# 日本古生物学會
# 報告・紀事

## Transactions and Proceedings

## of the

## Palaeontological Society of Japan

New Series　　No.　156

The fossil on the cover is *Phillipsia ohmorensis* Okubo, an Early Carboniferous trilobite from the Hikoroichi Formation in the Higuchizawa valley, Ofunato City, Iwate Prefecture, northeast Japan (Collected by A. Haga, PAt 5766, ×3.0; after Kobayashi and Hamada, 1980, pl. 6, fig. 4).

# 887. LARGER FORAMINIFERA FROM THE EOCENE SHIMIZU AND MIOCENE MISAKI FORMATIONS IN TOSA SHIMIZU CITY, KOCHI PREFECTURE, SHIKOKU, JAPAN*

KUNITERU MATSUMARU

Department of Geology, Faculty of Education,
Saitama University, Urawa 338

and

KOSHI KIMURA

Idowr Engineering Co. Ltd., Heiwa Bldg.,
Kouenji-Kita 2-19-6, Suginami, Tokyo 166

**Abstract.**   Larger foraminifers from two localities of the Eocene Shimizu and Miocene Misaki Formations in Tosa Shimizu City, Kochi Prefecture, Shikoku, Japan are first described and discussed.   Two species among five species described herein are new species, and all these species are useful for age determination and correlation of these formations in the Indo-Pacific region.

## Introduction

Recently, the junior author investigated the stratigraphy and sedimentary facies of the Tertiary Shimizu and Misaki Formations in the southwestern part of Shikoku (Kimura, 1985).   Both formations are distributed in and around Tosa Shimizu City, occupying a part of the Shimanto Terrain.   Some samples of tuffaceous mudstone and muddy sandstone collected in Tosa Shimizu City by the junior author were examined by means of random thin sections.   In two of these samples there occur interesting larger foraminifers, one of which represents Late Eocene, and the other is regarded as Early Miocene.

The purpose of this paper is to make a description of these species.   All specimens

described herein have been deposited in the collections of Department of Geology, Faculty of Education, Saitama University.

## Fossil localities and geologic setting

Fossil localities treated in this paper are in the hilly land, northwestern part of Tosa Shimizu City, Kochi Prefecture, Shikoku and samples from the following two localities were studied in detail (Figure 1).

Locality 1.   This locality is about 800 m northeast of Takahata, Tosa Shimizu City (32°49′55″N. Lat., 132°54′34″E. Long.).   Chaotic deposits of the Shimizu Formation exposed at Locality 1 are composed of irregular-shaped blocks and clasts of andesite, conglomerate and sandstone dispersed in argillaceous matrix.   The samples are taken from
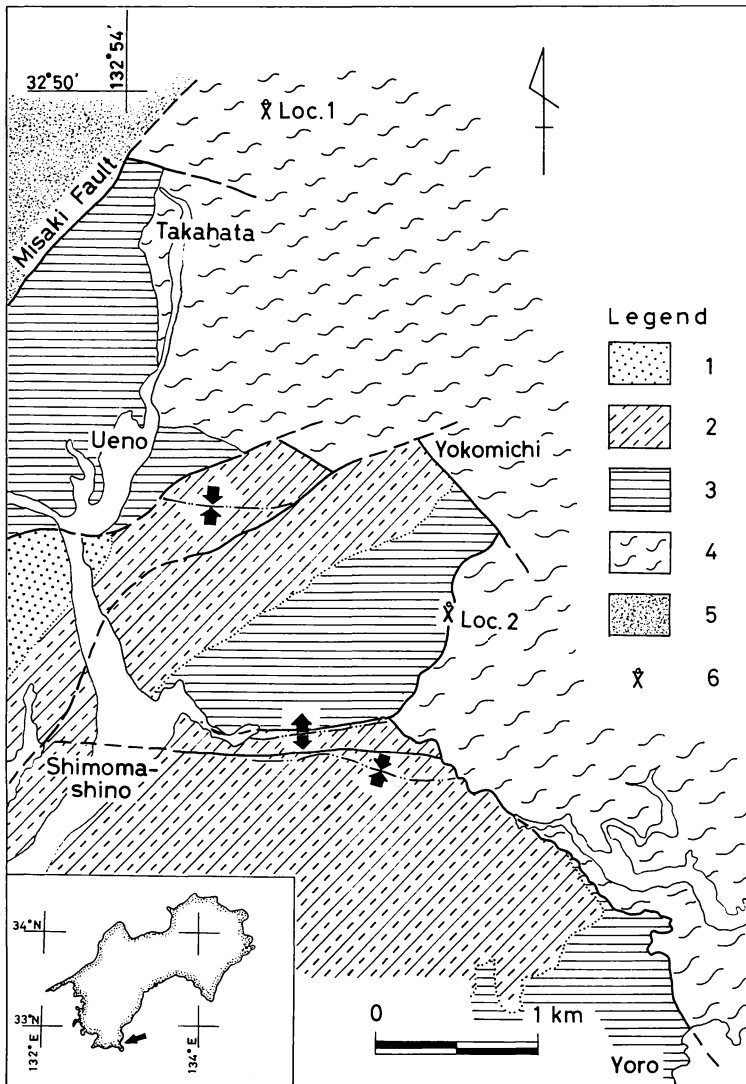
**Figure 1.** Map showing the fossil locality and geological sketch map of the studied area, Tosa Shimizu City, Kochi Prefecture, Shikoku. 1—3, Misaki Formation (1, Upper Member ; 2, Middle Member ; 3, Lower Member) ; 4, Shimizu Formation ; 5, Kurusuno Formation ; 6, Fossil locality.

gray colored tuffaceous mudstone in the matrix.

Locality 2. This locality is about 800 m south of Yokomichi, Tosa Shimizu City (32°48'20"N. Lat., 132°55'15"E. Long.). Samples are taken from poorly sorted muddy sandstone of the Lower Member of the Misaki Formation (Figure 2).

Tertiary rocks in Tosa Shimizu City are stratigraphically grouped into two forma-

tions, the Shimizu and Misaki Formations by the junior author (Kimura, 1985). The Shimizu Formation contains mainly chaotically mixed deposits, and partly coherently stratified sediments. As a whole, the Shimizu Formation is referable to submarine sliding deposits. Mudstone of the Shimizu Formation yields the following planktic foraminiferal species : *Globigerina ampliapertura* Bolli (from P17-21 of planktic for-
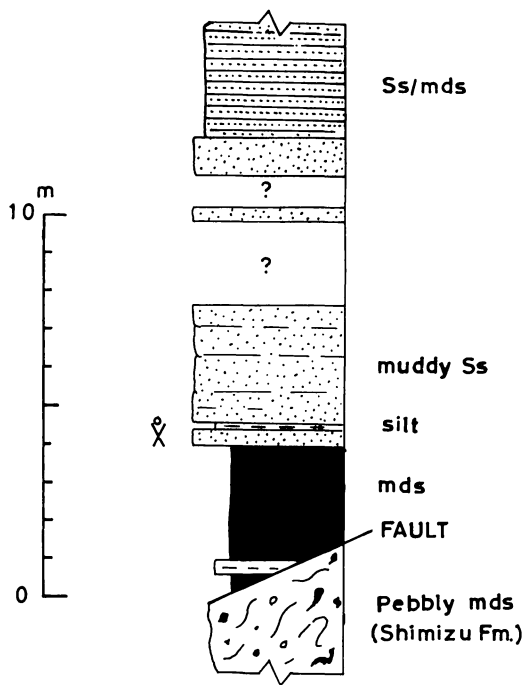
Figure 2. Columnar section of the Lower Member of the Misaki Formation, at the fossil locality (Loc. 2) of Figure 1. The symbol on left side of the columnar section shows the fossil-bearing bed.

Ss/mds = Alternation of sandstone and mudstone; Ss = sandstone: mds = mudstone; Fm. = Formation.

aminiferal Zone of Blow, 1969), and *G. anguliofficinalis* Blow (from P17–21 Zone) from sample s-4, and *Globorotalia opima opima* Bolli (from P20–21 Zone) from sample s-5 (Kimura, *op. cit.*, table 1). Therefore, the geological age of the Shimizu Formation at samples s-4 and s-5 is considered to range from Late Eocene to Late Oligocene (P17 to P21 of planktic foraminiferal Zone).

The thin sections of mudstone from Locality 1 show the presence of *Asterocyclina stella* (Gümbel), *Orbitoclypeus kimurai* Matsumaru, n. sp., *O.* sp., *Discocyclina sella* (d' Archiac), and other fossils as calcareous algae, echinoids, bryozoas and corals. *Asterocyclina stella* and *Discocyclina sella* have a common range of Middle Eocene (Lutetian) to Late Eocene (Priabonian), in the Aquitaine Basin, France (Neumann,

1958) and the Priabonian stratotype, Italy (Sirotti, 1978).

As having some morphological similarities with each other, the Takahata specimens of *Orbitoclypeus kimurai*, n. sp. are compared with the French specimens of *O. chudeaui* (Schlumberger) by Weijden (1940) and Neumann (1958), but both forms are not identical each other. According to Neumann (1977), *Orbitoclypeus chudeaui* from the Mesogean Eocene sediments in western Europe has a range from Middle Eocene (*Hantkenina aragonensis* Zone; P10 Zone of planktic foraminiferal Zone) to early Late Eocene (*Globogerapsis semiinvoluta* Zone; P15 Zone), and this species is in association with *Discocyclina sella* (d' Archiac). Also, according to Bieda (1963), *Orbitoclypeus chudeaui* occurs mainly from the Upper Tatra Eocene in Poland and Czechoslovakia, and this is in association with *Asterocyclina stella* (Gümbel). Sirotti (1978) described ten species of the Discocyclinidae, including *Asterocyclina stella* and *Discocyclina sella,* from the Priabonian type section in Lessini Mountains, Vicenza, Italy.

It is recognized that the Shimizu Formation at Locality 1 represents the presence of Late Eocene (Priabonian), based on the occurrence of *Asterocyclina stella, Discocyclina sella* and *Orbitoclypeus kimurai,* n. sp., which has similar morphology to *O. chudeaui.* In the field observation, the Shimizu Formation from the mudstones of Locality 1 to those of samples s-4 and s-5 (Kimura, 1985, fig. 8) is cut by the WNW-ESE trend fault, one branch of the Misaki Fault. Then, the stratigraphic position between both mudstones is unknown. On the basis of the concurrent ranges of the diagnostic species of larger and planktic foraminifers, it is concluded that the mudstones of Locality 1 may be situated in the lower horizon than those of samples s-4 and s-5.

On the other hand, the Misaki Formation is composed of alternation of sandstone and mudstone in various sand-mud content ratio.
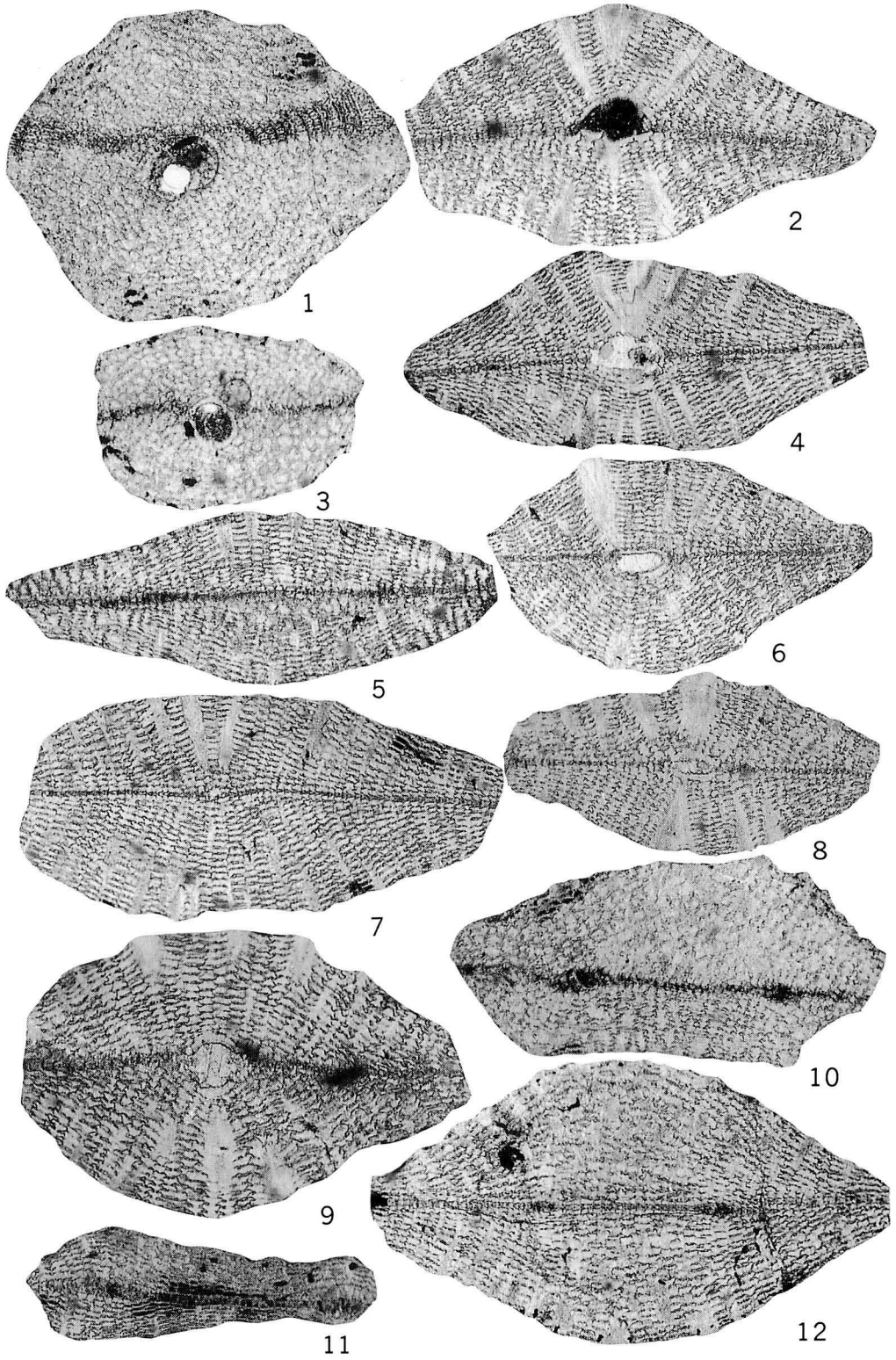
This formation is regarded as a shallow marine deposit, based on lithofacies, sedimentary structure and fossils. Following planktic foraminifers were discovered from mudstone samples of the Lower Member of the Misaki Formation at Locality 2 (sample m-3, Kimura, 1985, fig. 8, table 1), and four other localities (samples m-5, 7, 8 and 9 of Kimura, *op. cit.*): *Catapsydrax stainforthi* Bolli, Loeblich and Tappan (from N5-lower N7 Zone), *Globigerinoides altiapertura* Bolli (from N5-lower N7 Zone), *G. immaturus* LeRoy, *G. subquadratus* Brönnimann, *Globorotalia zealandica* Hornibrook (from Awamoan to Altonian of New Zealand stage, Hornibrook, 1968), *Globorotaloides suteri* Bolli and *Praeorbulina sicana* (de Stefani) (from uppermost N7-9 Zone). Accordingly, the geological age of the Lower Member of the Misaki Formation should be determined as late Early Miocene (Burdigalian).

The thin sections of mudstone from Locality 2 show the occurrence of *Nephrolepidina praejaponica* Matsumaru, n. sp., *Amphistegina radiata* (Fichtel and Moll), *Sphaerogypsina globulus* (Reuss), *Rotalia* sp., *Globigerina* sp., and other fossils as bryozoans, molluscs, echinoids and calcareous algae. *Nephrolepidina praejaponica,* n. sp. could be considered as an ancestor of *Nephrolepidina japonica* (Yabe), because of a small size and a primitive form of embryonic chambers which show an early stage of the embryonic acceleration of *Nephrolepidina* (Matsumaru, 1971).

## Description of species

Family Discocyclinidae Vaughan
and Cole, 1940
Subfamily Orbitoclypeinae
Brönnimann, 1945
Genus *Asterocyclina* Gümbel, 1868

*Asterocyclina stella* (Gümbel, 1861)

Figures 3-3, 8, 11 ; 4-1—5

1861 *Hymenocyclus stella* Gümbel, p. 653.
1868 *Orbitoides stella,* Gümbel, p. 716-717, pl. 2, figs. 117a-c ; pl. 4, figs. 8-10, 19.
1940 *Discocyclina* (*Discocyclina*) *stella* Gümbel, Weijden, p. 50-53, pl. 8, figs. 1-4.
1940 *Asterocyclina stella* Gümbel, Brönnimann, p. 28-29, pl. 1, figs. 3, 7 ; pl. 2, fig. 2.
1958 *Asterodiscus stella* (Gümbel), Neumann, p. 112-114, pl. 28, figs. 1-6 ; text-fig. 36.
1978 *Asterocyclina stella* (Gümbel), Sirotti, p. 62, 64, pl. 4, figs. 11-15.
1980 *Asterocyclina* cf. *stella* (Gümbel), Matsumaru, p. 217-218, pl. 25, figs. 1-14.

*Description :* — The test is small, thick lenticular or inflated, 1.8 to 2.6 mm in diameter ; 0.8 to 1.3 mm in thickness and 2.7 to 3.0 is the form ratio of the diameter to the thickness. There are 5 to 6 rays which are short with bluntly rounded ends and merge into the central part. Seven to 8 papillae occur on the central inflated portion of test and are 68 to 160 $\mu$m in diameter.

The embryonic chambers are bilocular and show nephrolepidine type : protoconch being subspherical is slightly embraced by a reniform deuteroconch. Internal diameters of protoconch $62 \times 68$, $84 \times 70$, $88 \times 84$, $126 \times 170$, $130 \times 110$, $158 \times 125$ $\mu$m, and deuteroconch $112 \times 85$, $125 \times 80$, $160 \times 98$, $144 \times 90$, $154 \times 102$, $182 \times 88$ $\mu$m, are measured respectively from six equatorial sectioned specimens. The outer wall of the embryonic chambers is 11 to 15 $\mu$m in thickness. Total diameter of embryonic chambers is $170 \times 169$, $196 \times 187$, $207 \times 197$ and $240 \times 270$ $\mu$m in four specimens.

Distinct nepionic chambers over deuteroconchal wall are flat-arcuate with radial diameters of 23 to 26 $\mu$m and tangential diameters of 33 to 35 $\mu$m. There are about

← **Figure 3.** **1, 2, 4—7, 9, 10, 12.** *Orbitoclypeus kimurai* Matsumaru, n. sp. **1.** Centered oblique section ; **2, 4, 6, 9.** Vertical sections ; **5, 7, 12.** Transeverse sections ; **10.** Oblique section. **3, 8, 11.** *Asterocyclina stella* (Gümbel) ; **3.** Centered oblique section ; **8.** Vertical section ; **11.** Nearly centered vertical section. All figures × 40.

22 to 25 nepionic chambers in the periembryonic ring. The equatorial chambers in the rays are radially elongated square with radial diameters of 50 to 70 $\mu$m and tangential diameters of 28 to 36 $\mu$m. The inter-ray chambers are tangentially elongate square to square or hexagonal in shape with radial diameters of 35 to 46 $\mu$m and tangential diameters of 18 to 35 $\mu$m.

The lateral chambers are arranged in regular tires in vertical section. The lateral chambers over the embryonic chambers have slit-like openings between thick floors and roofs, with length of 42 to 56 $\mu$m and height of 12 to 14 $\mu$m. The number of lateral chambers varies from 16 to 18 layers over the embryonic chambers. The pillars between lateral chambers are well developed in the central part of test, with a diameter of 68 to 160 $\mu$m.

*Stratigraphic horizon* : — Shimizu Formation.

*Geological age* : — Late Eocene (Priabonian).

*Remarks* : — The present specimens were critically compared with the specimens from Biarritz (Weijden, 1940) and Landes (Neumann, 1958), both in France, northwest Morocco (Brönnimann, 1940), and Priabona, Italy (Sirotti, 1978), which have been referred to *Asterocyclina stella* (Gümbel). The peculiar nephrolepidine embryonic chambers and distribution of pillars as seen in tangential section (Figure 4-5) are very similar to *Asterocyclina stella* from France and Morocco. However, the Tosa Shimizu specimens have more or less small sized embryonic chambers. But the specimens are safely identified with *Asterocyclina stella* (Gümbel) from France, Morocco and Italy.

The senior author (Matsumaru, 1980) figured specimens named as *Asterocyclina* cf. *stella* (Gümbel) from the Kurusuno Formation at Zaimisaki Cape, Tosa Shimizu City, Kochi Prefecture. Although these specimens are more or less stressed into the distorted forms, the specimens are the same as those from the Shimizu Formation in this paper, and all the specimens from the Kurusuno and Shimizu Formations are, therefore, identified as *Asterocyclina stella* (Gümbel).

The present species from Takahata (Locality 1) resembles *Asterocyclina stellatus* (d' Archiac) by Weijden (1940), Neumann (1958) and Sirotti (1978), but it is distinguished from the latter by its smaller shell size, smaller embryonic chambers and many nepionic chambers. The Takahata specimens resembles *Asterocyclina matanzensis* Cole from Eniwetok Atoll (Cole, 1957a) and Saipan (Cole, 1957b), but the former is discriminated from the latter by its large embryonic chambers.

Genus *Orbitoclypeus* Silvestri, 1907
*Orbitoclypeus kimurai* Matsumaru, n. sp.

Figures 3-1, 2, 4—7, 9, 10, 12 ; 5-1, 2, 5

*Type material* : — Holotype, equatorial section, Saitama University Coll. no. 8801 (Figure 5-5).

*Description* : — The test is with an umbonal central part surrounded by a thin flange. The umbo is either arched (Figures 3-2, 4, 10, 12), gently arched (Figures 3-5, 7) or flat-topped (Figures 3-6, 9) in the center. As most of the specimens are much worn, the flange is usually only partly preserved. The diameter of the specimens is more than 2.1 mm as the portion of available sections has this measurement. The thickness through the centre of test is 0.8 to 1.1 mm. The papillae, slightly raised, occur on the um-

→ **Figure 4.** *Asterocyclina stella* (Gümbel). **1—4.** Centered oblique sections. **1b,** enlarged of **1a,** and **2,** enlarged of Figure 3-3, showing the embryonic, nepionic and neanic chambers, and their chamber formations, respectively. **3—4.** Tangential sections, showing the embryonic, nepionic and neanic chambers, and their chamber formations, respectively. **5.** Tangential section, showing the distribution and development of pillars. All figures ×118, except ×45 of **1a** and **5.**

1a

1b

2

3

4

5
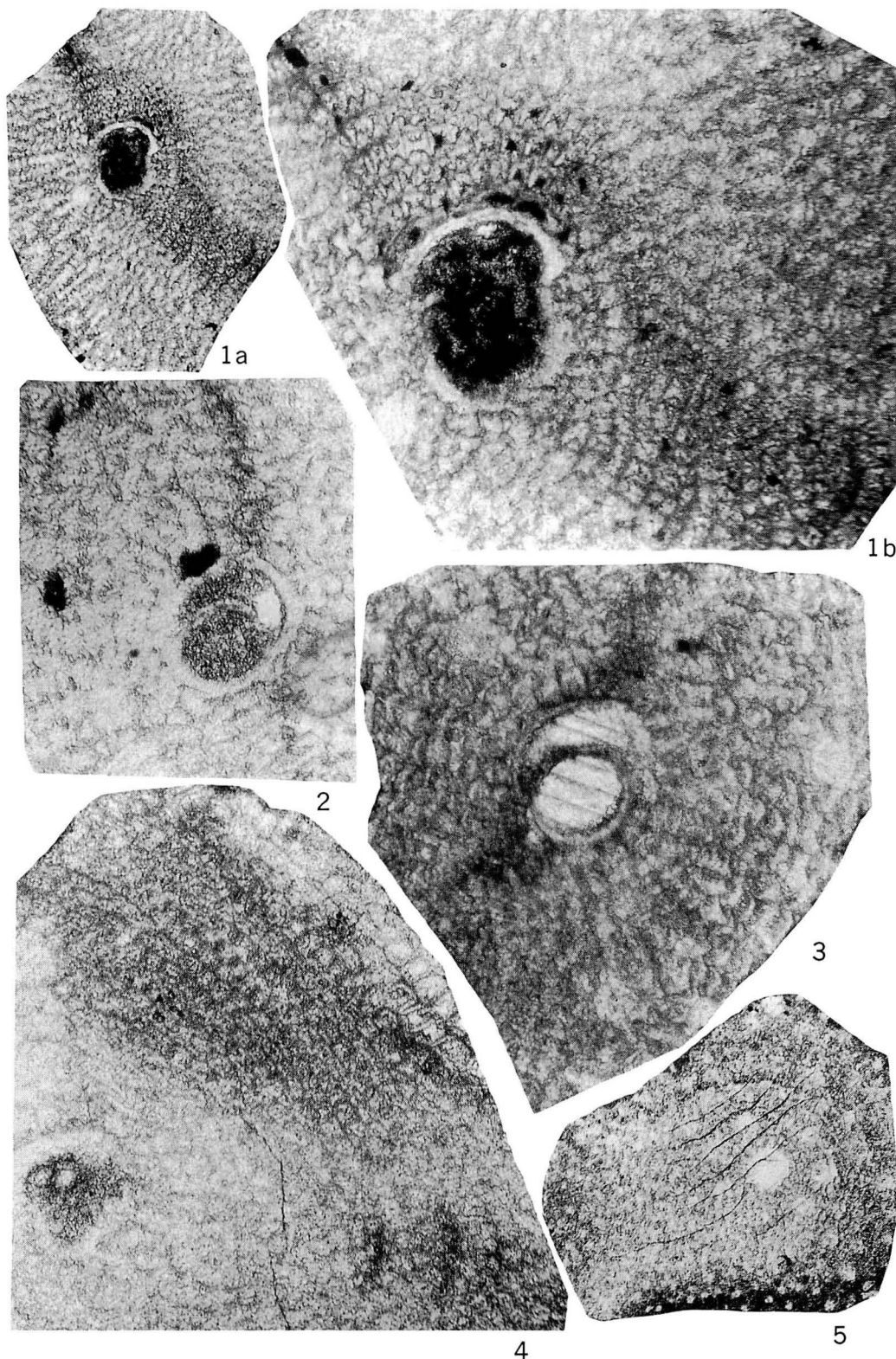
bonal part and have a diameter of 70 to 100 $\mu$m.

The embryonic chambers of eulepidine are consisting of a protoconch with diameters of $84 \times 84$, $104 \times 91$, $119 \times 105$ $\mu$m, and a deuteroconch with diameters of $189 \times 182$, $217 \times 189$, $210 \times 228$ $\mu$m, respectively from three equatorial sectioned specimens. The distance across both chambers is 190 to 230 $\mu$m. The outer wall of the embryonic chambers is 10 $\mu$m in thickness. The dividing partition between a protoconch and a deuteroconch is nearly circumflex and is 7 $\mu$m thickness. In vertical section, the large, elliptical- to pear-shaped embryonic chambers have lengths of 167 to 177 $\mu$m and heights of 70 to 100 $\mu$m.

The periembryonic chambers differ from chambers of the nearby ring. There are about 27 to 30 hexagonal chambers in the periembryonic ring. Distinct two primary auxilliary chambers are rectangular to short hexagonal with raidal diameters of 20 to 42 $\mu$m and tangential diameters of 42 to 49 $\mu$m. Nepionic chambers on the outer edge of the deuteroconch are hexagonal with radial diameters of 30 to 35 $\mu$m and tangential diameters of 25 to 35 $\mu$m. The annular stolon is situated on the proximal side of the radial chamber walls of nepionic chambers.

The equatorial chambers are arranged in irregular rings and connected to each other by radial stolons. The annular walls are usually thicker than the radial ones, which alternate regularly in adjacent annuli. There is a tendency for the rings to become stellate with 8 rays. The equatorial chambers are radially from square through spatulate to hexagonal with maximum radial diameters of 35 to 40 $\mu$m and maximum tangential diameters of 25 to 30 $\mu$m.

The lateral chambers are rectangular in shape and are arranged in regular tiers in vertical section. The chambers over the central area of test are spaceous, with a length of

45 to 80 $\mu$m and with a height of 13 to 28 $\mu$m. The thickness of floors and roofs is 6 to 18 $\mu$m. Number of lateral chambers per tier over the embryonic chambers is 16 to 18 layers. The pillars are well seen in the central part of test in vertical section.

*Stratigraphic horizon* : — Shimizu Formation.

*Geological age* : — Late Eocene (Priabonian).

*Remarks* : — The specimens from Locality 1 at Takahata closely resemble the specimens from France figured by Weijden (1940) and Neumann (1958) under the name of *Discocyclina chudeaui* (Schlumberger). However, the small embryonic and adauxiliary chambers, and many lateral chamber layers of the Takahata specimens are distinguishable from these of the French species. *Discocyclina chudeaui*, however, was treated as a species of the genus *Orbitoclypeus* by Sirotti (1987).

The vertical section of *Orbitoclypeus kimurai*, n. sp., is similar to that of *Asterocyclina stella* (Gümbel), but the present new species is discriminated from the latter in having higher lateral chambers. Hanzawa (1959) described *Fabiania cassis* (Oppenheim) and "*Discocyclina*" sp. from conglomerate of the Eocene Nimyo Formation, on the vicinity of Kuma, Ehime Prefecture, Shikoku. Though he found only two vertical sections of "*Discocyclina*" from more than twenty thin sections, he did not identify it in exact genus and species level. However, Hanzawa's specimens (pl. 9, figs. 16-17) are *Asterocyclina stella* (Figures 3-3, 8, 11) than *Orbitoclypeus kimurai*, n. sp. (Figures 3-2, 4-7, 9, 12) from the Shimizu Formation, because of small height of lateral chambers and development of pillars. From the occurrence of *Asterocyclina stella* from the Nimyo Formation, the Shimizu, Kurusuno and Nimyo Formations could be correlated each other.

The new species, *kimurai*, is named in

---

→ **Figure 5.** **1, 2, 5.** *Orbitoclypeus kimurai* Matsumaru, n. sp. **1.** Centered oblique section ; **2, 5.** Equatorial sections. **5.** Holotype, slide AZ 141-6, Saitama Univ. coll. no. 8801. **3.** *Orbitoclypeus* sp. Tangential section. **4.** *Discocyclina sella* (d'Archiac), Equatorial section. All figures $\times$ 120.
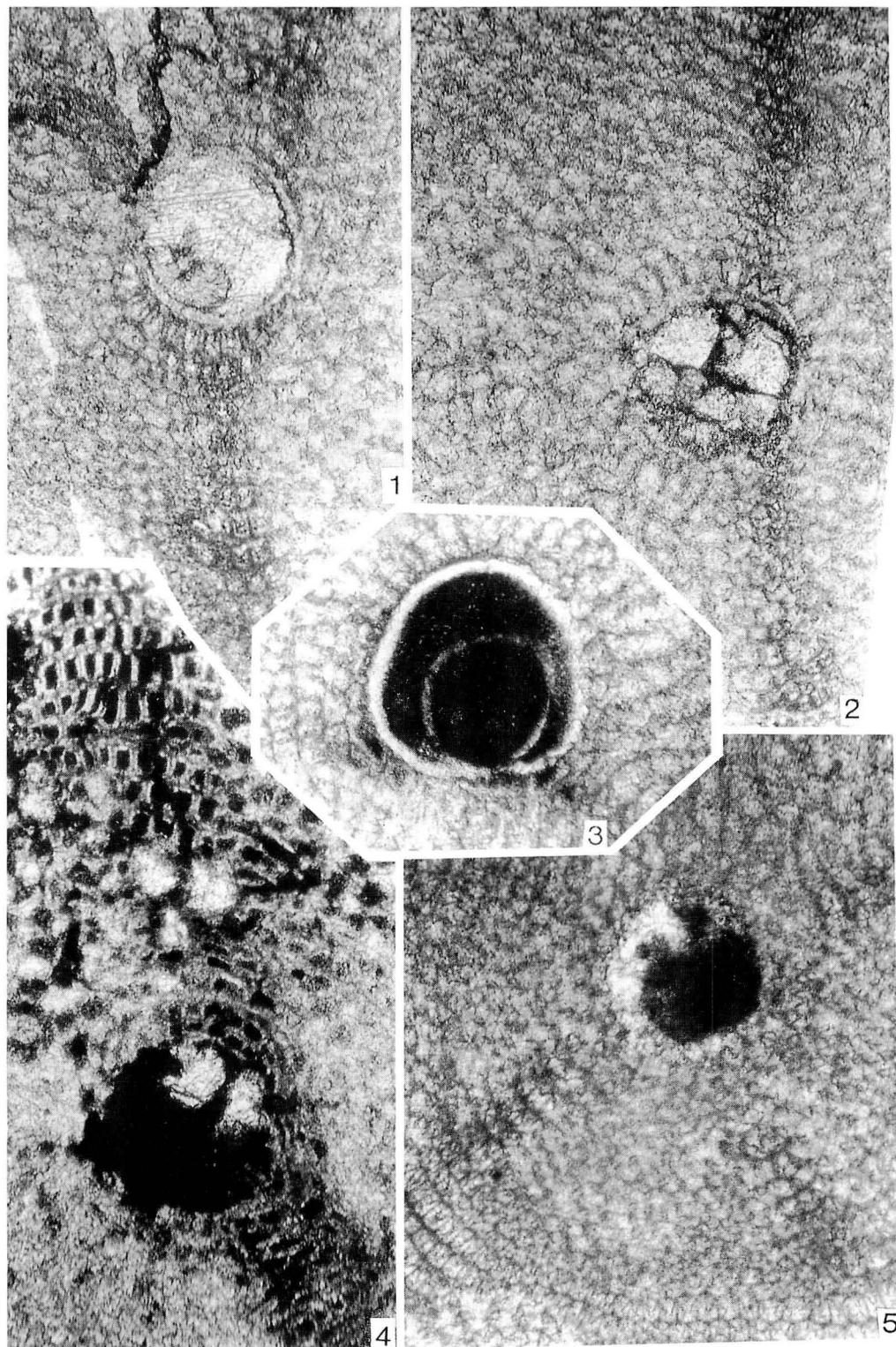
honor of the junior author who collected the material used in his paper.

### Orbitoclypeus sp.

#### Figure 5-3

*Description* : — A tangential section assigned to the genus *Orbitoclypeus* appears in one of random thin sections. This section, which is nearly centered, has a diameter of more than 1.7 mm. The embryonic chambers are eulepidine. The internal diameters of protoconch are $152 \times 164 \mu$m and protoconch is completely surrounded by a deuteroconch with diameters of $252 \times 255 \mu$m. The outer wall is thick lamellae, about $17 \mu$m in thickness. Two primary auxiliary chambers are rectangular with radial diameters of 20 to 22 $\mu$m and tangential diameters of 30 to 35 $\mu$m. The nepionic chambers are rectangular to spatulate with radial diameters of 20 to 35 $\mu$m and tangential diameters of 20 to 40 $\mu$m. The equatorial chambers are arranged in polygonal rings, and are from square to hexagonal in shape, with maximum radial diameter of 46 $\mu$m and maximum tangential diameter of 36 $\mu$m.

*Stratigraphic horizon* : — Shimizu Formation.

*Geological age* : — Late Eocene (Priabonian).

*Remarks* : —This specimen is characterized by peculiar features of large irregular protoconch, large deuteroconch and thick outer walls of embryonic chambers like *Eulepidina* (Lepidocyclinidae). Therefore, the present form may be assigned to *Discocyclina* ( = *Orbitoclypeus* ?) *ramaraoi* Samanta (1967). The former is, however, distinguished from the latter by its eulepidine embryonic chambers, and equatorial chambers.

Subfamily Discocyclininae Brönnimann, 1945
Genus *Discocyclina* Gümbel, 1868
*Discocyclina sella* (d'Archiac, 1850)

#### Figure 5-4

1850    *Orbitolites sella* d'Archiac, p. 405, pl. 8, figs. 16, 16a.
1922    *Discocyclina sella* (d'Archiac), Douvillé, p. 69-70, 89-90, pl. 4, figs. 6-7.
1940    *Discocyclina* (*Trybliodiscodina*) *sella* d'Archiac, Weijden, p. 48-50, pl. 7, figs. 3-5.
1958    *Discocyclina sella* (d'Archiac), Neumann, p. 106-109, pl. 22, figs. 1-8 ; pl. 26, figs. 5-7 ; pl. 36, figs. 2, 4 ; text-fig. 33.
1965    *Discocyclina sella* (d'Archiac), Samanta, p. 426, pl. 2, figs. 1-7 ; pl. 4, fig. 11.
1974    *Discocyclina changi* Hashimoto and Kurihara, p. 38-40, pl. 1, figs. 1-6 ; pl. 2, figs. 1-9 ; pl. 3, figs. 1-4.
1978    *Discocyclina sella* (d'Archiac), Sirotti, p. 59, pl. 2, figs. 3-7.

*Description* : — A centered oblique section was examined in a sample from Locality 1. This specimen has a diameter of more than 2 mm. The broken embryonic chambers are eulepidine. The protoconch has internal diameter of $91 \times 91 \mu$m and is nearly surrounded by deuteroconch having diameters of $231 \times 210 \mu$m. The partition between a protoconch and deuteroconch is $6 \mu$m in thickness. The outer wall of embryonic chambers is about $13 \mu$m in thickness. The nepionic chambers over the protoconchal chamber wall are shortly rectangular and have radial diameter of $14 \mu$m and tangential diameter of $42 \mu$m. The nepionic chamber wall is $8 \mu$m in thickness. There are more than 30 nepionic chambers in the periembryonic ring.

The equatorial chambers are elongated rectangular and have radial diameters of 29 to $43 \mu$m and tangential diameters of 18 to 22 $\mu$m. The annular stolon is situated on the proximal side of the radial chamber walls. The radial chamber walls are well developed and straight, with 11 to 12 $\mu$m thick. Those of one annulus row alternate in position with those of the next adjacent annuli. The radial

stolon is situated on the joining annular wall, with 15 to 16 $\mu$m in thickness, between alternate radial chamber walls.

*Stratigraphic horizon* : — Shimizu Formation.

*Geological age* : — Late Eocene (Priabonian).

*Remarks* : — Although there is no vertical sections of the specimen, the present form is easily identified as *Discocyclina sella* (d'Archiac) by small eulepidine embryonic, nepionic and equatorial chambers, and remarkable regular shape and arrangement. This species is described from the Middle Eocene (Lutetian) to Late Eocene (Priabonian) in France, Spain and Italy, and the Late Eocene of India (Assam).

According to Cotter (1938), the Late Eocene Yaw Shales (Stage) in north Minbu and Pakokku, Burma yielded *Nummulites yawensis* Cotter, *Discocyclina sella* (d'Archiac) and *Operculina* cf. *canalifera* d'Archiac. The Late Eocene Kyet-u-bok Bed in Burma also yielded *Discocyclina omphalus* Fritsch, *D. papyracea* Boubee var. *javana* Verbeek, *Gypsina globulus* Reuss, *Nummulites beaumonti* d'Archiac and Haime, *N. obesus* d'Archiac and *Operculina* cf. *canalifera* d'Archiac. Although the continuous tracing of the Kyet-u-bok Bed towards the Yaw Shales has been rendered difficult in the field, it is noted that the fauna of the former bed must be correlated with that of the Yaw Stage of Pakokku, because it may be noted that *Nummulites yawensis* is possibly present in the Kyet-u-bok Bed. Cotter (1938) described that the fauna of *Discocyclina sella* and *Nummulites yawensis* points to Late Eocene, and that the Yaw Stage is equivalent to the Nanggulan Stage in Java, Indonesia.

In the Phillipines, Hashimoto and Matsumaru (1984) regarded that the both Data Fauna from the Sagada Limestone of Bondoc, Mountain Province, Luzon and the Caguray Fauna from the Tertiary b-Formation of the Caguray River in Southern Mindoro are to be Late Eocene. Although *Discocyclina sella*

has not been recorded in both fauna, it may be expected to the near future. In Taiwan, Hashimoto and Kurihara (1974) once described *Discocyclina changi* from the Late Eocene Tsukeng Formation. However, this species agrees in all respects with features of *Discocyclina sella* described by many authors. *Discocyclina sella* is, therefore, one of the most widely distributed representatives and may be restricted to the Late Eocene in the Indo-Pacific region.

Family Lepidocyclinidae Scheffen, 1932
Genus *Nephrolepidina* H. Douvillé, 1911
*Nephrolepidina praejaponica*
Matsumaru, n. sp.

Figures 6-1—13.

*Type material* : — Holotype, central oblique section, Saitama University coll. no. 8802 (Figure 6-1)

*Description* : — The megalospheric specimens (Figures 6-1—12) are small lenticular test with diameter of 2.0 to 2.9 mm and thickness of 0.7 to 0.8 mm. Surface bears widely scattered low papillae between polygonal shallow pits bounded by low ridges of shell materials. The diameter of papillae is 60 to 100 $\mu$m.

The embryonic chambers are of nephrolepidine type. The protoconch is subcircular with diameter of 105 to 130 $\mu$m. The second large chamber, deuteroconch, which embraces the protoconch has internal diameters of 214 to 252 $\mu$m. The ratio (=DII/DI) of the inner diameter of deuteroconch (II) to that of protoconch (I) is 1.7 from the holotype specimen. The distance across both the protoconch and deuteroconch is 230 $\mu$m in one oriented vertical section. Two main periembryonic chambers (=adauxiliary chambers) occur, one at either end of the partition dividing the embryonic chambers.

The equatorial chambers are arcuate near the periembryonic chambers through ogival to short hexagonal near the periphery with
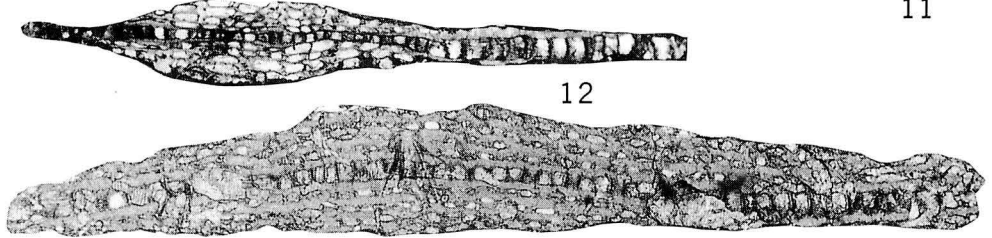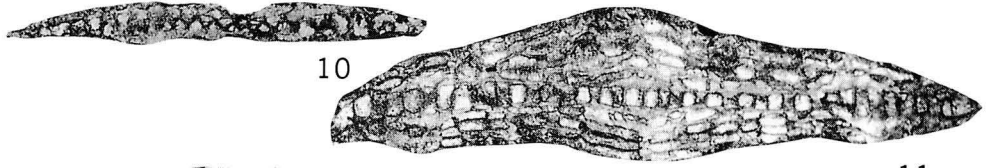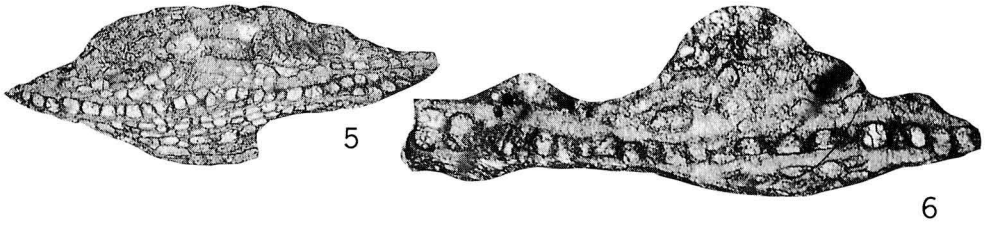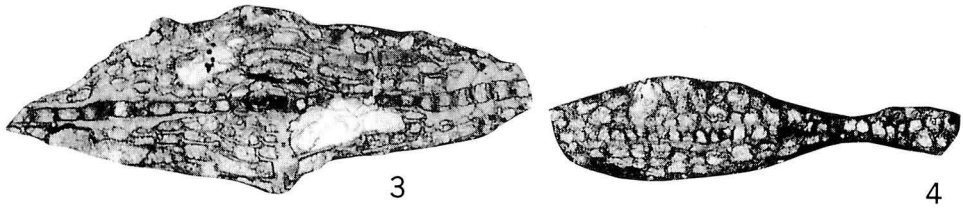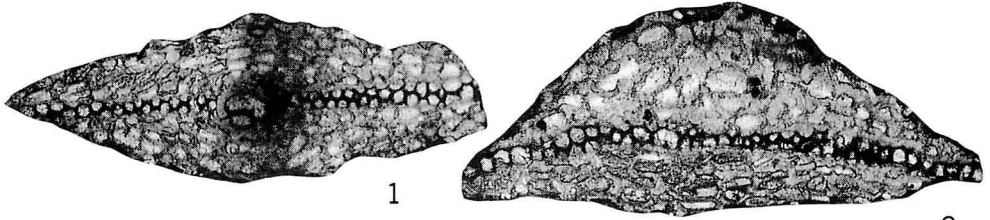
radial diameters of 50 μm near the periembryonic to 136 μm near the periphery. The height of the equatorial layer near the center is about 60 μm and at the periphery about 120 μm.

