra* is relatively rare in the Middle to Late Eocene assemblages of tropical and subtropical areas where species diversity is high. However, it may be a dominant form in Eocene higher latitudes assemblages and in Oligocene assemblages of both higher and lower latitudes.

Genus *Subbotina* Brotzen and Pozaryska, 1961

Subbotina frontosa boweri (Bolli, 1957)

Pl. 79, Figs. 1a, 2b, 3a

Globigerina frontosa Subbotina, 1953, p. 84, pl. 12, figs. 3—7.
Globigerina boweri Bolli, 1957, p. 163, pl. 36, figs. 1—2.
Subbotina frontosa boweri (Bolli). Blow, 1979, p. 1266, pl. 175, figs. 7—9, pl. 179, fig. 9, pl. 184, figs. 8—9.

This species was first described as belonging to the genus *Globigerina* from the basal Middle Eocene of northern Caucasus. After that, Brotzen and Pozaryska (1961) recognized the genus *Subbotina* separate from the genus *Globigerina* d'Orbigny (1826) on account of its reticulate surface. Afterwards, Jenkins (1971) accept it as a subgenus of *Globigerina*. Recent authors, however, have accepted the genus *Subbotina* as a valid name (Fleisher, 1974; Mckeel and Lipps, 1975; Blow, 1979).

Test subquadrate; final whorl composed of three strongly inflated chambers, the last chamber is hemispherical and is readily distinguishable from others by its exceptionally large size and characteristic shape; aperture large, with arched lip opening into umbilicus. The species occurs commonly in the mollusca-bearing sandstone at Ashikubo.

Subbotina inaequispira (Subbotina, 1953)

Pl. 79, Figs. 4a, 5a, b

Globigerina inaequispira Subbotina, 1953, p. 69–70, pl. 6, figs. 1–4.
Subbotina inaequispira (Subbotina). Blow, 1979, p. 1272, pl. 151, figs. 5–7, pl. 163, figs. 4–10, pl. 177, figs. 3, pl. 180, figs. 1–7, pl. 185, fig. 9, pl. 186, fig. 1, pl. 191, fig. 7.

This species was originaly described as belonging to the genus *Globigerina*. Test low trochospiral, four chambers in the final whorl, with an arrangement of chambers same as that in the genus *Globigerinella*, aperture small and low arched; surface finely cancellate.

Subbotina linaperta (Finlay, 1939)

Pl. 79, Figs. 6a, 7a, b

Globigerina linaperta Finlay, 1939, p. 125, pl. 13, figs. 54–57.
Globigerina (Subbotina) linaperta Finlay. Jenkins, 1971, p. 162, pl. 18, figs. 551–554.
Subbotina linaperta (Finlay). Blow, 1979, p. 1276, pl. 91, fig. 8, pl. 124, fig. 9, pl. 158, fig. 8, pl. 160, figs. 6–8, pl. 177, figs. 4–6, pl. 240, figs. 5–6.

This species was originally described under the genus *Globigerina*. Test with cancellate wall surface; the last whorl generally composed of three and a half subglobular compressed chambers which increase rapidly in size as added; the final chamber is variable in size, but it is generally larger than the penultimate one. Aperture is low and large with a distinct lip. The species resembles *Subbotina frontosa boweri*, but the former is distinguished by its distinctive lip and compressed chamber. The species has a long stratigraphic range from Zone P. 4 to P. 16 according to Blow (1979). It has been reported from Paleogene sequences of Amakusa (Asano, 1962b) and Hahajima (Saito, 1962).

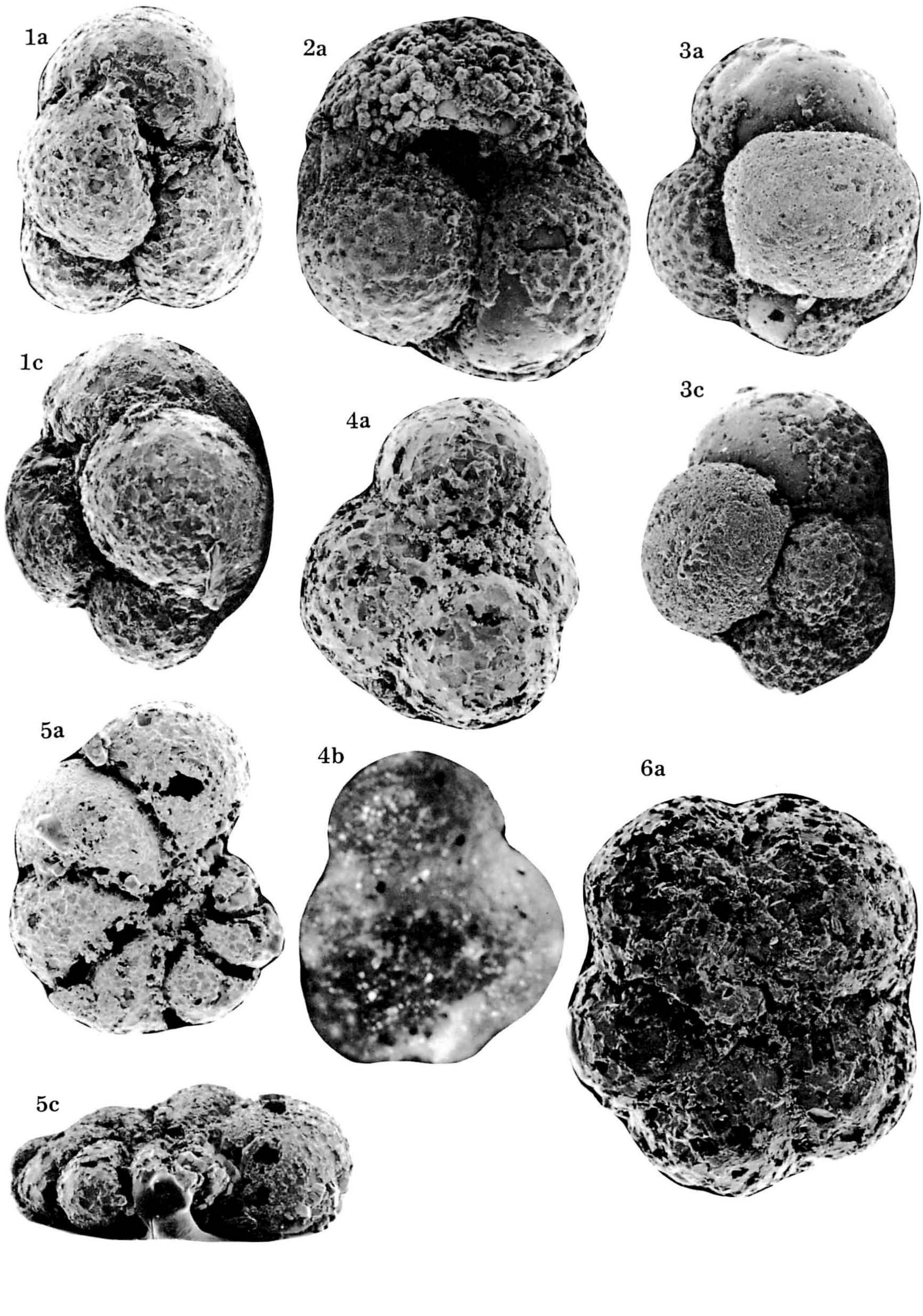
Subbotina pseudoeocaena (Subbotina, 1953)

Pl. 79, Fig. 8a

Explanation of Plate 78

a: umbilical view, b: dorsal view, c: side view

Figs. 1a, c. *Globigerina pera* Todd
Loc. Yokoyama L.s. 1a, c × 120
Fig. 2a. *Globigerinatheka index index* (Finlay)
Loc. Tachisawa L.s. 2a × 230
Figs. 3a, c. *Globigerinita globiformis* Blow and Banner
Loc. Tachisawa L.s. 3a, c × 180
Figs. 4a, b. *Muricoglobigerina senni* (Beckmann)
Loc. Yokoyama L.s. 4a & b, same sample, 4a, b × 190
Figs. 5a, c. *Pseudohastigerina micra* (Cole)
Loc. Yokoyama L.s. 5a, c × 170
Fig. 6a. *Truncorotaloides collactea* (Finlay)
Loc. Yokoyama L.s. 6a × 340


1a
2a
3a
1c
3c
4a
5a
4b
6a
5c

Globigerina pseudoeocaena Subbotina, 1953, p. 66, pl. 4, fig. 9.
Globigerina pseudoeocaena var. *pseudoeocaena* Subbotina, 1953, p. 66, pl. 4, fig. 9, pl. 5, figs. 1—2.
Subbotina pseudoeocaena (Subbotina). Blow, 1979, p. 1279, pl. 187, figs. 8—9.

This species was first described as belonging to the genus *Globigerina.* Test large, final whorl with four chambers, surface finely cancellate. The species superficially similar to *Subbotina inaequispira,* as suggested by Blow (1979) who considered the latter to be the ancestral form. Both species are, however, dinstinguishable by the size and arrangements of four chambers in the last whorl.

Morphotypes referable to *Subbotina pseudoeocaena* appear in a horizon assignable to Zone P. 11 and disappear in Zone P. 13 (Blow, 1979). This species is reported for the first time from Japan.

Family Heterohelicidae

Genus *Chiloguembelina* Loeblich and Tappan, 1957

Chiloguembelina cubensis (Palmer, 1934)

Pl. 77, Figs. 3a, c

Guembelina cubensis Palmer, 1934.
Chiloguembelina cubensis (Palmer). Beckmann, 1957, p. 89, fig. 14, nos. 5—8.

This species is characterized by having globular chambers which are biserially arranged.

Specimens of this species were recovered from limestones at Odatara, Megurisawa and Tachisawa, which are very small in size and are triangular in test form with eleven chambers. They have fine perforations on the surface.

Recently, this species has been reported from Oligocene sequences in some localities in Japan (Kaiho, 1981; Tsuchi et al., 1983).

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Explanation of Plate 79

a: umbilical view, b: dorsal view, c: side view

Fig. 1a. *Subbotina frontosa boweri* (Bolli)
Loc. mollusca-bearing sandstone at Ashikubo 1a x 190

Fig. 2b. *Subbotina frontosa boweri* (Bolli)
Loc. mollusca-bearing sandstone at Ashikubo 2b x 200

Fig. 3a. *Subbotina frontosa boweri* (Bolli)
Loc. mollusca-bearing sandstone at Ashikubo 3a x 170

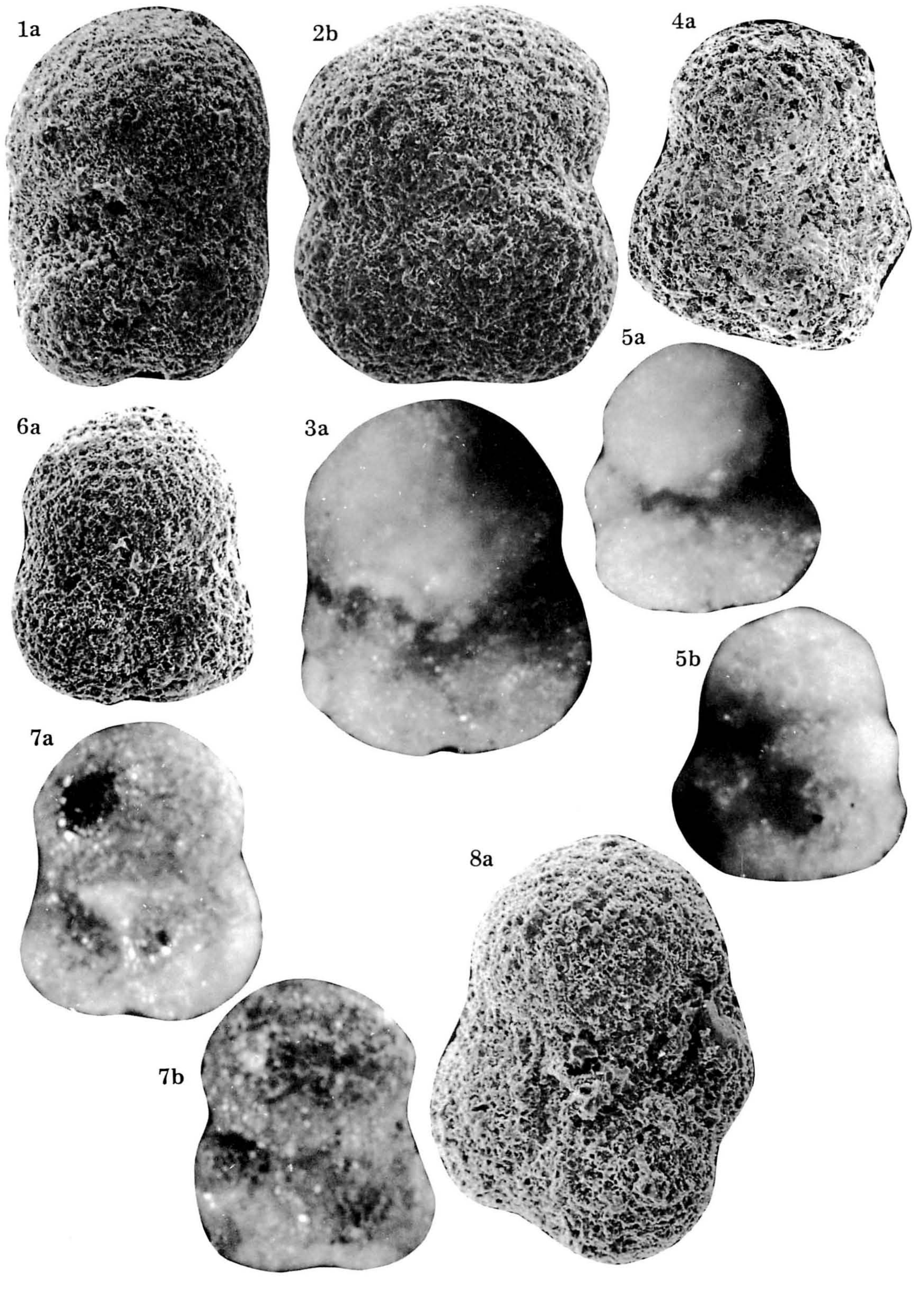
Fig. 4a. *Subbotina inaequispira* (Subbotina)
Loc. mollusca-bearing sandstone at Ashikubo 4a x 210

Figs. 5a, b. *Subbotina inaequispira* (Subbotina)
Loc. mollusca-bearing sandstone at Ashikubo 5a, b x 130

Fig. 6a. *Subbotina linaperta* (Finlay)
Loc. mollusca-bearing sandstone at Ashikubo 6a x 170

Figs. 7a, b. *Subbotina linaperta* (Finlay)
Loc. Yokoyama L.s. 7a, b x 220

Fig. 8a. *Subbotina pseudoeocaena* (Subbotina)
Loc. mollusca-bearing sandstone at Ashikubo 8a x 250


1a
2b
4a
5a
6a
3a
5b
7a
8a
7b

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瀬戸川層群の石灰岩層から産出した中・後期始新世の浮遊性有孔虫群：瀬戸川層群にはよく連続する石灰岩層が広く分布している。これらの石灰岩には，有孔虫などの微化石を含むことが知られていたが，石灰岩体から有孔虫を分離することがむずかしく，薄片による観察にとどまっていた。

今回，これらの石灰岩を塩酸または蟻酸で処理することにより，きわめて保存のよい浮遊性有孔虫を9地点から計23種得ることができた。足久保・口仙俣石灰岩のものは Blow (1969, 1979) の P. 12-13 帯（中期始新世），横山・宇津ノ谷・廻沢・千葉山石灰岩のものは P. 14 帯（中期始新世），立沢石灰岩のものは P. 16 帯（後期始新世）を示す。

その結果，瀬戸川層群には中期から後期始新世にわたる3層準の石灰岩層を含むことが明らかとなった。
茨木雅子

Trans. Proc. Palaeont. Soc. Japan, N.S., No. 135, pp. 415—426, October 15, 1984

784. URANIUM-SERIES AGE OF THE RIUKIU LIMESTONE ON HATERUMA ISLAND, SOUTHWESTERN RYUKYUS*

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Abstract. Uranium-series analyses of seventy-four coral samples imply that the Pleistocene Riukiu Limestone (Hanzawa, 1935) on Hateruma, Ryukyu Islands, were formed during at least four stages of high sea stand, two interstadials (ca. 81 and 103 ka B.P., respectively) and two interglacials (the last and penultimate ones). The oldest coral date was 300^{+40}_{-31} ka obtained from a *Porites* sample which was collected at a locality of about 33 m above the sea. Maybe this date is suggestive that the coral reef has already formed at the time of an another high sea stand (correlative to the stage 9 of the marine oxygen isotope record) in the place where the island is at present. The tidal flat around the coast of the island is likely to have been built since the last thousands years. The Riukiu Limestone on Hateruma is thus correlative with some of Pleistocene uplifted coral reefs on Barbados (Bender *et al.*, 1979), New Guinea (Bloom *et al.*, 1974) and Kikai (Konishi *et al.*, 1974) dated previously, and the tidal flat limestone with the Raised Coral Reef Limestone on Kikai (Ota *et al.*, 1978) and with the reef complex I on the Huon Peninsula, New Guinea (Bloom *et al.*, 1974).

