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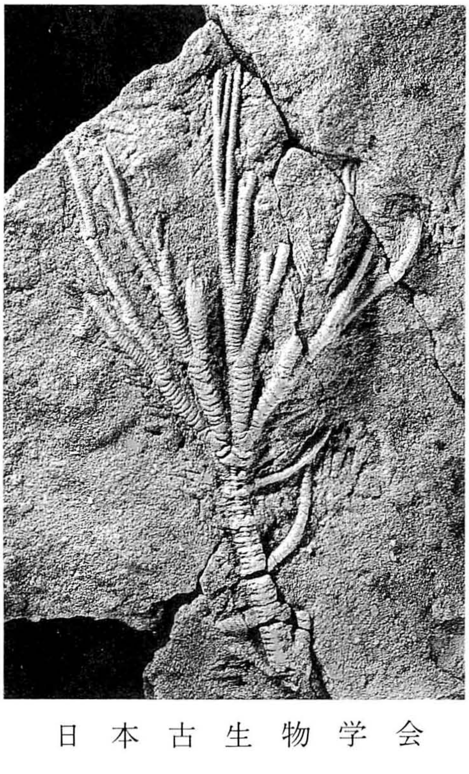

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The fossil on the cover is *Isocrinus* (*Chladocrinus*) *hanaii* Oji, an Early Cretaceous (Aptian) crinoid, which was described from the Hiraiga Formation exposed at Haipe, Tanohata-mura, Shimo-Hei County, Iwate Prefecture, Northeast Japan. (University Museum of the University of Tokyo coll. cat. no. ME6950, paratype specimen, length about 11 cm)

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953. MIDDLE AND UPPER CARBONIFEROUS FUSULINACEANS FROM THE TAISHAKU LIMESTONE GROUP, SOUTHWEST JAPAN*

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Abstract. Middle and Upper Carboniferous fusulinacean biostratigraphy of the Taishaku Limestone Group in the Unata area situated in the southern part of the Taishaku Plateau, Hiroshima Prefecture, is examined and five fusulinacean zones; the *Fusulinella bingoensis, Fusulina quasicylindrica,* and *Obsoletes* cf. *obsoletus-Protriticites ovatus* Zones in the uppermost part of the Eimyoji Formation, and the *Triticites* (*Rauserites*) *stuckenbergi-Jigulites dagmarae* and *Occidentoschwagerina chatcalica* Zones in the lowermost part of the Uyamano Formation in ascending order, are established. Based upon the faunal similarity of fusulinaceans between the Taishaku Limestone Group and the Carboniferous standard and reference sections of the Russian Platform and other regions, the *Fusulinella bingoensis* and *Fusulina quasicylindrica* Zones are correlated with the Myachkovsky Horizon of the late Moscovian, the *Obsoletes* cf. *obsoletus-Protriticites ovatus* Zone with the lower Kasimovian, and the *Triticites* (*Rauserites*) *stuckenbergi-Jigulites dagmarae* and *Occidentoschwagerina chatcalica* Zones with the Gzhelian in the Russian Carboniferous standard stratigraphic scheme. This fact reveals that at least the lowermost part of the Uyamano Formation in the Unata area, which has long been regarded as Permian, is in the Upper Carboniferous. In this paper, all the identified fusulinaceans including one new species, *Fusulinella bingoensis,* sp. nov., are described. The present report provides important evidence not only on the Middle and Upper Carboniferous fusulinacean biostratigraphy of the Taishaku Limestone Group but also on the biostratigraphic significance of the *Fusulina* fauna in the Akiyoshi "Terrane."

Key words. Akiyoshi "Terrane," *Fusulina* Zone, fusulinacean biostratigraphy, Middle and Upper Carboniferous, Taishaku Limestone Group.

Introduction

The Taishaku Limestone Group, located in the northeastern part of Hiroshima Prefecture, is one of the large greenstone-limestone bodies in the Akiyoshi "Terrane" in the Inner Zone of southwest Japan and has been interpreted to have originated in an oceanic seamount during Late Paleozoic time. After the pioneer works by Hanzawa (1941) and Fujimoto (1944), many students paleontologically and biostratigraphically studied foraminifers, corals, calcareous algae, mollusks, and bryozoans of the Taishaku Limestone Group. According to Okimura (1987), the Taishaku Limestone Group is biostratigra-

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phically subdivided into 12 foraminiferal zones. Paleontological and stratigraphical knowledge of the *Fusulina* (or *Beedeina*) and *Triticites* Zones (upper Middle and Upper Carboniferous) in the Taishaku Limestone Group, however, remains poor, especially knowledge of their faunal characteristics and stratigraphic relationship.

Recently, we investigated the Taishaku Limestone Group in the Unata area, which is one of the *Fusulina* localities presented by Hase *et al.* (1974), for the purpose of elucidating the biostratigraphic significance and faunal characteristics of the *Fusulina* Zone as well as the stratigraphic relationship between the Eimyoji and Uyamano Formations. We identified five fusulinacean faunas from a late Moscovian to Gzhelian age in the uppermost part of the Eimyoji and the lowermost part of the Uyamano Formations.

In the present paper, we discuss the fusulinacean biostratigraphy of the uppermost part of the Eimyoji and the lowermost part of the Uyamano Formations in the Unata area and the fusulinacean faunal succession near the Middle and Upper Carboniferous boundary in the Taishaku Limestone Group. Moreover, all the identified fusulinaceans including one new species, *Fusulinella bingoensis*, sp. nov., are described. This report includes the first systematic description of fusulinacean species comprising the *Fusulina* fauna in the Akiyoshi "Terrane" and provides many important data concerning the biostratigraphic significance of the *Fusulina* fauna and the stratigraphic relationship between the *Beedeina* and *Fusulina* Zones in the Akiyoshi "Terrane" in

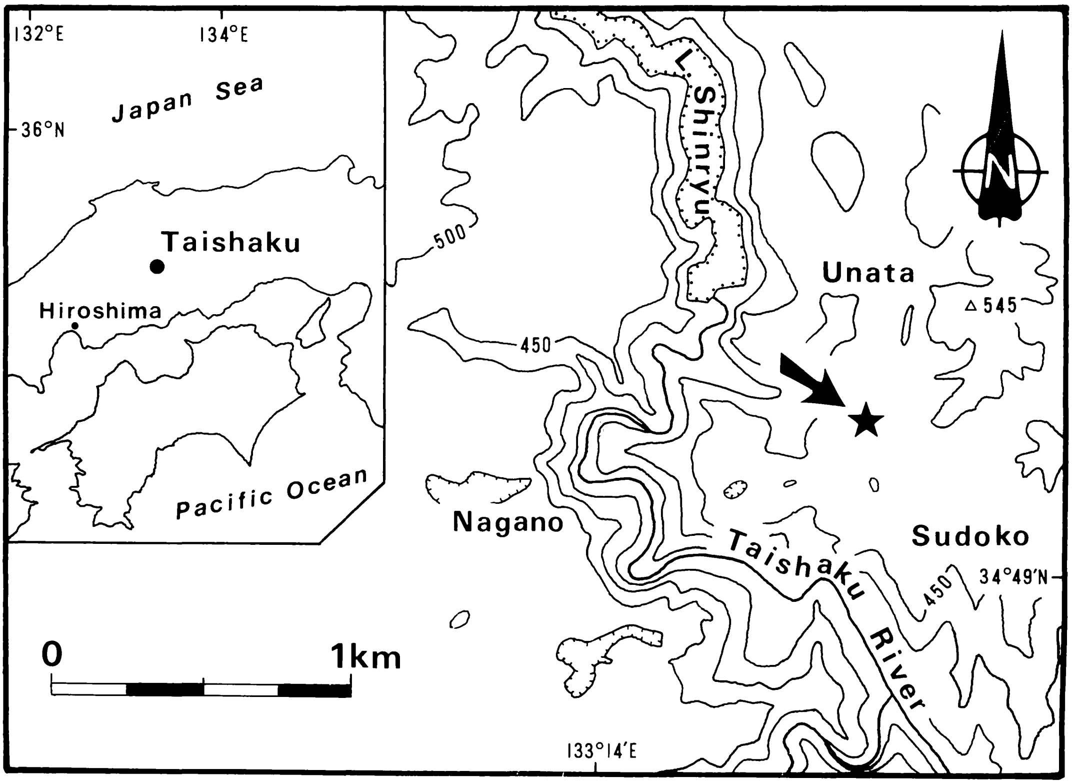

Figure 1. Index map of the Unata area in the Taishaku Plateau.

the Inner Zone of southwest Japan.

Review of foraminiferal biostratigraphy of the Taishaku Limestone Group

Biostratigraphic study of the Taishaku Limestone Group by foraminifers arose from the pioneer works by Hanzawa (1941) and Fujimoto (1944), and was furthered by Yokoyama (1959), Okimura (1966), Sada (1967, 1969, 1972, 1973, 1975, 1977), Sada and Yokoyama (1966, 1970), and Sada *et al.* (1984). Among them, Sada and Yokoyama (1970) reported the fusulinacean fauna of the *Fusulinella* Zone in the Taishaku Limestone Group and described the following three species; *Fusulinella taishakuensis* Sada, *F. biconica* (Hayasaka), and *Eoschubertella* sp. They correlated the *Fusulinella* fauna of the Taishaku Limestone Group with those of the Huanglong (Huanglung) Limestone in South China and the Upper Atokan in North Amer-

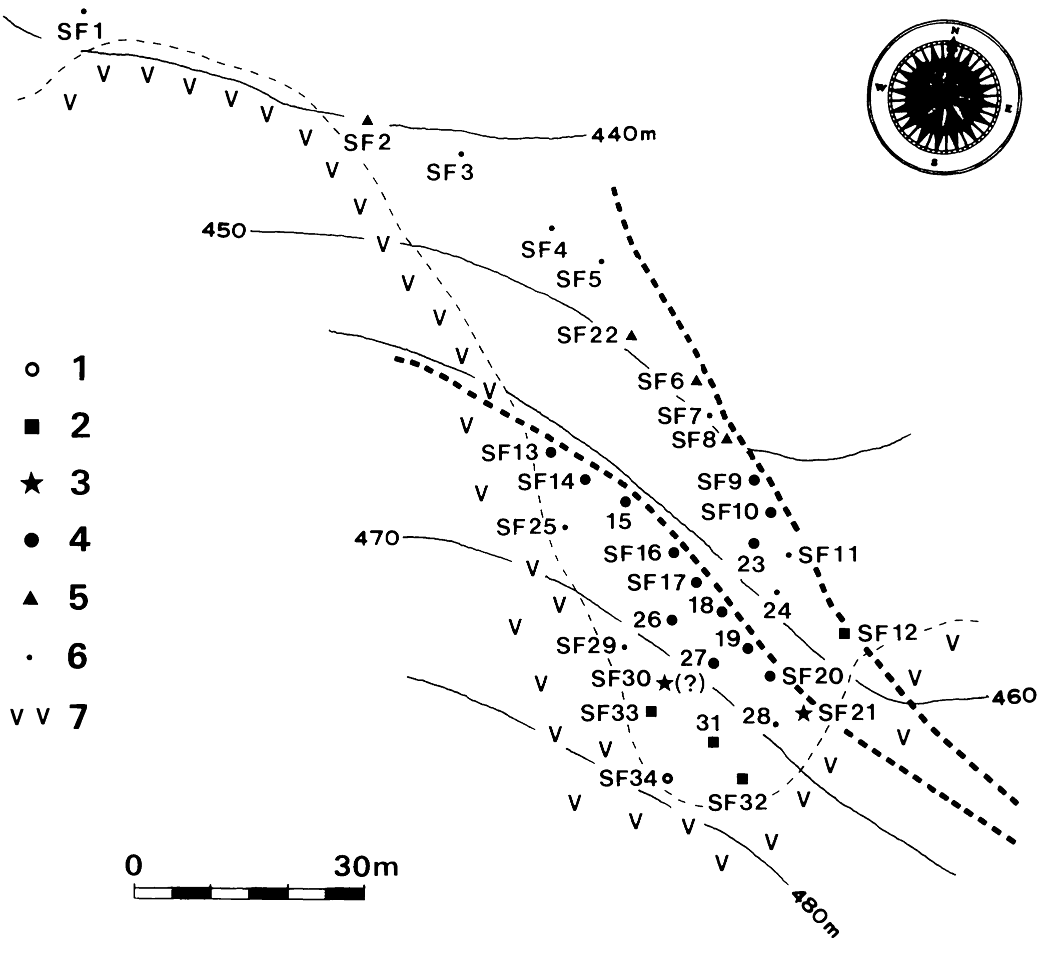

Figure 2. Map showing the localities of collected samples with the indications of contained fusulinacean faunas. 1 : *Occidentoschwagerina chatcalica* fauna, 2 : *Triticites* (*Rauserites*) *stuckenbergi-Jigulites dagmarae* fauna, 3 : *Obsoletes* cf. *obsoletus-Protriticites ovatus* fauna, 4 : *Fusulina quasicylindrica* fauna, 5 : *Fusulinella bingoensis* fauna, 6 : fauna uncertain, 7 : rhyolo-dacitic volcaniclastic rocks (Cretaceous).

ica.

Sada (1973) summarized the fusulinacean biostratigraphy of the Permian division of the Taishaku Limestone Group and established the *Triticites* sp. A Subzone in the *Pseudoschwagerina* Zone as the lowermost biostratigraphic unit, which was correlated with the lower Wolfcampian in North America. He determined that the *Triticites* sp. A Subzone (*Pseudoschwagerina* Zone) unconformably overlies the *Fusulinella* Zone in the Taishaku Limestone Group.

Later, Sada (1975) distinguished four fusulinacean zones in the Carboniferous division of the Taishaku Limestone Group, namely the *Eostaffella kanmerai* Zone in the Dangyokei Formation and the *Millerella bigemmicula, Profusulinella toriyamai,* and *Fusulinella taishakuensis* Zones in the Eimyoji Formation.

Hase *et al.* (1974) comprehensively investigated the stratigraphy of the Taishaku Limestone Group and recognized two distinctive sedimentary facies, the central and marginal ones. They explained that the central facies represents shallow marine sediments on reef proper and the marginal facies exemplifies rather deep water sediments on fore-reef slope to near-reef basin, which are derived mainly from the former. They divided the central facies of the Taishaku Limestone Group into the following three formations in ascending order, namely the Dangyokei, Eimyoji, and Uyamano Formations, and correlated the former two with the Lower and Middle Carboniferous and the last one with the Lower to Middle Permian, respectively. In that study, they noted that in the Unata area the upper Eimyoji Formation (*Fusulina* Zone) of late Middle Carboniferous age is unconformably overlain by the lower Uyamano Formation (*Pseudoschwagerina* Zone) of earliest Permian age and concluded that the Upper Carboniferous *Triticites* Zone is entirely lacking even in the whole area of the Taishaku Limestone Group.

Recently, Okimura (1987) reviewed the litho- and biostratigraphy of the Taishaku Limestone Group and distinguished the Eimyoji Formation into the *Millerella bigemmicula, Pseudostaffella antiqua, Profusulinella toriyamai, Fusulinella taishakuensis,* and *Fusulina* Zones in ascending order. He concluded, however, that paleontological knowledge of the *Fusulina* Zone in the Taishaku Limestone Group still remains poor because of its restricted, narrow distribution.

Geologic setting and fusulinacean biostratigraphy

The surveyed area, about 0.5 km south of Unata on the left bank of the Simotaishakukyo Gorge, is located about 8 km southwest of Tojo (Figure 1). In this area, it is known that the lower Uyamano Formation (*Pseudoschwagerina* Zone) and the upper Eimyoji Formation (*Fusulinella-Fusulina* Zone) of the central (main) facies of the Taishaku Limestone Group are exposed and the *Fusulina* Zone which is not well understood biostratigraphically in the Akiyoshi "Terrane" in the Inner Zone of southwest Japan is distributed restrictedly (Hase *et al.*, 1974). Rhyolo-dacitic volcaniclastic rocks of Cretaceous age (Hase *et al.*, 1974) widely cover the Taishaku Limestone Group in this area.

As shown in Figure 2, a total of 34 samples were collected systematically and their fusulinacean faunas and microfacies were examined. The Taishaku Limestone Group exposed in the Unata area is almost entirely composed of a massive and pure bioclastic limestone and reaches about 40 m in thickness (Figure 3). It is currently divided into the Eimyoji and Uyamano Formations. Sixteen species belonging to 11 genera of fusulinaceans were extracted. Based upon the stratigraphic distribution of fusulinaceans, the Eimyoji Formation is further subdivided biostratigraphically into the *Fusulinella bingoensis, Fusulina quasicylindrica,* and *Obsoletes* cf. *obsoletus-Protriticites*

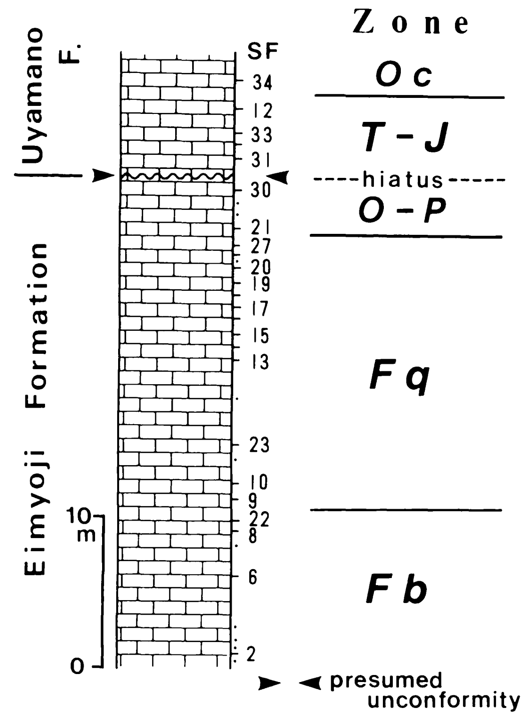

Figure 3. Columnar section of the uppermost part of the Eimyoji and the lowermost part of the Uyamano Formations in the Unata area. *Oc* : *Occidentoschwagerina chatcalica* Zone, *T-J* : *Triticites* (*Rauserites*) *stuckenbergi-Jigulites dagmarae* Zone, *O-P* : *Obsoletes* cf. *obsoletus-Protriticites ovatus* Zone, *Fq* : *Fusulina quasicylindrica* Zone, *Fb* : *Fusulinella bingoensis* Zone.

ovatus Zones, and the Uyamano Formation into the *Triticites* (*Rauserites*) *stuckenbergi-Jigulites dagmarae* and *Occidentoschwagerina chatcalica* Zones in ascending order (Figure 4).

The *Fusulinella bingoensis* Zone is the lowest stratigraphic unit in the surveyed area and is at least about 10 m in thickness. Algal-fusulinacean packstone is dominant and algal-fusulinacean grainstone is common. The fusulinacean fauna contains *Fusulinella bingoensis*, sp. nov., *Pseudofusulinella* (*Kanmeraia*) ex gr. *pulchra* (Rauser-Chernoussova and Beljaev), and *Pseudofusulinella* (*Kanmeraia*) sp.

The *Fusulina quasicylindrica* Zone, about 18 m thick, conformably overlies the *Fusulinella bingoensis* Zone and yields *Fusulina quasicylindrica* Lee, *Fusulinella bingoensis*, sp. nov., *Pseudofusulinella* (*Kanmeraia*) ex gr. *pulchra* (Rauser-Chernoussova and Beljaev), *Schubertella* sp., and *Nankinella* sp. Algal-fusulinacean grainstone and algal-fusulinacean packstone are predominant.

The *Obsoletes* cf. *obsoletus-Protriticites ovatus* Zone conformably overlies the *Fusulina quasicylindrica* Zone and is about 4 m thick. Algal grainstone and algal-fusulinacean grainstone are dominant. The diagnostic fusulinaceans in this zone are *Obsoletes* cf. *obsoletus* (Schellwien) and *Protriticites ovatus* Putrja.

The *Triticites* (*Rauserites*) *stuckenbergi-Jigulites dagmarae* Zone is about 5 m in thickness and ooid-algal grainstone and algal-crinoidal grainstone are predominant. A fusulinacean faunal break exists between the *Obsoletes* cf. *obsoletus-Protriticites ovatus* and the *Triticites* (*Rauserites*) *stuckenbergi-Jigulites dagmarae* Zones. The unconformable stratigraphic relationship is, therefore, assumed between the present zone and the subjacent one, although no evidence of unconformity is observed in the field. The following fusulinaceans are diagnostic: *Triticites* (*T.*) *schwageriniformis* Rauser-Chernoussova, *T.* (*Rauserites*) *stuckenbergi* Rauser-Chernoussova, *T.* (*R.*) *lucidus* Rauser-Chernoussova, *Jigulites dagmarae* (Rozovskaya), and *Jigulites* sp.

The *Occidentoschwagerina chatcalica* Zone is at least 5 m in thickness and algal-crinoidal grainstone is dominant. Fusulinacean fauna includes *Occidentoschwagerina chatcalica* Bensh, *Rugosofusulina* sp. A, and *Rugosofusulina* ? sp. B. This zone may conformably overlies the *Triticites* (*Rauserites*) *stuckenbergi-Jigulites dagmarae* Zone.

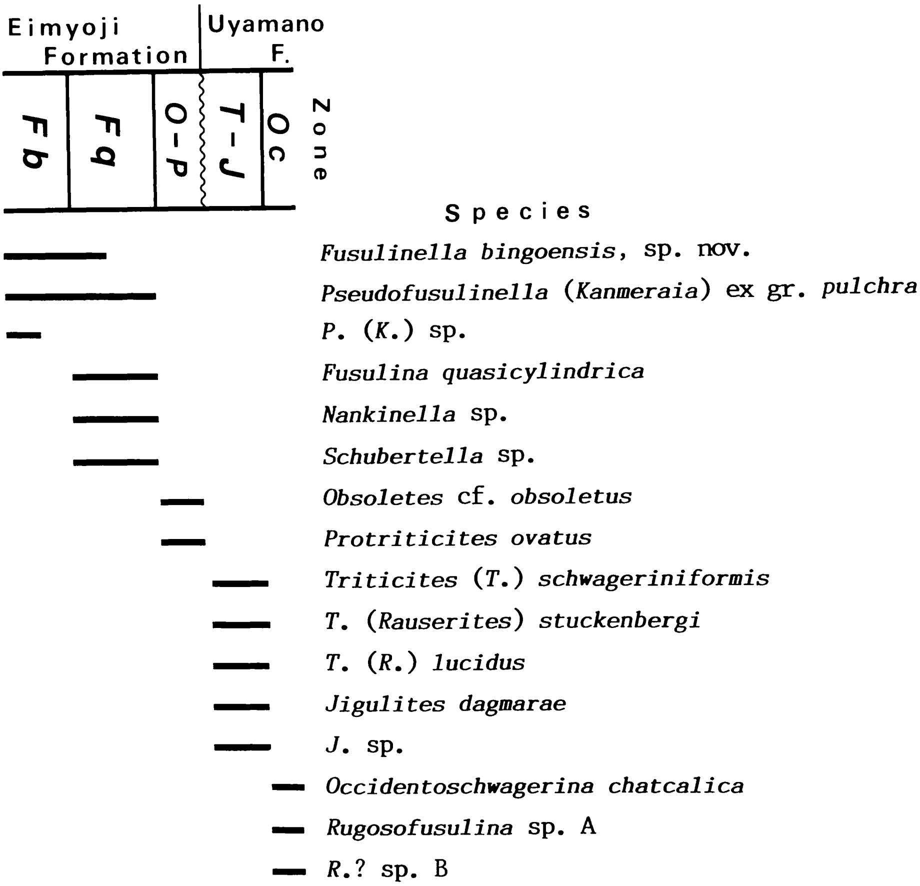

Figure 4. Stratigraphic distribution of fusulinaceans in the uppermost part of the Eimyoji and the lowermost part of the Uyamano Formations in the Unata area. Abbreviations of zone names: see legend of Figure 3.

Correlation

Most of the fusulinaceans identified in the Unata area are also rather common in or closely related to other species occurring in the Carboniferous standard or reference sections of the Moscow Syneclise, South Urals, Donets Basin, Central Asia, and South China. This makes it possible to discuss the precise correlation of the fusulinacean zones established in this study with those of the Middle and Upper Carboniferous standard stratigraphic scheme in the Russian stratotypes represented by Ivanova *et al.* (1979) and Rauser-Chernoussova *et al.* (1979). Correlation of fusulinacean zones in this study with the Russian Carboniferous standard stratigraphic scheme is shown in Table 1.

The index species of the *Fusulinella bingoensis* Zone is morphologically related to *F. vozhgalensis molokovensis* Rauser-Chernoussova and *F. pseudobocki ovoides* Rauser-Chernoussova, both of which were described from the lower Myachkovsky Horizon of the Moscovian in the Russian Platform (Rauser-Chernoussova *et al.*, 1951). This species is also closely similar to *Fusulinella*

Table 1. Correlation of fusulinacean zones established in this study with those in the Russian Carboniferous standard stratigraphic scheme.

			Moscow Syneclise Ivanova *et al.*, 1979 Rauser-Chernoussova *et al.*, 1979		**Taishaku Limestone Group** This study
			Horizon	Zone	Zone
PERM.	Assel.	E.	Sokoliegorsky	"*Schwagerina*" *vulgaris*- "*Schwagerina*" *fusiformis*	
CARBONIFEROUS	Gzhelian	L.	Noginsky	*Daixina sokensis*	*Occidentoschwagerina chatcalica*
		M.	Pavlo-Posadsky	*Jigulites jigulensis*	*Triticites* (*R.*) *stuckenbergi*- *Jigulites dagmarae*
		E.	Amerevsky	*Triticites* (*R.*) *stuckenbergi*	
			Rusavkinsky	*Triticites* (*R.*) *rossicus*	
	Kasimovian	L.	Yauzsky	*Triticites* (*T.*) *arcticus*	
			Dorogomilovsky	*Triticites* (*T.*) *acutus*	
		M.	Khamovnichesky	*Montiparus montiparus*	
		E.	Krevyakinsky	*Protriticites pseudomontiparus*- *Obsoletes obsoletus*	*Obsoletes* cf. *obsoletus*- *Protriticites ovatus*
	Moscovian	Late	Myachkovsky	*Fusulina cylindrica* *Fusulinella bocki* *Fusulinella eopulchra*	*Fusulina quasicylindrica*
					Fusulinella bingoensis
			Podolsky	*Fusulinella colaniae* *Fusulinella vozhgalensis* *Fusulina kamensis*	

chuanshanensis Lee and Chen from the Huanglong Limestone of South China where *Fusulinella pseudobocki* Lee and Chen, and *Fusulina quasicylindrica* Lee are associated (Lee *et al.*, 1930). *Fusulina quasicylindrica* Lee from the Taishaku Limestone Group is closely related to *F. cylindrica* (Fischer de Waldheim) which is considered to be an important element among the fusulinacean faunas in the upper Myachkovsky Horizon and its equivalents (Rauser-Chernoussova *et al.*, 1951 ; Sheng, 1958 ; Ivanova *et al.*, 1979). For these reasons, the *Fusulinella bingoensis* and *Fusulina quasicylindrica* Zones are correlated with the Myachkovsky Horizon of the Moscovian.

The succeeding zone contains *Obsoletes* cf. *obsoletus* (Schellwien) and *Protriticites ovatus* Putrja. The former is a well known species in the lower Kasimovian and its equivalents in the Tethyan province (Rauser-Chernoussova *et al.*, 1979 ; Aisenverg *et al.*, 1979 ; Watanabe, 1991 and others). The latter was originally described from the C_3^N ($=C_3^1$ (N)) and lower C_3^O($=C_3^2$ (O)) Suites of the eastern Donbass (Putrja, 1948). It was recorded also from the uppermost Moscovian and the lowermost Kasimovian of the Moscow Basin (Ivanova *et al.*, 1979). In general, the *Protriticites-Obsoletes* fauna is considered to be a good indicator of an early Kasimovian age (Rauser-Chernoussova *et al.*, 1979). Consequently, the *Obsoletes* cf. *obsoletus-Protriticites ovatus* Zone seems to be correlated with the lower Kasimovian *Protriticites pseudomontiparus-Obsoletes obsoletus* Zone in the Moscow Syneclise, Donets Basin, and Central Asia (Rauser-Chernoussova *et al.*, 1979 ; Aisenverg *et al.*, 1979 ; Bensh, 1972).

The *Triticites* (*Rauserites*) *stuckenbergi-Jigulites dagmarae* Zone contains species fairly identical to those recorded in the Carboniferous standard and reference sections in Russia and other regions. One of the zone species, *Triticites* (*Rauserites*) *stuckenbergi* Rauser-Chernoussova, is a good index of the lower Gzhelian (Rauser-Chernoussova, 1958 and others). The other zone species, *Jigulites dagmarae* (Rozovskaya), was originally described from the middle and upper Gzhelian (Rozovskaya, 1950). The genus *Jigulites* is, at present, considered to have flourished in the lower and middle Gzhelian (Popov *et al.*, 1985). *Triticites* (*Rauserites*) *lucidus* Rauser-Chernoussova was recorded from the lower Gzhelian *Triticites stuckenbergi* Zone (Rauser-Chernoussova, 1958 ; Rozovskaya, 1958). *Triticites* (*T.*) *schwageriniformis* is a rather long-ranging species which occurs from the upper Kasimovian to the lower Asselian (Rauser-Chernoussova *et al.*, 1979). According to the above-mentioned evidence, this zone is evidently referable to the lower and middle Gzhelian.

The index species of the *Occidentoschwagerina chatcalica* Zone was originally described by Bensh (1962) from the lowermost Permian of North Fergana, and also recorded from the Asselian *Occidentoschwagerina alpina* and "*Schwagerina*" *moelleri-Pseudofusulina*' *fecunda* Zones of South Fergana (Bensh, 1972). Recently, this species was reported from the *Daixina postsokensis* Zone which is equivalent to the lower half of the *Daixina bosbytauensis-Daixina robusta* Zone of late Gzhelian age (Davydov, 1990). Although the genus *Occidentoschwagerina* is common in the basal Permian, it is also an important element in the upper Gzhelian (Popov *et al.*, 1985). The genus *Rugosofusulina* is common in the uppermost Carboniferous and lowermost Permian (Popov *et al.*, 1985). From the evidence mentioned above as well as the stratigraphic relationship with the subjacent *Triticites* (*Rauserites*) *stuckenbergi-Jigulites dagmarae* Zone, and the fact that the fusulinacean fauna of the present zone does not contain any *Sphaeroschwagerina* or *Pseudoschwagerina* species which is considered to characterize the basal Permian (Watanabe, 1991), it may be correlated with the upper Gzhelian.

It becomes obvious that the uppermost part of the Eimyoji Formation in the Unata area is correlated with the uppermost Moscovian to lower Kasimovian, and the lowermost part of the Uyamano Formation with the Gzhelian. This means that at least the lowermost part of the Uyamano Formation in this area, which has long been considered to be Permian, is of Late Carboniferous age. Moreover, a stratigraphic hiatus which is almost equivalent to the middle and upper Kasimovian exists between the Eimyoji and Uyamano Formations in this area.

The upper Moscovian in the Akiyoshi "Terrane" in the Inner Zone of southwest Japan has long been represented as the *Beedeina* Zone, which is characterized by the occurrence of the genera *Beedeina, Fusulinella,* and *Pseudofusulinella,* such as *Beedeina akiyoshiensis* Zone by Ota (1977) and Ueno (1989), and *Beedeina akiyoshiensis, Fusulinella pseudobocki,* and *Pseudofusulinella hidensis* Zones by Ozawa and Kobayashi (1990) in the Akiyoshi Limestone Group and the *Fusulinella pulchra* Zone by Watanabe (1973) in the Omi Limestone Group. The equivalent zone is not known or less understood in the Atetsu and Taishaku Limestone Groups. In the present paper, we explained that the *Fusulina* fauna in the Taishaku Limestone Group is surely referable to that in the Moscovian Myachkovsky Horizon, probably its upper part. On the contrary, the *Beedeina* fauna (*Beedeina akiyoshiensis*

Zone) in the Akiyoshi Limestone Group, for example, is suggested to be referable to that in the upper Podolsky Horizon (Ueno, 1989; Ozawa and Kobayashi, 1990). It is concluded that the *Fusulina* fauna is younger than the *Beedeina* fauna (*Beedeina akiyoshiensis* Zone) in the Akiyoshi "Terrane," although the stratigraphic relationship between the *Beedeina* and *Fusulina* Zones is not confirmed in the Taishaku Limestone Group. This suggests that the *Fusulina* Zone can be redefined as a fusulinacean genus zone in the uppermost Moscovian or the upper half of the *Beedeina* Zone.

Systematic description

All specimens identified in this paper are deposited in the paleontological collections of the Institute of Geoscience, University of Tsukuba (IGUT).

Order Foraminiferida Eichwald, 1830
Suborder Fusulinina Wedekind, 1937
Superfamily Fusulinacea von Möller, 1878
Family Schubertellidae Skinner, 1931
Subfamily Schubertellinae Skinner, 1931
Genus *Schubertella* Staff and Wedekind, 1910

Schubertella sp.

Figures 5-3—8

Remarks.—The present species is closely similar to *Schubertella* aff. *kingi* Dunbar and Skinner described by Ueno (1991) from the lower Kasimovian *Quasifusulinoides toriyamai* Zone of the Akiyoshi Limestone Group.

Figured specimens.—Axial sections; IGUT-KU0466, IGUT-KU0468, IGUT-KU0469, IGUT-KU0470, IGUT-KU0471. Sagittal section; IGUT-KU0467. All specimens from Loc. SF15.

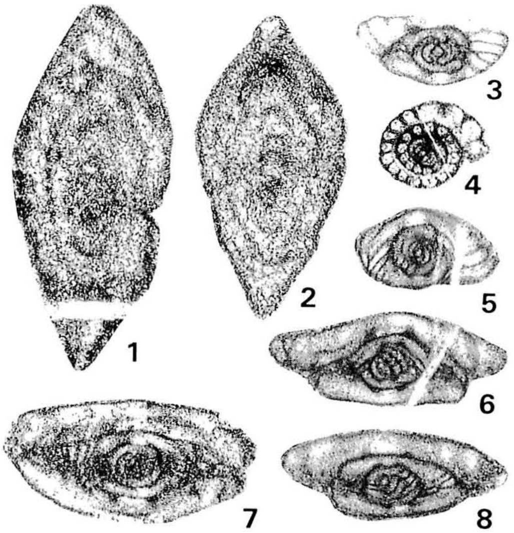

Figure 5. **1, 2**: *Nankinella* sp., axial sections, IGUT-KU0464, IGUT-KU0465. **3-8.** *Schubertella* sp., **3, 5-8**: axial sections, IGUT-KU0466, IGUT-KU0468, IGUT-KU0469, IGUT-KU0470, IGUT-KU0471, **4**: sagittal section, IGUT-KU0467. All ×40.

Family Fusulinidae von Möller, 1878
Subfamily Fusulinellinae Staff and Wedekind, 1910
Genus *Fusulinella* von Möller, 1877

Fusulinella bingoensis Ueno and Mizuno, sp. nov.

Figures 6-1—6

Diagnosis.—Large *Fusulinella* having a thickly biconvex shell with broadly rounded periphery, massive and highly asymmetrical chomata, and well defined tunnel path. Coiling planispiral throughout.