The lateral chambers are rectangular in shape and are arranged in regular tiers. The lateral chambers over the central area of test are spaceous, with a length of 170 to 180 μm and with a height of 25 to 30 μm. The thickness of more or less wavy floors and roofs is 15 to 17 μm.

The associated microspheric specimen (Figure 6-13) is thin lenticular test with a faint depressive to a tier on one side of the equatorial layer at the centre of test ; about 3.8 mm in diameter ; about 0.5 mm in thickness. The rectangular shaped lateral chambers are arranged in regular tiers. Number of lateral chambers per tier over the embryonic chambers is more than 6 layers.

*Stratigraphic horizon* : — Lower Member of Misaki Formation.

*Geological age* : — Late Early Miocene (Burdigalian).

*Remarks* : — The original description of *Orbitoides* (*Lepidocyclina*) *japonica* (Yabe) was incomplete and it is illustrated by drawings rather than photomicrographs (Yabe, 1906). Afterwards, Yabe and Hanzawa (1922) redescribed it from the *Lepidocyclina* Limestone, which has been defined as the Abuta Limestone Member of the Idozawa Formation by the senior author (Matsumaru, 1967). They were correct in the original assignment of *Lepidocyclina* (*Nephrolepidina*) and described more detail. However, they did not designate the holotype of this species and did not describe the dimension of the embryonic chambers. Later, the senior author (Matsumaru, *op. cit.*) described the topotype specimens of *Lepidocyclina* (*Nephrolepidina*) *japonica* (Yabe), and afterward he raised the subgenus *Nephrolepidina* to the

genus rank (Matsumaru, 1971).

The specimen from the Misaki Formation shows a remarkable similarity to *Nephrolepidina japonica,* but differs from the latter in having small test and small embryonic chambers in size, primitive form of embryonic chambers, short hexagonal equatorial chambers, more spaceous in lateral chambers and wavy floors and roofs. Also, the microspheric form from the Misaki Formation looks like an aberrant form of *Lepidocyclina omphalus* Tan Sin Hok (1935, pl. 1, figs. 4-8 ; pl. 2, figs. 1-10 ; pl. 3, figs. 1-9) and *Eulepidina omphalus* (Tan Sin Hok) described by Hashimoto and Matsumaru (1978, pl. 11, figs. 9, 11, 13-14), respectively. As a whole, the features of the Misaki form show more primitive than those of *Nephrolepidina japonica.* In addition, the present form is occurred from the Burdigalian on the view point of the planktic foraminiferal zone.

This new species resembles *Nephrolepidina sondaica* (Yabe and Hanzawa) from Klias Peninsula, Borneo, Indonesia (Yabe and Hanzawa, 1925) and from Cebu and Mindoro, Philippines (Yabe and Hanzawa, 1929), but the present species is discriminated from the latter in having lenticular test, considerably smaller embryonic chambers and hexagonal equatorial chambers. *Nephrolepidina praejaponica*, n. sp. resembles *Nephrolepidina sumatrensis* (Brady) from Saipan (Cole, 1957b), but is distinguished from the latter by its short hexagonal equatorial chambers and lateral chambers with spaceous floors and roofs arranged in regular tiers.

## Acknowledgments

← **Figure 6.** *Nephrolepidina praejaponica* Matsumaru, n. sp. **1.** Centered oblique section, holotype, slide 12, Saitama Univ. coll. no. 8802. **2, 4—6, 10.** Oblique sections. **3, 7—9, 11—13.** Vertical sections. **13,** showing the microspheric form. All figures ×30, except ×60 of **6** and **8.**

ogy, Faculty of Science, Hiroshima University, for his kind suggestions to transfer the fossil materials from the junior author to the senior.

## References

Archiac, E.J.A.d., 1850: Description des fossiles du groupe nummulitique recueillis par M.S.P. Pratt et M.J. Delbos aux environs de Bayonne et de Dax. *Soc. Geol. France, Mém., Ser. 2*, vol 3, pt. 2, p. 396-456, pls. 8-13.

Bieda, F., 1963: Duze otwosnice eocenu Tatrzanskiego (Larger foraminifers of the Tatra Eocene). *Inst. Geol. Prace*, vol. 37, p. 1-215, pls. 1-26.

Blow, W., 1969: Late Middle Eocene to Recent planktonic foraminiferal biostratigraphy. *In* Brönnimann, P. and Renz, H.H. eds., *Ist. Conf. on planktonic microfossils, Proc. (Geneva*, 1967). E.J. Brill, Leiden, p. 200-421.

Brönnimann, P., 1940: Über die tertiären Orbitoididen und die Miogypsiniden von Nordwest-Marokko. *Schweiz. Pal. Gesel., Abhandl.*, vol. 63, p. 1-113, pls. 1-11, 2 tabs.

——,1945: Zur Frage der verwanstschaftlichen Beziehungen zwischen *Discocyclina* s.s. und *Asterocyclina*. *Eclog. Geol. Helv.*, vol. 38, no. 2, . 579-615, pls. 21-22.

Cole, W.S., 1957a: Larger foraminifera from Eniwetok Atoll drill holes. *U.S. Geol. Surv. Prof. Paper*, 280-I, p. 321-360, pls. 94-118, 4 tables.

——, 1957b: Larger foraminifera [of Saipan]. *Ibid.*, 280-I, p. 321-360, pls. 94-118, 4 tabs.

Cotter, C. de P., 1938: The geology of parts of the Minbu, Myingyan, Pakokku and Lower Chindwein Districts, Burma. *Indian Geol. Surv. Mem.*, vol. 72, pt. 1, p. 1-136, pls. 1-11.

Douvillé, H., 1911: Les foraminiferes dans le Tertiaire des Philippines. *Philippines Jour. Sci.*, vol. 6, no. 2, p. 53-80, pls. A-D, 9 figs.

——, 1922: Révision des Orbitoîdes. Douxieme partie: Orbitoides du Danies et de l'Éocène. *Soc. Geol. France, Bull., Ser. 4*, vol. 22, p. 55-100, pls. 4-5, 28 figs.

Gümbel, C.W., 1861: Geognostische Beschreibung des bayerischen Alpengebirges und seines Vorlandes. *Gotha b. Just. Perthes*, Bd. 1, p. 536-653.

——,, 1868: Beiträge zur foraminiferenfauna der nord-alpinen Eocängebilge oder der Kressenberger Nummulitenschichten. *Abh. K. Bayer. Akad. Wiss.*, Bd. 10, Abt. 2, p. 581-730, pls. 1-4.

Hanzawa, S., 1959: The foraminiferal species

Fabiania cassis (Oppenheim), in Japan. *Cont. Cushman Found., Foram. Res.*, vol. 10, pt. 4, p. 119-122, pl. 9.

Hashimoto, W. and Kurihara, K., 1974: *Discocyclina* from Tsukeng Formation, Tsukeng, Nantou, Central Taiwan, and its geological significance. *Bull. Geol. Surv. Taiman*, no. 24, p. 35-49, pls. 1-3.

—— and Matsumaru, K., 1978: Larger foraminifera from the Philippines, VIII. Larger foraminifera from Central Samar. *Geol. Palaeont. Southeast Asia*, vol. 19, p. 81-88, pl. 11.

—— and——, 1984: Mesozoic and Cenozoic larger foraminifera of the Philippines and a references to those found from Borneo by the APRSA's paleontological reconnaissance. *Ibid.*, vol. 25, p. 147-166, 1 tab.

Hornibrook, N. de B., 1968: A handbook of New Zealand Microfossils (Foraminifera and Ostracoda). *N.Z. Dep. Scient. Ind. Res. Inf. Ser.*, no. 62, p. 1-136.

Kimura, K., 1985: Stratigraphy and sedimentary facies of the Tertiary Shimizu and Misaki Formations in the southeastern part of Shikoku. *Jour. Geol. Soc. Japan*, vol. 91, no. 12, p. 815-831 (*in Japanese with English abstract*).

Matsumaru, K., 1967: Geology of the Tomioka area, Gunma Prefecture, with a note on "*Lepidocyclina*" from the Abuta Limestone Member. *Sci. Rep., Tohoku Univ., 2nd Ser. (Geol.)*, vol. 39, no. 2, p. 113-147, pls. 7-8, 31 figs.

——, 1971: Studies on the genus *Nephrolepidina* in Japan. *Ibid.*, vol. 42, no. 2, p. 97-185, pls. 9-26, 42 figs.

——, 1980: On the genus *Asterocyclina* from the Kurusuno Formation, Tosa Simizu City, Kochi Prefecture, Shikoku, Japan. *In* Taira, A. and Tashiro, M. eds., *Geol. Paleont. Shimanto Belt, Select Paps., Hon. Prof. J. Katto*, p. 217-220, pl. 25.

Neumann, M., 1958: Révision des Orbitoïdides du Crétacé et de l'Éocène en Aquitaine occidentale. *Soc. Geol. France, Mém., N. S.*, vol. 37, no. 83, p. 1-174, pls. 1-36, 54 figs.

——, 1977: Le genre *Discocyclina* en Mesogee. Valeus stratigraphique des differentes especes. *Bol. Geol. Pub. Espec.*, no. 7, p. 1427-1449, 1 fig.

Samanta, B.K., 1965: *Discocyclina* from the Upper Eocene of Assam, India. *Micropaleont.*, vol. 11, no. 4, p. 415-430, pls. 1-4, 2 figs.

——, 1967: *Discocyclina* from the early Tertiary sediments of Pondichery, south India. *Ibid.*, vol. 13, no. 2, p. 233-242, pl. 1.

Scheffen, W., 1932: Zur morphologie und morphogenese der "Lepidocyclinen". *Paläont. Zeitschr.*, vol. 14, p. 233-256, pls. 9-10, 6 figs.

Silvestri, A., 1907: Fossil dordoniani dei dintorni di

Termini Imerese (Palermo). *Atti Pont. Accad. N. Lincei,* vol. 60, no. 3, p. 105-110.

Sirotti, A., 1978 : Discocyclinidae from the Priabonian type section (Lessini Mountains, Vicenza, Northern Italy). *Boll. Soc. Paleont. Italiana,* vol. 17, no. 1, p. 49-67, 2 figs.

——, 1987 : Ontogeny in Tethyan Discocyclinidae and Orbitoclypeidae (Foraminifera). *Idid.,* vol. 26, no. 3, p. 269-278, pls. 1-2, 5 figs.

Tan Sin Hok, 1935 : Zwei neue mikrosphere Lepidocyclinen von Java. *Ingenieur Ned. -Indies, Bandoeng, Java,* Jaarg. 2, Afd. 4 (*Mijnb. Geol.*), p. 9-18, pls. 4-7.

Vaughan, W. and Cole, W.S., 1940 : *Discocyclina, in* Cushman, J.A. Foraminifera, their classification and economic use. 3rd ed. Harvard Univ. Press (Cambridge Press), 353 p., 48 pls.

Weijden, W.J.M. van der, 1940 : Het genus *Discocy-*

*clina* in Europa. *Thesis Univ. Leiden,* p. 1-116, pls. 1-12, N.V. de Leidsche Courant, Leiden.

Yabe, H., 1906 : On the Orbitoid limestone from Kuboi on the north of the Lake Kawaguchi and from Nakakosaka. *Jour. Geol. Soc. Japan,* vol. 13, no. 156, p. 313-320, 1 fig. (*in Japanese*)

—— and Hanzawa, S., 1922 : *Lepidocyclina* from Naka-kosaka, Province of Kozuke. *Japan. Jour. Geol. Geogr.,* vol. 1, no. 1, p. 45-50, pls. 5-8.

—— and ——, 1925 : A *Lepidocyclina*-limestone from Klias Peninsula, B.N. Borneo. *Gedenkbock Verbeek, Geol. Mijnb. Genoot. Nederl. Kol. verh.,* vol. 8, p. 617-632, pls. 1-4, 4 figs.

—— and ——, 1929 : Tertiary foraminiferous rocks of the Philippines. *Sci. Rep. Tohoku Univ, 2nd Ser. (Geol.),* vol. 11, no. 3, p. 137-190, pls. 15-27.

高知県土佐清水市の始新世清水累層および中新世三崎累層産出の大型有孔虫：高知県土佐清水市北方の始新世清水累層から後期始新世 (Priabonian) の大型有孔虫化石3属4種が発見され，記載された。それらは，*Asterocyclina stella* (Gümbel), *Orbitoclypeus kimurai* Matsumaru, n. sp., *O.* sp., *Discocyclina sella* (d'Archiac) である。このうち，*Orbitoclypeus* 属の発見は日本において初めて記載される。中新世三崎層からは，初期中新世 (Burdigalian) の大型有孔虫化石 *Nephrolepidina praejaponica* Matsumaru, n. sp. が発見され，記載された。本種は *N. japonica* (Yabe) の祖先型に相当する。　　　松丸国照・木村公志

# 888. MIXED CONODONT ELEMENTS FROM HACHIMAN TOWN, MINO TERRANE, CENTRAL JAPAN*

HISAHARU IGO

Department of Astronomy and Earth Sciences,
Tokyo Gakugei University, Koganei, Tokyo 184

**Abstract.** Mixed conodont elements suggesting Early Permian to Late Triassic ages are abundant in a calcarenite that crops out near the Horikoshi Pass, Hachiman Town, Gujio County, Gifu Prefecture, central Japan. This calcarenite occurs as fillings of fissures developed within a limestone belonging to the late Early Permian Akuda Formation. Conodont elements seem to have been mixed by redeposition of washed out elements together with calcareous sand-streams filling fractures developed on a submarine carbonate cliff during late Norian to Middle Jurassic time.

Thirty-three species, including six subspecies and four unidentified species of conodonts belonging to six genera are discriminated herein. Of these *Neogondolella bisecta*, *N. polygnathiformis depressa* and *N. polygnathiformis magna* are newly proposed herein.

## Introduction and acknowledgments

A thick series of limestone, greenstone, sandstone, shale and chert occurs widely in Hachiman Town, Gujio County, Gifu Prefecture (Figure 1). Geologically, this area is in the central part of the Mino Terrane of the Inner Zone of Southwest Japan. The geology and fusulinacean biostratigraphy of this area were studied by Kanuma (1958a, b, 1959, 1960) and the following stratigraphic succession was established:

Permian {
Kayugawa Formation
Shimadani Formation   Kuchibora Formation
Akuda Formation
}

Subsequently, I restudied this area, using conodont biostratigraphy to confirm that the Kayugawa Formation and a part of

Shimadani and Kuchibora Formations are Triassic and that these units are olistostromes including allochthonous blocks of Carboniferous to earliest Jurassic chert, limestone and greenstone.

The Akuda Formation consists mainly of white to pale gray massive limestone and greenstone. Kanuma (1958a, b) described fusulinaceans from this limestone, such as *Pseudofusulina ambigua* (Deprat), *Pseudoschwagerina uddeni* (Beede and Kniker), *Minojapanella elongata* Fujimoto and Kanuma and others. These fusulinaceans indicate that the geologic age of the Akuda Formation is late Early Permian.

Recently, Wakita (1984) mapped this area and concluded that the Akuda Formation is huge allochthonous blocks in his Jurassic Nabigawa Formation.

I recovered abundant conodont elements indicating Early and Late Permian and Early to Late Triassic ages from calcarenite filling the fissures developed within a limestone of the Akuda Formation. This interesting
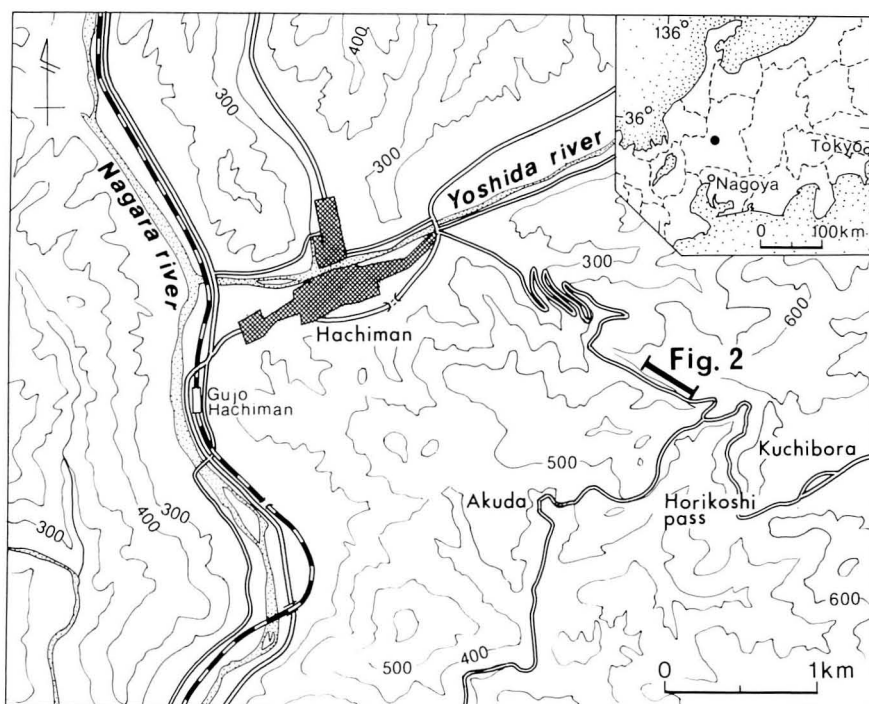
**Figure 1.** Map showing fossil locality.
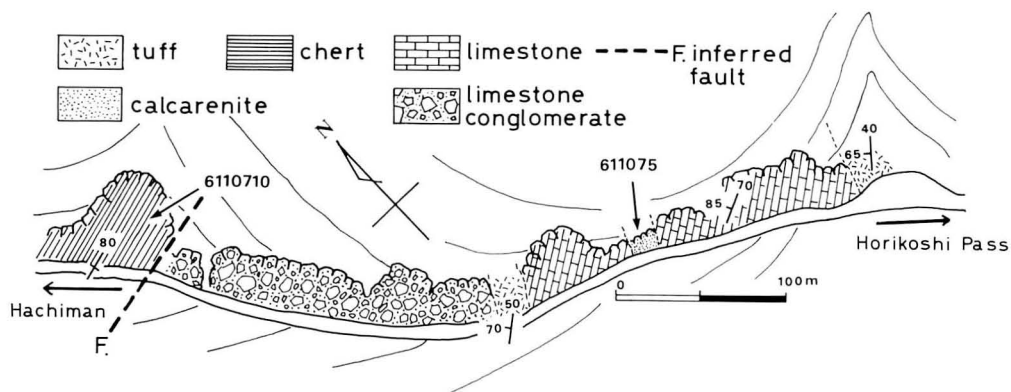


**Figure 2.** Rute map near fossil locality.

exposure crops out along the roadcut near the Horikoshi Pass, about 1 km northeast of Akuda (Figure 2). Calcarenite yielding mixed conodont elements and radiolarian chronology of the Nabigawa Formation provide dating of the deposition of this fissure filling calcarenite as late Norian to early Middle Jurassic.

The purpose of this paper is to discuss the origin of mixed conodont elements and their geologic significance, and to describe some conodont elements.

hama National University) gave me comments and suggestion for taxonomy. Dr. Mitsuyoshi Kimata (University of Tsukuba) identified mineral assemblage of calcarenite with X-ray diffractometer.

### Geologic setting

The conodont locality is about 2 km north of the Horikoshi Pass along the roadcut of prefectural road bound for Kanayama from Hachiman (Figure 1). A 550 m thick sequence including tuff and white to pale gray massive limestone of the Akuda Formation, and calcarenite, limestone conglomerate and radiolarian chert of the unnamed lithologic units is exposed along this road. The following stratigraphic sequence is in ascending order but partly superficial:

1.  Tuff; brown with a tint of green.....
    ...........................more
    than ..20 m thick, so far as exposed.
2.  Limestone; white to pale gray, massive, encrinal, including fragments of bryozoans and rare fusulinaceans (*Pseudofusulina* sp.)...............
    ...................about 90 m thick.
3.  Calcarenite; fissure filling, red and brown, conglomeratic at the southeast side of outcrop, including frequently clasts of limestone, well-laminated calcarenite and calcareous shale, a few

centimeters to 50 cm in diameter. ....
...thickness uncertain, but exposed in 6.5 to 10.5 m wide along the roadcut.
4.  Limestone; white to pale gray, massive, encrinal, including fragments of bryozoans.........about 70 m thick.
5.  Tuff; brown with a tint of green.....
    ........................15 m thick.
6.  Limestone conglomerate; including angular limestone clasts, several centimeters in diameter, and sporadically including red to brown shale breccias.
    ................about 200 m thick.
    ——— inferred fault ———
7.  Chert; red to brown, thin bedded, including an early Permian radiolarian (*Pseudoalbaillella* sp.)...............
    ..............more than 20 m thick.

Mixed conodont elements are abundant in the calcarenite (Unit 3 mentioned above). Figure 3 is a detailed sketch showing the occurrence and lithology of this calcarenite in the outcrop. There are many cracks and irregular shaped fissures in the uppermost part of massive limestone (Unit 2) of the Akuda Formation, and they are completely filled with calcarenite. The boundary between the massive limestone and calcarenite is marked very distinctly by color differences and its irregularly undulated or straight surface. The calcarenite exposed at
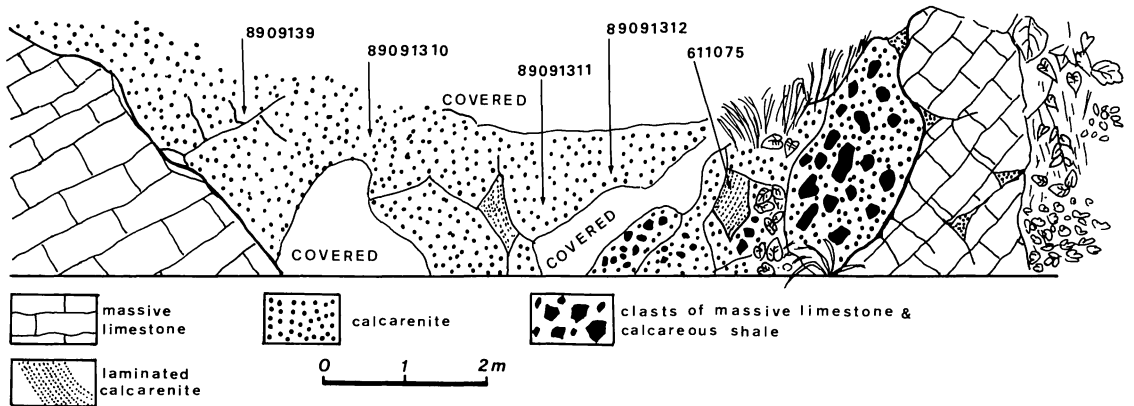


**Figure 3.** Sketch showing outcrop of calcarenite.
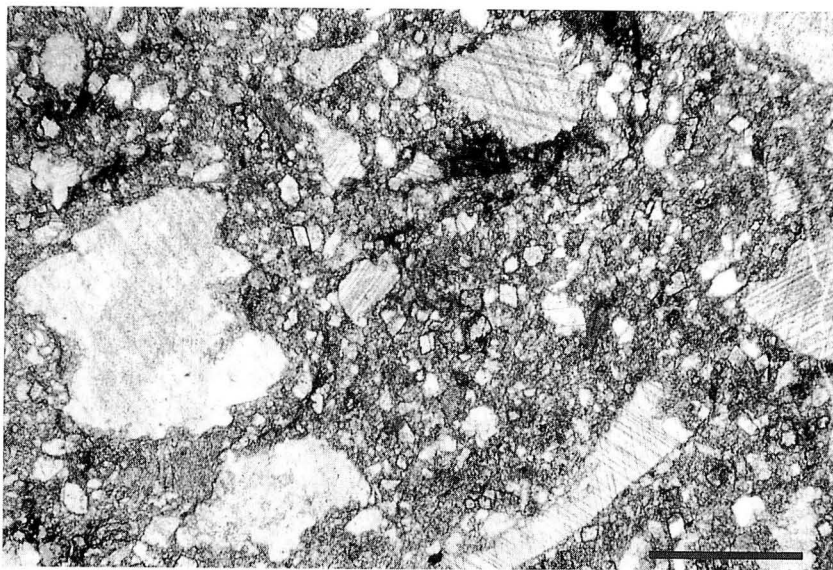
**Figures 4a (left), b (below).** Photomicrographs showing texture of calcarenite. a ; typical texture of calcarenite. b ; dolomitized part. Scale bars 0.5 mm.

the southeast side of the outcrop (right side of Figure 3) includes many angular clasts of a few centimeters to 50 cm in diameter of white to pale gray limestone, well-laminated calcarenite and sporadic red calcareous shale.

Under the microscope, calcarenite is poorly sorted and allochems form tight compacted fabric. It is made up largely of skeletal fragments, which are mostly crinoid columns and less commonly uncertain calcareous organisms, and small limestone clasts comprising peloid, micrite and compacted calcarenite. The skeletal fragments and limestone clasts are cemented with red to dark brown argillaceous matrix occasionally showing interlaminations. Skeletal fragments are variable in size and up to 2.5 mm across. Hence both calcarenite and calcirudite are present. These bioclasts show crude size grading, with larger ones irregularly distributed. Allochems are all fragmented and do not show any roundness (Figure 4a). Secondary growth of dolomite rhombs, 0.05 to 0.15 mm across, is mostly scattered, but the rhombs are partly concentrated in patches (Figure 4b). These dolomite rhombs are commonly zoned, having a central portion clouded with inclusions and a relatively clear peripheral part. The rhombs are ordinarily coated with thin
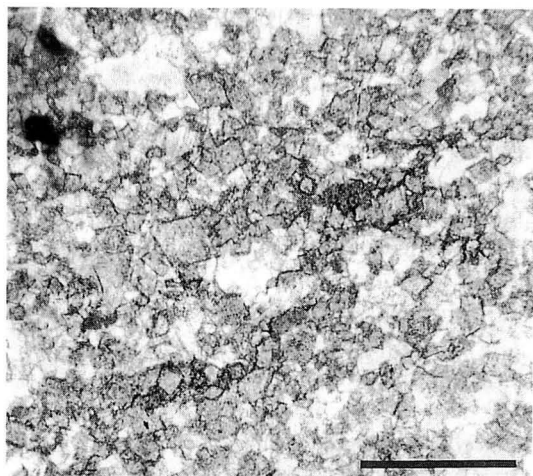


dark brown clay film. X-ray diffractometer pattern indicates that argillaceous matrix consists mainly of hematite.

I recovered conodont elements from all samples collected from the various points of Unit 3. However, samples numbered 89091310 and 8909139 collected from the northwestern side of the outcrop (left side of Figure 3), yield particularly abundant conodont elements. About 200 elements were obtained from 1 kg sample ; ramiform elements are mostly fragmented, but pectiniform elements are rather well-pre-

served and do not show any attrition. Observation of the etched surface of calcarenite with a scanning electron microscope confirmed that the red hematitic matrix includes conodont elements. Recovered conodont assemblages comprise elements indicating various geologic ages, but assemblages from different points have almost similar specific composition.

## Mixed conodont elements and their geologic significance

As noted above, conodont elements are abundant in calcarenite, but ramiform elements are mostly fragmented and their identification is almost impossible. Table 1 shows a list of pectiniform elements recovered from samples 8909139 and 89091310 and their suggested geologic age.

Among the listed elements, *Neogondolella foliata* (s.l.), which indicates a late Ladinian to early Carnian interval, is most abundant. Other elements indicating younger age than that of *N. foliata* (s.l.), such as *N. polygnathiformis polygnathiformis, N. nodosa, Epigondolella echinata* and *E. spatulata*, reduce their number. Conodonts suggesting older age than that of *N. foliata* (s.l.), such as *Carinella mungoensis, C. hungarica, N. excelsa* and *N. mombergensis* are rather rare. *Misikella hernsteini*, one of the latest survivors of conodont animals, is the most rare species in the present sample.

The origin of this mixture is puzzling. The occurrence of mixed conodont elements has been reported from several places in Japan (Koike *et al.*, 1974; Conodont Research Group, 1974; Koike, 1979; Watanabe *et al.*, 1979; Koike, 1981). Koike *et al.* (1974) and Conodont Research Group (1974) reported a mixed conodont assemblage from laminated limestone exposed in the Kuzu area, Tochigi Prefecture. This laminated limestone crops out elsewhere at the top of the Nabeyama Limestone Formation and fills fissures of the limestone, and it

also occurs as the matrix of limestone conglomerate including clasts of limestone and chert concretions derived from the Nabeyama Limestone. This laminated limestone and limestone conglomerate were thought to be the basal conglomerate of the Adoyama Formation. Mixture of abundant conodont elements suggesting Middle Permian to Late Triassic occurs in the laminated limestone. The Adoyama Formation consists mainly of bedded chert yielding successively Upper Triassic conodonts and Lower Jurassic radiolarians at the type section (Igo and Nishimura, 1984). Therefore, laminated limestone and limestone conglomerate superficially underlying the Adoyama Formation should be separated from the latter as an independent lithologic unit. Mixed conodont elements in this laminated limestone were said to be reworked from limestone dated as Middle Permian to Late Triassic.

Koike (1979) introduced Kinoshita's study (Kinoshita, 1974, MS) and mentioned the occurrence of Triassic mixed conodont assemblages from the Morisawa area, north of Kuzu, Tochigi Prefecture. He interpreted the origin of this mixing as redeposition of limestone from a shallow sedimentary basin to a deep basin. Koike (1979, 1981) also documented the mixture of conodont elements in thin beds of conglomeratic limestone intercalated with the Triassic Taho Limestone, Ehime Prefecture. His interpretation is very slow accumulation of reworked conodont elements.

Watanabe *et al.* (1979) discussed the origin of mixed elements in the Triassic Kamura Limestone of Miyazaki Prefecture and pointed out two causes: condensed lag deposits and reworking during deposition of the basal conglomerate.

The field occurrence of the present calcarenite is similar to that of laminated limestone reported from the Kuzu area. However, a difference has been recognized between the present case and that of Kuzu. The distribution of calcarenite of the Hachiman area is

**Table 1.** List of conodont elements recovered from samples 8909139 and 89091310 and their known range and relative abundance. Dashed line indicates uncertain range. (A): abundant, (C): common, (R): rare, (VR): vary rare.

| System | Permian | | | Triassic | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Series** | Low. | Mid. | Up. | Lower | | | Middle | | Upper | |
| **Taxa** Stage | | | | G.-D. | Smith. | Spath. | Anisian | Ladinian | Carnian | Norian |
| *Neospathodus homeri* (Bender) (R) | | | | | | ━ | | | | |
| *N. waggeni* Sweet (R) | | | | | ━━━ | | | | | |
| *N. timorensis* (Nogami) (VR) | | | | | | ━ | | | | |
| *Neogondolella subcarinata* Sweet (R) | | | ━━ | | | | | | | |
| *N. changxingensis* Wang and Wang (R) | | | ━━ | | | | | | | |
| *N. intermedia* Igo (R) | — | | | | | | | | | |
| *N. bulgarica* (Budurov and Stefanov) (C) | | | | | | | ━━ | | | |
| *N. bifurcata* (Budurov and Stefanov) (R) | | | | | | | ━━ | | | |
| *N. excelsa* (Mosher) (VR) | | | | | | | | ━ | | |
| *N. mombergensis* (Tatge) (VR) | | | | | | | | ━ | | |
| *N. aff. mombergensis* (Tatge) (R) | | | | | | | | ┈┈ | | |
| *N. foliata foliata* (Budurov) (A) | | | | | | | | | ━ | |
| *N. foliata inclinata* (Kovács) (A) | | | | | | | | | ━ | |
| *N.* sp. A (VR) | ··· | | | | | | | | | |
| *N.* sp. B (R) | | | | | | | | ┈┈ | | |
| *N.* sp. C (R) | | | | | | | | ┈┈ | | |
| *N.* sp. D (R) | | | ┈┈ | | | | | | | |
| *Gladigondolella tethydis* (Huckriede) (R) | | | | | | | ━━━ | | | |
| *G. malayensis malayensis* Nogami (R) | | | | | | | | ━━━ | | |
| *Carinella mungoensis* (Diebel) (R) | | | | | | | ━ | | | |
| *C. hungarica* (Kozur and Véga) (R) | | | | | | | | ━ | | |
| *Neogondolella polygnathiformis* (s.s.) (Budurov and Stefanov) (C) | | | | | | | | | ━ | |
| *N. aff. polygnathiformis* (s.s.) (Budurov and Stefanov) (R) | | | | | | | | | ┈┈┈ | |
| *N. polygnathiformis magna* Igo, n. subsp. (R) | | | | | | | | | ┈┈┈ | |
| *N. polygnathiformis depressa* Igo, n. subsp. (C) | | | | | | | | | ┈┈ | |
| *N. bisecta* Igo, n. sp. (R) | | | | | | | | | ┈┈┈ | |
| *N. nodosa* (Hayashi) (C) | | | | | | | | | ━┼ | |
| *N. aff. tadopole* (Hayashi) (R) | | | | | | | | | ━ | |
| *Epigondolella primitia* Mosher (C) | | | | | | | | | ┼ | |
| *E. abneptis* (Huckriede) (C) | | | | | | | | | ━┼ | |
| *E. echinata* (Hayashi) (R) | | | | | | | | | ┼ | |
| *E. spatulata* (Hayashi) (C) | | | | | | | | | | ━ |
| *E. postera* (Kozur and Mostler) (R) | | | | | | | | | | ━ |
| *Misikella hernsteini* (Mostler) (VR) | | | | | | | | | | ━ |

888. *Mixed conodonts from Mino*

275

very restricted, whereas the laminated limestone of the Kuzu area can be widely traced elsewhere at the top of the Nabeyama Limestone. Calcarenite in this area is characteristically red to brown and contains a considerable amount of hematitic argillaceous matrix, but laminated limestone in Kuzu is gray in color and does not contain any hematitic argillaceous matrix.

According to my interpretation, the Permian Akuda Limestone was deposited on a submarine bank or seamount whose basement was basic volcanic rock and related hyaloclastics. This limestone constituted an abruptly elevated steep submarine cliff rising above a deep basin and submerged beneath a shallow sea throughout Triassic times. This shallow sea had a lime-sand shoal in which repeated alternating sedimentation and denudation occurred. As a result, condensed thin calcareous sediments accumulated on the seafloor and incorporated mixed elements of conodont animals that inhabited the sea. Shallow carbonate sedimentation was mostly continued in late Ladinian to early Carnian ages, thus conodont elements indicating these ages, such as *Neogondolella foliata* (s.l.), are most abundant in the calcarenite.

The general sedimentary setting of the mentioned model recalls that of carbonate slopes of "by-pass margin" proposed by McIlreath and James (1979). A sudden shock such as an earthquake or tsunami caused the Triassic condensed sequence including conodont elements and the underlying Permian limestone near the submarine cliff collapse into the deep basin and be redeposited as peri-platform talus deposits. Limestone conglomerate and limestone breccia exposed in the present section may have been deposited by the proposed rock-fall and gravity-induced downslope mass movement. Calcarenite represents finer fractions of these deposits, such as sand-streams, that filled the fissures of the submarine cliff composed of the Akuda Limestone. Washout conodont elements suggesting an Early Permian to Late Triassic interval were also redeposited together with these calcareous grains and much finer argillaceous hematitic material. This argillaceous material consisting of matrix of calcarenite seems to be originated from residual soil, which was produced by chemical weathering of limestone and other rocks under a tropical or subtropical climate.

Chert bearing early Permian radiolarians, exposed in the northern part of this section, represents basin deposits and is contemporaneous but heterotopic with the massive limestone of the Akuda Formation.

## Paleontological notes on some interesting species

The present mixed conodont elements contain many well-known cosmopolitan species, which were repeatedly described by various authors. Description of these species is avoided, but brief paleontological notes of some interesting species are given herein.

*Epigondolella echinata* (Hayashi) originally described from chert of the Adoyama Formation of Kuzu, Tochigi Prefecture is rather rare in the present calcarenite. This species is distinguishable from the allied species, *E. abneptis* (Huckriede), in its relatively longer free blade and shorter non-denticulated platform. Honeycomb structure is well developed on the platform of each side of carina. This species also closely resembles *Neogondolella* aff. *tadpole* (Hayashi) of this paper, but the latter possesses a shorter free blade than that of the former. Detailed synonyms and remarks of *E. echinata* were given by Kovács and Kozur (1980a, p. 569).

*Epigondolella primitia* Mosher is common in the present locality and is similar to *E. abneptis*, but the former has an elongate quadrangle platform and 3 to 6 lateral nodes on the anterior two half length of the platform. This species is also related to *Neogondolella nodosa*, but the latter possesses a sharp pointed elongate anterior platform. Further-
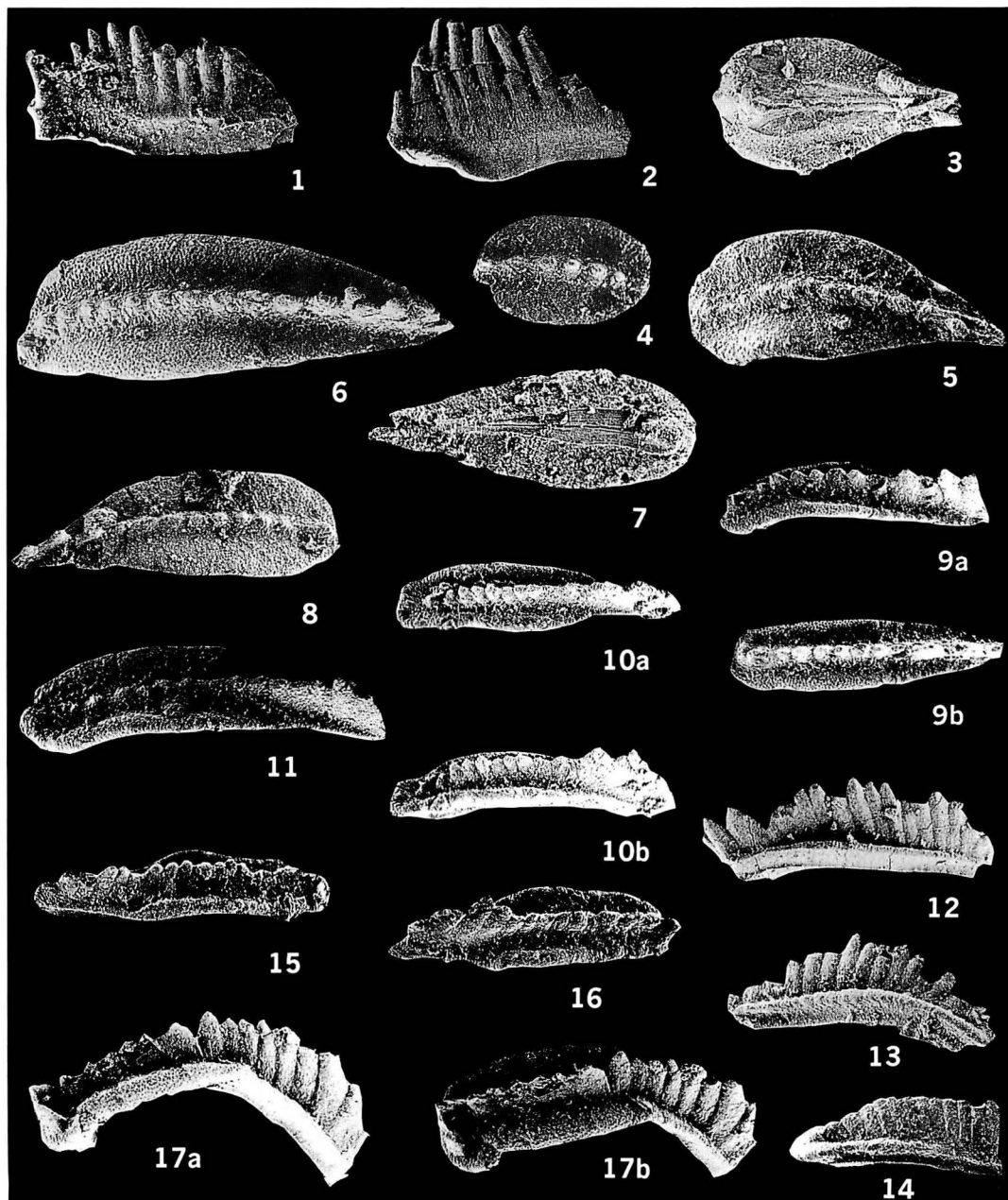
**Figure 5.**  **1,** *Neospathodus homeri* (Bender), lateral view, TGU. 1906.  **2,** *Neospathodus waggeni* Sweet, lateral view, TGU. 1913.  **3—5,** *Neogondolella subcarinata* Sweet, **4, 5,** oral views, **3,** aboral view, TGU. 1890-1892.  **6,** *Neogondolella* sp. A, lateral view, TGU. 1901.  **7, 8,** *Neogondolella changxingensis* Wang and Wang, **8,** oral view, **7,** aboral view, TGU. 1807, 1808.  **9a, b,** *Neogondolella* sp. C, slightly lateral and oral views, TGU. 1903.  **10a, b,** *Neogondolella* sp. B, slightly lateral and oral views, TGU. 1902.  **11,** *Neogondolella intermedia* Igo, slightly lateral view, TGU. 1845.  **12, 13,** *Neogondolella bulgarica* (Budurov and Stefanov), lateral views, TGU. 1798, 1799.  **14,** *Neogondolella excelsa* (Mosher), lateral view, TGU. 1811.  **15, 16,** *Neogondolella* sp. D, slightly lateral views, TGU.1904, 1905.  **17a, b,** *Neogondolella bifurcata* (Budurov and Stefanov), lateral and slightly lateral views, TGU. 1796.  All figures ×60.

more, *N. nodosa* has a keel with bifurcated posterior end in mature specimens. Koike (1982, p. 18) gave detailed synonyms and remarks of this species.

*Epigondolella spatulata* (Hayashi) was originally described from the Adoyama Formation of Kuzu, and its holotype selected by Hayashi was an immature form. Koike (1982) described *E. spatulata* from the Taho Limestone, Ehime Prefecture and showed many SEM micrographs of immature to gerontic stages. This species closely resembles *E. abneptis* but is characterized by a subcircular to triangular shaped platform. The present specimens have a longer platform than that of the holotype. The Taho specimens are characterized by a triangular platform or platform with bifurcated posterior end. Recently, detailed synonyms and description were given by Vrielynck (1986, p. 153-154).