Among marine terraces which were divided into eight steps (T1 through T8) by Ota *et al.* (1982), T2 and lower five terraces (T4 to T8) are inferred to be erosional in origin, based on the results of $^{230}Th/^{234}U$ age determination of corals which were collected on the same surface of the terraces. Ota *et al.* (1982) documented that the former shoreline of each terrace shows progressive westward tilting. The maximum uplift rate of approximate 0.3 m/ka is calculated in the eastern part of the island, assuming the constant rate of tectonic uplift and a sea level 6 m higher of the present one at the time of T3 terrace formation (ca. 128 ka B.P.). Accordingly, Hateruma is considered to have been situated tectonically in the compressive field since the last interglacial.

Introduction

The island of Hateruma is located in Lat. 24°02.4' to 24°04.0' N. and 123°45.1' to 123°48.6' E., southwestern end of Ryukyu Islands. It is roughly elliptical in shape having a length of about 5.9 km and a width of 2.9 km at its widest part and has an area of about 15 km^2. The island is flat as a whole, its highest point is 59.5 m above the sea, and staircase morphology is typically developed on it. The basement rock exposed at very limited small area on the island is dark bluish-gray colored siltstone, ranging in age from Upper Miocene to Pleistocene, which has been named the Shimajiri Group. This stratum is overlain by the reefy limestone which is a few to tens meters in thickness and covers almost all island.

After the initiative work of Hanzawa (1935) who divided into two time-stratigraphic units,

* Received Aug. 1, 1983;
read Jan. 23, 1983 at Tokyo

Pleistocene Riukiu Limestone and Holocene Raised Coral Reef Limestone, the limestone on Hateruma was classified into four morphostratigraphic units by Kawana and Oshiro (1978). They estimated by the ^{14}C method that their latest unit, the Surface IV, was formed approximately 30 ka (kilo anno = 1,000 years) B.P. By using the non-destructive $^{226}Ra/^{238}U$ dating technique, Konishi (1980) verified the first radiometric date of Middle Pleistocene from the raised coral reefs in the Ryukyu Islands area, for two coral samples from the Surface I and II of Kawana and Oshiro (1978), and revised the age estimation of Kawana and Oshiro for the Surface IV to be the last interglacial (ca. 120 to 130 ka B.P.). Emergent marine terraces on the island was recently subdivided into eight steps, T1 through T8, by Ota *et al.* (1982). They inferred, from the width of terraces, height of terrace riser, thickness and facies of limestone and presence of specific raised coral reef surface features, that only two terraces, T1 and T3, are constructive raised coral reefs formed in association with rising sea level, and that the other steps, T2 and T4 to T8, are erosional in origin. In addition, their conclusions founded on the results of the $^{230}Th/^{234}U$ dating for seven corals were that T3 was formed during the last interglacial and T1 during the preceding one. In the process of this study, the author has found and preliminarily reported the existence of limestone units which were formed during the times of two interstadials, ca. 80 and 102 ka B.P., respectively (Omura, 1983).

As stated above, age determination of the coralline limestone on Hateruma seems to have been under way little by little. The reliable radiometric dates, however, are definitely insufficient for age assignments of the entire limestone on the island and for correlation with those in other areas. The main aim of the present work is to gain enough numbers of $^{230}Th/^{234}U$ coral dates from Hateruma, as the most fundamental data, in order to discuss the tectonic history of the island and sea level change and relate them to various Pleistocene events in other areas.

Samples

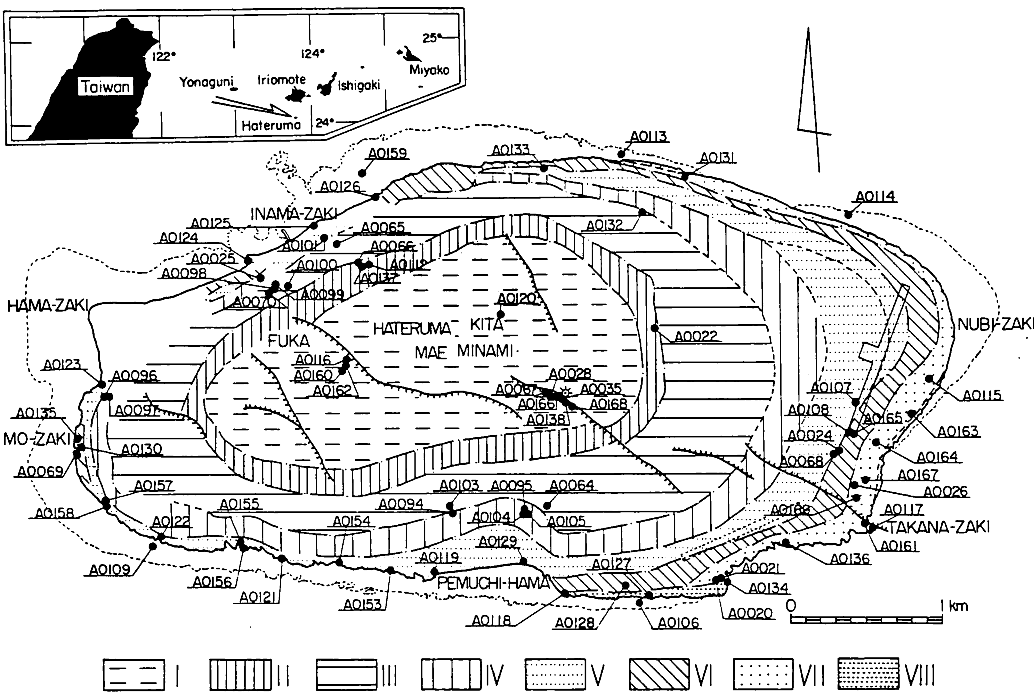
Seventy-four samples of hermatypic corals, which included ten genera, were chosen for dating purpose mainly from the reefy limestone on Hateruma Island, Southwestern Ryukyus. Among them, sixty-nine samples were taken from the Riukiu Limestone which was considered to be Pleistocene in age by Hanzawa (1935), and five from the limestone forming the present tidal flat around the coast of the island. Table 1 lists numbers, taxonomy and elevation of the samples analyzed in this study, and the terrace number of their localities, which were defined by Ota *et al.* (1982). The localities of all samples are plotted on the map showing their classification of geomorphic surface (Text-fig. 1).

Natural exposures of the Riukiu Limestone is very limited in number on the island except the coastal area, and therefore man-made outcrops like quarries, road-cuts and gullies, or even some gigantic masses of limestone dug in the cause of soil amendment were used effectively for field observation. However, they are not yet sufficient to examine geologically the Riukiu Limestone on Hateruma, based on the detailed litho- and biofacies analyses.

In the present study, coral samples for dating were collected as equably as possible from all of the morphostratigraphic units of Ota *et al.* (1982). Number of samples collected from each unit are shown in a figure (Text-fig. 2) mentioned later. Mode of occurrence and mineralogical nature of fossil corals were examined very carefully in the processes of searching coral samples suitable for dating. Most of samples for dating were selected, with some exceptions, from large-sized (more than 50 cm in diameter) coral colonies which were still in their original position of growth. One sample (A0131) was fair-sized (about 70 cm in diameter) but was apparently included as a gravel in non-reef facies (probably fore-reef facies) of limestone. Six samples (A0096, A0097, A0116, A0138, A0160 and A0162) could not be decided whether they are in situ or not. The field test for diagenetic altera-

Table 1. List of the fossil coral samples from the Riukiu Limestone on Hateruma. (KK-series samples were collected by Prof. K. Konishi of the Kanazawa Univ., OHB-series by Prof. Y. Ota of the Yokohama National Univ., Dr. N. Hori of the Hiroshima Univ. and Prof. A. L. Bloom of the Cornell Univ., and others were collected by the author himself. See Text-fig. 1 for the terrace number.)

Code Number	Sample Number	Genera	Elevation	Terrace
AO020	KK7807071-2		10 m	VII
AO021	KK7807071-3		10	VII
AO022	KK7807053-1	Cyphastrea	43	II
AO024	KK7807054-2		13	VI
AO025	KK7807051-2		9	III ?
AO026	KK7807084-1		8	VII
AO028	KK780706-2	Porites	48	I
AO035	81-11-28-1	Goniastrea	48	I
AO064	OHB801103-1	Porites	30	III
AO065	OHB801103-2	Porites	20	III
AO066	OHB801103-1	Porites	33	II
AO067	OHB801104-2	Goniastrea	48	I
AO068	OHB801104-8	Porites	15	V
AO069	OHB801105-3	Porites	5	VI
AO070	OHB801105-7	Porites	20	III
AO094	81-11-30-2	Porites	24	IV
AO095	81-12-5-2	Porites	23	IV
AO096	81-12-5-4	Porites	10	IV
AO097	81-12-5-5	Favites	10	IV
AO098	81-12-2-1	Porites	19	III
AO099	81-12-2-2	Porites	19	III
AO100	81-12-2-3	Porites	22	III
AO101	81-12-2-8	Porites	15	V
AO103	81-11-30-3	Porites	24	III
AO104	81-12-5-1	Porites	20	IV
AO105	81-12-5-3	Cyphastrea	18	IV
AO106	81-12-4-4	Favia	0	—
AO107	81-12-6-1	Porites	14	V
AO108	81-12-4-7	Porites	11	VI
AO109	81-12-1-2	Acropora	0	—
AO112	81-12-2-5	Porites	34	II
AO113	81-12-3-2	Goniastrea	0	—
AO114	81-12-3-4	Goniastrea	0	—
AO115	81-12-3-5	Goniastrea	3	VII
AO116	81-12-1-1A	Goniastrea	35	I
AO117	81-11-29-1	Leptoria	12	VII
AO118	81-11-29-7	Montipora	3	VIII
AO119	81-11-30-5	Porites	1	V
AO120	81-12-4-9	Goniastrea	43	I
AO121	81-11-30-8	Porites	5	V
AO122	81-12-1-3	Porites	3	V
AO123	81-12-5-6	Porites	2	V
AO124	81-12-2-4	Porites	3	VIII
AO125	81-12-2-7	Porites	4	V ?
AO126	81-12-2-9	Porites	3	VI ?
AO127	81-11-29-5	Montipora	4	VIII
AO128	81-11-29-6	Montastrea	7	VI
AO129	81-11-30-4	Porites	4	V
AO130	81-12-1-5A	Porites	2	VI
AO131	81-12-3-3	Porites	7	VII
AO132	81-12-3-1	Porites	26	III
AO133	81-12-2-10	Porites	8	V
AO134	81-11-29-4	Porites	8	VII
AO135	81-12-1-5B	Montastrea	3	VI
AO136	81-11-29-3	Porites	11	VII
AO137	81-12-2-6	Porites	32	II
AO138	81-12-4-1	Favites	48	I
AO153	81-11-30-6	Porites	3	V
AO154	81-11-30-7	Montipora	3	V
AO155	81-11-30-9A	Montipora	4	V
AO156	81-11-30-9B	Cyphastrea	4	V
AO157	81-12-1-4A	Porites	4	V
AO158	81-12-1-4B	Favia	4	V
AO159	81-11-30-1	Goniastrea	0	—
AO160	81-11-30-11	Platygyra	35	I
AO161	81-11-29-2	Porites	12	VII
AO162	81-12-1-1B	Goniastrea	35	I
AO163	81-12-3-6	Porites	3	VII
AO164	81-12-3-7	Platygyra	5	VII
AO165	81-12-4-8	Porites	11	VII
AO166	81-12-4-2	Goniastrea	48	I
AO167	81-12-4-5	Porites	7	VII
AO168	81-12-4-3	Goniastrea	48	I
AO169	81-12-4-6	Porites	7	VII



Text-fig. 1. Map showing the localities of fossil corals mentioned in this paper. (Roman numerals from I to VIII in the legend denote the terrace number of Ota *et al.*, 1982)

tion of a coral was to examine the existence of the secondary low-Mg calcite by the minute observation under a magnifier and the staining method using Feigl's solution. Ten genera listed in Table 1 are almost representatives of corals in reef facies of the Riukiu Limestone on Hateruma. *Porites* was the most predominant genus of all, due to its abundance and well-preservation in many exposures.

Uranium-Series Dating

Chemical and analytical procedures employed in uranium-series dating have been described previously (Omura, 1976). The coral fragments were mechanically cleaned, crushed into small (less than 5 mm in diameter) piecies, scrubbed ultrasonically in distilled water, dried in a drying furnace at low temperature (lower than 50°C), and ground to a fine (less than 200 mesh) powder. The concentration of uranium and thorium isotopes and the activity ratios of $^{234}U/^{238}U$, $^{230}Th/^{232}Th$ and $^{230}Th/^{234}U$ were measured by the alpha-spectrometry method, using a 4096 channels multi-channel pulse height analyzer coupled with four systems of silicon solid-state detectors. The Harwell spike solution of ^{232}U and ^{228}Th (Ivanovich and Warchal, 1981) was used as a yield tracer to check the overall chemical yield of uranium and thorium isotopes. The mineralogy of all specimens was examined with special care by X-ray diffraction analysis prior to the chemical treatment.

Results of the isotopic measurements on uranium and thorium are given in Table 2. The quoted errors are standard deviations (one sigma) derived from counting statistics.

Analyses of X-ray diffraction patterns proved that no or only a trace to 2 — 3 % low-Mg calcite was contained in all samples used here. Besides the mineralogical composition, it must be known whether the samples have been a closed system with respect to uranium and intermediate nuclides between ^{238}U and ^{230}Th.

The possibility of post-mortem addition or loss of uranium is considered from the age dependence of its concentration. There is, however, no systematic change in uranium concentration of the fossil corals with age (Table 2). It may, therefore, be safely said that the coral samples dated here have been closed system for uranium since the death of organisms. On the other hand, the $^{234}U/^{238}U$ activity ratios seem to decrease toward its secular equilibrium value of 1.00 with the ages of samples. This fact adds support to the inference that closed system respect to uranium isotopes has been held on throughout their diagenetic history.

$^{230}Th/^{234}U$ ages are calculated on the assumption that each sample was initially free of ^{230}Th. Such an assumption is supported by the observation that ^{232}Th concentrations in more than half samples in the table do not exceed the lower limit of detection (0.02 ppm). For the samples in which measurable amount of ^{232}Th was detected, ^{232}Th concentration is not much exceeding the limit, and furthermore the $^{230}Th/^{232}Th$ activity ratio is very much higher than those (1.4 to 3.0) in Ryukyuan present-day corals (Omura, 1976).

The above evidences suggest that all of the $^{230}Th/^{234}U$ ages in Table 2 are fully reliable.

Age and Correlation of the Riukiu Limestone on Hateruma

Barbados in the West Indies, the Huon Peninsula of New Guinea and Kikai in the Ryukyu Islands can be listed as the three major type localities for the Pleistocene coral reefs which have been chronologically studied by using the uranium-series dating techniques. The existence of several interstadials at intervals of approximately 20 ka, following the last interglacial, have been clearly vindicated in those regions by Bender *et al.* (1979), Bloom *et al.* (1974), Konishi *et al.* (1974) and others. In this paragraph, I attempt the age assignments of the Riukiu Limestone on Hateruma and the correlations of them with the counterparts in such areas.

As above-mentioned, it was extremely difficult to investigate the Riukiu Limestone in detail all over the island of Hateruma, because of the limited numbers of outcrops. That means the difficulty in minute facies analyses of the Riukiu Limestone which is overlaying the staircase topography of this island. For this reason, the nature and size of each reef complex could not be made clear in this study, although the Riukiu Limestone on Hateruma is very likely to be a composite of several reef complexes. Here, renaming the morphostratigraphic units defined by Ota *et al.* (1982) as Hateruma I, II, III, and so on, the ages of them are estimated and such units are correlated with the Pleistocene uplifted coral reefs reported from Barbados, Huon Peninsula and Kikai.

