The fossil on the cover is _Unuma (Spinunuma) echinatus_ ICHIKAWA and YAO, a Middle Jurassic multisegmented radiolaria from Unuma, Gifu Prefecture, central Japan (photo by A. YAO, × 260).

799. RECURRENT MOLLUSCAN ASSOCIATIONS OF THE OMMA-MANGANJI FAUNA IN THE GOJOME-OGA AREA, NORTHEAST HONSHU, PART 1. GENERAL DISCUSSIONS OF FAUNA AND SYSTEMATIC NOTES ON GASTROPOD AND SCAPHOPOD SPECIES*

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Abstract. Six recurrent associations are recognized in Pliocene to early Pleistocene marine molluscan assemblages in the Gojome-Oga Area, northeast Japan. The distribution of these associations are interpreted to be controlled by physical environmental factors such as bottom character and water depth. The *Palliolum* Association occupied the deepest basin bottom, where the turbidite deposits were accumulated. The *Nuculana* Association inhabited in deep muddy environments but shallower than the *Palliolum* Association. The *Acila-Turritella* Association appeared on muddy and sandy bottom, which was intermediate in water depth. The *Macoma tokyoensis* and the *Protothaca* Associations were the shallowest inhabitants. The *Thyasira bisecta* Association occurs in various lithofacies types and seems to have wide tolerance to sediment types. In the *Acila-Turritella* Association, stratigraphically alternative occurrence of *Acila nakazimai* and *Turritella saishuensis* is recognized. The alternative occurrence of the two species well corresponds with occurrences of right-coiling and left-coiling forms of a planktonic foraminiferal species *Neogloboquadrina pachyderma*. The occurrence seems to be controlled by sea level fluctuation induced by climatic change. Thirty-two species of gastropods and three species of scaphopods are described.

Introduction

The Pliocene-lower Pleistocene marine strata in the Gojome-Oga Area, northeast Honshu, Japan provide excellent materials for the paleoecological analysis of the Omma-Manganji Molluscan Fauna, which is a representative of cold water fauna in the northeast Japan during Pliocene and Pleistocene times. These deposits ubiquitously contain rich autochthonous molluscan fossils, in which recurring species associations can be recognized. In this paper, the recurrent molluscan associations recognized in

this area are described, and discussed in relation to their environments. Origin of some minor differences in composition within an association is also discussed. The environmental background of these associations are reconstructed by means of a detailed examination of lithologic characters of fossil-bearing sediments, as well as their stratigraphical and geographical distributions.

The Omma-Manganji Fauna has been repeatedly studied since Yokoyama (1923a), and has been known in the Japan Sea coast areas from Cheju Island, south of the Korean Peninsula, far north to Hokkaido. Chinzei (1978) noted that the Omma-Manganji Fauna

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is composed of Pliocene-early Pleistocene cold water dwellers and is roughly time-equivalent to the embayment Tatsunokuchi Fauna in the Pacific coast of northeast Japan and to the warm water Kakegawa Fauna in southwest Japan.

Previous works on the faunal analysis of this fauna have often treated sand-dominated strata (*e.g.* Kaseno and Matsuura, 1965; Ogasawara, 1977). It is relatively difficult to reconstruct the original compositions of molluscan associations in those sandy facies, because in most cases fossils enclosed in the sandy deposits have more or less experienced post-mortem transportation. Studies of off-shore muddy molluscus are relatively scarce. Chinzei (1973) recognized four association types based on the autochthonous molluscan fossils in the northern Akita district, of which two are the muddy associations and the other two are sandy associations. In the Gojome-Oga Area muddy deposits prevail throughout the Pliocene to lower Pleistocene formations, which contain abundant autochthonous molluscan fossils. Thus the area is adequate to study nature of muddy bottom associations of the Omma-Manganji Fauna.

Stratigraphical framework

The Gojome-Oga Area is located in the environs of Akita City, northeast Honshu (Text-fig. 1). The area is divided into two subareas: the Gojome Area and the Oga Area. The late Cenozoic marine strata of the two subareas are isolated from each other by younger alluvial deposits. The marine late Cenozoic strata are composed of, in upward sequence, basal volcanic rocks ("Green Tuff"), sandstone and siltstone (Nishikurosawa Formation), fine-grained mudstone (Onnagawa and Funakawa Formations), siltstone, sandy siltstone and sandstone. The rocks last mentioned are the subjects of this study and will be noted below in detail. The succession (Text-fig. 2) is interpreted to represent a sedimentary cycle beginning with rapid transgression followed by slow regression. Molluscan fossils abundantly occur both in the initial trasnsgressive deposits and in the later regressive deposits. This study is focused on the molluscan faunas in the regressive stage. The stage is represented by fossiliferous muddy and sandy deposits, which are divided into two formations in each subareas, the Tentokuji and Sasaoka Formations in the Gojome Area, and the Kitaura and Wakimoto Formations in the Oga Area. A detailed description of these strata was given by Matsui (1981).