The specimens identified with *Neogondolella bifurcata* (Budurov and Stefanov) are broken and more or less deformed, but their diagnostic character coincides with that of the specimens described by Budurov and Stefanov (1972). This species is very rare and only three specimens are yielded from the present locality.

*Neogondolella bulgarica* (Budurov and Stefanov) originally described by Budurov and Stefanov (1975) has a highly arched basal edge of unit and also arched upper edge of carina, but some of their specimens have a straight line of upper edge of carina. This morphological variation is rather commonly observed in most European specimens (*e.g.* Kováscs and Kozur, 1980b, pl. 2, figs. 1, 2 ; Pisa *et al.*, 1980, pl. 60, figs. 1a, b ; pl. 61, figs. 1-12). Koike (1982) described immature to mature stages of this species came from Kedah of western Malaysia. Most of his specimens have a carina with weekly to highly arched upper edge, and nearly straight basal edge of unit. Similar morphological characters are also observed in most of the present specimens. It is not certain that the above

mentioned morphological variation is only restricted to the Asiatic specimens.

*Neogondolella foliata foliata* and *N. foliata inclinata* are most abundant elements recovered from the present calcarenite. *N. foliata* was originally described by Budurov (1975) as the genus *Paragondolella*. Subsequently, Kovács (1983) discriminated *N. foliata inclinata* from *N. foliata foliata* and pointed out that the characteristic diagnosis of *N. foliata foliata* in a straight basal edge of the unit anterior to pit. Furthermore, the upper edge of carina in *foliata foliata* is mostly straight in the anterior two-thirds, and the platform anteriorly tapers abruptly. He claimed that *N. foliata foliata* evolved from *N. foliata inclinata*. Previously, Koike (1982) described *N. foliata* from Bukit Kechil, Malaysia and the Kamura Limestone of Miyazaki Prefecture, Japan. His specimens included the mentioned two subspecies.

*N. foliata inclinata* (Kovács) has an arched basal edge, and the platform extends full length of unit. In mature stage, the anterior part of platform margin is crenulated. Koike (1982, pl. 2, figs. 19-22) and Kovács (1983, pl. 1, figs. 1c, 2c, 3c) already noted presence of these crenulations. Most of the present specimens referable to this subspecies have these crenulations. I consider that these crenulations are another important criterion to distinguish this subspecies from *foliata foliata*. Detailed synonyms and description were given by Kovács (1983, p. 110-112).

*Neogondolella subcarinata* Sweet is rare in this collection. This species was originally described as a subspecies of *N. carinata* (Clark) by Sweet (*in* Teichert *et al.*, 1973). I restudied *N. asiatica*, which was proposed from the Akuda Formation of this area (Igo, 1981), and inclined to believe that this species is a junior synonym of *N. subcarinata*.
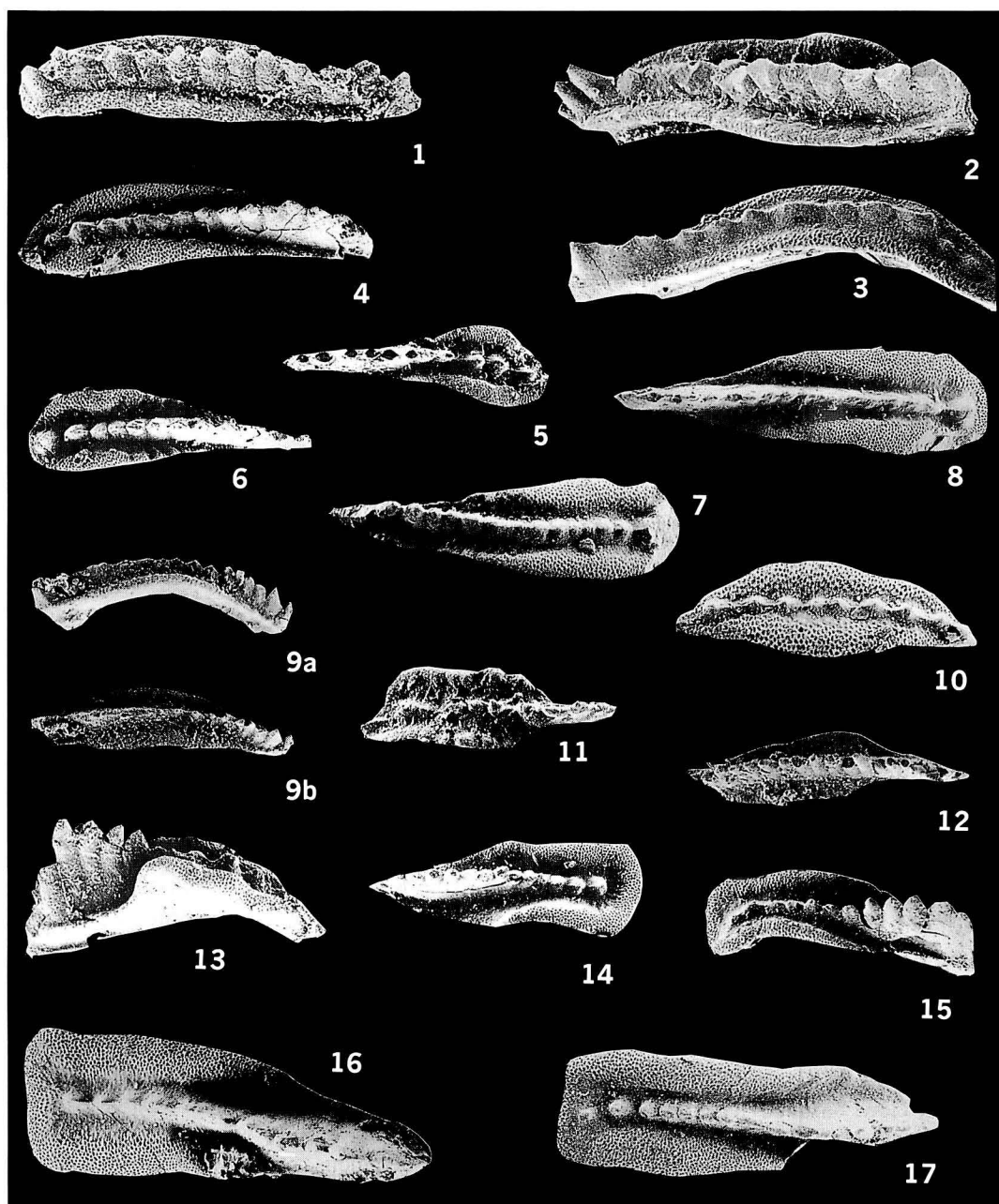
**Figure 6.** **1, 2,** *Neogondolella* aff. *mombergensis* (Tatge), slightly lateral views, ×120, TGU. 1916, 1917. **3,** *Gladigondolella tethydis* (Huckriede), slightly lateral view, TGU. 1788. **4—6,** *Neogondolella foliata foliata* (Budurov), oral views, TGU. 1812-1814. **7, 8,** *Neogondolella foliata inclinata* (Kovács), oral views, TGU. 1822, 1823. **9a, b,** *Neogondolella mombergensis* (Tatge), **b,** oral view, **a,** lateral view, TGU. 1847. **10,** *Gladigondolella malayensis malayensis* Nogami, oral view, TGU. 1791. **11,** *Carinella mungoensis* (Diebel), oral view, TGU. 1753. **12,** *Carinella hungarica* (Kozur and Véga), oral view, TGU. 1754. **13—15,** *Neogondolella polygnathiformis polygnathiformis* (Budurov and Stefanov), **13,** lateral view, **14, 15,** oral views, TGU. 1864-1866. **16, 17,** *Neogondolella polygnathiformis magna* Igo, n. subsp., oral views, **16,** holotype, **17,** paratype, TGU. 1888, 1889. All figures ×60, except for **1, 2.**

## Description of species

Genus *Neogondolella* Bender and
Stoppel, 1965
*Neogondolella bisecta* Igo, n. sp.

Figures 7-1, 2

*Gondolella polygnathiformis* Budurov and Stefanov;
    Krystyn, 1973, pl. 2, figs. 1-3.

*Diagnosis*. — Posterior platform bifurcated.
Anterior half of platform anteriorly tapers
abruptly. Anterior one to three denticles
free blade.

*Description*. — In oral view, posterior end
of platform bifurcated. Anterior half of
platform anteriorly tapers abruptly and being
sharply pointed at anterior end. Two or
three node-like crenulations occur on anterior
inner lateral part of platform at mature stage.
Deep and narrow lateral furrows developed
on anterior platform of each side of carina.
Honeycomb structure well observed all over
platform except for narrow lateral furrows.

Main denticle indistinct and lies at center
of platform. One or two node-like denticles
developed at posterior to main denticle.
Two low indistinct ridges stretch to inner and
outer corners of posterior end of platform and
form terminal node-like denticle.

In lateral view, oral surface straight and
aboral surface step-like. Anterior carina
high and consist of sharply pointed denticles.
Posterior half of carina low and composed of
node-like denticles.

In aboral view, basal cavity elongate ellipti-
cal, shallow, and lies one-third anteriorly
from posterior end of platform. Keel nar-
row, high and extends to anterior end. Loop
low and remarkably bifurcated.

*Remarks*. — This new species closely
resembles *Epigondolella triangularis* (Budur-
ov), but the latter bears characteristic mar-
ginal node and beams. *N. bisecta* is closely
related to *N. polygnathiformis polygnathifor-
mis*, but it is easily distinguished from the

latter by relatively bifurcated flat posterior
platform.

Reg. nos. TGU. 1805 (holotype : Figure 7-
1), 1806 (paratype : Figure 7-2).

*Neogondolella changxingensis* Wang
and Wang

Figures 5-7, 8

*Neogondolella subcarinata changxingesis* Wang and
    Wang, 1981a, p. 117-118, pl. 2, figs. 13-16 ;
    Wang and Wang, 1981b, p. 230-231, pl. 1, figs. 6-
    7.
*Neogondolella changxingensis* Wang and Wang;
    Clark and Wang, 1988, figs. 3-24.
*Neogondolella gujioensis* Igo, 1981, p. 37-38, pl. 3,
    figs. 1-19 ; pl. 4, figs. 1-6.
Non *Neogondolella gujioensis* Igo ; Igo and Hisada,
    1986, p. 521, pl. 97, figs. 1-9.

*Remarks*. — This species was originally
described as a subspecies of *Neogondolella
subcarinata* (Sweet) from the Longtan and
Changhsing Formations of Changxing, China
(Wang and Wang, 1981a), and the same
material was also described by the same
authors (Wang and Wang, 1981b, *in* Teichert,
Liu and Chen 1981b). Previously, I pro-
posed *Neogondolella gujioensis* from a lime-
stone conglomerate of the Akuda Formation
of the present area (Igo, 1981). This species
has exactly the same morphological character
to *N. changxingensis* Wang and Wang, which
was proposed in the same year as the former,
but the latter takes priority.

Recently, Igo and Hisada (1986) described
*N. gujioensis* ($=N.$ *changxingensis*) from
Lower Permian limestone exposed at the
Ogawadani Valley, western part of Tokyo.
The specimens came from the Ogawadani
probably represent early to middle growth
stages of *N. bisselli* (Clark and Behnken).

Reg. nos. TGU. 1807, 1818.

*Neogondolella polygnathiformis depressa*
Igo, n. subsp.

Figures 7-3, 4

*Diagnosis*. — Platform wide and pointed anteriorly. Posterior end of platform rounded. Anterior carina high and bears fused denticles, but posterior carina low and consists of node-like denticles.

*Description*. — In oral view, platform extends full length of unit. Anterior platform tapers and sharply pointed at anterior end. Posterior end of platform rounded. Posterior half of platform wide and almost flat. Honeycomb structure well observed all over platform except for narrow furrows on each side of carina. Widest part of platform one-third posteriorly. Carina does not extend to posterior end of platform. Anterior carina high and bears fused denticles and reduces rapidly in height posteriorly. Posterior denticles discrete and node-like. Main denticle indistinct.

In lateral view, platform arched. In aboral view, basal cavity subcircular and shallow, lies beneath main denticle and extends to anterior end of unit as a narrow groove. Loop rectangular or bifurcated in mature specimens.

*Remarks*. — This new subspecies is similar to *Neogondolella polygnathiformis polygnathiformis*, but it is easily distinguished from the latter in having an anterior free blade. Lateral margins of the central part of platform turned up orally in this new subspecies. It is also similar to *N. foliata inclinata*, but the former has a wider flat posterior platform than that of the latter.

Reg. nos. TGU. 1838 (holotype : Figure 7-3), 1839 (paratype : Figure 6-4).

### *Neogondolella polygnathiformis magna* Igo, n. subsp.

Figures 6-16, 17

*Diagnosis*. — Unit large and elongate. Posterior end of platform rectangular. Anterior half of platform tapered gradually. Platform extends full length of unit. Basal cavity small and shallow. Loop low and bifurcated.

*Description*. — In oral view, unit large and elongate. Anterior half of platform tapers gradually and anteriorly pointed. Posterior half of platform keeps the same width. Posterior end of platform rectangular. Carina extends to near posterior end and carries 14 to 15 denticles. Anterior half of carina composed of tall and fused denticles. Posterior half of carina consists of node-like denticles, and its height reduces posteriorly. Main denticle lies at posterior end of carina but rather indistinct. One node-like denticle developed posterior to main denticle in one specimen (Figure 6-17).

In aboral view, basal cavity elliptical and shallow. Loop bifurcated and low.

*Remarks*. — This new subspecies closely resembles *Metapolygnathus communisti* Hayashi morphotype A of Krystyn (1980, pl. 12, figs. 8-14), but the latter has a remarkable free blade. *N. polygnathiformis magna* has an anterior platform extending from the anterior terminal of carina. This subspecies is very similar to *N. polygnathiformis polygnathiformis*, but the former has a larger unit, more elongate platform and lower bifurcate loop than those of the latter.

Reg. nos. TGU. 1888 (holotype : Figure 6-16), 1889 (paratype : Figure 6-17).

### *Neogondolella intermedia* Igo

Figures 5-11

*Neogondolella intermedia* Igo, 1981, p. 38, 39, pl. 4, figs. 7-11.
*Neogondolella* cfr. *intermedia* Igo ; Dong, Wang and Wang, 1987, pl. 3, fig. 21.

*Description*. — Platform narrow, elongate and anteriorly tapers gradually. Anterior one-third of carina slightly high and being gradually lower toward posterior. Platform margin turned up orally. Anterior end of platform pointed and its posterior end roundly square. Main denticle inconspicuous and located near posterior end. Basal cavity

*Hisaharu Igo*
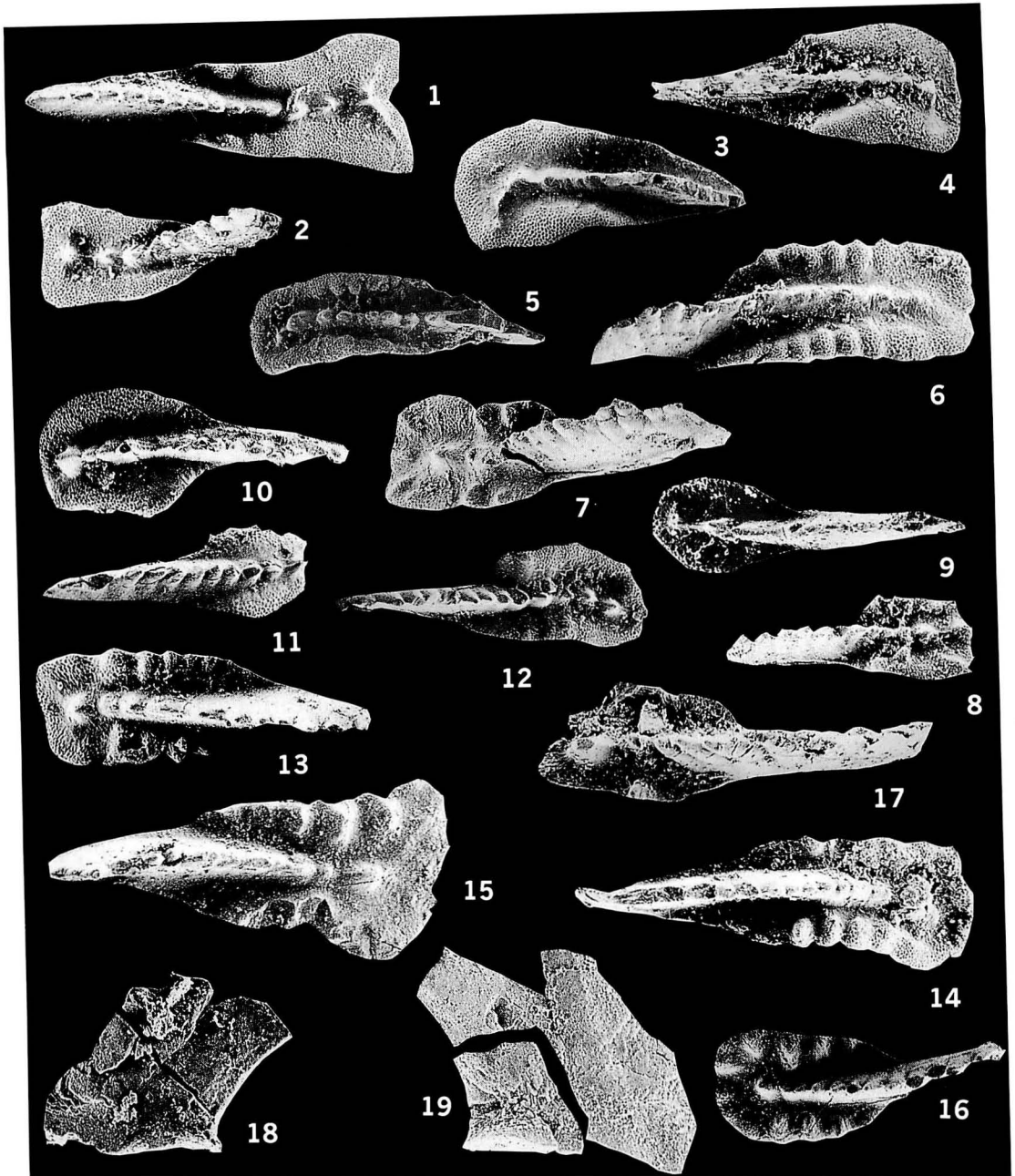


**Figure 7.** **1, 2,** *Neogondolella bisecta* Igo, n. sp., oral views, **1,** holotype, **2,** paratype, TGU. 1805, 1806.
**3, 4,** *Neogondolella polygnathiformis depressa* Igo, n. subsp., oral views, **3,** holotype, **4,** paratype, TGU. 1838,
1839. **5, 6,** *Neogondolella nodosa* (Hayashi), oral views, TGU. 1850, 1851. **7, 8,** *Epigondolella abneptis*
(Huckriede), oral views, TGU. 1757, 1758. **9,** *Epigondolella echinata* (Hayashi), oral view, TGU. 1774. **10,
11,** *Neogondolella* aff. *tadpole* (Hayashi), oral views, TGU. 1898, 1899. **12,** *Neogondolella* aff. *polygnathi-
formis polygnathiformis* (Budurov and Stefanov), oral view, TGU. 1919. **13, 14,** *Epigondolella primitia*
Mosher, oral views, TGU. 1778, 1779. **15, 16,** *Epigondolella spatulata* (Hayashi), oral views, TGU. 1784,
1785. **17,** *Epigondolella postera* (Kozur and Mostler), oral view, ×120, TGU. 1775. **18, 19,** *Misikella
hernsteini* (Mostler), lateral views, ×120, TGU. 1793, 1794. All figures ×60, except for **17—19.**

small and elliptical, lies beneath main denticle. Keel broad and low. Loop low and elliptical or square.

*Remarks.* — The present material is identical with the original specimens obtained from Ichinose and the Kuchibora Formation of this area. This species represents the evolutionary link between *Neogondolella bisselli* and *Neogondolella idahoensis* (Igo, 1981).

Reg. no. TGU. 1845.

### *Neogondolella* sp. A

Figure 5-6

*Neogondolella* sp. A, Igo, 1981, p. 39, pl. 4, fig. 12.

*Description.* — Unit very small and elongate navicular shape. Carina composed of low node-like subequal sized denticles. Platform extends full length of unit and widest part at half length of unit. Honeycomb structure observed all over platform except for furrows of each side of carina. Basal cavity small and lies beneath anterior to second denticle from posterior terminal denticle. Loop elliptical and keel low and inflated laterally.

*Remarks.* — This unnamed species was already described by the present author (Igo, 1981). I also refrained specific identification this time because only one specimen is at hand.

Reg. no. TGU. 1901.

### *Neogondolella* sp. B

Figures 5-10a, b

*Description.* — Unit small and slightly arched. Anterior one-fourth of carina high and composed of fused denticles. Posterior carina low and having sharply pointed denticles. Posterior terminal denticle situated anteriorly one-fifth from end of platform. Anterior one-fourth length of unit free blade.

In oral view, posterior end of platform has two rectangular corners. Anterior half length of platform edges turned up orally. In aboral view, basal cavity lies beneath posterior terminal denticle. Keel fairly narrow and ending in loop.

*Remarks.* — This unidentified species is slightly similar to *Neogondolella bulgarica*, but carina of the former does not extend to posterior end of platform and bears shorter denticles and less prominent main denticle than those of the latter. This unidentified species is probably new to science.

Reg. no. TGU. 1902.

### *Neogondolella* sp. C

Figures 5-9a, b

*Description.* — Unit small, elongate and arched. Anterior carina high and composed of four denticles. Posterior carina low and having sharply pointed denticles. In oral view, platform full length of unit and anterior one-third length of unit slightly corrugated. Posterior terminal carina located at posterior end of platform. Posterior half length of platform edges turned up orally and observed honeycomb structure on platform margins. Posterior end of platform bluntly rounded.

In aboral view, basal cavity small and located beneath posterior terminal denticle. Keel narrow and low, ending in small elliptical low loop.

*Remarks.* — The present unnamed species is similar to *Neogondolella constricta* (Mosher and Clark) and some other Anisian to Ladinian species of *Neogondolella*, but the former does not have any constriction on the posterior part of platform. This unnamed species is probably a new species.

Reg. no. TGU. 1903.

### *Neogondolella* sp. D

Figures 5-15, 16

*Description.* — Unit elongate and small. In oral view, platform narrow. Anterior one-third of unit free blade. Posterior end of platform rounded. Carina extends to posterior end and composed of fused denticles but their upper part discrete. Anterior

three to five denticles being high free blade. Height of carina reduces abruptly toward posterior. Main denticle located at posterior end of carina but not so conspicuous. Both outer and inner sides of platform turn up orally and make deep lateral furrows. Basal cavity small and shallow, lies near posterior end. Loop elliptical. Keel narrow and high posteriorly.

*Remarks.* — This unnamed species closely resembles *Neogondolella bulgarica*, but the former is easily distinguishable in having free blade. Platform of *N. bulgarica* is full length of the unit.

Recently, Clark and Wang (1988) illustrated *N. denticulata* Clark and Behnken came from the uppermost bed of the Changhsing Formation of Changxing, China. The present unnamed species closely resembles *N. denticulata* reported from China.

Reg. nos. TGU 1904, 1905.

Repository: All specimens treated in this paper are deposited in the Department of Astronomy and Earth Sciences, Tokyo Gakugei University with the prefix TGU.

### References cited

Budurov, K., 1975: *Paragondolella foliata* sp. n. (Conodonta) von der Trias des Ost-Balkans. *Re, Bulgarian Geol. Soc.*, vol. 36, part 1, p. 79-81, pl. 1.

—— and Stefanov, S., 1972: Platform-Conodonten und ihre Zonen in der Mittleren Trias Bulgariens. *Mitt. Ges. Geol. Bergbaustud*, vol. 21, p. 829-852, pls. 1-4.

—— and ——, 1975: Neue Daten uber die Conodontenchronologie der Balkaniden mitteren Trias. *Compt. Rendu. l'Acad. Bulgare, Sci.*, vol. 28, no. 6, p. 791-794, pl. 1.

Clark, D.L. and Wang, C.Y., 1988: Permian neogondolellids from South China: significance for evolution of the *serrata* and *carinata* groups in North America. *Jour. Paleont.*, vol. 62, no. 1, p. 132-138, figs. 1-4.

Conodonts Research Group, 1974: Conodonts at the Permian-Triassic boundary in Japan — Stratigraphy and faunas of the Nabeyama and Adoyama formations in Karasawa area, southeast Ashio

mountains —. *Earth Sci.*, vol. 28, no. 3, p. 86-98. (*in Japanese with English abstract*)

Dong, Z.Z., Wang, C.Y. and Wang, Z.H., 1987: Carboniferous and Permian conodont sequence in Northwestern Yunnan. *Act. Pal. Sinica*, vol. 26, no. 4, p. 411-419, pls. 1-3. (*in Chinese with English summary*)

Hayashi, S., 1968: The Permian conodonts in chert of the Adoyama Formation, Ashio mountains, central Japan. *Earth Sci.*, vol. 22, no. 2, p. 63-77, pls. 1-4.

Igo, Hisaharu, 1981: Permian conodont biostratigraphy of Japan. *Pal. Soc. Japan, Special Papers*, no. 24, p. 1-50, pls. 1-12.

—— and Hisada, K., 1986: Lower Permian conodonts from the Kawanori Formation of the southwestern Kanto Mountains, Tokyo. *Trans. Proc. Pal. Soc. Japan, N.S.*, no. 144, p. 516-527. pls. 96-98.

—— and Nishimura, H., 1984: The late Triassic and early Jurassic radiolarian biostratigraphy in the Karasawa, Kuzuu town, Tochigi Prefecture (preliminary report). *Bull. Tokyo Gakugei Univ., Sect. 4*, vol. 36, p. 173-193. (*in Japanese with English abstract*)

Kanuma, M., 1958a: Stratigraphical and paleontological studies of the southern part of the Hida plateau and north-eastern part of the Mino mountainland. *Jubilee Publ. Comm. Prof. H. Fujimoto*, p. 1-48.

——, 1958b: *Ditto.*, part II, Paleontology, No. 2. *Bull. Tokyo Gakugei Univ.*, vol. 9, p. 29-49, pls. 2-3.

——, 1959: *Ditto.*, No. 3, *Pseudoschwagerina*, *Pseudofusulina* and *Parafusulina*. *Ibid.*, vol. 10, p. 59-107, pls. 4-9.

——, 1960: *Ditto.*, No. 4, Ozawainellinae, Schubertellinae and Neoschwagerininae. *Ibid*, vol. 11, p. 55-83, pls. 10-13.

Kinoshita, T., 1974: Geology of the southern part of the Ashio mountains (MS). *Master thesis of Tokyo Gakugei University*. p. 1-63. (*in Japanese*)

Koike, T., 1979: Conodont biostratigraphy in the Taho Limestone (Triassic), Shirokawa-cho, Higashiuwa-gun, Ehime Prefecture. *Mem. Vol. Prof. Mosaburo Kanuma*, p. 115-126. (*in Japanese*)

——, 1981: Biostratigraphy of Triassic conodonts in Japan. *Sci. Repts. Yokohama Natl. Univ., Sec. II*, no. 28, p. 25-46, pls. 1-2.

——, 1982: Review of some platform conodonts of the Middle and Late Triassic in Japan. *Ibid.*, no. 29, p. 15-27, pls. 1-3.

——, Igo, H., Igo, H. and Kinoshita, S., 1974: Gelogical significance of the unconformity between the Permian Nabeyama and Triassic

Adoyama Formations in the vicinity of Kuzuu, Tochigi Prefecture. *Jour. Geol. Soc. Japan*, vol. 80, no. 7, p. 293-306. (*in Japanese with English abstract*)

Kovács, S., 1983: On the evolution of *excelsa*-stock in the upper Ladinian-Carnian (Conodonta, genus *Gondolella*, Triassic). *Schrift. Erdwiss. Komm. Osterr. Akad. Wiss.*, vol. 5, p. 107-119, pls. 1-6.

——, and Kozur, H., 1980a: Some remarks on middle and upper Triassic platform conodonts. *Recent Researches in Geology*, vol. 5, p. 541-581, pls. 1-5.

—— and ——, 1980b: Stratigraphische Reichweite der wichtigsten Conodonten (ohne Zahnreihenconodonten) der Mittel-und Obertrias. *Geol. Palaont. Mitt. Innsbruck*, vol. 10, no. 2, p. 47-78, pls. 1-15.

Krystyn, L., 1973: Zur Ammoniten-und Conodonten-Stratigraphie der Hallstatter Obertrias (Salzkammergut, Osterreich). *Verh. Geol. B.A., Jahrgang 1973*, no. 1, p. 113-153, pls. 1-5.

——, 1980: Triassic conodont localities of the Salzkammergut region (Northern Calcareous Alps). *In* Guidebook and abstract of ECOS II, *Abh. Geol. Bundesanstalt*, vol. 35, p. 61-98, pls. 11-14.

McIlneath, I.A. and James, N.P., 1979: Facies Models 12, Carbonate slopes. *In* Walker, R.G. (*ed.*), Geoscience Canada, reprint series, Facies Models. p. 133-143.

Mosher, C.L. and Clark, D.L., 1965: Middle Triassic conodonts from the Prida Formation of northwestern Nevada. *Jour. Pal.*, vol. 39, no. 4, p. 551-565, pls. 65-66.

Pisa, G., Perri, C. and Veneri, P., 1980: Upper Anisian conodonts from Dont and M. Bivera Formations, southern Alps (Italy). *Riv. Ital. Paleont*, vol. 85, nos. 3-5, p. 807-828, pls. 60, 61.

Teichert, C., Kummel, B. and Sweet, W., 1973: Permian-Triassic strata, Kuh-E-Ali Bashi northwestern Iran. *Bull. Mus. Comp. Zool.*, vol. 145, no. 8, p. 359-446, pls. 1-14.

Vrielynck, B., 1986: Conodonts du Trias perimediterraneen. systematique, stratigraphie. *Docum. Lab. Geol. Lyon*, no. 97, p. 1-301, pls. 1-15.

Wakita, K., 1984: Geology of the Hachiman district. *Quadrangle series, scale : 50,000*. Kanazawa (10), no. 70, Geol. Surv., Japan. (*in Japanese with English abstract*)

Wang, C.Y. and Wang, Z.H., 1981a: Permian conodonts from the Longtan Formation and Changhsing Formation of Changxing, Zhejkiang and their stratigraphical and paleontological significance. *In selected papers on the 1st convention of Micropalaeontological Society of China*. p. 114-120, pls. 1-2. (*in Chiense*)

—— and ——, 1981b: Permian conodont biostratigraphy of China. *Geol. Soc. America, Special Paper*, 187, p. 227-232, pls. 1-2.

Watanabe, K., Kanmera, K. and Nakajima, K., 1979: Conodont biostratigraphy in the Kamura Limestone (Triassic), Takachihocho, Nishiusuki-gun, Miyazaki Prefecture. *Mem. Vol. Prof. Mosaburo Kanuma*, p. 127-137. (*in Japanese*)

---

Akuda 安久田, Hachiman 八幡, Horikoshi Pass 堀越峠, Kanayama 金山, Kayugawa 粥川, Kuchibora 口洞, Nabigawa 那比川, Shimadani 島谷.

---

美濃帯八幡町から産出したコノドントの混在群集：初期ペルム紀から後期三畳紀にわたるコノドントの多くの種が，岐阜県郡上郡八幡町の堀越峠付近に露出するカルカレナイトの基質をつくる含赤鉄鉱泥質部から混在して多数得られた。このカルカレナイトは赤色を呈し分級はきわめて悪く，石灰岩や頁岩などの角礫を含み，初期ペルム紀後期の安久田層の石灰岩に発達した割れ目を充塡したような産状を呈する。コノドントの混在の原因は次のような可能性が考えられる。ペルム紀後期から三畳紀後期にかけて安久田層の石灰岩の上に生じた浅海で，炭酸塩岩が堆積と侵食を繰り返し，コノドントは何度となく洗い出され凝縮して混在した。とくにに後期ラディニアンから初期カーニアンを指示する *Neogondolella foliata* (s.l.) が他と比較して個体数が圧倒的に多いのは，この時期に堆積が卓越したものと見られる。なお，初期ペルム紀のコノドントは安久田層に由来する石灰砂や石灰角礫からもたらされたものであろう。後期ノーリアンから中期ジュラ紀までのある時期に，これら混在群集を含む石灰砂や含赤鉄鉱泥質物からなる浅海堆積物は，津波などの急激なショックによって，海底で崖を形成していた安久田層の石灰岩に沿って浅海域から sand-stream となって流れ下り，カルカレナイトとしてその割れ目を充塡したものとみられる。コノドントはカルカレナイトのどこをとってもほぼ同じような組み合わせの混在を示し，6属，6亜種，4未定種を含む34種が識別されたが，そのうち1種ならびに2亜種は新しく提唱した。　　　　　　　　　　　　　　　　　　猪郷久治

---

# 889. GROWTH AND LIFE MODE OF A PLEISTOCENE BRACHIOPOD, *KIKAITHYRIS HANZAWAI* (YABE)*

KAZUYOSHI ENDO

Department of Geology, University of Glasgow
Glasgow G12 8QQ, Scotland, U.K.

**Abstract.** The onset of sexual maturity in the Pleistocene free-living brachiopods appears to be reflected in shell morphology. This interpretation is based upon the demonstration of a two phase relationship between shell length and shell convexity, and assumes that the phase change is triggered by, or at least closely correlated with the first development of gonadal tissues. The results suggest that *Kikaithyris hanzawai* became sexually mature prior to the adoption of a secondary free-living life habit. A similar relationship between morphology and sexual maturity has been demonstrated in the Recent brachiopod *Laqueus rubellus*, which belongs to the same family as *Kikaithyris hanzawai*.

**Key words.** Brachiopoda, Laqueidae, Pleistocene, relative growth, gonad development, life habit.

## Introduction

Gonads first develop in juvenile specimens, extending greatly at the onset of maturity (Rudwick, 1965). Their presence in fossil specimens is usually inferred from their traces on the inner shell surface (*i.e.* pallial sinuses, see Williams, 1956). Recently, Endo (1987) indicated that gonad development affects the relative growth pattern in an extant laqueid species, which is represented as a diphasic allometry between the shell convexity and the shell length with a turning point between the juveniles and the adults. This relationship between gonads and shell allometry could be applied to fossil species, to discuss the average size at which individuals achieve sexual maturity.

This paper reports the analysis attempted on *Kikaithyris hanzawai* (Yabe), a Pleistocene extinct laqueid. The life style of this species which has the characteristic morphol-ogy of a secondarily free-living brachiopod is also discussed.

## Material

Among the Pleistocene biogenic carbonate sediments of the Ryukyu Group which yield *Kikaithyris hanzawai* (Yabe), the best preservation is seen at the type locality in the unconsolidated grainstone of the Wan Formation. The locality is about 500 metres north of Kamikatetsu, Kikai Island, Kagoshima Prefecture, Japan. Forty-two complete specimens of various growth stages from the locality were used for the measurements, while numerous fragmentary specimens from the same locality enabled the examination of internal features. The deposited environment is considered by Mori (1987) to have been a fore-reef in excess of 50 metres deep, dated radiometrically at $82,000 \pm 2,000$ years B.P. (Omura, 1983). The studied specimens are from the collections of the University

Museum, University of Tokyo (UMUT), and the Institute of Geology and Paleontology, Tohoku University, Sendai (IGPS).

## Morphology and life habit

The shell of *Kikaithyris hanzawai* (Yabe) was first described by Yabe (1932) and has been subsequently described by Hatai (1940) and Cooper (1957). Endo (1987) briefly referred to the life habit of this species.

Adult shells of *K. hanzawai* are large and are distinguished from juveniles by posteriorly thickened shell and strongly incurved beak with a relatively minute mesothyrid foramen (Figures 1–3). These features are characteris-

tic of the secondary free-living life style of many species. The size of foramen shows little increase with growth, while the curvature of ventral beak increases continuously (Figure 2). Specimens larger than about 25 mm in shell length have the beak angle of over 90 degrees, and also have differentially thickened posterior shell. Thus the change into free-living life is considered to have occurred at the shell length of about 25 mm. The biconvex valves, which have a planar or almost planar commissure (Figure 1), become posteriorly thickened (Figure 3). The small foramen, incurved beak and posterior thickening indicate a self-righting tumbler-like position similar to that described by Surlyk (1972).

The diductor and the adductor muscle systems are readily reconstructed from the evidence provided by muscle scars on the inner shell surface, on the ventral median ridge, and the cardinal process. However, the adjustor muscle system of *Kikaithyris hanzawai* may have degenerated in some adult individuals because the stoutly thickened cardinalia of adult shells provides very little space for the adjustor muscles (Figure 3). This strongly
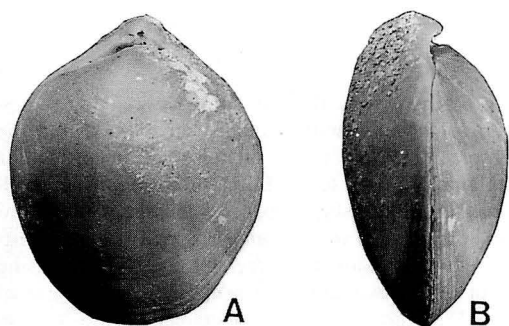


**Figure 1.** Dorsal (A) and lateral (B) views of an adult specimen of *Kikaithyris hanzawai* (Yabe) from the Wan Formation (Type locality). Specimen UMUT CB18196a in natural size.
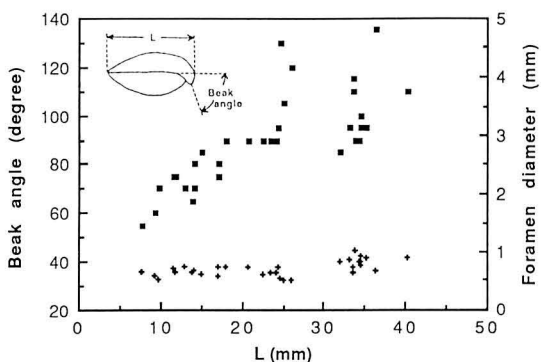


**Figure 2.** Ontogenetic change of the beak angle (squares) and the foramen diameter (crosses) of *Kikaithyris hanzawai*. Sample UMUT CB18196, N = 33.
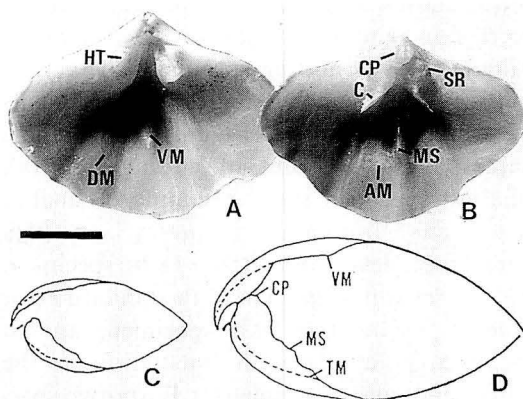


**Figure 3.** Interior of ventral (A) and dorsal (B) valves and median sections at sessil (C) and free-living (D) growth stages. Sample CB18196. Scale bar indicates 1 cm. Abbreviations: AM, adductor muscle attachment; C, crus; CP, cardinal process; DM, diductor muscle attachment; HT, hinge teeth; MS, median septum; SR, inner socket ridge; TM, trace of muscle scar; VM, ventral median ridge.

suggests that the pedicle of adult individuals, if any, was hardly functional.

## Shell size at sexual maturation

In a living laqueid species, *Laqueus rubellus* (Sowerby), larger inidviduals with gonads show positive allometry of shell convexity to shell length, while smaller ones without gonads indicate isometrical relationship between them (Endo, 1987). The size at sexual maturation would therefore be revealed if the same relationship applied to a fossil species.

Conventional dimensions of shell length ($L$) and shell height ($H$) were taken in *Kikaithyris hanzawai* using vernier calipers. Figure 4B shows size distribution plotted on a double logarithmic scatter diagram. The distribution pattern seems diphasic, with the point of inflection occuring at around 20 mm in shell length. This is supported by a series of accumulative regressions. The reduced major axis regression coefficient ($\alpha$, the slope of allometry in a log-log plot) between log $L$ and Log $H$ was calculated using the smallest and the second smallest specimens. The third smallest specimen was then added to the regression, and the regression coefficient recalculated. By adding specimens of increasing size one by one, 41 regression coefficients were finally obtained. Figure 4A gives these values after the point of adding the 10th smallest specimen the sub-sample of smaller specimens indicates isometry at 95% confidence level until the 18th specimen. The regression coefficient with standard error exceeds 1.0 at the 19th specimen, and it increases gradually with fluctuation as the addition of more specimens. Forty-two specimens are then divided into two groups of 18 "juvenile" and 24 "adult" specimens. The reduced major axes were obtained separately for the two groups and superimposed on the diagram. Both axes fit well to the plots, the slopes of them also appear reasonable: almost 1.0 for the smaller specimens, indicat-
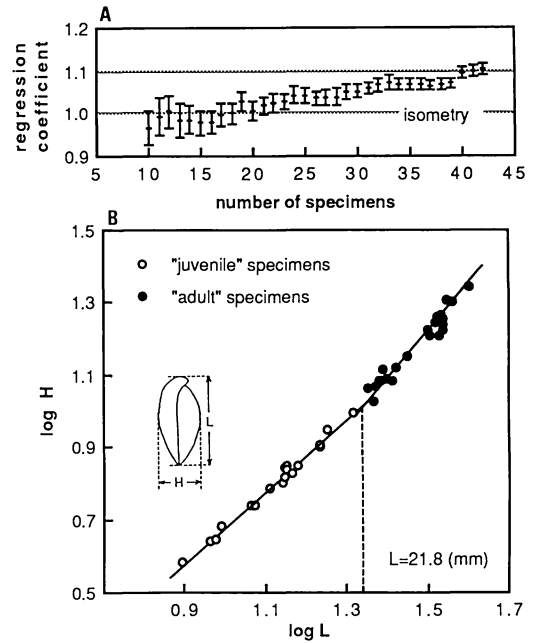


**Figure 4. A.** Relationship between the regression coefficients (with standard error bars) and the sample size of the "smaller specimens." For explanation, see text. **B.** Double logarithmic allometric relationship between shell length ($L$) and shell height ($H$) in *Kikaithyris hanzawai* with best-fit reduced major axis regressions. The crossing point of the two axes represents the average size of sexual maturation. Nine specimens from sample IGPS 29436 and 33 specimens from sample UMUT CB18196, all of which were collected from the type locality of the Wan Formation.

ing "isometry", and 1.22 for the larger specimens, indicating remarkable positive allometry of $H$ to $L$.

The diphasic pattern is similar to that found for *L. rubellus,* which has been explained in terms of the gonad development (Endo, 1987). The shell length at the transition point is calculated as 21.8 mm, the probable size of onset of maturity in *K. hanzawai* from this locality.

## Discussion

### *Permanent free living forms*

Species with similar life habit to *Kikaithyris hanzawai* have been cited by Rudwick

(1970) and Surlyk (1972) as free living forms. Bassett (1984) categorized the life stategies of Silurian brachiopods, calling this life style "ambiotic liberosessile". These brachiopods usually keep the anterior of the shell above the sediment by means of the thickening of the umbo, which shifts the center of gravity posteriorly. Rudwick (1970) pointed out that the importance and extent of the posterior weighting increases as the pedicle becomes reduced to a mere "tether". Why does the animal abandon the functional pedicle- which is excellent to keep the feeding position ? I suggest that it would occur when the available substrate is restricted to unconsolidated sediments. Recent brachiopods are not confined to rocky substrates, but are also found on unconsolidated sediments. (Richardson, 1987). On unconsolidated substrates, *e.g.,* shell fragments, pebbles, coarse bryozoan sands, *etc.*, even pedunculate brachiopods often become effectively free living, that is, the relatively small substrate provides insufficient anchorage and suport for the adult shells. On such sediments, the pedicle may function merely as a tether, and a specialized free living form could be selectively advantageous. The strong currents which govern these coarse sediments may accelerate the selection of differentially weighted shells (Richardson and Watson, 1975) ; a conclusion supported by the observation that *K. hanzawai* is always found in coarse grained deposits.