The $^{230}Th/^{234}U$ dates which are younger than the age (120 to 130 ka) of the last interglacial were obtained for the first time from the Riukiu Limestone on the other island than Kikai in the Ryukyu Islands region (Table 2). The other dates, except the oldest one in the table, are nearly equivalent to the ages of two interglacials the last and penultimate ones. The oldest coral date is 300^{+40}_{-31} ka of A0066 sample which is a *Porites* collected at a locality of about 33 m above the sea. This date imply that the coral reef has already been formed at that time in the place where the island is at present. In comparison with the ages of the coral reefs in above-mentioned areas, $^{230}Th/^{234}U$ dates may be arranged into five or possibly six groups as shown in Table 2, which are thousands years (younger than 10 ka), approximately 70 to 90 (81 ± 3, in average) ka, 100 to 106 (103 ± 1) ka, 110 to 158 (128 ± 7) ka, 190 to 260 (207 ± 3) ka, and 300 or more ka, respectively. In other words, the Pleistocene Riukiu Limestone on Hateruma is considered to have been formed during four or possibly five stages, which include two interstadials, two interglacials and possibly an another interglacial correlative to the stage 9 inferred from the isotope record of core V28-238 (Shackleton and Opdyke, 1973: Table 3).

Text-fig. 2 is a simplified topographic cross section in which eight steps of marine terraces developing on the island of Hateruma is schematically

Table 2. Isotopic composition and estimated ages of fossil corals from the Riukiu Limestone on Hateruma.

Code Number	Isotope Concentration ^{238}U (ppm)	^{234}U (dpm/g)	^{232}Th (ppm)	^{230}Th (dpm/g)	Activity Ratio $^{234}U/^{238}U$	$^{230}Th/^{232}Th$	$^{230}Th/^{234}U$	Estimated Age (ka)
A0109	4.05 ± 0.04	3.44 ± 0.03	< 0.02	0.0292±0.0016	1.14 ± 0.01		0.00847±0.00046	0.92±0.05
A0114	2.93 ± 0.03	2.55 ± 0.03	< 0.02	0.0691±0.0031	1.17 ± 0.01		0.0271±0.0012	3.0 ± 0.2
A0113	2.80 ± 0.03	2.39 ± 0.03	< 0.02	0.0974±0.0030	1.14 ± 0.01		0.0408±0.0013	4.5 ± 0.2
A0106	2.70 ± 0.03	2.35 ± 0.03	< 0.02	0.116 ± 0.005	1.17 ± 0.01		0.0492±0.0022	5.5 ± 0.3
A0159	2.29 ± 0.04	1.92 ± 0.03	0.0219±0.0035	0.106 ± 0.004	1.13 ± 0.02	20.1±3.3	0.0550±0.0022	6.0 ± 0.5
A0119	2.88 ± 0.03	2.33 ± 0.03	< 0.02	1.11 ± 0.02	1.09 ± 0.01		0.475 ± 0.009	69 ± 2
A0096	2.57 ± 0.03	2.12 ± 0.02	< 0.02	1.02 ± 0.01	1.11 ± 0.01		0.482 ± 0.008	71 ± 2
A0118	2.81 ± 0.03	2.26 ± 0.02	< 0.02	1.26 ± 0.02	1.08 ± 0.01		0.555 ± 0.011	87 ± 3
A0125	2.70 ± 0.03	2.24 ± 0.02	0.0266±0.0036	1.27 ± 0.01	1.12 ± 0.01	199 ± 27	0.566 ± 0.009	89 ± 3
A0126	2.53 ± 0.02	2.05 ± 0.02	< 0.02	1.16 ± 0.01	1.09 ± 0.01		0.564 ± 0.008	89 ± 2
A0108	2.62 ± 0.03	2.18 ± 0.02	< 0.02	1.25 ± 0.01	1.12 ± 0.01		0.573 ± 0.009	91 ± 3
A0153	2.72 ± 0.03	2.24 ± 0.02	0.0314±0.0039	1.29 ± 0.02	1.11 ± 0.01	171 ± 21	0.574 ± 0.009	91 ± 3
A0124	2.84 ± 0.03	2.28 ± 0.03	< 0.02	1.39 ± 0.02	1.08 ± 0.01		0.607 ± 0.011	100 ± 3
A0101	3.53 ± 0.03	2.63 ± 0.02	0.0409±0.0044	1.79 ± 0.02	1.11 ± 0.01	183 ± 20	0.616 ± 0.009	102 ± 3
A0157	2.63 ± 0.03	2.19 ± 0.04	0.0206±0.0036	1.39 ± 0.02	1.13 ± 0.01	281 ± 49	0.623 ± 0.011	103 ± 3
A0094	2.42 ± 0.02	1.98 ± 0.02	< 0.02	1.24 ± 0.01	1.10 ± 0.01		0.623 ± 0.008	104 ± 3
A0127	2.82 ± 0.03	2.37 ± 0.03	< 0.02	1.50 ± 0.02	1.12 ± 0.01		0.632 ± 0.012	106 ± 4
A0129	2.65 ± 0.03	2.22 ± 0.02	0.0526±0.0050	1.40 ± 0.02	1.12 ± 0.01	111 ± 11	0.631 ± 0.010	106 ± 3
A0130	2.74 ± 0.03	2.22 ± 0.02	< 0.02	1.43 ± 0.02	1.09 ± 0.01		0.644 ± 0.010	110 ± 3
A0021	2.73 ± 0.05	2.24 ± 0.04	0.0278±0.0070	1.47 ± 0.03	1.10 ± 0.02	221 ± 55	0.656 ± 0.019	112 ± 7
A0133	2.62 ± 0.02	2.11 ± 0.02	< 0.02	1.37 ± 0.04	1.08 ± 0.01		0.652 ± 0.018	112 ± 6
A0097	2.52 ± 0.02	2.10 ± 0.02	< 0.02	1.38 ± 0.02	1.12 ± 0.01		0.657 ± 0.012	113 ± 4
A0158	2.63 ± 0.05	2.19 ± 0.04	0.0258±0.0034	1.44 ± 0.02	1.12 ± 0.02	233 ± 30	0.660 ± 0.014	114 ± 4
A0020	2.88 ± 0.06	2.41 ± 0.05	0.0334±0.0057	1.60 ± 0.03	1.12 ± 0.02	199 ± 34	0.664 ± 0.017	115 ± 5
A0107	2.78 ± 0.03	2.34 ± 0.03	0.0292±0.0033	1.58 ± 0.02	1.13 ± 0.01	225 ± 25	0.675 ± 0.010	118 ± 3
A0135	2.33 ± 0.03	1.91 ± 0.02	< 0.02	1.28 ± 0.02	1.10 ± 0.01		0.671 ± 0.011	118 ± 4
A0163	2.74 ± 0.03	2.27 ± 0.02	0.0200±0.0039	1.53 ± 0.02	1.11 ± 0.02	318 ± 61	0.672 ± 0.012	118 ± 4
A0103	3.57 ± 0.03	2.93 ± 0.03	< 0.02	1.97 ± 0.02	1.10 ± 0.01		0.675 ± 0.010	119 ± 4
A0165	2.80 ± 0.03	2.27 ± 0.02	0.0229±0.0035	1.54 ± 0.02	1.09 ± 0.01	281 ± 43	0.680 ± 0.011	121 ± 4
A0095	2.69 ± 0.03	2.23 ± 0.02	0.0252±0.0039	1.53 ± 0.02	1.11 ± 0.01	254 ± 40	0.686 ± 0.011	122 ± 4
A0024	2.65 ± 0.06	2.23 ± 0.05	< 0.02	1.54 ± 0.05	1.13 ± 0.02		0.691 ± 0.027	123 ± 9
A0123	2.85 ± 0.03	2.37 ± 0.02	< 0.02	1.64 ± 0.02	1.12 ± 0.01		0.693 ± 0.012	124 ± 4
A0115	2.46 ± 0.03	2.01 ± 0.02	< 0.02	1.41 ± 0.01	1.10 ± 0.01		0.701 ± 0.011	128 ± 4

A0132	2.81 ± 0.03	2.36 ± 0.03	< 0.02	1.13 ± 0.01	1.13 ± 0.01		0.705 ± 0.011	128 ± 4
A0069	2.71 ± 0.03	2.28 ± 0.02	0.0362±0.0055	1.62 ± 0.03	1.13 ± 0.01	187 ± 29	0.711 ± 0.014	130 ± 5
A0121	2.62 ± 0.03	2.18 ± 0.02	< 0.02	1.54 ± 0.02	1.11 ± 0.01		0.708 ± 0.011	130 ± 4
A0134	2.78 ± 0.03	2.31 ± 0.03	< 0.02	1.65 ± 0.02	1.12 ± 0.01		0.712 ± 0.012	131 ± 5
A0025	2.74 ± 0.08	2.17 ± 0.06	< 0.02	1.54 ± 0.02	1.06 ± 0.02		0.709 ± 0.023	132 ± 8
A0136	2.53 ± 0.03	2.12 ± 0.04	< 0.02	1.53 ± 0.02	1.12 ± 0.01		0.720 ± 0.012	133 ± 5
A0169	2.66 ± 0.03	2.20 ± 0.03	< 0.02	1.59 ± 0.02	1.11 ± 0.01		0.719 ± 0.012	133 ± 5
A0098	2.72 ± 0.03	2.24 ± 0.02	< 0.02	1.61 ± 0.02	1.10 ± 0.01		0.722 ± 0.011	135 ± 4
A0026	2.69 ± 0.05	2.22 ± 0.04	0.0243±0.0070	1.61 ± 0.04	1.10 ± 0.02	276 ± 80	0.725 ± 0.023	136 ± 9
A0070	2.80 ± 0.04	2.29 ± 0.03	< 0.02	1.66 ± 0.02	1.10 ± 0.01		0.725 ± 0.019	136 ± 7
A0122	2.50 ± 0.03	2.04 ± 0.02	0.0260±0.0034	1.48 ± 0.02	1.10 ± 0.01	237 ± 32	0.724 ± 0.012	136 ± 5
A0164	2.60 ± 0.03	2.12 ± 0.02	0.0288±0.0048	1.54 ± 0.02	1.09 ± 0.01	223 ± 37	0.726 ± 0.013	137 ± 5
A0161	2.63 ± 0.03	2.16 ± 0.02	0.0233±0.0041	1.96 ± 0.02	1.10 ± 0.01	282 ± 50	0.732 ± 0.013	138 ± 5
A0128	2.21 ± 0.03	1.83 ± 0.02	< 0.02	1.35 ± 0.02	1.11 ± 0.01		0.738 ± 0.013	140 ± 5
A0167	2.52 ± 0.03	2.10 ± 0.02	0.0347±0.0041	1.57 ± 0.02	1.11 ± 0.01	188 ± 22	0.747 ± 0.012	143 ± 5
A0068	2.76 ± 0.03	2.27 ± 0.02	< 0.02	1.71 ± 0.03	1.10 ± 0.01		0.753 ± 0.015	147 ± 6
A0117	2.45 ± 0.03	2.01 ± 0.02	0.0211±0.0029	1.52 ± 0.02	1.10 ± 0.01	301 ± 41	0.756 ± 0.012	148 ± 5
A0065	2.64 ± 0.03	2.14 ± 0.03	0.0220±0.0030	1.65 ± 0.02	1.08 ± 0.01	312 ± 43	0.771 ± 0.012	155 ± 5
A0099	2.66 ± 0.02	2.17 ± 0.02	0.0241±0.0032	1.69 ± 0.02	1.09 ± 0.01	291 ± 39	0.779 ± 0.011	158 ± 5
A0100	2.76 ± 0.03	2.20 ± 0.02	0.0257±0.0037	1.70 ± 0.02	1.07 ± 0.01	277 ± 40	0.775 ± 0.012	158 ± 5
A0154	3.35 ± 0.03	2.73 ± 0.03	0.0438±0.0050	2.30 ± 0.03	1.09 ± 0.01	219 ± 25	0.844 ± 0.012	191 ± 8
A0112	2.48 ± 0.03	2.00 ± 0.02	0.0222±0.0029	1.69 ± 0.02	1.08 ± 0.01	316 ± 41	0.844 ± 0.012	192 ± 8
A0105	3.45 ± 0.05	2.83 ± 0.04	0.0391±0.0044	2.40 ± 0.02	1.10 ± 0.01	256 ± 29	0.850 ± 0.014	194 ± 9
A0155	3.32 ± 0.03	2.69 ± 0.03	< 0.02	2.29 ± 0.02	1.09 ± 0.01		0.851 ± 0.012	196 ± 8
A0131	3.02 ± 0.04	2.38 ± 0.04	< 0.02	2.02 ± 0.02	1.05 ± 0.01		0.853 ± 0.015	201 +11 -10
A0116	3.39 ± 0.04	2.67 ± 0.03	0.0277±0.0031	2.30 ± 0.02	1.06 ± 0.01	346 ± 39	0.862 ± 0.012	207 ± 9
A0028	2.65 ± 0.07	2.20 ± 0.06	< 0.02	1.92 ± 0.03	1.11 ± 0.02		0.873 ± 0.029	208 +22 -18
A0104	3.11 ± 0.04	2.49 ± 0.03	0.0332±0.0055	2.15 ± 0.03	1.07 ± 0.01	270 ± 44	0.867 ± 0.016	208 +12 -11
A0137	2.65 ± 0.03	2.17 ± 0.02	< 0.02	1.89 ± 0.02	1.10 ± 0.01		0.872 ± 0.014	208 +10 - 9
A0162	2.72 ± 0.03	2.17 ± 0.02	< 0.02	1.88 ± 0.02	1.07 ± 0.01		0.867 ± 0.013	209 ± 10
A0067	2.73 ± 0.03	2.15 ± 0.02	0.0229±0.0052	1.87 ± 0.03	1.06 ± 0.01	340 ± 77	0.870 ± 0.018	212 +14 -12
A0166	2.75 ± 0.03	2.24 ± 0.02	< 0.02	1.96 ± 0.02	1.09 ± 0.01		0.876 ± 0.013	212 +10 - 9
A0156	2.79 ± 0.03	2.25 ± 0.03	< 0.02	1.97 ± 0.03	1.08 ± 0.01		0.876 ± 0.016	214 +13 -11
A0035	2.65 ± 0.06	2.13 ± 0.05	0.0724±0.0041	1.87 ± 0.06	1.07 ± 0.03	108 ± 26	0.878 ± 0.033	217 +28 -22
A0022	2.56 ± 0.06	2.06 ± 0.04	0.0246±0.0062	1.83 ± 0.04	1.08 ± 0.02	309 ± 77	0.888 ± 0.028	223 +22 -20
A0168	2.77 ± 0.03	2.23 ± 0.03	< 0.02	1.99 ± 0.02	1.08 ± 0.01		0.892 ± 0.015	226 +13 -12
A0064	2.57 ± 0.03	2.06 ± 0.02	< 0.02	1.84 ± 0.02	1.08 ± 0.01		0.893 ± 0.016	227 +14 -13
A0120	2.77 ± 0.03	2.22 ± 0.02	0.0233±0.0046	1.98 ± 0.03	1.08 ± 0.01	354 ± 69	0.893 ± 0.016	227 +14 -13
A0138	2.94 ± 0.03	2.35 ± 0.02	< 0.02	2.12 ± 0.03	1.07 ± 0.01		0.901 ± 0.014	235 +14 -13
A0160	2.48 ± 0.03	2.00 ± 0.02	0.0287±0.0037	1.85 ± 0.02	1.08 ± 0.01	269 ± 35	0.924 ± 0.014	256 +16 -14
A0066	2.50 ± 0.03	2.00 ± 0.02	0.0304±0.0070	1.91 ± 0.04	1.07 ± 0.01	262 ± 60	0.955 ± 0.022	300 +40 -31

Table 3. Stages and their ages when the uplifted coral reefs on Hateruma were formed.