The Tentokuji Formation is composed of gray, massive, fine- to coarse-grained siltstone. It overlies the fine-grained mudstone of the Funakawa Formation and continues upward into the Sasaoka Formation. The Sasaoka Formation includes various rock types, which laterally and vertically grade into each other, and is divided into following seven members: Minamizawa Sandy Siltstone, Tofuiwa Alternation, Machimura Sandy Siltstone, Terasawa Sandstone, Odai Sandstone, Sodenosawa Sandstone, Tomita Volcanic Sandstone, among which the Machimura Member occupies the main part and represents lithofacies of the formation.

The Kitaura Formation consists of fine-grained siltstone and intercalating graded sandstone. It is covered by the Wakimoto Formation which consists of greenish gray siltstone and occasional intercalations of pebbly sandstone.

These four formations are intercalated by many fine- to medium-grained acidic tuff beds, which are effective to trace isochronous horizons and to correlate these formations (Mitsunashi *et al.*, 1963; Kitazato, 1975; Matsui, 1981). Matsui (1981) recognized that several tuff layers are continuous between the Gojome and Oga Areas and that the Tentokuji and Sasaoka Formations in the Gojome Area are respectively correlative with upper part of the Funakawa Formation to middle part of the Kitaura Formation and with middle to upper parts of the Funakawa Formation in the Oga Area. Microbiostratigraphical and magnetostratigraphical data (Kimura, 1974; Kitazato, 1975; Nakamura and Matoba, 1978; Matsui, 1981) support this correlation, and suggest that the Pliocene-Pleistocene boundary is drawn in the base of the Kitaura Formation.
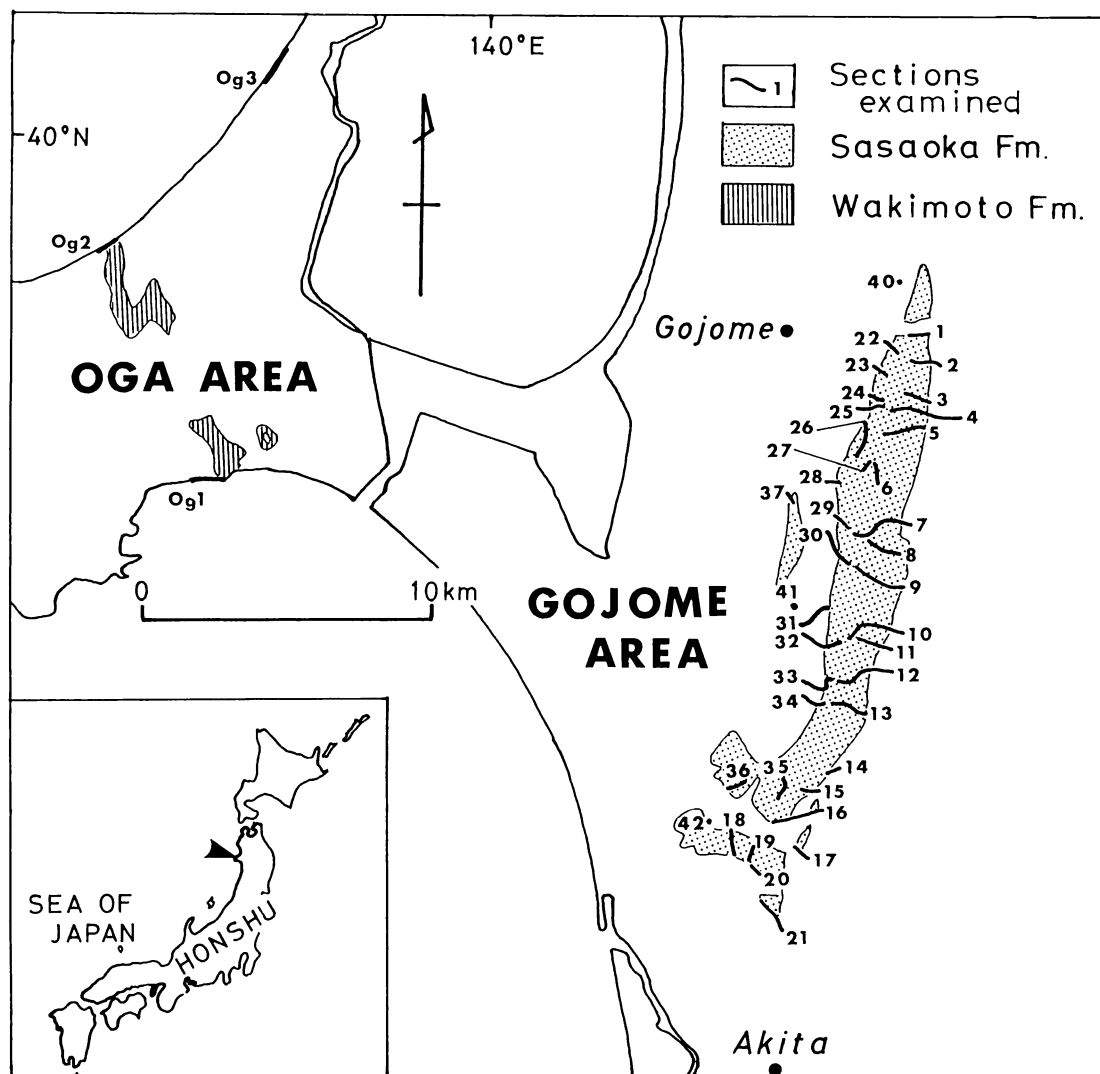
Text-fig. 1.   Locations of stratigraphic sections examined, and exposures of fossiliferous formations.