*Gonad development in Kikaithyris hanzawai*

The observed diphasic growth pattern of *Kikaithyris hanzawai* supports my supposition that gonad development explains the positive allometry of shell convexity to shell length in adult laqueids. Gonad development would require enough space to host bands of gonads (Endo, 1987), or it would require a larger enclosed volume for brooding and ventilation.

An alternative explanation to the diphasic growth pattern is possible considering the free-living mode of life : as the animal becomes free living, a posterior shift in the centre of gravity is advantageous to maintain a prefered orientation, thus the less elongated shell form could have been selected. *Terebratella inconspicua* (Sowerby) which is only free-living by misadventure (see Lee, 1978) also has a diphasic pattern when height is plotted against length, and the point of inflection occuring at a shell length of approximately 15 mm corresponds well to Doherty's first reported spawning at a length of 14 mm (Doherty, 1979).

The observation of Recent *L. rubellus* shows that gonads first develop at various size, and plots of the juveniles and the adults in the *L-H* diagram overlap around the turning point of the two phases (Endo, 1987). Thus the separation of the larger and the smaller specimens in *K. hanzawai* does not strictly mean the separation of the adults and the juveniles. However, as the transition point in *L. rubellus* corresponds to a biological minimum (first gonad development), so the point in *K. hanzawai* is expected to give an approximation to the biological minimum within this population. In conclusion, this species is inferred to have become capable of reproduction slightly before the individuals became free living at a length of 20 mm.

## Summary

1. The morphological features of *Kikaithyris hanzawai* (Yabe) indicate the secondarily free-living mode of life, which is an adaptational form to the life on unconsolidated substrates.

2. The diphasic allometric trend in the relationship between the shell length and the shell height enables the approximation of the biological minimum, or shell size at first reproduction in this species.

## Acknowledgments

## References

Bassett, M.G., 1984: Life stategies of Silurian brachiopods. *Special Papers in Palaeontology*, vol. 32, p. 237-263.

Cooper, G.A., 1957: Tertiary and Pleistocene brachiopods of Okinawa Ryukyu Islands. *U.S.G.S. Professional Paper*, 314-A, p. 1-20, pls. 1-5.

Doherty, P.J., 1979: A demographic study of subtidal population of the New Zealand articulate brachiopod *Terebratella inconspicua*. *Marine Biology*, vol. 52, p. 331-342.

Endo, K., 1987: Life habit and relative growth of some laqueid brachiopods from Japan. *Trans. Proc. Palaeont. Soc. Japan*, N.S., no. 147, p. 180-194.

Hatai, K., 1940: The Cenozoic Brachiopoda from Japan. *Sci. Rep. Tohoku Imp. Univ., Ser. 2*, vol. 20, p. 1-413, pls. 1-12.

Lee, D.E., 1978: Aspects of the ecology and paleoecology of the brachiopod *Notosaria ni-*gricans (Sowerby). *Jour. Roy. Soc. N. Z.*, vol. 8, p. 395-417.

Mori, K., 1987: Intraspecific morphological variations in a Pleistocene solitary coral, *Caryophyllia (Premocyathus) compressa* Yabe and Eguchi. *Jour. Paleont.*, vol. 61, p. 21-31.

Omura, A., 1983: Uranium-series ages of some solitary corals from the Riukiu Limestone on the Kikai-jima, Ryukyu Islands. *Trans. Proc. Palaeont. Soc. Japan*, N.S., no. 130, p. 117-122.

Richardson, J.R., 1987: Brachiopods from carbonate sands of the Australian shelf. *Proc. R. Soc. Vict.*, vol. 99, no. 1, p. 37-50.

—— and Watson J.E. 1975: Form and function of the Recent free living brachiopod *Magadina cumingi. Paleobiology*, vol. 1, p. 379-387.

Rudwick, M.J.S., 1965: Ecology and paleoecology. pp. H199-H214 *in* R.C. Moore (*ed*): *Treatise on invertebrate paleontology. Part H, Brachiopoda.* 927p. *Geol. Soc. Am. and Univ Kansas Press,* Lawrence, Kansas.

——, 1970: *Living and fossil brachiopods.* 199p. Hutchinson, London.

Surlyk, F., 1972: Morphological adaptations and population structures of the Danish chalk brachiopods (Maastrichtian, Upper Cretaceous). *Kongelige Danske Vidensk. Selsk. Biol, Skrifter,* vol. 19, p. 1-57, pls. 1-5.

Williams, A., 1956: The calcareous shell of the Brachiopoda and its importance to their classification. *Cambridge Philos. Soc., Biol. Reviews 7* vol. 31, p. 243-287.

Yabe, H., 1932: Brachiopods of the Genus *Pictothyris* Thomson 1927. *Sci. Rep. Tohoku Imp. Univ., Ser. 2*, vol. 15, p. 193-197, pl. 1.

更新世腕足動動 *Kikaithyris hanzawai* (Yabe) の成長と生活様式：更新統琉球層群より産する *Kikaithyris hanzawai* は，その形態的特徴より，二次的に固着生活から自由生活へ移行したと考えられる。また，殻の長さに対する殻のふくらみの相対成長は，ある成長段階において等成長から優成長に変化する。この二相のパターンは，この種と同じ科に属する *Laqueus rubellus* (Sowerby) の現生種でも知られ，生殖巣の発達と関連していると考えられる。*K. hanzawai* において求められた二相の変移点は，この種が，二次的自由生活に移行するより前に性的に成熟していたことを示唆する。     遠藤一佳

# 890. A NEW DEVONIAN CEPHALOPOD FROM THE NAKAZATO FORMATION OF THE SOUTHERN KITAKAMI MOUNTAINS*

SHUJI NIKO

Department of Earth Science and Astronomy, College of Arts and Sciences,
The University of Tokyo, Komaba, Tokyo 153

**Abstract.** A new pseudorthoceratid species, *Geisonocerella nakazatoensis* Niko, is described from the N3 Member of the Middle Devonian Nakazato Formation. This species is characterized by its weakly annulated large shell with elliptical cross section, deeply concaved septa, centrally located siphuncle, slightly suborthochoanitic septal necks and episeptal-mural cameral deposits.

**Key words.** Cephalopoda, *Geisonocerella nakazatoensis*, Middle Devonian, Nakazato Formation, Kitakami Mountains.

## Introduction

The Middle to Upper Paleozoic strata in the southern Kitakami Mountains serve as the standard of reference for less complete marine deposits in Japan. Among them, the Nakazato Formation has been attracting the attention of paleontologists as the fauna and flora can provide a lot of information on the Middle Devonian biostratigraphy and biogeography of Japan. Nevertheless, only cephalopods in this fauna have been little investigated by recent workers. Collections of invertebrates, other than orthoceratids, from the formation have been described in works by Sugiyama and Okano (1941), Okubo (1956), Kobayashi (1957), Kobayashi and Hamada (1977), Minato and Kato (1977), Copper *et al.* (1982), Kaneko (1984, 1985), Kase and Nishida (1986), Tazawa (1988), and others.

*Geisonocerella nakazatoensis* Niko, sp. nov. described herein is the first orthoceratid reported from the Middle Paleozoic strata of the southern Kitakami Mountains, and also

the first record of the genus from East Asia.

## Systematic paleontology

Specimens utilized in this report are stored at the University Museum of the University of Tokyo with abbreviation UMUT.

Subclass Nautiloidea Agassiz, 1847
Order Orthocerida Kuhn, 1940
Superfamily Pseudorthocerataceae Flower and Caster, 1935
Family Pseudorthoceratidae Flower and Caster, 1935
Subfamily Spyroceratinae Shimizu and Obata, 1935
Genus *Geisonocerella* Zhuravleva, 1978

*Type species :* — *Geisonocerella mitis* Zhuravleva, 1978.

*Geisonocerella nakazatoensis* Niko, sp. nov.

Figures 1-1—4

*Type specimen :* — Holotype, UMUT PM 18470, an unperfect phragmocone.

*Diagnosis* : — Weakly annulated large orthocone with elliptical cross section and deeply concaved septa. Siphuncular position central ; septal necks slightly suborthochoanitic. Cameral deposits mainly episeptal-mural.

*Description* : — The holotype is an orthoconic shell, approximately 75 mm in length, which consists of ten camerae with a deep septal curvature (Figures 1-2, 3). It is elliptical in cross section ; conch diameter is 24.3 mm × 28.0 mm at the adoral end. Sutures are not observable but they can be assumed, by the septal shape, to be nearly transverse. The shell surface is marked with widely spaced annulations and lirae that run parallel to the annulet. The annulations are low and slightly oblique to the conch axis. The septal spacing is close ; the number of camera ranges from three to three and one-half in relation to the corresponding apical conch diameter. The siphuncle occupies the central position of the shell ; septal necks are short and slightly suborthochoanitic (Figure 1—4). Cameral deposits consist of episeptal-mural deposits, and bosses which are in the episeptal or hyposeptal position in some camerae. No endosiphuncular deposits are evident.

*Discussion* : — Although the preservation of the holotype is poor in that the connecting rings are missing and the surficial ornamentation is obscure, it is referred to the genus *Geisonocerella* because of the possession of the slightly oblique annulations and lirae, and the suborthochoanitic septal necks.

*Geisonocerella nakazatoensis* Niko, sp, nov. is closely allied to *Geisonocerella pershinae* Zhuravleva (1978, p. 113, pl. 13, figs. 3, 4) from the Emsian of U.S.S.R. in that it has an elliptical cross section of the shell and

relatively narrow annulations with fine transverse lirae. In the latter, however, the siphuncular position is considerably more eccentric and the septa are shallower in comparison with the former. The present species is somewhat similar in the overall shell form to *Geisonocerella mitis* Zhuravleva (1978, p. 111, 112, pl. 13, figs. 1, 2a-b) from the Givetian of U.S.S.R., but it is distinguishable by the less distinct transverse lirae and narrower annulations. *Geisonocerella vajgachensis* Zhuravleva (1978, p. 112, pl. 13, figs. 5a-b, 6a-b) from the Gedinnian of U.S.S.R. also resembles *G. nakazatoensis*, but differs from the latter in having a larger siphuncular diameter to external shell width ratio.

A Devonian orthoconic cephalopod was also recovered by Toshio Kawamura of Miyagi University of Education from the same formation in the Simosabukurazawa of the Sabukura area, Sumita-cho. Unfortunately, this specimen is a natural mold and does not retain the internal structure. Thus, convincing classification and a detailed comparison with the type specimen of *Geisonocerella nakazatoensis* Niko, sp. nov. cannot be done.

With the exception of the present species, the following species have been described under or assigned to *Geisonocerella* :

*Geisonocerella* (?) *bicingulata* (Sandberger and Sandberger) from the Emsian of Novaya Zemlya, Rossiyskaya S.F.S.R. and the Eifelian of the Rheinland, West Germany. (Kuzmin, 1965 ; Zhuravleva, 1978)

*G. mitis* Zhuravleva, 1978 from the Givetian of the Pai-khoi Mountains, Rossiyskaya S.F.S.R.

*G.* (?) *novosemelica* (Kuzmin, 1965) from the Emsian of Novaya Zemlya, Rossiyskaya S.F.S.R.

---

→ **Figure 1.** *Geisonocerella nakazatoensis* Niko, sp. nov., holotype, UMUT PM 18470. **1,** lateral view of silicone rubber cast from the external mold, coated with ammonium chloride. **2,** interior view of the septate conch, coated with ammonium chloride ; cavities mainly represent impressions of the shell and cameral deposits. **3,** polished median section of the conch, submerged in water. Arrow points to the position of siphuncle. **4,** partial enlargement of Figure 3. Arrow indicates relatively well-preserved septal neck. Scale bars represent 20 mm for Figures 1-3 and 5 mm for Figure 4.
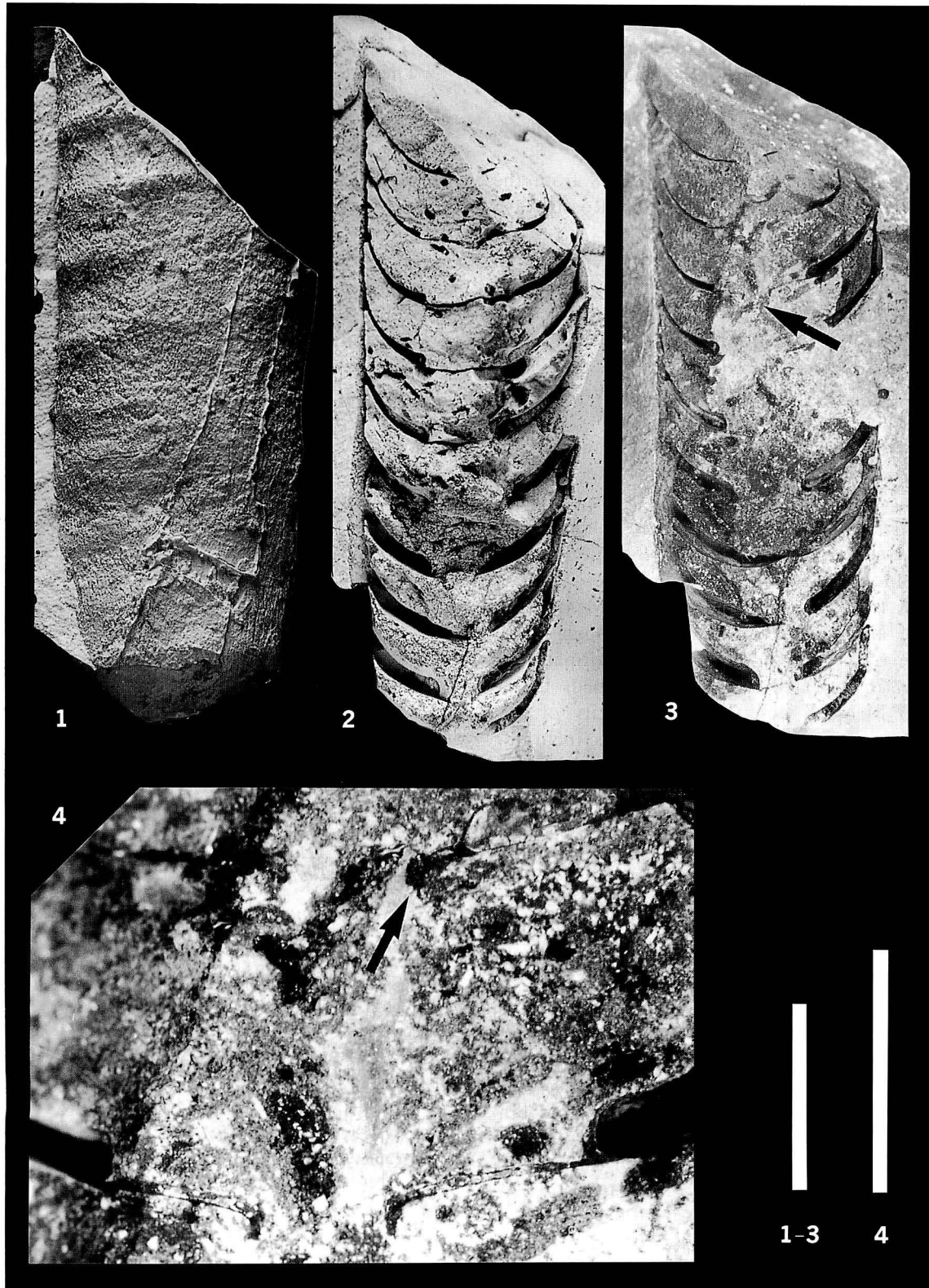
*G. orientalis* Zhuravleva, 1978 from the Givetian of Kuzbass, the Rossiyskaya S.F. S.R.

*G. pershinae* Zhuravleva, 1978 from the Emsian of the basin of the River Pechora, Komi A.S.S.R.

*G. vajgachensis* Zhuravleva, 1978 from the Gedinnian of Ostrov Vaygach, Rossiyskaya S.F.S.R.

Although the information on the Devonian cephalopods in East Asia is too limited to make an accurate presumption of biogeography at that time, it seems that the occurrence of the genus *Geisonocerella* has previously been restricted to only the Old World Province as mentioned above.

*Occurrence and age*: — The holotype of *Geisonocerella nakazatoensis* Niko, sp. nov. and a specimen (UMUT PM 18471, a crushed internal mold of the large body chamber) of questionable assignment to the species were found by Atsushi Kaneko of Kyoto University from the upper portion (N3 Member) of the Nakazato Formation. Although fossils are rather poor in the Nakazato Formation, a few intercalated thin sandstone beds in the N3 Member yield a large quantity of brachiopods, trilobites and mollusks including the present cephalopods. Both specimens were collected at an outcrop in a small tributary of the Higuchizawa of the Hikoroichi area, Ofunato City, southern Kitakami Mountains (141°40′8″E, 39°6′55″N), where a greenish gray colored fossiliferous sandstone bed (approximately 1 m thick) is intercalated within thin alternating beds of tuffaceous sandstone and sandy shale.

Biostratigraphic investigations of the fauna offer a consensus favoring the Couvinian to Givetian (*e.g.*, Kobayashi and Hamada, 1977; Kato and Minato in Minato *et al.*, 1979). Recent research on the atrypoid brachiopod by Copper *et al.*, (1982) provided a more defined age determination, the middle or late Eifelian. Similar conclusions were reached by Kaneko (1984, 1985) based on trilobites.

## References

Copper, P., Tazawa, J., Mori, K. and Kato, M., 1982: *Atrypa* (Devonian Barchiopoda) from Japan. *Trans. Proc. Palaeont. Soc. Japan, N.S.*, no. 127, p. 368-374, pl. 59.

Flower, R.H. and Caster, K.E., 1935: The stratigraphy and paleontology of northwestern Pennsylvania. Part II: Paleontology. Section A: The cephalopod fauna of the Conewango Series of the Upper Devonian in New York and Pennsylvania. *Bull. American Paleont.*, vol. 22, no. 75, p. 199-271.

Kaneko, A., 1984: A Middle Devonian trilobite fauna from the Kitakami Mountains, northeast Japan-I. The Lachidae. *Trans. Proc. Palaeont. Soc. Japan, N.S.*, no. 136, p. 474-491, pls. 87-89.

——, 1985: Ditto-II. The Calymenidae. *Ibid.*, no. 138, p. 94-110, pls. 14-16.

Kase, T. and Nishida, T., 1986: A Middle Devonian gastropod faunule from the Nakazato Formation of Kitakami, northeast Japan. *Bull. Nat. Sci. Mus., Ser, C*, vol. 12, no. 3, p. 73-89.

Kobayashi, T., 1957: Notes on two Devonian trilobites from the Kitakami Mountains in Japan. *Jour. Fac. Sci., Univ. Tokye, Sec. II*, vol. 11, p. 1-10, pl. 1.

—— and Hamada, T., 1977: Devonian trilobites of Japan in comparison with Asian, Pacific and other faunas. *Palaeont. Soc. Japan, Spec. Pap.*, no. 22, 202 p., 13 pls.

Kuzmin, A.M., 1965: Devonian cephalopods (Superorder Nautiloidea) from the southern islands of

Novaya Zemlya. *Uchenye Zapiski Nauchno-Issledovate'skii Institute Geologii Arktiki (NIIGA), Ministerstva Geologii SSR, Paleontologii i Biostratigrafii*, vypusk 9, p. 8-40, pls. 1-8 (*in Russian*).

Minato, M. and Kato. M., 1977: A reticulate speriferid from the Devonian Nakazato Formation of the Kitakami Mountains, Japan. *Jour. Fac. Sci. Hokkaido Univ., Ser. IV*, vol. 17, no. 4, p. 619-627.

——, Hunahashi, M., Watanabe, J. and Katto, M. (*eds.*), 1979: *The Abean Orogeny*. 427 p., Tokai Univ. Press, Tokyo.

Okubo, M., 1956: Same Devonian brachiopods and trilobites of the southern Kitakami Mountainland. *Japan. Jour. Geol. Geogr.*, vol. 27, p. 37-45, pls. 1-3.

Shimizu. S. and Obata, T., 1935: New genera of Gotlandian and Ordovician nautiloids. *Shanghai Sci. Inst., Jour., Sec. 2*, vol. 2, p. 1-10.

Sugiyama, T. and Okano, H., 1941: On the discovery of *Phacops* (s.s.) from the Nakazato Series (Middle Devonian) of the Kitakami Mountainland. *Japan. Jour. Geol. Soc. Japan*, vol. 48, no. 574, p. 357-361.

Tazawa, J., 1988: *Zdimir* (Devonian Brachopoda) from the Kitakami Mountains, northeast Japan and its paleobiogeographical significance. *Ibid.*, vol. 94, no. 12, p. 1013-1016 (*in Japanese*).

Zhuravleva, F.A., 1978: Devonian orthocerids —Superorder Orthoceratoidea—. *Akademia Nauk SSSR, Trudy Paleontologicheskogo Institut*, vol. 168, 227 p. (*in Russian*).

Higuchizawa 樋口沢, Hikoroichi 日頃市, Kitakami Mountains 北上山地, Nakazato 中里, Ofunato 大船渡, Ohno 大野, Sabukura 寒倉, Simosabukura-zawa 下寒倉沢, Sumita-cho 住田町.

南部北上山地中里層産デボン紀頭足類の一新種：南部北上山地の岩手県大船渡市日頃市地域に分布する中部デボン系中里層N3部層より産出した頭足類（シュードオルソセラス科）の一新種，*Geisonocerella nakazatoensis* Niko を記載する。本種は，長円状の殻断面を示し殻表に弱い輪環が認められる大型種で深く屈曲する隔壁，殻体の中心に位置する体管，わずかに亜オルソセラス型を示す隔壁襟，episeptal-mural 気空内沈殿物を有することにより特徴づけられる。　　　　　　　　　　　　　　　　児子修司

# 891.  FOSSIL OSTRACODE ASSEMBLAGES FROM THE PLIOCENE SASAOKA FORMATION, AKITA CITY, JAPAN
## —— WITH REFERENCE TO SEDIMENTOLOGICAL ASPECTS* ——

TOSHIAKI IRIZUKI

Institute of Geology and Paleontology, Tohoku University,
Aobayama, Sendai 980

**Abstract.**  Two hundred sixteen species of fossil ostracodes coming under 71 genera are recognized in the Pliocene Sasaoka Formation distributed in the eastern part of Akita City, northeast Japan.  In general, cryophilic species which either live today in Japan or have been reported from the Plio-Pleistocene of that region are predominant in each sample, with subordinate amounts of such circumpolar species as *Acanthocythereis dunelmensis* (Sars), *Hemicythere emerginata* (Sars), *Elofsonella concinna* (Jones) and *Palmenella limicola* (Norman).  In addition to such cold water species, warm water species inhabiting sea areas under the influence of the Kuroshio current are contained in each sample, running up to a few percent of the total.

Q-mode cluster analysis of ostracode occurrence data brings out four clusters of samples (A, B, C and D).  The results from grain size analysis of sediments containing fossil ostracodes are compared with the size of ostracode valves, the ratio of left to right valves, the ratio of adult to total valves, species diversity and equitability, with intention of understanding these four clusters.  In general, physical agents had a great influence upon the distribution of fossil ostracode assemblages in the Sasaoka Formation, thus the depositional environment is to be assessed not only on the ecological side of ostracodes but also on the sedimentological side.

## Introduction

Paleontologists are often confronted with some problems when inferring paleoenvironments by using fossils.  One of these is difficulties in distinguishing such microfossils as ostracodes into autochthonous and allochthonous material.  If the fossil assemblages are in situ, their ecological aspects may be emphasized, and if they have been influenced by physical, chemical and/or biological agents, sedimentological aspects are more important in interpreting a paleoenvironment.  Consequently, large numbers of paleoecologists are seeking to study the processes which give rise to post-mortem modification of the remains of organisms.  There are two different ways in taphonomic studies.  One is laboratory experiments.  In relation to fossil ostracodes, for example, Kontrovitz (1975) conducted flume experiments on their differential transportation and concluded that carapaces (articulated valves) are involved in a traction current at lower velocities than are valves (disarticulated valves) of the same species.  Moreover, Kontrovitz and Nicolich (1979) showed that the shape of carapaces and valves is more important factors than their size in undergoing transportation and suggested a high likeli-

hood of success in predicting threshold velocities by using shape parameters. Whatley, Trier and Dingwall (1982) indicated that durability of ostracode carapaces varies greatly: some robust species have the greater potential for preservation than fragile ones. Another is carried out through comparisons between living and subfossil assemblages in the hope of guiding feasible interpretations of fossil assemblages. Kilenyi (1969) studied the living and death assemblages from the Thames Estuary and assessed sorting effects by using the ratios of carapaces to valves and adults to juveniles. Okada (1979) discussed the degree of mixtures of ostracode communities by comparing the structure of fossil assemblages from the Shibikawa and Anden Formations with that of Recent communities. Frydl (1982) also inferred the degree of sorting of fossil ostracode assemblages from the Boso Peninsula in Japan by means of community structures, the ratios of each instar to the total numbers and the left to right valves. Izuka and Kaesler (1986) compared biotopes based on ternary plots and cluster analyses of living ostracode assemblages with those from subfossil assemblages from a small reef flat and showed that a mixing of algae-dwelling and sediment-dwelling ostracode assemblages easily occurs and thin shelled species are largely destroyed by biostratinomic agents. Moreover, they mentioned that transportation of ostracodes does not completely homogenize subfossil assemblages, nor does it completely obliterate distributional patterns of living ostracodes. van Harten (1986) investigated living ostracode assemblages in the Mediterranean and concluded that displaced ostracode assemblages typically contain relatively few adult specimens and selective sorting leads to over representation of certain size classes and may cause the ratio of left to right valves to shift from the original ratio of one to one. Moreover, he inferred the paleodepth of the Prasas Marl sediments, taking those results into consideration.

The purpose of this study is to delineate the depositional environment of the Pliocene Sasaoka Formation, Akita City in Japan, by means of fossil ostracodes. Thus, as to infer whether they have been subjected to selective physical agents or not, it is important to recognize the relationships between sediment grain size and the composition of fossil ostracode assemblages in addition to turning to account the above-mentioned varied taphonomic knowledge of ostracode valves. Ostracodes are of great advantage in conducting taphonomy because their growth stages can be recognized even in fossil assemblages and their carapace consists of two asymmetrical valves.

## Geological setting

Late Cenozoic deposits in the study area, the eastern part of Akita City, are classified, from the bottom upward, into the Onnagawa, Funakawa, Tentokuji, Sasaoka and Takaoka Formations (Figure 1). These formations are broadly folded into a syncline (Wada Syncline), whose axis passes through the center of the study area from north to south. Many geologists have investigated this area (*e.g.* Huzioka *et al.*, 1977; Ozawa *et al.*, 1981). The stratigraphic scheme resulted from the present survey is basically the same as in previous investigations (Figure 2).

The Onnagawa Formation, resting conformably on the Sunakobuchi Formation which consists of basaltic breccia and lava, is composed mainly of 420 to 600 m thick stratified hard mudstone. Along the Sannaigawa River, thick and massive rhyolitic tuff and tuff breccia called the Kamisannai Tuff Member of this formation, are well exposed.

The Funakawa Formation conformably overlies the Onnagawa Formation and consists of dark gray massive mudstone. The upper part distributed in the northern part is composed of massive pumice tuff and tuff breccia.

The Tentokuji Formation, resting unconformably on the Funakawa Formation, con-
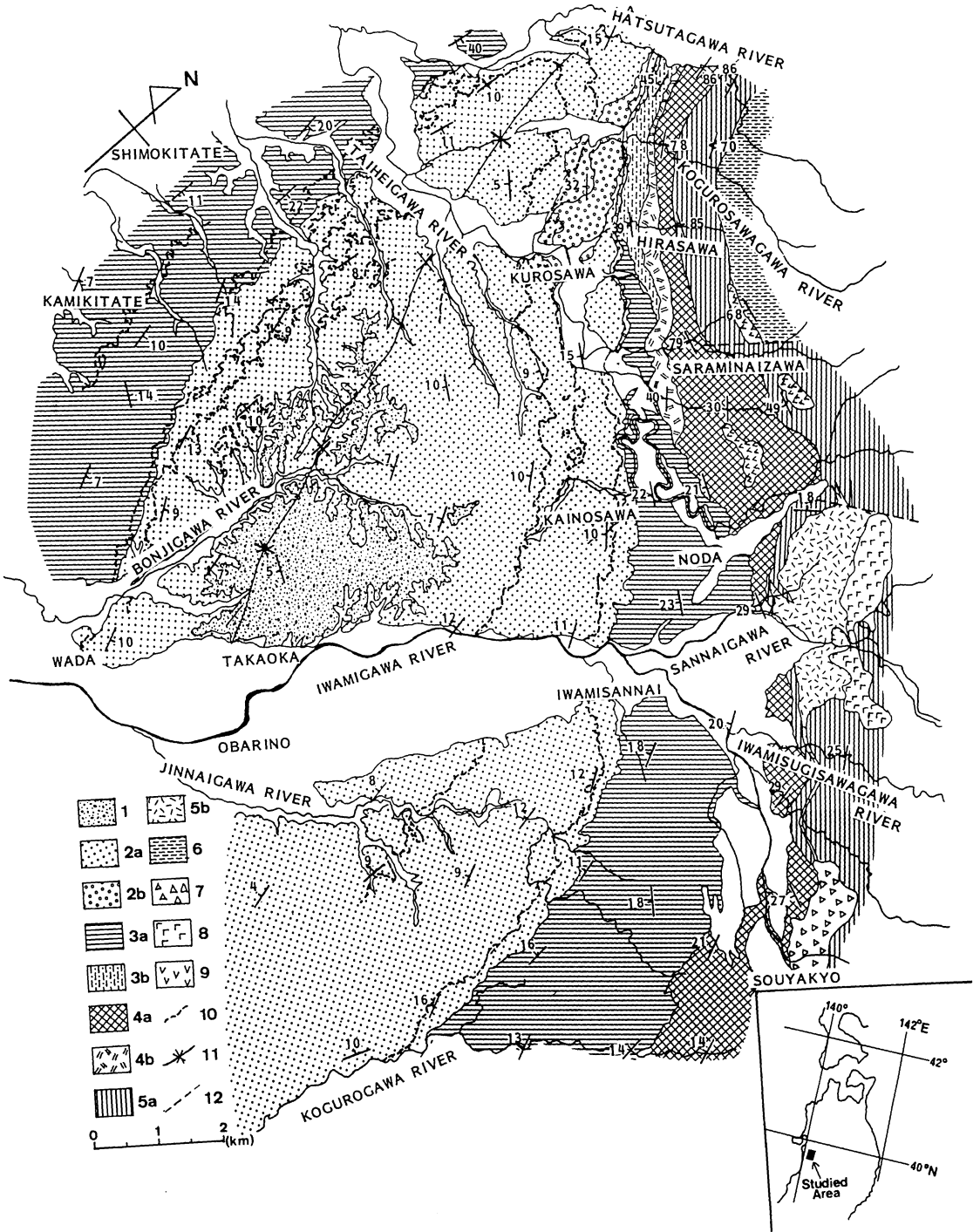
| | SW | NE | |
|---|---|---|---|
| AGE | STRATIGRAPHY | | THICK-NESS |
| | terrace deposits | | |
| PLIOCENE ? | Takaoka Formation | | 30-100m |
| | Sasaoka | | 300- |
| | Formation | | 600m |
| | Tentokuji Formation | | 150-620m |
| MIOCENE | Funakawa Formation S.A. | | 180-900m |
| | Onnagawa K.T. Formation T.R. | | 0-450 m / 420-600m |
| | Sunakobuchi Formation | | |

**Figure 2.** Stratigraphic units. S.A.: Souya-kyo Andesite, K.T.: Kamisannai Tuff Member, T. R.: Tsukushimori Rhyolite.

sists of an alternation of conglomerate and sandy siltstone (Katsurane facies) and silt-stone. Such ostracodes as *Acanthocythereis dunelmensis* (Sars) and *Robertsonites reticuliforma* (Ishizaki) are also observed, but are generally, not in abundance.

The Sasaoka Formation overlies the Tento-kuji Formation conformably on both the eastern and western sides of the syncline, but unconformably in the northern part where a few meter thick basal conglomerate is recognized. The formation in the southern part consists mainly of tuffaceous silty sandstone which grades upward into fine sandstone. In the northeastern part, the formation is composed maily of 300 to 600 m thick fine to medium sandstone but silty sandstone grading upward into fine sandstone, and granule conglomerate and pebbly sandstone are seen along the Hatsutagawa River, and along the Kogurosawagawa River and Hirasawa, respectively. Some thin beds of white to cream colored fine tuff are widely traceable in the study area. The formation yields large quantities of calcareous fossils called the Omma-Manganji Fauna which originally referred to cold-water inhabiting molluscan assemblages in the Pliocene of Japan (Otuka, 1936). According to Maiya (1978), the lower and middle parts of the Sasaoka Formation represent the planktonic foraminiferal *Neogloboquadrina pachyderma/Globorotalia orientalis* Zone (late Pliocene). However, its upper part, which has not yielded any age-controlling fossils, may run up in age to the Pleistocene, judging from the great thickness of 300 m.

The Takaoka Formation, resting unconformably on the Sasaoka Formation, is distributed only in the central part. It is composed of 30 to 100 m thick cross-laminated fine to coarse sand and gravel with a thin lignite bed. No marine fossils have been obtained from this formation. In consequence, the whole formation may be of terrigenous origin.

## Materials and methods

A total of 21 samples collected from the Sasaoka Formation were used for ostracode analyses (Figures 3, 4). Eighty grams of

← **Figure 1.** Index and geological maps. 1: Takaoka Formation, 2: Sasaoka Formation, 2a: sandstone, 2b: conglomerate and pebbly sandstone, 3: Tentokuji Formation, 3a: mainly siltstone, 3b: alternation of conglomerate and silty sandstone, 4: Funakawa Formation, 4a: massive mudstone, 4b: pumice tuff, 5: Onnagawa Formation, 5a: stratified hard mudstone, 5b: rhyolitic tuff and tuff breccia (Kamisannai Tuff Member), 6: Sunakobuchi Formation, 7: Souyakyo Andesite, 8: Tsukushimori Rhyolite, 9: dolerite, 10: key beds (fine tuff), 11: Wada Syncline, 13: inferred fault.
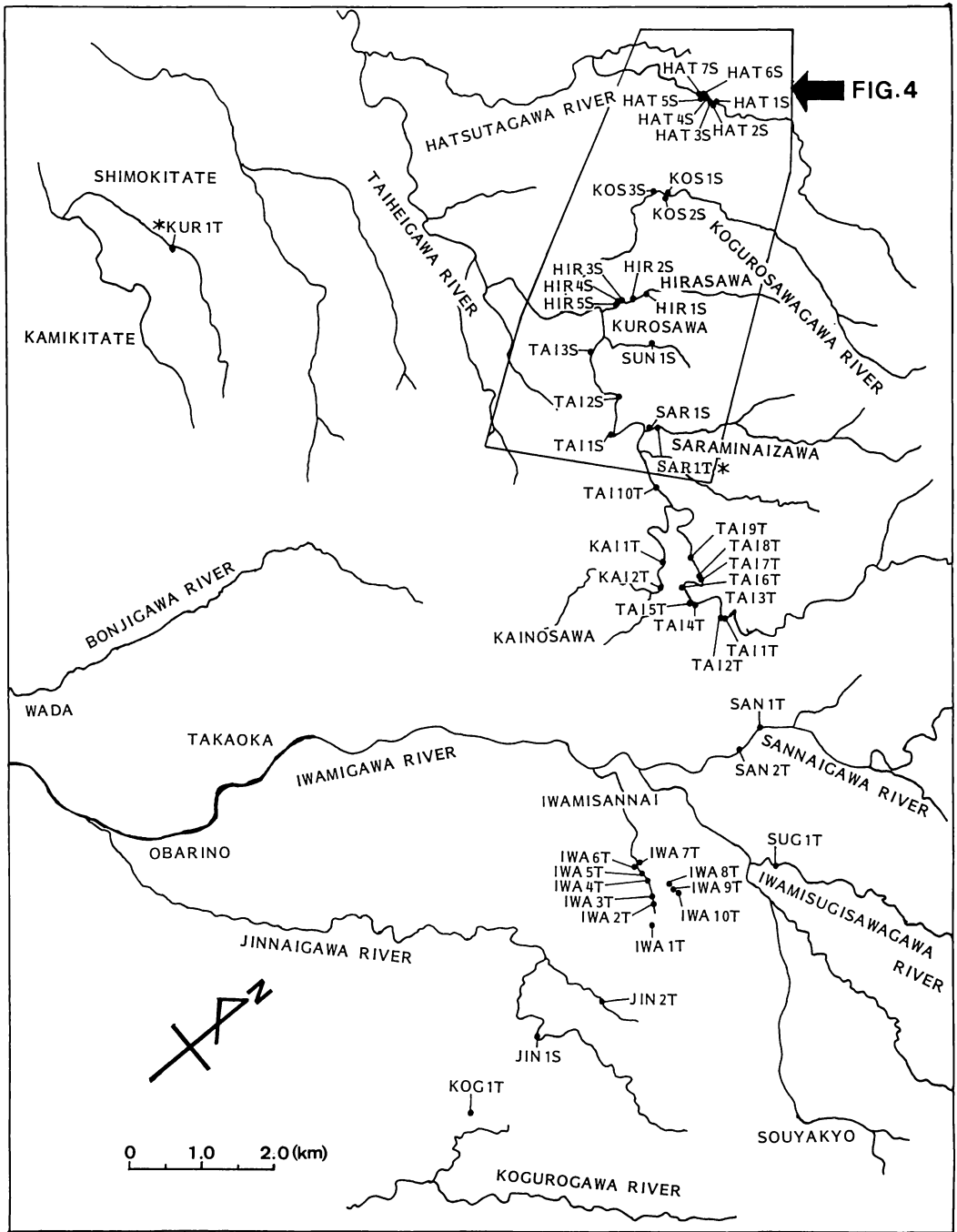
**Figure 3.** Map showing fossil localities in the Tentokuji and Sasaoka Formations.    Asterisks show the location of samples barren of ostracodes but analyzed for grain size.
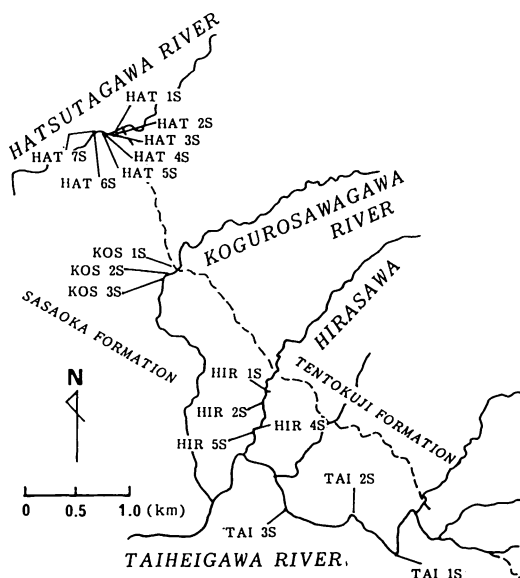
**Figure 4.** Map showing fossil localities in the Sasaoka Formation distributed around Kurosawa.

dried sediment were basically disaggregated making use of a saturated sodium sulphate solution and naphtha for rock maceration (Maiya and Inoue, 1973), washed through a 200 mesh sieve screen, and dried again. A fraction coarser than 177 $\mu$m (80 mesh) was sieved and divided by a sample splitter into aliquot parts, from which about 200 specimens of ostracodes were picked on an assemblage slide, when possible.

### General features of ostracode specimens in the Sasaoka Formation

Two hundred sixteen species belonging to 71 genera of ostracodes were discriminated in the Sasaoka Formation. 20 samples with the exception of JIN-1S were taken from the middle and lower parts of the Sasaoka Formation distributed to the east of the synclinal axis (Figures 3, 4). Specimens and species are generally numerous. General features of ostracode species are as follows.

Circumpolar species such as *Palmenella limicola* (Norman), *Hemicythere emerginata* (Sars), *Acanthocythereis dunelmensis* (Sars)

and *Elofsonella concinna* (Jones), which have been known from the Arctic seas off British Isles, eastern North America, Scandinavia and Europe (Cronin and Ikeya, 1987), are common in each sample. There are many cryophilic species such as *Finmarchinella* spp., *Robertsonites* spp., *Schizocythere okhotskensis* Hanai, *Howeina higashimeyaensis* Ishizaki, *Hemicythere* spp. and *Urocythereis* ? spp., which either live today in cold water seas around Japan or are reported from the Plio-Pleistocene of that region. In contrast, species which inhabit bay areas do not occur: *Bicornucythere bisanensis* (Okubo), *Spinileberis quadriaquleata* (Brady), and *Pistocythereis bradyi* (Ishizaki), and warm water species represented by *Loxoconcha optima* Ishizaki, *Cythere omotenipponica* Hanai, and *Pacambocythere* spp. run into a few percent in every sample. As mentioned above the Sasaoka Formation exclusively contains cryophilic and circumpolar species, and represent a deposit in coastal environments, not in embayment.

### Analyses and discussion

#### a)   Species diversity and equitability

First of all, in order to comprehend the structure of each of the ostracode assemblages in 17 samples which yielded about 200 specimens, species diversity was examined by using the Shannon-Weaver's information function:
$H(S) = -\Sigma pi \ln p_i$, where $p_i$ means the proportion of the $_i$ th species in a sample. Incidentally, Buzas and Gibson (1969) expressed equitability by the following formula: $E = e^{H(S)}/S$, where $S$ stands for the number of species. It equals the formula, $H(S) = \ln (S \cdot E)$ which plots the relationships among the number of species, diversity and equitability on a graph (Figure 5). A basis for comparison is constructed by using following literature data:

1   Inner Bay of Uranouchi (Ishizaki, 1968)
2   Outer Bay of Uranouchi (Ishizaki, 1968)
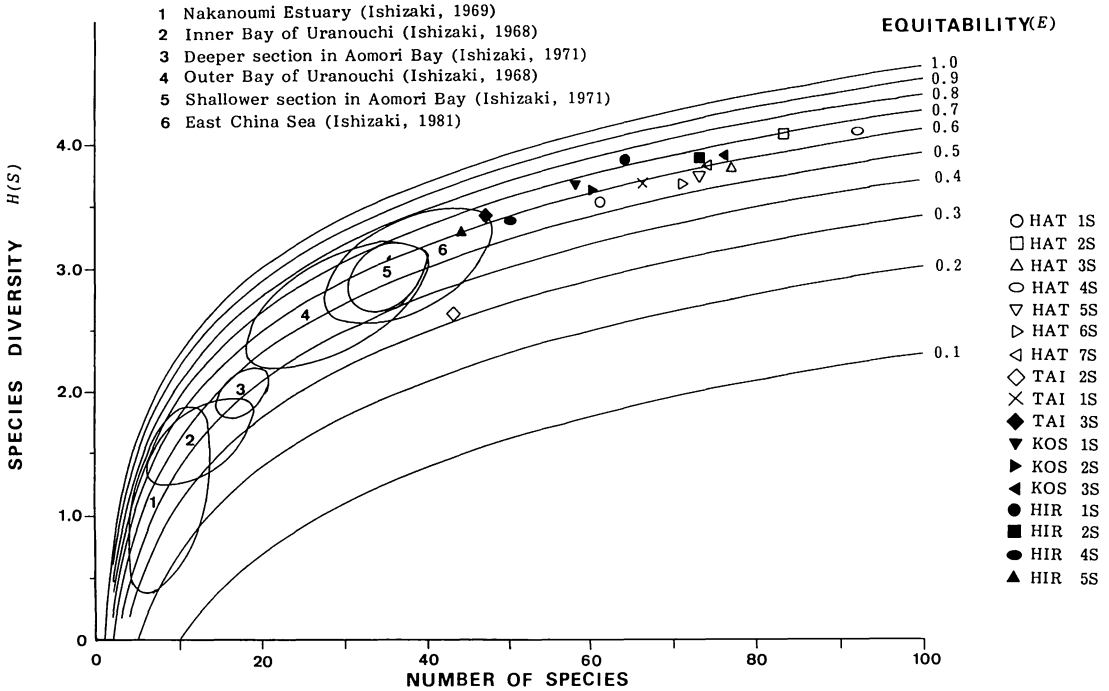3   Nakanoumi Estuary (Ishizaki, 1969)

**Figure 5.** Diagram showing the positions of 17 samples from the Sasaoka Formation in relation to species diversity, equitability, and number of species. Large ellipses show sample groups constructed by using the data from Ishizaki (1968, 1969, 1971, 1981).