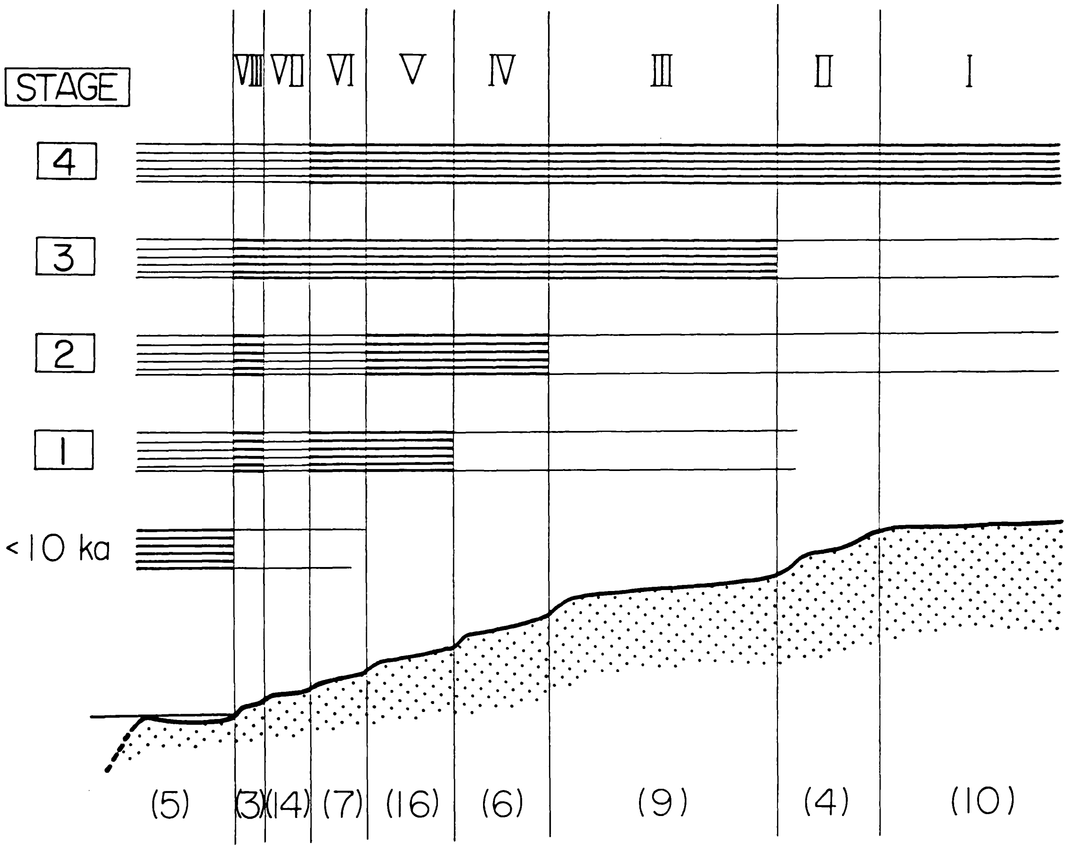
Stage	N*	Years B.P.	Isotope Stage**
1	(7)	81,000 ± 3,000	5
2	(6)	103,000 ± 1,000	5
3	(35)	128,000 ± 7,000	5
4	(20)	207,000 ± 3,000	7
5 ?	(1)	300,000 or more	9

*N, number of samples
** after Shackleton and Opdyke (1973)

illustrated. In the text-figure, the terrace numbers of Ota *et al.* (1982) are given by using Roman numerals from I to VIII and parenthesized figures mean number of coral samples collected from respective terrace. The stripes drawn in bold strokes over the cross section denote that the samples assigned to each stage were collected from the under terrace, and the portion drawn in fine stripes that the corals alive during each stage were not found so far. Namely, Text-fig. 2 shows that the coral dates of the stage 4 were obtained from the terraces I to VI, those of the stage 3 from III to VIII, those of the stage 2 from IV, V and VIII, and those of the stage 1 from V, VI and VIII. No coral date suggestive of Pleistocene was found from the limestone forming the present tidal flat around the coast of Hateruma. The tidal flat is thus considered to have been built since the last thousands years. It may be

Table 4. Correlation of the uplifted coral reefs on Hateruma with the counterparts reported from Barbados, Huon Peninsula and Kikai.
(One and two star marks mean that the uplifted coral reefs in each area are defined as morphostratigraphic and time-stratigraphic units, respectively.)

Barbados*	Huon Peninsula, New Guinea**	Ryukyu Islands: Kikai**	Ryukyu Islands: Hateruma*
Mesolella et al. (1969) and others	Bloom et al. (1974) and others	Konishi et al. (1974) and others	this paper
——	Reef Complex I (5 - 9 ka)	Raised Coral Reef Limestone (2 - 7 ka)	Tidal Flat Limestone
——	Reef Complex II ? (28 - 29 ka)	——	——
——	Reef Complex IIIb (41 ka)	Araki Limestone (35 - 45 ka)	——
Barbados 0 ? (60 ka)	Reef Complex IV (61 ka)	Younger Member of Riukiu Limestone (55 - 65 ka)	——
Barbados I (82 ka)	Reef Complex V (85 ka)	Middle Member of Riukiu Limestone (80 - 100 ka)	Hateruma VIII (81 ± 3 ka)
Barbados II (105 ka)	Reef Complex VI (107 ka)		Hateruma IV (103 ± 1 ka)
Barbados III (127 ka)	Reef Complex VII (118 - 142 ka)	Older Member of Riukiu Limestone (120 - 130 ka)	Hateruma III (128 ± 7 ka)
198, 220, 242, 268 (ka)			Hateruma I (207 ± 3 ka)
Barbados X, XI			
Barbados XII, XIII			? (300 or more ka)
Barbados XIII ?			



Text-fig. 2. Schematic illustration of eight steps of marine terraces on Hateruma. (Topographic cross-section is drawn not to scale. Roman numerals indicate the morphostratigraphic units of Ota *et al.*, 1982. Parenthesized figures mean number of coral samples dated. See text for details.)

put in another way that the sea level has attained at least up to the highest point among the localities of coral samples assigned to each stage. The morphostratigraphic units on Hateruma are conclusively correlative, as summarized in Table 4, with the Holocene and Pleistocene coral reefs reported from Barbados, Huon Peninsula and Kikai, respectively.

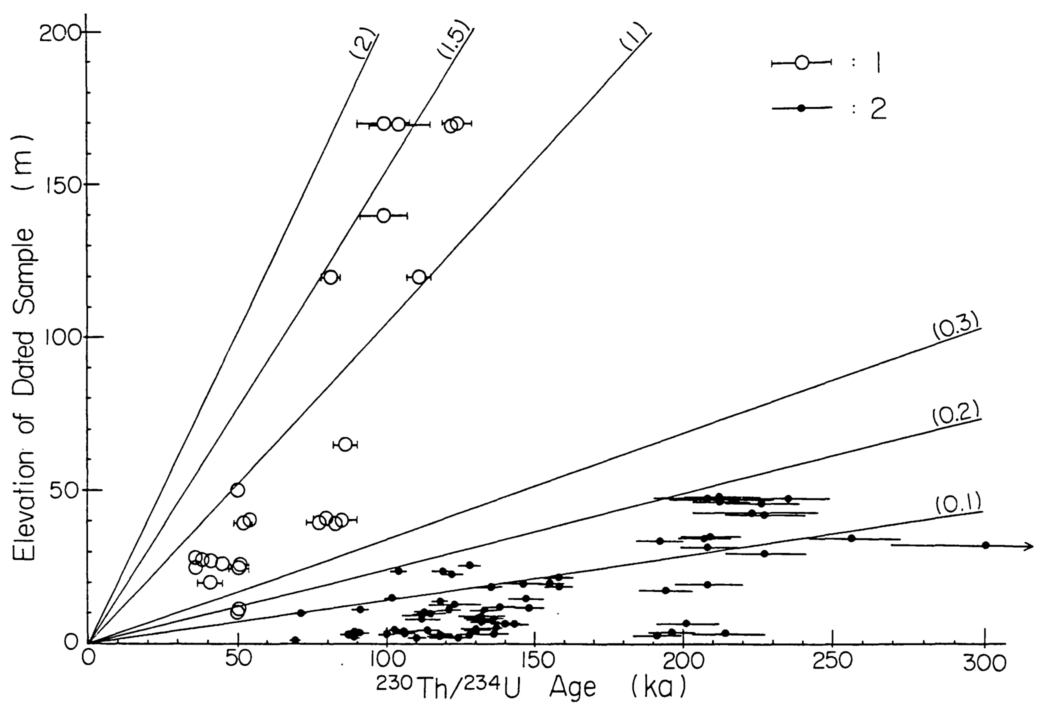
The occurrence of corals dated to be older (for an example, 214^{+13}_{-11} ka of A0156 sample) from the lower terrace (the terrace V for the sample) may suggest that the limestone of younger than the time of the last interglacial was formed as a small-scaled fringing reef in the limited parts and/or a very thin veneer. In either case, the lower terraces of IV to VIII are very likely to have been eroded since emerging ashore, because of no surface features peculiar to raised coral reef, narrowness of terrace and poor occurrence of coral heads. It may therefore be said that the terraces on Hateruma are partly (only terraces I and III) constructive and partly (the other terraces) erosional in origin.

Sea Level and Tectonic History

The elevation of the terraces I through VIII must involve at least two variables, the sea level at the time of reef formation and the tectonic uplift since then. In order to interpret the geology and geomorphology of Hateruma in terms of sea level and tectonic history, it is the first consideration to settle the present altitude of the paleosea level of the time when each reef was formed. As stated above, it may be safely said that the paleosea covered up the terraces I and III during the last and preceding interglacials, respectively. Because the author could not confirm the reef-crest elevation as yet, the paleosea level is supposed here as a first-order model to have attained up to the present elevation of the break in topographic surface, the boundary between the terraces II and III, during the last interglacial.

Ota *et al.* (1982) evaluated, by using a precesion altimeter, for the present elevation of the then sea level to vary from 40 – 41 m in eastern part of the island to about 20 m in western part. They concluded from this fact that the island of Hateruma has been progressively tilting westwards. Assuming that uplift has been constant in each block bounded by some faults as seen in Text-fig. 1 and that the paleosea level during the terrace III time (128 ± 7 ka B.P.) was plus 6 m relative to the present datum (Bloom *et al.*, 1974; and others), the uplift rate of Hateruma is calculated to be 0.27 m/ka in eastern part of the island and 0.11 m/ka in western part, respectively. These values are an order of magnitude lower than a value of 1 – 2 m/ka estimated for the last interglacial emerged reef (Older Limestone Member of Riukiu Limestone: Konishi *et al.*, 1974) on Kikai. Text-fig. 3 verfies such a difference in neotectonic rate of vertical movement between the islands of Hateruma and Kikai. In addition, the absence of the Holocene Raised Coral Reef Limestone uplifted on the island like Kikai also may support that the uplift rate of Hateruma is much lower than that of Kikai.

Konishi (1980) has previously pointed out a great difference in the rate of neotectonic uplift between the islands of Kikai and Hateruma, after



Text-fig. 3. Comparison on elevation of dated corals from the Riukiu Limestone and uplift rates between the islands of Kikai and Hateruma.
(1 and 2 show the samples collected on Kikai and Hateruma, respectively. Data on coral samples of Kikai were referred from Konishi *et. al.*, 1974 and others, and unpublished dates also are plotted. Parenthesized figures mean the uplift rate in unit of m/ka.)

he evaluated the uplift rate of Hateruma to be so low or even in the magnitude of practically almost none. By the citation of the theory of Uyeda and Kanamori (1979), he attributed this difference to the disparity in mode of subduction of the West Philippine Sea plate. Both Kikai and Hateruma are the most trenchward islands in the Central and Southwest Ryukyu blocks, respectively, which are bounded by the Miyako Depression. Depending on Konishi (1980), Kikai has been uplifted rapidly and tilted towards the Asian continent through compression arisen from gently (25° — 35° in dipping angle of the Wadati-Benioff zone) subsiding of the West Philippine Sea plate as the "Chilean-type" of plate convergence by Uyeda and Kanamori (1979). On the other hand, the Southwest Ryukyu block inclusive of Hateruma sits next to a steeply dipping (55° — 65° in average and more at the lower tip) Wadati-Benioff zone and is now in the tensile field behind the frontal arc like the case of "Mariana-type" of plate convergence.

The resultant obtained in this study implies that Hateruma has been situated tectonically in the compressive field since the last interglacial. Although the uplift rate of this island is undoubtedly lower than that of Kikai, its maximum is comparable to the value estimated from one of the standard traverses, the Christ Church traverse, settled on Barbados by Bender *et al.* (1979). Without the tectonic uplift of such an order, it is hardly possible that the dates suggestive of two interstadials after the last interglacial are obtained from the fossil corals in the Riukiu Limestone on Hateruma.

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波照間島琉球石灰岩のウラン系列放射年代：琉球弧の中でも西南琉球ブロック中のもっとも海溝側に位置する波照間島の琉球石灰岩について，その形成時代を明らかにするため，74個の礁性サンゴ化石から $^{230}Th/^{234}U$ 年代値を求めた。その結果，本島の琉球石灰岩は更新世後期の4回の高海水準期（おおよそ 81,000 年と 103,000 年前の2度の亜間氷期と，128,000 年と 207,000 年前の2回の間氷期）に形成されたことが明らかになった。本研究で得られた最古のものは，$300,000^{+40,000}_{-31,000}$ 年で，この年代値は，より以前の（深海底有孔虫酸素同位体比ステージ9に対比される）間氷期に現在の波照島の位置にすでにサンゴ礁が形成されていたことを示唆している。潮汐平底を構成している石灰岩から採集された5個のサンゴ化石は，いずれも 10,000 年以若の年代（920±50 年〜6,000±500 年）を示した。すなわち，現在島の周囲を縁取って発達している潮汐平底は，過去数千年間にわたって形成されてきたものといえよう。このように，波照間島の琉球石灰岩を，西インド諸島の Barbados 島，ニューギニア Huon 半島や中部琉球ブロック中の喜界島などの更新統隆起サンゴ礁に対比することが可能になった。

各段丘から採集されたサンゴ化石の年代測定結果にもとづき，Ota *et al.* (1982) によって8段に細分された海成段丘（T1〜T8）のうち，上位から2段目（T2）と下位の5段（T4〜T8）は，侵食面と考えられる。さらに，彼らは地形学的手法によって，各段丘形成時の旧汀線高度を求め，本島が西方へ傾動していると結論した。今回，最終間氷期に形成されたことが確証された T3 面の旧汀線高度と，隆起運動の等速性および当時の古海水準を現在より 6 m 高かったと仮定することにより，本島の最大隆起速度は，おおよそ 0.3 m/1,000 年と計算される。以上の事実を考えあわせると，波照間島は，最終間氷期以降，造構造的には圧縮場におかれてきたと思われる。

大村明雄

Trans. Proc. Palaeont. Soc. Japan, N.S., No. 135, pp. 427—444, pls. 80, 81, October 15, 1984

785. HEMIASTERID ECHINOIDS FROM THE UPPER CRETACEOUS OF JAPAN*

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Abstract. In this paper selected eight species of *Hemiaster* from the Upper Cretaceous of Japan are described. They are assigned to the subgenera *Hemiaster* (5 species), *Leymeriaster* (2 species) and *Mecaster* (1 species). Among them, one is new, another is a hitherto described Japanese species, and some of the rest are provisionally comparable with but distinct from certain foreign species, but I postpone to establish new taxa until more and better material is obtained. Some brief remarks are given on the *Hemiaster* faunal aspect, the mode of occurrence and the inferred mode of life.

Introduction

Echinoid fossils are found in the Upper Cretaceous strata in many places of Japan, although they are subordinate constituents of the Upper Cretaceous marine fauna. Nevertheless, few palaeontological investigations have been made on them. In fact, only eight species belonging to six genera have been described (Jimbo, 1894; Lambert in Lambert and Thiéry, 1924; Morishita, 1955, 1962; Saito, 1959; Nisiyama, 1966, 1968; Tanaka, 1984). Under these circumstances, I have endeavoured to obtain by myself echinoid specimens from various Upper Cretaceous outcrops of this country. Meanwhile, echinoid specimens collected by several other persons have been supplied to me. Thus, a considerable number of Upper Cretaceous echinoid specimens have been assembled for the study. They are. however, so poorly preserved that it is often difficult to identify them at generic or even family level. Anyhow, of the material examined eight species belonging to the genus *Hemiaster* have been identified. One of them is new, another is a previously described species from Japan, and the rest are new to this country. Thus, selected species of *Hemiaster* are to be described in this paper.

The material for this study came from various areas in Japan, from Hokkaido to Kyushu. The areas concerned are as follows:

Kamisarufutsu area, Kitami Province, northern Hokkaido
Shimukappu area, Iburi Province, southern Hokkaido
Urakawa area, Hidaka Province, southern Hokkaido
Yuasa area, Wakayama Prefecture
Awaji Island, Hyogo Prefecture
Asan Mountain Range, Kagawa Prefecture
Uwajima area, Ehime Prefecture
Onogawa area, Oita Prefecture
Koshiki Islands, Kagoshima Prefecture

The repositories of the specimens described here are the Geological Survey of Japan, Tsukuba (GSJ) and the Yokosuka City Museum (YCM).