Description.—Shell large for genus and thickly biconvex with broadly rounded periphery and bluntly pointed polar ends. Mature specimens of 6 ½ to 7 volutions 4.45 to 5.60 mm in length and 2.25 to 2.60 mm in width, giving form ratios of 1.98 to 2.21. Average form ratio 2.10 for 4 specimens. The holotype of 7 volutions 4.98 mm in

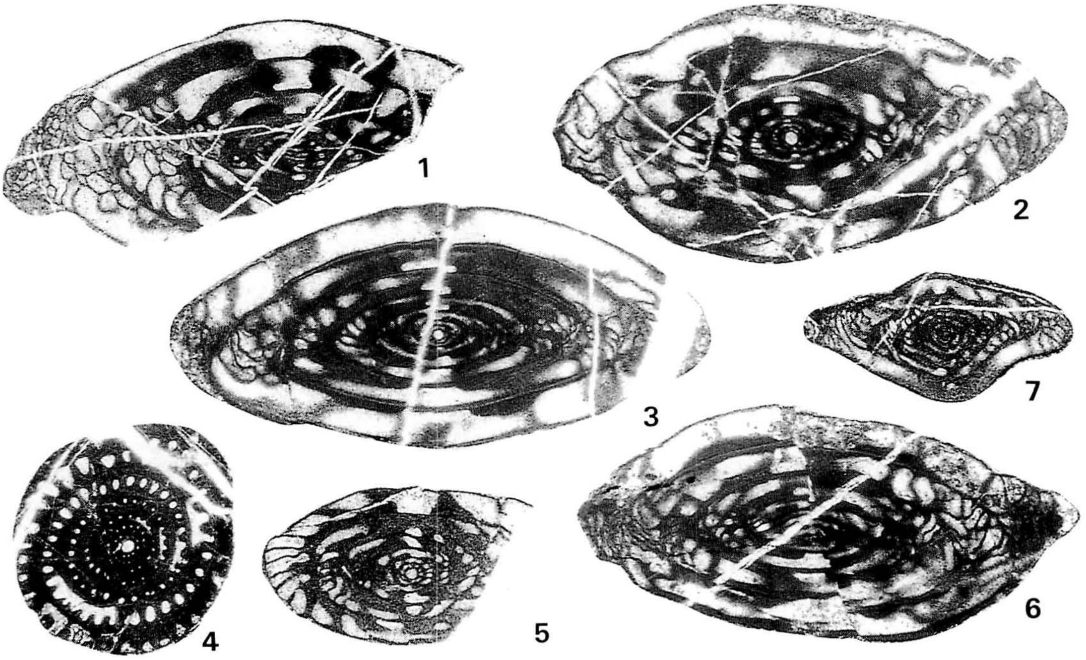

Figure 6. **1–6.** *Fusulinella bingoensis* Ueno and Mizuno, sp. nov., **3**: axial section of the holotype, IGUT-KU0474, **1, 6**: tangential sections of paratypes, IGUT-KU0472, IGUT-KU0477, **2**: axial section of paratype, IGUT-KU0473, **4**: sagittal section of paratype, IGUT-KU0475, **5**: axial section of immature specimen of paratype, IGUT-KU0476, ×15. **7**: *Pseudofusulinella* (*Kanmeraia*) sp., axial section, IGUT-KU0478, ×20.

length and 2.25 in width with a form ratio of 2.21.

Shell uniformly expanded and planispirally coiled throughout growth. Radius vectors of the first to seventh volution of the holotype 0.10, 0.15, 0.22, 0.36, 0.56, 0.82, and 1.14 mm, and form ratios 1.20, 1.93, 2.30, 2.43, 2.33, 2.40, and 2.19, respectively.

Proloculus small and spherical. Its outside diameter ranges from 0.120 to 0.150 mm, averaging 0.137 mm for 5 specimens.

Spirotheca rather thick and composed of a tectum, thin diaphanotheca, and thick upper and lower tectoria. Thickness of spirotheca of the first to seventh volution of the holotype 0.025, 0.030, 0.035, 0.050, 0.060, 0.070, and 0.050 mm.

Septa weakly fluted only in extreme polar regions. Chomata broad and massive, highly asymmetrical, and well developed in all volutions except for the last half volution. They extend to polar regions while decreasing in height. Tunnel side of chomata very steep, but their outside slopes very gentle. Tunnel path almost straight. Tunnel angles of the third to sixth volution of the holotype 40, 45, 38 and 45 degrees.

Remarks.—*Fusulinella bingoensis,* sp. nov. is one of the largest species in the genus. It is closely related with *Fusulinella vozhgalensis molokovensis* and *F. pseudobocki ovoides,* both described by Rauser-Chernoussova (in Rauser-Chernoussova *et al*., 1951) from the lower Myachkovsky Horizon of the Russian Platform. The former, however, differs from the latter in having a larger shell and more massive chomata.

The present new species is similar to *Fusulinella chuanshanensis* described by Lee and Chen (in Lee *et al.*, 1930) from the Huanglong Limestone of South China. The latter species, however, has a more compactly coiled shell than does ours.

Fusulinella bingoensis, sp. nov. somewhat resembles *Fusulinella biconica* (Hayasaka), the well known species in the Moscovian *Fusulinella* Zone of the Akiyoshi "Terrane," but can be easily distinguished from the latter in having a larger shell and form ratio.

Etymology.—The specific name is derived from Bingo, the ancient name for the country around the eastern half of Hiroshima Prefecture, where the Taishaku Plateau is located.

Figured specimens.—Axial section of the holotype; IGUT-KU0474 from Loc. SF2. Axial section of paratype; IGUT-KU0473 from Loc. SF2. Axial section of immature specimen of paratype; IGUT-KU0476 from Loc. SF2. Sagittal section of paratype; IGUT-KU0475 from Loc. SF26. Tangential sections of paratypes; IGUT-KU0472 from Loc. SF2, IGUT-KU0477 from Loc. SF16.

Genus *Pseudofusulinella* Thompson, 1951
Subgenus *Kanmeraia* Ozawa, 1967

Pseudofusulinella (*Kanmeraia*) ex gr. *pulchra* (Rauser-Chernoussova and Beljaev, 1940)

Figures 7-1—30

Fusulinella pulchra Rauser-Chernoussova and Beljaev in Rauser-Chernoussova *et al.*, 1940, p. 23-27, 73, pl. 5, figs. 1-6.

Description.—Shell medium for genus and elongate fusiform with bluntly pointed polar ends and straight to slightly concave lateral slopes. Mature specimens having 6 to 7 ½ volutions, 3.00 to 4.43 mm in length and 1.10 to 1.80 mm in width. Form ratio ranges from 2.25 to 3.16, averaging 2.57 for 22 specimens.

Shell rather compactly coiled throughout growth. Axis of coiling straight. Radius vectors of the first to seventh volution of typical oriented specimen (Figure 7-8a) 0.10, 0.15, 0.20, 0.29, 0.40, 0.53, and 0.72 mm, and form ratios 1.50, 1.80, 1.86, 1.90, 2.63, 2.82, and 2.65, respectively.

Proloculus small and spherical. Its outside diameter ranges from 0.075 to 0.130 mm, averaging 0.102 mm for 38 specimens.

Spirotheca thin and composed of a tectum, diaphanotheca, and thin upper and lower tectoria. Lower tectorium unobserved in outer one or two volutions of some specimens. Thickness of spirotheca of the first to seventh volution of specimen mentioned above 0.025, 0.025, 0.030, 0.030, 0.030, 0.035, and 0.030 mm.

Septa almost plane or very weakly fluted only in extreme polar regions. Septal counts of the first to sixth volution of one illustrated sagittal section (Figure 7-13) 10, 13, 15, 16, 18, and 21. Chomata highly asymmetrical, small and high to broad and massive, and well developed in all volutions except for the last half volution of some specimens. Tunnel side of chomata very steep, overhanging in some cases, but their outside slopes moderate to gentle. Tunnel path narrow and almost straight. Tunnel angles of the second to sixth volution of above-mentioned axial section 19, 20, 19, 25, and 31 degrees. No axial fillings present.

Remarks.—The following species are considered to comprise the species group of *pulchra ; Fusulinella usvae* Dutkevich, 1934; *Fusulinella pulchra* Rauser-Chernoussova and Beljaev, 1940; *Wedekindellina prolifica* Kanmera, 1954; *Wedekindellina* ? *hidensis* Kanuma, 1958; *Pseudofusulinella tempelensis* Ross, 1965; *Pseudofusulinella praeantiqua* Wilde, in Nassichuk and Wilde, 1977.

Pseudofusulinella (*Kanmeraia*) ex gr. *pulchra* (Rauser-Chernoussova and Beljaev) can be distinguished from "*P.* (*K.*) ex gr. *itoi* (Ozawa) et *subpulchra* Putrja" proposed by Ginkel (1987) in having a larger and more elongate fusiform shell and larger form ratio. Moreover, the former occupies a higher stratigraphic position than the latter.

Broad morphological variations in the shape of chomata and thickness of spirotheca are observed in the Taishaku specimens. Specimens with broad, massive and highly asymmetrical chomata and relatively thick spirotheca (*e.g.* Figure 7-29) are generally found in micritic limestone, whereas specimens having high and small chomata and relatively thin spirotheca (*e.g.* Figure 7-8a) commonly occur in limestone with sparitic matrix.

Figured specimens.—Axial sections; IGUT-KU0506, IGUT-KU0507 from Loc. SF10, IGUT-KU0479, IGUT-KU0480, IGUT-KU0482, IGUT-KU0484, IGUT-KU0485, IGUT-KU0486, IGUT-KU0488, IGUT-KU0489, IGUT-KU0490, IGUT-KU0493, IGUT-KU0498, IGUT-KU0500, IGUT-KU0502, IGUT-KU0504 from Loc. SF15, IGUT-KU0501, IGUT-KU0503, IGUT-KU0505 from Loc. SF20. Sagittal sections; IGUT-KU0481, IGUT-KU0483, IGUT-KU0491, IGUT-KU0492, IGUT-KU0496, IGUT-KU0497 from Loc. SF15, IGUT-KU0508 from Loc. SF19. Tangential sections; IGUT-KU0494, IGUT-KU0495, IGUT-KU0499 from Loc. SF15.

Pseudofusulinella (*Kanmeraia*) sp.

Figure 6-7

Remarks.—This unidentified species can be easily distinguished from *Pseudofusulinella* (*Kanmeraia*) ex gr. *pulchra* (Rauser-Chernoussova and Beljaev) in having a much smaller shell.

Figured specimen.—Axial section; IGUT-KU0478 from Loc. SF2.

Genus *Protriticites* Putrja, 1948

Protriticites ovatus Putrja, 1948

Figures 8-11—13

Protriticites ovatus Putrja, 1948, p. 93-94, pl. 1, fig. 9; Rauser-Chernoussova *et al.*, 1951, p. 318-319, pl. 57, fig. 3; Mikhaylova, 1974, p. 46, pl. 1, figs. 11-12, 14.

Protriticites subschwagerinoides Rozovskaya, 1950, p. 9-10, pl. 1, figs. 5-7.

Description.—Shell small and fusiform with rounded periphery. Mature specimens having 6 ½ to 7 volutions, 3.40 to 4.07 mm in length and 1.57 to 2.10 mm in width, giving form ratios of 1.94 to 2.17. Inner few volutions rather tightly coiled. Shell planispirally coiled throughout growth. Proloculus small and spherical, being 0.085 to 0.110 mm in outside diameter. Spirotheca thin and consists of a tectum, poorly defined diaphanotheca, and upper and lower tectoria in inner volutions, but of a tectum and rather thick lower perforated layer in outer ones. Septa weakly fluted only in extreme polar regions. Chomata massive and highly asymmetrical, and well developed in all volutions. Tunnel path somewhat irregular.

Remarks.—*Protriticites ovatus* was originally described by Putrja (1948) from the C_3^N ($=C_3^1$ (N)) and lower C_3^O ($=C_3^2$ (O)) Suites of eastern Donbass and can be distinguished from *P. globulus* Putrja, the type species of the genus, in having a smaller shell. The Taishaku specimens quite agree with the original one by Putrja (1948).

Protriticites subschwagerinoides described by Rozovskaya (1950) from the uppermost

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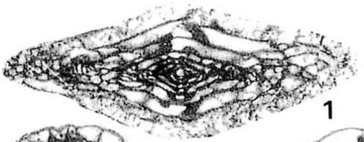
→ **Figure 7.** **1-30.** *Pseudofusulinella* (*Kanmeraia*) ex gr. *pulchra* (Rauser-Chernoussova and Beljaev), **1, 2, 4, 6-8a, 10-12, 15, 20, 22-29**: axial sections, IGUT-KU0479, IGUT-KU0480, IGUT-KU0482, IGUT-KU0484, IGUT-KU0485, IGUT-KU0486, IGUT-KU0488, IGUT-KU0489, IGUT-KU0490, IGUT-KU0493, IGUT-KU0498, IGUT-KU0500, IGUT-KU0501, IGUT-KU0502, IGUT-KU0503, IGUT-KU0504, IGUT-KU0505, IGUT-KU0506, IGUT-KU0507, **3, 5, 9, 13, 14, 18, 19, 30**: sagittal sections, IGUT-KU0481, IGUT-KU0483, IGUT-KU0487, IGUT-KU0491, IGUT-KU0492, IGUT-KU0496, IGUT-KU0497, IGUT-KU0508, **16, 17, 21**: tangential sections, IGUT-KU0494, IGUT-KU0495, IGUT-KU0499, ×15, **8b**: enlarged part of **8a**, ×50.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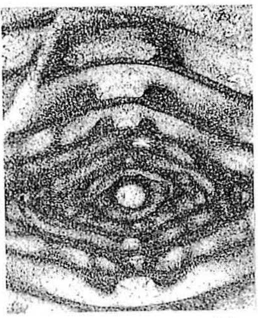
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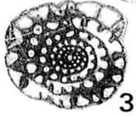
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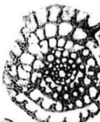
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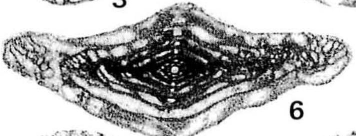
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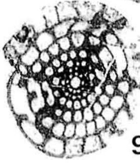
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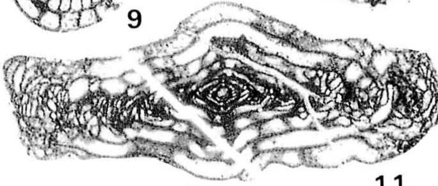
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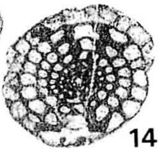
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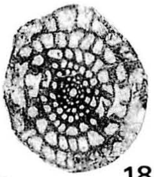
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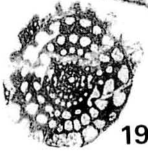
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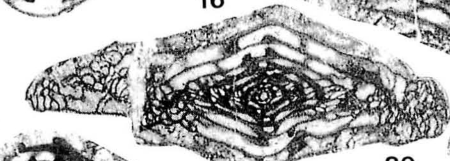
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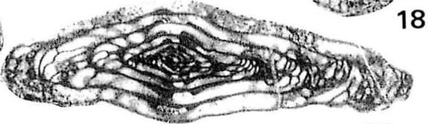
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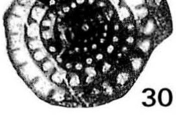
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part of the Middle Carboniferous (C_2^4 = Myachkovsky Horizon) and the lowermost part of the Upper Carboniferous ($C_3^{1-a} = C_3A_1$) of the Russian Platform has massive chomata and rather tightly coiled inner volutions, and almost the same dimension as *Protriticites ovatus* Putrja. The former seems to be identical with the latter.

Figured specimens.—Axial sections ; IGUT-KU0520, IGUT-KU0521. Sagittal section ; IGUT-KU0519. All specimens from Loc. SF21.

Genus *Obsoletes* Kireeva, 1950

Obsoletes cf. *obsoletus* (Schellwien, 1908)

Figures 8-1—9, 10 (?)

Compare.—

Fusulina obsoleta Schellwien, 1908, p. 167-168, pl. 19, figs. 5-7.

Neofusulinella obsoleta (Schellwien). Lee, 1927, p. 18-19, pl. 2, fig. 19.

Protriticites obsoletus (Schellwien). Putrja, 1948, p. 94, pl. 1, fig. 7 ; Rozovskaya, 1950, p. 10-11, pl. 1, figs. 1-4 ; Sheng, 1966, p. 37, pl. 5, fig. 1 (same as pl. 10, fig. 12 of Sheng, 1958, p. 36-37, 95-96).

Obsoletes obsoletus (Schellwien). Rauser-Chernoussova and Fursenko, 1959, pl. 7, fig. 8

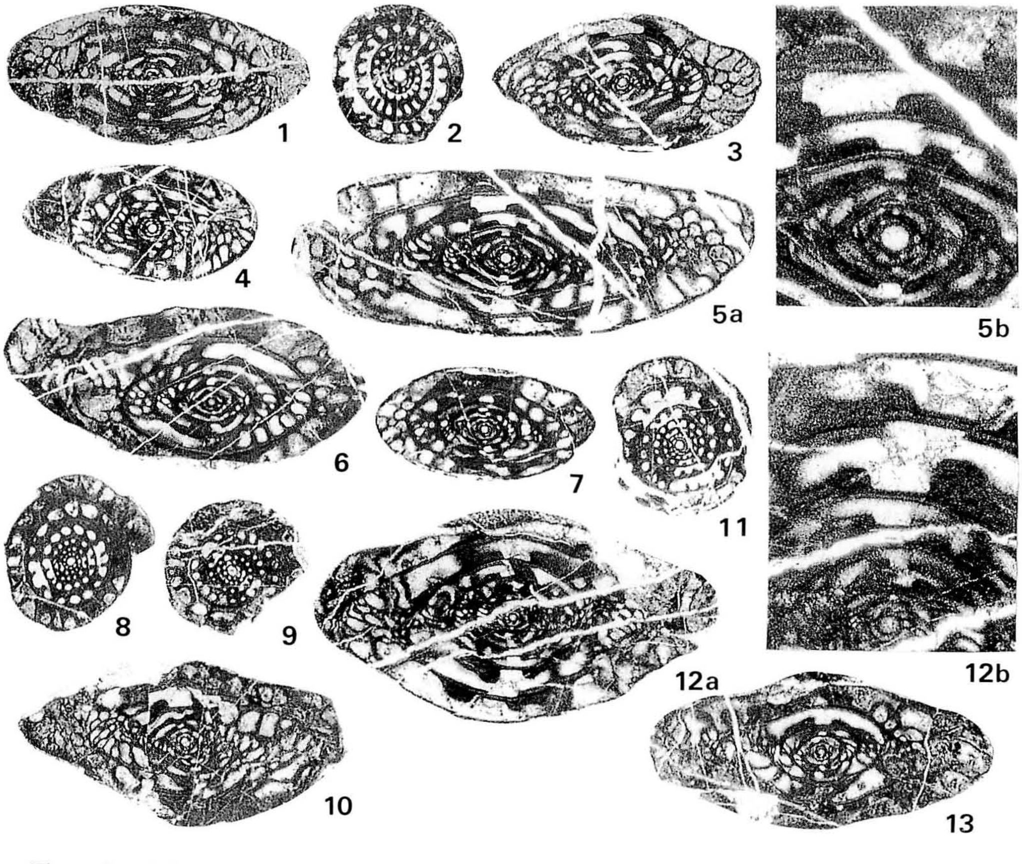


Figure 8. 1-9, 10(?). *Obsoletes* cf. *obsoletus* (Schellwien), **1, 3, 4, 5a, 6, 7, 10** : axial sections, IGUT-KU0509, IGUT-KU0511, IGUT-KU0512, IGUT-KU0513, IGUT-KU0514, IGUT-KU0515, IGUT-KU0518, **2, 8, 9** : sagittal sections, IGUT-KU0510, IGUT-KU0516, IGUT-KU0517, ×15, **5b** : enlarged part of **5a**, ×40. **11-13.** *Protriticites ovatus* Putrja, **12a, 13** : axial sections, IGUT-KU0520, IGUT-KU0521, **11** : sagittal section, IGUT-KU0519, ×15, **12b** : enlarged part of **12a**, ×40.

(same as pl. 1, fig. 2 of Rozovskaya, 1950, p. 10-11); Chen, 1963, pl. 1, figs. 2-3, pl. 2, fig. 3; Pasini, 1965, pl. 7, fig. 1 (same as pl. 19, fig. 7 of Schellwien, 1908, p. 167-168); Niikawa, 1978, p. 562-563, pl. 12, figs. 1-2; Fang, 1988, pl. 1, figs. 5-6; Ozawa and Kobayashi, 1990, pl. 3, figs. 16-18; Ozawa *et al.*, 1991, figs. 3-1—2 (same as pl. 3, figs. 16, 18 of Ozawa and Kobayashi, 1990); Watanabe, 1991, figs. 20-1—23, 22-1—3.

Obsoletes obsoletes (Schellwien). Grozdilova, 1966, p. 263-264, pl. 2, figs. 1-2; Rozovskaya, 1975, pl. 12, figs. 5-6 (5: same as pl. 19, fig. 7 of Schellwien, 1908, p. 167-168, 6: same as pl. 1, fig. 2 of Rozovskaya, 1950, p. 10-11); Grozdilova *et al.*, 1975, p. 52-53, pl. 11, fig. 2.

Obsoletes obsoleta (Schellwien). Loeblich and Tappan, 1988, pl. 267, figs. 10-12 (same as pl. 19, figs. 5-7 of Schellwien, 1908, p. 167-168).

Obsoletes cf. *obsoletus* (Schellwien). Ueno, 1991, p. 818, figs. 4-9—13.

Protriticites aff. *obsoletus* (Schellwien). Sheng, 1958, p. 36-37, 95-96, pl. 10, fig. 12.

? *Obsoletes obsoletes* (Schellwien). Mikhaylova, 1974, p. 47, pl. 1, fig. 13.

Remarks.—The Taishaku specimens possess a slightly larger shell than those previously referred to *Obsoletes obsoletus* (Schellwien) including the original ones. The referral to *Obsoletes obsoletus* (Schellwien) is therefore tentative.

The present species is probably conspecific with *Obsoletes* cf. *obsoletus* (Schellwien) described by Ueno (1991) from the uppermost part of the *Protriticites* sp. Zone of the Akiyoshi Limestone Group, southwest Japan.

Figured specimens.—Axial sections; IGUT-KU0509, IGUT-KU0511, IGUT-KU0512, IGUT-KU0513, IGUT-KU0514, IGUT-KU0515, IGUT-KU0518. Sagittal sections; IGUT-KU0510, IGUT-KU0516, IGUT-KU0517. All specimens from Loc. SF21.

Subfamily Fusulininae von Möller, 1878

Genus *Fusulina* Fischer de Waldheim, 1829 emend. Ishii, 1958

Fusulina quasicylindrica Lee, 1927

Figures 9-1—23

Fusulina (*Girtyina*) *quasicylindrica* Lee, 1927, p. 35-39, pl. 4, figs. 10-19; Lee and Chen in Lee *et al.*, 1930, p. 133-134, pl. 12, figs. 8-14, pl. 13, figs. 1-4.

Girtyina quasicylindrica var. *brevis* Lee, 1927, p. 39-40, pl. 5, figs. 1-2.

Fusulina quasicylindrica (Lee). Rauser-Chernoussova in Rauser-Chernoussova *et al.*, 1951, p. 305-306, pl. 52, figs. 2-4; Sheng, 1958, p. 48, 107-108, pl. 15, figs. 15-18, pl. 16, figs. 1-4; Sheng, 1966, p. 46, pl. 6, fig. 6 (same as pl. 4, fig. 15 of Lee, 1927, p. 35-39); Sheng *et al.*, 1976, pl. 3, figs. 17-21; Lin *et al.*, 1977, p. 29-30, pl. 6, fig. 2; Wang *et al.*, 1982, p. 47, pl. 8, fig. 14; Xie, 1982, p. 15, pl. 5, fig. 12; Zhang and Jiang, 1984, pl. 1, figs. 22, 26; Xia and Zhang, 1985, p. 61-62, pl. 7, fig. 1; Wang, 1987, pl. 1, fig. 28; Zhang *et al.*, 1987, p. 257, pl. 4, fig. 5; Lin *et al.*, 1991, p. 101, pl. 17, figs. 18, 19, 21.

Fusulina quasicylindrica var. *compacta* Sheng, 1958, p. 48-49, 108, pl. 16, figs. 5-7; Sheng, 1966, p. 47, pl. 6, fig. 10 (same as pl. 16, fig. 5 of Sheng, 1958, p. 48-49, 108); Wu *et al.*, 1974, pl. 5, fig. 23; Zhang and Wang, 1974, p. 260, pl. 131, fig. 12; Xia and Zhang, 1985, p. 62, pl. 6, fig. 8.

Fusulina quasicylindrica var. *megasphaerica* Sheng, 1958, p. 49, 108, pl. 16, figs. 8-10; Sun *et al.*, 1983, p. 15, pl. 3, fig. 14; Zhang *et al.*, 1987, p. 257, pl. 4, figs. 6-7.

Fusulina quasicylindrica var. *brevis* (Lee). Sheng, 1966, p. 46-47, pl. 6, fig. 11 (same as pl. 5, fig. 1 of Lee, 1927, p. 39-40)

Fusulina megasphaerica Sheng. Lin *et al.*, 1991, p. 100, pl. 17, figs. 14-16.

? *Fusulina quasicylindrica* (Lee). Kanuma, 1958, p. 33, pl. 3, figs. 24-26.

Description.—Shell large for genus and elongate cylindrical with bluntly pointed axial regions. Mature specimens having 6 to 8, rarely 8 ½ volutions, 5.20 to 7.95 mm in length and 1.70 to 2.80 mm in width. Form ratio varies from 2.87 to 3.98, averaging 3.24 for 11 specimens.

Shell rather tightly coiled throughout growth. Axis of coiling straight. Radius vectors of the first to eighth volution of typical axial section (Figure 9-6a) 0.11, 0.16, 0.22, 0.28, 0.38, 0.50, 0.66, and 0.88 mm, and form ratios 1.09, 1.63, 2.09, 3.34, 3.67, 4.02, 4.01, and 3.93, respectively.

Proloculus commonly spherical, but rarely somewhat irregular. Outside diameter of proloculus ranges from 0.160 to 0.265 mm, averaging 0.212 mm for 27 specimens.

Spirotheca thin and composed of a tectum, diaphanotheca, and poorly defined upper and lower tectoria. Thickness of spirotheca of the second to eighth volution of above-mentioned specimen 0.020, 0.025, 0.025, 0.030, 0.025, 0.045, and 0.050 mm.

Septa thin, numerous, and intensely and regularly fluted throughout shell length except for tunnel path. Septal counts of the first to eighth volution of one sagittal section (Figure 9-20) 12, 20, 24, 27, 35, 40, 43, and 49 ?, respectively. Chomata small and commonly developed in only inner few volutions, but rarely observed in middle ones of some specimens. Tunnel path narrow and straight. Tunnel angles of the second to seventh volution of above-mentioned axial section 13, 16, 17, 20, 20, and 26 degrees. Weak axial fillings developed in most specimens.

Remarks.—The Taishaku specimens are almost identical with the original ones of *Fusulina quasicylindrica* Lee, except for having a slightly larger shell, more volutions and slightly smaller form ratio.

Sheng (1958) proposed two new varieties, *compacta* and *megaspherica,* for *Fusulina quasicylindrica* Lee. The former is characterized by a compactly coiled shell and small proloculus, and the latter by a larger proloculus, somewhat loosely coiled shell, and absence of axial fillings. These morphological characters, however, are seemingly considered to demonstrate merely an intraspecific variation.·

Fusulina quasicylindrica Lee can be distinguished from *F. cylindrica* (Fischer de Waldheim), the type species of the genus, in having a larger shell and more volutions.

Figured specimens.—Axial sections (including slightly oblique sections); IGUT-KU0543 from Loc. SF9, IGUT-KU0522, IGUT-KU0524, IGUT-KU0525, IGUT-KU0526, IGUT-KU0527, IGUT-KU0529, IGUT-KU0530, IGUT-KU0531, IGUT-KU0532, IGUT-KU0535, IGUT-KU0536, IGUT-KU0537, IGUT-KU0538, IGUT-KU0539, IGUT-KU0540, IGUT-KU0544 from Loc. SF15. Sagittal sections; IGUT-KU0523, IGUT-KU0528, IGUT-KU0533, IGUT-KU0534, IGUT-KU0541, IGUT-KU0542 from Loc. SF15.

Family Schwagerinidae Dunbar and Henbest, 1930

Subfamily Schwagerininae Dunbar and Henbest, 1930

Genus *Triticites* Girty, 1904

Subgenus *Triticites* Girty, 1904

Triticites (*Triticites*) *schwageriniformis* Rauser-Chernoussova, 1938

Figures 10-13—15

Triticites schwageriniformis Rauser-Chernoussova, 1938, p. 107-108, 155, pl. 3, figs. 1-3 ; Grozdilova and Lebedeva, 1960, p. 177-178, pl. 32, fig. 4 ; Chen and Wang, 1983, p. 59-60, pl. 6, fig. 14, pl. 8, figs. 12-14, pl. 9, fig. 1 ; Zhou *et al.*, 1987, pl. 1, figs. 9-10 ; Lin *et al.*, 1991, p. 106-107, pl. 18, figs. 16-18.

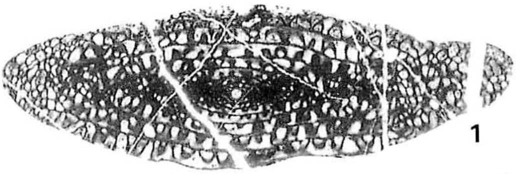
Triticites (*Triticites*) *schwageriniformis schwageriniformis* Rauser-Chernoussova. Rozovskaya, 1950, p. 23, pl. 5, figs. 1-5 ; Rozovskaya, 1958, p. 88, pl. 3, fig. 11

Triticites schwageriniformis parallelos Scherbovich, 1969, p. 9-10, pl. 2, figs. 6-10 ; Isakova and Nazarov, 1986, p. 26-27, pl. 2, fig. 1.

Triticites schwageriniformis parallelos forma *compacta* Scherbovich, 1969, p. 10, pl. 2, fig. 11.

Triticites schwageriniformis schwageriniformis Rauser-Chernoussova. Mikhaylova, 1974, p.

→ **Figure 9. 1-23.** *Fusulina quasicylindrica* Lee, **1, 3-5, 6a, 8-11, 14-19, 22, 23** : axial sections (including slightly oblique axial sections), IGUT-KU0522, IGUT-KU0524, IGUT-KU0525, IGUT-KU0526, IGUT-KU0527, IGUT-KU0529, IGUT-KU0530, IGUT-KU0531, IGUT-KU0532, IGUT-KU0535, IGUT-KU0536, IGUT-KU0537, IGUT-KU0538, IGUT-KU0539, IGUT-KU0540, IGUT-KU0543, IGUT-KU0544, **2, 7, 12, 13, 20, 21** : sagittal sections, IGUT-KU0523, IGUT-KU0528, IGUT-KU0533, IGUT-KU0534, IGUT-KU0541, IGUT-KU0542, ×10, **6b** : enlarged part of **6a,** ×50.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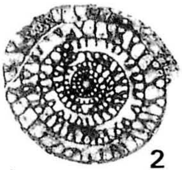
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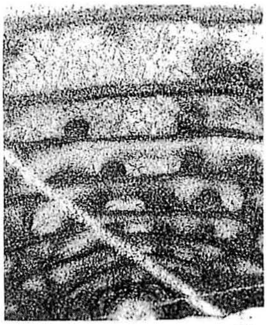
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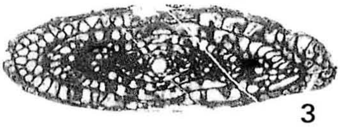
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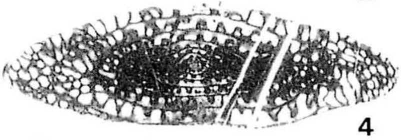
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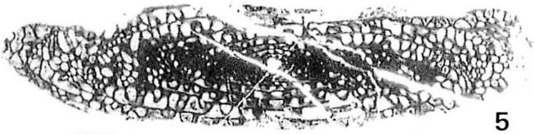
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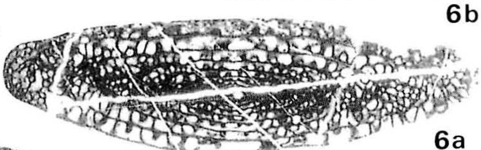
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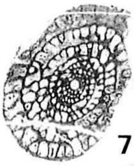
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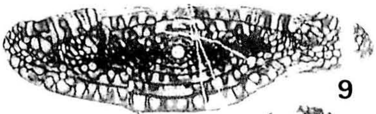
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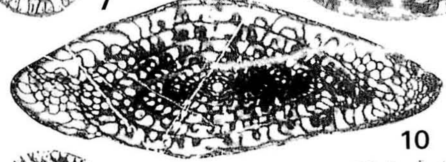
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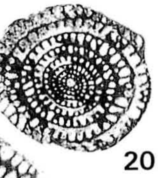
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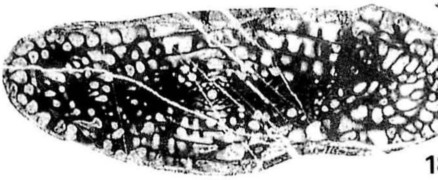
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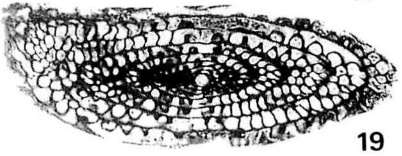
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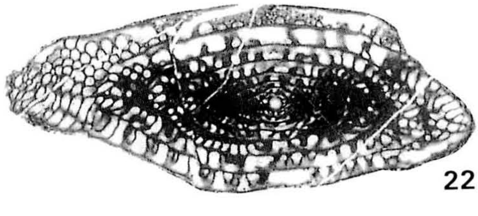
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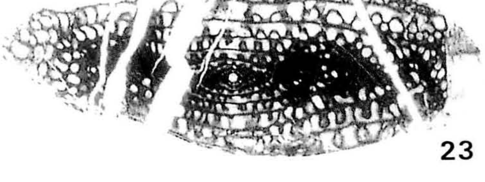
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54-55, pl. 3, figs. 7-8 ; Grozdilova *et al*., 1975, p. 57, pl. 13, fig. 1.

Remarks.—Several subspecies have been proposed for *Triticites* (*T.*) *schwageriniformis* Rauser-Chernoussova. Among them, *Triticites* (*T.*) *schwageriniformis parallelos*, originally described by Scherbovich (1969) from the upper Kasimovian and Gzhelian of the Precaspian Syneclise, seems to be conspecific with *Triticites* (*T.*) *schwageriniformis* (s.s.), judging from the original illustration.

Figured specimens.—Axial sections ; IGUT-KU0556 from Loc. SF32, IGUT-KU0557 from Loc. SF12. Sagittal section ; IGUT-KU0558 from Loc. SF12.

Subgenus *Rauserites* Rozovskaya, 1948

Triticites (*Rauserites*) *stuckenbergi* Rauser-Chernoussova, 1938

Figures 10-1—5

Triticites stuckenbergi Rauser-Chernoussova, 1938, p. 110-112, 155-156, pl. 3, figs. 4, 9 ; Grozdilova and Lebedeva, 1960, p. 173-174, pl. 29, fig. 4 ; Mikhaylova, 1974, p. 59, pl. 4, fig. 6 ; Grozdilova *et al*., 1975, p. 57, pl. 12, fig. 9 (same as pl. 29, fig. 4 of Grozdilova and Lebedeva, 1960, p. 173-174) ; Rozovskaya, 1975, pl. 13, fig. 2 (same as pl. 3, fig. 4 of Rauser-Chernoussova, 1938, p. 110-112, 155-156) ; Chen and Wang, 1983, p. 66-67, pl. 10, fig. 16, pl. 20, fig. 13 ; Xia and Zhang, 1985, p. 82, pl. 8, fig. 13 ; Loeblich and Tappan, 1988, pl. 284, fig. 10 (same as pl. 3, fig. 4 of Rauser-Chernoussova, 1938, p. 110-112, 155-156) ; Fang, 1988, pl. 1, fig. 24 ; Xia in Ding *et al*., 1991, pl. 4, fig. 13 ; Watanabe, 1991, figs. 4-21—24, 27, 9-1—6.