4 Shallower section in Aomori Bay (Ishizaki, 1971)

5 Deeper section in Aomori Bay (Ishizaki, 1971)

6 East China Sea (Ishizaki, 1981)

Ostracode assemblages in bay areas display lower values of $S$, $H(S)$ and $E$, but those in open seas such as the East China Sea show higher values. The equitability values of the assemblages in the Sasaoka Formation are shown between 0.5-0.8 with the exception of TAI-2S. Those diversity values are all relatively high, except for TAI-2S, TAI-3S, HIR-4S, and HIR-5S. Generally all the examined assemblages except in TAI-2S display changes in diversity depending on the number of species rather than equitability values and seem to be representatives of open sea areas.

**b) Cluster analysis**

As one of the useful ways to find out biotopes based on similarities among the samples with respect to the composition of ostracode species, Q-mode cluster analysis was conducted by using NEAC-ACOS model 1000 computer in the Tohoku University Computer Center. The computer program used was written by Shiro Hasegawa. Similarities are given by the Horn's overlap index (Horn, 1966) between samples, and clustering is practiced by using the weighted variable group method with arithmetic averages. 110 species which are represented by more than three specimens in any of the samples were used for this calculation. As a result, four clusters (A, B, C and D) were recognized in the dendrogram (Figure 6).

**Cluster A** : Localities — HAT-2S, HAT-3S, HAT-4S, HAT-5S, HAT-6S, HAT-7S, and KOS-1S

Main species — *Cytheropteron sawanense* Hanai, *Finmarchinella (Barentsovia) japonica* (Ishizaki), *Cythere boreokurila* Schornikov, and *Cornucoquimba moniwensis* (Ishiza-

ki)

**Cluster B** :  Localities — HAT-1S,  KOS-2S, KOS-3S, HIR-1S, HIR-2S and HIR-4S

Main    species — *Howeina    higashimeya-*



**Figure 6.**  Dendrogram  from  Q-mode  cluster analysis.  A, B, C and D show biotopes.

*ensis, Schizocythere okhotskensis,* and *Cornucoquimba moniwensis*

**Cluster C** :  Localities — HIR-5S,  TAI-2S and TAI-3S

Main species — *Urocythereis* ? *gorokuensis* Ishizaki, *Normanicythere japonica* Tabuki, *Finmarchinella (Barentsovia) nealei* Okada, and *Howeina higashimeyaensis*

**Cluster D** :  Locality — TAI-1S

Main species — *Urocythereis* ? *gorokuensis,* and *Callistocythere reticulata* Hanai

The  clusters  A  to  D  are  disposed  diachronouslly from northwest to southeast (Figure 7).   Toward  a  better  understanding  of these  clusters,  examined  are  the  relationships between the size of fossil ostracode specimens and sediment grain size, which may imply the degree to which the original material has been influenced  by  physical  agents  such  as  water currents.

**c)   Grain  size  analysis**

Twenty-two samples (19 ostracode-bearing samples  from  the  Sasaoka  Formation,  one ostracode-bearing  and  two  barren  samples from  the  Tentokuji  Formation)  were  analyzed for the  frequency  distribution  of grain size by a settling tube which is able to measure
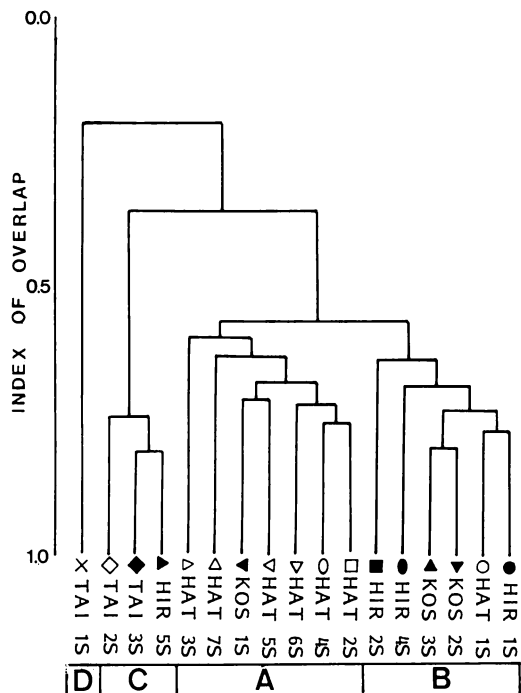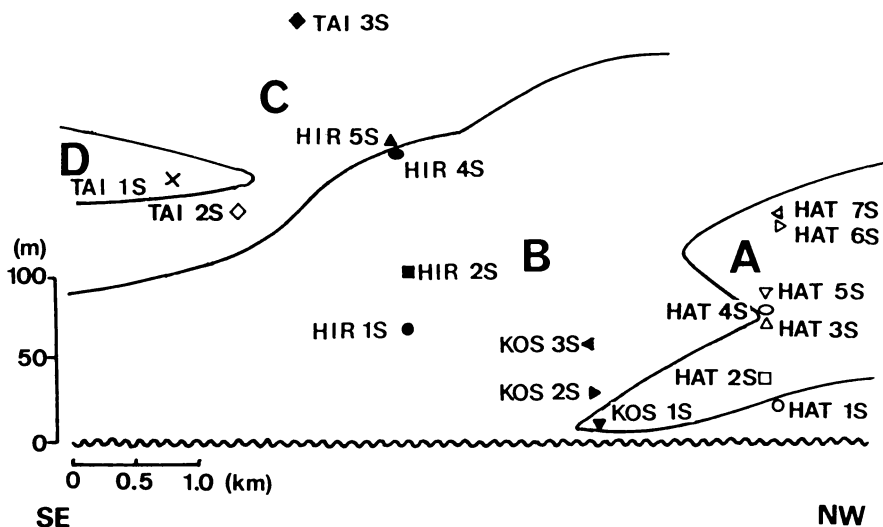


**Figure 7.**  Diagram  showing  the  stratigraphic  distribution  of  clusters  determined  by  Figure 6  on  a schematic cross section (Figure 9).

particles ranging in size from $-1$ to 4.5 $\phi$ (Minoura *et al*., 1988).

As a result, three types (I, II and III) were recognized in grain size distribution (Figure 8). Figure 9 is a cross section showing the distribution of those three types of sediments.

**Type I**: The peak in frequency distribution of grain size is around 3.0 $\phi$. Sorting is well to fair. Mud content is 6.9–35.0%. Two subtypes are discriminated, *i.e.*, Type Ia is characterized by the secondary peak around 0 $\phi$ which is indiscernible in Type Ib. Three samples (KOS-3S, HIR-4S, HIR-5S) belong to Type Ia and six samples (KOS-1S, KOS-2S, HIR-1S, HIR-2S, TAI-1S, TAI-3S) to Type Ib.

**Type II**: The peak in distribution of grain size is around 4.0 $\phi$. Sorting is poor. Mud content is 39.0–71.7%. Eight samples (HAT-

1S, HAT-2S, HAT-3S, HAT-4S,HAT-5S, HAT-6S, HAT-7S, TAI-2S) come under this type.

**Type III**: The peak in distribution of grain size is beyond 4.0 $\phi$. Mud content is 58 and 74%. Two sterile samples from the Tentokuji Formation (KUR-1T, SAR-1T) belong to this type. SAR-1T yielded such benthic foraminifera as *Euuvigerina juncea* (Cushman and Todd), *Epistominella pulchera* Husezima and Maruhasi, and *Trifarina koko-zuraensis* (Asano), which represent the upper to middle bathyal zones.

Types I and II sediments in the Sasaoka Formation are comparable with modern sediments in the Sea of Japan off Nishi-Tsugaru and off Kyogamisaki and in the Bay of Mutsu. In addition, 3.0 $\phi$ fractions which dominate Type I sediments are recognized in an environment where sediments are being deposited under 20 to 30 cm/sec currents (Sundborg, 1967). Sediments with that grain size, frequency distributions and mud contents are known to be distributed on the seafloor within 20 km both off Nishi-Tsugaru (Inouchi *et al*., 1979) and off Kyogamisaki (Katayama and Ikehara, 1988) on an almost parallel with the coast. Type Ia sediments with a bimodal distribution may be a result from two different agents: coarser fractions (around 0 $\phi$) have been brought into mingle with 3 $\phi$ fractions through creeping. In the Bay of Mutsu, Type Ia sediments are characteristically recognized in channel deposits (Minoura *et al*., 1988). Namely, Type I sediments are thought to have been deposited in high-energy environments where coarser grains are to be supplied. Three samples coming under this type belong to clusters B and C.

Type II sediments having high mud contents are being deposited both in more offshore areas than those of Type I sediments and in the mouth of small bays. Because 3.5 to 4.0 $\phi$ fractions, which make a peak in Type II sediments, are sensitive to the movement of water, it is thought that the fractions were



TYPE Ia (HIR 5S)

TYPE Ib (HIR 2S)

TYPE I+II (SUN 1S)

TYPE II (HAT 6S)

TYPE II+III (TAI 9T)

TYPE III (KUR 1T)

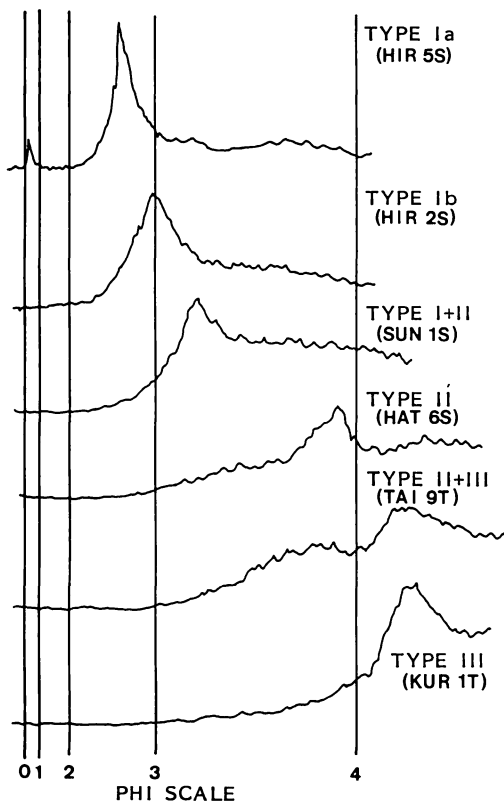0 1  2          3                    4
        PHI SCALE

**Figure 8.** Frequency distribution of grain size.
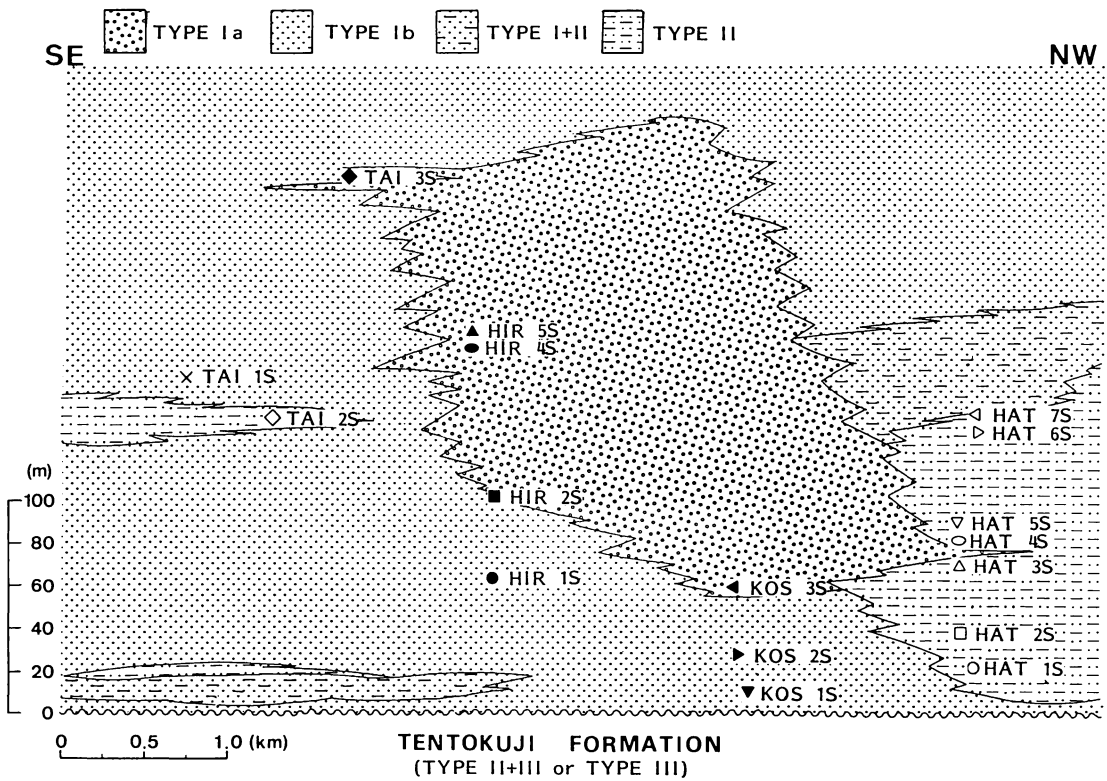
**Figure 9.** Schematic cross section in the Sasaoka Formation constructed by using the result of grain size analysis. Vertical axis represents thickness of the formation.

sediments settled out of suspension in stagnant and low-energy environments where hardly any coarser grains will be supplied. Most of the samples in cluster A come under Type II sediments.

Besides those three types, medium types (Type I+II, Type II+III) are distinguished. Two samples yielding a few fossil ostracodes (SUN-1S, SAR-1S) are grouped under Type I+II. Type II+III comprises TAI-9T which yielded the most fossil ostracodes of all the samples from the Tentokuji Formation (50 specimens/80 g sediments).

**d)  Measurement of ostracode shell**

To investigate whether there are relationships between grain size and ostracodes shell size, eight species which are common in 17 samples were selected for measurements of their length and height: *Cornucoquimba*

*moniwensis, Cythere boreokurila, Cytheropteron sawanense, Finmarchinella (Barentsovia) hanaii* Okada, *Finmarchinella (Barentsovia) japonica, Schizocythere okhotskensis, Urocythereis* ? *gorokuensis*, and *Urocythereis* ? sp. A.  If relationships are suggested, ostracode valves are thought to have been sorted by water currents.  The mean and standard deviation of their size are shown in Figure 10.  Measured are either right or left valves because most ostracodes have more or less asymmetrical valves.  As for *Cythere boreokurila*, left valves are measured with the exception of HIR-2S and HAT-5S, in which right valves are reluctantly used because most left valves are broken.

The valves of *Urocythereis* ? *gorokuensis* from samples belonging to sediment Type I (solid symbols) are larger than those of Type II (open symbols) except for TAI-2S.  An

Legend:

TYPE II
- ○ HAT 1S
- □ HAT 2S
- △ HAT 3S
- ◇ HAT 4S
- ▽ HAT 5S
- ▷ HAT 6S
- ◁ HAT 7S
- ◇ TAI 2S

TYPE I
- ◆ TAI 3S
- ✕ TAI 1S
- ▼ KOS 1S
- ▶ KOS 2S
- ◀ KOS 3S
- ● HIR 1S
- ■ HIR 2S
- ⬤ HIR 4S
- ▲ HIR 5S
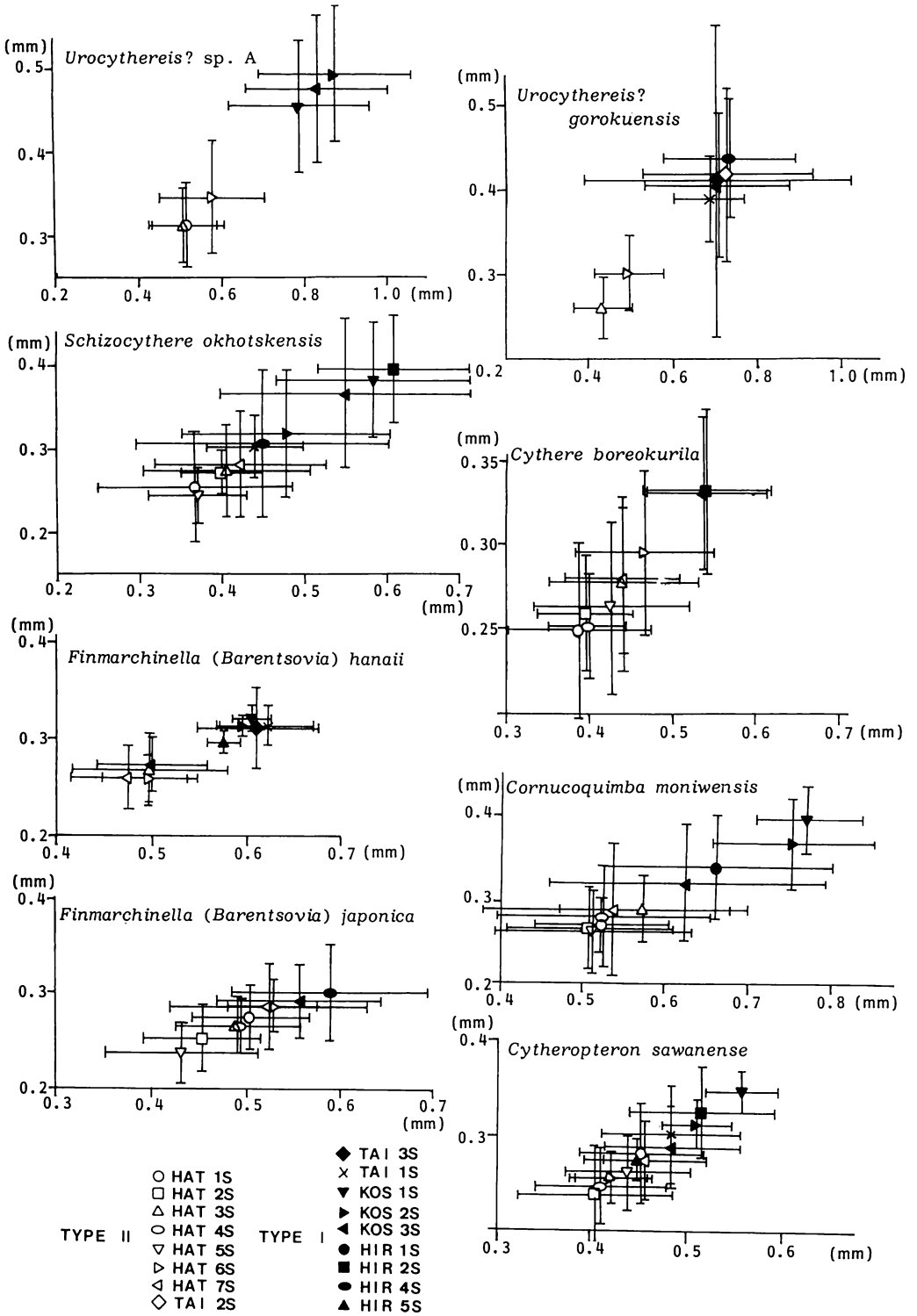
apparent break is recognized between sediment Type II and Type I for *Urocythereis ?* sp. A which has relatively large valves. As to the remaining six species, Type I samples contain larger valves than in Type II. As valve sizes of *Urocythereis ? gorokuensis* in TAI-2S are not related to grain size, they may not be influenced much by water currents.

Similar results were also obtained from a study of age distributions of dominant species in each sample (Figures 11, 12). Frydl

(1982) and van Harten (1986) inferred the degree of sorting from their studies of age distributions. Most ostracodes molt eight times from hatch to adult. Their castoff carapaces are usually fragile and potentially less preservable as fossils. Therefore it seems likely that each instar of fossil ostracodes represents largely their time of death.

There are few or no adult valves but numerous juvenile ones in samples of Type II sediments. For example, valves of *Cythere bor-*



**Figure 11.** Histograms showing the abundance of various growth stages of dominant species present in each sample of sediment Type II. The numerals show the number of total specimens and the numbers in parentheses stand for adult specimens. Shaded column and abbreviation A represent an adult stage, and -1, -2, ······for successive younger stages. Ac. A. : *Acanthocythereis* sp. A, Ba. h. : *Baffinicythere howei*, Co. m. : *Cornucoquimba moniwensis*, Co. s. : *Cornucoquimba saitoi*, Co. A. : *Cornucoquimba* sp. A, Cy. b. : *Cythere boreokurila*, Cy. s. : *Cytheropteron sawanense*, Fi. j. : *Finmarchinella (Barentsovia) japonica*, Lo. s. : *Loxoconcha subkotoraforma*, No. j. : *Normanicythere japonica*, Pa. h. : *Paijenborchella hanaii*, Pa. t. : *Paijenborchella tsurugasakensis*, Pa. r. : *Patagonacythere robusta*, Sc. o. : *Schizocythere okhotskensis*, Ur. g. : *Urocythereis? gorokuensis.*

← **Figure 10.** Mean and standard deviation of the valve size of eight species which are common in 17 samples. Horizontal and vertical axes represent length and height, respectively.
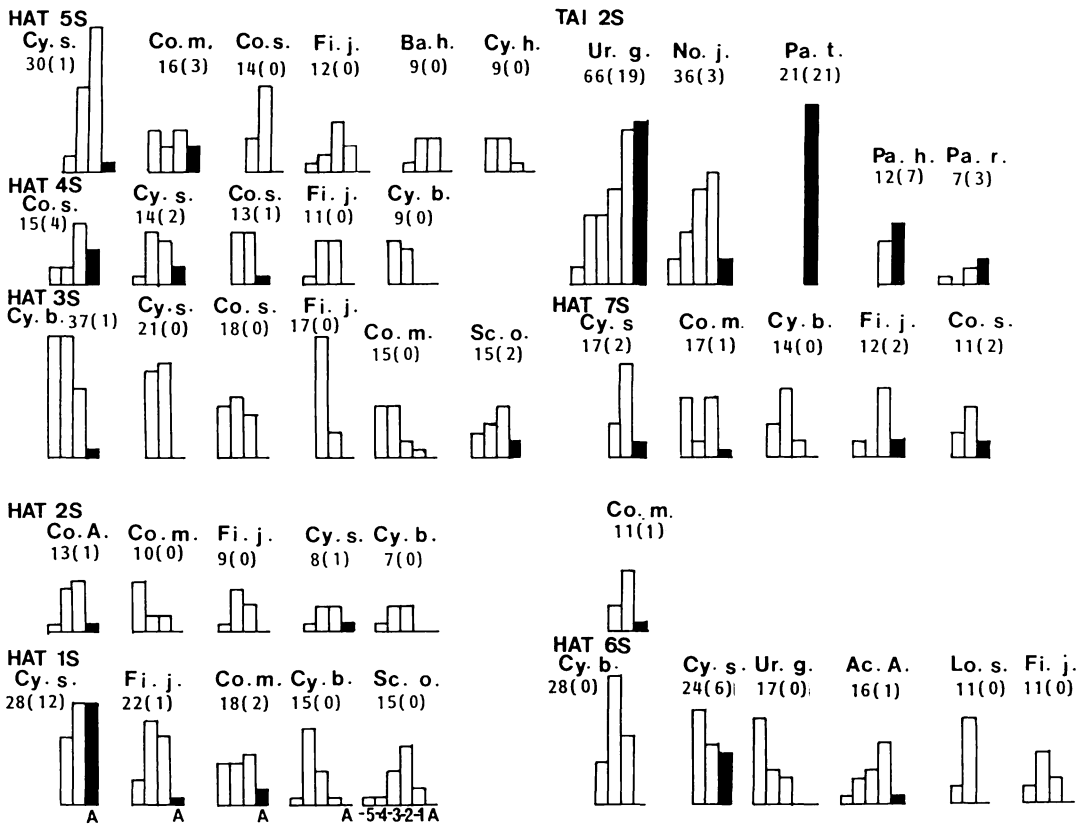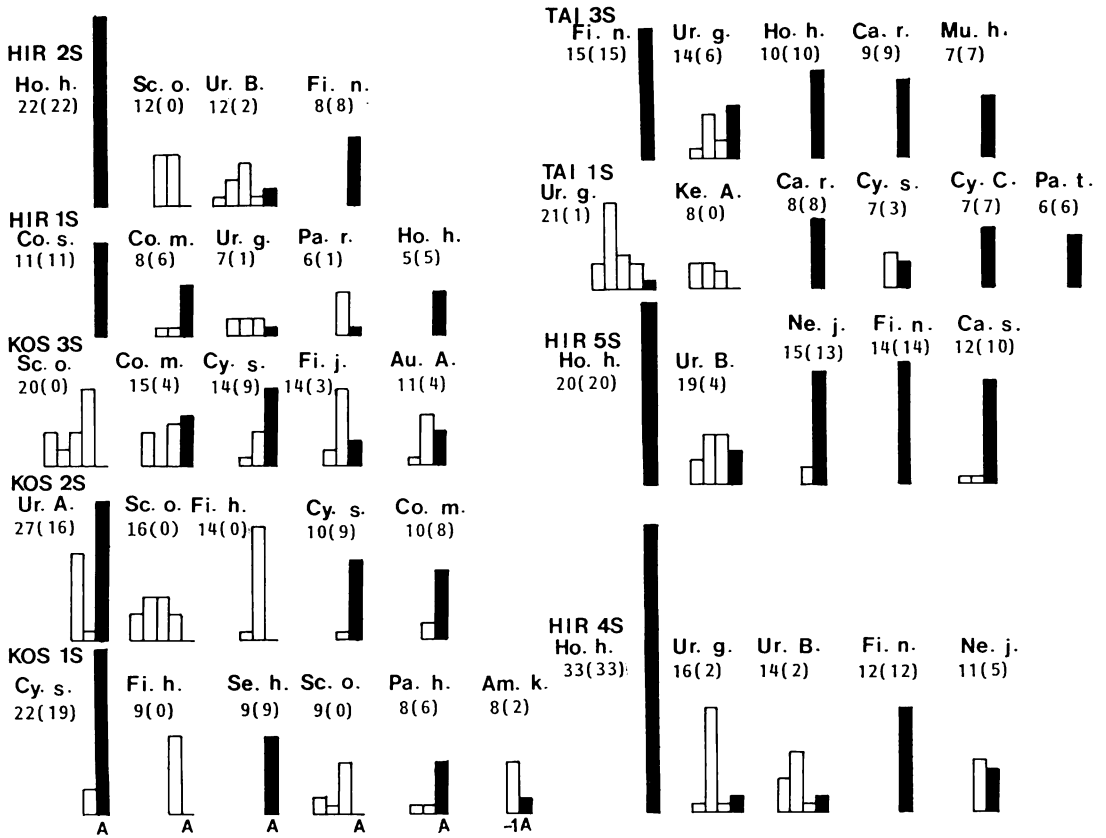
**Figure 12.** Histograms showing the abundance of various growth stages of dominant species present in each sample of sediment Type I. Abbreviations are the same as those on Figure 11. Am. k. : *Ambostracon kitanipponica*, Au. A. : *Aurila* sp. A, Ca. r. : *Callistocythere reticulata*, Ca. s. : *Callistocythere setanensis*, Cy. C. : *Cytherura* sp. C, Fi. h. : *Finmarchinella (Barentsovia) hanaii*, Fi. n. : *Finmarchinella (Barentsovia) nealei*, Ho. h. : *Howeina higashimeyaensis*, Ke. A. : *Keijella*? sp. A, Mu. h. : *Munseyella hatatatensis*, Ne. j. : *Neomonoceratina japonica*, Se. h. : *Semicytherura henryhowei*, Ur. A. : *Urocythereis*? sp. A, Ur. B. : *Urocythereis*? sp. B.

eokurila and *Schizocythere okhotskensis* are abundant, but few adult valves are contained in each sample : only one adult valve of the former species is present in HAT-3S. As *Cythere boreokurila* inhabits today largely intertidal zones in the Kuril Islands (Schornikov, 1974), it seems that species in Type II samples have been displaced at least in part from upper sublittoral zones. In this way some small juvenile valves of certain species are those displaced. In contrast, TAI-2S of the same Type II sediment is dominated by specimens in A to A-4 instar of *Urocythereis* ? *gorokuensis* and *Normanicythere japon-*

ica, and A to A-1 of *Paijenborchella hanaii* Tabuki and *Patagonacythere robusta* Tabuki. Namely, these species in TAI-2S have not been influenced much by water currents and there is a possibility that they are in situ ones.

Dominant species in samples of sediment Type I are represented by numerous adult and few or no juvenile specimens. For example, such species as *Howeina higashimeyaensis* in HIR-1S, HIR-2S, HIR-4S, HIR-5S and TAI-3S, *Finmarchinella (Barentsovia) nealei* in HIR-4S, HIR-5S and TAI-3S, and *Callistocythere reticulata* in TAI-1S and TAI-3S

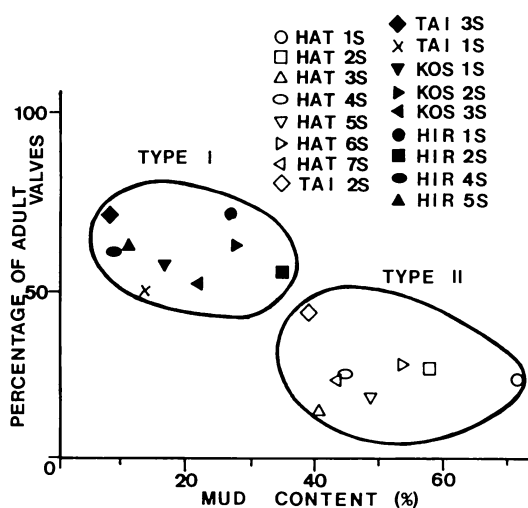**Figure 13.** Diagram showing the relationship between mud content and percentages of adult valves.

are represented by only adult valves being thick and strong. Juvenile valves of these species may have been winnowed away. There is also an over representation of A-1 instar in Type I samples due to selective sorting: *Finmarchinella (Barentsovia) hanaii* in KOS-1S and KOS-2S, and *Finmarchinella (Barentsovia) japonica* in KOS-3S. As mentioned above, physical agents had a great

influence upon the assemblages in Type I sediments. Similar aspects are indicated in Figure 13 where the relationship between the percentage of adult valves in each sample and mud content are demonstrated. In this graph samples containing adult valves of more than 50% can be distinguished from those of less than 30%. Adult valves are numerous, being no less than 73.2% in TAI-3S (mud content is the least (7.8%) and the reverse is generally true in samples with high mud content.

**e) The ratio of right to left valves**

Another way to know whether shells have been influenced by physical agents is to test the ratio of right to left valves. If ostracodes are fossilized utterly in situ after death, their ratios of right to left valves should be 1 : 1. Because their valves are more or less asymmetrical, however, it is likely that ostracode valves are differentially sorted by water currents and that their ratios may shift from original ones. Using the chi-square test, whether the hypothesis (L : R = 1 : 1) is adopted or not was determined at the 5% level of significance (Table 1).

The following species were rejected by means of the chi-square test: *Finmarchinella*

**Table 1.** Numbers of left and right valves and the result of chi-square test of dominant species in each sample. A to D show clusters. Open and solid symbols represent sediments of Type II and Type I, respectively. + : acceptance, ∕ : rejection (at 5% level).

| LOCALITY SPECIES | L.V. | R.V. | 5% |
|---|---|---|---|
| **HAT-1S (○, B)** | | | |
| *Cytheropteron sawanense* Hanai | 28 | 20 | + |
| *Finmarchinella (Barentsovia) japonica* (Ishizaki) | 14 | 22 | + |
| *Cornucoquimba moniwensis* (Ishizaki) | 18 | 12 | + |
| *Cythere boreokurila* Schornikov | 15 | 10 | + |
| *Schizocythere okhotskensis* Hanai | 11 | 15 | + |
| **HAT-2S (□, A)** | | | |
| *Cornucoquimba* sp. A | 6 | 13 | + |
| *Cornucoquimba moniwensis* (Ishizaki) | 10 | 10 | + |
| *Finmarchinella (Barentsovia) japonica* (Ishizaki) | 9 | 8 | + |
| *Cytheropteron sawanense* Hanai | 8 | 7 | + |
| *Cythere boreokurila* Schornikov | 6 | 7 | + |

| LOCALITY SPECIES | L.V. | R.V. | 5% |
|---|---|---|---|
| **HAT-3S (△, A)** | | | |
| Cythere boreokurila Schornikov | 34 | 37 | + |
| Cytheropteron sawanense Hanai | 20 | 21 | + |
| Cornucoquimba saitoi (Ishizaki) | 18 | 8 | / |
| Finmarchinella (Barentsovia) japonica (Ishizaki) | 13 | 17 | + |
| Cornucoquimba moniwensis (Ishizaki) | 12 | 15 | + |
| Schizocythere okhotskensis Hanai | 12 | 15 | + |
| **HAT-4S (○, A)** | | | |
| Cornucoquimba saitoi (Ishizaki) | 15 | 11 | + |
| Cytheropteron sawanense Hanai | 14 | 10 | + |
| Cornucoquimba moniwensis (Ishizaki) | 13 | 10 | + |
| Finmarchinella (Barentsovia) japonica (Ishizaki) | 11 | 3 | / |
| Cythere boreokurila Schornikov | 7 | 9 | + |
| **HAT-5S (▽, A)** | | | |
| Cytheropteron sawanense Hanai | 23 | 30 | + |
| Cornucoquimba moniwensis (Ishizaki) | 2 | 16 | / |
| Cornucoquimba saitoi (Ishizaki) | 2 | 14 | / |
| Finmarchinella (Barentsovia) japonica (Ishizaki) | 12 | 8 | + |
| Baffinicythere cf. howei Hazel | 6 | 9 | + |
| Cythere boreokurila Schornikov | 9 | 5 | + |
| **HAT-6S (▷, A)** | | | |
| Cythere boreokurila Schornikov | 28 | 22 | + |
| Cytheropteron sawanense Hanai | 11 | 24 | / |
| Urocythereis ? gorokuensis Ishizaki | 17 | 10 | + |
| Acanthocythereis sp. A | 16 | 11 | + |
| Loxoconcha subkotoraforma Ishizaki | 4 | 11 | + |
| Finmarchinella (Barentsovia) japonica (Ishizaki) | 7 | 11 | + |
| Cornucoquimba moniwensis (Ishizaki) | 11 | 11 | + |
| **HAT-7S (◁, A)** | | | |
| Cytheropteron sawanense Hanai | 15 | 17 | + |
| Cornucoquimba moniwensis (Ishizaki) | 4 | 17 | / |
| Cythere boreokurila Schornikov | 13 | 14 | + |
| Finmarchinella (Barentsovia) japonica (Ishizaki) | 12 | 5 | / |
| Cornucoquimba saitoi (Ishizaki) | 11 | 8 | + |
| **KOS-1S (▼, A)** | | | |
| Cytheropteron sawanense Hanai | 22 | 16 | + |
| Finmarchinella (Barentsovia) hanaii Okada | 7 | 9 | + |
| Semicytherura henryhowei Hanai and Ikeya | 9 | 4 | + |
| Schizocythere okhotskensis Hanai | 9 | 3 | / |
| Paijenborchella hanaii Tabuki | 8 | 8 | + |
| Ambostrakon kitanipponica Tabuki | 8 | 7 | + |
| **KOS-2S (▶, B)** | | | |
| Urocythereis ? sp. A | 27 | 27 | + |
| Schizocythere okhotskensis Hanai | 16 | 16 | + |
| Finmarchinella (Barentsovia) hanaii Okada | 10 | 14 | + |
| Cytheropteron sawanense Hanai | 10 | 10 | + |
| Cornucoquimba moniwensis (Ishizaki) | 10 | 8 | + |

(to be continued)

| LOCALITY                                                          SPECIES | L.V. | R.V. | 5% |
|---|---|---|---|
| **KOS-3S  (◀,  B)** | | | |
| *Schizocythere okhotskensis* Hanai | 20 | 15 | + |
| *Cornucoquimba moniwensis* (Ishizaki) | 11 | 15 | + |
| *Cytheropteron sawanense* Hanai | 13 | 14 | + |
| *Finmarchinella (Barentsovia) japonica* (Ishizaki) | 14 | 6 | / |
| *Aurila* sp. A | 9 | 11 | + |
| **HIR-1S  (●,  B)** | | | |
| *Cornucoquimba saitoi* (Ishizaki) | 7 | 11 | + |
| *Cornucoquimba moniwensis* (Ishizaki) | 8 | 6 | + |
| *Urocythereis* ? *gorokuensis* Ishizaki | 3 | 7 | + |
| *Patagonacythere robusta* Tabuki | 6 | 2 | |
| *Howeina higashimeyaensis* Ishizaki | 5 | 3 | |
| **HIR-2S  (■,  B)** | | | |
| *Howeina higashimeyaensis* Ishizaki | 22 | 21 | + |
| *Schizocythere okhotskensis* Hanai | 12 | 11 | + |
| *Urocythereis* ? sp. B | 12 | 12 | + |
| *Pectocythere quadrangulata* Hanai | 7 | 8 | + |
| **HIR-4S  (●,  B)** | | | |
| *Howeina higashimeyaensis* Ishizaki | 28 | 33 | + |
| *Urocythereis* ? *gorokuensis* Ishizaki | 16 | 14 | + |
| *Urocythereis* ? sp. B | 7 | 14 | + |
| *Finmarchinella (Barentsovia) nealei* Okada | 12 | 9 | + |
| *Neomonoceratina japonica* (Ishizaki) | 6 | 11 | + |
| **HIR-5S  (▲,  C)** | | | |
| *Howeina higashimeyaensis* Ishizaki | 20 | 12 | + |
| *Urocythereis* ? sp. B | 17 | 19 | + |
| *Neomonoceratina japonica* (Ishizaki) | 15 | 13 | + |
| *Finmarchinella (Barentsovia) nealei* Okada | 14 | 13 | + |
| *Callistocythere setanensis* Hanai | 9 | 12 | + |
| **TAI-1S  (×,  D)** | | | |
| *Urocythereis* ? *gorokuensis* Ishizaki | 21 | 18 | + |
| *Keijella* ? sp. A | 8 | 6 | + |
| *Callistocythere reticulata* Hanai | 8 | 8 | + |
| *Cytheropteron sawanense* Hanai | 7 | 7 | + |
| *Cytherura* sp. C | 0 | 7 | / |
| *Paijenborchella tsurugasakensis* Tabuki | 6 | 6 | + |
| **TAI-2S  (◇,  C)** | | | |
| *Urocythereis* ? *gorokuensis* Ishizaki | 66 | 52 | + |
| *Normanicythere japonica* Tabuki | 35 | 36 | + |
| *Paijenborchella tsurugasakensis* Tabuki | 21 | 14 | + |
| *Paijenborchella hanaii* Tabuki | 12 | 12 | + |
| *Patagonacythere robusta* Tabuki | 6 | 7 | + |
| **TAI-3S  (◆,  C)** | | | |
| *Finmarchinella (Barentsovia) nealei* Okada | 12 | 15 | + |
| *Urocythereis* ? *gorokuensis* Ishizaki | 9 | 14 | + |
| *Howeina higashimeyaensis* Ishizaki | 10 | 4 | + |
| *Callistocythere reticulata* Hanai | 9 | 7 | + |
| *Munseyella hatatatensis* Ishizaki | 7 | 4 | + |

*(Barentsovia) japonica* (HAT-4S, HAT-7S, KOS-3S); *Cornucoquimba moniwensis* (HAT-5S, HTA-7S); *Cornucoquimba saitoi* (Ishizaki) (HAT-3S, HAT-5S); *Cytheropteron sawanense* (HAT-6S); and *Schizocythere okhotskensis* (KOS-1S).

It is notable to see that more species were rejected in Type II than in Type I sediments.

**f) The number of species, diversity and equitability in HAT-section**

Successive changes of the number of species, species diversity, and equitability were examined in HAT-section where the Sasaoka Formation in composed of 120 m thick silty sandstone with rare intercalations of granule conglomerate beds. Seven samples consist entirely of Type II sediments, of which six (except for HAT-1S) belong to cluster A. Figure 14 shows density (specimens/1 g sediments), the number of species, species diversity $[H(S)]$, equitability, percentages of cold water species and shallow water species, and mud content. Cold water

forms were selected from the large literature (Cronin, 1981; Cronin and Ikeya, 1987; Hanai, 1970; Hazel, 1967, 1968; Ishizaki, 1966, 1971; Ishizaki and Matoba, 1985; Neale, 1974a, 1974b; Neale and Howe, 1975; Neale and Schmidt, 1967; Okada, 1979; Schornikov, 1974; Siddiqui and Grigg, 1975; Swain, 1963; Swain and Gilby, 1974; and Tabuki, 1986) as follows; *Baffinicythere, Elofsonella, Finmarchinella, Hemicythere, Howeina, Muellerina, Normanicythere, Palmenella, Urocythereis ?, Cythere boreokurla, Cythere uranipponica* Hanai, *Callistocythere setanensis* Hanai, *Cytheropteron sawanense, Munseyella hokkaidoana* Hanai, *Patagonacythere robusta* Tabuki, *Schizocythere okhotskensis* and *Semicytherura subundata* (Hanai). The following upper sublittoral forms were picked out from such accounts as Ishizaki (1971), Ikeya and Hanai (1982), and Tabuki (1986): *Aurila, Callistocythere, Hemicytherura, Loxoconcha, Pontocythere, Robustaurila, Xestoleberis, Neonesidea mutsuensis* (Ishizaki),
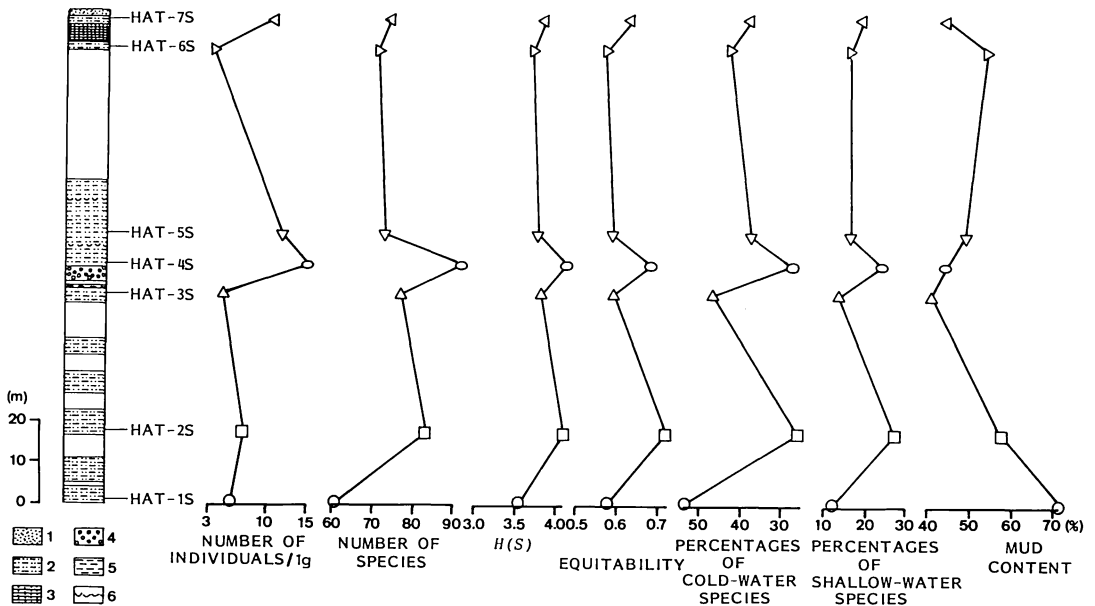


**Figure 14.** Vertical changes of various aspects of ostracode faunas and mud content in HAT-section. 1 : well-sorted fine sandstone (Type I), 2 : silty sandstone (Type II), 3 : alternations of Type I and Type II, 4 : well-sorted granule conglomerate, 5 : mudstone, 6 : shell beds.