Before going further, I wish to express my sincere gratitude to Professor Emeritus Tatsuro Matsumoto of Kyushu University for his valuable suggestions and kindness in critical reading of the manuscript. I am also indebted to Dr. Ikuwo

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Obata of the National Science Museum, Tokyo for his much help in studying the Museum specimens, and also to Dr. Yoji Teraoka of the Geological Survey of Japan, Professor Masahiro Okubo of Shimane University and Dr. Yasumitsu Kanie of the Yokosuka City Museum who kindly showed me some valuable specimens for this study. Finally my thanks are due to Mr. Yoshio Masai of the Geological Survey of Japan for photographing the specimens.

Systematic Descriptions

Order Spatangoida Claus, 1876

Suborder Hemiasterina Fischer, 1966

Family Hemiasteridae Clark, 1917

Genus *Hemiaster* Desor, 1847

Remarks: — The genus *Hemiaster* was classified into seven sections by Lambert and Thiéry (1924) and into eight sections by Mortensen (1950). Later, Fischer (in Moore, ed., 1966) raised these sections to the level of subgenera, with some modification. In the frameworks of classification proposed by previous authors, the division into subgenera is based largely on shape of the test, depth of the frontal sinus, flexuosity of the paired petals and on length ratio of the anterior to the posterior petals. Thus, the species described here are assigned to the subgenera *Hemiaster*, *Leymeriaster* and *Mecaster*.

Subgenus *Hemiaster* Desor, 1847

Hemiaster (*Hemiaster*) *uwajimensis* Morishita

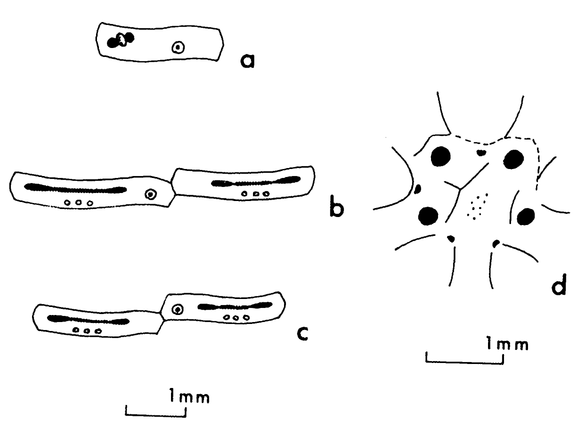
Pl. 80, Figs. 1—3; Text-fig. 1

1962. *Hemiaster uwajimensis* Morishita, *Jour. Earth Sci., Nagoya Univ.*, vol. 10, p. 113—116, pl. 1, figs. 1—7.

1968. *Hemiaster uwajimensis*, Nisiyama, *Palaeont. Soc. Japan, Special Papers*, no. 13, p. 196, 197; pl. 18, figs. 2, 5, 9 (1966, *ibid.*).

Material: — Four specimens are available: GSJ. F6196A, B (A, internal mould; B, external mould of aboral surface), from loc. UF-65, about 500 m south of Sakura-toge, Hiromi-cho, Kita-uwa-gun, Ehime Prefecture, middle part of the Oguwa Formation of Teraoka et al. (1980), Shimanto Supergroup, Middle Turonian (coll. Teraoka); GSJ. F6197, 6198 and 6199, represented by an internal and/or an external mould respectively, from loc. UF-8, Sakashitazu, Uwajima City, Ehime Prefecture, Furushiroyama Formation, Uwajima Group, Coniacian (coll. Teraoka). One comparable specimen was also examined: GSJ. F6062 from loc. UF-68, about 500 m southeast of Tanikira, Hiromi-cho, Kita-uwa-gun, Ehime Prefecture, middle part of the Oguwa Formation, Middle Turonian (coll. Teraoka).

Diagnosis: — Test small, roundly-cordate in outline, shallowly emarginate in front, nearly as long as wide, widest somewhat in front of the midpoint, constricted behind, rather low; frontal sinus wide, more or less deep, open towards the ambitus with constant depth, forming a rather broad and shallow notch at the anterior margin of the test, extending to the peristome. Aboral surface rather evenly inflated, highest somewhat behind the apical system, gradually sloping anteriorly, abruptly truncated posteriorly, more or less strongly inflated near the apical system in the antero-lateral interambulacral areas with a somewhat prominent median carina in the



Text-fig. 1. *Hemiaster* (*Hemiaster*) *uwajimensis* Morishita, GSJ. F6196. a, Frontal ambulacrum. b, Left anterior petal. c, Left posterior petal. d, Apical system.

posterior interambulacral area; oral surface flattish on the whole, depressed around the peristome, somewhat inflated in the plastronal region. Apical system small, somewhat posterior, ethmophract, with four gonopores; madreporite extending as far back as to separate the posterior genital plates, touching the posterior occular plates.

Frontal ambulacrum rather long and wide, widening from the proximal to the middle part and from the middle to the distal passing with parallel sides, moderately sunken throughout its length, subpetaloid; poriferous zones much narrower than half the width of the interporiferous zone; pores small, round; pores of each pair oblique, close together, separated by a distinct, oblong and transverse granule.

Paired ambulacra broad, wider than the frontal ambulacrum, widest at the middle, deeply sunken, petaloid. Anterior paired petals rather long, somewhat longer, more or less wider and much more divergent than the posterior, slightly flexuous, somewhat closed distally, extending about two-thirds the way to the margin; poriferous zones wider than the interporiferous; anterior zones slightly narrower than the posterior; pores slit-shaped, acuminated inwards, somewhat longer in the outer row than in the inner row; pores of each pair opposite, widely set. Posterior paired petals rather short, 0.55—0.65 as long as and somewhat narrower than the anterior petals, diverging from each other at an angle a little more than half as large as in the anterior, slightly flexuous, closed distally, extending about halfway to the margin; poriferous zones nearly equal in width, wider than the interporiferous zones; pores somewhat shorter than those of the anterior paired petals, slit-shaped, acuminated inwards; pores in each pair opposite, widely set. Each pore pair in the paired petals conjugate, separated from the next by a row of granules the number of which is three in the middle part of the petals and two in the proximal and distal.

Peristome very eccentric in front (near the anterior sixth), very wide, about three times as wide as high, transverse. Plastron protamphisternous. Periproct small, oval, vertically elongate, high up on the posterior truncated surface, partly visible from above. Tubercles of various sizes, perforate, crenulate, scrobiculate, somewhat larger on the oral surface than on the aboral, crowded on the plastron, widely scattered elsewhere; tubercles on the aboral surface larger on both sides of the frontal sinus and near the ambitus in the anterior region; interporiferous zones of all the ambulacra dotted with smaller tubercles. A peripetalous fasciole distinct, wide, slightly curved towards the ambitus in the antero-lateral interambulacra, bending shallowly towards the apical system in the postero-lateral interambulacra, passing rather straight in the posterior interambulacrum; no other fascioles.

Measurements: — The specimens available are secondarily deformed, and their original dimensions are hardly estimated. Nevertheless, they roughly measure between 15 mm and 20 mm in length. In the secondarily least depressed specimen the test is a little less than two-thirds as high as long.

Remarks: — The original specific diagnosis given by Morishita (1962) and the later, more detailed description by Nisiyama (1968) are mostly available, but some remarks on the specific diagnosis are given in the lines to follow. As mentioned before, this species has a heart-shaped test which is as wide as long. Nisiyama (1968), on the other hand, maintained that the test was roundly quadrate in outline, short and wider than long. Judging from my observation of the specimens available, his figured specimen (Nisiyama, 1966, pl. 18, figs. 2, 5, 9) is evidently compressed longitudinally by the subsequent distortion so as to show a test outline seemingly shorter and broader than the normal form. Morishita (1962) and Nisiyama (1968) described the frontal sinus of the present species to be rather vague or very shallow. However, this is considered to be due to the secondary deformation, since the frontal sinus is more or less deep at least as far as the specimens examined are concerned.

In one of the specimens, GSJ. F6196, each poriferous zone of the frontal ambulacrum comprises about 20 pore pairs within the fasciole, that of the anterior petals about 27 pore pairs and that of the posterior petals about 21 pore pairs. It should also be noted that the apical system, not mentioned in detail by previous authors, is ethmophract, the madreporite extending as far back as to separate the posterior genital plates and touching the posterior occular plates.

Comparison: — This species closely resembles *Hemiaster* (*Hemiaster*) *frontacutus* Stoliczka (1873, p. 13 (83), pl. 1 (11), figs. 7—8) from the Utatur Group (Cenomanian — Turonian) of southern India. But it differs from that species in having a heart-shaped test and a very anteriorly displaced peristome. Moreover, there is a minor but distinct difference in course of the peripetalous fasciole between the two. In *Hemiaster* (*Hemiaster*) *frontacutus* the peripetalous fasciole passes rather straight in the anterolateral interambulacra and curves towards the ambitus in the posterior interambulacrum.

H. (*H.*) *uwajimensis* is also closely similar to *H.* (*H.*) *forbesi* Baily (Baily, 1855, p. 463, pl. 12, fig. 1; Woods, 1906, p. 280, pl. 33, figs. 8—9), from the Senonian of southern Africa, especially in the general shape of the test, structure of the apical system and course of the fasciole. However, it is distinguished from that species by its less distinct anterior notch and more anterior position of the peristome. It also somewhat resembles *Hemiaster* (*Hemiaster*) *similaris* Stoliczka (1873, p. 10 (80), pl. 1 (11), fig. 1) from the Utatur Group, but differs from that species in its smaller test and the frontal sinus having constant depth throughout its length.

The present species is to some extent similar to *Hemiaster* (*Mecaster*) sp. aff. *H.* (*M.*) *indicus* Stoliczka to be described below, but possesses wider frontal ambulacrum, paired petals that are more unequal in length and have longer, slit-shaped pores, anterior petals being rather open distally, and a peripetalous fasciole with less regularly oval course.

Occurrence: — Uwajima area, western Shikoku; middle part of the Oguwa Formation, Shimanto Supergroup, siltstone, Middle Turonian and Furushiroyama Formation, Uwajima Group, siltstone, Coniacian. A number of specimens of this species have been obtained from the Turonian and Coniacian at some other localities of the Uwajima area (Morishita, 1962; Nisiyama, 1968). The type locality of this species (Morishita, 1962) is in the Yoshida area, north of Uwajima, being contained in the upper part of the Coniacian Yoshida Formation of Teraoka et al. (1985) of the Shimanto Supergroup.

Hemiaster (*Hemiaster*) sp. A aff. *H.* (*H.*) *stella* (Morton)

Pl. 80, Figs. 4—6; Text-figs. 2, 3

Compare:

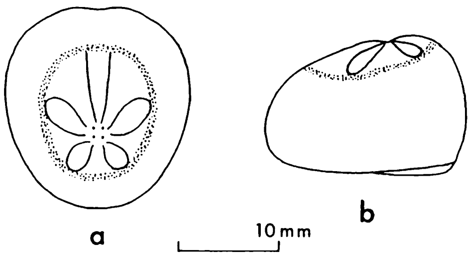
1854. *Hemiaster stella*, d'Orbigny, *Paléont. franç.*, *Terr. crét.*, Echin., ser. 1, vol. 6, p. 245, pl. 882, figs. 1—9.

1858. *Hemiaster stella*, Desor, *Synopsis*, p. 373.

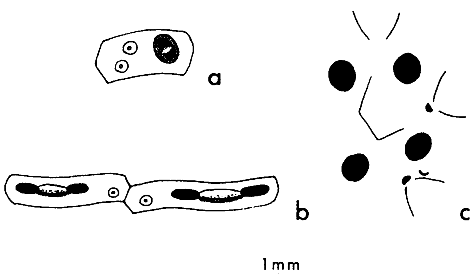
1915. *Hemiaster stella*, Clark in Clark and Twitchell, *Monogr. U. S. Geol. Surv.*, vol. 54, p. 93, pl. 48, fig. 2.

Material: — Three specimens are available: GSJ. F6065 (external mould of aboral surface), from loc. K-424, south of Tokuda (about 500 m northeast of Kumasumi-ike), Kibi-cho, Arida-gun, Wakayama Prefecture, Lower Shale Member of Hirayama and Tanaka (1956a), Futakawa Formation, Santonian (coll. Tanaka); GSJ. F6097A, B (A, internal mould; B, external mould of aboral surface), from loc. U-15, upper course of the Chinomi-gawa, Urakawa-cho, Urakawa-gun, Hokkaido, upper part of Unit U_0 of Kanie (1966), Upper Yezo Group, Coniacian (coll. Tanaka); GSJ. F6099A, B (A, internal mould; B, incomplete external mould of aboral surface), from loc. KS-72, upper course of the Sekitambetsu-gawa, Sarufutsu-mura, Soya-gun, Hokkaido, Unit U_5 of Tanaka (1960), Upper Yezo Group, Upper Santonian (coll. Tanaka). One comparable specimen, GSJ. F6195 (internal mould; coll. Tanaka), from loc. U-15 is also available.

Description: — The specimens examined are incomplete and secondarily deformed and their original dimensions are hardly estimated. Nevertheless, they roughly measure between 17 mm



Text-fig. 2. Suggested figure of *Hemiaster* (*Hemiaster*) sp. A aff. *H.* (*H.*) *stella* (Morton). a, Aboral view. b, Left lateral view. Restored from the material available.



Text-fig. 3. *Hemiaster* (*Hemiaster*) sp. A aff. *H.* (*H.*) *stella* (Morton). a, Frontal ambulacrum. b, Right anterior petal. (GSJ, F6065). c, Apical system. (GSJ. F6099).

and 23 mm in length. In the least secondarily depressed specimen (GSJ. F6099), the test may be about 0.7 as high as long.

The test is small, ovate in outline, widest somewhat anterior to the midpoint and relatively high. The frontal sinus is narrow and shallow, becoming indistinct beyond the fasciole; the anterior notch, if any, is indistinct. The aboral surface is inflated posteriorly, sloping anteriorly from the highest point which is between the apical system and the posterior ambitus. The oral surface is flattish on the whole and inflated in the plastronal region. The apical system is small, somewhat posterior and ethmophract, with four gonopores; the posterior genital plates are mutually contiguous.

The frontal ambulacrum is narrow, very shallowly sunken and subpetaloid, having poriferous zones which are much narrower than half the width of the interporiferous zone. Each pore pair is placed in an oblong depression, and the pores of each pair are round, oblique and close together, being separated by a transverse granule.

The paired ambulacra are wide and shallowly sunken, having rather small petals. The anterior paired petals are shorter than the petaloid part of the frontal ambulacrum, longer and more divergent than the posterior, broadly lanceolate, somewhat flexuous and closed distally. Their anterior poriferous zones are somewhat narrower than the posterior zones and nearly as wide as the interporiferous zones. The pores are oval in the anterior poriferous zones and longer and elongate oval to oblong in the posterior; the pores in each pair are opposite and widely set. The posterior paired petals are shortest, as wide as and about 0.6 as long as the anterior, oval, more or less flexuous and closed distally. They consist of poriferous zones of nearly equal width which are nearly as wide as the interporiferous zones. The pores of each pair are similar, elongate oval and opposite, being widely spaced. Each pore pair in the paired petals is conjugate and separated by a bourrelet adjoining the conjugation groove between the pores.

The peristome is situated near the anterior fourth. The plastron is mesamphisternous. The tubercles on the aboral surface are of various sizes, perforate, crenulate and widely scrobiculate, being widely spaced. Larger tubercles are rather close on both sides of the frontal sinus and scattered near the ambitus in the anterior region. The interporiferous zones of all the ambulacra are dotted with smaller tubercles. Numerous granules are present between the tubercles. The peripetalous fasciole is well developed and has rather oval course. No other fascioles are present.

Remarks: — Since the specimens available are poorly preserved, a periproct is not discernible and tuberculation of the oral surface is not known. Each poriferous zone of the frontal ambulacrum consists of about 12 pore pairs within the fasciole, that of the anterior petals about 15 to 16 pore pairs and that of the posterior petals about 13 pore pairs.

Comparison: — This species most closely resembles *Hemiaster* (*Hemiaster*) *stella* (Morton) from the Senonian of France and the Upper Cretaceous along the eastern coast of the United States in many respects, particularly in the general outline of the test, features of the pore pairs in all the ambulacra and course of the peripetalous fasciole. But it differs from that species in its rather small, wide and somewhat flexuous paired petals and less close tuberculation at least on the aboral surface.

The present species is easily distinguishable from *Hemiaster* (*Hemiaster*) *uwajimensis* Morishita described above by its oval outline of the test, shallower frontal sinus and by its features of the pore pairs in all the ambulacra. It is also similar to *Hemiaster* (*Hemiaster*) sp. B aff. *H.* (*H.*) *punctatus* d'Orbigny to be described below in the general features of the test. In the latter species, however, the frontal sinus does not extend distally beyond the fasciole and the paired petals have oblong pore pairs, the closely set and conjugate pores of each pair being not separated by a bourrelet adjoining the conjugation groove between the pores.