Triticites (*Rauserites*) *stuckenbergi* Rauser-Chernoussova. Rozovskaya, 1950, p. 33-34, pl. 6, figs. 10-13 ; Rozovskaya, 1958, p. 94, pl. 6, fig. 4 ; Chuvashov *et al*., 1986, p. 77, pl. 11, fig. 7 ; Ozawa and Kobayashi, 1990, pl. 4, fig. 12 ; Ozawa *et al*., 1991, figs. 3-12—13.

Description.—Shell medium for genus and fusiform with bluntly pointed polar ends. Mature shell of 6 to 7 ½ volution 4.50 to 5.15 mm in length and 2.13 to 2.55 mm in width, giving form ratios of 2.05 to 2.14.

Early volutions somewhat tightly coiled as compared with outer ones. Axis of coiling straight throughout. Radius vectors of the first to seventh volution of oriented specimen illustrated on Figure 10-1 ; 0.10, 0.17, 0.26, 0.41, 0.62, 0.87, and 1.16 mm, and form ratios 1.40, 1.28, 1.66, 1.74, 1.94, 2.02, and 2.03, respectively.

Proloculus small and spherical. Its outside diameter ranges from 0.120 to 0.190 mm, averaging 0.145 mm for 4 specimens.

Spirotheca thin and composed of a tectum and keriotheca. Thickness of spirotheca of the first to seventh volution of above-mentioned specimen 0.015, 0.030, 0.030, 0.050, 0.070, 0.075, and 0.045 mm.

Septa moderately fluted in polar regions, but intensity decreases toward central part of shell. Chomata present in all volutions except for the last one in some specimens. Tunnel angles of the first to sixth volution of above-mentioned specimen 29, 20, 20, 22, 28, and 38 degrees.

Remarks.—*Triticites* (*Rauserites*) *stuckenbergi* was originally described by Rauser-Chernoussova (1938) from the Upper Carboniferous of the Samara Bend in the Russian Platform. Recently, Watanabe (1991) illustrated many specimens of the present species from the *Schwagerina* ? *satoi* Zone of the Atetsu Limestone Group, southwest Japan. The Taishaku specimens are almost identical with the Atetsu ones.

Figured specimens.—Axial sections ; IGUT-KU0545, IGUT-KU0546 from Loc. SF31, IGUT-KU0547 from Loc. SF32. Sagittal section ; IGUT-KU0549 from Loc. SF32. Tangential section ; IGUT-KU0548 from Loc. SF12.

Triticites (*Rauserites*) *lucidus* Rauser-Chernoussova, 1958

Figures 10-6—8

Triticites lucidus Rauser-Chernoussova, 1958, p. 133-134, pl. 1, fig. 4.

Triticites (*Rauserites*) *lucidus* Rauser-Chernoussova.

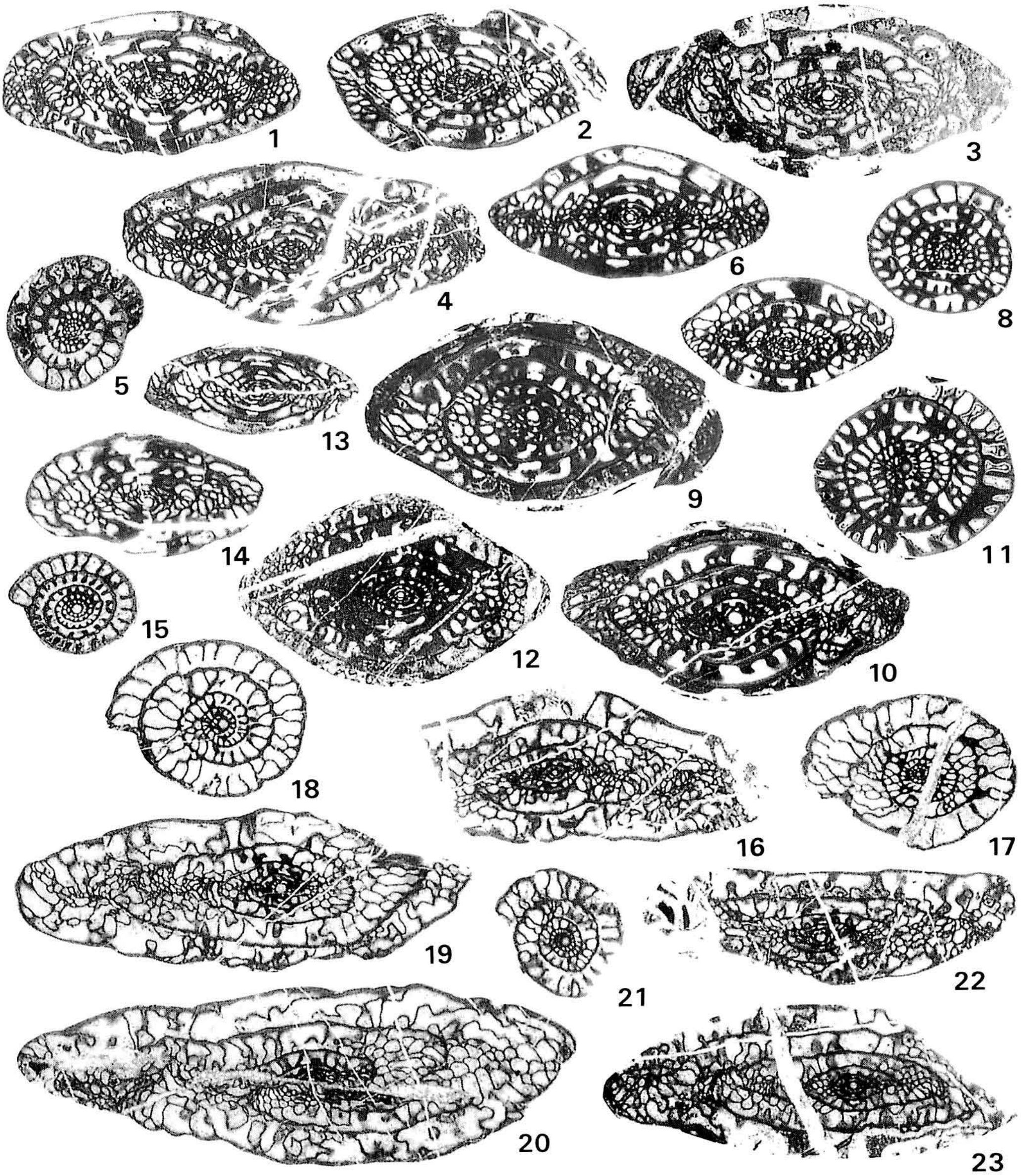

Figure 10. **1–5.** *Triticites* (*Rauserites*) *stuckenbergi* Rauser-Chernoussova, **1–3**: axial sections, IGUT-KU0545, IGUT-KU0546, IGUT-KU0547, **4**: tangential section, IGUT-KU0548, **5**: sagittal section, IGUT-KU0549. **6–8.** *Triticites* (*Rauserites*) *lucidus* Rauser-Chernoussova, **6, 7**: axial sections, IGUT-KU0550, IGUT-KU0551, **8**: sagittal section, IGUT-KU0552. **9–11.** *Jigulites dagmarae* (Rozovskaya), **9, 10**: axial sections, IGUT-KU0553, IGUT-KU0554, **11**: sagittal section, IGUT-KU0555. **12**: *Jigulites* sp., axial section, IGUT-KU0559. **13–15.** *Triticites* (*Triticites*) *schwageriniformis* Rauser-Chernoussova, **13, 14**: axial sections, IGUT-KU0556, IGUT-KU0557, **15**: sagittal section, IGUT-KU0558. **16, 17.** *Occidentoschwagerina chatcalica* Bensh, **16**: axial section, IGUT-KU0560, **17**: sagittal section, IGUT-KU0561. **18–20.** *Rugosofusulina* sp. A, **18**: sagittal section, IGUT-KU0562, **19, 20**: axial sections, IGUT-KU0563, IGUT-KU0564. **21–23.** *Rugosofusulina* ? sp. B, **21**: sagittal section, IGUT-KU0565, **22, 23**: axial sections, IGUT-KU0566, IGUT-KU0567. All ×10.

Rozovskaya, 1958, p. 100, pl. 9, figs. 6-7.

Description.—Shell small and fusiform with bluntly pointed axial regions and gently rounded periphery. Mature shell of 6 to 7 volutions 3.13 to 4.28 mm in length and 1.75 to 2.15 mm in width, giving a form ratio of 1.79 to 2.11.

Axis of coiling straight throughout. Inner few volutions rather compactly coiled, but outer ones uniformly expanded. Radius vectors of the first to seventh volution of one axial section (Figure 10-6) 0.09, 0.15, 0.23, 0.38, 0.57, 0.81, and 1.08 mm, and form ratios of 1.33, 1.47, 1.63, 1.56, 1.88, 1.94, and 1.96, respectively.

Proloculus small and spherical, being 0.085 to 0.130 mm in outside diameter.

Spirotheca thin and composed of a tectum and keriotheca. Thickness of spirotheca of the first to seventh volution of above-mentioned specimen 0.015, 0.025, 0.040, 0.050, 0.060, 0.075, and 0.055 mm.

Septa moderately and regularly fluted throughout length of shell, except for its central part. Chomata small and developed in all volutions. Tunnel path narrow and almost straight. Tunnel angles of the second to seventh volution of specimen mentioned above 22, 21, 23, 23, 28, and 31 degrees.

Remarks.—The Taishaku specimens are slightly larger in shell size than Rauser-Chernoussova's original ones from the *Triticites stuckenbergi* Zone of an early Gzhelian age.

Figured specimens.—Axial sections ; IGUT-KU0550, IGUT-KU0551. Sagittal section ; IGUT-KU0552. All specimens from Loc. SF31.

Genus *Jigulites* Rozovskaya, 1948

Jigulites dagmarae (Rozovskaya, 1950)

Figures 10-9—11

Triticites (*Jigulites*) *dagmarae* Rozovskaya, 1950, p. 39-40, pl. 8, figs. 6-7 ; Rozovskaya, 1958, p. 103, pl. 10, fig. 6.

Jigulites ? ex gr. *dagmarae* (Rozovskaya). Davydov, 1990, pl. 1, fig. 5.

Schwagerina dagmarae (Rozovskaya). Watanabe, 1991, figs. 9-12—18.

Description.—Shell medium for genus and inflated fusiform with broadly expanded periphery and almost straight lateral slopes. Mature specimens having 5 to 6 volutions, 5.20 to 5.53 mm in length and 2.78 to 2.88 mm in width with form ratios of 1.81 to 1.99.

The first volution tightly coiled. Shell expands rather rapidly beyond the second volution. Axis of coiling straight throughout growth. Radius vectors of the first to fifth volution of one illustrated axial section (Figure 10-10) 0.18, 0.30, 0.51, 0.81, and 1.18 mm, and form ratios 1.05, 2.03, 1.96, 1.71, and 1.75, respectively.

Proloculus almost spherical and measures from 0.190 to 0.170 mm in outside diameter.

Spirotheca rather thick and composed of a tectum and keriotheca. Thickness of spirotheca of the first to fifth volution of above-mentioned specimen 0.030, 0.045, 0.060, 0.100, and 0.080 mm.

Septa intensely and regularly fluted throughout shell length, forming narrow and high septal loops. Chomata massive and developed from the first to penultimate volution. Tunnel path narrow and somewhat irregular.

Remarks.—*Jigulites dagmarae* was described by Rozovskaya (1950) from the C_3^{1-d} and *Pseudofusulina* Horizons (middle and upper Gzhelian) of the Russian Platform. Recently, Watanabe (1991) reported this species from the *Schwagerina* ? *satoi* Zone of the Omi Limestone Group, central Japan.

Figured specimens.—Axial sections ; IGUT-KU0553 from Loc. SF33, IGUT-KU0554 from Loc. SF32. Sagittal section ; IGUT-KU0555 from Loc. SF32.

Jigulites sp.

Figure 10-12

Remarks.—The present unidentified

species can be distinguished from *Jigulites dagmarae* (Rozovskaya) in having a more inflated and tightly coiled shell, more massive chomata and smaller proloculus.

Figured specimen.—Axial section ; IGUT-KU0559 from Loc. SF12.

Genus *Occidentoschwagerina* Miklukho-Maklay, 1959

Occidentoschwagerina chatcalica Bensh, 1962

Figures 10-16—17

Occidentoschwagerina fusulinoides chatcalica Bensh, 1962, p. 220-221, pl. 14, figs. 1-2.

Occidentoschwagerina chatcalica Bensh. Bensh, 1972, p. 115, pl. 26, figs. 1-2 ; Davydov, 1990, pl. 3, figs. 3-4.

Descriptive remarks.—Shell small for genus and fusiform with bluntly pointed polar ends. Mature specimens of 5 to 6 volutions 5.60 to 6.30 mm in length and 2.40 to 2.90 mm in width, giving form ratios of 2.33 to 2.63. Inner few volutions tightly coiled. Outer ones expand rather rapidly and become loose. Proloculus small, being 0.050 to 0.070 mm in outside diameter. Spirotheca thin and composed of a tectum and keriotheca, and showing some rugosity. Septa intensely and rather irregularly fluted throughout shell length. Chomata observed only in inner volutions.

Occidentoschwagerina chatcalica was originally described by Bensh (1962) from North Fergana. Later, it was recorded from the Asselian *Occidentoschwagerina alpina* and *"Schwagerina" moelleri-Pseudofusulina fecunda* Zones of South Fergana by Bensh (1972). Recently, this species was reported from the uppermost Gzhelian *Daixina postsokensis* Zone of the Predonets Depression by Davydov (1990).

Occidentoschwagerina tianshanensis described by Chang (1963) from Xinjiang is the closest to the present species. However, the former differs from the latter in having a larger form ratio and less expanded outer volutions.

Figured specimens.—Axial section ; IGUT-KU0560. Sagittal section ; IGUT-KU0561. Both specimens from Loc. SF34.

Subfamily Rugosofusulininae Davydov, 1980

Genus *Rugosofusulina* Rauser-Chernoussova, 1937

Rugosofusulina sp. A

Figures 10-18—20

Remarks.—The present unidentified species somewhat resembles *Rugosofusulina alpina* (Schellwien), especially *R. alpina* var. *communis* described and illustrated by Schellwien (1898). The former, however, differs from the latter in having more massive chomata and more compactly coiled inner volutions.

This species can be distinguished from *Rugosofusulina prisca* [(Ehrenberg) emend. Möller], the type species of the genus, in having a larger shell and more expanded outer volutions.

Figured specimens.—Axial sections ; IGUT-KU0563, IGUT-KU0564. Sagittal section ; IGUT-KU0562. All specimens from Loc. SF34.

Rugosofusulina ? sp. B

Figures 10-21—23

Remarks.—This species can be easily distinguished from *Rugosofusulina* sp. A in having a smaller and more elongate shell, and larger form ratio. It is slightly similar to some species of the genus *Schagonella.* In this study, the present species is, therefore, tentatively referred to the genus *Rugosofusulina.*

Figured specimens.—Axial sections ; IGUT-KU0566, IGUT-KU0567. Sagittal section ; IGUT-KU0565. All specimens from Loc. SF34.

Family Staffellidae Miklukho-Maklay, 1949

Genus *Nankinella* Lee, 1934

Nankinella sp.

Figures 5-1—2

Remarks.—The present species somewhat resembles *Nankinella yokoyamai* described by Sada (1972) from the *Profusulinella* Zone of the Taishaku Limestone Group. The exact specific identification of this species, however, is postponed owing to insufficiency of material.

Figured specimens.—Axial sections; IGUT-KU0464, IGUT-KU0465 from Loc. SF15.

Acknowledgments

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Akiyoshi 秋吉, Atetsu 阿哲, Dangyokei 断魚渓, Eimyoji 永明寺, Hiroshima 広島, Huanglong (Huanglung) 黄龍, Omi 青海, Taishaku 帝釈, Tojo 東城, Simotaishakukyou 下帝釈峡, Unata 宇那田, Uyamano 宇山野, Xinjiang 新彊.

西南日本，帝釈石灰岩層群の中−上部石炭系紡錘虫類：西南日本内帯，帝釈台南部の宇那田地域南方に分布する帝釈石灰岩層群中央相の永明寺層最上部および宇山野層最下部の紡錘虫生層序を検討し，永明寺層中に *Fusulinella bingoensis* 帯，*Fusulina quasicylindrica* 帯，*Obsoletes* cf. *obsoletus-Protriticites ovatus* 帯を，そして宇山野層中に *Triticites* (*Rauserites*) *stuckenbergi-Jigulites dagmarae* 帯，*Occidentoschwagerina chatcalica* 帯を設定した。各化石帯の紡錘虫群集とモスコー陸向斜，南部ウラル，ドネツ盆地，中央アジア，南部中国などで知られている紡錘虫群集との比較から，*Fusulinella bingoensis* 帯と *Fusulina quasicylindrica* 帯が Moscovian 後期の Myachkovsky Horizon に，*Obsoletes* cf. *obsoletus-Protritcites ovatus* 帯が前期 Kasimovian に *Triticites* (*Rauseries*) *stuckenbergi-Jigulites dagmarae* 帯と *Occidentoschwagerina chatcalica* 帯が Gzhelian にそれぞれ対比できる。こ

の対比により，宇那田地域では永明寺層と宇山野層はほぼ中―上部Kasimovianを欠く不整合関係で接しており，また従来下―中部ペルム系とされていた宇山野層の一部は少なくとも上部石炭系であることが明らかとなった。本論では1新種（*Fusulinella bingoensis*, sp. nov.）を含む11属16種の紡錘虫類を記載するとともに，秋吉帯の上部古生界石灰岩地域ではこれまであまりよく理解されていなかった*Fusulina*帯とその紡錘虫群集の生層序学的意義についても述べる。

上野勝美・水野嘉宏

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954. THE RELATIONSHIP BETWEEN BATHYMETRIC DEPTH AND CLIMATE CHANGE AND ITS EFFECT ON MOLLUSCAN FAUNAS OF THE KAKEGAWA GROUP, CENTRAL JAPAN*

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Abstract. Seven types of molluscan assemblages are recognized in the muddy sand and silt facies of the Plio-Pleistocene Kakegawa Group, central Japan. Both facies are continuously distributed throughout late Pliocene to earliest Pleistocene times. The assemblages have species compositions comparable to the living faunas in upper sublittoral to bathyal depths under influence of the Kuroshio warm current. I trace the temporal distributions of species characteristic of each bathymetric zone. Groups of warm-water species in the upper sublittoral zone disappeared in steps through the time interval considered in this paper. By contrast, warm-water species in the lower sublittoral zone and Japonic endemic species in all depths occurred throughout the interval. The assemblages of the lower sublittoral and bathyal zones show no marked changes through time, and are closely similar to those of the present sea off central Japan. Next, to confirm the cooling effect on organisms in each bathymetric zone, I also compare temporal distributions between taxonomically close species and specify the habitats of the disappearing species, the other ecological characters being similar. The comparisons indicate that the cooling effect was restricted to the upper sublittoral zone. The results reflect fluctuations of the thermal structure of the sea off central Japan during Plio-Pleistocene time.

Key words. Kakegawa Group, Kakegawa fauna, molluscan assemblage, cooling of sea water, water mass structure, Plio-Pleistocene.

Introduction

The Plio-Pleistocene Kakegawa Group is exposed in the western part of Shizuoka Prefecture, central Japan. It is one of the type areas of the Neogene series along the Pacific coast of Southwest Japan. The standard sequence has been established on the basis of planktonic foraminiferal biostratigraphy (*e.g.*, Saito, 1960; Ibaraki, 1986a, b), magnetostratigraphy (Yoshida and Niitsuma, 1976; Ishida *et al.*, 1980), and fission track dating (Nishimura, 1977). The Kakegawa Group yields abundant marine molluscan fossils and many paleontological studies have been made since the descriptive works of Yokoyama (1923, 1926) and Makiyama (1927). The molluscan fauna consists of communities in an open sea condition. It is called "the Kakegawa fauna" and is well known in Japan as the late Pliocene-earliest Pleistocene warm-water fauna of southwestern Japan.

Tsuchi (1961) showed a stratigraphic range chart of representative molluscan species of the Kakegawa fauna. On the basis of temporal changes in the fauna, Tsuchi (1961) divided the Kakegawa Group into four

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stages, the Totomian, Suchian, Kechienjian and Yuzanjian, in ascending order. Many warm-water species are abundant in the Suchian stage. They are characteristic species of the Kakegawa fauna, such as *Amussiopecten praesignis, Venericardia panda, Chlamys satoi, Turritella perterebra* and so on. Some of these species declined during the Kechienjian stage and most of them disappeared during the Yuzanjian stage. Moreover, some Japonic endemic genera such as *Suchium* and *Siphonalia* show morphological changes at the subspecific or specific level through these stages (Makiyama, 1925, 1941). Tsuchi (1990) suggested that these faunal changes are related to cooling of the sea water. These cooling events were recognized also as temporal changes in the planktonic foraminiferal assemblage of the Kakegawa Group (Ibaraki, 1986b).

The stratigraphic range chart of the molluscan species shown by Tsuchi (1961), however, focused on key species whose temporal distributions are restricted to particular stages. It is not clear from his chart which species occur throughout the four stages. Moreover, almost all of the key species used for the recognition of the stages occur mainly in shallow, marginal facies such as the Dainichi Formation. With respect to the deep offshore molluscan fauna, Chinzei (1980) described molluscan associations characteristic of lower sublittoral to upper bathyal depths along an isochronous tuff layer in rocks ascribed to the Kechienjian stage. Paleontological studies of the deep offshore fauna, however, have not covered all the Kakegawa Group, and the temporal change in the deep molluscan fauna has not been studied. Therefore, the relationship between bathymetric depth and the cooling effect on marine organisms has not been examined previously.

In this paper, I examine the temporal change of molluscan assemblages in each depth zone from the Suchian to the Yuzanjian. I recognize seven types of fossil molluscan assemblages. Their depositional environments range from a muddy sand bottom in the upper sublittoral zone to a silt bottom in the bathyal zone. I compare assemblages of different ages that were deposited at similar depths and with similar bottom characters. Morphological change at the subspecific level through time, however, is beyond the scope of this report, because I could not obtain enough specimens to study these forms biometrically. This study focuses on tracing the temporal distributions of species characteristic of each depth zone to make clear the thermal fluctuations of the sea water through time in each depth zone.

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Geologic setting of collecting localities

The upper part of the Kakegawa Group is ascribed to the Suchian to Yuzanjian stages. Its lithofacies changes laterally. That is, a northwestern shallow-sea facies grades laterally into a southeastern deep-sea facies (Figures 1, 2). The northwestern part consists of the Dainichi Formation (fine to medium-grained sand), the Ukari Formation (fine-grained sand and muddy sand), and the Soga Formation (gravels, fine to medium-grained sand, and muddy sand), in ascending order. The southeastern part consists of the Horinouchi Formation (alternating beds of sand and silt of turbidite facies), and the Hijikata Formation (massive silt), in ascending order. The vertical change in the lithofacies possibly results from a global eustatic sea-level change during the Plio-Pleistocene (Masuda and Ishibashi, 1991). The middle parts of the Ukari and Hijikata Formations are at the climax of the transgression, and the Soga Formation was deposited during the regressive phase.

Several tuff layers have been traced through the different lithofacies, forming key horizons in the Kakegawa Group. Of these, the Hosoya Tuff and the Soga Tuff are important key beds in the upper part of the Kakegawa Group.

The Hosoya Tuff (Tsuchi, 1961) is interbedded in the lower part of the Ukari Formation and the uppermost part of the Horinouchi Formation. The tuff has been dated at 1.9

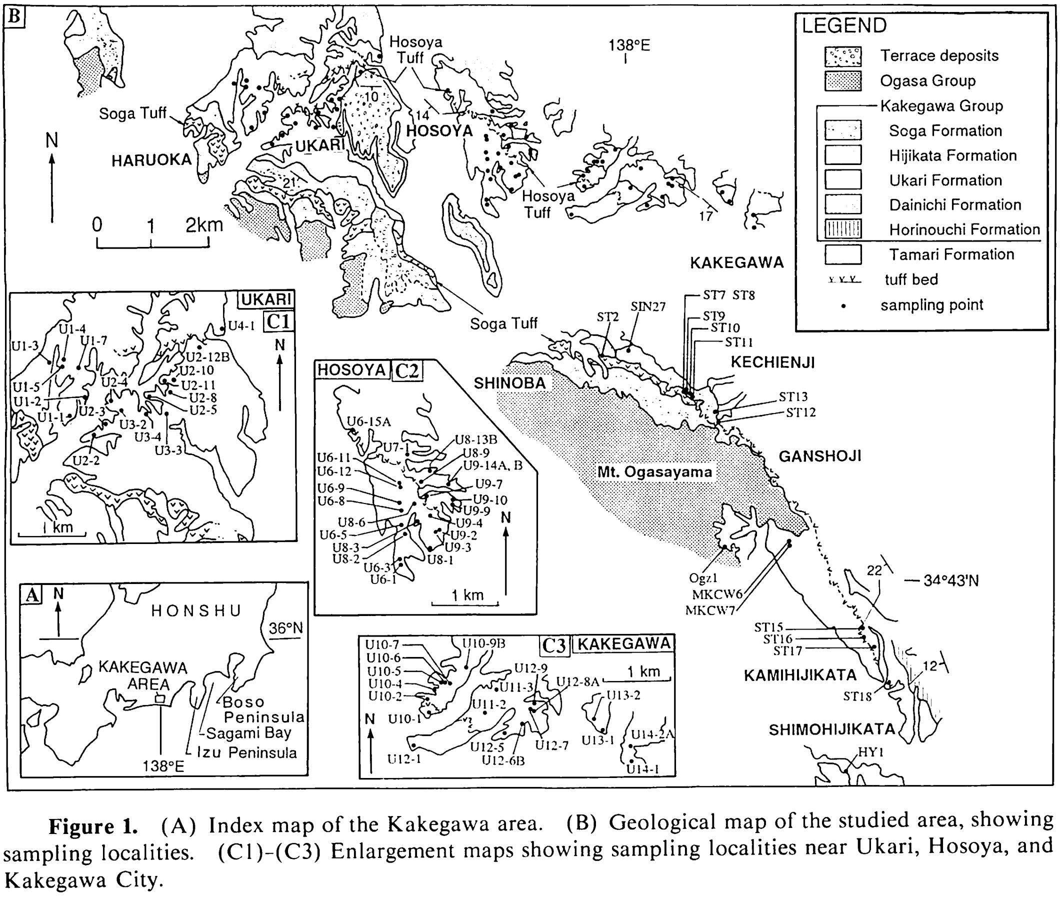


Figure 1. (A) Index map of the Kakegawa area. (B) Geological map of the studied area, showing sampling localities. (C1)-(C3) Enlargement maps showing sampling localities near Ukari, Hosoya, and Kakegawa City.

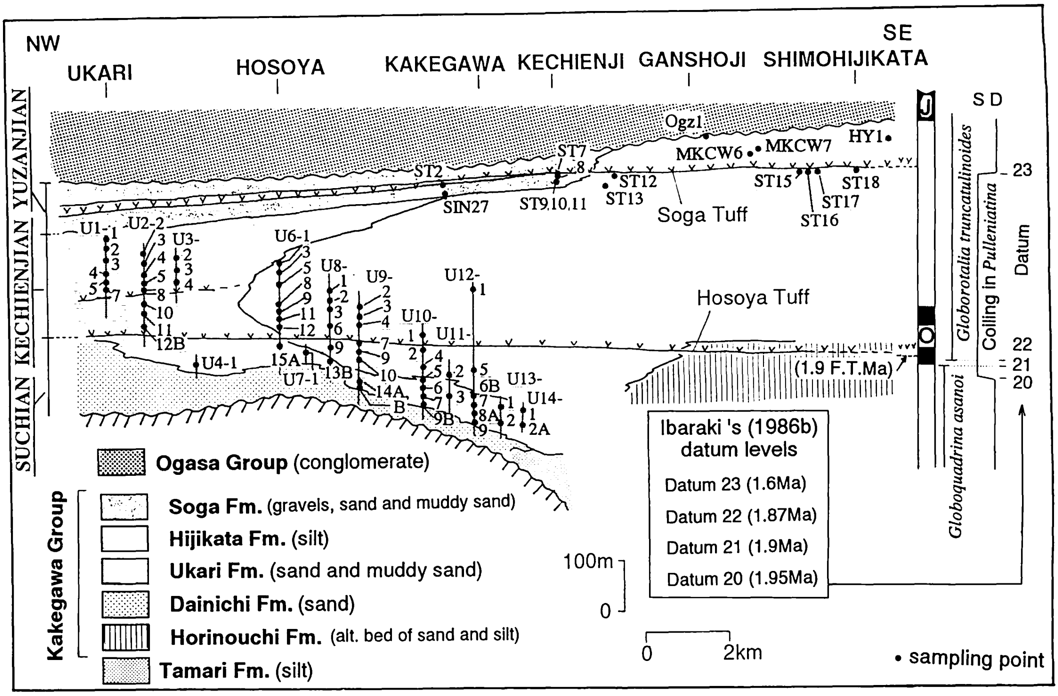


Figure 2. Schematic stratigraphic section of the upper part of the Kakegawa Group, showing the distribution of the sampling localities. The time scale was compiled from the data of magnetostratigraphy (Yoshida and Niitsuma, 1976), fission track age (Nishimura, 1977) and planktonic foraminiferal biostratigraphy (Ibaraki, 1986b).

F.T. Ma (Nishimura, 1977), and its magnetic-microbiostratigraphical position is near the base datum of *Globorotalia truncatulinoides* and the base of the Olduvai event (Ibaraki, 1986b). The Soga Tuff (Tsuchi, 1961) is intercalated in the middle part of the Soga Formation and the uppermost part of the Hijikata Formation. Tsuchi (1976) set the boundary between the Suchian and Kechienjian stages at the base of the Hosoya Tuff. The deposits of the Yuzanjian stage are the Soga Formation and the correlative uppermost part of the Hijikata Formation. According to Ibaraki's (1986b) planktonic foraminiferal biostratigraphy, Datum 23 (the second coiling-direction change in *Pulleniatina* spp. from sinistral to dextral) is clearly identified near the boundary between the Kechienjian and Yuzanjian stages. Ibaraki (1986b) estimated the age of the datum at 1.6 Ma on the basis of correlation to the magnetostratigraphical time scale.

Muddy sand to silt facies are recognized in every stage: through the Suchian to Yuzanjian, as shown in Figure 2. I have investigated the molluscan fossil assemblages of these facies, *i.e.*, of the Ukari, Hijikata, and Soga Formations. They yield abundant molluscs that live today in upper sublittoral to bathyal depths.

Brief description of the fossil molluscan assemblages

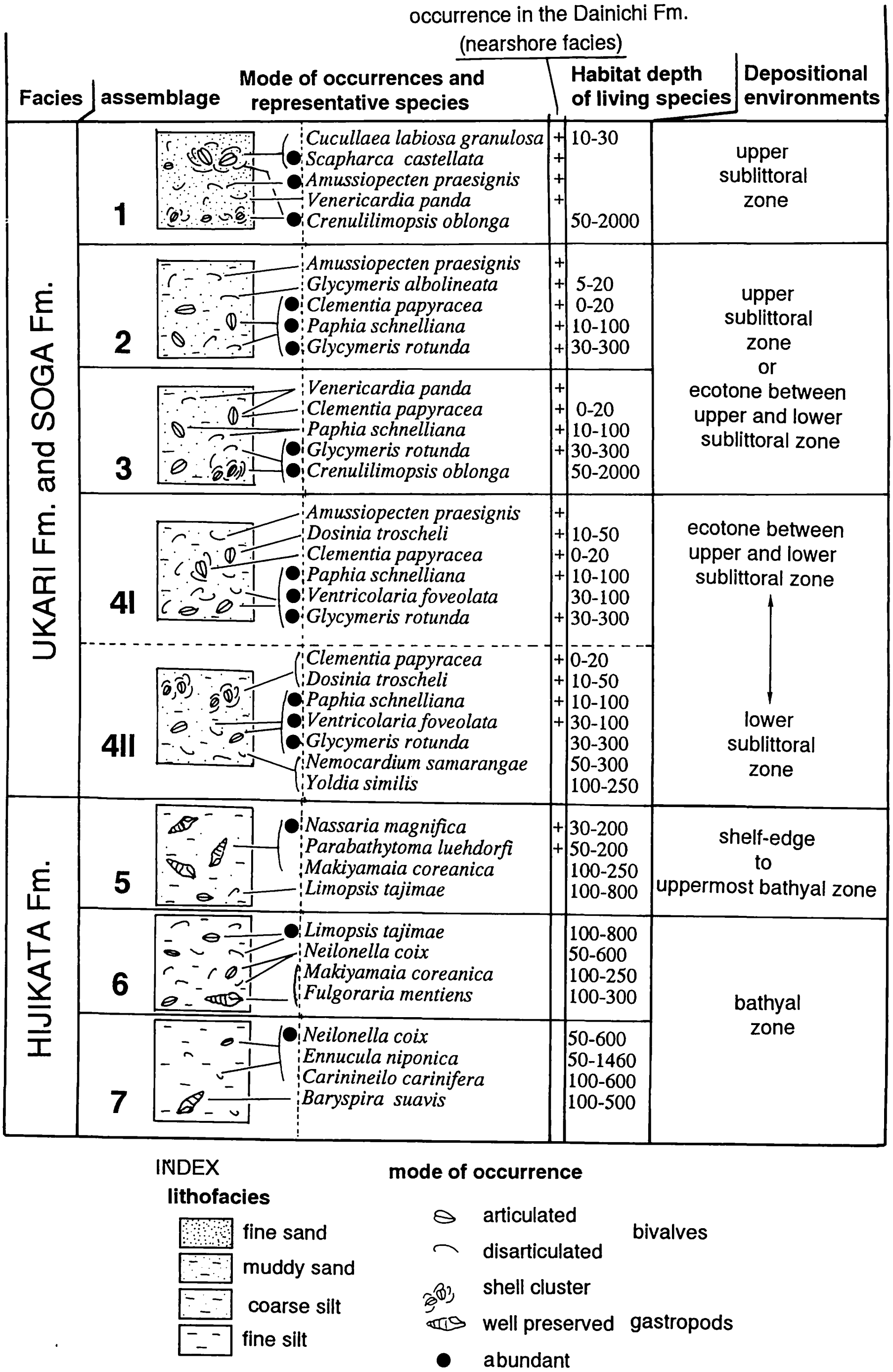
I have collected molluscan fossils from 77 localities (Figure 1), and obtained 124 species in 78 genera (listed in appendix tables 1-3). Before describing fossil molluscan assemblages, a few remarks should be made concerning modes of fossil occurrence. Kidwell *et al.* (1986) defined the following terms on fossil occurrences: autochthonous assemblage (composed of specimens derived from the local community and preserved in life position); parautochthonous assemblage (composed of autochthonous specimens that have been reworked to some degree but not transported out of the original life habitat); allochthonous assemblage (composed of specimens transported out of their life habitats and occurring in a foreign substratum). In the open sea such as the "Plio-Pleistocene Kakegawa sea", shells, in particular, those living in upper sublittoral depths under the influence of storms, can be easily reworked and transported. Consequently, some assemblages may be composed of specimens of different origins. According to Kidwell *et al.* (1986), they are referred to as mixed autochthonous-parautochthonous, parautochthonous-allochthonous, or autochthonous-allochthonous. It is difficult, however, to recognize autochthonous specimens because most of the species identified in this study are shallow-burrowers or epifauna which are easily reworked. Moreover, if an assemblage contains several species in the same matrix sediment and their habitat depths are distinct from each other, it is difficult to decide whether the assemblage is an actual ecotone between the different depths or a mixed one containing shells transported from different depths.