*Pistocythereis bradyformis* (Ishizaki), *Schizocythere kishinouyei* (Kajiyama), and *Semicytherura miurensis* (Hanai). They are dwellers on algae and sand bottoms at depths less than about 10 to 20 m.

Excepting mud content, six of the parameters correlate to each other: samples which include many shallow water species and few cold water species are represented by high values of density, $H(S)$, equitability and large numbers of species. Certainly, these assemblages in HAT-section display changes in diversity and equitability depending on the number of species. Such consistencies lead to the following three hypotheses: 1) Relative decreases in number of cold water species and high values of $H(S)$ have resulted from periodic inflows of warm water masses; 2) The value of $H(S)$ and relative frequencies of shallow water species have fluctuated in accordance with sea level changes resulting from isostatic or tectonic movements; 3) Depth changes were negligible, and relative quantities of displaced specimens from shallower into deeper areas brought about fluctuations of $H(S)$.

It is necessary to discuss these hypotheses so as to figure out the most working one. It is certain that there were periodic inflows of warm water masses, as indicated by the occurrence of *Globorotalia inflata* (d'Orbigny). Unlike any other group such as molluscs or foraminifers, benthic ostracodes have no planktonic life even in their larval stages, thus their ability of dispersion seems to be lower. Small percentages of warm water species [*Loxoconcha optima*, *Pacambocythere* spp., *Proteoconcha* spp., *Kangarina* spp., *Schizocythere kishinouyei*, and *Xestoleberis sagamiensis* (Kajiyama)] are not enough to bring about fluctuations of the number of species. Mud contents of six samples except for HAT-1S are about 40-60%. These samples resemble each other and are assigned to Type II sediments. Adult specimens occurring along HAT-section are less than 20% in HAT-3S and HAT-5S, less than 30% in the

others. That is to say, the continuation of the same sediment type and the dominant occurrence of small and juvenile valves show that the third hypothesis is more probable than the second.

### Depositional environment of the Sasaoka Formation

On the basis of the results mentioned above, the depositional environment of the Sasaoka Formation will be discussed in the following lines (Figure 15). Six samples belonging to cluster A are under Type II sediments (massive silty sandstone), and characterized by a large number of species, fewer adult valves than those of any other clusters, and dominant species with ratios of right to left valves significantly different from 1 : 1. *Argilloecia* spp. and *Propontocypris* spp. which inhabit largely outer sublittoral silty sediments and *Robertsonites reticuliforma* which is commonly contained in the Tentokuji Formation are recognized. Fossil assemblages in cluster A contain fragile juvenile valves. According to Whatley (1983), their percentages are comparable with those of biocoenosis. However, it is certain that there are both upper and lower sublittoral species, and as the result of chi-square test, some small valves are thought to have been transported in the state of suspension from high-energy environments into relatively deep and stagnant areas in which are being preserved original assemblages containing small juveniles to adults because of low-energy. It seems that such displacement from upper sublittoral areas and preservability of in situ valves led to a large number of species.

Five samples in cluster B are under Type I sediments, and are characterized by high species diversity and equitability, relative to moderate numbers of species, and contain dominant large hard valves and only a small number of juvenile valves. This shows that the valves may have been lag material behind strong currents — the majority of juvenile

*Toshiaki Irizuki*
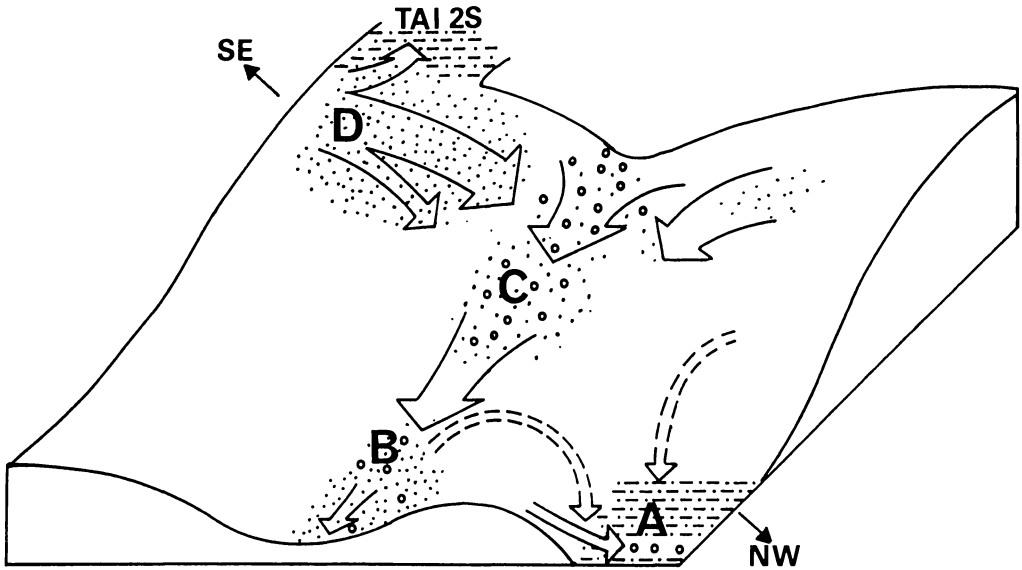


| Cluster | Sample | Sediment Type | No. of species | $H(S)$ | $E$ | Large valves | $\chi^2$ test | Paleodepth |
|---------|--------|---------------|----------------|--------|-----|--------------|---------------|------------|
| A | HAT 2S 3S 4S<br>HAT 5S 6S 7S<br>KOS 1S | Mainly TYPE II | 58 – 92 | 3.70<br>$\mid$<br>4.13 | 0.57<br>$\mid$<br>0.72 | Few | × | Lower sublittoral |
| B | KOS 2S 3S<br>HIR 1S 2S 4S<br>HAT 1S | Mainly TYPE I | 50 – 76 | 3.42<br>$\mid$<br>3.91 | 0.58<br>$\mid$<br>0.77 | Abundant | O | Lower sublittoral |
| C | HIR 5S<br>TAI 3S | TYPE I | 44 – 47 | 3.32<br>$\mid$<br>3.46 | 0.63<br>$\mid$<br>0.68 | Abundant | O | Upper sublittoral |
| C | TAI 2S | TYPE II | 43 | 2.66 | 0.33 | Common | O | Upper sublittoral |
| D | TAI 1S | TYPE I | 66 | 3.71 | 0.62 | Abundant | O | Upper sublittoral |

**Figure 15.** Idealized diagram showing the formative process of ostracode biotopes (A, B, C and D) in the Sasaoka Formation. Broken and solid arrows represent suspension and rotation, respectively and show relative abundances of displaced ostracodes. ○ : Acceptance × : Rejection

valves may have been transported into deeper places. As the species with thick carapaces, coming under, for example, *Cornucoquimba* and *Urocythereis* ? have strong hinges, they were preserved in the state of intact carapaces rather than valves, thus their ratio of right to left valves is close to 1 : 1.

TAI-3S and HIR-5S in cluster C are under Type I sediments with main peaks at less than 3 $\phi$ and mud contents of 7.8 and 11.1%, respectively. These values are lower than

those of many samples in cluster B and show strong current conditions. Those two samples are characterized by lower values of species diversity and a smaller number of species than those of clusters A and B, and by a large number of adult valves (73.2% in TAI-3S and 63.4% in HIR-5S). There exist no such deep water species as *Robertsonites reticuliforma* but *Callistocythere* spp. in abundance in both samples, which inhabit upper sublittoral sandy sediments. Fossil assem-

blages in both TAI-3S and HIR-5S are represented only by valves more resistant against physical agents than those in cluster B and may have remained selectively on the upper sublittoral area, leading to lower species diversity and numbers of species. TAI-2S in the same cluster C is, however, different from those two samples in age composition and sediment grain size. It belongs to Type II (silty sandstone) and contains not only fragile juvenile valves but also large adult valves. The most dominant species, *Urocythereis* ? *gorokuensis* (66/207 total specimens), is abundant on shallower mud to silty mud in Aomori Bay (Ishizaki, 1971). The subordinate species, *Paijenborchella tsurugasakensis* (21/207 total specimens), also inhabits bay areas (Hanai and Yamaguchi, 1987). About 70% of specimens in TAI-2S are dominated by five species (142/207 total specimens). It seems, therefore, that fossil assemblage in TAI-2S may have inhabited a calm sea and has not been modified in comparison with those in any other samples. Namely, such species as *Urocythereis* ? *gorokuensis*, *Normanicythere japonica*, and *Paijenborchella tsurugasakensis* dominated largely their own ecological niches, and into this low equitability assemblage, some species were transported from high-energy environments, leading to 40 species. Such being the case, cluster C spans two types of sediment which yield different compositions of fossil assemblages.

Cluster D is very different from other clusters. The dominant species such as *Pontocythere* spp., *Callistocythere* spp. and *Loxoconcha optima* and abundant in coastal shallow areas. The sample in this cluster belongs to Type I sediments which have the main peak at 3 $\phi$ and a mud content of 13.4%, presenting the shallowest area where coastal currents were relatively strong, and possibly, large valves of such species as *Urocythereis* ? *gorokuensis* and *Paijenborchella tsurugasakensis* were transported from a calm sea to mix with those sand dwellers.

The above results show shallowing of depositional environments of the Sasaoka Formation upward in the sequence and southeastward (Figures 7, 9). It is noteworthy that our inference of depositional environments has to be made both on the sedimentological and ecological sides of ostracode assemblages because the assemblages in all samples except for those of TAI-2S were under strong influences of current winnowing. The values of species diversity and equitability, determined in this study, are those modified owing to physical agents, and do not involve much ecological meaning.

## Concludng remarks

Three conclusions reached through cluster analysis of fossil ostracode data obtained from the Sasaoka Formation, examination of varied parameters with respect to ostracode assemblages, and grain size analysis of sediments containing fossil ostracodes are as follows:

1) Fossil ostracode assemblages in the Sasaoka Formation are characterized, in general, by circumpolar and cryophilic species which are common in the Omma-Manganji Fauna in Japan (Cronin and Ikeya, 1987).

2) Sedimentological and ostracode faunal analyses show that the Sasaoka Formation was deposited under cold and upper to lower sublittoral environments, where high-energy currents largely modified the original (in situ) ostracode assemblages.

3) In interpreting depositional environments by using fossil ostracodes, a factor that seems to be of prime importance is their indigenity which should be assessed from both sedimentological and paleontological aspects.

## Acknowledgments

Paleontology, Faculty of Science, Tohoku Univerity, for advice and continuous encouragement throughout the course of the present study and critical reading of the manuscript. Deep appreciations are also expressed to Dr. Shiro Hasegawa of the same institute and Dr. Kyu-Kui Jung, a former graduate student at the same institute, for constructive discussions and suggestions. The author is much indebted to Professor Koji Minoura and Mr. Toshiaki Susaki, of the Institute of Geology and Paleontology, Faculty of Science, Tohoku University, and Mr. Kazutoshi Fujioka of Takigashira Elementary School, for helpful advice and discussion concerning sedimentology.

## References cited

Buzas, M.A. and Gibson, T.G., 1969: Species diversity: benthonic Foraminifera in western North Atlantic. *Science*, no. 163, p. 72-75.

Cronin, T.M., 1981: Paleoclimatic implications of Late Pleistocene marine ostracodes from the St. Lawrence Lowlands. *Micropaleontology*, vol. 27, no. 4, p. 384-418, 11 pls.

—— and Ikeya, N., 1987: The Omma-Manganji ostracod fauna (Plio-Pleistocene) of Japan and the zoogeography of circumpolar species. *Jour. Micropaleont.*, vol. 6, no. 2, p. 65-88, 3 pls.

Frydl, P.M., 1982: Holocene ostracods in the southern Boso Peninsula. *In* Hanai, T., *ed*., Studies on Japanese Ostracoda. *Bull. Univ. Tokyo, Univ. Mus.*, no. 20, p. 61-140, pls. 8, 9.

Hanai, T., 1970: Studies on the ostracod subfamily Schizocytherinae Mandelstam. *Jour. Paleont.*, vol. 44, no. 4, p. 693-729, pls. 107, 108.

—— and Yamaguchi, T., 1987: Plio-Pleistocene ostracod fauna of Shimokita, Aomori Prefecture (Preliminary Report). *Mem. Natn. Sci. Mus., Tokyo*, no. 20, p. 45-51 (*in Japanese with English summary*).

Harten, D. van, 1986: Use of ostracodes to recognize downslope contamination in paleobathymetry and a preliminary reappraisal of the paleodepth of the Prasas Marls (Pliocene), Crete, Greece. *Geology*, vol. 14, p. 856-859.

Hazel, J.E., 1967: Classification and distribution of the Recent Hemicytheridae and Trachyleberidae (Ostracoda) off northeastern North America. *U.S. Geol. Surv., Prof. Paper* 564, 49 p., 11 pls.

——, 1968: Pleistocene ostracode zoogeography in

Atlantic Coast submarine canyons. *Jour. Paleont.*, vol. 42, no. 5, p. 1264-1271.

Horn, H.S., 1966: Measurement of "overlap" in comparative ecological studies. *Amer. Natur.*, vol. 100, p. 419-424.

Huzioka, K., Ozawa, A., Takayasu, T. and Ikebe, Y., 1977: Geology of the Akita District. Quadrangle Series, Scale 1 : 50,000, *Geol. Surv. Japan*, 75 p., 1 map (*in Japanese with English abstract*).

Ikeya, N. and Hanai, T., 1982: Ecology of Recent ostracods in the Hamana-ko region, the Pacific coast of Japan. *In* Hanai, T., *ed.*, Studies of Japanese Ostracoda. *Bull. Univ. Tokyo, Univ. Mus.*, no. 20, p. 15-59, pls. 1-7.

Inouchi, Y., Kinoshita, Y. and Murakami, F., 1979: Sedimentological map of Nishi-Tsugaru Basin. Marine Geology Map Series (12), Scale 1 : 200,000, *Geol. Surv. Japan*, 5 appendixes, 1 map.

Ishizaki, K., 1966: Miocene and Pliocene ostracodes from the Sendai area, Japan. *Sci. Rep., Tohoku Univ., 2nd Ser. (Geol.)*, vol. 37, no. 2, p. 131-163, pls. 16-19.

——, 1968: Ostracodes from Uranouchi Bay, Kochi Prefecture, Japan. *Ibid.*, vol. 40, no. 1, p. 1-45, pls. 1-9.

——, 1969: Ostracodes from Shinjiko and Nakanoumi, Shimane Prefecture, western Honshu, Japan. *Ibid.*, vol. 41, no. 2, p. 197-224, pls. 24-26.

——, 1971: Otsracodes from Aomori Bay, Aomori Prefecture, northeast Honshu, Japan. *Ibid.*, vol. 43, no. 1, p. 59-97, pls. 1-7.

——, 1981: Ostracodes from the East China Sea. *Ibid.*, vol. 51, nos. 1-2, p. 37-65, pls. 8-15.

—— and Matoba, Y., 1985: Akita (Early Pleistocene cold, shallow water Ostracoda). Guidebook of excursions Exc. 5: 9th Intern. Symp. Ostracoda, 12 p., pls. 1-8.

Izuka, S.K. and Kaesler, R.L., 1986: Biostratinomy of ostracode assemblages from a small reef flat in Maunalua Bay, Oahu, Hawai. *Jour. Paleont.*, vol. 60, p. 347-360.

Katayama, H. and Ikehara, K., 1988: Surface deposits off Sanin to Hokuriku. *In* Arita, M. and Moritani, T., *eds.*, Preliminary report of geological mapping programs of the continental shelf area around southwest Japan. — Off Kyogamisaki and Gentatsuse —. *Geol. Surv. Japan*, p. 69-105 (*in Japanese*).

Kilenyi, T.I., 1969: The problems of ostracod ecology in the Thames Estuary. *In* Neale, J.W., *ed.*, *The taxonomy, morphology and ecology of Recent Ostracoda*, p. 251-265, Oliver and Boyd, Edinburgh.

Kontrovitz, M., 1975: A study of the differential transportation of ostracodes. *Jour. Paleont.*, vol. 49, no. 5, p. 937-941.

—— and Nicolich, M.J., 1979 : On the response of ostracode valves and carapaces to water currents. *In* Krstić, N., *ed.*, *Taxonomy, biostratigraphy and distribution of ostracodes* (7th Proc., Intern. Symp. Ostracodes), p. 269-272, Beograd, Serbian Geol. Soc.

Maiya, S., 1978 : Late Cenozoic planktonic foraminiferal biostratigraphy of oil-field region of Northeast Japan. *In Cenozoic geology of Japan* (Prof. N. Ikebe Mem. Vol.), p. 35-60 (*in Japanese with English abstract*).

—— and Inoue, Y., 1973 : On the effective treatment of rocks for microfossil analysis. *Fossils* (*Palaeont. Soc. Japan*), nos. 25/26, p. 87-96 (*in Japanese*).

Minoura, K., Yamauchi, H., Fujioka, K. and Shiba, M., 1988 : New-designed grain-size analyzer with settling tube system and its application to bottom sediments of Mutsu Bay. *Sci. Rep. Hirosaki Univ.*, vol. 35, p. 50-63.

Neale, J.W., 1974a : The genus *Finmarchinella* Swain 1963 (Crustacea : Ostracoda) and its species. *Bull. Br. Mus. Nat. Hist.* (*Zool.*), vol. 27, no. 2, p. 83-93, pls. 1, 2.

——, 1974b : Ostracod faunas from the Celtic Sea. *Geosci. Man.*, vol. 6, p. 81-98.

—— and Howe, H.V., 1975 : The marine Ostracoda of Russian Harbour, Novaya Zemlya and other high latitude faunas. *In* Swain, F.M., *ed.* Biology and Paleobiology of Ostracoda. *Bull. Am. Paleont.*, vol. 65, no. 282, p. 381-431, 7 pls.

—— and Schmidt, R.A.M., 1967 : On *Normanicythere leioderma* (Norman) and *Normanicythere concinella* Swain. *Micropaleontology*, vol. 13, no. 3, p. 345-350.

Okada, Y., 1979 : Stratigraphy and Ostracoda from the Late Cenozoic strata of the Oga Peninsula, Akita Prefecture. *Trans. Proc. Palaeont. Soc. Japan, N.S.*, no. 115, p. 143-173, 2 pls.

Otuka, Y., 1936 : Pliocene Mollusca from Manganzi in Kotomo-mura, Akita Prefecture, Japan. *Jour. Geol. Soc. Japan*, vol. 43, no. 516, p. 729-736, pls. 41, 42.

Ozawa, A., Kano, H., Maruyama, T., Tsuchiya, N., Ito, M., Hirayama, J. and Shinada, S., 1981 : Geology of the Taiheizan District. Quadrangle Series, Scale 1 : 50,000, *Geol. Surv. Japan*, 69 p., pls. 1-11, 1 map (*in Japanese with English abstract*).

Schornikov, E.I., 1974 : On the study of Ostracoda (Crustacea) from the intertidal zone of the Kuril Islands. *Trans. Acad. Sci. USSR, Far East Sci. Center, Inst. Mar. Biol.*, no. 1, p. 137-214, pls. 1-4 (*in Russian*).

Siddiqui, Q.A. and Grigg, U.M., 1975 : A preliminary survey of the ostracodes of Halifax Inlet. *In* Swain, F.M. (*ed.*) Biology and paleobiology of Ostracoda. *Bull. Am. Paleont.*, vol. 65, no. 282, p. 369-379, 2 pls.

Sundborg, Å., 1967 : Some aspects of fluvial sediments and fluvial morphology. I. General views and graphic methods. *Geogr. Ann.*, vol. 49, p. 333-343.

Swain, F.M., 1963 : Pleistocene Ostracoda from the Gubik Formation, Arctic coastal plain, Alaska. *Jour. Paleont.*, vol. 37, no. 4, p. 798-834, 5 pls.

—— and Gilby, J.M., 1974 : Marine Holocene Ostracoda from the Pacific coast of North and Central America. *Micropaleontology*, vol. 20, no. 3, p. 257-352, pls. 1-7.

Tabuki, R., 1986 : Plio-Pleistocene Ostracoda from the Tsugaru Basin, North Honshu, Japan. *Bull. Coll. Educ., Univ. Ryukyus*, vol. 29, no. 2, p. 27-160, pls. 1-20.

Whatley, R.C., 1983 : The application of Ostracoda to palaeoenvironmental analysis. *In* Maddocks, R.F., *ed.*, *Applications of Ostracoda*. Department of Geosciences, University of Houston, p. 51-77, Houston.

——, Trier, K. and Dingwall, P.M., 1982: Some preliminary observations on certain mechanical and biophysical properties of ostracode carapace. *In* Bate, R.H., Robinson, E. and Sheppard, L.M. eds., *Fossil and Recent Ostracods*. p. 76-104, Ellis Horwood Limited, Chichester.

---

Bonjigawa 梵子川, Funakawa 船川, Hatsutagawa 八田川, Hirasawa 平沢, Iwamigawa 岩見川, Iwamisannai 岩見三内, Iwamisugisawagawa 岩見杉沢川, Jinnaigawa 神内川, Kainosawa 貝ノ沢, Kamikitate 上北手, Kamisannai 上三内, Katsurane 桂根, Kogurogawa 小黒川, Kogurosawagawa 小黒沢川, Kurosawa 黒沢, Kyogamisaki 経ヶ岬, Noda 野田, Obarino 大張野, Omma-Manganji 大桑-万願寺, Onnagawa 女川, Sannaigawa 三内川, Saraminaizawa 皿見内沢, Sasaoka 笹岡, Shimokitate 下北手, Souyakyo 岨谷峡, Sunakobuchi 砂子渕, Taiheigawa 太平川, Takaoka 高岡, Tentokuji 天徳寺, Tsukushimori 筑紫森, Wada 和田.

---

秋田市笹岡層産貝形虫化石群集 — 堆積学的側面との関連性 一: 秋田市東部に分布する笹岡層から71属216種の貝形虫化石を産出した。これらは極めて種多様度の高い群集を構成する。一般に現在日本近海，及び鮮新-更新統から産する，好冷性の種と，北極周辺に現生

する *Acanthocythereis dunelmensis* (Sars), *Hemicythere emerginata* (Sars), *Elofsonella concinna* (Jones), *Palmenella limicola* (Noman) などが卓越する。

　これらの寒流系種に加え，黒潮影響下に生息する暖流系種が，いずれのサンプルにも，数％程度含まれる。以上の貝形虫化石群集をＱモードクラスター分析した結果４つのクラスター (A, B, C, D) が識別された。これをもとに笹岡層の堆積環境を推定した。その際，化石として保存されるまでに受けた物理的影響，それによって生じた群集構造の変化を考慮するため，堆積物の粒度分析を行ない，その結果と群集中の貝形虫殻のサイズ，左殻と右殻の比率，成体殻の割合，種多様度・均衡度の変化を検討し，改めて４つのクラスターを考察した。一般に，物理的要因が貝形虫化石群集の分布に多大な影響を与えており，堆積環境の解析にあたり，貝形虫の生態学的側面のみならず，堆積学的側面をも考慮にいれなければならない好事例を示す。　　　　　　　　　　　　　　　　　入月俊明

———————————————————————

# 892. SYSTEMATICS OF THE AMMONITE GENUS *TETRAGONITES* FROM THE UPPER CRETACEOUS OF HOKKAIDO*

YASUNARI SHIGETA

Geological Institute, University of Tokyo,
Tokyo 113, Japan

**Abstract.** The ammonite genus *Tetragonites* (Lytoceratina, Lytocerataceae) from the Upper Cretaceous (Turonian to Maastrichtian) of Hokkaido includes three species: *T. glabrus* (Jimbo), *T. minimus*, n. sp. and *T. terminus*, n. sp., based on the shell size, apertural shape and early internal shell structure. Although the three species are similar in external shell shape, they are clearly distinguishable from one another on the basis of the above characters without any intermediate form.

*T. glabrus*, occurring in the Middle Turonian to the Upper Campanian, exhibits remarkable variation in shell form, and the previously described species *T. sphaeronotus* (Jimbo), *T. crassus* (Jimbo), *T. popetensis* Yabe and *T. glabrus problematicus* Matsumoto should all be regarded as synonyms of this species. The specimens illustrated as *T. superstes* Van Hoepen and *T. epigonus* Kossmat from Hokkaido are also identified with this species. *T. glabrus* shows a chronocline in which the sizes of initial chamber and ammonitella decrease with time. *T. minimus*, n. sp., occurring from the Lower Turonian to the Upper Campanian, is much smaller in adult shell size (less than 30 mm in diameter) than *T. glabrus*, and shows also a chronocline of miniaturization in adult shell size and of narrower umbilicus toward later forms. *T. terminus*, n. sp., restricted to the Lower Maastrichtian, has an unusually large embryonic shell and a peculiar early internal shell structure.

**Key words.** *Tetragonites*, Upper Cretaceous, Hokkaido, variation, aperture, internal shell structure.

## Introduction

The genus *Tetragonites*, established by Kossmat in 1895, is considered to be one of the derivatives from the lytoceratid main stock (Murphy, 1967b). It was defined by the suture formula $ELU_2U_3(=S)U_1Is$, irregularly bifid or trifid termination for the first lateral saddle (E/L), and nearly symmetrical lobe (L) (Drushchits and Mikhailova, 1976; Krivoshapkina, 1978). *Tetragonites* ranges from the Late Aptian to the Early Maastrichtian, having an almost world-wide distribution (Collignon, 1956). Specimens of this genus occur in the Albian to the Lower

Maastrichtian sequences of the Yezo Group or Yezo Supergroup (Okada, 1979, 1983) in Hokkaido, and are relatively common in the Turonian to the Campanian horizons (*e.g.* Matsumoto, 1942a, 1943; Tanabe *et al.*, 1977).

In spite of the seemingly conservative shell characters, this genus includes many "species" based on the external shell characters (*i.e.* whorl shape and ornamentation). However, taxonomic validity of these characters has not been confirmed by studies of large samples. Furthermore, more critical characters such as early internal shell features have little been investigated in *Tetragonites*.

In this paper, I evaluate the taxonomic validity of various morphological characters

in specimens of *Tetragonites* from horizons in
the Upper Cretaceous of Hokkaido, and
discuss the systematics of *Tetragonites*.

## Previous studies

Japanese species of *Tetragonites* were first
described by Jimbo (1894) from the Upper
Cretaceous Yezo Group of Hokkaido. He
distinguished three species based on umbili-
cal shape and ornamentation: *Lytoceras
glabrum*, *L. sphaeronotum* and *L. crassum*.
One of the two syntypes of *L. sphaeronotum*
was later regarded by Matsumoto (1942b) as a
variety of *Epigoniceras glabrum* (Jimbo).
*Tetragonites epigonus* Kossmat was proposed
by Spath (1925) as the type species for the
genus *Epigoniceras*, but Howarth (1958)
pointed out that this genus is a synonym of
*Tetragonites*. The other syntype of *L.
sphaeronotum* is a deformed specimen of
*Desmophyllites* cf. *diphylloides* (Forbes)
(Matsumoto, 1942b, 1963).

Yabe (1903) pointed out that the holotype
of *L. crassum* could be an immature example
of *T. glabrus* (Jimbo).  Later, this specimen
was regarded by Matsumoto (1942b) as a
variety of *E. glabrum* (Jimbo). Matsumoto
(1942b) also described a varietal form of this
species from Sakhalin as *E. glabrum* var.
*problematica*, but later he regarded it as a
subspecies, *T. glabrus problematicus* (Matsu-
moto, 1959). The fourth species was de-
scribed by Yabe (1903) as *T. popetensis*.
Afterwards, Matsumoto (1942b) reported a
varietal form of this species as *E. popetense*
var. *frequence*, but detailed description and
illustration of the shell were not presented.
Several specimens of *Tetragonites* from the
Yezo Group were hitherto referred to the
following species that were originally de-
scribed from abroad: *T. epigonus* Kossmat
reported by Yabe (1903) and *T. superstes*
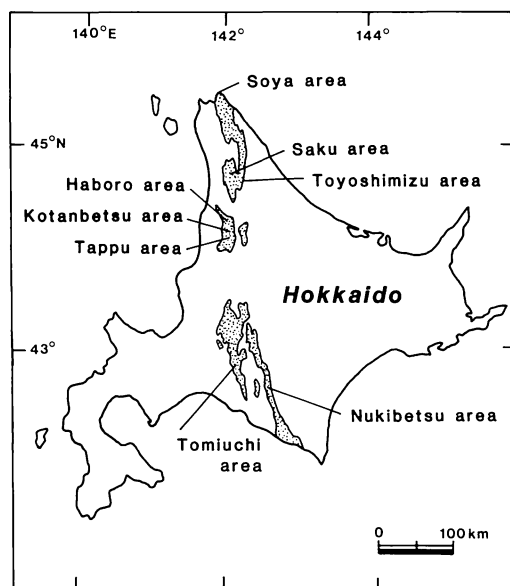Van Hoepen by Matsumoto and Miyauchi
(1984).



**Figure 1.**  Map showing the distribution of
Cretaceous deposits in the central zone of Hokkaido
(dotted) and sampling areas of the specimens
examined.

## Material and methods

**Material**: A total 320 specimens belong-
ing to 48 samples of *Tetragonites* were
examined in this study (Table 1).  These
specimens were collected from the Upper
Cretaceous (Turonian to Maastrichtian)
deposits of Soya, Saku, Toyoshimizu, Ha-
boro, Kotanbetsu, Tappu, Tomiuchi and
Nukibetsu areas from north to south of
Hokkaido (Figure 1).

Specimens in each sample were extracted
from several calcareous nodules at the same
horizon in an outcrop (AW1001A, AW1003,
SM1048 and SF1104) or from a single nodule
(remaining samples).  The localities and
biostratigraphic ages of the samples examined
are summarized in Table 1.  All specimens
are kept at the University Museum, University
of Tokyo (UMUT).

### Analysis of external shell morphology:
A total 229 specimens (Table 1) were used
for the biometric analysis of the shell

**Table 1.** List of material. Specimens used in SEM observation are shown in parentheses. For details of sampling localities with the following prefixes see the following papers; H and T (except for T1220): Matsumoto (1942a), W: Matsumoto and Miyauchi (1984), Nk: Kanie *et al.* (1981), RH, RK and RO: Toshimitsu (1988), R: Tanabe *et al.* (1977), and T1220: Sekine *et al.* (1985).

| Sample | N | Registered number | Locality | Horizon |
|---|---|---|---|---|
| SM1048 | 8 | UMUT MM18635 [1-6,(7,8)] | Tomiuchi,H12d | L. Maast. |
| SM1041 | 3 | UMUT MM18636 [(1-3)] | Tomiuchi,H12a | L. Maast. |
| SF1104 | 6 | UMUT MM18637 [1-3,(4-6)] | Tomiuchi,Tonaizawa.R. | L. Maast. |
| AW1001A | 110 | UMUT MM18638 [1-90,(91-110)] | Soya,W7A | Up. Camp. |
| AW1001B | 3 | UMUT MM18639 [1-3] | Soya,W7A | Up. Camp. |
| AW1003 | 18 | UMUT MM18640 [1-15,(16-18)] | Soya,W7C | L. Camp. |
| AS2038A | 7 | UMUT MM18641 [1-6,(7)] | Saku,T313 | L. Camp. |
| AS2038B | 9 | UMUT MM18642 [1-5,(6-9)] | Saku,T313 | L. Camp. |
| AS3027A | 3 | UMUT MM18643 [1-3] | Saku,T205 | L. Camp. |
| AS3027B | 1 | UMUT MM18644 [1] | Saku,T205 | L. Camp. |
| AS3014P | 1 | UMUT MM18645 [1] | Saku,T208 | L. Camp. |
| AS-TY1 | 3 | UMUT MM18646 [(1-3)] | Toyoshimizu,Teshio R. | L. Camp. |
| SN1001 | 2 | UMUT MM18647 [1,2] | Nukibetsu,Nk11 | L. Camp. |
| SN2001 | 1 | UMUT MM18648 [1] | Nukibetsu,Soushibetsu R. | L. Camp. |
| TP422 | 2 | UMUT MM18649 [1,2] | Tappu,Akanosawa R. | Up. Sant. |
| AH3064 | 7 | UMUT MM18650 [1,(2-7)] | Haboro,RH1262 | L. Sant. |
| AH4032 | 3 | UMUT MM18651 [1,(2,3)] | Haboro,RH4032 | L. Sant. |
| AH1018 | 2 | UMUT MM18652 [1,2] | Haboro,RH5036 | L. Sant. |
| AH6033P | 1 | UMUT MM18653 [1] | Haboro,RH5107 | L. Sant. |
| AK1029A | 1 | UMUT MM18654 [1] | Kotanbetsu,RK0043 | L. Sant. |
| AK1029B | 4 | UMUT MM18655 [1-3,(4)] | Kotanbetsu,RK0043 | L. Sant. |
| AK1033 | 3 | UMUT MM18656 [1-3] | Kotanbetsu,RK0046 | L. Sant. |
| AK1018 | 2 | UMUT MM18657 [1,2] | Kotanbetsu,RK0030 | L. Sant. |
| AT-AR1A | 1 | UMUT MM18658 [1] | Tappu,Arakizawa R. | L. Sant. |
| AT-AR1B | 2 | UMUT MM18659 [1,(2)] | Tappu,Arakizawa R. | L. Sant. |
| AT8025 | 14 | UMUT MM18660 [1-13,(14)] | Tappu,R2663 | L. Sant. |
| AT8026 | 1 | UMUT MM18661 [1] | Tappu,R2665 | L. Sant. |
| AT1514 | 10 | UMUT MM18662 [1-10] | Tappu,Kawakami | L. Sant. |
| AT8023 | 1 | UMUT MM18663 [1] | Tappu,R2662 | L. Sant. |
| AT7067 | 1 | UMUT MM18664 [1] | Tappu,R2185 | L. Sant. |
| AH4087 | 2 | UMUT MM18665 [(1,2)] | Haboro,RH2131 | Con. |
| AT6003 | 2 | UMUT MM18666 [(1,2)] | Tappu,R2144 | Con. |
| AT1551 | 1 | UMUT MM18667 [1] | Tappu,T1220 | Con. |
| AS1000 | 6 | UMUT MM18668 [1-5,(6)] | Saku,T679 | Up. Tur. |
| AT1206 | 3 | UMUT MM18669 [1,(2,3)] | Tappu,R4016 | Mid. Tur. |
| AT1201A | 15 | UMUT MM18670 [1-4,(5-15)] | Tappu,R4018 | Mid. Tur. |
| AT1201B | 3 | UMUT MM18671 [1-3] | Tappu,R4018 | Mid. Tur. |
| AT1207 | 6 | UMUT MM18672 [1,2,(3-6)] | Tappu,R4019 | Mid. Tur. |
| AT1208 | 11 | UMUT MM18673 [1-5,(6-11)] | Tappu,R4020 | Mid. Tur. |
| AT1214 | 2 | UMUT MM18674 [(1,2)] | Tappu,R7001 | Mid. Tur. |
| AT1202 | 5 | UMUT MM18675 [1-5] | Tappu,R4017 | Mid. Tur. |
| AT1103 | 13 | UMUT MM18676 [1-10,(11-13)] | Tappu,R4001 | Mid. Tur. |
| AT1575 | 5 | UMUT MM18677 [(1-5)] | Tappu,R2115 | Mid. Tur. |
| AT1578 | 7 | UMUT MM18678 [1-4,(5-7)] | Tappu,R2110 | Mid. Tur. |
| AT1577 | 1 | UMUT MM18679 [1] | Tappu,R2113 | Mid. Tur. |
| AT1562 | 2 | UMUT MM18680 [1,2] | Tappu,R2129 | Mid. Tur. |
| AW2001P | 2 | UMUT MM18681 [1,2] | Soya,Higashiura | L. Tur. |
| AT2100 | 4 | UMUT MM18682 [1-4] | Tappu,R6394 | L. Tur. |

form. Shell diameter (D), umbilical diameter (U), whorl height (H) and whorl breadth (B) were measured with the aid of a slide caliper (accuracy, $\pm$ 0.05 mm) and two geometric parameters: relative umbilical size (U/D) and relative whorl thickness (B/H), were calculated for each specimen (abbreviations used in the text are shown in parentheses) (Figure 2).
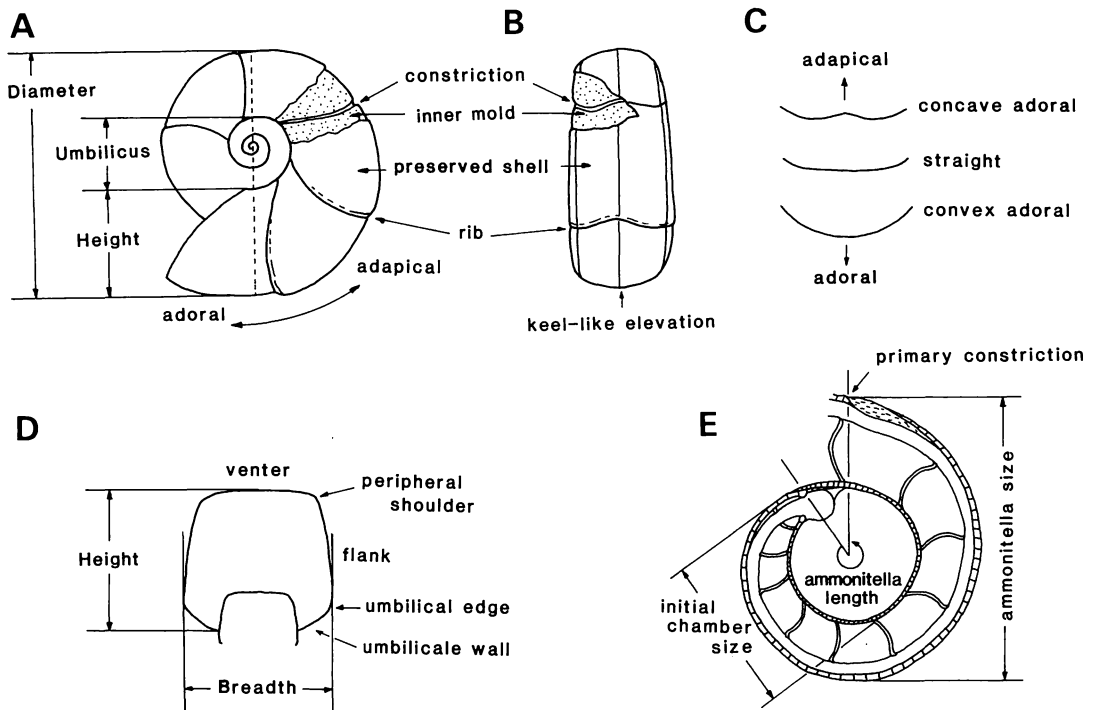
**Figure 2.** Morphology and measurements of *Tetragonites*. A. Lateral view. B. Ventral view. C. Apertural margin on the venter. D. Whorl cross section. E. Early whorls in median section.

Additionally, 7 specimens (UMUT MM 18638-1~4, MM 18642-5, MM 18678-4, MM 18637-3) were selected and prepared in the following manner for ontogenetic study of the shell form. Every specimen was cut and polished along the median plane, and subsequently the "median-sectioned" specimen was also cut along a plane perpendicular to the polished surface at the base of the caecum. The cross-sectioned surface was etched with 10% acetic acid for two to three minutes, and then an acetate peel was prepared by pressing a sheet of triacetylcellulose film (25 $\mu$m in thickness) onto the etched surface while it is flooded with acetone. The four portions (D, U, H, B/2) were measured at intervals of a half volution (90°) on the peeled cross section using a digital micrometer (accuracy $\pm 1$ $\mu$m) attached to a profile projector (Nikon Model V-16D).

**Analysis of early internal shell morphology**: A total 236 specimens (Table 1) were used for observations of early internal shell morphology. For this purpose every specimen was cut and polished along the median plane, and the internal features of early whorls in median section were observed under a binocular microscope with magnification of 20 times. Moreover, 91 specimens among them were prepared in the following manner for scanning electron microscopy. The polished median plane of each specimen was etched with 5% acetic acid for one to two

--- 

→ **Figure 3.** Diagrams of early internal shell structural types of *Tetragonites* in median section. A ; IA type. B and C ; IB type. D and E ; IC type. Terminologies from Branco (1879-80), Grandjean (1910), Drushchits and Khiami (1970). am : ammonitella, amw : ammonitella wall, c : caecum, f : flange, ic : initial chamber, icw : initial chamber wall, na : neck-like attachment, pc : primary constriction, ps : proseptum, psh : prosiphon, sp : siphunclar tube.
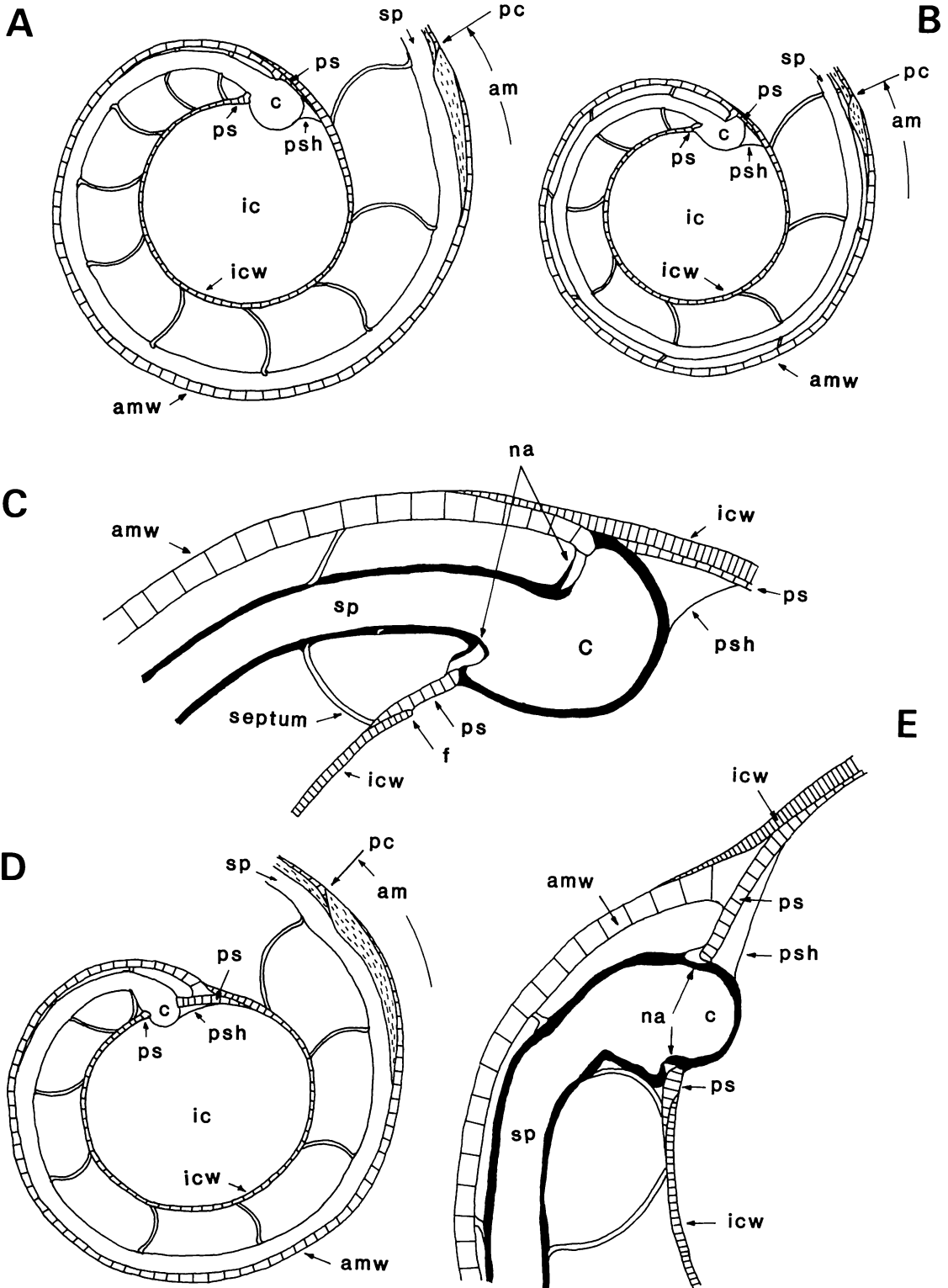
minutes, and the etched surface was then coated with platinum using an ioncoater (Eiko Engineering Model IB-5). The early internal features of each specimen were then observed by means of a scanning electron microscope (SEM) (Hitachi Model S-430). The following three characters were measured on the enlarged SEM photograph ($\times$100-$\times$500): maximum initial chamber size, ammonitella size and ammonitella length (Figure 2).