The present form is somewhat similar to *Hemiaster tamulicus* Kossmat (1897, p. 96, pl. 10, fig. 5) from the *Trigonoarca* Beds (Upper Senonian) of southern India, but is separated from that species by its lower test and wider paired petals. However, the details of the features of pore pairs in all the ambulacra are not known in the above Indian species. This makes impossible further comparison between the two species.

To sum up, the present form probably represents a new species of *Hemiaster* (*Hemiaster*) which is allied to but distinct from *H.* (*H.*) *stella.* However, the available specimens are too poorly preserved to propose a new specific name.

Occurrence: — Coniacian: lower part of the Upper Yezo Group, mudstone, Urakawa area, Hidaka Province, Hokkaido. Santonian: lower part of the Futakawa Formation, mudstone, Yuasa area, Wakayama Prefecture; middle part of the Upper Yezo Group, calcareous concretion in mudstone, Kamisarufutsu area, Kitami Province, Hokkaido.

Hemiaster (*Hemiaster*) sp. B aff. *H.* (*H.*) *punctatus* d'Orbigny

Pl. 80, Fig. 7; Text-fig. 4

Compare:

1854. *Hemiaster punctatus* d'Orbigny, *Paléont. franç., Terr. crét.*, Echin., ser. 1, vol. 6, p. 251, pl. 886, figs. 1—10.

1927. *Hemiaster punctatus*, Lambert, *Mém. Mus. Cienc. Nat. Barcelona*, sér. Géol., vol. 1, p. 49.

1932. *Hemiaster punctatus*, Lambert, *Mém. Soc. Géol. France*, nouv. série, vol. 7, no. 16, p. 115.

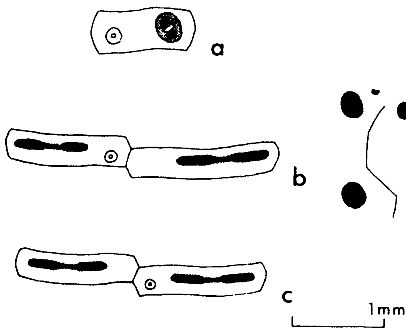
Material: — YCM. 665, represented by an external mould of the aboral surface, from Shimukappu-chuo, Shimukappu-mura, Yufutsu-gun, Hokkaido, Unit U_1 of Kanie (1966), Upper Yezo Group, Coniacian (coll. Kanie).

Description: — This specimen is incomplete and secondarily deformed. It may reach the length of at least 25 mm.

The test is small, subcircular in outline, rounded anteriorly and slightly constricted behind. The frontal sinus is narrow and shallow, extending distally only to the fasciole; an anterior notch is absent. The apical system is small, somewhat posterior and ethmophract, with four gonopores; the posterior genital plates are mutually contiguous.

The frontal ambulacrum is narrow, shallowly sunken and subpetaloid. Each poriferous zone is much narrower than half the width of the interporiferous zone. Each pore pair is placed in an oblong depression, and the pores in each pair are round, oblique and close together, being separated by a transverse granule.

The paired ambulacra are wide and very shallowly sunken, having rather small petals. The anterior paired petals are shorter than the petaloid part of the frontal ambulacrum, longer and more divergent than the posterior, broadly lanceolate, more or less flexuous and somewhat closed distally. Their poriferous zones have oblong pores which are longer in the posterior poriferous zones than in the somewhat narrower anterior.



Text-fig. 4. *Hemiaster* (*Hemiaster*) sp. B aff. *H.* (*H.*) *punctatus* d'Orbigny, YCM.665. a, Frontal ambulacrum. b, Right anterior petal. c, Right posterior petal. d, Apical system.

The posterior paired petals are shortest, slightly narrower than and about 0.6 as long as the anterior, oval and closed distally. They consist of poriferous zones of equal width which are broader than the interporiferous zones, having similar oblong pores. The pores of each pair in the paired petals are opposite, close together and conjugate.

The tubercles on the aboral surface are of various sizes, perforate, crenulate and widely scrobiculate, being rather widely spaced. Larger tubercles are rather crowded on both sides of the frontal sinus and scattered near the ambitus in the anterior region. The interporiferous zones of all the ambulacra are dotted with smaller tubercles. The peripetalous fasciole is well developed and has rather oval course which is truncated in the antero-lateral interambulacra and nearly straight in the postero-lateral interambulacra. No other fascioles are present.

Remarks: — Neither a peristome nor a periproct is preserved, and tuberculation of the oral surface is not ascertained. Each poriferous zone of the frontal ambulacrum, anterior petals and posterior petals comprises about 12, about 16 and more than 10 pore pairs within the fasciole, respectively.

Comparison: — The present form is closely similar to *Hemiaster* (*Hemiaster*) *punctatus* d'Orbigny from the Santonian to Campanian of western Europe and northern Africa in the general outline of the test, features of the frontal sinus, width of the paired petals and features of the pore pairs in all the ambulacra. But the former is distinguished from the latter by its less sunken paired petals, shorter anterior petals, longer and more closely set pores in each pair, less close tuberculation, and by its peripetalous fasciole being truncated in the antero-lateral interambulacra and nearly straight in the postero-lateral.

This species resembles *Hemiaster* (*Hemiaster*) sp. A aff. *H.* (*H.*) *stella* (Morton) described above in the general features of the test. But it differs from that species in that the frontal sinus extends distally only to the fasciole and in that the pores of each pair in the paired petals are oblong and close together, being not separated by a bourrelet adjoining the conjugation groove between the pores.

This form also resembles *Hemiaster integer* Lambert (1933, p. 21, pl. 3, figs. 5, 6) from the Upper Turonian of Madagascar. Although the original specific diagnosis of the latter was given too briefly, our form has a peripetalous fasciole that does not bend towards the apical system but passes nearly straight in the postero-lateral interambulacra.

To sum up, the present form probably represents a new species of *Hemiaster* (*Hemiaster*) which is allied to but distinct from *H.* (*H.*) *punctatus*. However, the establishment of the new species is suspended until more specimens of better preservation are obtained.

Occurrence: — Shimukappu area, Iburi Province, southern Hokkaido; Upper Yezo Group, mudstone, Coniacian.

Hemiaster (*Hemiaster*) sp. C

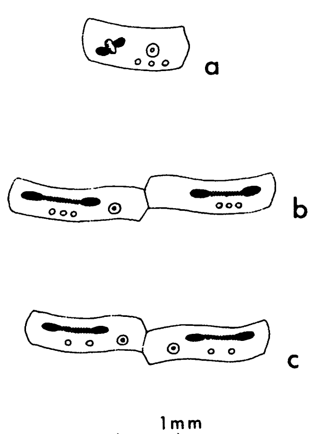
Pl. 80, Fig. 8, Text-fig. 5

Material: — GSJ. F6187, represented by an imperfect and fragmentary external mould of the aboral surface, from loc. OF-6, about 500 m southwest of Kashibaru, Oita City, Oita Prefecture, upper part of the Ryozen Formation, Lowermost Subgroup of the Onogawa Group, Upper Turonian (coll. Teraoka).

Description: — This specimen is incomplete and secondarily much deformed. The frontal sinus is rather broad and shallow, widening distally. It may become indistinct beyond the fasciole.

The frontal ambulacrum is rather wide, shallowly sunken and subpetaloid. Its poriferous zones are much narrower than half the width of the interporiferous zone and composed of small oval pores which are transverse in the outer row and oblique in the inner row; the pores of each pair are close together and separated by an oblong and transverse granule. The interporiferous area of each ambulacral plate is provided with a row of granules the number of which is two, three and four in the proximal, middle and distal parts of the petaloid area, respectively.

The paired ambulacra are wide, slightly broader than the frontal ambulacrum, shallowly sunken and petaloid, having poriferous zones somewhat narrower than the interporiferous. The anterior paired petals are somewhat longer, slightly wider and much more divergent than the posterior and rather open distally. The posterior paired petals are rather short and about 0.6 as long as and more or less narrower than the anterior and closed distally. The pores of each pair in the paired petals are elongate oval, opposite, widely set and conjugate. The successive pore pairs of the anterior petals are separated by a row of granules the number of which is three in the middle part of the poriferous zones and two in the proximal and distal parts. Those of the posterior petals are separated by a row of two granules throughout its length of the poriferous zones.



Text-fig. 5. *Hemiaster* (*Hemiaster*) sp. C, GSJ.F6287. a, Frontal ambulacrum. b, Left anterior petal. c, Right posterior petal.

The tubercles are of various sizes, perforate, crenulate and narrowly scrobiculate. On the aboral surface, they are somwhat close and larger in the apical half of the antero-lateral interambulacral areas, being the largest on both sides of the frontal sinus, but rather widely scattered elsewhere. The interporiferous zones of all the ambulacra are dotted with smaller tubercles. The peripetalous fasciole is distinct and broad, being slightly curved towards the ambitus in the antero-lateral interambulacra and embayed in the postero-lateral interambulacra.

Comparison: — This species resembles *Hemiaster* (*Hemiaster*) *uwajimensis* Morishita described above in some respects. But it differs from that species in the frontal sinus not extending distally beyond the fasciole and in the presence of a row of several granules in the interporiferous area of each ambulacral plate of the frontal ambulacrum. I refrain from further taxonomic discussion of the present form, because of the poor preservation of the material available.

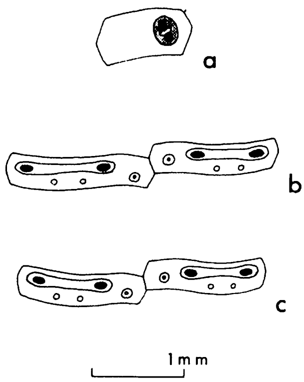
Occurrence: — Onogawa area, eastern Kyushu; upper part (*Inoceramus teshioensis* Zone) of the Ryozen Formation, Onogawa Group, mudstone interlaminated with sandstone, Upper Turonian.

Hemiaster (*Hemiaster*) sp. D

Pl. 80, Fig. 9; Text-fig. 6

Material: — GSJ. F6194, represented by an external mould of the aboral surface, from loc. UF-7, northwest of Fukuura, Uwajima City, Ehime Prefecture, Yorimatsu Formation of Teraoka and Obata (1975), Uwajima Group, Lower Santonian (coll. Teraoka).

Description: — This specimen is incomplete and secondarily deformed. It may be about 20 mm or a little more in length.



Text-fig. 6. *Hemiaster* (*Hemiaster*) sp. D, GSJ.F6194. a, Frontal ambulacrum. b, Left anterior petal. c, Left posterior petal.

The test seems to have an oval outline. The frontal sinus is narrow and shallow, extending distally only to the fasciole.

The frontal ambulacrum is shallowly sunken and subpetaloid. Its pores are round and each pore pair is placed in an oblong depression; the pores in each pair are oblique and close together, being separated by a transverse granule.

The paired ambulacra are relatively wide and very shallowly sunken, having rather short petals. The anterior paired petals are much longer and more divergent than the posterior, broadly lanceolate, somewhat flexuous and more or less closed distally. Their anterior poriferous zones are slightly narrower than the posterior zones and nearly equal to the interporiferous zones in width. The posterior paired petals are slightly narrower than and about two-thirds as long as the anterior, oval, slightly flexuous and closed distally. They consist of poriferous zones of nearly equal width which are similar in width to the interporiferous zones. The pores of the paired petals are similar and oval; the pores of each pair are opposite and widely set. Each pore pair is bordered by a bourrelet which is not interrupted between the pores and is seaparated from the next by a row of two granules.

The tubercles are of various sizes, perforate, crenulate and widely scrobiculate. They are rather widely spaced on the aboral surface. Larger tubercles are scattered near the ambitus, and much larger ones are rather close on both sides of the frontal sinus. The interporiferous zones of the paired petals are dotted with smaller tubercles. Numerous granules are densely crowded between the tubercles. The peripetalous fasciole is distinct, rather wide and of oval shape on the whole.

Comparison: — The present form resembles *Hemiaster* (*Hemiaster*) sp. A aff. *H.* (*H.*) *stella* (Morton) and *Hemiaster* (*Hemiaster*) sp. B. aff. *H.* (*H.*) *punctatus* d'Orbigny described above, in many respects. But it distinctly differs from those species in that the successive bourrelet-bordered pore pairs in each poriferous zone of the paired petals are separated by a row of two granules. The specimen has about 12, 23 and 13 pore pairs within the fasciole in each poriferous zone of the frontal ambulacrum, anterior petals and posterior petals, respectively. Pore pairs in the anterior petals is distinctly more numerous in the present form than in the other two species mentioned above. The material is, however, too poorly preserved for further taxonomic discussion.

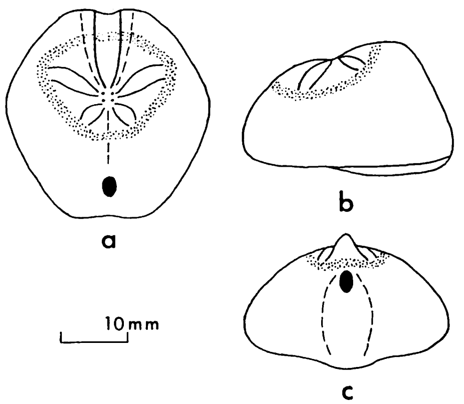
Occurrence: — Uwajima area, western Shikoku; Yorimatsu Formation, Uwajima Group, mudstone interlaminated with sandstone, Lower Santonian.

Subgenus *Leymeriaster* Lambert et Thiéry, 1924

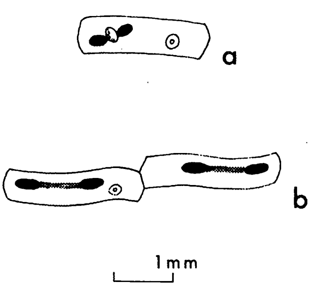
Hemiaster (*Leymeriaster*) *polygonalis* sp. nov.

Pl. 81, Figs. 1, 2; Text-figs. 7, 8

Material: — Holotype, GSJ. F6063A, B (A, internal mould; B, external mould of aboral surface), from a station about 700 m west-southwest of Shichiminami, Seidan-cho, Mihara-gun, Hyogo Prefecture, Shichi Shale Member of Sasai (1936), Anaga Formation, Lower Subgroup of the Izumi Group, Campanian; paratype, GSJ. F6072, represented by an internal mould, from a station about 500 m south of the peak of Mt. Toyajo, Kanaya-cho, Arida-gun, Wakayama Prefecture, Silty Fine-grained Sandstone Member of Hirayama and Tanaka (1956b), Toyajo



Text-fig. 7. Suggested figure of *Hemiaster* (*Leymeriaster*) *polygonalis* sp. nov. a, Abroral view. b, Left lateral view. c, Posterior view. Restored from the holotype and paratype.



Text-fig. 8. *Hemiaster* (*Leymeriaster*) *polygonalis* sp. nov., GSJ. F6063. a, Frontal ambulacrum. b, Left posterior petal.

Formation, Campanian (coll. Tanaka). Several specimens (GSJ. F6163 etc.) which are comparable with this species are found in Division C (Campanian) of Tanaka and Teraoka (1973) of the Himenoura Group in Shimokoshiki-jima, the Koshiki Islands.

Diagnosis: — Test medium-sized, hexagonal in outline, nearly as long as wide, widest near the midpoint, contracted behind, with rounded angles at the ambitus; frontal sinus wide, shallow, somewhat open towards the ambitus with constant depth, forming a broad and shallow notch in the anterior edge of the test, extending to the peristome. Aboral surface inflated, highest fairly behind the midpoint, gradually sloping anteriorly, obliquely truncated posteriorly, with a distinct, convex-topped median carina between the apical system and near the periproct, which is the highest part of the test; posterior truncated surface slightly concave; posterior margin very shallowly emarginate. Oral surface more or less convex on the whole, somewhat more inflated in the plastronal region, shallowly depressed around the peristome. Apical system somewhat eccentric anteriorly.

Frontal ambulacrum widening from the proximal to the middle part and from the middle to the distal passing with parallel sides, shallowly sunken throughout its length, subpetaloid; poriferous zones narrower than half the width of the interporiferous zone; pores small, roundly oval; outer pores transversely set; inner pores obliquely set; pores in each pair close together, separated by a small, oblong and transverse granule.

Paired ambulacra somewhat flexuous, deeply sunken, very unequal in length, petaloid. Anterior paired petals very much longer and much more divergent than the posterior, slightly curved backwards, moderately closed distally; each poriferous zone much broader than the interporiferous zone, having oblong pore pairs; pores of each pair opposite, widely set. Posterior paired petals about 0.4 to 0.5 as long as the anterior, moderately closed distally; each poriferous zone somewhat wider than the interporiferous zone; pores elongate oval; pores in each pair opposite, widely set, conjugate.