Therefore, I classify occurrence modes mainly into two types, namely "**A-type**" and "**B-type**," for convenience. In the A-type occurrence, shells are randomly distributed in the matrix sediment. Shell clusters are also often found but the shells in the clusters are supported by the sediment, which is nearly the same as that around the clusters. Moreover, the species composition is compatible with the sedimentary facies. Most of the shells are likely to be parautochthonous, although some might have been transported from different depths. The B-type is shell concentrations in lenses and clusters. In contrast with the A-type, the sediments in the lenses and clusters are clearly discriminated from the matrix sediment around them. Moreover, the species composition of the shells is incompatible with the sedimentary facies around them. The assemblages are clearly recognized to be allochthonous.

I classify fossil molluscan assemblages in the A-type occurrence into seven types on the basis of the occurrences of some dominant species and/or characteristic species (Figure 3). The depositional environments of the assemblages range from an upper sublittoral sandy bottom to a bathyal muddy bottom. Paleobathymetric interpretation is made mainly based on the habitat depths of living species shown by Habe (1977) and Higo (1973). Special attention is paid to the occurrence modes of bathymetrically key species whose habitats are nearly restricted to one bathymetric zone: upper sublittoral depths (*e.g., Clementia papyracea, Dosinia troscheli*); lower sublittoral depths (*e.g., Cryptopecten vesiculosus, Nemocardium samarangae*); bathyal depths (*e.g., Limopsis tajimae, Carinineilo carinifera*). Moreover, the depositional environments of the assemblages are cross-checked by Ishibashi's (1989) study on sedimentary facies in the Kakegawa area, because there is close relationship between the assemblages and the lithofacies.

1. *Amussiopecten praesignis—Scapharca castellata* assemblage (Loc. U9-14A)

This assemblage is found in a slightly muddy, fine sand bed, about 2.5 m thick, at U9-14A. This sand bed is intercalated in muddy sand of the lowermost part of the Ukari Formation. This assemblage is characterized by abundant shells of *Amussiopecten praesignis* (Yokoyama) and *Scapharca castellata* (Yokoyama). Disarticulated shells of *A. praesignis* are distributed with their commissure planes parallel to the bedding but the shells do not form a cluster or bed. In contrast, *S. castellata* are crowded together in large shell clusters, over 10 cm thick and about 50 cm long. The



Facies	assemblage	Mode of occurrences and representative species	occurrence in the Dainichi Fm. (nearshore facies)	Habitat depth of living species	Depositional environments
UKARI Fm. and SOGA Fm.	1	*Cucullaea labiosa granulosa* ● *Scapharca castellata* ● *Amussiopecten praesignis* *Venericardia panda* ● *Crenulilimopsis oblonga*	+ + + + 	10-30 50-2000	upper sublittoral zone
	2	*Amussiopecten praesignis* *Glycymeris albolineata* ● *Clementia papyracea* ● *Paphia schnelliana* ● *Glycymeris rotunda*	+ + + + +	 5-20 0-20 10-100 30-300	upper sublittoral zone or ecotone between upper and lower sublittoral zone
	3	*Venericardia panda* *Clementia papyracea* *Paphia schnelliana* ● *Glycymeris rotunda* ● *Crenulilimopsis oblonga*	+ + + + 	 0-20 10-100 30-300 50-2000	
	4I	*Amussiopecten praesignis* *Dosinia troscheli* *Clementia papyracea* ● *Paphia schnelliana* ● *Ventricolaria foveolata* ● *Glycymeris rotunda*	+ + + + +	 10-50 0-20 10-100 30-100 30-300	ecotone between upper and lower sublittoral zone ↕ lower sublittoral zone
	4II	*Clementia papyracea* *Dosinia troscheli* ● *Paphia schnelliana* ● *Ventricolaria foveolata* ● *Glycymeris rotunda* *Nemocardium samarangae* *Yoldia similis*	+ + + + 	0-20 10-50 10-100 30-100 30-300 50-300 100-250	
HIJIKATA Fm.	5	● *Nassaria magnifica* *Parabathytoma luehdorfi* *Makiyamaia coreanica* *Limopsis tajimae*	+ + 	30-200 50-200 100-250 100-800	shelf-edge to uppermost bathyal zone
	6	● *Limopsis tajimae* *Neilonella coix* *Makiyamaia coreanica* *Fulgoraria mentiens*		100-800 50-600 100-250 100-300	bathyal zone
	7	● *Neilonella coix* *Ennucula niponica* *Carinineilo carinifera* *Baryspira suavis*		50-600 50-1460 100-600 100-500	

Figure 3. Molluscan fossil assemblages in the A-type occurrence and their depositional environments. Square: schematic occurrence mode in vertical sections normal to the bedding plane.

shells of *Scapharca* are well preserved and disarticulated or articulated. Some articulated shells are open. Many shells of *Crenulilimopsis oblonga* (A. Adams) are also found, both in the shell clusters and in the fine sand matrix. *Cucullaea labiosa granulosa* Jonas, *Venericardia panda* (Yokoyama) and *Chlamys satoi* (Yokoyama) occur also in the clusters and/or in matrix sand.

Except for *Crenulilimopsis oblonga,* most of the component species live in the upper sublittoral zone and/or are commonly found in shell beds in the Dainichi Formation, which corresponds to nearshore facies of Ishibashi (1989). The lithofacies of this bed is slightly muddy and seems to be transitional between nearshore fine sand facies of the Dainichi Formation and offshore massive muddy sand facies of the Ukari Formation. These facts indicate that this assemblage was formed in upper sublittoral depths, mixed with reworked shells such as *Scapharca castellata.*

2. *Paphia schnelliana—Clementia papyracea—Glycymeris rotunda* assemblage (representative localities: U10-9B, U12-9, ST8)

This assemblage occurs in a muddy sand facies in the lower part of the Ukari Formation and in the Soga Formation. This assemblage is characterized by common articulated shells of *Paphia schnelliana* (Dunker) and *Clementia papyracea* Gray. In particular, *C. papyracea* which lives today at depths of 0-20 m (Habe, 1977) frequently shows vertical, posterior-up shell position. *Glycymeris rotunda* (Dunker) also occurs abundantly, with its shells articulated at some localities (U12-9, U10-9B). These species are associated with many species living today only in upper sublittoral depths, and with species found commonly in the shallow-water Dainichi Formation; for example, *Glycymeris albolineata* (Lischke), *Amussiopecten praesignis* (Yokoyama), *Venericardia panda* (Yokoyama), and *Dosinia troscheli* Lischke. These shells are well preserved and are randomly distributed together with the dominant species. Species living in lower sublittoral depths, such as *Nemocardium samarangae* (Makiyama), also occur at ST8 but only a few specimens have been found.

The species composition and the autochthonous occurrence of *C. papyracea* suggest that this assemblage lived in upper sublittoral depths, or in depths transitional between the upper and lower sublittoral zones.

3. *Crenulilimopsis oblonga—Glycymeris rotunda* assemblage (representative localities: U8-13B, U9-14B, U13-1, U14-2A, ST10)

This assemblage occurs in a muddy sand facies in the lower part of the Ukari Formation and in the Soga Formation. This assemblage is characterized by abundant articulated shells of *Glycymeris rotunda* (Dunker) and *Crenulilimopsis oblonga* (A. Adams), the latter of which is rare or absent in the *Paphia schnelliana—Clementia papyracea—Glycymeris rotunda* assemblage described above. The two dominant species are randomly distributed and also form many loose clusters, up to about 15 cm in diameter. This assemblage also includes many species living only in upper sublittoral depths, or those found in the shallow-water Dainichi Formation, just as the *Paphia—Clementia—Glycymeris* assemblage does. They are *Amussiopecten praesignis* (Yokoyama), *Babylonia elata* (Yokoyama), *Scapharca* species, *Glycymeris albolineata* (Lischke), *Clementia papyracea* Gray, *Dosinia troscheli* Lischke, and so on. Except for *Glycymeris rotunda* and *Crenulilimopsis oblonga,* species living in the lower sublittoral zone occur in small numbers in this assemblage: for example, *Cryptopecten vesiculosus* (Dunker) at U13-1 and U14-2A. The shells of associated species are well preserved and randomly distributed as are those of the dominant ones.

The species composition suggests that this assemblage lived in upper sublittoral depths or in depths transitional between the upper and lower sublittoral zones.

4. *Glycymeris rotunda—Ventricolaria foveolata* assemblage (representative local-

ities: 4I-type; U1-1, U1-2, U1-3. 4II-type; U2-8, U2-10, U6-15A)

This assemblage occurs in the muddy sand of the Ukari Formation at many localities, where the typical offshore facies of Ishibashi (1989) is exposed. Shells of both upper and lower sublittoral elements occur abundantly, with random distribution. The shells also form many fist-sized loose clusters or matrix-supported shell beds up to about 15 cm thick. This assemblage is characterized by the dominance of *Glycymeris rotunda* (Dunker) and *Ventricolaria foveolata* (Sowerby). Commonly associated species are *Paphia schnelliana* (Dunker), *Crassatellites takanabensis* Shuto, *Nassarius siguijorensis* (A. Adams), *Cryptopecten vesiculosus* (Dunker), *Cycladicama cumingii* (Hanley), and *Nemocardium samarangae* (Makiyama). Compared with the three assemblages described above, shells of lower sublittoral species are common in this assemblage. The shells of the dominant species, *Glycymeris rotunda* and *Ventricolaria foveolata,* are well preserved and many articulated specimens are found. The two species are representatives of the lower shelf fauna burrowing in mud at present, at depths greater than 40 m in Sagami Bay (Horikoshi, 1957).

This assemblage is subdivided into two types. The first type, designated the "4I-type assemblage", includes many species living in upper sublittoral depths as well as those living in lower sublittoral depths. For example, *Amussiopecten praesignis* (Yokoyama), *Clementia papyracea* Gray, and *Solecurtus divaricatus* (Lischke) occur at U1-1, U1-2 and U1-3. By contrast, the second type, designated the "4II-type assemblage" is associated with species living in shelf-edge depths, such as *Yoldia similis* Kuroda et Habe at U2-8 and U2-10. At some localities (U2-4, U2-5), however, many shells of the upper sublittoral depths are mixed into a 4II-type assemblage, and the species composition is transitional between the two types. With respect to the distributions of the two types in the Ukari Formation, the 4I-type assemblage occurs in the uppermost part (earliest regressive phase) whereas the 4II-type assemblage occurs in the middle part (climax of the transgressive phase).

This assemblage corresponds to the *Glycymeris rotunda-Venus foveolata* Association of Chinzei (1980). He stated that the association is characteristic of lower sublittoral depths. Moreover, he noted that the association in the most western part of the distribution area (the 4I-type assemblage) is estimated to be a biofacies transitional from the shallower-water assemblage of the Dainichi Formation. It is estimated here that some 4I-type assemblages are parautochthonous assemblages of an ecotone between the upper and lower sublittoral zones. Others, however, probably lived in lower sublittoral depths and include some shallower-water shells transported from upper sublittoral depths.

5. *Nassaria magnifica* assemblage (representative localities: U6-1, U6-11, ST13, MKCW6)

This assemblage occurs in the coarse silt facies of the Hijikata Formation. Well preserved shells of gastropods are disseminated sporadically in the massive silt with random orientation. Many gastropod shells have protoconchs. This assemblage is characterized by gastropod shells markedly exceeding bivalve shells in numbers of both species and individuals.

Nassaria magnifica (Lischke) is dominant, associated with some other gastropods, such as *Parabathytoma luehdorfi* (Lischke), *Makiyamaia coreanica* (Adams et Reeve), *Bathybembix argenteonitens* cf. *hirasei* (Taki et Otuka), *Fulgoraria* species, and by many minute unidentified gastropods. Several bivalve species characteristic of deep-sea facies, such as *Limopsis tajimae* Sowerby and *Yoldia similis* Kuroda et Habe, also are associated with this assemblage. This assemblage has a composition similar to the *Nassaria magnifica* Association of Chinzei

(1980).

The dominant species, *Nassaria magnifica,* lives now at depths of 30-200 m and some associated gastropods such as *Parabathytoma luehdorfi* also have similar habitat depths (Higo, 1973). This assemblage, however, contains many shelf-edge to bathyal elements such as *Makiyamaia coreanica* and *Limopsis tajimae* in the same matrix silt sediment. Moreover, the localities of this assemblage are distributed in the sedimentary facies of slope and basin plain shown by Ishibashi (1989). Good preservation of the shells and their random orientation in the matrix sediment indicate that these species were not transported and mixed so far from distinct environments. Therefore, it is reasonable to consider that this assemblage lived at shelf-edge to uppermost bathyal depths.

6. *Limopsis tajimae* assemblage (representative localities : U6-8, U8-3, U11-2, MKCW7)

This assemblage occurs at many localities in silt facies through the Suchian to Yuzanjian stages. It is characterized by dominant *Limopsis tajimae* Sowerby. Abundant individuals of *L. tajimae* are disseminated in silt, with random shell orientation. The shells are well preserved and many articulated specimens can be found. The assemblage has some gastropods associated, such as *Makiyamaia coreanica* (Adams et Reeve) and *Fulgoraria mentiens* (Fulton), and also some nuculoid shells, such as *Neilonella coix* Habe. This assemblage corresponds to the *Limopsis tajimae* Association of Chinzei (1980).

Most of the component species extend their habitat depths to the bathyal zone. The sedimentary facies at the localities are those of slope and basin plain shown by Ishibashi (1989), although some gastropods such as *Nassaria magnifica* which live at depths shallower than 200 m are included at some localities. Kondo (1989) reported a dense population of *Limopsis tajimae* at depths of about 280 m in Suruga Bay. Therefore, this assemblage is likely to have lived in upper bathyal depths.

7. Nuculoids-dominant assemblage (representative localities: U9-3, U12-5, ST12, ST17, HY1)

This assemblage is characterized by dominant nuculoid bivalves. The shells are scattered sporadically in the massive silt of the Hijikata Formation. They are generally well preserved and many are still articulated. This assemblage has various dominant species at various localities ; for example, *Acila* aff. *divaricata* (Hinds) at U12-5, *Ennucula niponica* (Smith) at ST12, *Neilonella coix* Habe at U9-3, and *Neilonella coix* and *N. japonica* Okutani at HY1. Other nuculoid shells such as *Carinineilo carinifera* (Habe), *Bathymalletia inaequilateralis* Habe, and *Nuculana* spp. are commonly associated forms. Several specimens of *Limopsis tajimae* Sowerby are found at U9-3. Some gastropod species also are associated at U12-5 and HY1 including *Parabathytoma luehdorfi* (Lischke), *Euspira plicispira* (Kuroda), *Makiyamaia coreanica* (Adams et Reeve), *Bathybembix argenteonitens* cf. *hirasei* (Taki et Otuka), and *Baryspira suavis* (Yokoyama). Several unidentified small gastropods are also found at every locality.

Most of the component species live in lower sublittoral to bathyal depths, according to the present data of Habe (1977) and Higo (1973). Hickman (1984), however, suggested that dominance of protobranch bivalves is a characteristic feature of deep-sea communities. Moreover, this assemblage occur in the sedimentary facies of slope and basin plain shown by Ishibashi (1989). Good preservation of the shells and their random orientation suggest that they are autochthonous to parautochthonous. These facts indicate that this assemblages lived in bathyal depths.

All the assemblages described above are plotted on the schematic stratigraphic cross section (Figure 4). Their distribution is nearly concordant with the change in lithofacies demonstrating the transgressive-

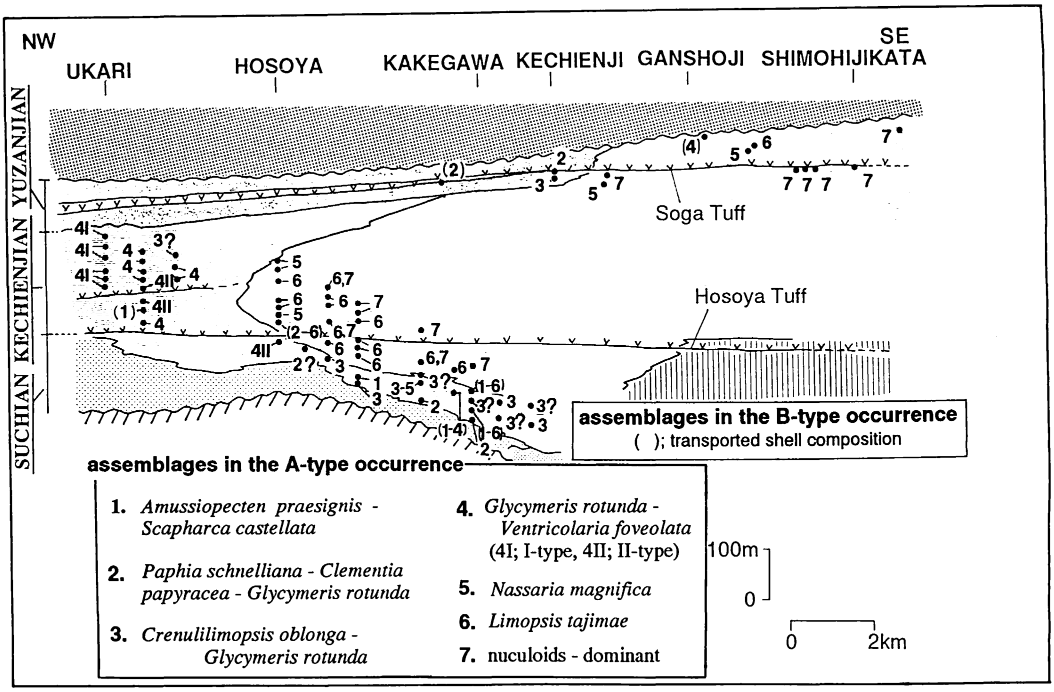


Figure 4. Distributions of the molluscan assemblages.

regressive cycle described by Ishibashi (1989). In Ishibashi's (1989) figure 13, the Ukari, Hijikata, and Soga Formations correspond to the offshore, slope and basin plain, and submarine channel facies, respectively. However, Aoshima (1978) suggested that foraminiferal assemblages in nearshore conditions are found in the basal and uppermost parts of the Ukari Formation and in the Soga Formation. The distributions of the foraminiferal assemblages nearly correspond to those of the molluscan assemblages of 1-, 2-, 3-, and 4I-types in Figures 3 and 4. These assemblages contain many species living at upper sublittoral depths. In addition, some assemblages in the allochthonous B-type occurrence also contain the shallow species. Therefore, as shown in this figure, I obtained material of assemblages representing the upper sublittoral to bathyal zones in each of the Suchian to Yuzanjian stages. Using this material, I can trace the temporal distributions of species characteristic of each depth zone.

Temporal distribution of species characteristic of each bathymetric depth zone

In order to clarify the relationship between bathymetric depth and cooling effect on the molluscan fauna, I pay attention to the relationship between the temporal distributions of species and their habitats (geographical distribution and bathymetric depth).

The geographical distribution of each species reflects its tolerance for sea water temperature. For species that are still living, I use the following terms for water regimes, based on the data on their geographical distributions along the Pacific side of Japan (Habe, 1977 ; Higo, 1973 ; Kuroda and Habe, 1952) : "Kuroshio" (0°-34°N), "Kuroshio-Japonic" (0°-35°N), "Southwestern Japonic" (31°N-35°

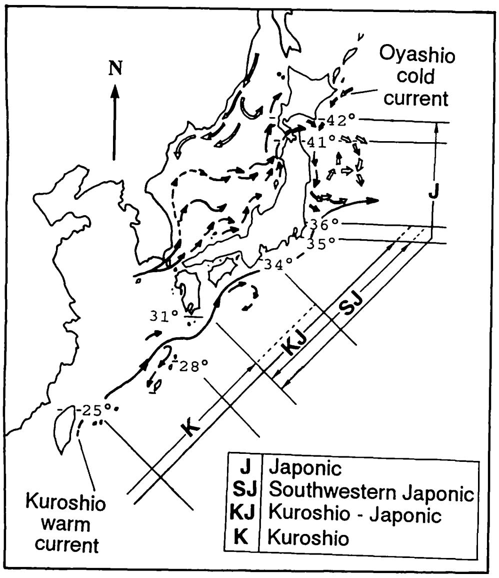


Figure 5. Terminology of the water regimes (based on geographic distribution) of molluscs living now on the Pacific coast of Japan. Courses of ocean currents are compiled after Natural Astronomical Observatory (1992).

N), and "Japonic" (31°N-42°N) (shown in Figure 5). In this paper, the species occupying the first two regimes are called "warm-water elements" and those occupying the last two are called "Japonic endemic elements." For extinct species, "warm-water elements" are defined as taxa whose distributions extend to tropical regions such as Taiwan and Okinawa Island (*e.g., Amussiopecten praesignis, Venericardia panda*), and "Japonic elements" are defined as taxa whose distributions are restricted to Japan (*e.g., Mizuhopecten tokyoensis*).

The habitat depths are inferred mainly from the data of living species (Habe, 1977; Higo, 1973). The data, however, are synthesized from various reports in the sea around Japan and some species possibly had narrower depth ranges in the local "Plio-Pleistocene Kakegawa sea." Moreover, some species are extinct ones. Therefore, the interpretations on habitat depths are supplemented by the depositional environments of the assemblages in which the species occurs. In order to avoid a vicious circle, the depositional environments are cross-checked by the results of the sedimentary facies analysis (Ishibashi, 1989) and of the study on foraminiferal assemblages (Aoshima, 1978), as noted before. The species whose habitat depths are cross-checked by these data are marked with "#" in Figure 6.

Figure 6 shows examples of the temporal distributions of characteristic species in each bathymetric depth at representative localities.

As noted in the introduction to this paper, the temporal change in the Kakegawa fauna is defined partly by the stepwise disappearance of warm-water species, and almost all of those are found commonly in the shallowest facies such as the Dainichi Formation. In the Kechienjian and Yuzanjian stages, however, muddy sand to silt facies are the dominant fossiliferous lithofacies, instead of shallow-water sandy facies such as the Dainichi Formation in the Suchian stage. In order to confirm that the stepwise disappearance was caused by cooling, I compare the temporal distributions of many species within the same muddy sand facies in each stage, depositional conditions being nearly equal.

From each stage, Suchian to Yuzanjian, I have collected species assigned to the assemblages which are considered to have lived on a muddy sand bottom in the upper sublittoral zone, or in transitional depths between the upper and lower sublittoral zones. The assemblages are (1) the *Amussiopecten praesignis-Scapharca castellata* assemblage, (2) the *Paphia schnelliana-Clementia papyracea-Glycymeris rotunda* assemblage, (3) the *Crenulilimopsis oblonga-Glycymeris rotunda* assemblage and (4) the *Glycymeris rotunda-Ventricolaria foveolata* assemblage (4I-type). The localities of these assemblages nearly correspond to the distribution of the nearshore foraminiferal assemblages shown by Aoshima (1978). I trace the temporal distributions of species that live now in upper sublittoral depths or whose occurrences are

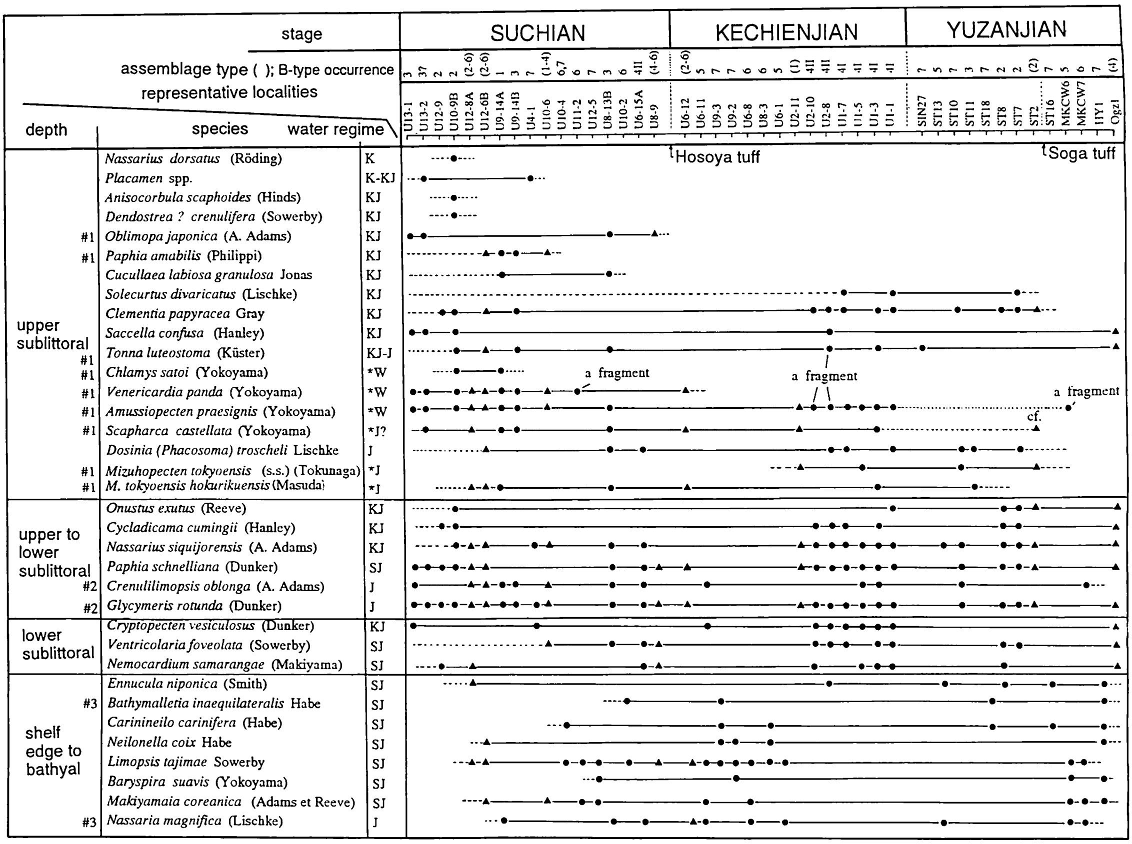


Figure 6. Temporal distributions of the species characteristic of each bathymetric depth. Supplementary interpretation on habitat depths: #1 = species which commonly occur in the Dainichi Fm. and whose occurrences are restricted to the assemblages of 1- to 4I-types in Fig. 3; #2 = species which now live in lower sublittoral depths and the deeper zones but also occur abundantly in the assemblages of 1- to 3-types; #3 = species which now lives on the shelf but also occur abundantly in the assemblages of 5- to 7-types. Water regimes for living species: K, KJ, SJ, J (see Fig. 5); those for extinct species: *W = warm-water; *J = Japonic. Fossil occurrence: circle = A-type; triangle = B-type.

restricted to the four assemblages noted above and to the Dainichi Formation. They can be assumed to have been upper sublittoral species.

The assemblages in rocks of the Suchian stage include many warm-water elements such as *Amussiopecten praesignis, Venericardia panda, Paphia amabilis, Placamen* spp., *Oblimopa japonica,* and so on. *A. praesignis* and *V. panda* are found at most of the localities representing the Suchian stage. In particular, *Amussiopecten praesignis* is abundant at some localities (*e.g.*, U10-9B, U13-1). Some warm-water elements such as *Nassarius dorsatus, Anisocorbula scaphoides,* and *Dendostrea ? crenulifera* are found only at U10-9B, but many individuals of these species occur at this locality.

In rocks of the Kechienjian stage, some of the warm-water species listed above are not present. For example, the *Glycymeris rotunda-Ventricolaria foveolata* assemblage (4I-type) at U1-1 contains many species living in upper sublittoral depths and abundant shells of *Amussiopecten praesignis,* whereas other warm-water elements such as *Venericar-*

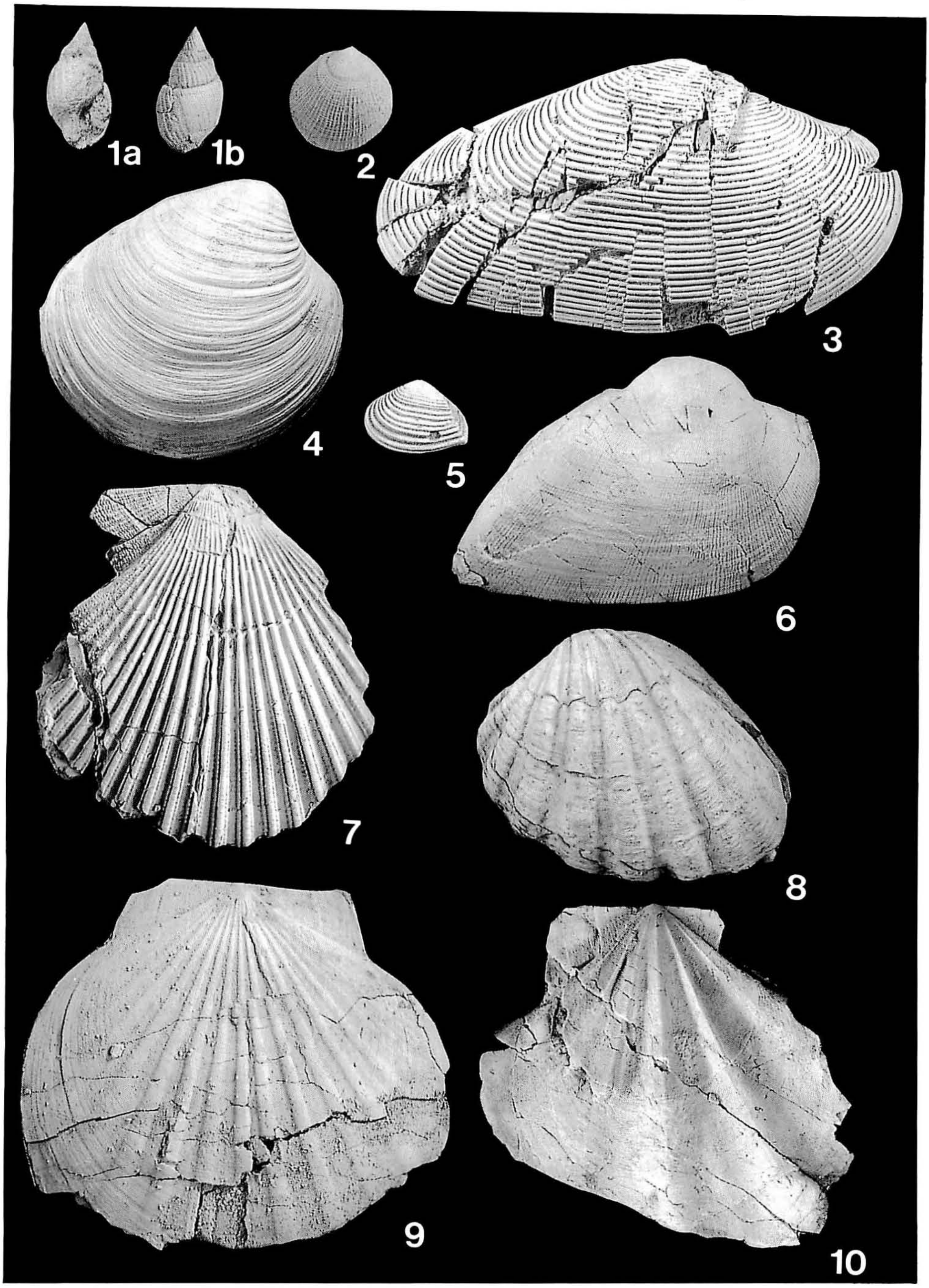


Figure 7. Characteristic species of each bathymetric depth (1). upper sublittoral depths. **1a, b,** *Nassarius dorsatus* (Röding), ×0.9, ESN50013, Loc. U10-9B ; **2,** *Oblimopa japonica* (A. Adams), ×1.5, ESN50014, Loc. U13-2 ; **3,** *Paphia amabilis* (Philippi), ×0.68, ESN50015, Loc. U9-14B ; **4,** *Clementia papyracea* Gray, ×0.9, ESN50016, Loc. ST8 ; **5,** *Anisocorbula scaphoides* (Hinds), ×0.9, ESN50017, Loc. U10-9B ; **6,** *Cucullaea labiosa granulosa* Jonas, ×0.65, ESN50018, Loc. U8-13B ; **7,** *Chlamys satoi* (Yokoyama), ×0.72, ESN50019, Loc. U9-14A ; **8,** *Venericardia panda* (Yokoyama), ×0.68, ESN50020, Loc. U13-1 ; **9,** *Amussiopecten praesignis* (Yokoyama), ×0.68, ESN50021, Loc. U8-13B ; **10,** *Mizuhopecten tokyoensis hokurikuensis* (Masuda), ×0.75, ESN50022, Loc. U12-6B.

dia panda and *Oblimopa japonica* are absent. This is possibly due to the slight difference in depositional environments between the 4I-type assemblage and the other assemblages of the 1-, 2-, and 3-types in the Suchian stage. At U2-11, however, an allochthonous assemblage transported from the upper sublittoral or shallower depths is present in the B-type occurrence, but it contains no shells of *Venericardia panda* or *Oblimopa japonica.*

In rocks of the Yuzanjian stage, several assemblages in the A-type occurrence are found to contain many species that live now in upper sublittoral depths. Their dominant and subdominant species are the same as those of the Suchian assemblages, *i.e., Paphia schnelliana, Clementia papyracea, Glycymeris rotunda,* and *Crenulilimopsis oblonga.* The warm-water Suchian species that are absent from the previous Kechienjian stage also are not found in these shallow Yuzanjian assemblages. *Amussiopecten praesignis* occurs in this stage but only rarely, as a fragment, whereas its well preserved shells are abundant in the Suchian and Kechienjian assemblages.

As noted above, some warm-water elements in the upper sublittoral assemblages disappeared in steps. In contrast to this, some Kuroshio-Japonic species survived in the upper sublittoral zone through three stages. They are *Clementia papyracea, Solecurtus divaricatus, Saccella confusa* and *Tonna luteostoma. S. divaricatus* was not found in Suchian rocks in this survey, but Yoshida (1981) reported the species from the Dainichi Formation. Japonic endemic elements such as *Dosinia troscheli* also survived in the upper sublittoral zone through all three stages.

With respect to species living in upper to lower sublittoral depths (or which live now in the lower sublittoral and the deeper zones but also occur abundantly in fossil assemblages of 1-, 2-, and 3-types in Figure 3), both the warm-water and the Japonic endemic elements also occurred throughout all three stages, as shown in Figure 6.

This continuous occurrence is true of species living in lower sublittoral to bathyal depths. Warm-water elements living in lower sublittoral depths, such as *Cryptopecten vesiculosus,* are found in all three stages. Japonic endemic elements also occurred throughout the three stages. Besides the species cited as examples in Figure 6, many other Japonic elements in these depth zones are found throughout the three stages, such as *Yoldia similis* and *Fulgoraria mentiens.* Chinzei (1980) studied the deep offshore fossil molluscan fauna in rocks of the Kechienjian stage and stated that it mostly is composed of species living now in waters off central Japan. These deep-water faunas seem to have been poor in warm-water elements throughout the sequence, including the Suchian stage, as shown in Figure 6. Some of the Southwestern Japonic living species, however, for example *Makiyamaia coreanica,* have been reported from the Shinzato Formation of Okinawa Island by Noda (1980). It appears likely that their geographical distributions in Pliocene age were very similar to those of the fossil warm-water elements. Whether the species are warm-water elements or not, the species compositions of the deep assemblages seem to have been stable throughout the three stages.