### Shell morphology of *Tetragonites*

**External shell morphology**: As shown diagrammatically in Figure 2, most of the specimens examined possess a round to subrectangular whorl section and a fairly narrow (U/D=0.20) to wide (U/D=0.37) umbilicus in the middle to late growth stage. The umbilicus is surrounded by a nearly vertical to subvertical wall, and has a subangular to abruptly rounded shoulder. The outer shell surface is nearly smooth throughout the post-ammonitella stage, and is marked only with fine and dense growth lines and rib-like weak elevations. Some specimens have a keel-like elevation on the venter in the middle to late growth stage. In many specimens the apertural margin is strongly prorsiradiate on the flank and possesses an adorally concave sinus on the venter. Some specimens, however, have an adorally convex aperture on the venter. These two apertural types are distinct, with any intermediate form between them.

**Internal shell structure**: The early whorls of *Tetragonites* consist of initial chamber (="protoconch"), proseptum, caecum, prosiphon, flange, septa, siphuncular tube and outer shell wall (Figure 3, for details of these structures, see Ohtsuka, 1986), as in other Mesozoic Ammonoidea. The early internal features of the specimens can be divided into three types; here named **IA, IB** and **IC types** (Figure 3).

**IA type** (Figures 3A and 11A-B) — The initial chamber is nearly circular in median section. Caecum is subellipsoid with a weakly constricted base at the connected portion with proseptum. One to three short, adorally concave prosiphons extend from the adapical portion of caecum to the inner side of initial chamber. Initial chamber wall connects with proseptum at the dorsal side of caecum, forming an indistinct short flange. Siphuncle occupies a central position in the earliest portion of the first whorl near the proseptum, but rapidly shifts toward the ventral side near the second or third septum. Thereafter, it retains a ventral position.

**IB type** (Figures 3B-C and 11C-D) — The initial chamber is nearly circular in median section. Caecum is hemispherical with a strongly constricted base; hence the shape of the earliest portion of the caecum-siphuncle system is like a mushroom. It is linked with the inner surface of the initial chamber wall by one to three short, adorally concave prosiphons. Flange is short as in IA type, and is sometimes obscure in some specimens. Siphuncle is initially located at a central position in the early portion of the first whorl, and subsequently shifts its position gradually toward the venter. The marginal approximation of siphuncle is completed at the end of the first to second whorls.

**IC type** (Figures 3D-E and 11E-F) — The initial chamber is nearly circular in median section. The caecum is elongate and subelliptical, without a conspicuous constricted base. It is connected with the inner surface of initial chamber by a relatively long and nearly straight prosiphon. Proseptum resting on the ventral side of initial chamber wall is long, and acutely projects toward the caecum. Early portion of the first whorl swells markedly as a result of discordant underlay of the ammonitella wall with the initial chamber wall. Siphuncle is initially located at dorsal side. At the middle part of the first camera it makes an abrupt turn inward, and thereafter it immediately approx-

imates to the ventral side within the second-third camerae. The first septum is adorally concave, but subsequent septa are adorally convex.

The above characteristic features of the early internal shell structure are consistent in all the examined specimens of each type, and no intermediate forms have been found.

## Grouping of specimens

The 236 specimens studied in median section can be classified into three groups, **A**, **B**, and **C**, based on the characteristic features in the early internal shell structure and apertural shape (Table 2). The 84 specimens used for observations of external morphology can also be classified into the above three groups by using the differences in adult shell size and apertural shape, because the specimens with the same early internal shell structural type

share the same apertural shape. Diagnostic features of each group other than the early shell structure are summarized below.

**Group A** : Specimens of this group possess the early internal morphology of IA type and adorally concave sinus of aperture on the venter. They exhibit wide but continuous variation in overall shell shape ; a round to subrectangular whorl section and a fairly narrow to wide umbilicus. Specimens of this group were collected from the Middle Turonian to the Upper Campanian of many areas of Hokkaido. Morphologic variation in the specimens from various horizons is summarized as follows.

*Variation in juvenile stage* — Specimens of this group show wide variation in the sizes of initial chamber and ammonitella in median section, ranging from 475 to 875 $\mu$m and from 900 to 1,700 $\mu$m in diameter, respectively

**Table 2.** Classification of 236 specimens of *Tetragonites* based on the early internal shell morphology and apertural shape. CC : adorally concave, CV : adorally convex.

| Sample | No. | | N | Internal morphology | | | Aperture | | Group |
|--------|-----|--|---|-----|-----|-----|-----|-----|-------|
| | | | | IA | IB | IC | CC | CV | |
| AW1001 | MM18638 | (1-110) | 110 | X | | | X | | |
| AW1003 | MM18640 | (9-18) | 10 | X | | | X | | Group A |
| AS2038A | MM18641 | (1-7) | 7 | X | | | X | | |
| AS3027A | MM18643 | (1-3) | 3 | X | | | X | | |
| AS-TY1 | MM18646 | (1-3) | 3 | X | | | X | | |
| AH3064 | MM18650 | (2-7) | 6 | X | | | X | | |
| AH4032 | MM18651 | (2,3) | 2 | X | | | X | | |
| AT8025 | MM18660 | (5-14) | 10 | X | | | X | | |
| AH4087 | MM18665 | (1,2) | 2 | X | | | X | | |
| AT6003 | MM18666 | (1,2) | 2 | X | | | X | | |
| AS1000 | MM18668 | (1-6) | 6 | X | | | X | | |
| AT1206 | MM18669 | (2,3) | 2 | X | | | X | | |
| AT1201A | MM18670 | (5-15) | 11 | X | | | X | | |
| AT1207 | MM18672 | (3-6) | 4 | X | | | X | | |
| AT1208 | MM18673 | (4-11) | 8 | X | | | X | | |
| AT1214 | MM18674 | (1,2) | 2 | X | | | X | | |
| AT1202 | MM18675 | (1-5) | 5 | X | | | X | | |
| AT1103 | MM18676 | (1-13) | 13 | X | | | X | | |
| AT1575 | MM18677 | (1-5) | 5 | X | | | X | | |
| AS2038B | MM18642 | (3-9) | 7 | | X | | | X | |
| AS3027B | MM18644 | (1) | 1 | | X | | | X | |
| AT-AR1B | MM18659 | (1,2) | 2 | | X | | | X | Group B |
| AK1029B | MM18655 | (4) | 1 | | X | | | X | |
| AT1578 | MM18678 | (2-7) | 6 | | X | | | X | |
| SM1048 | MM18635 | (7,8) | 2 | | | X | X | | |
| SM1041 | MM18636 | (1-3) | 3 | | | X | X | | Group C |
| SF1104 | MM18637 | (4-6) | 3 | | | X | X | | |

(Figure 8). The extent of variation of the two measurements is, however, reduced in specimens selected from a stratigraphic interval, and furthermore both sizes tend to decrease upwards in stratigraphic succession (Figure 8).

The spiral length of the ammonitella is, in contrast, less variable than the ammonitella size. The sample mean of the Turonian specimens is larger by 10° than that of the Campanian specimens, but the difference is not significant statistically (Figure 9).

*Variation in the middle to late growth stage* — Wide variation in the shell shape is
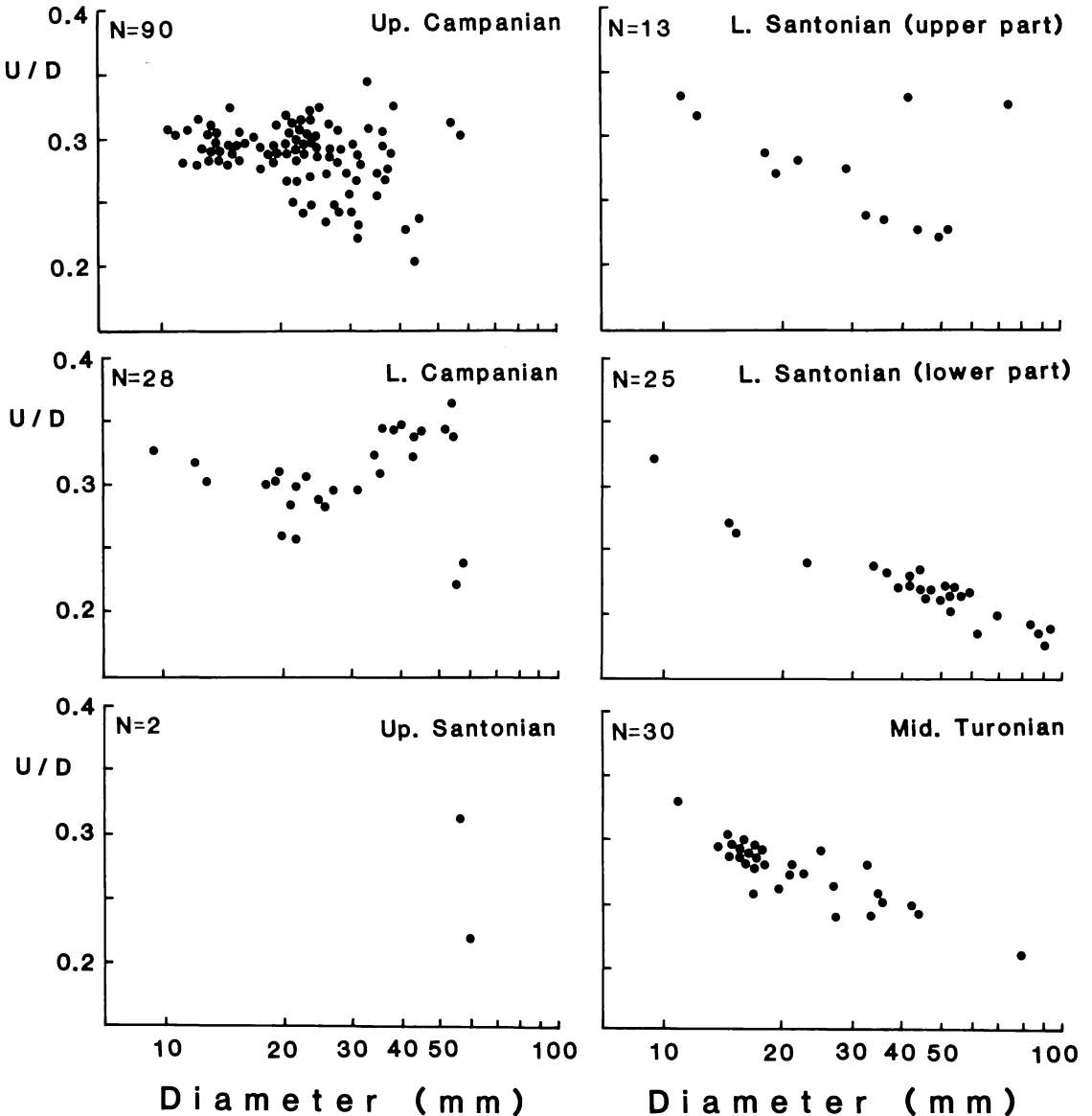


**Figure 4.** Semi-logarithmic diagram showing the relationship between umbilicus/diameter ratio (U/D) and shell diameter (D) for middle- to large-sized specimens of Group A from different horizons. Turonian and most Santonian specimens tend to become narrowly umbilicate with growth. Campanian specimens exhibit wide variation in U/D ratio, even in the middle to late growth stages.
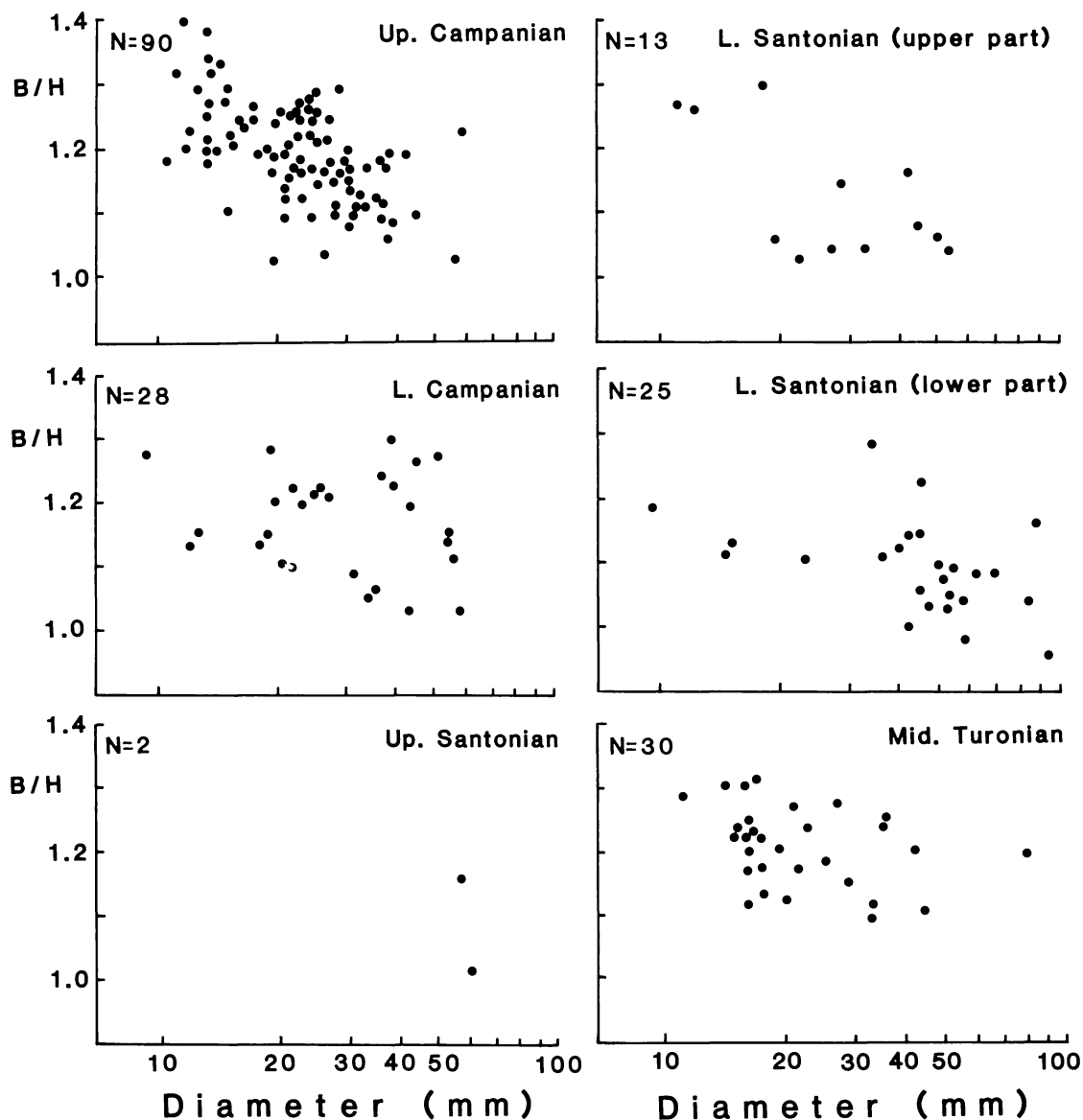
**Figure 5.** Semi-logarithmic diagram showing the relationship between breadth/height ratio (B/H) and the shell diameter for middle- to large-sized specimens of Group A from different horizons. The specimens of each horizon exhibit wide variation in this parameter.

recognized in the middle- to large-sized specimens of this group (Figures 4 and 5). The Turonian specimens are narrowly umbilicate (U/D=0.20-0.28) with more or less round whorl sections (B/H=1.1-1.3) in the growth stages of more than 30 mm in diameter. Almost all specimens lack conspicuous ribs

and a keel-like elevation.

Although the sufficient Coniacian specimens could not be observed, their shell shape and surface ornament essentially resemble those of the Turonian specimens.

Most Santonian specimens have also a narrow umbilicus (U/D=0.18-0.25) and a

round whorl section (B/H = 1.0-1.3) without a keel in the middle to late growth stage (D > 30 mm), but two specimens (UMUT MM 18652-1, MM 18654-1) from the upper Lower Santonian and one (UMUT MM 18649-1) from the Upper Santonian have a relatively wide umbilicus (U/D = 0.30-0.35) even in the stage of more than 40 mm in diameter. In such specimens the whorls are subrectangular in cross section, with a keel-like elevation on the relatively flat venter.

Shell shape variation is conspicuous in the Campanian specimens, especially in the Late Campanian ones (UMUT MM 18638-1~90). Even in the specimens of similar size, the shells are widely to narrowly umbilicate (U/D = 0.20-0.37) with a round to subrectangular whorl section (B/H = 1.0-1.3). A keel-like elevation is fairly common in the Early Campanian specimens, although the state of development varies from specimen to specimen. Such a morphotype is rare in the Late Campanian specimens.

*Ontogenetic shell variation* — At about 2 mm in diameter, every specimen has a wide umbilicus in relation to shell diameter (U/D = 0.4) (Figure 7). Thereafter the shell becomes narrowly umbilicate up to 10 mm in diameter. In the stage larger than 10 mm in diameter the whorl umbilication is fairly variable from specimen to specimen.

In every specimen the whorl cross-section is relatively depressed in the early stage (B/H = 1.2-1.4) (Figure 7). Except for specimen no. 4 in Figure 7 (UMUT MM18638-3), it generally becomes more compressed (B/H = 1.05-1.15) in growth stages of more than 20 mm in diameter.

**Group B :** The specimens belonging to this group are small in size, less than 30 mm in diameter even in the adult stage, being characterized by the early internal morphology of IB type, adorally convex aperture on the venter, round to subrectangular whorl section and fairly narrow to wide umbilicus. They are found less commonly in the Middle

Turonian to the Lower Campanian sequence of the Yezo Group. Although sufficient material could not be analyzed, the morphological features of this group are summarized below.

*Variation in juvenile stage* — Initial chamber size, ammonitella size and its spiral length in median section are from 500 to 600 $\mu$m, from 900 to 1,050 $\mu$m and 320 to 340°, respectively (Figures 8 and 9). The ranges of variation of these characters among the specimens of different stages largely overlap one another.

*Variation in the middle to late growth stage* — Both Turonian and Coniacian specimens have a wide umbilicus (U/D = 0.27-0.36) and a round whorl section (B/H = 1.1-1.3) with a keel-like elevation in the stage of
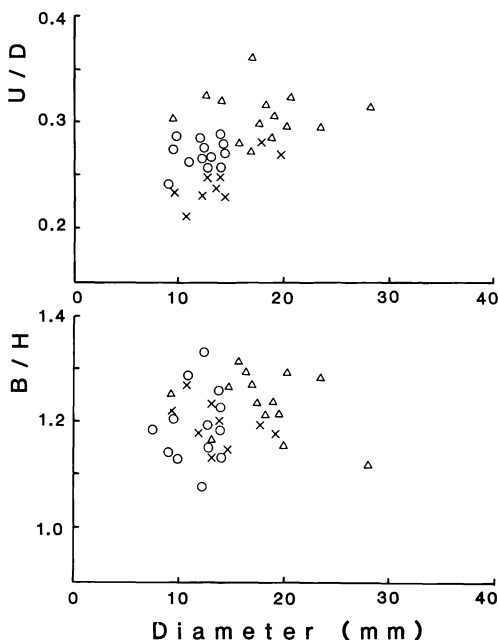


**Figure 6.** Double scatter plots of umbilicus/ diameter ratio (U/D) and breadth/height ratio (B/ H) versus shell diameter (D) for specimens of Groups B and C. Triangle : Turonian and Coniacian specimens of Group B. Circles : Santonian and Campanian specimens of Group B. Cross mark : Specimens of Group C. Both Turonian and Coniacian specimens of Group B have a relatively wider umbilicus than the Santonian and Campanian specimens of Group B.
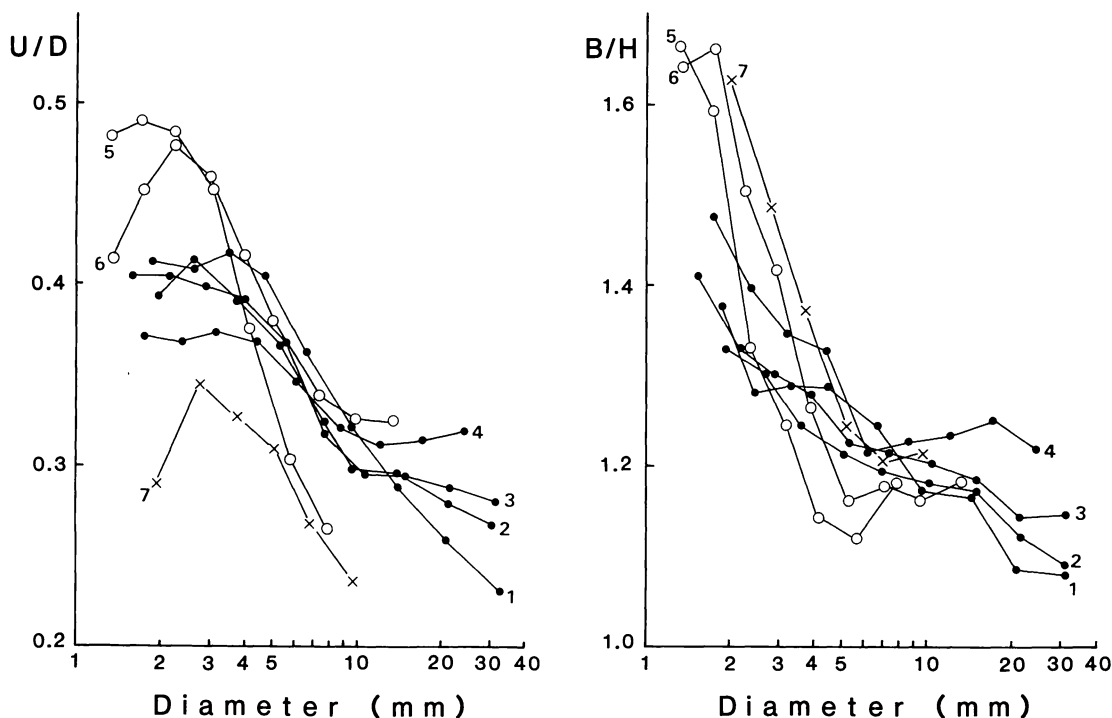
**Figure 7.** Ontogenetic changes of umbilicus/diameter ratio (U/D) and breadth/height ratio (B/H) versus shell diameter (D) for specimens of Groups A, B and C. Black circle : Specimens of Group A (1 : UMUT MM18638-1, 2 : UMUT MM18638-2, 3 : UMUT MM18638-4, 4 : UMUT MM18638-3, sample AW1001A, the Upper Campanian). White circle : Specimens of Group B (5 : UMUT MM18642-5, sample AS2038B, the Lower Campanian ; 6 : UMUT MM18678-4, sample AT1578, the Middle Turonian). Cross mark : Specimen of Group C (7 : UMUT MM18637-3, sample SF1104, the Lower Maastrichtian).

more than 10 mm in diameter (Figure 6). Diagnostic features of an adult stage, such as approximation of the last two septa, and thickening of the last septum, are observable at 20 mm in phragmocone diameter of some specimens.

The Santonian and Campanian specimens are narrowly umbilicate (U/D = 0.24–0.29) with more or less round whorl section (B/H = 1.0–1.3) at the middle to late growth stage (D > 10 mm) (Figure 6). The phragmocone diameter in adult stage is usually 10 mm, which is smaller than those of Turonian and Coniacian specimens. Also the state of development in a keel-like elevation is less conspicuous in comparison with that of the Turonian and Coniacian specimens.

*Ontogenetic shell variation* — In the early stage of about 2 mm in diameter, the two

specimens are widely umbilicate, but thereafter they become narrowly umbilicate (Figure 7). Decreasing of U/D ratio versus diameter (D) for specimen no. 6 (UMUT MM18678-4) in Figure 7 is smaller than that for specimen no. 5 (UMUT MM18642-5). In both specimens, B/H ratio decreases from 1.7 to 1.1 as the shells grow, and the whorl becomes higher than broad in the adult stage.

**Group C** : The specimens of this group possess early internal morphology of IC type, adorally concave ventral sinus at aperture, round to subrectangular whorl section, flat venter, rounded umbilical shoulder and fairly narrow umbilicus. The shell surface is generally smooth but some specimens have numerous rib-like elevations. A keel-like elevation on the venter is obsent. All speci-

mens possess an unusually large initial chamber (925–1,050 $\mu$m in median diameter) and ammonitella (1,700–1,900 $\mu$m in diameter) (Figure 8). Ammonitella length ranges from 330 to 345° (Figure 9). The specimens of this group are restricted to the Lower Maastrichtian.

The shell at 3 mm in diameter is widely umbilicate (U/D=0.35) but it becomes narrowly umbilicate (U/D=0.24) with growth (Figure 7). The relative whorl thickness (B/H) is initially large (=1.6), but gradually decreases with growth up to 5 mm in diameter (Figure 7). The parameter remains constant

in the stage of more than 5 mm in diameter (Figure 6).

### Taxonomic relationship

**Group A** : All specimens of this genus hitherto described from Hokkaido and Sakhalin are characterized by the possession of an adorally concave aperture on the venter, a round to subrectangular whorl section and fairly narrow to wide umbilicus (Table 3). Such features agree with the characteristics of Group A. As already stated, the specimens of this group exhibit remarkably wide varia-
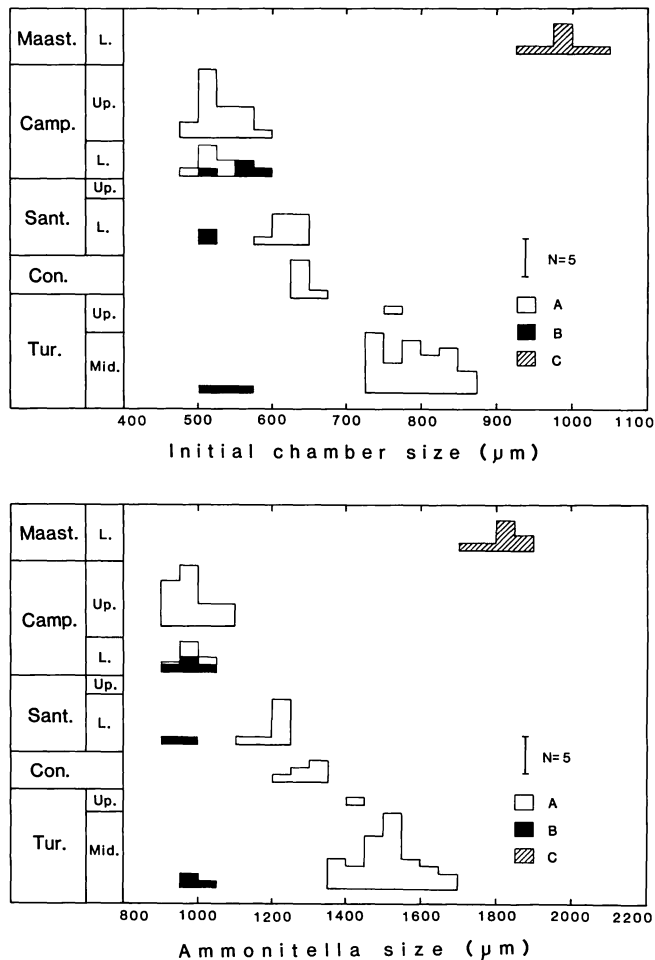


**Figure 8.** Variation in initial chamber size and ammonitella size for specimens of Groups A, B and C from different horizons. In Group A both sizes tend to decrease toward the upward sequence.
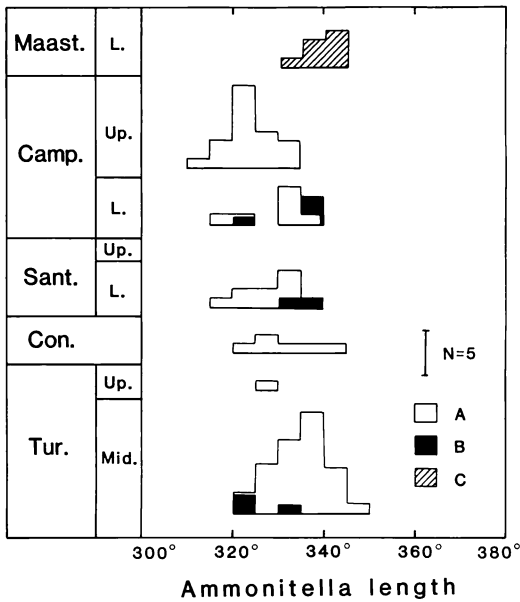
**Figure 9.** Variation in ammonitella length for specimens of Groups A, B and C from different horizons. There is no significant difference in the ammonitella length among the three groups.

tion in the external shell shape. They cannot be divided into subgroups by the shell form ratios because of the wide and continuous range of the variation. Sample AW1001A from the Upper Campanian of Soya area is a typical example showing wide shell shape variation. Furthermore, the shell form ratios (U/D, B/H) of the type and previously illustrated specimens are mostly included in the range of variation of the specimens in the sample (Figure 10). This evidence strongly suggests that these specimens merely represent the variants in a single species. Although the internal structure of these specimens cannot be examined, all the previously described species, *T. glabrus* (Jimbo), *T. sphaeronotus* (Jimbo), *T. crassus* (Jimbo), *T. popetensis* Yabe and *T. glabrus problematicus* Matsumoto, show an adorally concave aperture on the venter. These species should be, therefore, treated as synonymous, and are all included in Group A. The oldest species name, *T. glabrus*, is used here for these specimens in Group A. Judging from the aperturral features and shell sizes of the figured specimens, *T.* cf. *epigonus* (Kossmat) and *T. superstes* Van Hoepen illustrated respectively by Yabe (1903) and Matsumoto and Miyauchi (1984) can also be identified as *T. glabrus*.

**Group B** : This group is represented by small-sized specimens with an adorally con-

**Table 3.** Measurements (in mm) of previously described or illustrated specimens of *Tetragonites* from the Upper Cretaceous of Hokkaido.

| Authors | No. | Species | D | U | B | H | U/D | B/H | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| Jimbo(1894) | (1) | Lytoceras glabrum | 51.1 | 11.3 | 21.5 | 24.2 | 0.22 | 1.09 | MM7513 |
| | (2) | L. shaeronotum | 40.8 | 8.9 | 21.6 | 19.8 | 0.22 | 1.17 | MM7494 |
| | (3) | L. crassum | 24.9 | 6.8 | 13.2 | 11.6 | 0.27 | 1.14 | MM7515 |
| Yabe(1903) | (4) | Tetragonites glabrus | 35.0 | 8.0 | 19.0 | 17.0 | 0.24 | 1.17 | MM7461 |
| | (5) | T. glabrus | 65.0 | 14.0 | 36.0 | 32.0 | 0.22 | 1.12 | |
| | (6) | T. shaeronotus | 145.0 | 30.0 | 72.0 | 70.0 | 0.21 | 1.02 | |
| | (7) | T. shaeronotus | 68.9 | 13.5 | 36.7 | 34.3 | 0.18 | 1.07 | MM7540 |
| | (8) | T. popetensis | 34.0 | 10.5 | 15.0 | 14.5 | 0.31 | 1.03 | MM7460 |
| | (9) | T. popetensis | 20.5 | 5.5 | 9.0 | 9.0 | 0.27 | 1.00 | MM7541 |
| | (10) | T. cf. epigonus | 34.4 | 9.4 | 16.1 | 14.7 | 0.27 | 1.09 | MM7459 |
| Matsumoto (1942b) | (11) | Epigoniceras glabrum var. problematica | 87.0 | 21.0 | 37.3 | 40.7 | 0.24 | 0.92 | MM5529 |
| Matsumoto & | (12) | T. superstes | 41.3 | 11.2 | 18.6 | 12.7 | 0.28 | 1.05 | MNH.502 |
| Miyauchi(1984) | (13) | T. popetensis | 66.6 | 21.2 | 27.0 | 26.4 | 0.32 | 1.02 | MNH.501 |
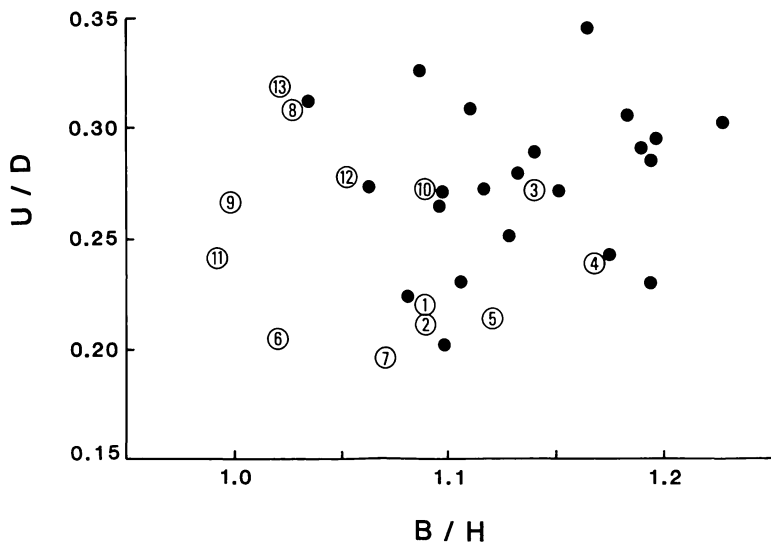
**Figure 10.** Scatter plot of umbilicus/diameter ratio (U/D) versus breadth/height ratio (B/H) for 22 specimens of Group A (black circle; more than 30 mm in diameter) in the Upper Campanian sample AW1001A from Soya area and 13 previously described or illustrated specimens of *Tetragonites* from Hokkaido (white circle). Number in each white circle corresponds to that in Table 3. The shell form ratios of type and illustrated specimens largely overlap with those of the specimens in the sample AW1001A.

vex aperture on the venter. Such a morphotype has not yet been described from the Upper Cretaceous of the North Pacific region including Hokkaido. Although the adult shell form and size more or less differ between the specimens from the Turonian — Coniacian and those from the Santonian — Campanian, because of the similarity in other shell characters, it is considered that the difference should be attributed to the phyletic transition within a lineage. A new species name, *T. minimus*, n. sp., is therefore given to this group.

**Group C :** Matsumoto (1942b, 1943) listed *Epigoniceras poptense* var. *frequence* from the Lower Maastrichtian of Tomiuchi area. Judging from Matsumoto's (1942b, p. 673) description, this variety appears to resemble some specimens of Group C in having numerous rib-like elevations on the whorls and a fairly narrow umbilicus. However, he did not describe the diagnostic characters of the variety, nor illustrated any material. Therefore, Group C is treated as a new species, *T.*

*terminus*, n. sp.

**Phylogeny**

Although the phylogenetic relationships of the post-Cenomanian *Tetragonites* species have not been studied, those of Aptian to Cenomanian species have been discussed by Murphy (1967a) and Wiedmann (1973). Murphy (1967a) classified seventeen species into three morphological groups, based on their apertural shape, suture line and shell form. The *T. timotheanus* group was characterized by species with an adorally convex aperture on the venter, and has as its ancestor the Upper Aptian species, *T. subbeticus*. This group includes *T. timotheanus* from the Upper Albian, and *T. spathi* from the Lower Cenomanian.

*T. minimus*, n. sp. also possesses an adorally convex aperture on the venter, and therefore, according to Murphy's classification, it belongs to the *T. timotheanus* group. Furthermore, the Turonian specimens of this species resemble *T. spathi*, in having a wide

umbilicus and a keel-like elevation on the venter. Therefore, *T. minimus* is considered to have originated from a species of this group, and its probable ancestor is *T. spathi*.

Other morphological groups proposed by Murphy (1967a) are the *T. rectangularis* group and the *T. kichini* group, both of which are represented by species with an adorally concave sinnous aperture on the venter. The former group was possibly the dominant stock of *Tetragonites*, and includes most species of mid-Cretaceous representatives. According to Murphy's (1967a) definition, *T. glabrus* can be assigned to this group. Many Albian and Cenomanian species of this group have been described by previous authors (*e.g.* Wiedmann, 1962; Kennedy and Klinger, 1977), but details of the intra- and interpopulational variation of shell form and phylogenetic relationships have not yet been realized. *T. glabrus* seems to have originated from a species of this group. However, it is at present difficult to identify its ancestor.

Santonian and Campanian *Tetragonites* having an adorally concave sinuous aperture on the venter consist of the following species: *T. margaritatus* Marshall, *T. simplex* (Marshall), *T. marshalli* (Collignon), *T. superstes* Van Hoepen, *T. mitraikyensis* Collignon, *T. beantalyensis* Collignon, *T. garudus* Forbes, *T. epigonus* Kossmat and *T. glabrus* (Jimbo) (Collignon, 1956; Kennedy and Klinger, 1977). *T. terminus*, n. sp., with the same apertural type, may have been derived from a species of this group. The exact ancestor of this species is, however, unknown because of the insufficiency of data on intra- and interpopulational variation and exact stratigraphical distribution for the above foreign species.

On the other hand, the three species of *Tetragonites* examined are well defined by their unique early internal shell features. The significance of early internal shell structure in the major classification of the Mesozoic Ammonoidea have been demonstrated

by several paleontologists (Druschchits and Khiami, 1970; Druschchits and Doguzhayeva, 1974; Zakharov, 1974; Druschchits *et al.*, 1977; Tanabe *et al.*, 1979; Tanabe and Ohtsuka, 1985; Ohtsuka, 1986). According to Ohtsuka (1986), the Gaudryceratidae are characterized by the following early internal morphology in median section: nearly circular initial chamber, semi-circular caecum with a weakly constricted base, one to three short prosiphons and ventrally located siphuncle in most of the post-ammonitella growth stages. Such features are commonly observed in *T. glabrus*. The Tetragonitidae are now regarded as having been derived in the Aptian from the Gaudryceratidae (Wiedmann, 1962; Murphy, 1967b). If this interpretation is correct, it is apparent that *T. glabrus* preserves more ancestral characters in the early stage than *T. minimus* and *T. terminus*. The present study also suggests that *T. terminus*, n. sp. and *T. minimus*, n. sp. might have been derived from the stock with the early internal morphology of IA type including *T. glabrus*. Because of the similarity of apertural shapes, such a stock may correspond to the *T. rectangularis* group of Murphy (1967a).

According to Wiedmann (1973), *Tetragonites* rapidly diversified throughout the Tethyan realm during the Albian and Cenomanian, and thereafter had a distinct decline from Turonian to Maastrichtian. However, in Hokkaido in the northwestern Pacific region generally, the diversity of the Albian and Cenomanian members remained nearly constant until the end of Campanian or Maastrichtian.

## Concluding remarks

This study reveals that the intrapopulational variation of shell form in *Tetragonites glabrus* is relatively wide, especially in the middle to later growth stage, and that many of the previously described species under the name of *Tetragonites* are synonymous with

*T. glabrus.* Moreover, the seemingly small variability of shell form in the previously described "species" was a result of extreme taxonomic splitting. More than twenty species of *Tetragonites* have hitherto been described from the Aptian to Cenomanian of the world. Their taxonomic and phylogenetic relationships should be re-examined by adequate evaluation of taxonomic characters from the viewpoint of population concept.

The smooth and featureless external morphology in *Tetragonites* causes difficult problems for phylogenetic reconstruction. However, three morphological types of early internal shell structure are clearly distinguished in *Tetragonites*. It is believed that such early characters are stable within a given species irrespective of time and may be strongly controlled by phylogenetic (genetic) factors. They may serve as a key for phylogenetic reconstruction not only in *Tetragonites* but also in other ammonoids.

### Systematic description

Order Ammonoidea Zittel, 1884
Suborder Lytoceratina Hyatt, 1889
Superfamily Tetragonitaceae Hyatt, 1900
Family Tetragonitidae Hyatt, 1900
Genus *Tetragonites* Kossmat, 1895

*Type species.* — *Ammonites timotheanus* Pictet, 1848

#### *Tetragonites glabrus* (Jimbo)

Figures 11A—B, 12

*Lytoceras glabrum* Jimbo, 1894, p. 180, pl. 22, figs. 2, 2a.
*Lytoceras sphaeronotum* Jimbo, 1894, p. 181, pl. 22, fig. 4.
*Lytoceras crassum* Jimbo, 1894, p. 181, pl. 22, figs. 5, 5a, 5b.
*Tetragonites glabrus* : Yabe, 1903, p. 43, pl. 7, figs. 2, 5 ; Tanabe and Kanie, 1978, p. 8, pl. 1, figs. 2a, 2b.
*Tetragonites sphaeronotus* : Yabe, 1903, p. 45, pl. 7, figs. 1a, 1b.
*Tetragonites popetensis* Yabe, 1903, p. 48, pl. 7, figs. 4, 6 ; Matsumoto and Miyauchi, 1984, p. 52, pl. 23, figs. 3a, 3b.
*Tetragonites* cf. *epigonus* : Yabe, 1903, p. 49, pl. 7, fig. 3.
*Epigoniceras glabrum* var. *problematica* Matsumoto, 1942, p. 672, fig. 1.
*Tetragonites superstes* : Matsumoto and Miyauchi, 1984, p. 52, pl. 23, fig. 2.

*Type.* — The holotype (UMUT MM7513 ; Jimbo, 1894, pl. 22, figs. 2, 2a) is a large-sized specimen with a deformed body chamber from the Upper Cretaceous of Ikandai, Urakawa area.