Peristome near the anterior third, transverse. Plastron protamphisternous. Periproct rather small, oval, vertically elongate, at the upper end of the posterior truncated surface, visible from above. Tubercles on the aboral surface perforate, crenulate, scrobiculate, of similar size, uniformly and rather closely spaced; interporiferous zones of all the ambulacra dotted with smaller tubercles. A peripetalous fasciole distinct, broad, triangular in shape on the whole, narrowly truncated posteriorly; no other fascioles.

Measurements: — Both the holotype and the paratype are secondarily deformed, and their original dimensions are hardly estimated with precision. The holotype in the deformed state measures 34 mm long, 32 mm wide and 15 mm high. Its peripetalous fasciole is about 2 mm wide.

Remarks: — In the holotype, the test is more intensely deformed in its anterior part than elsewhere and is somewhat lowered owing to the secondary depression. The paratype is longitudinally much compressed so as to be much shorter than wide and much inflated. In the two specimens the structure of the apical system is not known because of the poor preservation. The paratype has about 27, more than 30 and about 21 pore pairs within the fasciole in each poriferous zone of the frontal ambulacrum, anterior petals and posterior petals, respectively.

Comparison: — This new species closely resembles *Hemiaster* (*Leymeriaster*) *sexangulatus* d'Orbigny (d'Orbigny, 1854, p. 256, pl. 889, figs. 1—9; Stoliczka, 1873, p. 18 (88), pl. 3 (13), fig. 6) from the Ariyalur Group (Campanian-Maastrichtian) of southern India, especially in the shape of the test, length ratio of the anterior to the posterior petals and course of the peripetalous fasciole. But, it differs from that species in its shallower frontal sinus, shallower anterior notch, shorter and elongate oval pores of each pair in the paired petals and broader fasciole.

The present species is distinctly separated from the contemporary *Hemiaster* (*Leymeriaster*) sp. aff. *H.* (*L.*) *regulusanus* d'Orbigny to be described below. The former has a hexagonal test with a frontal sinus extending beyond the fasciole to the peristome, whereas the latter has a rounded or oval test with a frontal sinus extending distally only to the fasciole. Moreover, in the former the pores of each pair are conjugate; such is not the case with the latter in which a median longitudinal groove is placed at the middle of the width of each ambulacral plate.

Occurrence: — Southwestern part of Awaji Island, Shichi Shale Member, Anaga Formation, Izumi Group, siltstone, Campanian; Yuasa area, Wakayama Prefecture, Toyajo Formation, siltstone, Campanian. Comparable specimens are found in the siltstone of Division C (Campanian) of the Himenoura Group in the Koshiki Islands.

Hemiaster (*Leymeriaster*) sp. aff. *H.* (*L.*) *regulusanus* d'Orbigny

Pl. 81, Fig. 3; Text-fig. 9

Compare:

1854. *Hemiaster regulusanus* d'Orbigny, *Paléont. franç., Terr. crét.*, Echin., ser. 1, vol. 6, p. 248, pl. 884, figs. 1—9.

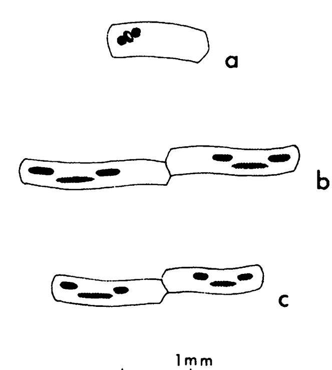
1927. *Hemiaster regulusi*, Lambert, *Mém. Mus. Cienc. Nat. Barcelona*, sér. Géol., vol. 1, p. 49.

1936. *Hemiaster regulusi*, Lambert, *Bull. Soc. Hist. Natur. Toulouse*, vol. 69, p. 83.

Material: — GSJ. F6172A, B (A, internal mould; B, external mould of aboral surface), from Ebisukui, Onohara-cho, Mitoyo-gun, Kagawa Prefecture, Ebisukui Mudstone Member of C. Nakagawa (1961), Lower Subgroup of the Izumi Group, Campanian. This specimen was collected by T. Nakagawa and donated to the Geological Survey of Japan through the late Dr. M. Nakano.

Description: — This is poorly preserved and secondarily deformed. It roughly measures a little more than 20 mm in length.

The test seems to have a rounded or oval outline not emarginated in front. The frontal



Text-fig. 9. *Hemiaster* (*Leymeriaster*) sp. aff. *H.* (*L.*) *regulusanus* d'Orbigny, GSJ. F6172. a, Frontal ambulacrum. b, Left anterior petal. c, Left posterior petal.

sinus is very shallow, extending distally only to the fasciole. An anterior notch is absent.

The frontal ambulacrum is narrow, very shallowly sunken and subpetaloid. It has round pore pairs; the pores in each pair are obliquely set and close together, being separated by an oblong and transverse granule.

The paired ambulacra are wide and very shallowly sunken. The anterior paired petals are much longer than the posterior, lanceolate, slightly flexuous and moderately closed distally. Their pores are elongate oval in the anterior poriferous zones and are slightly longer and oblong in the somewhat wider posterior poriferous zones which are nearly equal to the interporiferous zones in width; the pores in each pair are opposite, widely set and nonconjugate. The posterior paired petals are much shorter than, a little under half as long as and nearly as wide as the anterior ones, oval, nearly straight and distinctly closed distally. They consist of poriferous zones of nearly equal width, having similar elongate oval pore pairs. The pores of each pair in the posterior petals are opposite, widely set and nonconjugate. In the paired petals a median longitudinal groove is placed at the middle of the width of each ambulacral plate.

The peripetalous fasciole is distinct.

Remarks: — Because of unfavourable preservation, the structure of the apical system is not known and neither a peristome nor a periproct is discernible.

Comparison: — This species closely resembles *Hemiaster* (*Leymeriaster*) *regulusanus* d'Orbigny from the Santonian of France and Spain, in the general outline of the test, the anterior petals being very much longer than the posterior (the former being about twice as long as the latter), and in the features of the ambulacral plates of the paired petals (a median longitudinal groove being placed at the middle of the width of each plate). However, there are some minor but distinct differences between them. In *H.* (*L.*) *regulusanus* the pores of the paired petals are acuminated inwards. Such is not the case with the present form. In our specimen the approximate number of pore pairs is 11, 23 and 15 within the fasciole in each poriferous zone of the frontal ambulacrum, anterior petals and posterior petals, respectively. The anterior petals of the present species have a much smaller number of pore pairs than do those of *Hemiaster* (*Leymeriaster*) *regulusanus* with a much larger test. As to the frontal ambulacrum and posterior petals, on the other hand, their respective number of pore pairs are similar in the two species.

The present form is clearly distinguished from the contemporary *Hemiaster* (*Leymeriaster*) *polygonalis* sp. nov. described above by its rounded or oval outline of the test, frontal sinus not extending distally beyond the fasciole and the non conjugate pore pairs in the paired petals.

To sum up, a possibility cannot be denied that the present form represents a new subspecies of *Hemiaster* (*Leymeriaster*) *regulusanus* which is allied to but distinct from the typical form from France. However, I provisionally call it *Hemiaster* (*Leymeriaster*) sp. aff. *H.* (*L.*) *regulusanus* d'Orbigny, without proposing a new subspecific name, until more and better specimens are obtained.

Occurrence: — Western part of the Asan Mountain Range, eastern Shikoku; Ebisukui Mudstone Member, Izumi Group, mudstone, Campanian.

Subgenus *Mecaster* Pomel, 1883

Hemiaster (*Mecaster*) sp. aff. *H.* (*M.*) *indicus* Stoliczka

Pl. 80, Fig. 10; Pl. 81, Figs. 4, 5; Text-fig. 10

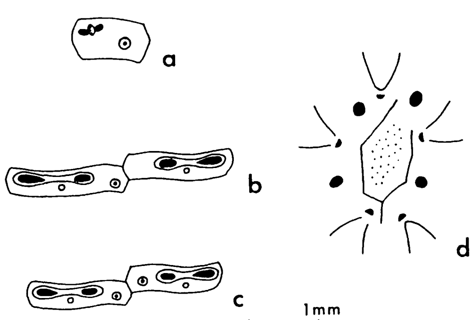
Compare:

1873. *Hemiaster indicus* Stoliczka, *Mem. Geol. Surv. India, Palaeont. Indica,* ser. 8, vol. 4, pt. 3, p. 16 (86), pl. 2 (12), figs. 6, 7, pl. 3 (13), fig. 1.

Material: — Three specimens are available: GSJ. F6183A, B (A, internal mould of aboral surface; B, external mould of aboral surface), from loc. OF-54, about 800 m northwest of Nakahata, Shitsuru, Oita City, Oita Prefecture, Ugaku Formation of Teraoka (1970), Middle Subgroup of the Onogawa Group, Lower Santonian (coll. Teraoka); GSJ. F6186, imperfect external mould of the aboral surface, from loc. OF-71, about 500 m southwest of Taishogun, Suehiro, Usuki City, Oita Prefecture, Mizugajo Formation of Teraoka (1970), Upper Subgroup of the Onogawa Group, Lower Santonian (coll. Teraoka); GSJ. F6188, internal mould, from loc. OF-64, about 500 m east of Hisaeuchi, Usuki City, Takeyama Formation, Middle Subgroup of the Onogawa Group, Lower Santonian (coll. Teraoka).

Description: — The specimens are poorly preserved and secondarily depressed. The test seems rather ovate in outline. The frontal sinus is narrow and shallow, widening towards the ambitus. The aboral surface is somewhat strongly inflated near the apical system in the antero-lateral interambulacral areas and has a more or less distinct median carina in the posterior interambulacral area. The apical system is small, slightly posterior and ethmophract, having four gonopores. The madreporite extends as far back as to separate the posterior genital plates and then to touch the posterior occular plates.

The frontal ambulacrum is narrow, widening from the proximal to the middle part and from the middle to the distal passing with parallel sides. It is shallowly sunken and subpetaloid. Each poriferous zone is narrower than half the width of the interporiferous zone and has small oval pores within the fasciole. The pores of each pair are transverse in the outer row, oblique



Text-gig. 10. *Hemiaster* (*Mecaster*) sp. aff. *H.* (*M.*) *indicus* Stoliczka, GSJ. F6183. a, Frontal ambulacrum. b, Left anterior petal. c, Left posterior petal. d, Apical system.

in the inner row and close together, and are separated by an oblong and transverse granule.

The paired ambulacra are rather broad, rather moderately flexuous, shallowly sunken and petaloid. The anterior paired petals are nearly as long as and much wider than the petaloid part of the frontal ambulacrum. They are longer, somewhat wider and much more divergent than the posterior paired petals, being rather open distally. In the anterior petals, the anterior poriferous zones are more or less narrower than the posterior poriferous zones which are nearly equal to the interporiferous zones in width. The pores are oval in the inner row of each poriferous zone and oblong and acuminated inwards in the outer row. The posterior paired petals are rather long, about four-fifths as long as and somewhat narrower than the anterior petals and more or less closed distally. Their poriferous zones are of nearly equal width and nearly as wide as the interporiferous zones. Each poriferous zone is provided with oval inner pores and elongate oval outer ones acuminated inwards. The pores of each pair in the paired petals are opposite and widely set. In these petals, each pore pair is bordered by a bourrelet which is not interrupted between the pores, being separated from the next by a granule.

The peristome is near the anterior fifth. The periproct is small, oval in outline and vertically elongate. The tubercles are of various sizes, perforate, crenulate and scrobiculate. They are widely scattered on the aboral surface with the largest of them on both sides of the proximal half of the frontal sinus. The interporiferous zones of all the ambulacra are dotted with smaller tubercles. The peripetalous fasciole is well developed and has oval course.

Remarks: — One of the specimens, GSJ. F6183, though poorly preserved and secondarily deformed, roughly measures 29 mm in length. In this specimen, each poriferous zone of the frontal ambulacrum, anterior petals and posterior petals comprises about 17, about 27 and about 23 pore pairs within the fasciole, respectively.

Comparison: — The present form most closely resembles *Hemiaster* (*Mecaster*) *indicus* Stoliczka, from the Ariyalur Group (Campanian — Maastrichtian) of southern India, among many other hitherto described foreign species of the subgenus in the general features of the test. But it is distinguished from that species by the narrower frontal sinus, the paired petals that are less closed distally and have bourrelet-bordered pore pairs, and by the more regularly oval course of the peripetalous fasciole.

The present species is somewhat similar to *Hemiaster* (*Hemiaster*) *uwajimensis* Morishita described above, but differ from that species in that the frontal ambulacrum is narrower, the paired petals are subequal in length, the anterior petals are rather open distally, the pores of the paired petals are shorter and nonconjugate, and in that the peripetalous fasciole has more regularly oval course.

To sum up, the present form probably represents a new species of *Hemiaster* (*Mecaster*) which is allied to but distinct from *H.* (*M.*) *indicus*. However, I postpone proposing a new specific name until more and better specimens are obtained.

Occurrence: — Onogawa area, eastern Kyushu; Ugaku Formation (sandy siltstone) and Takeyama Formation (sandy mudstone), Middle Subgroup of the Onogawa Group, Lower Santonian, and Mizugajo Formation, Upper Subgroup of the Onogawa Group, mudstone, Lower Santonian.

Concluding Remarks

Summarizing the systematic descriptions, the following eight species belonging to the genus *Hemiaster* are identified on the material from the Upper Cretaceous of Japan, with indication of their stratigraphic occurrence in parentheses:

Hemiaster (*Hemiaster*) *uwajimensis* Morishita (Turonian — Coniacian)
Hemiaster (*Hemiaster*) sp. A aff. *H.* (*H.*) *stella* (Morton) (Conician — Santonian)
Hemiaster (*Hemiaster*) sp. B aff. *H.* (*H.*) *punctatus* d'Orbigny (Coniacian)
Hemiaster (*Hemiaster*) sp. C (Turonian)
Hemiaster (*Hemiaster*) sp. D (Santonian)
Hemiaster (*Leymeriaster*) *polygonalis* sp. nov.

Explanation of Plate 80

Figs. 1—8. *Hemiaster* (*Hemiaster*) *uwajimensis* Morishita . . . . Page 428
1. GSJ. F6196 from loc. UF-65, Uwajima area, aboral view, × 2.
2. GSJ. F6198 from loc. UF-8, Uwajima area, aboral (a) and oral (b) views, × 2.
3. GSJ. F6199 from loc. UF-8, Uwajima area, aboral (a), oral (b) and right lateral (c) views, × 2.

Figs. 4—6. *Hemiaster* (*Hemiaster*) sp. A aff. *H.* (*H.*) *stella* (Morton) . . . . Page 430
4. GSJ. F6065 from loc. K-424, Yuasa area, aboral view of an external mould, × 2.
5. GSJ. F6097 from loc. U-15, Urakawa area, aboral view, × 1.5.
6. GSJ. F6099 from loc. KS-72, Kamisarufutsu area, aboral view, × 2.5.