Thus, the effect of cooling on faunal change seems to have been restricted to the upper sublittoral zone. Some problems, however, remain. First, the deep assemblages contain many minute unidentified gastropods whose temporal distributions are not clear. Secondly, the effect of cooling on organisms possibly differs not only with habitat depth, but also with other ecological parameters such as food source and whether they are infaunal or epifaunal. Therefore, in order to confirm the effect of cooling in each bathymetric zone, I compare the temporal distributions of some taxonomically close species that have similar ecological characters (life habits, food sources) but lived at different depths and/or in different water regimes. The com-

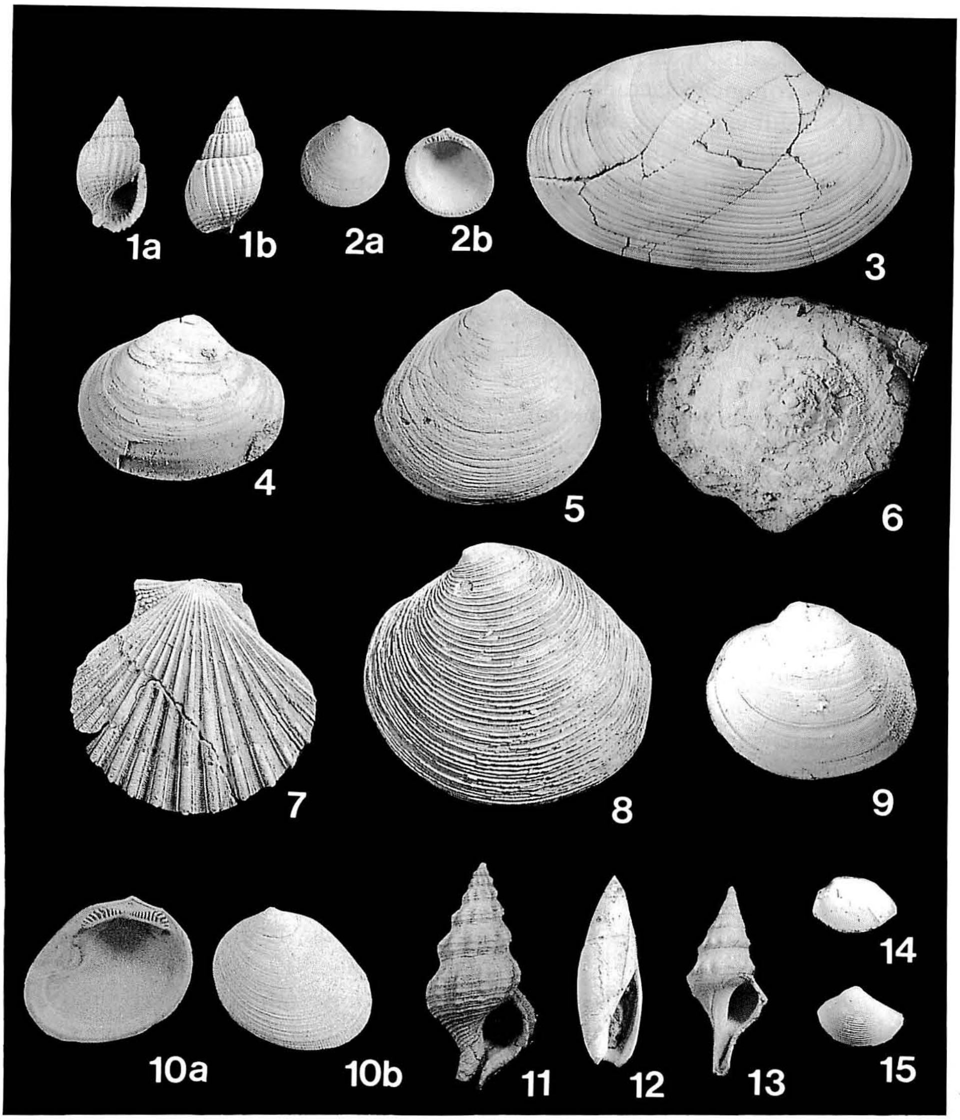


Figure 8. Characteristic species of each bathymetric depth (2). **1a-6,** upper to lower sublittoral depths ; **7-9,** lower sublittoral depths ; **10-15,** shelf-edge to bathyal depths. **1a, b,** *Nassarius siquijorensis* (A. Adams), ×0.9, ESN50023, Loc. U3-4 ; **2a, b,** *Crenulilimopsis oblonga* (A. Adams), ×1.5, ESN50024, Loc. U10-5 ; **3,** *Paphia schnelliana* (Dunker), ×0.8, ESN50025, Loc. U6-15A ; **4,** *Cycladicama cumingii* (Hanley), ×0.9, ESN50026, Loc. U2-3 ; **5,** *Glycymeris rotunda* (Dunker), ×0.8, ESN50027, Loc. U1-3 ; **6,** *Onustus exutus* (Reeve), ×1.1, ESN50028, Loc. Ogz1 ; **7,** *Cryptopecten vesiculosus* (Dunker), ×0.9, ESN50029, Loc. U2-10 ; **8,** *Ventricolaria foveolata* (Sowerby), ×0.9, ESN50030, Loc. U1-3 ; **9,** *Nemocardium samarangae* (Makiyama), ×0.9, ESN50031, Loc. U1-3 ; **10a, b,** *Limopsis tajimae* Sowerby, ×0.9, ESN50032, Loc. U6-12 ; **11,** *Nassaria magnifica* (Lischke), ×0.9, ESN50033, Loc. MKCW6 ; **12,** *Baryspira suavis* (Yokoyama), ×0.9, ESN50034, Loc. MKCW7 ; **13,** *Makiyamaia coreanica* (Adams et Reeve), ×0.9, ESN50035, Loc. MKCW6 ; **14,** *Ennucula niponica* (Smith), ×1.2, ESN50036, Loc. ST12 ; **15,** *Neilonella coix* Habe, ×1.5, ESN50037, Loc. U9-3.

parisons reveal which bathymetric zone and which water regime the disappearing species lived in, all other ecological factors being nearly equal. The result can be regarded as a typical faunal change for a cooling event, which can be applied to all faunal components.

Figure 9a-d shows four examples of the comparison of temporal distributions at all 77 localities in this survey. Life habit of each example species has not been confirmed except for life positions of some species. Superfamilies of bivalves, however, have tended to remain constant with regard to feeding types throughout their histories (Stanley, 1968). Therefore, the feeding types of the following four species groups are mainly inferred based on the feeding categories of Stanley (1968, 1970).

1) *"Limopsis"* species (non-siphonate suspension feeders) (Figure 9a)

Three living species, *Oblimopa japonica* (a Kuroshio-Japonic element), *Crenulilimopsis oblonga* (a Japonic element) and *Limopsis tajimae* (a Southwestern Japonic element) occur abundantly at the localities where each species is found. Kondo (1987) showed that these three species are semi-infauna (partly exposed) and/or shallow burrowers (2-3 cm beneath the surface).

Oblimopa japonica occurs in the Kakegawa Group only in the *Crenulilimopsis oblonga-Glycymeris rotunda* assemblage containing many upper sublittoral species, although Recent *Oblimopa japonica* has been recorded from depths of 10-400 m (Habe, 1977). Therefore, it is reasonably inferred that *Oblimopa japonica* lived in the upper sublittoral zone and did not live in the deeper zones in the "Plio-Pleistocene Kakegawa sea". *Crenulilimopsis oblonga* lives today in depths of 50-2,000 m (Habe, 1977). The fossils of this species occur widely in sublittoral to bathyal facies. In particular, the species is one of the dominant species of the *Crenulilimopsis oblonga-Glycymeris rotunda* assemblage. *Limopsis tajimae* lives in depths of 100-800 m (Habe, 1977), and fossils correspondingly occur in shelf-edge to bathyal assemblages (the *Nassaria magnifica,* the *Limopsis tajimae,* and the nuculoids-dominant assemblages).

Comparison of the temporal distributions of these three species indicates that *Oblimopa japonica* disappeared near the base of the Kechienjian stage but that the other two *"Limopsis"* occurred throughout the three stages. That is, the warm-water element in the upper sublittoral zone disappeared, whereas the Japonic endemic elements in the deeper zones survived.

2) *Paphia* species (infaunal siphonate suspension feeders) (Figure 9b)

The temporal distributions of two living species, *Paphia amabilis* (a Kuroshio-Japonic element) and *P. schnelliana* (a Southwestern Japonic element), are compared in Figure 9b. Their actual life habits have not been observed. It is, however, most likely that they are shallow burrowers, because their shell outlines and pallial sinuses resemble those of *Ruditapes philippinarum* (Adams et Reeve) which has been confirmed to be an active shallow burrower by Kondo (1987).

Both species live today in sublittoral depths (*P. amabilis,* 10-70 m ; *P. schnelliana,* 10-100 m) (Habe, 1977). Fossil *P. schnelliana* is commonly found in every sublittoral assemblage and its fossil occurrence agrees with its living depth range. By contrast, fossil *P. amabilis* is found only in assemblages containing many upper sublittoral species (in the *Amussiopecten praesignis-Scapharca castellata* assemblage, the *Crenulilimopsis oblonga-Glycymeris rotunda* assemblage, and some allochthonous assemblages). *P. amabilis* also occurs in the Dainichi Formation (Yoshida, 1981). This occurrence indicates that *P. amabilis* lived only at upper sublittoral depths in the Kakegawa area during the Pliocene.

The temporal distributions of these species indicate that *P. amabilis* disappeared near the base of the Kechienjian stage but that *P.*

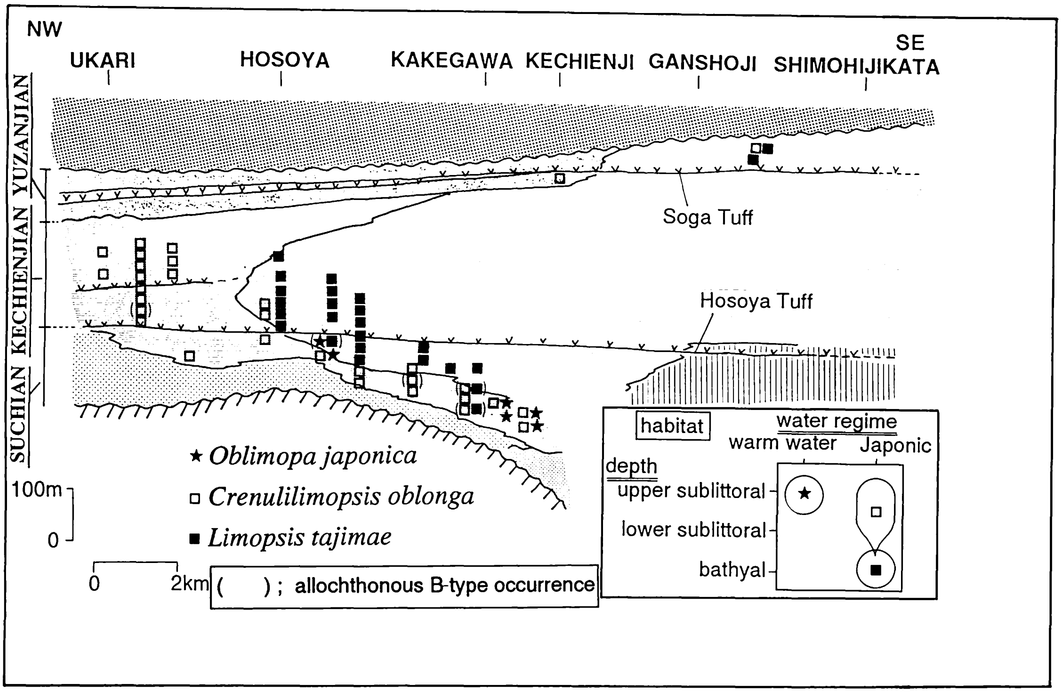
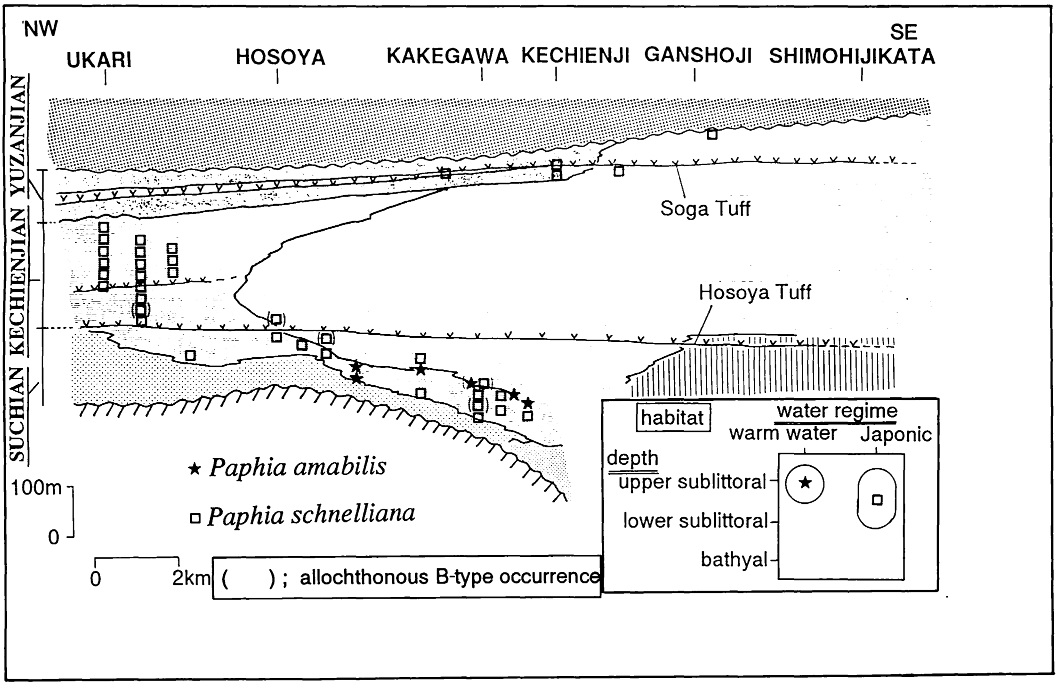


Figure 9. Comparison of the distributions of taxonomically close species.
9a. Distributions of *"Limopsis"* species.



9b. Distributions of *Paphia* species.

schnelliana occurred throughout the three stages. That is, the warm-water element in the upper sublittoral zone disappeared, whereas the Japonic endemic element occurred throughout the stages.

3) *"Chlamys"* species (epifaunal suspension feeders) (Figure 9c)

The temporal distributions of two species, *Chlamys satoi* (a fossil species) and *Cryptopecten vesiculosus* (a living species) are compared in Figure 9c. *Chlamys* species are generally considered to be sessiles with byssuses (Hayami, 1990). Hayami (1984) stated that *Cryptopecten vesiculosus* is almost certain to lie on the sea floor with the left valve facing up, like many other byssate pectinids, on the basis of their behaviour in aquaria.

Both species, *Chlamys satoi* and *Cryptopecten vesiculosus,* are warm-water elements. According to Masuda (1962), *Chlamys satoi* occurs in Neogene rocks in the Miyazaki area in Kyushu, at Miyako Island in Okinawa, and in Taiwan, as well as in the Kakegawa area. *Cryptopecten vesiculosus* lives now at 50–600 m in the Kuroshio-Japonic water regime (Habe, 1977). Its fossil geographical distribution extends from the Neogene of Boso Peninsula southwards to the Sumagui Formation in the Philippine Islands (Masuda, 1962). Therefore, both species lived in nearly the same water regime during the Pliocene. However, their fossil occurrences confirm that their habitat depths were different in the Kakegawa area during Pliocene time. *Chlamys satoi* occurs only in upper sublittoral facies (in the *Amussiopecten praesignis-Scapharca castellata* and *Paphia schnelliana-Clementia papyracea-Glycymeris rotunda* assemblages). By contrast, *Cryptopecten vesiculosus* is common in lower sublittoral facies (the *Glycymeris rotunda-Ventricolaria foveolata* assemblage) and occurs rarely in the transitional facies between the upper and lower sublittoral zones (the *Crenulilimopsis oblonga-Glycymeris rotunda* assemblage).

With respect to the temporal distributions in the Kakegawa Group, *Chlamys satoi* disappeared near the base of the Kechienjian stage while *Cryptopecten vesiculosus* occurred throughout the three stages. Although the occurrence of *C. vesiculosus* in the Yuzanjian stage is the allochthonous B-type, the abundance and good preservation of the shells indicate that the species lived near the deposition site during the Yuzanjian stage. Thus, of these two Chlamydinae, only the upper sublittoral species disappeared near the base of the Kechienjian stage, although both species are warm-water elements.

4) Species of *Amussiopecten* and *Mizuhopecten* (epifaunal suspension feeders) (Figure 9d)

Amussiopecten praesignis, Mizuhopecten tokyoensis (*s.s.*) and *Mizuhopecten tokyoensis hokurikuensis* occur at many localities. With respect to their life habits, Hayami (1990) suggested that individuals of these genera can swim by clapping their valves together.

Masuda's (1962) data on the geographical distributions of these species suggested that *Amussiopecten praesignis* is a warm-water element and that *Mizuhopecten tokyoensis* (*s.s.*) and *M. tokyoensis hokurikuensis* are Japonic endemic elements. The water regimes of these species are different but their living depths are estimated to have been the same (in the upper sublittoral zone) on the basis of their fossil occurrences. That is, these species occur in assemblages containing many upper sublittoral species (the *Amussiopecten praesignis-Scapharca castellata* assemblage, the *Paphia schnelliana-Clementia papyracea-Glycymeris rotunda* assemblage, the *Crenulilimopsis oblonga-Glycymeris rotunda* assemblage, and the *Glycymeris rotunda-Ventricolaria foveolata* I-type assemblage). Co-occurrence of *Amussiopecten* and *Mizuhopecten* was observed at many localities (U1-3, U1-5, U2-11, U8-13B, U9-14A, U12-6B, and U12-8A).

Amussiopecten praesignis commonly occurs

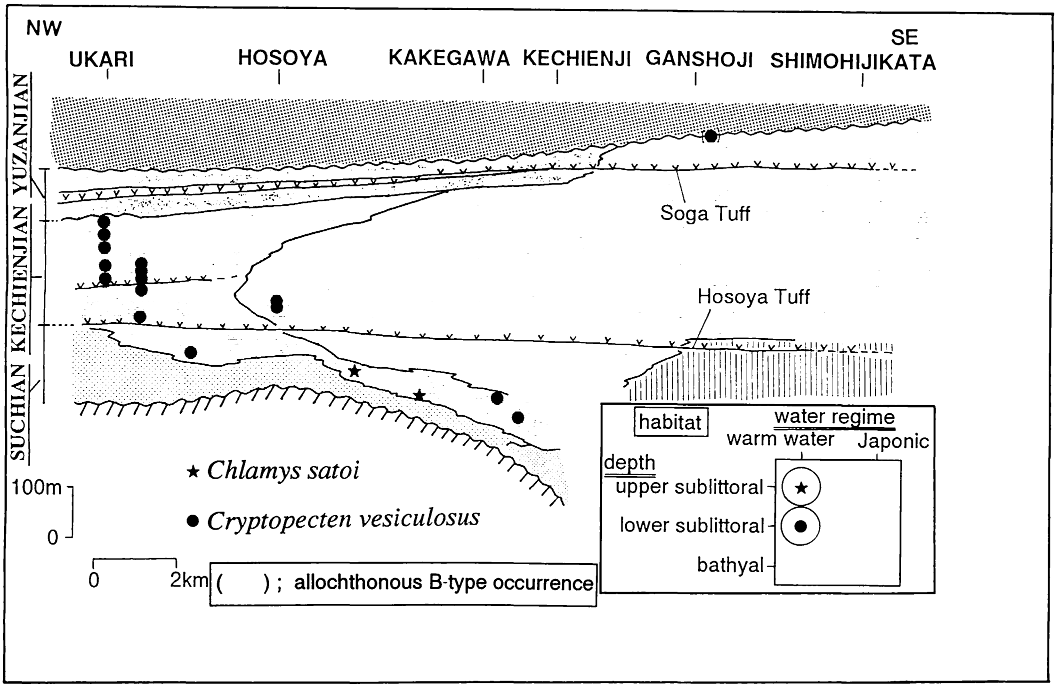
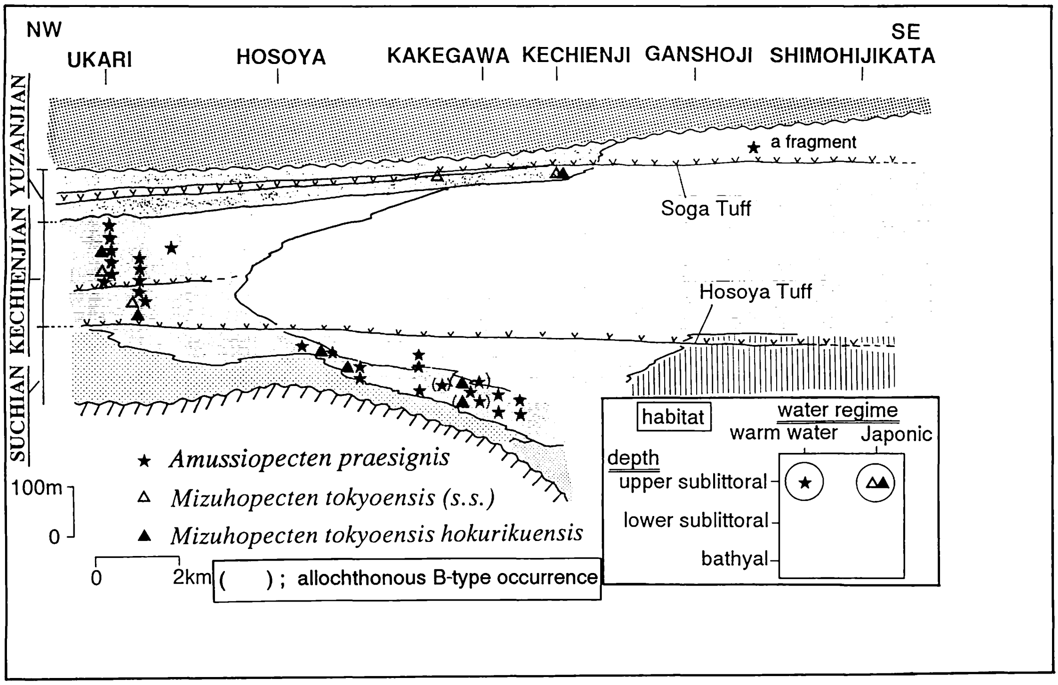


Figure 9. Comparison of the distributions of taxonomically close species. (continued)
9c. Distributions of *"Chlamys"* species.



9d. Distributions of *Amussiopecten* and *Mizuhopecten.*

in rocks of the Suchian and Kechienjian stages. In rocks of the Yuzanjian stage, however, only one small fragment of the species was found in the *Nassaria magnifica* assemblage at MKCW6. By contrast, *Mizuhopecten tokyoensis hokurikuensis* occurs at many localities in rocks of the Suchian and Kechienjian stages and many disarticulated specimens were obtained at ST10 (in rocks of the Yuzanjian stage). *Mizuhopecten tokyoensis* (*s.s.*) rarely occurs in rocks of the Kechienjian and Yuzanjian stages. Masuda (1962) suggested that *Mizuhopecten tokyoensis hokurikuensis* is an ancestral form of *M. tokyoensis* (s.s.). Therefore, in the upper sublittoral zone, Japonic endemic elements survived through all three stages, whereas the warm-water element is likely to have disappeared early in Yuzanjian time.

The common pattern recognized in these four examples is that the warm-water elements living in the upper sublittoral zone disappeared near the base of the Kechienjian stage or early in the Yuzanjian stage. By contrast, other species, such as the warmwater elements in the lower sublittoral zone and Japonic endemic elements in all depth zones, survived through all three stages.

These examples therefore demonstrate that the cooling effect of the sea water on the fauna in the Kakegawa area is restricted to the upper sublittoral zone.

Water mass fluctuation causing the faunal change

The cooling of sea water recognized by the faunal changes seems to have occurred in correspondence with regressive phases recognized by the vertical change of the lithofacies. It is most likely that the fluctuation of sea water temperature associated with eustatic sea-level change caused the faunal change. The results noted above, however, suggest that the cooling effect was restricted to the upper sublittoral zone and that the thermal change in the deeper zones was too small to cause marked faunal change.

The Kakegawa fauna was under the control of the "paleo-Kuroshio warm current" in the same way as the present southwestern Japanese marine fauna is controlled by the Kuroshio warm current. It cannot be considered that the warm-water current vanished and was replaced by a cool current, because the Kuroshio-Japonic species, such as *Clementia papyracea, Nassarius siquijorensis* and *Cryptopecten vesiculosus,* continuously occurred throughout the three stages from Suchian to Yuzanjian, as shown in Figure 6. The difference in the faunal change between depths is most likely to be related to the water thermal structure in the nearshore-offshore area under the influence of the "paleo-Kuroshio warm current." Chinzei and Aoshima's (1976) isotopic analysis along tuff layers in the Kechienjian stage showed that the water thermal structure at the earliest Pleistocene was quite similar to that of the present-day Kuroshio water. Almost all of the localities for their analysis, however, yields molluscan assemblages only under the influence of offshore, oceanic water. Therefore, the conditions of the water masses in the nearshore sea need to be considered for discussion on this selective faunal change.

The nearshore facies of the Kakegawa area was under the influence of coastal water during both the Suchian and Yuzanjian stages, as reported by Aoshima (1978). According to him, the indicators of a coastal water mass, such as a low percentage of planktonic foraminifera and low species diversity of benthic foraminifera, can be recognized in the Dainichi Formation, in the basal and uppermost parts of the Ukari Formation, and in the Soga Formation. The localities indicating the influence of coastal water nearly correspond to the localities yielding upper sublittoral species in this survey. Therefore, the upper sublittoral fauna is likely to have been under the influence of the coastal water. By contrast, lower sublittoral and bathyal species were under the influence of oceanic Kuroshio water, as suggested by Aoshima's (1978) foraminiferal indicators.

Coastal water is distinguished from offshore, oceanic water by its low salinity (Aoshima, 1978). According to Horikoshi (1987), coastal water is formed by the influx of fresh water from the land during summer, when the water masses are strongly stratified. Horikoshi (1987) stated that coastal water covers the inner shelf in the summer but disappears in winter, when the sea surface is cooled and the water conditions are convectional. Conditions of coastal water are controlled by various factors such as terrestrial climate (atmospheric temperature and amount of precipitation), and topography of coastline (embayment, gulf, or open sea). Changes in such factors could have intensified the effect of cooling associated with eustatic sea-level changes and could have caused the difference of the faunal change between depths.

For example, the Japanese terrestrial climate deteriorated from a warm temperate to a more arctic one with severe winters during the late Pliocene to early Pleistocene interval, as shown in the terrestrial floral change in Osaka, Aizu, and Niigata areas by Suzuki and Nasu (1988). During this interval, the Tertiary type plants, such as *Metasequoia* and *Glyptostrobus,* disappeared in steps, and some boreal elements, such as *Pinus koraiensis* and *Picea jezoensis,* appeared for the first time. Some problems still remain unsolved in correlations between marine sediments and terrestrial (and fresh water) ones, as noted by Nakagawa (1988). The terrestrial floral succession, however, leads to one possible scenario for explaining the selective fluctuation of water masses, as follows.

During the Suchian stage (late Pliocene), the terrestrial climate was warm-temperate throughout the year. That is, the winter climate was mild and the annual temperature range was relatively small. Thus, winter convectional conditions were difficult to initiate, and warm coastal water is estimated to have covered the nearshore area all year round.

By contrast, during the Kechienjian and Yuzanjian stages (earliest Pleistocene), the winter terrestrial climate became more severe than in the Suchian stage. As a result, winter convectional conditions occurred in the nearshore sea and warm coastal water disappeared during the winter. This change in the water seasonality seems likely to have had a more severe effect on organisms in the upper sublittoral zone than on those in the lower sublittoral zone, because upper sublittoral species had lived in the warm coastal water stratified throughout the year during the Suchian stage, whereas lower sublittoral species were under the influence of offshore Kuroshio water all year round, as they previously had been. This intensified seasonality caused the faunal change in the nearshore area.

This scenario focuses on coastal water conditions. On the contrary, it is possible to consider that physical factors of the oceanic Kuroshio water, such as current intensity, primarily controlled the nearshore faunal change. On a global scale, the current intensity is related to heat transport to the latitude. On a local scale, more directly influenced by the oceanic water current, an upper shelf fauna contains more warm-water species, as suggested in Sagami Bay by Horikoshi (1957). Therefore, changes of the current course also could have influenced the faunal change.

At present it cannot be specified what the trigger is which leads to the disappearance of warm-water species only in the upper sublittoral zone. More studies and investigations are needed, in particular on the interaction of the terrestrial climate and marine climate in each depth zone and on thermal structural changes in the Kuroshio current along the vertical (depth) and horizontal (latitude) axes. The results of this paper on faunal change, however, enable a start to be made in understanding the fluctuation of the water mass structure associated with eustatic sea-level change over a period near the Pliocene/Pleistocene boundary.

Conclusions

1) Seven types of molluscan assemblages are recognized in muddy sand to silt facies of the upper part of the Kakegawa Group. Their depositional environments range from a muddy sand bottom in the upper sublittoral zone to a silt bottom in the bathyal zone, as shown in Figure 3.

2) I traced the temporal distributions of species characteristic of each bathymetric depth zone. Some warm-water elements in the upper sublittoral zone disappeared in step in the earliest Pleistocene. By contrast, warm-water elements in the lower sublittoral zone and Japonic endemic elements at all depths occurred throughout the period from the late Pliocene to earliest Pleistocene.

3) To confirm the cooling effect on organisms in each bathymetric depth zone, I compared the temporal distributions of taxonomically close species and specified the habitats (bathymetric depth and water regime) of the disappearing species, all other ecological characters being similar. All four examples indicate that the cooling effect on faunal change was restricted to the upper sublittoral zone.

4) It is most likely that the faunal change was caused by the fluctuation of sea water temperature associated with eustatic sea-level change, but the difference in the faunal change between depths probably is related to water thermal structure in the nearshore-offshore area. The results on the faunal change give clues to the understanding of the fluctuation of water mass structure associated with eustatic sea-level change over a period of time near the Pliocene/Pleistocene boundary.