*Material.* — In addition to the holotype, 267 specimens [UMUT MM18638 (N = 110), UMUT MM18640 (N = 18), UMUT MM18641 (N = 7), UMUT MM18643 (N = 3), UMUT MM18645 (N = 1), UMUT MM18646 (N = 3), UMUT MM18647 (N = 2), UMUT MM18648 (N = 1), UMUT MM18649 (N = 2), UMUT MM18650 (N = 7), UMUT MM18651 (N = 3), UMUT MM18652 (N = 2), UMUT MM18653 (N = 1), UMUT MM18654 (N = 1), UMUT MM18656 (N = 3), UMUT MM18557 (N = 2), UMUT MM18658 (N = 1), UMUT MM18660 (N = 14), UMUT MM18661 (N = 1), UMUT MM18662 (N = 10), UMUT MM1863 (N = 1), UMUT MM18664 (N = 1), UMUT MM18665 (N = 2), UMUT MM18666 (N = 2), UMUT MM18668 (N = 6), UMUT MM18669 (N = 3), UMUT MM18670 (N = 15), UMUT MM18672 (N = 6), UMUT MM18673 (N = 11), UMUT MM18674 (N =

---

→ **Figure 11.** Scanning electron micrographs of the early internal shell structure of three *Tetragonites* species in median section. Scale bars in A, C and E : 200 $\mu$m. Scale bars in B, D and F : 50 $\mu$m. **A-B.** *Tetragonites glabrus* (Jimbo), the Coniacian, Haboro area, Sample AH4087, UMUT MM 18665-1. **C-D.** *Tetragonites minimus*, n. sp., the Lower Campanian, Saku area, Sample AS2038B, UMUT MM18642-6, paratype. **E-F.** *Tetragonites terminus*, n. sp., the Lower Maastrichtian, Tomiuchi area, Sample SM1041, UMUT MM18636-2, paratype.
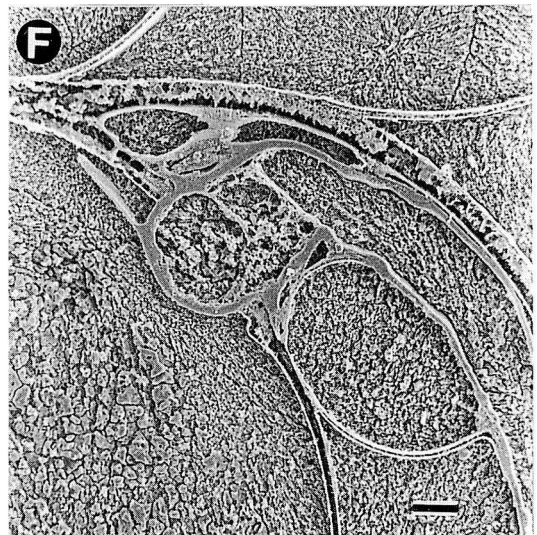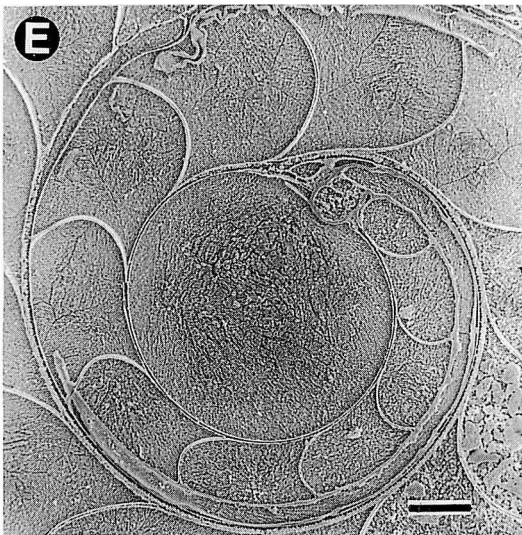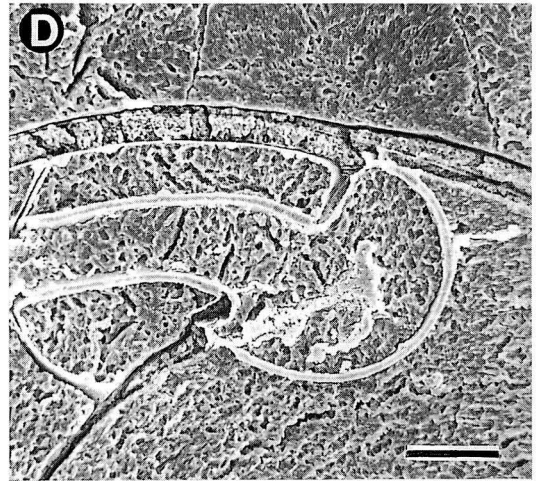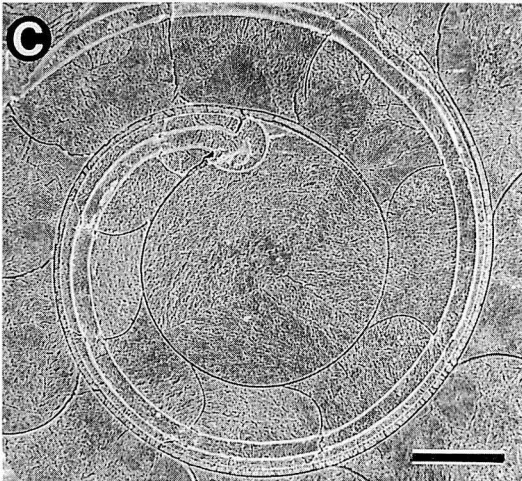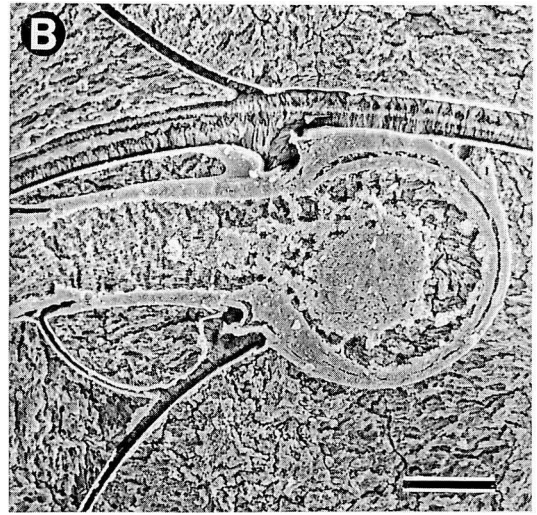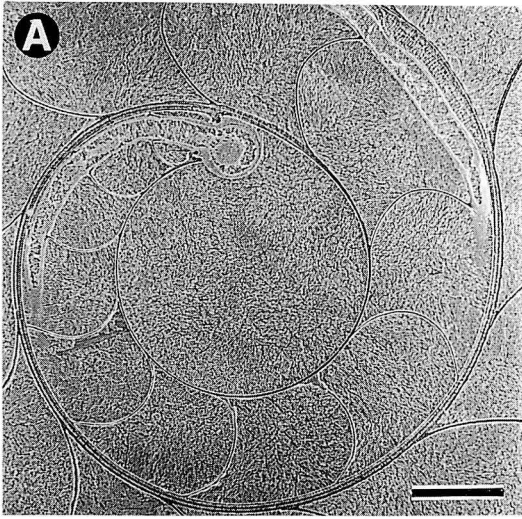
2), UMUT MM18675 (N=5), UMUT MM18676 (N=13), UMUT MM18677 (N= 5), UMUT MM18679 (N=1), UMUT MM18680 (N=2)] are referable to the present species. The localities and ages of them are summarized in Table 1.

*Diagnosis.* — Large-sized species of *Tetragonites* characterized by adorally concave sinuous aperture on venter, nearly circular initial chamber in median section, subellipsoid caecum with weakly constricted base, and ventrally located siphuncle except for earliest first to fourth chamber stage.

*Description.* — Shell large, sometimes, exceeding 80 mm in diameter, rather evolute to moderately involute, with a fairly narrow to wide umbilicus even in the stage of more than 30 mm in diameter. Whorl round to subrectangular in cross section, with a rounded to flat venter, nearly flat to gently convex flanks, subangular to rounded umbilical shoulder and nearly vertical to subvertical umbilical wall. Shell surface nearly smooth, with fine and dense growth lines, and infrequent conspicuious rib-like elevations. They are prorsiradiate on the flanks, curved adapically at the peripheral shoulder and cross the venter with a shallow backward sinus. A keel-like elevation sometimes occurs in middle to late stage of the Santonian and Campanian specimens. Initial chamber nearly circular in median section. Caecum subelliptical in lateral view with a weakly constricted base, and its adapical end connects with the initial chamber wall by one to three short, adorally concave prosiphons. Flange weakly developed. Siphuncle occupies a central position near the proseptum, and then immediately shifts toward the venter in second to forth chamber stage. Thereafter it keeps a ventral position. Initial chamber and ammonitella medium- to large-sized (ranging 475-875 $\mu$m and 900-1,700 $\mu$m in median diameter, respectively), both showing a clear chronocline in size decrease in the Upper Cretaceous seqeunce of Hokkaido. Variation of ammonitella length

is rather small (310 to 350° in volution), never marking a conspicuous historical trend.

*Dimensions.* —

| | D (mm) | U (mm) | B (mm) | H (mm) | U/D | B/H |
|---|---|---|---|---|---|---|
| Holotype | 51.1 | 11.3 | 26.5 | 24.2 | 0.22 | 1.10 |

For the measurements of other specimens, see Figures 4, 5, 7, 8 and 9.

*Remarks.* — In overall shell morphology *T. glabrus* (Jimbo) closely resembles some foreign species such as *T. epigonus* Kossmat (1895, p. 135, pl. 17, figs. 4, 5, 10), *T. superstes* Van Hoepen (1921, p. 10, pl. 2, figs. 17-20), *T. garudus* (Forbes) (1846, p. 102, pl. 7, fig. 1), *T. mitraikyensis* Collignon (1956, p. 86, pl. 11, fig. 2), *T. beantalyensis* Collignon (1956, p. 83, pl. 10, fig. 1), *T. marshalli* (Collignon) (1956, p. 86), *T. margaritatus* Marshall (1926, p. 151, pl. 20, fig. 5, pl. 30, figs. 5, 6) and *T. simplex* (Marshall) (1926, p. 150, pl. 20, figs. 11, 11a, pl. 32, figs. 3, 4). The narrowest and the widest umbilicate forms of *T. glabrus* also suggest affinities with *Pseudophyllites indra* Forbes (1846, p. 105, pl. 11, fig. 7) and *Saghalinites nuperus* (Van Hoepen) (1921, p. 13, pl. 3, figs. 3, 4).

The taxonomic relationship between *T. glabrus* and the above foreign species is, however, at present uncertain because of insufficient data on the intra- and interpopulational variation and exact stratigraphical distribution of the later.

*Occurrence.* — This species occurs abundantly from the Middle Turonian to the Upper Campanian of the Yezo Group in Hokkaido and south Sakhalin. This species is also known from the Turonian-Campanian of California (Matsumoto, 1959).

*Tetragonites minimus*, n. sp.

Figures 11C—D, 13-1—7b

*Type.* — A small-sized specimen (UMUT MM18667-1) from the Coniacian outcrop exposed along the middle course of the Obirashibe River (Loc. T1220 of Sekine *et al.,*
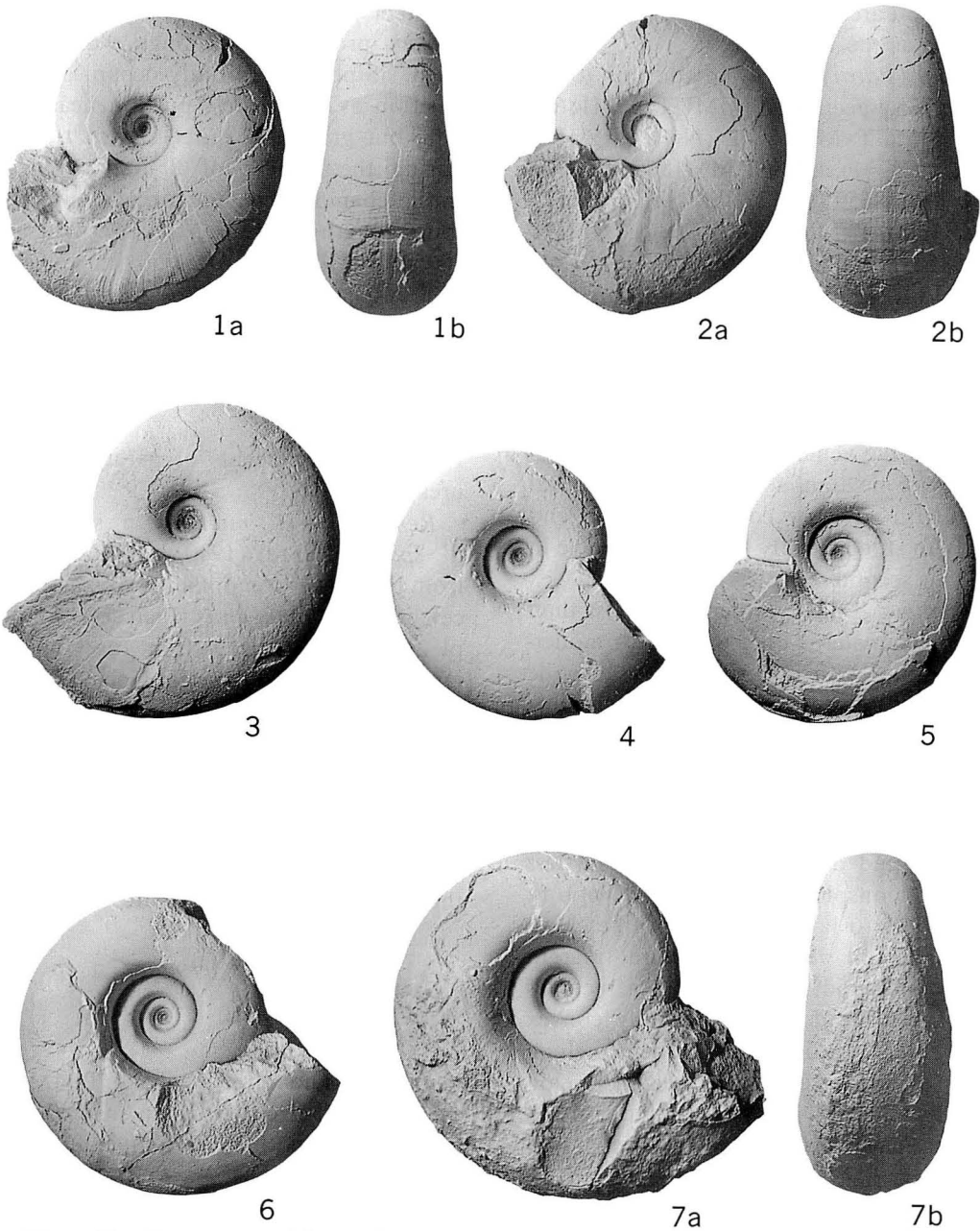
1a    1b    2a    2b

3    4    5

6    7a    7b

**Figure 12.** *Tetragonites glabrus* (Jimbo). For localities see Table 1. **1a-b.** UMUT MM18662-5, Sample AT1514, the lower Lower Santonian, Tappu area, ×0.8. **2a-b.** UMUT MM18653-1, Sample AH6033P, the upper Lower Santonian, Haboro area, ×0.8. **3.** UMUT MM18638-16, Sample AW1001A, the Upper Campanian, Soya area, ×1.0. **4.** UMUT MM18638-15, Sample AW1001A, the Upper Campanian, Soya area, ×1.0. **5.** UMUT MM18638-13, Sample AW1001A, the Upper Campanian, Soya area, ×1.0. **6.** UMUT MM18640-3, Sample AW1003, the Lower Campanian, Soya area, ×0.8. **7a-b.** UMUT MM18654-1, Sample AK1029A, the upper Lower Santonian, Kotanbetsu area, ×0.7.

1985), Tappu area, northwestern Hokkaido is designated as the holotype.

*Material* (*Paratypes*). — In addition to the holotype, 35 specimens [UMUT MM18639 (N=3), UMUT MM18642 (N=9), UMUT MM18644 (N=1), UMUT MM18655 (N=4), UMUT MM18659 (N=2), UMUT MM18671 (N=3), UMUT MM18678 (N=7), UMUT MM18681 (N=2), UMUT MM18682 (N=4)] from various localities of Hokkaido are used in the following description. Their localities and ages are summarized in Table 1.

*Diagnosis*. — Small-sized species of *Tetragonites* characterized by adorally convex aperture on the venter, nearly circular initial chamber in median section, hemispherical caecum with strongly constricted base, and centrally to sub-centrally located siphuncle in the first to second whorls.

*Description*. — Shell rather small, less than 30 mm in diameter, rather evolute to moderately involute, with a fairly narrow to wide umbilicus. Whorl rounded to subquadrate in cross section with a round venter, nearly flat to gently convex flanks, round umbilical shoulders and a nearly vertical umblilical wall. Shell surface sculptured with regularly spaced fine and dense growth lines and less frequent, inconspicuous rib-like elevations. In the middle to late stage, a keel-like elevation appears on venter. Apertural margin markedly prorsiradiate on the flanks, recurves at peripheral shoulder and adorally convex on the venter. Initial chamber nearly circular in median section. Caecum hemispherically shaped with a strongly constricted base. Its adapical end connects with initial chamber wall by one to three short, adorally convex prosiphons. Flange weakly developed. Siphuncle initially occupies a central position at the earliest portion near proseptum, but gradually shifts toward the venter during the growth of first-second whorls. Initial chamber size, ammonitella size and its spiral length in median section range from 500 to 600 $\mu$m, 900 to 1,050 $\mu$m and 320 to 340°, respectively.

*Dimensions*. —

|  | D (mm) | U (mm) | B (mm) | H (mm) | U/D | B/H |
|---|---|---|---|---|---|---|
| Holotype | 28.1 | 8.9 | 12.3 | 11.0 | 0.32 | 1.12 |

For the measurements of paratypes see Figures 6–9.

*Remarks*. — *T. minimus*, n. sp. resembles *T. spathi* (Fabre) (1940, p. 214, pl. 6, fig. 1) from the Lower Cenomanian of Cassis (France), and *T. timotheanus* (Pictet) (1848, p. 295, pl. 2, fig. 6, pl. 1, fig. 9) from the Upper Albian of the French Alps near Geneva in having an adorally projected or nearly straight aperture on the venter, but it is distinguished from these taxa in having an arch-shaped apertural margin on the venter.

*Occurrence*. — This species ranges from the Lower Turonian to the Upper Campanian of the Yezo Group in Hokkaido.

*Tetragonites terminus*, n. sp.

Figures 11E—F, 13-8—10

*Type*. — The holotype (UMUT MM18635-1) is a small-sized specimen from the lower Maastrichtian of the Ichiyanagi-no-sawa

---

→ **Figure 13.** 1—7: *Tetragonites minimus*, n. sp., ×1.5. For localities see Table 1. **1.** UMUT MM18642-1, Sample AS2038B, the Lower Campanian, Saku area, paratype. **2a-b.** UMUT MM18655-1, Sample AK1029B, the upper Lower Santonian, Kotanbetsu area, paratype. **3a-b.** UMUT MM18678-1, Sample AT1578, the Middle Turonian, Tappu area, paratype. **4a-b.** UMUT MM18667-1, Sample AT1551, the Coniacian, Tappu area, holotype. **5a-b.** UMUT MM18671-1, Sample AT1201B, the Middle Turonian, Tappu area, paratype. **6a-b.** UMUT MM18682-1, Sample AT2100, the Lower Turonian, Tappu area, paratype. **7a-b.** UMUT MM18681-1, Sample AW2001P, the Lower Turonian, Soya area, paratype. **8** **—10**: *Tetragonites terminus*, n. sp., ×1.5. **8a-b.** UMUT MM18635-1, Sample SM1048, the Lower Maastrichtian, Tomiuchi area, holotype. **9.** Sectional view, UMUT MM18635-2, Sample SM1048, the Lower Maastrictian, Tomiuchi area, paratype. **10a-b.** UMUT MM18635-4, Sample SM1048, the Lower Maastrichtian, Tomiuchi area, paratype.

(Loc. H12d in Matsumoto 1942a), Tomiuchi area, southern central Hokkaido.

*Material (Paratypes).* — In addition to the holotype, 7 specimens [UMUT MM18635-2 ~8] from the type locality and 9 specimens [UMUT MM18636 (N = 3), UMUT MM18637 (N = 6)] from other localities are used in the following description. Their
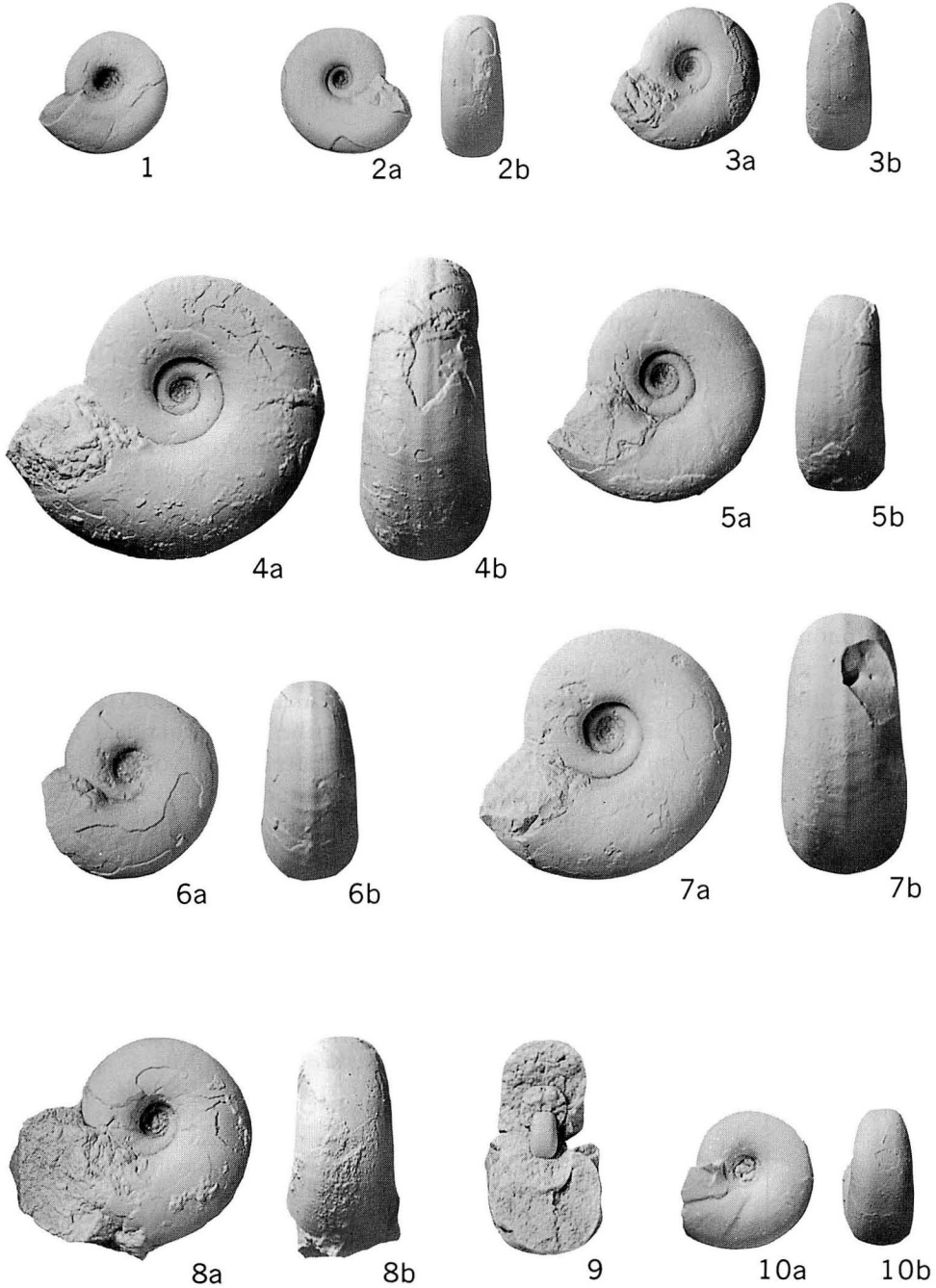
localities and ages are summarized in Table 1.

*Diagnosis.* — Small-sized species of *Tetragonites* characterized by adorally concave sinuous aperture on venter, unusually large-sized initial chamber, elongate subellipsoid caecum without any conspicuous constriction at its base, relatively long and straight prosiphon, and abrupt shift of siphuncular position from dorsum to venter within the first camera.

*Description.* — Shell rather small, less than 20 mm in diameter even in adult, involute, with a fairly narrow umbilicus. Whorls round to subrectangular in cross section, with a flat venter, gently convex flanks, rounded umbilical shoulder and subvertical umbilical wall. Shell surface seemingly smooth, but ornamented with fine growth lines and wide-spaced rib-like elevations, both of which are prorsiradiate on the flank, recurve near the peripheral shoulder and cross the venter with a shallow backward sinus. Initial chamber elliptical in median section. Subellipsoid caecum lacks a conspicuous constricted base. Its adapical end connects with the inner surface of initial chamber by a long and nearly straight prosiphon. Proseptum is relatively long and acutely projects toward the caecum. Early portion of the first whorl swells remarkably as a result of discordant underlay of the ammonitella wall with the initial chamber wall. Siphuncle initially occupies a dorsal position within the first camera, and then immediately shifts its position toward the ventral side. Marginal approximation is completed in the third camera, and thereafter, it retains a ventral position. The first septum is adorally concave, but subsequent septa are adorally convex. Median diameter of initial chamber, and maximum diameter and spiral length of ammonitella range from 925 to 1,050 μm, 1,700 to 1,900 μm and 330 to 345°, respectively.

*Dimensions.* —

|  | D (mm) | U (mm) | B (mm) | H (mm) | U/D | B/H |
|---|---|---|---|---|---|---|
| Holotype | 19.4 | 5.2 | 10.1 | 8.6 | 0.27 | 1.17 |

For the measurements of other paratypes see Figures 6-9.

*Remarks.* — *T. terminus*, n. sp. resembles the narrowly umbilicate form of *T. glabrus* (Jimbo) in the external shell shape, but the two species are easily distinguished by the difference in the early internal shell features.

*Occurrence.* — This species is restricted to the Lower Maastrichtian of the Yezo Group in the Tomiuchi area.

## Acknowledgments

## References

Anderson, F.M., 1958: Upper Cretaceous of the Pacific Coast. *Mem. Geol. Soc. Amer.*, vol. 71, p. 1-378, pls. 1-75.

Branco, W., 1879-80: Beiträge zur Entwickelungeschichte der fossilen Cephalopoden. *Palaeontographica* (Stuttgart), Bd. 26, p. 15-50, pls. 4-13 (1879); Bd. 27, p. 17-81, pls. 3-11 (1880).

Collignon, M., 1956: Ammonites néocretacées du Menabe (Madagascar). IV. Les Phylloceratidae; V. Les Gaudryceratidae. VI. Les Tetragonitidae. *Ann. Geol. Serv. Mines*, vol. 23, p. 1-106, pls. 1-11.

Drushchits, V.V. and Doguzhayeva, L.A., 1974: Some morphogenetic characteristics of

phylloceratids and lytoceratids (Ammonoidea). *Paleont. J.*, 1974, no. 1, p. 37-48, pls. 3-4.

—— and ——, 1981 : *Ammonites under the electron microscope.* Moscow Univ. Press ; Moscow. 240 pp., 43 pls. (*in Russian*).

——, —— and Mikhaylova, I.A., 1977 : The structure of the ammonitella and the direct development of ammonites. *Paleont. J.*, 1977, no. 2, p. 188-199, pls. 5-6.

—— and Khiami, N., 1970 : Structure of the septa, protoconch walls and initial whorls in early Cretaceous ammonites. *Ibid.*, 1970, no. 1, p. 26-38.

—— and Mikhailova, I.A., 1976 : Ontogenetic development of early Cretaceous tetragonitids (Ammonoidea). *Ibid.*, 1976, no. 2, p. 159-169.

Fabre, S., 1940 : Le Crétacé supérieur de la Basse-Provence occidentale. 1. Cénomanien et Turonien. *Annls. Fac. Sci. Marseille*, (2) 14, 355 pp., 10 pls.

Forbes, E., 1846 : Report on the Cretaceous fossil invertebrates from southern India, collected by Mr. Kaye and Mr. Cunliffe. *Trans. Geol. Soc. Lond.*, (2) 7, p. 97-174, pls. 7-19.

Grandjean, F., 1910 : Le siphon des ammonites et des belémnites. *Soc. géol. France, Bull., Ser. 4*, vol. 10, p. 496-519.

Henderson, R.A., 1970 : Ammonoidea from the Mata Series (Santonian-Maastrichtian) of New Zealand. *Palaeontology, Spec. Pap.*, no. 6, p. 1-82, pls. 1-15.

Howarth, M.K., 1958 : Upper Jurassic and Cretaceous ammonite faunas of Alexander Land and Graham Land. *Sci. Rep., Falkld. Isl. Dep. Surv.*, vol. 21, p. 1-16.

Jimbo, K., 1894 : Beiträge zur Kenntniss der Fauna der Kreideformation von Hokkaido. *Paläont. Abh., N.F.*, Bd. 2, no. 3, p. 149-194, pls. 17-25.

Kanie, Y., Kawashita, Y. and Fossil Club, Tokai-Dai-Sagami High School, 1981 : Occurrence of a giant capulid gastropod from the Upper Cretaceous of the Kaminukibetsu area, southern-central Hokkaido. *Sci. Rept., Yokosuka City Mus.*, no. 28, p. 85-90, pls. 20-21 (*in Japanese with English abstract*).

Kennedy, W.J. and Klinger, H.C., 1977 : Cretaceous faunas from Zululand and Natal, South Africa. The ammonite family Tetragonitidae Hyatt, 1900. *Ann. S. Afr. Mus.*, vol. 73, no. 7, p. 149-197.

Kossmat, F., 1895-1898 : Untersuchungen über die Südindische Kreideformation. *Beitr. Paläont. Geol. Öst.-Ung.*, Bd. 9, p. 97-203, pls. 15-25 (1895) ; Bd. 11, p. 1-46, pls. 1-8 (1897) ; Bd. 11, p. 89-152, pls. 14-19 (1898).

Krivoshapkina, V.S., 1978 : The ontogeny of the suture in late Cretaceous tetragonitids from Sakhalin. *Paleont. J.*, 1987, no. 1, p. 64-70.

Marshall, P., 1926 : The Upper Cretaceous ammonites of New Zealand. *Trans. N.Z. Inst.*, vol. 56, p. 129-210, pls. 19-47.

Matsumoto, T., 1942a : Fundamentals in the Cretaceous stratigraphy of Japan. Part 1. *Mem. Fac. Sci., Kyushu Univ., Ser. D*, vol. 1, no. 3, p. 129-280, pls. 5-20.

——, 1942b : A note on the Japanese ammonoid species belonging to the Tetragonitidae. *Proc. Imp. Acad. Tokyo*, vol. 18, no. 10, p. 671-673.

——, 1943 : Fundamentals in the Cretaceous stratigraphy of Japan. Parts 2 and 3. *Mem. Fac. Sci., Kyushu Univ., Ser. D*, vol. 2, no. 1, p. 98-237.

——, 1959 : Upper Cretaceous ammonites of California. Part 2. *Ibid., Spec. Vol.*, 1, p. 1-172, pls. 1-41.

——, 1963 : A survey of the fossils from Japan illustrated in classical monographs, Part 10. *Palaeont. Soc. Japan, 25th Ann. Vol.*, p. 41-48, pls. 60-68.

—— and Miyauchi, T., 1984 : Some Campanian ammonites from the Soya area (Studies of the Cretaceous ammonites from Hokkaido-LI). *Ibid., Spec. Pap.*, no. 27, p. 33-76, pls. 10-31.

Marshall, P., 1926 : The Upper Cretaceous ammonites of New Zealand. *Trans. New Zeal. Inst.*, vol. 56, p. 129-210, pls. 19-47.

Murphy, M.A., 1967a : The Aptian-Cenomanian members of the ammonite genus *Tetragonites*. *Univ. Calif. Publs., Geol. Sci.*, vol. 69, p. 1-78, pls. 1-7.

——, 1967b : Aptian and Albian Tetragonitidae (Ammonoidea) from Northern California. *Ibid.*, vol. 70, p. 1-32, pls. 1-5.

Ohtsuka, Y. (1986) : Early internal shell microstructure of some Mesozoic Ammonoidea : Implications for higher taxonomy. *Trans. Proc. Palaeont. Soc. Japan., N.S.*, no. 141, p. 275-288, pls. 45-50.

Okada, H., 1979 : The geology of Hokkaido and its plate tectonics. *Earth Monthly*, no. 1, p. 869-877 (*in Japanese*).

——, 1983 : Collision orogenesis and sedimentation in Hokkaido, Japan. *In "Accretion Tectonics in the Circum-Pacific Regions"* (Hashimoto, M. and Uyeda, S. *eds.*), p. 91-105, Terra Scientific Publishing Co., Tokyo.

Pictet, F.J., 1848 : Description des Mollusques fossiles qui se trouvent dans les Grés Verts des environs de Géneve. 1. Céphalopodes. *Mem. Soc. Phys. Hist. nat. Geneve*, vol. 11, p. 257-412, pls. 1-15.

Sekine, H., Takagi, A. and Hirano, H., 1985 : Biostratigraphical study of the Upper Cretaceous of the northeast part of the Obira area, Hokkaido. *Kaseki (Fossils). Palaeont. Soc. Japan*, no. 38,

p. 1-15 (*in Japanese with English abstract*).

Spath, L.F., 1925: On Senonian Ammonoidea from Jamaica. *Geol. Mag.*, vol. 62, p. 28-32.

Tanabe, K., Hirano, H., Matsumoto, T. and Miyata, Y., 1977: Stratigraphy of the Upper Cretaceous deposits in the Obira area, northwestern Hokkaido. *Sci. Rep., Dept. Geol. Kyushu Univ.*, vol. 12, no. 3, p. 181-202 (*in Japanese with English abstract*).

—— and Kanie, Y., 1978: Colour markings in two species of tetragonitid ammonites from the Upper Cretaceous of Hokkaido, Japan. *Sci. Rep., Yokosuka City Mus.*, no. 25, p. 1-6, pl. 1.

——, Obata, I., Fukuda, Y. and Futakami, M., 1979: Early shell growth in some Upper Cretaceous ammonites and its implications to major taxonomy. *Bull. Nat. Sci. Mus. Tokyo, Ser. C (Geol.)*, vol. 5, no. 4, p. 153-176, pls. 1-6.

—— and Ohtsuka, Y., 1985: Ammonoid early internal shell structure: its bearing on early life history. *Paleobiology*, vol. 11, no. 3, p. 310-322.

Toshimitsu, S., 1988: Biostratigraphy of the Upper Cretaceous Santonian stage in the northwestern Hokkaido. *Mem. Fac. Sci., Kyushu Univ., Ser. D, Geol.*, vol. 26, no. 2, p. 125-192, pls. 23-29.

Van Hoepen, E.C.N., 1921: Cretaceous Cephalopoda from Pondoland. *Ann. Transv. Mus.*, vol. 8, p. 1-48, pls. 1-11.

Wiedmann, J., 1962: Ammoniten aus der Vascogothischen Kreide (Nordspanien). 1. Phylloceratina, Lytoceratina. *Palaeontographica*, Bd. 118A, p. 119-327, pls. 8-14.

——, 1973: The Albian and Cenomanian Tetragonitidae (Cretaceous Ammonoidae) with special reference to the circum-indic species. *Eclog. Geol. Helv.*, vol. 66, p. 585-616, pls. 1-8.

Yabe, H, 1903: Cretaceous Cephalopoda from Hokkaido. Part 1. *Jour. Coll. Sci., Imp. Univ. Tokyo*, vol. 18, no. 2, p. 1-55, pls. 1-7.

Zakharov, Y.D., 1974: New data on internal shell structure in Carboniferous, Triassic and Cretaceous ammonoids. *Paleont. J.*, 1974, no. 1, p. 25-36.

---

Haboro 羽幌, Ikandai 井寒台, Kotanbetsu 古丹別, Nukibetsu 貫気別, Obira 小平, Saku 佐久, Soya 宗谷, Tappu 達布, Tomiuchi 富内, Toyoshimizu 豊清水, Urakawa 浦河.

---

北海道上部白亜系産 *Tetragonites* 属アンモナイトの分類: 北海道の白亜系蝦夷層群より産出する Tetragonites 属アンモナイトについて, 既存種の模式・図示標本を加えた豊富な標本をもとに諸形質の分類学的評価を行った。その結果に基づき, T. glabrus (Jimbo) を再定義するとともに2新種を識別し, *T. minimus, T. terminus* と命名し記載した。
これら3種は初期殻体内部構造や殻口縁の形など不連続な形質によって容易に識別される。*T. glabrus* はチューロニアン階中部からカンパニアン階上部に産し, 螺環の形や表面装飾などに大きな変異がみられる。従来記載された *T. sphaeronotus* (Jimbo), *T. crassus* (Jimbo), *T. popetensis* Yabe などは本種内の変異型とみなせる。*T. minimus* は小型の種で, チューロニアン階下部からカンパニアン階上部に産する。*T. terminus* はマストリヒチアン階下部のみに産し, 巨大な胚殻を有する。                    重田康成

---

# 日本古生物学会への拠金のお願い

　日本古生物学会は，1935年の創立以来，我が国の古生物学の研究と普及の中核的な団体として活動を続け，近年では会員の皆様のご努力により，一段と近代化と国際化が進み，著しい発展をとげつつあると思います。しかしながら，我が国の経済発展とは裏腹に，基礎的な自然史科学は巨大化した生物科学・地球科学のはざまにあって，古生物学をとりまく内外の情勢はきびしさを増していく方向にあると言わざるを得ません。

　現在，本会の会員数は，「化石友の会」会員を加えても1,000名に満たず，最近の円高から，在外会員の数も減少の傾向にあります。また文部省からの出版助成金の減額，50周年基金に対する利率の低下や消費税の影響などもあって，学会は経理面でますます困難な状況を迎えております。学会事務センターに対する負債も次第に増えつつあります。本会では，評議員会，常務委員会，その他の委員会の開催，投稿原稿の校閲なども，ほとんど関係者諸氏のボランティアに頼って経費の節減に努めて来ました。一方，本会に対しては，将来の古生物学を担う若手研究者のためのショートコース・現地討論会，種々のワーキンググループへの援助，内外の研究者のシンポジウムへの招聘，国際交流，会誌の充実，ニュースの発行などが要望されておりますが，経費の面を考えると，いずれも現状では実現が困難です。

　この数年，本会の会誌(報告紀事・化石)発行に要する費用は，直接出版費だけで年間約650万円を要しています。これは会員の皆様に一人あたり原価6,000円強の出版物をお送りしていることになります。しかし，本会の年会費は，他の学会に比べて決して安いとは言えず，安易な会費の改定(値上げ)は極力避けたいと考えております。

　そこで，誠に恐縮ですが，外国の諸学会が行っているように，本会でも会員・「友の会」会員の皆様の自由なご意志による拠金(寄付金)を次の要領で常時申し受け，予測される窮状を打開致したいと考えます。何卒よろしくご協力下さいますようお願いいたします。

## 記

1. 拠金金額　特に上限・下限はありません。千円単位でお願いします。
2. 送金方法　次の拠金専用の振替口座を設けましたので，随時この口座にお振込下さい。
   　　　　東京　4-410780　平野弘道(日本古生物学会会計係)
3. 拠金いただいた方には受領書とお礼状を差し上げ，ご芳名を随時「化石」誌上に公表させていただきます。

<div align="right">

日本古生物学会会長

速　水　　　格
</div>

## Palaeontological Society of Japan, Special Papers
## List of available back numbers [This new price list is available from January 1, 1990]

| | (yen) | (U.S.$) |
|---|---|---|
| No. 9 (1962): Bibliography of Japanese Palaeontology and Related Sciences, 1951–1960. By F. Takai (ed.) | 3,600 | 33 |
| No. 13 (1968): The Echinoid Fauna from Japan and Adjacent Regions. Part 2. By S. Nisiyama | 6,800 | 49 |
| No. 15 (1971): Early Devonian Brachiopods from the Lesser Khingan District of Northeast China. By T. Hamada | 3,800 | 34 |
| No. 16 (1971): Tertiary Molluscan Fauna from the Yakataga District and Adjacent Areas of Southern Alaska. By S. Kanno | 5,000 | 40 |
| No. 17 (1973, reprinted 1980): Revision of Matajiro Yokoyama's Type Mollusca from the Tertiary and Quaternary of the Kanto Area. By K. Oyama | 5,500 | 43 |
| No. 18 (1974): Silurian Trilobites of Japan in Comparison with Asian, Pacific and other Faunas. By T. Kobayashi and T. Hamada | 4,500 | 38 |
| No. 19 (1976): Bivalve Faunas of the Cretaceous Himenoura Group in Kyushu. By M. Tashiro | 4,100 | 36 |
| No. 20 (1977): Devonian Trilobites of Japan in Comparison with Asian, Pacific and other Faunas. By T. Kobayashi and T. Hamada | 6,300 | 47 |
| No. 21 (1977): Mid-Cretaceous Events-Hokkaido Symposium, 1976. By T. Matsumoto (org.) | 5,200 | 41 |
| No. 22 (1978): Bibliography of Palaeontology in Japan, 1961–1975. By K. Kanmera and H. Ujiie (ed.) | 6,300 | 47 |
| No. 23 (1980): Carboniferous Trilobites of Japan in Comparison with Asian, Pacific and other Faunas. By T. Kobayashi and T. Hamada | 5,800 | 44 |
| No. 24 (1981): Permian Conodont Biostratigraphy of Japan. By H. Igo | 4,700 | 39 |
| No. 25 (1982): Multidisciplinary Research in the Upper Cretaceous of the Monobe Area, Shikoku. By T. Matsumoto and M. Tashiro | 5,800 | 44 |
| No. 26 (1984): Permian Trilobites of Japan in Comparison with Asian, Pacific and other faunas. By T. Kobayashi and T. Hamada | 5,800 | 44 |
| No. 27 (1984): Some Ammonites from the Campanian (Upper Cretaceous) of Northern Hokkaido. By T. Matsumoto | 6,800 | 49 |
| No. 28 (1985): Bibliography of Palaeontology in Japan, 1976–1980. By T. Kase and K. Asama | 4,100 | 36 |
| No. 29 (1986): Japanese Cenozoic Molluscs — Their Origin and Migration. By T. Kotaka et al. | 10,800 | 69 |
| No. 30 (1988): A Monograph of the Puzosiidae (Ammonoidea) from the Cretaceous of Hokkaido. By T. Matsumoto | 7,100 | 51 |

# PALAEONTOLOGICAL SOCIETY OF JAPAN, SPECIAL PAPERS

## ORDER FORM

To : c/o Dr. Juichi YANAGIDA
    Editor of Special Papers, Palaeontological Society of Japan, Department of Geology,
    Faculty of Science, Kyushu University 33, FUKUOKA 812, JAPAN

From   (in block letters) :

_____

_____

_____

Please send me, by surface mail, the following copies (copy) of Special Papers

| Cat. No. | Quantity | Short Title | Total Price (yen or U.S.$) |
|---|---|---|---|
| | | | |
| | | | |
| | | | |

Payment (Please tick one box)
    □ A   International Postal Money Order
             (To : Palaeontological Society of Japan,
                 c/o Department of Geology, Kyushu University
                 33, FUKUOKA 812, Japan)
    □ B   Postal Transfer Account
             (To : No. 5-19014 FUKUOKA)
    □ C   Cheque
             (made payable to the Palaeontological Society of Japan) for U.S. dollars.

Notes.   Prices include bank commission and shipping.   Bank commission for changing money
         costs 15 U.S. dollars in Japan.

        Date : _____

        Signature : _____

```
·············· 行 事 予 定 ··············
```

◎1990年年会・総会は1990年2月2日〜4日 **早稲田大学** で開催されます。
◎1990年137回例会は6月30日・7月1日に**瑞浪市化石博物館**で開催の予定です。講演申
　込は1990年4月15日締切です。
◎講演申込は共著を含めて一人2題までとし，講演時間は討論を含め15分です。一題目ず
　つ葉書で期日までに下記宛申し込んで下さい。

　　　　〒113　東京都文京区弥生2-4-16
　　　　　　　日本学会事務センター
　　　　　　　日本古生物学会行事係

　　　　　　　　　　　　　　　　　　　　　　　　　　　　（行事係）

# Transactions and Proceedings of the Palaeontological Society of Japan

New Series No. 156                    December 30, 1989

## CONTENTS