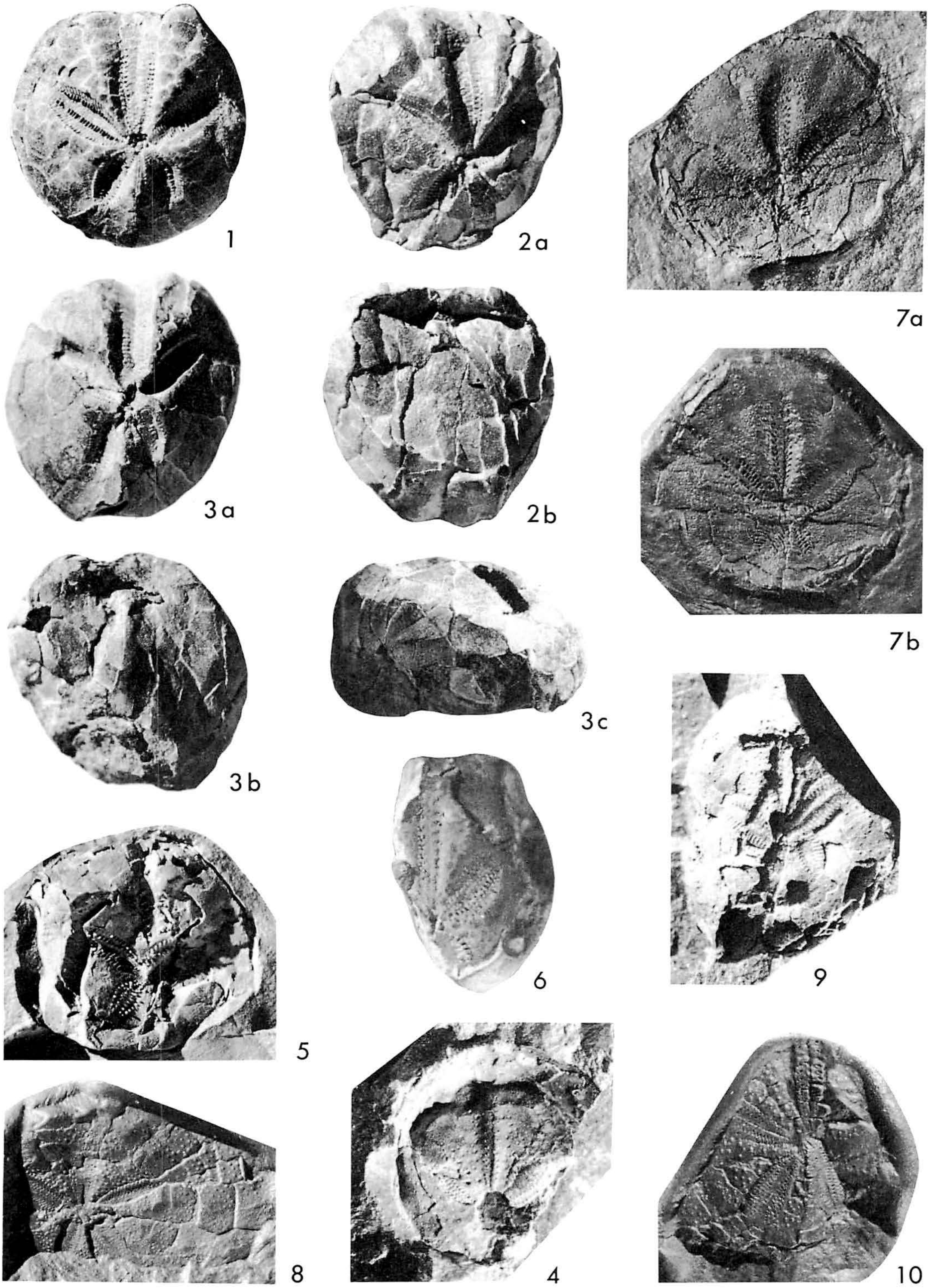
Fig. 7. *Hemiaster* (*Hemiaster*) sp. B aff. *H.* (*H.*) *punctatus* d'Orbigny . . . . Page 432
YCM.665 from the Shimukappu area, aboral views of an external mound (a) and of a gum cast taken from the same external mould (b), × 2.

Fig. 8. *Hemiaster* (*Hemiaster*) sp. C . . . . Page 433
GSJ. F6187 from loc. OF-6, Onogawa area, aboral view of a gum cast taken from the external mould of a fragmentary test, × 1.3.

Fig. 9. *Hemiaster* (*Hemiaster*) sp. D . . . . Page 434
GSJ. F6194 from loc. UF-7, Uwajima area, aboral view of the external mould of a fragmentary test, × 2.

Fig. 10. *Hemiaster* (*Mecaster*) sp. aff. *H.* (*M.*) *indicus* Stoliczka . . . . Page 438
GSJ. F6186 from loc. OF-71, Onogawa area, aboral view of a gum cast taken from the external mould of a fragmentary test, × 2.

All speciments illustrated here are internal moulds, unless otherwise stated.


1
2a
7a
3a
2b
7b
3c
3b
6
9
5
8
4
10

(Campanian)

Hemiaster (*Leymeriaster*) sp. aff. *H.* (*L.*) *regulusanus* d'Orbigny (Campanian)

Hemiaster (*Mecaster*) sp. aff. *H.* (*M.*) *indicus* Stoliczka (Santonian)

Hemiasterid echinoids are the dominant constituents in the Upper Cretaceous echinoid fauna of Japan. Actually, in addition to the species listed above, there are many other *Hemiaster* specimens from various areas of Japan, which are specifically undeterminable because of the poor preservation.

The species belonging to the subgenus *Hemiaster* described here fall into three groups, α, β and γ. The α group has a heart-shaped test, a wide and relatively deep frontal sinus extending to the ambitus, a rather distinct anterior notch, a wide and moderately deeply sunken frontal ambulacrum and broad and deeply sunken paired petals. This group is referred to the typical form of the subgenus *Hemiaster*, being represented by *Hemiaster* (*Hemiaster*) *uwajimensis* Morishita.

In the β group, the test is oval in outline, the frontal sinus is rather wide and shallow, extending at least to the fasciole and the frontal ambulacrum and paired petals are wide and shallowly sunken. *Hemiaster* (*Hemiaster*) sp. C is included in this group.

The γ group is characterized by the oval to subcircular test, the narrow and shallow frontal sinus extending only to the fasciole, the anterior notch being absent or indistinct, the narrow and shallowly sunken frontal ambulacrum and by the rather small paired petals which are broad and shallowly sunken. This group comprises *Hemiaster* (*Hemiaster*) sp. A aff. *H.* (*H.*) *stella* (Morton), *Hemiaster* (*Hemiaster*) sp. B aff. *H.* (*H.*) *punctatus* d'Orbigny and *Hemiaster* (*Hemiaster*) sp. D.

The above features of the γ group somewhat recall *Integraster* (Lambert and Thiéry, 1924; section) that is now synonymous with the subgenus *Hemiaster* according to Lambert (1931 – 32) and Fischer (in Moore, ed., 1966). On the other hand, the general outline of the test and faint frontal sinus, together with the rather small paired petals, show some resemblance of the γ group to the subgenus *Bolbaster*. However, the test of at least *Hemiaster* (*Hemiaster*) sp. A aff. *H.* (*H.*) *stella* is not so high and subglobular as the test of *Bolbaster* species. In short, the β group is of intermediate form between the α group and the γ group, being more closely allied to the latter. As to the γ group, it should also be noticed that in the frontal ambulacrum each pore pair is placed in a depression and the tubercles are widely scrobiculate. These features, however, are not seen in the α and β groups. The above-mentioned feature of the pore pairs in the frontal ambulacrum is one of the prominent features of *Hemiaster* (*Hemiaster*) *stella* and *H.* (*H.*) *punctatus* to which *Hemiaster* (*Hemiaster*) spp. A and B are similar respectively. The two foreign species were allocated to *Integraster*. Because of the insufficiency of the material, I refrain from further discussion of these taxonomic problems.

Hemiaster (*Hemiaster*) *uwajimensis* of the α group is closely allied to certain species from the Utatur Group (Cenomanian – Turonian) of southern India and also to a certain species from the Senonian of Pondoland, southern Africa, which, in turn, is to some extent similar to one of the above Indian species. *Hemiaster* (*Hemiaster*) spp. A and B of the γ group present close resemblance to certain Senonian species from western Europe respectively, one of which occurs also in the Upper Cretaceous along the eastern coast of the United States. Moreover, hemiasterids resembling those of the γ group occur in the Upper Cretaceous of southern India and Madagascar as well as in that of western Europe. *Hemiaster* (*Leymeriaster*) *polygonalis* sp. nov. and the *Hemiaster* (*Mecaster*) species are closely allied to certain upper Senonian species of southern India, respectively. On the other hand, another *Hemiaster* (*Leymeriaster*) species somewhat resembles a certain species from the Senonian (Santonian) of western Europe. In addition, *Hemiaster* (*Mecaster*) *mikasaensis* Tanaka (1984, p. 196, pl. 3, figs. 1–3) from the Lower Cenomanian of Hokkaido closely resembles a certain *Hemiaster* (*Mecaster*) species from the Cenomanian (probably Lower Cenomanian) of western India. Thus, it may be well said that the Upper Cretaceous hemiasterid assemblage of Japan has some affinity with that of the Indo-malagasy province (including southern Africa) on the one hand and with that of the west European province in lesser degree on the other.

Finally, a brief remark is given on the mode of occurrence and mode of life of the described *Hemiaster* species. According to Mortensen (1950), Recent species of *Hemiaster* inhabit depths of about 140 to about 4,000 m. Thus, the *Hemiaster* species described here which occur in argillaceous rocks were generally mud-dwellers living in "deep sea." They were burrowers. Scattered specimens of *Hemiaster* (*Hemiaster*) *uwajimensis* of the α group are found in fossiliferous siltstone (probably of shelf facies) at many localities of the Uwajima area. The rock from which *Hemiaster* (*Hemiaster*) sp. A aff. *H.* (*H.*) *stella* and *Hemiaster* (*Hemiaster*) sp. B aff. *H.* (*H.*) *punctatus* of the γ group came, is mudstone which is regarded as having been deposited in an offshore, deep environment. *Hemiaster* (*Hemiaster*) sp. D of the same group was obtained from relatively fine-grained mudstone interlaminated with sandstone of shaly flysch facies in the Uwajima area. Hence, it is very likely that *Hemiaster* (*Hemiaster*) *uwajimensis* generally preferred a silt substratum and the *Hemiaster* (*Hemiaster*) species of the γ group preferred either a mud substratum or that onto which sand material was frequently supplied forming laminae, though allochthonous in some cases. Moreover, it seems probable that *Hemiaster* (*Hemiaster*) *uwajimensis* lived in shallower waters than *Hemiaster* (*Hemiaster*) species of the γ group. And, by the way, the rock containing *Hemiaster* (*Hemiaster*) sp. C of the β group is relatively coarse-grained mudstone interlaminated with sandstone.

Hemiaster (*Hemiaster*) *uwajimensis* has a longer, wider, deeper frontal sinus, a deeper anterior notch, more pore pairs in the frontal ambulacrum and larger, more deeply sunken paired petals with more numerous and more elongated pore pairs than do the *Hemiaster* (*Hemiaster*) species of the β and γ groups. Moreover, this species has a more anteriorly positioned peristome than *Hemiaster* (*Hemiaster*) sp. A aff. *H.* (*H.*) *stella*. In view of information regarding the functional significance of morphological features of certain spatangoid echinoids (e.g. Nichols, 1959; McNamara and Philip, 1980), these differences suggest that *Hemiaster* (*Hemiaster*) *uwajimensis* burrowed into muddy bottom sediments more deeply than did the other species of *Hemiaster* (*Hemiaster*).

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Explanation of Plate 81

Figs. 1, 2. *Hemiaster* (*Leymeriaster*) *polygonalis* sp. nov. . . . . Page 435

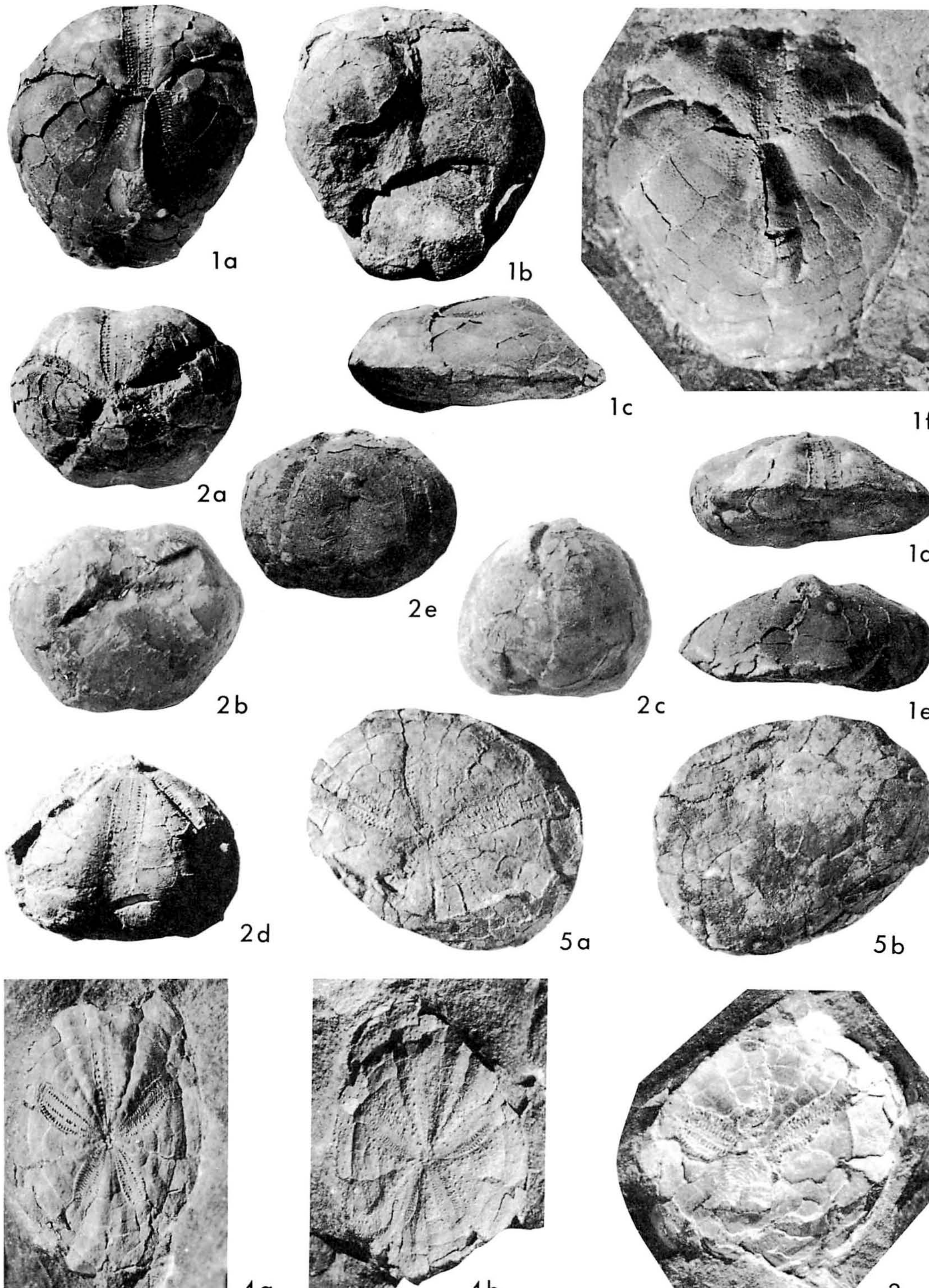
1. GSJ. F6063, holotype, from Awaji Island, aboral (a), oral (b), left lateral (c), anterior (d) and posterior (e) views of an internal mould (A), × 1.2, and aboral view of an external mould (B) (f), × 1.5.
2. GSJ. F6072, paratype, from the Yuasa area, aboral (a), oral (b), left lateral (c), anterior (d) and posterior (e) views, × 1.2.

Fig. 3. *Hemiaster* (*Leymeriaster*) sp. aff. *H.* (*L.*) *regulusanus* d'Orbigny . . . . Page 437
GSJ. F6172 from the Asan Mountain Range, aboral view, × 2.

Fig. 4, 5. *Hemiaster* (*Mecaster*) sp. aff. *H.* (*M.*) *indicus* Stoliczka . . . . Page 438

4. GSJ. F6183 from loc. OF-54, Onogawa area. 4a, Aboral view of an internal mould (A), × 1.5. 4b, Aboral view of an external mould (B), × 1.5.
5. GSJ. F6188 from loc. OF-64, Onogawa area, aboral (a) and oral (b) views, × 2.

All specimens illustrated here are internal moulds, unless otherwise stated.


1a
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日本産白亜紀後期 *Hemiaster* 類のウニ化石： 本邦各地の上部白亜系から産した *Hemiaster* 属のウニ化石について，*Hemiaster* (5種)，*Leymeriaster* (2種) 及び *Mecaster* (1種) の3亜属8種を識別し，古生物学的記載を行った。*Hemiaster* 亜属の1種は本邦の既知種であり，*Leymeriaster* 亜属の1種は新種で，カンパニアンから産する。*Hemiaster* 亜属の種は形態上3群に分けられる。問題の *Hemiaster* 動物群はインド〜マダガスカル（南アフリカを含む）区の要素と類縁があり，一部西ヨーロッパの要素に似たものも含んでいる。なお，*Hemiaster* 亜属の各種の産状にも言及し，一部の種について生活様式を推定した。 田中啓策

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日本学会事務センター　日本古生物学会　行事係

○1985年2月1日に国立科学博物館で日本古生物学会創立50周年記念式典を行う予定です。会員各位には別途御案内致します。

誤 植 訂 正

本誌 No. 134 に次の誤植がありましたので訂正します。

Errata

Majima (1984): Observations on occurrences of Japanese Neogene naticids (Gastropoda) bearing calcareous opercula. *Trans. Proc. Palaeont. Soc. Japan*, N. S., No. 134, p. 361-373, pls. 68-70.

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