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Shizuoka 静岡, Kakegawa 掛川, Ukari 宇刈, Hosoya 細谷, Ogasa 小笠, Dainichi 大日, Soga 曾我, Horinouchi 堀之内, Hijikata 土方, Totomi 遠江, Suchi 周智, Kechienji 結縁寺,

Yuzanji 油山寺

鮮新―更新統掛川層群産貝類群集の水深別に見た変遷過程：鮮新―更新統上部掛川層群の砂泥質―泥質層より産する7つの貝化石群集型を識別した。それらの群集の生息環境は上部浅海帯砂泥底から漸深海帯泥底に及び，各水深を代表する群集が時代を通して認められ，生息水深毎に特徴種の時間分布を追跡することができた。その結果，上部浅海帯に生息する暖流系種の一部は段階的に消滅しているが，下部浅海帯以深に生息していた群集の構成にはほとんど時間変化が認められなかった。海水温の低下が生物群の消長に及ぼした影響を水深毎に特定するために，食性，生活型など類似の生態的特性を持つと思われる近縁種間で，各々の種の生息深度，地理分布に着目して時間分布を比較した。その結果，水温の低下が種の消長に及ぼした影響は，上部浅海帯以浅の水深に限られることが確かめられた。生物群の時間変化について水深間で認められるこの差異は，鮮新―更新世の海洋の温度構造の変化を反映しているものと考えられる。

延原尊美

Appendix tables 1-3. List of molluscan fossils at representative localities. R=1-2, F=3-4, C=5-9, A=10-19, VA=20-, in number of specimens.

mode of occurrence	A-type																																B-type								
assemblage type	1	2			3					4I			4II			5				6				7									→2	→4			→4	→6?			→7
localities	U9-14A	U10-9B	U12-9	ST8	U8-13B	U9-14B	U13-1	U14-2	ST10	U1-1	U1-2	U1-3	U6-15A	U2-8	U2-10	U6-1	U6-11	ST13	MKCW6	U11-2	U6-8	U8-3	MKCW7	U12-5	U9-2	U9-3	U10-1	ST12	ST15	ST16	ST17	HY1	ST2	U10-6	U11-3B	U2-11	Ogzl	U12-6B	U6-12	U8-6	U12-8A
stage species	S	S	S	Y	S	S	S	S	Y	K	K	K	S	K	K	K	K	Y	Y	S	K	K	Y	S	K	K	K	Y	Y	Y	Y	Y	Y	S	S	K	Y	S	K	K	S
Bathybembix argenteonitens (s.s.) (Lischke)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
B. argenteonitens cf. *hirasei* (Taki et Otuka)	·	·	·	R	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	F	·	·	·	·	·	·	·	·	·
B. argenteonitens forma *convexiusculus* (Yokoyama)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
B. sp.	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·
"Tristichotrochus" sp.	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Suchium suchiense suchiense (Yokoyama)	·	·	·	·	·	·	A	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	C	·	·	·
S. suchiense subsuchiense (Makiyama)	·	·	·	·	·	·	·	·	A	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
S. giganteum (Lesson)	·	·	·	·	·	·	·	·	F	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
S. cf. *mysticum* (Yokoyama)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·
S. obsoletum arenarium (Makiyama)	·	·	·	·	·	·	R	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Turritella perterebra Yokoyama	F	·	·	·	R	R	F	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	R	·	·	·
T. perterebra var.	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Orectospira aff. *excelsa* (Yokoyama)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	C	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
O. sp.A	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Onustus exutus (Reeve)	·	F	·	R	·	·	·	·	·	F	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	F	·	·	·	·	R	·	·	·	C	·	·	·	·
Volva volva habei Oyama	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·
Euspira plicispira (Kuroda)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	C	·	·	·	R	·	·	·	·	·	·	·	·	F	·	·	·	·	·	R	·	·	·
Tonna luteostoma (Küster)	·	R	·	·	·	R	·	·	·	·	·	R	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	F	R	·	·	·
Neptunea kuroshio Oyama	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·
Babylonia elata (Yokoyama)	·	·	·	·	R	R	A	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	F	·	·	R
B. elata var.	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	F	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Siphonalia declivis declivis Yokoyama	·	·	·	·	F	F	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	C	·	·	·
S. declivis biconica Makiyama	·	·	R	·	·	·	A	·	·	F	·	·	·	·	·	·	C	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R
S. declivis subsp.	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
S. tonohamaensis totomiensis Makiyama	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	R	A	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
S. mikado Melvill	·	·	·	·	R	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	R	·	·	·	·
S. modificata (Reeve)	·	F	·	·	·	·	R	R	·	·	R	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	F	·	·	F	·	·	·
S. spadicea (Reeve)	·	·	·	R	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·
S. trochula (Reeve)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	C	·	·	R	·	·	·	·	·	·	·	·	·	R	·	·	·
S. spp.	·	·	·	·	·	·	R	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·
Nassaria magnifica (Lischke)	R	·	·	·	R	·	·	·	·	·	·	·	F	·	·	A	VA	F	VA	·	A	·	C	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·
N. sp.	·	·	·	·	·	·	·	R	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Nassarius (Zeuxis) siquijorensis (A. Adams)	·	R	·	C	R	·	·	·	R	C	C	R	F	F	C	·	·	R	·	·	·	·	·	·	·	·	·	R	·	·	·	·	F	C	F	R	C	R	·	·	R
N. (Z.) dorsatus (Röding)	·	C	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Granulifusus cf. *nipponicus* (Smith)	·	·	·	R	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·
G. kiranus Shuto	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	C	·	·	·	·	·	·	·	·	·
Uromitra nakamurai Makiyama	·	A	F	·	·	·	F	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Baryspira albocallosa (Lischke)	·	·	·	·	·	·	·	R	R	R	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·
B. urashima Kira	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	A	·	·	·	·	F	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
B. suavis (Yokoyama)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	C	R	·	R	·	·	·	·	R	·	·	·	·	·	·	·	·	·
B. sp.	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	R	·	·	·	·
Fulgoraria totomiensis Makiyama	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	F	·	·	·
F. prevostiana (Crosse)	·	·	·	·	F	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	F	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
F. mentiens (Fulton)	·	·	·	·	·	·	F	·	·	·	·	·	·	·	·	R	F	·	R	R	R	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	R
F. concinna (Broderip)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·
F. cf. *hirasei* (Sowerby)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
F. spp.	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	F	·	R	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R
Marginella (Stazzania) flaccida (Yokoyama)	·	·	·	·	·	·	·	·	·	·	·	·	R	·	R	·	·	·	C	·	·	·	·	F	·	·	·	·	·	·	·	·	·	·	·	·	·	C	·	·	·
Makiyamaia coreanica (Adams et Reeve)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	C	·	A	R	R	·	A	R	·	·	·	·	·	·	·	F	·	R	·	·	·	R	·	·	·
M. subdeclivis (Yokoyama)	·	·	C	·	R	·	R	C	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·

mode of occurrence	A-type																																B-type								
assemblage type	1	2			3					4I			4II			5				6				7									·2	→4			·4	→6?			→7
localities	U9-14A	U10-9B	U12-9	ST8	U8-13B	U9-14B	U13-1	U14-2	ST10	U1-1	U1-2	U1-3	U6-15A	U2-8	U2-10	U6-1	U6-11	ST13	MKCW6	U11-2	U6-8	U8-3	MKCW7	U12-5	U9-2	U9-3	U10-1	ST12	ST15	ST16	ST17	HY1	ST2	U10-6	U11-3B	U2-11	Ogz1	U12-6B	U6-12	U8-6	U12-8A
species / stage	S	S	S	Y	S	S	S	S	Y	K	K	K	S	K	K	K	K	Y	Y	S	K	K	Y	S	K	K	K	Y	Y	Y	Y	Y	Y	S	S	K	Y	S	K	K	S
Gemmula totomiensis (Makiyama)	R	F	R	R	·	F	R	R	F	·	C	R	·	·	·	·	R	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R
Parabathytoma luehdorfi (Lischke)	·	·	·	R	·	R	R	R	·	·	R	R	R	·	R	R	VA	·	A	·	C	·	C	·	·	·	·	·	·	·	·	R	·	·	·	·	·	A	·	·	·
Thatcheria sp.	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·
Nipponoscaphander cumingii (A. Adams)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·
N. teramachii (Habe)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	F	·	·	·	·	·	·	·	·	·
Fissidentalium yokoyamai Makiyama	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	C	·	·	·	·	·	·	·	·	A	·	·	·	·	F	C	·	·	·
Spadentalina tubiformis (Boissevain)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·
Entalia quadrangularis Boissevain	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	C	·	·	·	·	·	·	·	·	·
Nucula sp.	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·
Lamellinucula tokyoensis (Yokoyama)	R	·	·	·	C	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	F	R	·	·	·
L. sp.	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	C	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·
Acila aff. *divaricata* (Hinds)	R	R	F	F	R	·	·	·	R	A	F	R	R	F	R	·	R	F	·	·	·	·	·	A	·	R	·	C	·	·	·	F	·	R	·	·	·	F	·	·	R
A. minuta Makiyama	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
A. sp.	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Ennucula niponica (Smith)	·	·	·	R	·	·	·	·	·	·	·	·	·	R	·	·	·	F	·	·	·	·	·	·	R	·	·	VA	·	R	·	R	·	·	·	·	·	·	·	·	R
E. cyrenoides (Kuroda)	·	·	·	·	R	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
E. sp.	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Sarepta japonica A. Adams	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
"*S.*" sp.	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·
Bathymalletia inaequilateralis Habe	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	F	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·
Carinineilo carinifera (Habe)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	C	·	·	R	R	·	R	·	·	·	·	·	·	·	R	·
Neilonella coix Habe	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	A	·	·	F	A	R	·	·	·	·	VA	·	·	·	·	·	R	·	R	·
N. japonioca Okutani	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	VA	·	·	·	·	·	·	·	·	·
N. sp.	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	F	VA	·	·	·	·	·	·	·	·	·
Nuculana pernula sadoensis (Yokoyama)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	R	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·
N. yokoyamai (Kuroda)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R
N. yokoyamai arai Habe	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R
N. acinacea Habe	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·
N. sp.	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	R	·	·	F	·	·	·	·	·	·	·	·	·
Saccella confusa (Hanley)	·	R	·	·	·	·	F	F	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·
S. gordonis (Yokoyama)	R	R	·	R	R	R	·	·	R	C	R	F	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	R	·	·	R	·
S. sematensis (Suzuki et Isizuka)	·	·	·	·	·	·	F	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
S. sp.	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Yoldia naganumana (Yokoyama)	·	·	R	·	·	·	R	·	·	·	·	·	F	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·
Y. similis Kuroda et Habe	·	·	·	·	·	·	·	·	·	·	·	·	·	R	R	·	·	·	R	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	F	·	·	·	·
Y. cf. *glauca* Kuroda et Habe	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	C	·	·	·	·	·	·	·	·	·
Y. sp.	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	R	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Portlandia japonica (Adams et Reeve)	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	R	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·
P. lischkei (Smith)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·
Scapharca castellata (Yokoyama)	A	·	·	·	R	F	·	·	·	·	R	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	F	·	·	F	·	A
S. cf. *castellata* (Yokoyama)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·
S. suzukii (Yokoyama)	·	A	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
S. broughtonii (Schrenck)	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Cucullaea labiosa granulosa Jonas	R	·	·	·	F	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Glycymeris rotunda (Dunker)	R	A	A	F	A	A	A	A	C	A	A	VA	A	A	A	·	·	·	·	·	·	·	·	R	·	·	·	R	·	·	·	·	C	A	F	A	VA	A	F	R	A
G. albolineata (Lischke)	·	·	R	·	·	·	F	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	R
Tucetilla pilsbry (Yokoyama)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·
Limopsis tajimae Sowerby	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	VA	·	F	VA	A	VA	VA	C	R	F	·	·	·	·	·	·	·	·	·	·	·	A	VA	R	R
Crenulilimopsis oblonga (A. Adams)	VA	·	·	·	A	VA	A	VA	VA	·	·	R	VA	·	·	·	A	·	·	·	·	·	F	·	·	·	·	·	·	·	·	·	·	F	·	·	·	A	·	·	A
Oblimopa japonica (A. Adams)	·	·	·	·	R	·	F	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·

mode of occurrence	A-type																																B-type								
assemblage type	1	2			3					4I			4II			5				6				7									→2	→4			→4	→6?			→7
localities	U9-14A	U10-9B	U12-9	ST8	U8-13B	U9-14B	U13-1	U14-2	ST10	U1-1	U1-2	U1-3	U6-15A	U2-8	U2-10	U6-1	U6-11	ST13	MKCW6	U11-2	U6-8	U8-3	MKCW7	U12-5	U9-2	U9-3	U10-1	ST12	ST15	ST16	ST17	HY1	ST2	U10-6	U11-3B	U2-11	Ogz1	U12-6B	U6-12	U8-6	U12-8A
stage / species	S	S	S	Y	S	S	S	S	Y	K	K	K	S	K	K	K	K	Y	Y	S	K	K	Y	S	K	K	K	Y	Y	Y	Y	Y	Y	S	S	K	Y	S	K	K	S
Solamen spectabilis (A. Adams)	·	·	·	·	·	·	·	·	·	R	·	R	·	·	·	R	·	·	R	·	R	·	R	·	·	·	·	·	R	·	·	·	·	·	·	·	A	·	·	R	·
Ctenamusium clancularium (Yokoyama)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	VA	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Bathyamussium jeffreysi (Smith)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	F	·	·	·	·	·	·	·	·	·
Chlamys satoi (Yokoyama)	F	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
C. cf. *asperulata* Adams et Reeve	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·
Cryptopecten vesiculosus (Dunker)	·	·	·	·	·	·	R	R	·	F	R	F	·	R	F	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	A	·	·	·	·
Amussiopecten praesignis (Yokoyama)	VA	VA	·	·	A	F	A	R	·	A	R	F	·	R	R	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	R	C	·	F	·	·	A
Mizuhopecten tokyoensis (s.s.) (Tokunaga)	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	R	·	·	·	·	·
M. tokyoensis hokurikuensis Masuda	F	·	·	·	R	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	R	·	R
Yabepecten tokunagai (Yokoyama)	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·
Anomia chinensis Philippi	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Acesta goliath (Sowerby)	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Limatula vladivostokensis Scarlato	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·
Dendostrea ? crenulifera (Sowerby)	·	A	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Lucinoma annulata (Reeve)	·	·	·	C	·	·	·	·	A	F	·	·	R	R	·	·	·	R	·	·	·	·	·	·	·	·	·	·	F	·	·	·	·	·	·	·	F	·	·	·	·
Cycladicama cumingii (Hanley)	·	F	R	F	·	·	·	·	·	·	·	R	·	F	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	A	·	·	·	·
Venericardia panda (Yokoyama)	R	C	·	·	·	R	F	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	R	R	·	·	C	R	·	R
V. ferruginosa (Adams et Reeve)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	F	·	·	·	·
Pleuromeris pygmaea Kuroda et Habe	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	F	·	·	·	·
Indocrassatella oblongata (Yokoyama)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	A	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Crassatellites takanabensis Shuto	R	·	·	·	A	A	·	·	·	·	C	C	A	·	C	·	F	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	C	A	·	R	R
C. uchidanus (Yokoyama)	·	·	·	·	·	·	C	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Nemocardium samarangae (Makiyama)	·	·	R	R	·	·	·	·	·	F	R	R	F	·	F	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	VA	·	·	R	R
Lutraria maxima Jonas	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·
Angulus vestalioides (Yokoyama)	·	·	·	F	·	·	·	·	R	C	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Abra maxima Sowerby	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	C	·	·	·	·	·	·	·	·	·
A. soyoae Habe	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	F	·	·	·	·	·	·	·	·	·
A. sp.	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·
Gari anomala (Deshayes)	·	·	·	·	·	·	·	·	·	F	R	C	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
G. sibogai Prashad	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
G. sp.	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·
Solecurtus divaricatus (Lischke)	·	·	·	·	·	·	·	·	·	F	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
S. sp.	·	·	·	·	·	·	·	·	·	·	R	R	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Solen gordonis Yokoyama	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·
"Cultellus" sp.	·	R	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Meiocardia tetragona (Adams et Reeve)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	C	·	·	·	·
Ventricolaria foveolata (Sowerby)	·	·	·	R	R	·	·	·	·	A	A	A	A	C	A	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	A	·	·	A	·	·	·	·
Mercenaria yokoyamai (Makiyama)	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	A	·	·	·
Pitar sp.	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·
Dosinia (Phacosoma) japonica (Reeve)	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·
D. (P.) troscheli Lischke	·	·	·	·	R	·	·	·	F	R	·	·	R	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·
D. sp.	·	·	·	·	·	R	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Paphia amabilis (Philippi)	R	·	·	·	·	F	F	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	F	·	·	·
P. schnelliana (Dunker)	·	A	C	C	A	·	R	R	F	A	A	F	A	F	A	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	F	·	·	R	R	A	R	·	R
Callista chinensis (Holten)	·	·	·	·	·	R	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	F	·	·	R
Clementia papyracea Gray	·	A	A	F	·	R	·	·	R	R	F	R	·	R	F	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	F	·	·	·	·	R	·	·	·
Anisocorbula scaphoides (Hinds)	·	A	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Solidicorbula erythrodon (Lamarck)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·
Panopea japonica A. Adams	·	·	·	·	·	·	R	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·
Periploma plane Ozaki	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·

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955. MORPHOLOGY AND TAXONOMY OF SOME JAPANESE HEMICYTHERIN OSTRACODA —— WITH PARTICULAR REFERENCE TO ONTOGENETIC CHANGES OF MARGINAL PORES ——*

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Abstract. Hemicytherin ostracodes are diverse in late Neogene deposits and include some forms occurring in both the northern Atlantic and northwestern Pacific. To clarify phylogenetic relations among these hemicytherin ostracodes, 21 species in eight genera (*Baffinicythere, Daishakacythere* n. gen., *Finmarchinella, Hemicythere, Johnnealella, Normanicythere, Patagonacythere,* and *Urocythereis* ?) are subjected to a morphological investigation of such characters as reticulation, muscle scars, hingement, and pore canals. The present study demonstrates for the first time that ontogenetic changes of marginal pores, which are distributed along the anterior valve margin, provide useful information about the taxonomy of hemicytherin ostracodes and their phylogenetic reconstruction. On the basis of ontogenetic changes of distributional patterns both of normal and marginal pores, the examined species can be divided into three groups. One new genus, *Daishakacythere*, and two new species, *Finmarchinella subrectangulata* and *Patagonacythere sasaokensis*, are described herein.

Key words. Ostracoda, Hemicytherinae, ontogenetic change, marginal pore, Northeast Japan.

Introduction

The subfamily Hemicytherinae comprises a number of genera, which have been defined on the basis of different characters by different workers. Some ostracodologists describe their genera in a narrow sense, thus it is not unusual that one genus contains only one species (monotypic genus). In addition, there are a number of endemic sublittoral ostracode species because of the absence of planktonic larval periods. As a result, many genera have been proposed by ostracode workers in various regions of the world. It is generally regarded, and the author also believes, that a genus is a group of species which have morphological characters more similar to each other than to species of other genera. Those characters should be genetically controlled (not ecophenotypic characters) and homologous. In the taxonomic work of ostracodes, a common practice has been to rely mainly on the ornamentation and morphology of carapaces in the adult stage. We cannot determine, however, whether similarities between the compared characters are derived from adaptive convergence (analogy) or phylogenetic descent (homology), on the basis only of adult morphology. Actually, some ostracodes belonging to phylogenetically different genera become more similar in shape to each other

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toward adulthood due to allometric elongation of male valves or inflation of female ones of nearly all species to accomodate the copulation apparatus. Thus, it is important to investigate ontogenetic changes and trajectories of characters to distinguish phylogenetically related species groups (genera). Hemicytherin ostracodes have many advantageous characteristics for studying morphologic ontogenetic changes: relatively large and heavily calcified valves which fossilize easily, numerous pore canals on the valve, straight pores along the valve margin, conspicuous reticulation, ridges, well developed hingements, and muscle scars. These qualities facilitate the taxonomy and phylogenetic reconstructions of hemicytherin ostracodes with reference to ontogenetic changes.

The purpose of the present study is to reevaluate some characters which have been considered important for ostracode taxonomy, and to demonstrate that distributional patterns of marginal pores through ontogeny are very useful for the taxonomy and understanding the phylogeny of hemicytherin ostracodes.

Materials

Many hemicytherin ostracodes except for the tribe Aurilini have been reported mainly from Plio-Pleistocene deposits in Northeast Japan (Cronin and Ikeya, 1987; Hanai and Ikeya, 1991; Hanai and Yamaguchi, 1987; Hanai *et al.*, 1977; Hayashi, 1988; Irizuki, 1989; Ishizaki and Matoba, 1985; Okada, 1979; Tabuki, 1986). Among these ostracodes 21 species were discriminated, including one new genus and two new species which are described in this paper (Figure 2). Figure 1 and Table 2 show the location of samples used in this paper. Most of the materials were collected by the author, but some were borrowed from others. In the present study, examined were such characters as reticulation, pores distributed on the valve surface and along the anterior valve margin, muscle scars, and hingements of the species as defined by previous workers. Examinations show that the following assortment is reasonable for further study.

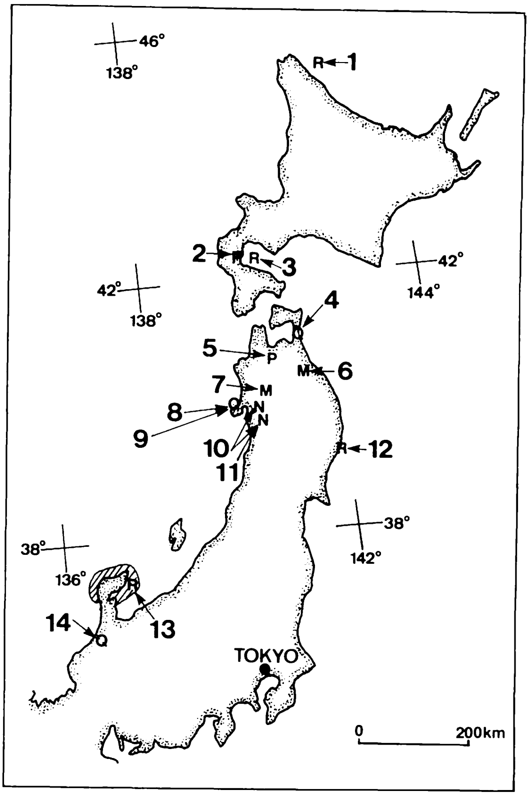

Figure 1. Sample localities in northern Japan. 1: off Hamatonbetsu, 2: Setana Formation, 3: Funka Bay, 4: Hamada F., 5: Daishaka F., 6: Shitazaki F., 7: Fujikotogawa F., 8: Anden F., 9: Shibikawa F., 10: Sasaoka F., 11: Tentokuji F., 12: Otsuchi Bay, 13: Toyama Bay, 14: Omma F. M: Miocene, N: Pliocene, P: Plio-Pleistocene, Q: Pleistocene, R: Recent

Baffinicythere: Three species (*B.* sp. 1, *B.* sp. 2 and *B.* sp. 3) were discriminated in this genus. *Baffinicythere* sp. 3 is identical with *B. howei* of Cronin and Ikeya (1987). These species will be described in another paper.

Finmarchinella: Five species (*F. hanaii* Okada, *F. japonica* (Ishizaki), *F. nealei* Okada, *F. rectangulata* Tabuki and *F. uranipponica* Ishizaki) and a new species (*F.*

subrectangulata) to be described herein were distinguished.

Hemicythere: Four species (*H. emarginata* (Sars), *H. kitanipponica* (Tabuki), *H. ochotensis* Schornikov, and *H. orientalis* Schornikov) are placed here. *Hemicythere emarginata* was placed in the genus *Baffinicythere* by Hazel (1967) and *Hemicythere kitanipponica* was described as *Ambostracon kitanipponica* by Tabuki (1986).

Patagonacythere: Patagonacythere robusta Tabuki and a new species (*P. sasaokensis*) which is described in this paper were distinguished.

Normanicythere: One species (*N. japonica* Tabuki) was determined.

"Urocythereis": In the present study, a group of taxa which has loosely been assigned to *"Urocythereis"* was divided into three different genera: *Johnnealella* (*J. nopporoensis* Hanai and Ikeya), *Urocythereis*? (*U.*? *gorokuensis* Ishizaki), and the new genus *Daishakacythere* (*D. abei* (Tabuki), *D. posterocostata* (Tabuki) and *D.* sp. 1). These revisions will be justified based on the following analyses.

Reevaluation of some important characters

First the author discusses reevaluation of valve characters such as reticulation, muscle scars, and hingements, which have been considered to be of phylogenetic significance and important for ostracode taxonomy.

a) Reticulation

Reticulation is an ornamentation resembling the mesh of nets which covers most of the valve surface. Okada (1981, 1982a, b) showed that each fossa corresponds to the underlying epidermal cell. Patterns of reticulation have been used in taxonomy and phylogenetic analyses (Liebau, 1969, 1971, 1977 (English version 1971); Benson, 1972, 1977; Valicenti, 1977). In the present study, Liebau's (1969) system was followed as faithfully as possible to examine 13 species having prominent reticulation patterns: *B.* sp. 1, *B.* sp. 2, *B.* sp. 3, *D. abei, D. posterocostata, F. japonica, F. nealei, H. emarginata, H. kitanipponica, H. ochotensis, U.? gorokuensis, J. nopporoensis,* and *P. sasaokensis.* Figure 3 shows the location of c-type pores (Hanai and Ikeya, 1991) and fossal patterns on the left valve of *Baffinicythere* sp. 1. Alphanumerals are keyed to those in Liebau' s system. It is surprising that all the illustrated pores are located at homologous positions relative to those of *Limburgina* and *Oertliella,* both belonging to the Trachyleberidinae (see Abb. 1 of Liebau, 1969). Therefore, the position of c-type pores provides an excellent guide to determining homologous fossae among species. As a result, all the

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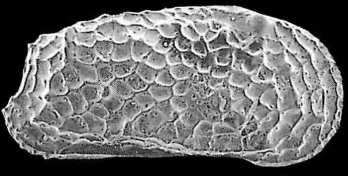
→ **Figure 2.** Twenty-one species examined in this study. All figures are SEM micrographs of right valves in lateral view. Scale bars are 0.5 mm: A for 1-6, 17-21; B for 7-16. **1,** *Baffinicythere* sp. 1, male, Loc. PSK-7, IGPS 101616; **2,** *Baffinicythere* sp. 2, male, Loc. 914-5, IGPS 101627; **3,** *Baffinicythere* sp. 3, male, Loc. St. 31, IGPS 101639; **4,** *Daishakacythere abei* (Tabuki, 1986), gen. nov., male, Loc. 523-6, IGPS 101655; **5,** *Daishakacythere posterocostata* (Tabuki, 1986), gen. nov., male, Loc. MAE-3, IGPS 101664; **6,** *Daishakacythere* sp. 1, gen. nov., A-1 stage, Loc. MAE-3, IGPS 101673; **7,** *Finmarchinella hanaii* Okada, 1979, male, Loc. 523-6, IGPS 101706; **8,** *Finmarchinella japonica* (Ishizaki, 1966), male, Loc. 523-6, IGPS 101715; **9,** *Finmarchinella nealei* Okada, 1979, male, Loc. 523-6, IGPS 101723; **10,** *Finmarchinella rectangulata* Tabuki, 1986, male, Loc. SK-3, IGPS 101732; **11,** *Finmarchinella subrectangulata,* sp. nov., male, Loc. 523-6, IGPS 101740; **12,** *Finmarchinella uranipponica* Ishizaki, 1969, male, Loc. 523-6, IGPS 101749; **13,** *Hemicythere emarginata* (Sars, 1865), male, Loc. PSK-5, IGPS 101758; **14,** *Hemicythere kitanipponica* (Tabuki, 1986), male, Loc. SK-3, IGPS 101767; **15,** *Hemicythere orientalis* Schornikov, 1974, male, Loc. 523-6, IGPS 101784; **16,** *Hemicythere ochotensis* Schornikov, 1974, male, Loc. SK-3, IGPS 101775; **17,** *Johnnealella nopporoensis* Hanai and Ikeya, 1991, male, Loc. 523-9, IGPS 101800; **18,** *Urocythereis*? *gorokuensis* Ishizaki, 1966, female, Loc. HIR-2S, IGPS 101792; **19,** *Normanicythere japonica* Tabuki, 1986, adult, Loc. TAI-2S, IGPS 101808; **20,** *Patagonacythere robusta* Tabuki, 1986, male, Loc. KOS-3S, IGPS 101815; **21,** *Patagonacythere sasaokensis,* sp. nov., male, Loc. HIR-3S, IGPS 101823.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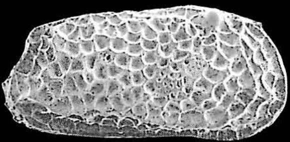
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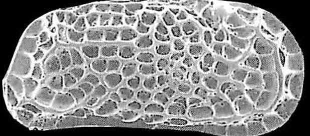
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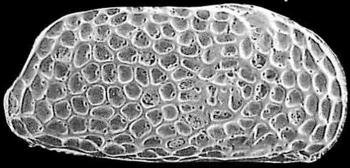
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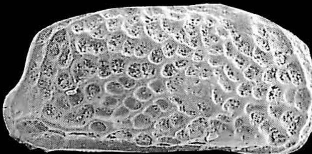
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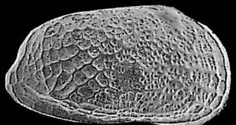
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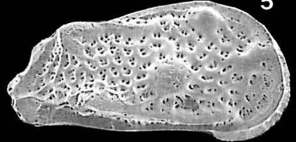
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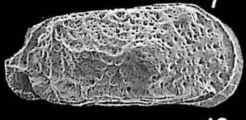
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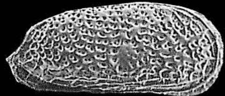
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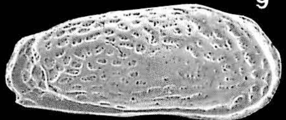
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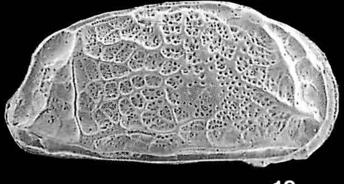
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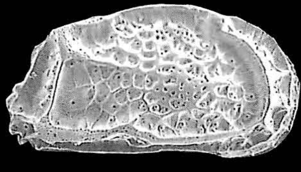
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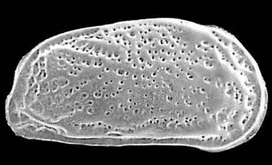
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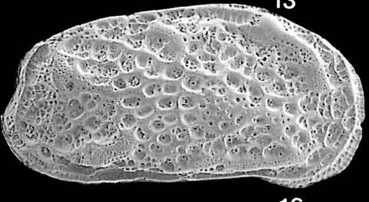
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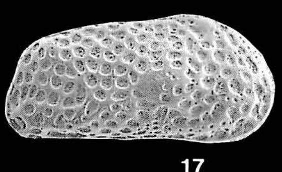
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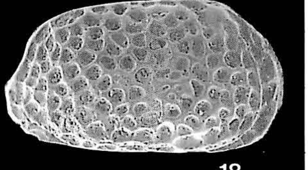
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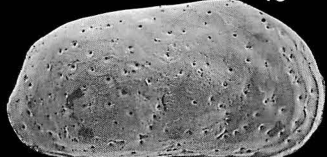
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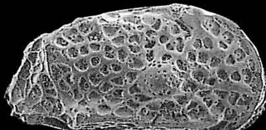
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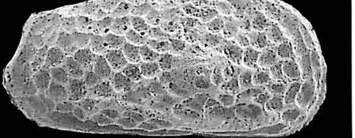
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A

B

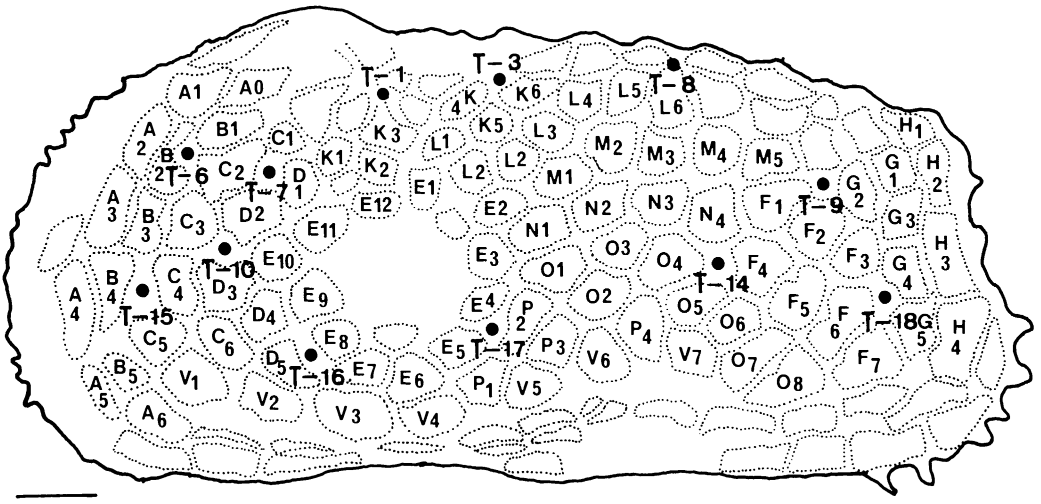


Figure 3. C-type pore canals and reticulation in *Baffinicythere* sp. 1 (male LV), following Liebau's (1969) system. Scale bar is 100 μm.

examined species have almost the same reticulation pattern as shown in Figure 3, although they show some variation in the posterodorsal portion at the L2 and O3 fossae: the former is often subdivided further and the latter is in some cases not divided even within the same species. In comparison with the illustrations of Liebau (1969, 1971), Benson (1972, 1977) and Valicenti (1977), it follows that species in the Trachyleberididae have similar reticulation patterns to those in the Hemicytheridae. Thus, the number of epidermal cells is very conservative even in different families. In this way, each species has basically the same number of epidermal cells, and the positioning of each cell seems to be genetically constrained (for example the A1 cell is next to the A2 cell). However, each species has its own ornamentation and valve shape because of the different size, shape and arrangement of the epidermal cells.

b) Muscle scar patterns

Various muscle scars can be recognized on the inner surface of ostracode valves. These represent where the soft parts were attached with several muscles. There are three kinds of muscle scars: dorsal, frontal and adductor. Their characteristics have been used for classifying families and genera and constructing their phylogenetic trends. Hazel (1967) depicted the phylogenetic tree of some genera belonging to both the Trachyleberididae and Hemicytheridae on the basis of frontal and adductor muscle scar patterns. He put much emphasis on the frontal scar patterns and concluded that the time-successive development of three scars from two in the Hemicytherinae must be considered a phylomorphogenic trend. Similarly, he suggested that there was a trend through time in the Hemicytherinae toward the division of the median adductor muscle scars. Schornikov (1974) investigated the muscle scar patterns of some *Hemicythere* species (*H. emarginata*, *H. nana* Schornikov, and *H. borealis* (Brady)). The genus *Hemicythere* has usually been considered to have two frontal scars, but Schornikov (1974) found specimens having both two and three frontal scars and various numbers of adductor scars. In the present study, specimens having three frontal scars were recognized in *Hemicythere orientalis*. Doruk (1974a, b, c) and Athersuch and Ruggieri (1975) also showed variations in

Urocythereis species (*U. favosa, U. seminulum, U. labyrinthica,* and *U. phantastica,* respectively) in the number of frontal scars from two to three and in the division of the four adductor scars. In this way, hemicytherin ostracodes have considerable variations in muscle scar patterns. However, there is a dominant pattern in each species. Species having three frontal scars belong to *Patagonacythere, Normanicythere, Baffinicythere,* and *Finmarchinella* (except for *F. rectangulata*). In contrast, species having two frontal scars are members of *Johnnealella, Urocythereis* ?, *Daishakacythere,* and *Hemicythere,* and *F. rectangulata.* The number of adductor muscle scars differs even within the same genus: *Daishakacythere abei* has divided ventromedian scars but *D. posterocostata* has an elongated one; and *P. robusta* has divided dorsal scars but *P. sasaokensis* has an elongated one (Figure 13-8c). As pointed out by Doruk (1974a, b, c), Athersuch and Ruggieri (1975), and Wouters (1979), even in the same species from a single locality there are some variations: some of the specimens of *Baffinicythere* sp. 2 from OK-1 (Setana Formation) have divided dorsal scars and others an elongate one.

c) Hingements

All the examined species have the same holamphidont hingement except for those belonging to *Finmarchinella* (antimerodont) although some variations are seen. For example, *Urocythereis* had been considered to have a stepped anterior hinge element, but Doruk (1974a) showed that a single species belonging to that genus has a stepped to smooth anterior element.

Ontogenetic changes of pore distributional patterns

Most ostracodes have two calcified valves (carapace) on which there are many pore canal openings for bristles. These pores have been dealt with by most ostracodologists in bipartite fashion: normal pores distributed on the valve surface versus marginal pores located along the valve margin; and simple pores versus sieve pores. Hanai and Ikeya (1991), however, thought that normal pores are the same as marginal pores in terms of development; ostracode valves consist of a single sheet layer (Kornicker, 1969) and the shape of pores is changeable in response to the surrounding environments. They defined c- and v-types of pores. The former pertains to pores which remain constant in position and number through ontogeny, but the latter is variable in these aspects. Okada (1982b, 1983) compared pore morphologies on the valve surface (normal pores) with those along the valve margin (marginal pores) of *Bicornucythere bisanensis* (Okubo) and concluded that they have very similar characteristics although the length and position of pores are variable. Even more significantly, the location of pores, or bristles, is genetically controlled and constant in each species (Hanai, 1970; Rosenfeld, 1982; Tsukagoshi, 1990). Bristles emanating from the valve margin may be functionally different from other pores distributed on the valve surface based on their unique positioning. Thus, investigated were the ontogenetic changes of pores both on the valve surface and along the anterior valve margin, which hereafter are called "marginal pores" only for the sake of convenience. Marginal pores in the present study are assigned to so-called radial pore canals.

a) Methods

To observe normal pore patterns, specimens soaked in water were observed by using a transmitted light microscope, making reference to scanning electron micrographs. Previous observations were made on specimens soaked in a glycerin water solution, which was found to induce the specimens to break down as they dried. Therefore, only water instead of glycerin was used in this study. Hemicytherin ostracodes have so many pores on the valve in the adult stage (*e.g.*, an adult *Baffinicythere* sp. 1 has about 250 pores on

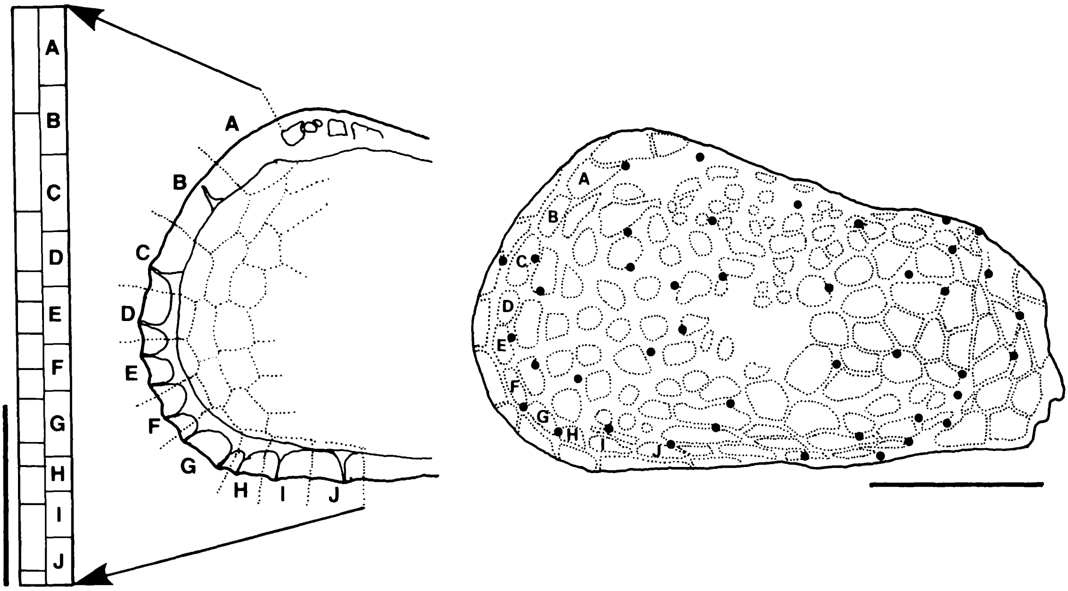


Figure 4. Procedures for investigating ontogenetic changes of pores distributed along the anterior valve margin. A to J represent the alphabetized fossa. Silhouettes of the valve are drawn after micrographs of the A-3 instar left valve of *Finmarchinella nealei* Okada. This specimen has 11 marginal pores. Scale bars are 100 μm.

the valve surface) that it is difficult to recognize every pore if fossil specimens are poorly preserved. Thus, examined in this study were normal pore distributional patterns of 21 hemicytherin ostracodes in A-5 to A-3 instars to demonstrate intergeneric relationships among them. Marginal pores were studied in left valves of A-3 to adult specimens. Table 1 shows the examined species in A-5 to A-3 stages ; the earliest stage is A-6 of *Baffinicythere* sp. 2. Specimens immersed in water on a glass slide were photographed using a Nikon transmitted-light microscope at 40× and/or 80× magnifications. Figure 4 summarizes procedures for the analyses.

Each fossa (reticulum) distributed along the anterior valve margin was alphabetized from A to J. D and E cells are divided at an ecdysis from A-4 to A-3 stages. Anterior marginal pores were illustrated along the line from the anterior end of the hinge to the J mesh ; the length of this line was standardized to facilitate a comparison of pore locations among specimens.

b) Ontogenetic changes of pores on the valve surface

Studies of the distribution of pores on the valve surface have been made by many workers. The intraspecific stability of distributional patterns of pores has been recognized in various ostracode species (Hanai, 1970 ; Rosenfeld, 1982 ; Tsukagoshi, 1990). Hence, these patterns can be used for classifying and relating the examined species. Plusquellec and Sandberg (1969) distinguished some consistent pore patterns, useful for phylogenetically relating species belonging to the same genus. They also used differences in pore patterns for separating similar genera. Hanai (1970) observed little intraspecific variability in pore patterns and suggested that species may be distinguished based on these patterns. Benson (1972, 1975, 1976) used interspecific differences in homologous pore patterns to display quantitatively differences in valve morphology. Rosenfeld (1982) investigated pore distributional patterns of two brackish-water species (*Loxoconcha elliptica* Brady and *Cyprideis torosa* (Jones)) and concluded that even in a brackish-water environment subject to high stresses, their pore patterns are stable and may be genetically controlled. Tsukagoshi (1990) showed the phylogenetic scheme of species belonging to the genus *Cythere* on the basis of ontogenetic changes of pores distributed on the valve surface. He indicated that all the *Cythere* species have the same pore patterns in the A-3 stage, and that interspecific differentiation in morphology occurs in later growth stages, resulting in several species groups. Up till now, ontogenetic changes of pores in each species belonging to a single genus have been examined, but changes in species belonging to different allied genera have not previously been investigated.

Figure 5 and Table 1 show the distributional patterns of pores on the valve surface in A-5 to A-3 stages. The outlines of the examined valves were drawn relative to micrographs of *Baffinicythere* sp. 2. For the A-5 instar, specimens of only four species (*B.* sp. 2, *D. abei, F. hanaii,* and *N. japonica*) could be obtained for this analysis. These four species have the same pore patterns (Table 1 and Figure 5). In the A-4 stage, two groups are discernible: 1) *Baffinicythere, Daishakacythere, Hemicythere emarginata,* and *H. orientalis,* each having pore D in common; 2) *Finmarchinella, Hemicythere ochotensis, Johnnealella, Normanicythere, Patagonacythere,* and *Urocythereis* ?, which have their inherent pore E or E′. Thirty-nine pores are common to all species in the A-3 stage (solid circles on the A-3 instar valve in Figure 5), but ten groups are discernible on the basis of inherent pores (Pores A to H′ in Figure 5 and Table 1). It is clearly shown that on the one hand some species within the same genus have different pore patterns (*e.g.*, species in the genera *Baffinicythere, Finmarchinella, Hemicythere,* and *Patagonacythere*). On the other hand, other species belonging to different genera have the same pore patterns in the A-3 stage (*e.g.*, two *Baffinicythere* species and three *Daishakacythere* species have the same pores) (Table 1).

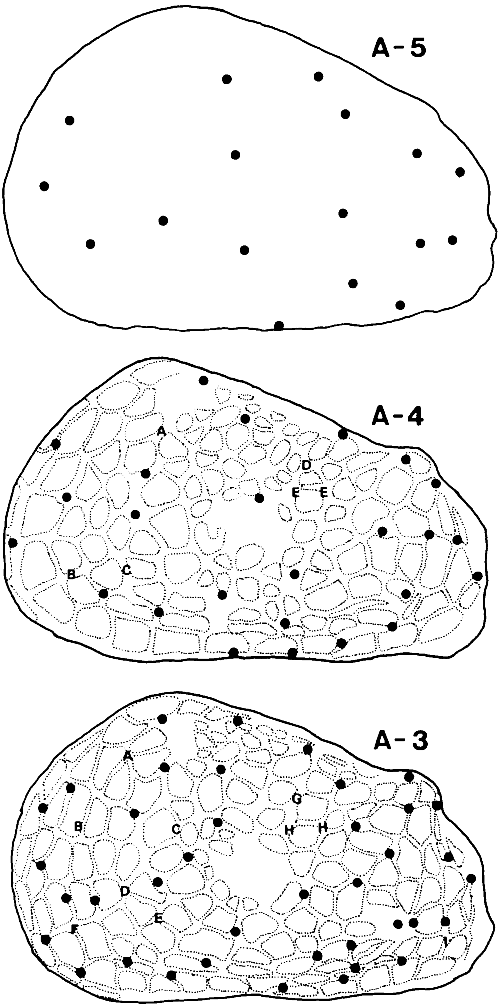


Figure 5. Ontogenetic changes of pores distributed on the valve surface. Solid circles represent common pores in all species. A to I stand for pores specific to certain species (see Table 1). Silhouettes of specimens are drawn after micrographs of *Baffinicythere* sp. 2.

c) Ontogenetic changes of marginal pore patterns

The characteristics of marginal pores of adult specimens were used for suprageneric

Table 1. Species-specific normal pores in the A-5 to A-3 stages and the number of anterior marginal pores (AMP) in the adult stage. Specimens shown by "/" could not be examined. Letters refer to cells where normal pores are observed in correspondence to Figure 5. Four species in the A-5 stage have the same normal pore pattern (*). In the A-3 stage, ten groups are discernible on the basis of inherent normal pores. All normal pores in A-3 instar juveniles of *Patagonacythere sasaokensis* are common to the other examined species (*P. sasaokensis* has no species-specific pores).

Species	normal pores specific to species			No. of AMP.
	A-5	A-4	A-3	Adult
Baffinicythere sp. 1	/	A D	A B C D E F G H	82-83
B. sp. 2	*	D	B C F G	69-72
B. sp. 3	/	D	B C F G	61-63
Daishakacythere abei	*	D	B C F G	56-57
D. posterocostata	/	D	B C F G	60
D. sp. 1	/	D	B C F G	/
Finmarchinella hanaii	/	E	B C H	39-40
F. japonica	/	/	B C H	42-43
F. nealei	/	E	B C H	40-43
F. uranipponica	*	E	B C H	37-39
F. rectangulata	/	/	B H	32-33
F. subrectangulata	/	E	B H	32-35
Hemicythere emarginata	/	D	F G	55-56
H. kitanipponica	/	/	F G	55-56
H. orientalis	/	B D F	C F G I	55-56
H. ochotensis	/	E′	C H′	37-42
Johnnealella nopporoensis	/	E	C G H	40-42
Urocythereis ? gorokuensis	/	E	C G H	35-36
Normanicythere japonica	*	E′	H′	31-33
Patagonacythere robusta	/	C E	H	34-35
P. sasaokensis	/	/		33

taxonomy by Plusquellec and Sandberg (1969) and Liebau (1975). Plusquellec and Sandberg (1969) suggested that the arrangement of marginal pores is of major importance to the study of speciation in the genus *Proteoconcha*. However, ostracodologists have not thoroughly studied ontogenetic changes of marginal pores with the intention of finding potential clues to the taxonomy of ostracode genera and their phylogenetic reconstruction.

It was impossible to group the examined species by the morphology of marginal pores of the adult specimens, which all have straight pores slightly inflated in the middle part and sometimes fused. Their morphology is similar to that of *Bicornucythere bisanensis* studied by Okada (1982b). In general, there are few variations in the number of marginal pores in early juveniles, but intraspecific variations are recognized in the A-1 and adult stages. Table 1 shows the number of marginal pores of 20 species at the adult stage (adults of *D.* sp. 1 could not be obtained), demonstrating that they fall into two groups: one has relatively numerous pores (55–83) and the other has 31 to 43 pores. The former includes *Baffinicythere, Daishakacythere,* and the *Hemicythere villosa* group, and the latter contains *Finmarchinella, Hemicythere borealis* group, *Johnnealella, Normanicythere, Patagonacythere,* and *Urocythereis* ?. Schornikov (1974) divided *Hemicythere* into two groups on the basis of ornamentation and valve morphology, the *H. villosa* group (*Hemicythere emarginata, H. orientalis,* and perhaps *H. kitanipponica*) and the *H. borealis* group (*H. ochotensis*). These two groups also differ in the number of marginal pores.

From the ontogenetic changes of marginal pores, some groups can be discerned on the basis of the distributional patterns and the number. Figure 6 shows two examples of the ontogenetic changes of the anterior marginal pores of *Baffinicythere* sp. 1 (Figures 6A-D) and *Finmarchinella nealei* (Figures 6E-H). Figure 7 indicates the ontogenetic trajectories of the number of marginal pores shown by the 21 species.

A-5 juveniles of *Baffinicythere* sp. 2, *D. abei, F. hanaii, N. japonica,* and *P. robusta* have the same number (4) and location of marginal pores (B, DE, G, I) (Figures 8, 9, 11).

At the A-4 stage, two types are manifested. Species of the first type have seven marginal pores and nearly the same pattern (A, DE, F1, F2, G, H, I) (Figures 6E, 9–11). These belong to such genera as *Finmarchinella, Hemicythere, Johnnealella, Normanicythere,*

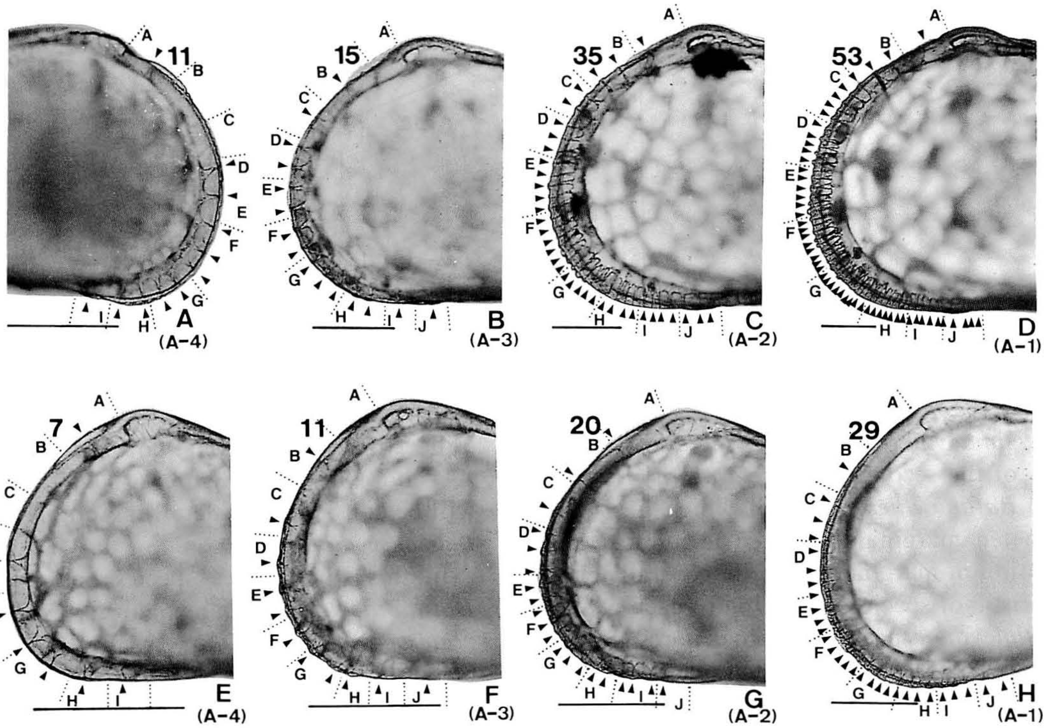


Figure 6. Changes of anterior marginal pore patterns in *Baffinicythere* sp. 1 (A-D) and *Finmarchinella nealei* (E-H). Numerals refer to the number of anterior marginal pores. A to J around the valve margin represent the alphabetized fossa. Arrow heads show each anterior marginal pore. Scale bars are 100 μm.

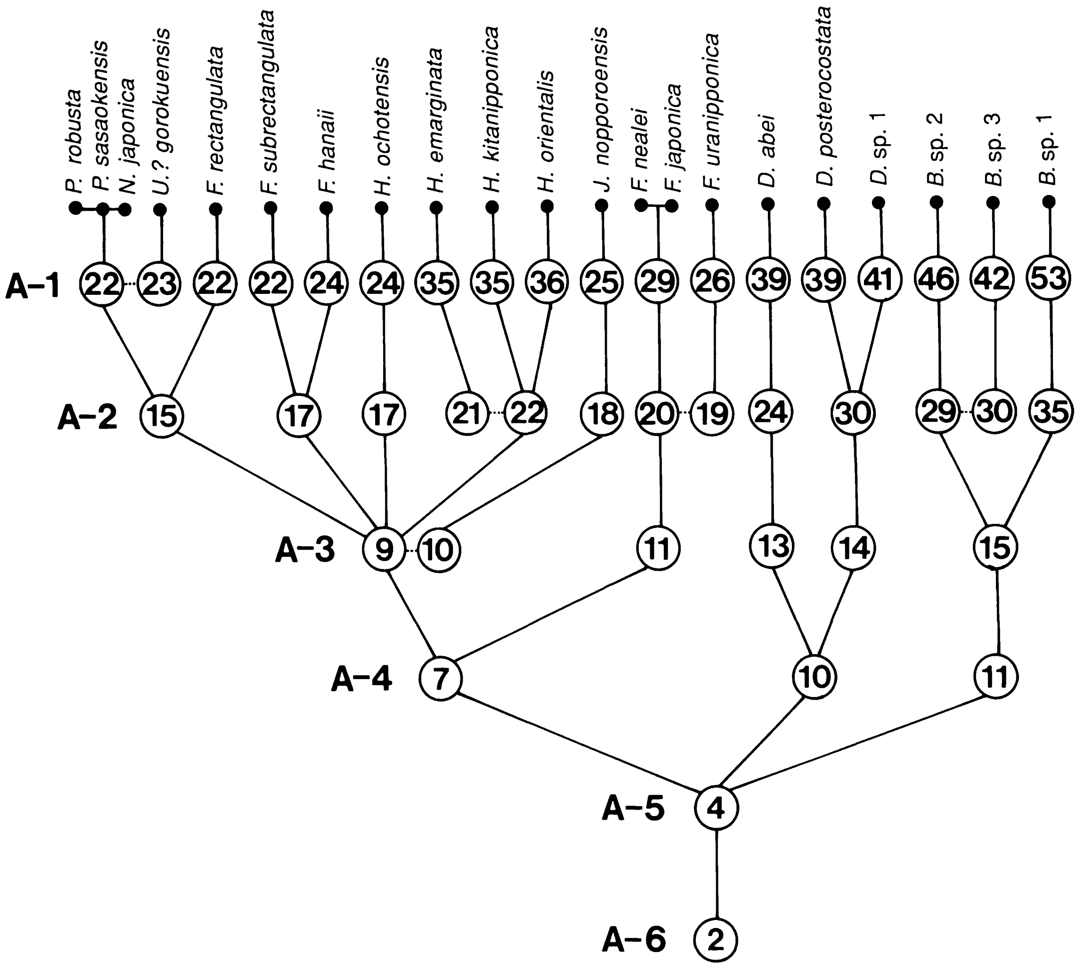


Figure 7. Ontogenetic trajectories of the examined species, as shown by patterns of marginal pores. Numerals indicate the number of anterior marginal pore canals.

Patagonacythere and *Urocythereis* ?. Members of the second type are *Daishakacythere* and *Baffinicythere*, each of which has more than ten marginal pores. The number and location of marginal pores are generally characteristic of species belonging to each genus: *Baffinicythere* has 11 marginal pores (Figure 6A) and *Daishakacythere* ten marginal pores (Figure 8).

The detailed ontogenetic trajectories of marginal pores in each genus are as follows.

Baffinicythere

Three species of *Baffinicythere* (*B*. sp. 1, 2, 3) have the same marginal pore patterns in the A-4 and A-3 stages (Figures 6A-D, 7). These will be considered in detail in another paper.

Daishakacythere

In this study, three species belonging to *Daishakacythere* were recognized, *D. abei*, *D. posterocostata*, and *D*. sp. 1 ; adult specimens of the last could not be found. At the A-4 stage these three species have the same marginal pore patterns mentioned above. In the A-3 stage, both *D. posterocostata* and *D*. sp. 1 have 14 marginal pores in the same arrangement, whereas most specimens of *D. abei* have

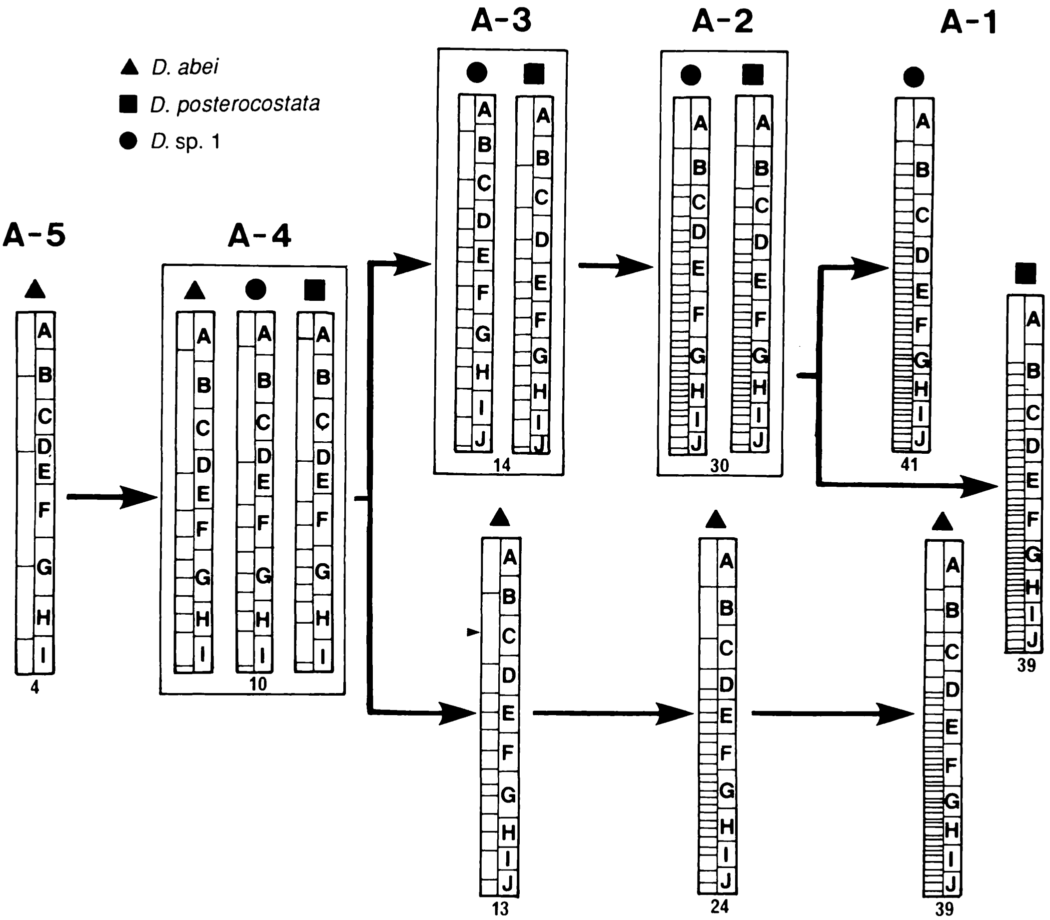


Figure 8. Ontogenetic changes of anterior marginal pores of *Daishakacythere* on the basis of such diagrams as shown in Figure 6. A to J stand for the alphabetized anterior marginal fossa in Figures 5 and 6. Small arrow heads (➤) show the location where some specimens have inset pores. Numerals indicate the number of anterior marginal pore canals. Each species in a frame has the same distributional pattern of anterior marginal pores.

smaller numbers of marginal pores due to a loss of one in the C cell (in the Shibikawa Formation, 10 percent of the individuals have a marginal pore in the C cell). Also in the A-2 stage, *D. posterocostata* and *D.* sp. 1 have the same pattern. The three species at the A-1 stage have their own patterns (Figure 8).

Finmarchinella

The genus *Finmarchinella* was established by Swain (1963). In addition, Neale (1974) created two subgenera: *Finmarchinella* (*Finmarchinella*) and *Finmarchinella* (*Barentsovia*). Species of the subgenus *Barentsovia* have conspicuous subcentral tubercles, whereas those of the subgenus *Finmarchinella* do not have such prominent ones. Such a distinction is, however, inconsistent even within a single species: specimens of *Finmarchinella nealei* from the Shibikawa Formation have subcentral tubercles, while those from the Sasaoka Formation have no conspicuous tubercles. Thus, it is difficult in reality to assign species to one or the other. In this study, the rank of subgenus is not used.

Nine *Finmarchinella* species have been described from Japan, but only six species (*F. hanaii, F. japonica, F. nealei, F. rectangulata, F. subrectangulata* sp. nov., and *F. uranipponica*) were examined in this study, because A-3 specimens of three species (*F. daishakaensis* Tabuki, *F.* sp. of Tabuki (1986), and *F.* ? sp. of Tabuki (1986)) could not be obtained. These five species (except for *F. rectangulata,* for which A-4 specimens could not be obtained) have the same A-4 marginal pore patterns mentioned above, but two groups are manifested in the A-3 stage: 9-marginal-pore and 11-marginal-pore types. Each of these types includes three species: the 9-pore type includes *F. hanaii, F. rectangulata,* and *F. subrectangulata* (B, C, D, E, F, G, H, I, J), and the 11-pore type *F. japonica, F. nealei,* and *F. uranipponica* (B, C, D, E1, E2, F, G1, G2, H, I, J). *Finmarchinella japonica* and *F. nealei* have the same patterns in the A-4 to A-1 stages, but *F. uranipponica* has a slightly different pattern in the A-2 and A-1 stages. In the A-2 stage, *F. hanaii* and

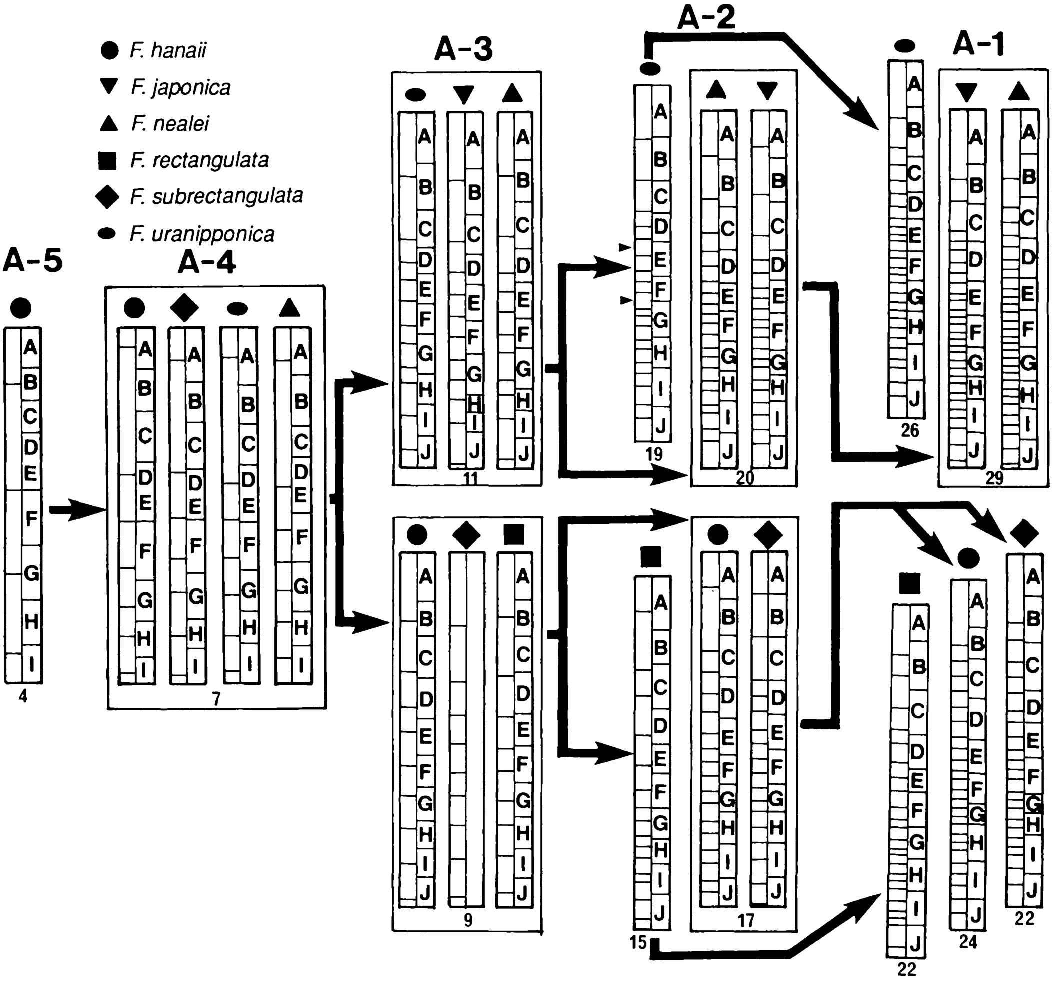


Figure 9. Ontogenetic changes of anterior marginal pores of *Finmarchinella.* Abbreviations are the same as in Figure 8.

F. subrectangulata of the 9-pore type have almost the same patterns and *F. rectangulata* has two fewer marginal pores than do the other two species (Figure 9).

Hemicythere

Schornikov (1974) described many *Hemicythere* species from the Kurile Islands. In A-3 and A-4 stages, all these *Hemicythere* species have almost the same pattern (nine marginal pores in the A-3 stage (B, C, D, E, F, G, H, I, J)). At the A-2 stage, two groups are recognized : 22 (21)-pore and 17-pore types. The former contains *H. emarginata, H. kitanipponica,* and *H. orientalis,* all of which also have patterns similar to each other at the A-1 stage (35 or 36 marginal pores). The latter type is shown by *H. ochotensis,* having fewer marginal pores at the A-1 stage (only 24 marginal pores). In addition, Schornikov's (1974) illustrations of the *H. villosa* and *H. borealis* groups show that the former has more marginal pores than the latter (Figure 10).

***Johnnealella, Normanicythere, Patagonacythere,* and *Urocythereis* ?**

Patagonacythere and *Urocythereis* have been considered to belong to the tribe

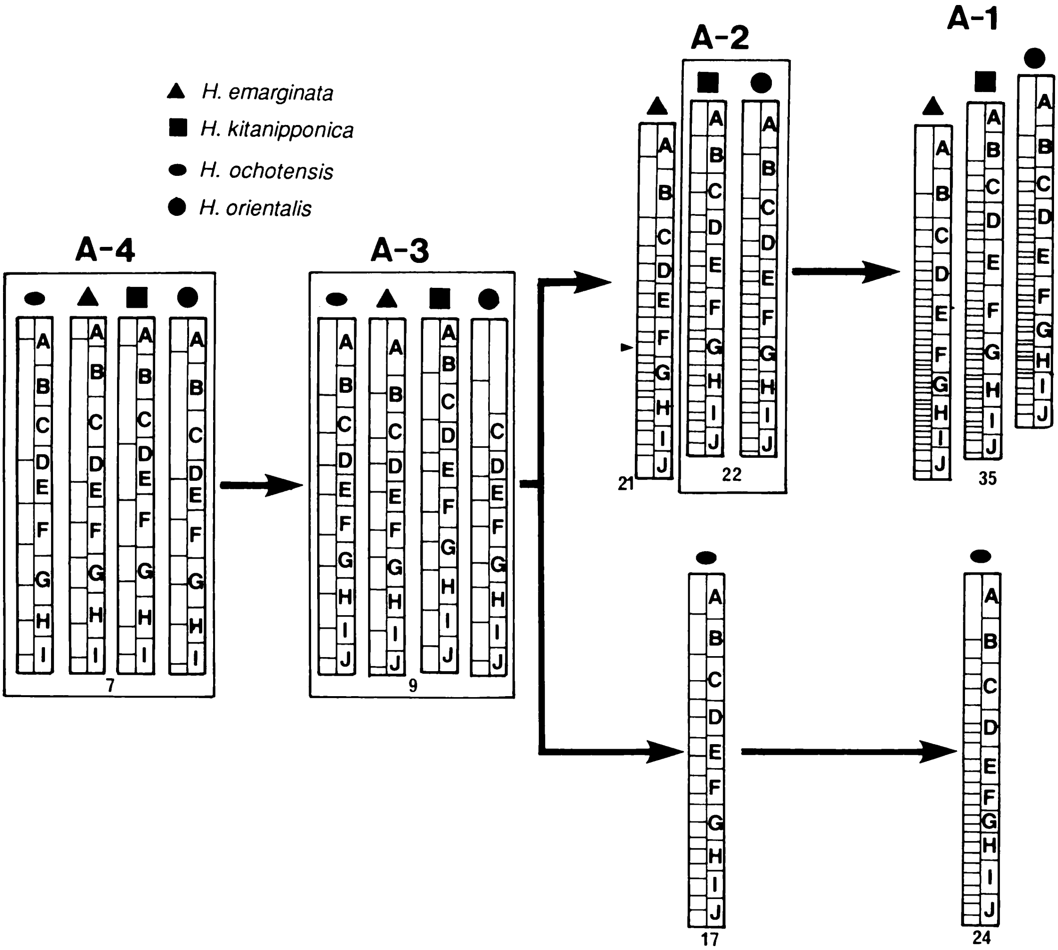


Figure 10. Ontogenetic changes of anterior marginal pores of *Hemicythere*. Abbreviations are the same as in Figure 8.

Urocythereidini. In the meantime, *Normanicythere japonica* was described by Tabuki (1986). *Johnnealella,* established by Hanai and Ikeya (1991), has a similar morphology to *Urocythereis* ? *gorokuensis* and is monotypic at present. Ontogenetic patterns of these four genera were examined. *Patagonacythere robusta* and *N. japonica* have the same marginal pore patterns in the A-5 to A-1 stages; *Patagonacythere sasaokensis* also has this pattern in the stages examined (A-3 to A-1). *Urocythereis* ? *gorokuensis* has the same pattern as *Patagonacythere* and *Normanicythere* in the A-4 to A-2 stages, but at the A-1 stage, it has one more marginal pore than do the other three species. A-3 juveniles of *J. nopporoensis* generally have ten marginal pores (one more marginal pore in the F cell), but some have nine marginal pores as in the other four species. In the A-2 stage, it has three more marginal pores than do the others (Figure 11).

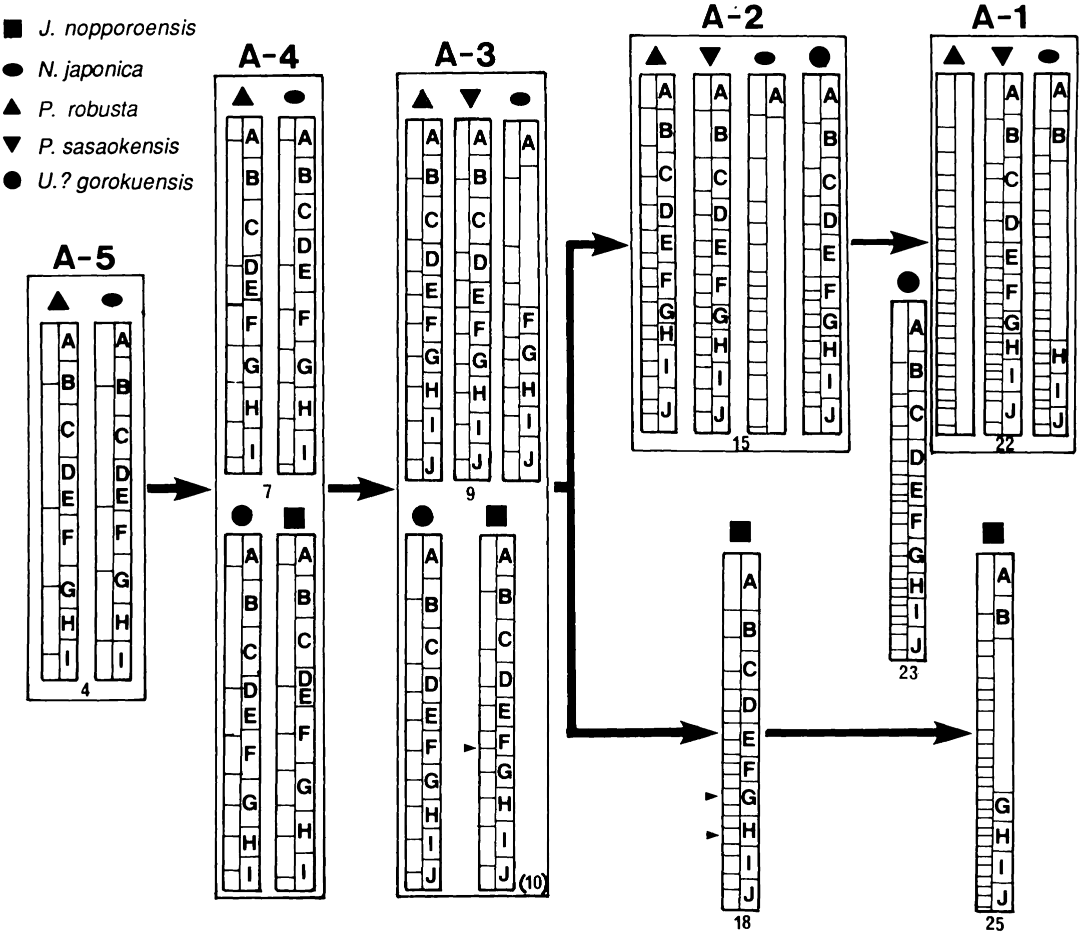


Figure 11. Ontogenetic changes of anterior marginal pores of *Johnnealella, Normanicythere, Patagonacythere,* and *Urocythereis* ?. Abbreviations are the same as in Figure 8.

Discussion

The taxonomy of fossil ostracodes is based by paleontologists on the characteristics of the carapaces, whereas living ones are studied by using features both of the carapace morphology and soft tissues (*e.g.*, sexual organs, appendages, *etc.*) ; classifications based only on the valve morphology are sometimes different from those derived from study of the soft tissues. However, various features of reticulation and pores on the ostracode carapace are direct reflections of the arrangement of underlying epidermal cells and nerve or secretory cells, respectively. Muscle scars express attachments for soft tissues. Therefore, we can classify fossil ostracodes using characters of biologic significance. Genera first described as fossils are defined on the basis of carapace morphology : prominent ornamentation, hingements, and musle scar patterns. Reticulation patterns based on Liebau's (1969) system are the same in all the examined species. Hence, this method can be of no help for species division, but may be useful for defining homologous fossae among species.

Hemicytherin ostracodes are very conservative with respect to the distribution and order of division of reticulation because Eocene species of *Patagonacythere* illustrated by Valicenti (1977) have very similar reticulation patterns to those of the late Miocene to Pleistocene species (*P. robusta* and *P. sasaokensis*). Frontal muscle scar patterns may be of some help for generic classification with some exceptions. However, as shown by Hazel's (1967) phylogenetic tree, similar frontal muscle scar patterns are shared among different branches (analogy) ; in view of the pore patterns mentioned later, it is questionable whether species having the same frontal muscle patterns are related to each other. Large variations in adductor muscle scar patterns are shown even among species in the same genus. Thus, these characters may be of no use in generic taxonomy. Ontogenetic changes of the distributional patterns of anterior marginal pores examined first in the present study provide useful information for taxonomy and phylogeny.

Species which have been assigned to a single genus by previous workers follow similar ontogenetic trajectories with the exception of *"Urocythereis"*. Species belonging to *Patagonacythere, Normanicythere,* or *F. rectangulata* have almost the same ontogenetic trajectories (4-7-9-15-22-33 in pore number). Other *Finmarchinella* species, *Johnnealella,* and *Urocythereis* ? have smaller numbers of marginal pores (*U.* ? *gorokuensis* has the same trajectory up to the A-2 stage as *Patagonacythere*). Therefore, these genera are thought to be related to each other. With regard to pores distributed on the valve surface, *Finmarchinella, Johnnealella* and *Urocythereis* ? develop the H or H' pore at the A-3 stage, as do *Normanicythere* and *Patagonacythere robusta.* This supports the above inference based on the results of ontogenetic trajectories of anterior marginal pores. Species in the *Hemicythere villosa* group (*H. emarginata, H. kitanipponica,* and *H. orientalis*) have fewer pores at early instars, but in the A-2 to adult stages, they have more marginal pores than those in the *Patagonacythere* group. They do not have the H pore, but have similar pores to species of the *Baffinicythere* group.

Hemicythere ochotensis differs from the *Hemicythere villosa* group in both marginal and valve surface pores. The carapace morphology of *H. ochotensis* also differs from that of the *H. villosa* group. The former has quadrate and large valves, whereas the latter has subtriangular valves. Thus, they may be divided into two subgenera or genera in the future.

Of the examined genera, *Patagonacythere* has the oldest fossil records, which extend as far back as the Eocene in Patagonia (Valicenti, 1977). In Japan, no ostracodes have been investigated for the Paleogene to early Miocene, but Yajima (1988) reported

Cornucoquimba saitoi from the early middle Miocene. It is actually identical with *Ambostracon* sp. 2 of Tabuki (1986) and should eventually be assigned to *Patagonacythere*. Similarly, *Finmarchinella hanaii* was recognized from the early middle Miocene Togi Formation, central Japan (Yajima, 1988). Therefore, it may be that *Finmarchinella* species were descended from the *Patagonacythere* group (Urocythereidini). With respect to marginal pores, *Baffinicythere* and *Daishakacythere* correspond to the *Patagonacythere* group at the A-5 stage, but differ in their subsequent juvenile and adult stages. In this way, *D. abei* and *D. posterocostata*, which have been considered comparable to a genus related to *Urocythereis* ? *gorokuensis*, should be placed in a genus different from *U.* ? *gorokuensis*. In this study, a new genus, *Daishakacythere*, is proposed to include *U.* ? *abei* and *U.* ? *posterocostata*. In the A-3 instars, *B.* sp. 2, *B.* sp. 3 and three species of *Daishakacythere* have the same normal pores, suggesting that these species are descended from a common ancestor (Table 1). *Daishakacythere* and *Baffinicythere* are also very similar in their marginal pores: A-4 instar juveniles of *Daishakacythere* have one less marginal pore in the DE cell than those of *Baffinicythere*, and A-3 juveniles of *D. posterocostata* and *D.* sp. 1 have one less pore in the G cell than those of *Baffinicythere* (Figures 6 and 8). *Hemicythere emarginata* was placed under *Baffinicythere* (Hazel, 1967), but the results from the above analyses support Schornikov (1974) and Horne and Whittaker (1983) in the view that *emarginata* should remain in *Hemicythere*.

Conclusions

The following conclusions are drawn from the study of morphological relationships among hemicytherin genera:

1. Distributional patterns of reticulation and c-type pore canals are very conservative among species, not only in the Hemicytherinae but also among its related subfamilies.
2. Ontogenetic changes of the distributional patterns of pores on the valve surface appear to be a good guide to the elucidation of interspecific relationships, but A-3 instar juveniles of some species have different pore patterns even within the same genus.
3. Ontogenetic changes of marginal pores provide a good clue to the taxonomy of ostracode genera and their phylogenetic reconstruction.
4. On the basis of marginal pores, *Patagonacythere, Normanicythere, Johnnealella, Urocythereis* ?, and *Finmarchinella* are related to each other; *Baffinicythere* and *Daishakacythere* together form another group.
5. The *Hemicythere villosa* group differs from the *Hemicythere borealis* group in both marginal pores and normal pores. Thus, the similarity of their valve morphology may have resulted from convergence.

Systematic descriptions

All the illustrated and measured specimens are deposited in the collections of the Institute of Geology and Paleontology, Faculty of Science, Tohoku University (IGPS). Sample localities are listed in Table 2. In this section, one new genus and two new species are described, and brief comments are made on three species.

Suborder Podocopina Sars, 1866
Superfamily Cytheracea Baird, 1850
Family Hemicytheridae Puri, 1953
Subfamily Hemicytherinae Puri, 1953
Genus *Daishakacythere*, gen. nov.

Type species.—*Urocythereis* ? *abei* Tabuki, 1986

Etymology.—After the name of formation from which the type specimen was collected.

Diagnosis.—A genus characterized by retic-

Table 2. Localities of the examined specimens. Numerals in parentheses refer to those in Figure 1. Abbreviations V., T., C., and P. in "Region" stand for Village, Town, City, and Prefecture, respectively. Detailed locations of samples from the Sasaoka and Tentokuji Formations, Otsuchi Bay, and Toyama Bay are described in Irizuki (1989), Fujioka *et al.* (1988), and Katayama (1989), respectively.

No.	Sample	Latitude	Longitude	Locality	Region
RECENT					
(1)	STA-1	45°13.1′N	142°46.1′E	off Hamatonbetsu	(depth = 106 m)
(3)	F12	42°6.6′N	140°48.3′E	Funka Bay	(depth = 40 m)
(12)	ST. 31	39°22′10″N	142°00′00″E	Otsuchi Bay	(depth = 82 m)
(13)	G3702	37°33.41′N	136°52.22′E	Toyama Bay	(depth = 102 m)
(13)	G3705	37°32.40′N	137°01.51′E	Toyama Bay	(depth = 89 m)
(13)	G3768	37°28.76′N	137°24.84′E	Toyama Bay	(depth = 83 m)
(13)	G3794	37°26.34′N	137°28.94′E	Toyama Bay	(depth = 147 m)
(13)	G3771	37°20.04′N	137°18.26′E	Toyama Bay	(depth = 70 m)
(13)	G3631	37°14.78′N	136°37.56′E	Toyama Bay	(depth = 71 m)
(13)	G3775	37°09.51′N	137°07.16′E	Toyama Bay	(depth = 78 m)
(13)	G3629	37°04.87′N	136°39.61′E	Toyama Bay	(depth = 61 m)
MIDDLE TO UPPER PLEISTOCENE					
(8)	523-4	39°58′08″N	139°51′01″E	Anden F.	Oga C., Akita P.
(9)	523-6	39°58′07″N	139°50′58″E	Shibikawa F.	Oga C., Akita P.
(9)	523-9	39°58′06″N	139°50′56″E	Shibikawa F.	Oga C., Akita P.
LOWER PLEISTOCENE					
(4)	CHI-13	41°11′14″N	141°17′16″E	Hamada F.	Mutsu C., Aomori P.
(4)	CHI-9	41°11′08″N	141°17′02″E	Hamada F.	Mutsu C., Aomori P.
(4)	CHI-6	41°11′03″N	141°16′48″E	Hamada F.	Mutsu C., Aomori P.
(4)	MAE-4	41°10′26″N	141°16′48″E	Hamada F.	Mutsu C., Aomori P.
(4)	MAE-3	41°10′25″N	141°16′47″E	Hamada F.	Mutsu C., Aomori P.
(14)	L. 32	36°31′45″N	136°41′04″E	Omma F.	Kanazawa C., Ishikawa P.
(14)	L. 31	36°31′45″N	136°41′04″E	Omma F.	Kanazawa C., Ishikawa P.
(14)	L. 30	36°31′45″N	136°41′04″E	Omma F.	Kanazawa C., Ishikawa P.
(14)	L. 29	36°31′45″N	136°41′04″E	Omma F.	Kanazawa C., Ishikawa P.
(14)	L. 20	36°31′43″N	136°41′05″E	Omma F.	Kanazawa C., Ishikawa P.
(14)	L. 13	36°31′42″N	136°41′05″E	Omma F.	Kanazawa C., Ishikawa P.
(14)	No. 66	36°31′36″N	136°41′10″E	Omma F.	Kanazawa C., Ishikawa P.
(14)	No. 65	36°31′36″N	136°41′10″E	Omma F.	Kanazawa C., Ishikawa P.
(14)	No. 43	36°31′34″N	136°41′10″E	Omma F.	Kanazawa C., Ishikawa P.
(14)	R. 20	36°31′34″N	136°41′15″E	Omma F.	Kanazawa C., Ishikawa P.
(14)	No. 26	36°31′34″N	136°41′11″E	Omma F.	Kanazawa C., Ishikawa P.
(14)	R. 14	36°31′34″N	136°41′15″E	Omma F.	Kanazawa C., Ishikawa P.
PLIO-PLEISTOCENE					
(2)	OK-1	42°20′17″N	140°17′00″E	Setana F.	Yakumo T., Hokkaido
(2)	OK-2	42°20′17″N	140°17′00″E	Setana F.	Yakumo T., Hokkaido
(2)	PSK-5	42°19′16″N	140°08′13″E	Setana F.	Yakumo T., Hokkaido
(2)	PSK-6	42°19′16″N	140°18′15″E	Setana F.	Yakumo T., Hokkaido
(2)	PSK-7	42°19′15″N	140°08′15″E	Setana F.	Yakumo T., Hokkaido
(2)	SK-3	42°18′41″N	140°08′03″E	Setana F.	Yakumo T., Hokkaido
(2)	SK-1	42°18′40″N	140°07′59″E	Setana F.	Yakumo T., Hokkaido
(5)	914-5	40°45′12″N	140°38′35″E	Daishaka F.	Aomori C., Aomori P.
(5)	914-6	40°45′12″N	140°38′35″E	Daishaka F.	Aomori C., Aomori P.
(5)	916-7	40°42′46″N	140°38′30″E	Daishaka F.	Namioka T., Aomori P.
(5)	916-8	40°42′46″N	140°38′30″E	Daishaka F.	Namioka T., Aomori P.
UPPER PLIOCENE					
(10)	524-8	39°56′00″N	140°10′10″E	Sasaoka F.	Gojonome T., Akita P.
(10)	MON-2	39°55′07″N	140°10′03″E	Sasaoka F.	Gojonome T., Akita P.
(10)	HAT-1S	39°45′55″N	140°13′05″E	Sasaoka F.	Akita C., Akita P.
(10)	HAT-7S	39°45′54″N	140°12′55″E	Sasaoka F.	Akita C., Akita P.
(10)	HAT-6S	39°45′54″N	140°12′55″E	Sasaoka F.	Akita C., Akita P.
(10)	HAT-4S	39°45′53″N	140°13′00″E	Sasaoka F.	Akita C., Akita P.
(10)	HAT-3S	39°45′53″N	140°13′02″E	Sasaoka F.	Akita C., Akita P.
(10)	HAT-2S	39°45′53″N	140°13′05″E	Sasaoka F.	Akita C., Akita P.
(10)	HAT-5S	39°45′52″N	140°12′59″E	Sasaoka F.	Akita C., Akita P.
(10)	KOS-1S	39°45′13″N	140°13′25″E	Sasaoka F.	Akita C., Akita P.
(10)	KOS-2S	39°45′11″N	140°13′26″E	Sasaoka F.	Akita C., Akita P.
(10)	KOS-3S	39°45′09″N	140°13′22″E	Sasaoka F.	Akita C., Akita P.
(10)	HIR-1S	39°44′36″N	140°14′05″E	Sasaoka F.	Akita C., Akita P.
(10)	HIR-2S	39°44′33″N	140°14′03″E	Sasaoka F.	Akita C., Akita P.
(10)	SUN-1S	39°44′26″N	140°14′28″E	Sasaoka F.	Akita C., Akita P.
(10)	HIR-3S	39°44′25″N	140°13′59″E	Sasaoka F.	Akita C., Akita P.
(10)	HIR-4S	39°44′25″N	140°13′59″E	Sasaoka F.	Akita C., Akita P.
(10)	HIR-5S	39°44′25″N	140°13′59″E	Sasaoka F.	Akita C., Akita P.
(10)	SAR-1S	39°44′02″N	140°15′05″E	Sasaoka F.	Akita C., Akita P.
(10)	TAI-3S	39°44′00″N	140°14′11″E	Sasaoka F.	Akita C., Akita P.
(10)	TAI-2S	39°43′59″N	140°14′40″E	Sasaoka F.	Akita C., Akita P.
(10)	TAI-1S	39°43′47″N	140°14′55″E	Sasaoka F.	Akita C., Akita P.
(11)	TAI-9T	39°43′40″N	140°16′16″E	Tentokuji F.	Akita C., Akita P.
(11)	KAI-1T	39°43′30″N	140°16′09″E	Tentokuji F.	Akita C., Akita P.
UPPER MIOCENE					
(6)	STZ-3	40°20′20″N	141°15′35″E	Shitazaki F.	Ninohe C., Iwate P.
(6)	STZ-2	40°20′19″N	141°15′33″E	Shitazaki F.	Ninohe C., Iwate P.
(7)	FC-11	40°03′20″N	140°21′49″E	Fujikotogawa F.	Kamikoani V., Akita P.
(7)	FC-15	40°02′35″N	140°22′42″E	Fujikotogawa F.	Kamikoani V., Akita P.
(7)	FC-14	40°02′30″N	140°22′40″E	Fujikotogawa F.	Kamikoani V., Akita P.
(7)	FC-13	40°02′28″N	140°22′38″E	Fujikotogawa F.	Kamikoani V., Akita P.
(7)	FC-12	40°02′27″N	140°22′35″E	Fujikotogawa F.	Kamikoani V., Akita P.

ulation over the whole carapace, two frontal scars, and many pores distributed along marginal area. This genus contains three species: *Daishakacythere abei* (Tabuki, 1986), *D. posterocostata* (Tabuki, 1986), and *D.* sp. 1. This is a representative Pleistocene cryophilic genus in northern Japan.

Description.—Carapace very large, subtrapezoidal, slightly tapering posteriorly, highest at anterior cardinal angle. Dorsal margin nearly straight or slightly sinuous. Ventral margin gently arched. Anterior margin broadly rounded, slightly extended below. Posterior margin slightly concave in its upper half and convex in its lower half, and acuminate. Subcentral tubercle rather obscure. Eye tubercle low but prominent. Coarse reticulation covers entire surface, but obscure in younger instars, when carapace slightly auriform. Radiating ridges recognizable both in anterior and posterior portions. Sinuate ventral ridge prominent. Marginal infold narrow along entire margin. Hinge holamphidont. Muscle scars consisting of two rounded frontal scars and a row of four adductor scars: an elongated dorsal scar, two rounded dorsomedian scars, two rounded scars (*D. abei*) or an elongated scar (*D. posterocostata* and *D.* sp. 1) ventromedially, and an elongated ventral scar. Sexual dimorphism marked: males more elongated than females.

Remarks.—Two species belonging to this genus (*D. abei* and *D. posterocostata*) have been described under the genus *Urocythereis* ?. *Daishakacythere* is, however, different from *Urocythereis* ? in having many pores along the carapace margin and in being auriform in juvenile stages. Ontogenetic changes of pore distribution (normal and marginal) suggest that this genus is related to the genus *Baffinicythere* despite different numbers of frontal scars.

Daishakacythere abei (Tabuki, 1986)

Figures 1-4, 12-1—4b

Urocythereis gorokuensis Ishizaki; Ishizaki and Matoba, 1985, pl. 6, figs. 11, 13 (non *Urocythereis gorokuensis* Ishizaki, 1966, p. 144, 145, pl. 19, figs. 9, 10, text-fig. 1, fig. 7).

Urocythereis ? *abei* Tabuki, 1986, p. 71-73, pl. 6, figs. 1-11, pl. 20, fig. 5, text-fig. 18-6.

Dimensions.—Fig. 12-1, male LV, Loc. 523-6, IGPS 101653, L = 1.205 mm, H = 0.625 mm; Figs. 12-2a—b, female LV, Loc. 523-6, IGPS 101654, L = 1.106 mm, H = 0.640 mm; Figs. 2-4, 12-3, male RV, Loc. 523-6, IGPS 101655, L = 1.269 mm, H = 0.609 mm; Figs. 12-4a—b, female RV, Loc. 523-6, IGPS 101656, L = 1.129 mm, H = 0.630 mm.

Occurrence.—Dominant in the Shibikawa Formation. Common in the Setana, Hamada, Daishaka, and Anden Formations.

Remarks: This species resembles *Daishakacythere* sp. 1 in its overall shape and ornamentation, but differs in having the posteroventral ridge and two divided ventromedian scars.

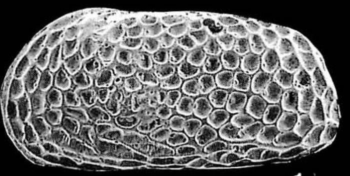
Daishakacythere posterocostata (Tabuki, 1986)

Figures 2-5, 12-5a—8

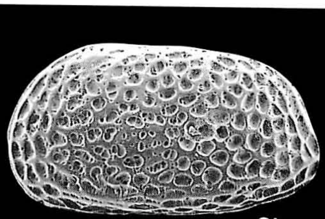
Urocythereis ? *posterocostata* Tabuki, 1986, p. 73, 74, pl. 8, figs. 1-10, text-fig. 18-7.

not *"Urocythereis" posterocaudata* Cronin and Ikeya,

—› **Figure 12.** **1-4,** *Daishakacythere abei* (Tabuki, 1986), gen. nov. **1**: lateral view of male LV, Loc. 523-6, IGPS 101653; **2a-b**: internal and lateral views of female LV, Loc. 523-6, IGPS 101654; **3**: lateral view of male RV, Loc. 523-6, IGPS 101655; **4a-b**: internal and lateral views of female right valve, Loc. 523-6, IGPS 101656. **5-8,** *Daishakacythere posterocostata* (Tabuki, 1986), gen. nov. **5a-b**: lateral and internal views of male LV, Loc. MAE-3, IGPS 101662; **6**: lateral view of female LV, Loc. MAE-3, IGPS 101663; **7a-b**: lateral and internal views of male RV, Loc. MAE-3, IGPS 101664; **8**: lateral view of female RV, Loc. MAE-3, IGPS 101665. **9-12,** *Daishakacythere* sp. 1, gen. nov. **9**: lateral view of A-1 stage LV, Loc. CHI-9, IGPS 101672; **10a-b**: internal and lateral views of A-1 stage RV, Loc. MAE-3, IGPS 101673; **11**: lateral view of A-2 stage LV, Loc. CHI-9, IGPS 101674; **12**: lateral view of A-2 stage RV, Loc. CHI-9, IGPS 101675. Scale bars are 0.5 mm: A for 1-8; B for 11, 12.


1


2a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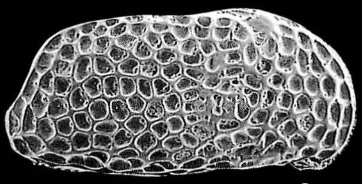
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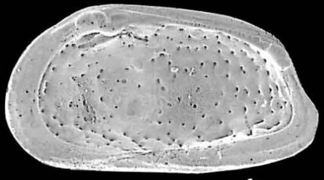
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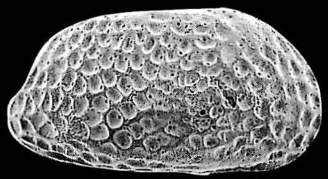
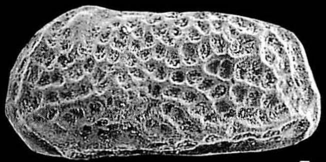
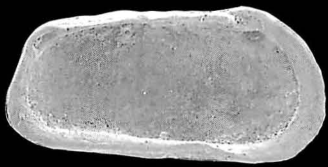

4b


5a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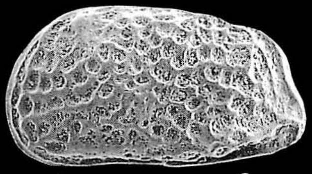
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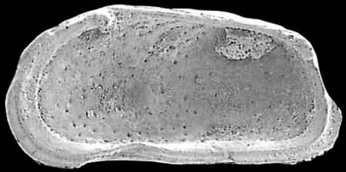
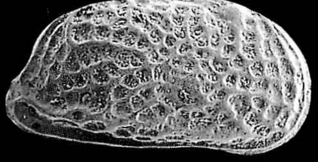
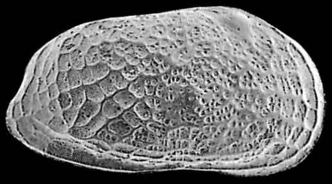
7a


7b


8


9


10a


10b


11


12

1987, p. 82, pl. 1, fig. 18.

Dimensions.—Figs. 12-5a—b, male LV, Loc. MAE-3, IGPS 101662, L=1.113 mm, H=0.57 mm; Fig. 12-6, female LV, Loc. MAE-3, IGPS 101663, L=1.069 mm, H=0.613 mm; Figs. 2-5, 12-7a—b, male RV, Loc. MAE-3, IGPS 101664, L=1.188 mm, H=0.584 mm; Fig. 12-8, female RV, Loc. MAE-3, IGPS 101665, L=1.081 mm, H=0.60 mm.

Occurrence.—Common in the Setana, Hamada and Daishaka Formations; rare in the Shibikawa Formation.

Remarks.—This species resembles *Daishakacythere abei* in its overall shape and ornamentation, but differs in having posteroventral and posterodorsal rims.

Daishakacythere sp. 1

Figures 2-6, 12-9—12

Diagnosis.—*Daishakacythere* characterized by lack of posterior rims in juveniles.

Dimensions.—Fig. 12-9, A-1 instar LV, Loc. CHI-9, IGPS 101672, L=0.815 mm, H=0.468 mm; Figs. 2-6, 12-10a—b, A-1 instar RV, Loc. MAE-3, IGPS 101673, L=0.820 mm, H=0.400 mm; Fig. 12-11, A-2 instar LV, Loc. CHI-9, IGPS 101674, L=0.643 mm, H=0.378 mm; Fig. 12-12, A-2 instar RV, Loc. CHI-9, IGPS 101675, L=0.659 mm, H=0.393 mm.

Occurrence.—The Setana, Hamada, and Daishaka Formations.

Remarks.—Adult specimens of this species could not be found in the examined samples. Juvenile valves are similar to *Normanicythere japonica* Tabuki, 1986, but the latter has posterior denticles and fewer pores along the valve margin.

Genus *Finmarchinella* Swain, 1963

Finmarchinella subrectangulata sp. nov.

Figures 2-11, 13-1—4c

Etymology.—After valve shape.

Diagnosis.—*Finmarchinella* characterized by subrectangular valve shape, posteroventral ridge, two ovate and one small frontal scars and overall microreticulation.

Description.—Carapace small in male and moderate in female, thin, elongate, subrectangular in lateral view, highest at anterior cardinal angle. Dorsal margin straight. Ventral margin sinuous; concave in anterior third. Anterior margin broadly and evenly rounded. Posterior margin concave in its upper half, meeting dorsal margin at an obtuse angle, and lower half protruding into a caudal process. As viewed dorsally, subcentral and eye tubercles obscure. Surface ornamented with fine reticulation. Prominent ventral ridge, starting in anteroventral area, curving upward at about posterior one-fifth of valve length, terminating at the tip of caudal process. Two weak ridges radially extending from subcentral tubercle to anterior margin. Pores scattered on valve surface moderate in number. Marginal pores moderate in number along anteroventral margin. Marginal infold moderate in width along anterior margin, but narrow along ventral margin. Line of concrescence coincident with inner margin. Hinge antimerodont. Muscle scars consist of three frontal scars, of which middle scar is smaller, and an oblique row of four adductor scars: an elongated dorsal scar, two elongated dorsomedian scars, imperfectly divided and elongated ventromedian scars, and one ventral scar. Sexual dimorphism remarkable: males smaller and more elongate than females.

Types and Dimensions.—Holotype: female LV, Loc. 523-6, IGPS 101739, Figs 13-2a—b, L=0.639 mm, H=0.306 mm; paratypes: male LV, Loc. 523-6, IGPS 101738, Fig. 13-1, L=0.526 mm, H=0.244 mm; female RV, Loc. 523-6, IGPS 101741, Figs. 13-4a—c, L=0.638 mm, H=0.294 mm; male RV, Loc. 523-6, IGPS 101740, Figs. 2-11, 13-3, L=0.498 mm, H=0.230 mm.

Type locality.—Middle Pleistocene Shibik-

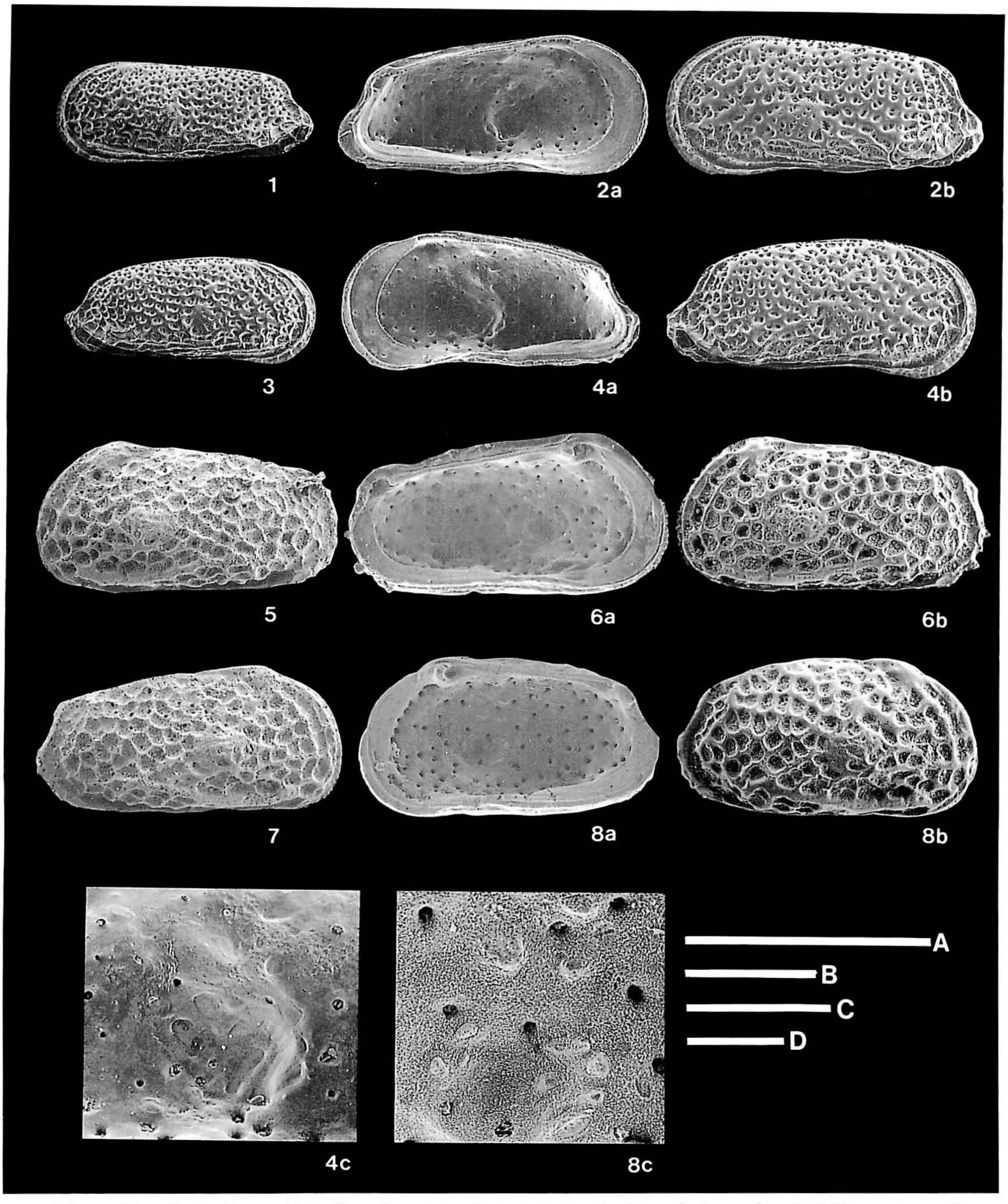


Figure 13. **1-4,** *Finmarchinella subrectangulata* sp. nov., **1** : lateral view of male LV, paratype, Loc. 523-6, IGPS 101738 ; **2a-b** : internal and lateral views of female LV, holotype, Loc. 523-6, IGPS 101739 ; **3** : lateral view of male RV, paratype, Loc. 523-6, IGPS 101740 ; **4a-c** : internal and lateral views and muscle scars of female RV, paratype, Loc. 523-6, IGPS 101741. **5-8,** *Patagonacythere sasaokensis* sp. nov., **5** : lateral view of male LV, paratype, Loc. HIR-3S, IGPS 101821 ; **6a-b,** internal and lateral views of female LV, paratype, Loc. SUN-1S, IGPS 101822 ; **7** : lateral view of male RV, paratype, Loc. HIR-3S, IGPS 101823 ; **8a-c** : internal and lateral views and muscle scars of female RV, holotype, Loc. HIR-5S, IGPS 101824. Scale bars A and B are 0.5 mm and C and D are 0.1 mm : A for 1-4b ; B for 5-8b ; C for 4c ; D for 8c.

awa Formation, Loc. 523-6

Occurrence.—Common in the Shibikawa Formations; rare in the Daishaka and Hamada Formations.

Remarks.—This species is similar, possibly related, to *Finmarchinella* ? sp. of Tabuki (1986), but differs in having a posteroventral ridge. It differs from *Finmarchinella rectangulata* Tabuki in having no posterodorsal projection and a more elongated carapace. It is also similar to *Finmarchinella finmarchica,* but differs in having elongated valves and caudal processes.

Genus *Patagonacythere* Hartmann, 1962

Patagonacythere sasaokensis, sp. nov.

Figures 2-21, 13-5—8c

Etymology.—After the name of formation which yielded the type specimen of this species.

Diagnosis.—*Patagonacythere* charcterized by anterior ridge and overall reticulation.

Description.—Carapace large, subrectangular in lateral view, highest at anterior cardinal angle. Anterior margin broadly rounded and slightly extended below. Dorsal margin straight. Ventral margin slightly sinuate. Posterior margin rounded in LV, but triangular in RV; upper half concave but lower half rounded. Surface ornamented entirely by coarse reticulations. An anterior marginal ridge distinct. Ventral ridge relatively strong, starting at anterior marginal ridge toward mid-ventral margin, then turning toward posteroventral area. A narrow posterior marginal ridge starting just before posterior cardinal angle to inside acumination. Subcentral tubercle low but distinct in adult stage. Eye tubercle not prominent. Pores scattered on valve surface moderate in number. Marginal pores nearly straight, moderate in number in anteroventral margin. Marginal infold moderately broad along anterior and posterior margins, but narrow along ventral margin. Vestibule present along entire free margin, but narrow along ventral and posterior margins. Hinge holamphidont. Muscle scars consist of three frontal scars (middle one is very small) and a row of four adductor scars: an elongated dorsal scar, two divided dorso- and ventromedian scars, and an elongated ventral scar. Sexual dimorphism distinct: males more slender than females. In younger juveniles, posterior cardinal rims, subcentral tubercle, and radiating anterior ridges are very prominent.

Types and Dimensions.—Holotype: female RV, Loc. HIR-5S, IGPS 101824, Figs. 13-8a—c, L = 1.126 mm, H = 0.631 mm; paratypes: female LV, Loc. SUN-1S, IGPS 101822, Figs. 13-6a—b, L = 1.226 mm, H = 0.638 mm; male LV, Loc. HIR-3S, IGPS 101821, Fig. 13-5, L = 1.143 mm, H = 0.606 mm; male RV, Loc. HIR-3S, IGPS 101823, Figs. 2-21, 13-7, L = 1.163 mm, H = 0.579 mm.

Type locality.—Upper Pliocene Sasaoka Formation, Loc. HIR-5S.

Occurrence.—This species was found by the author only from the late Pliocene Sasaoka and late Miocene Fujikotogawa Formations.

Remarks.—This species is possibly related to *Ambostracon* sp. 1 of Tabuki (1986). It resembles *Patagonacythere robusta,* but has conspicuous reticulation, no posterodorsal or ventral ribs, and a thinner valve anterior. It is also similar to *Daishakacythere posterocostata,* but has fewer pores along the valve margin and posterior denticles.

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Hokkaido 北海道, Hamatonbetsu 浜頓別, Yakumo 八雲, Setana 瀬棚, Funka Bay 噴火湾, Aomori 青森, Mutsu 陸奥, Hamada 浜田, Namioka 浪岡, Daishaka 大釈迦, Iwate 岩手, Ninohe 二戸, Shitazaki 舌崎, Akita 秋田, Kamikoani 上小阿仁, Fujikotogawa 藤琴川, Oga 男鹿, Anden 安田, Shibikawa 鮪川, Gojonome 五城目, Sasaoka 笹岡, Tentokuji 天徳寺, Otsuchi Bay 大槌湾, Toyama Bay 富山湾, Ishikawa 石川, Kanazawa 金沢, Omma 大桑.

日本産 Hemicytherinae 亜科貝形虫の形態と分類—特に縁辺毛細管の成長過程での変化に着目して：Hemicytherinae 亜科の貝形虫は後期新生代において多様性が高く，その中には北大西洋と北西太平洋にまたがって分布する種もある。これら Hemicytherinae 亜科貝形虫の系統関係を考察するために，8 属 (*Baffinicythere, Daishakacythere*, n. gen., *Finmarchinella, Hemicythere, Johnnealella, Normanicythere, Patagonacythere, Urocythereis* ?) の 21 種について，それぞれの網状装飾，筋肉痕，蝶番，そして毛細管の形態を詳細に調べた。縁辺毛細管の成長段階における変化が，Hemicytherinae 亜科貝形虫の分類要素として，また系統関係を考察する上で有効な手がかりを与えることを示している。垂直および縁辺毛細管の成長過程における殻上での分布パターンの変化から，21 種は 3 グループにまとめられる。1 新属 (*Daishakacythere*), 2 新種 (*Finmarchinella subrectangulata, Patagonacythere sasaokensis)* を識別し，記載した。

入月俊明

Erratum

UENO, KATSUMI

Permian foraminifers from the Takakurayama Group of the southern Abukuma Mountains, northeast Japan. *Trans. Proc. Palaeont. Soc. Japan, N.S.*, no. 168, p. 1265-1295, December, 1992.

On page 1289, in the explanation of Figure 11, line 3 from bottom. For *Agathammina maxima*, read *Agathammina magna.*

行事予定

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