Lithofacies and depositional environments

The Tentokuji and Sasaoka Formations in the Gojome Area and the Kitaura and Wakimoto Formations in the Oga Area are variable in lithology both in vertical and horizontal directions. Six lithofacies types are recognized in these formations. Each of them may represent a characteristic depositional environment and is useful for reconstruction of Pliocene-early Pleistocene paleoenvironments.

(1) Turbidite facies. The facies is represented by alternation of massive or thinly laminated fine-grained siltstone and tuffaceous fine-grained sandstone, which often shows graded bedding. The facies is typically seen in the Kitaura Formation in the southern coast of the Oga Area and includes the Kitaura and Wakimoto Formations of the southern coast. No turbidite facies is recognized in the Gojome Area. The turbiditic sandstone beds become coarser-grained and thicker upward. Molluscs are rare in the
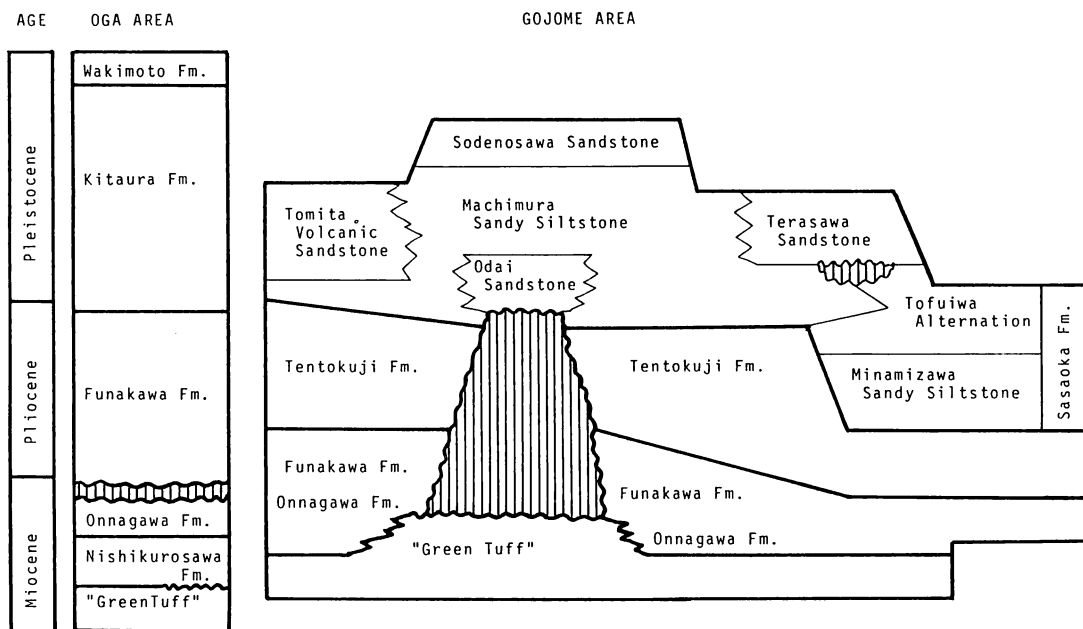
Text-fig. 2.   Summary of the stratigraphy of the upper Cenozoic strata in the Gojome-Oga Area.

siltstone.

(2) Silt facies. The facies is represented by massive greenish fine- to coarse-grained siltstone. The facies is very homogeneous, but in the upper horizons the silt becomes more coarser-grained and more frequently exhibits obscure parallel laminations than in the lower part. The facies includes the Tentokuji Formation in the Gojome Area, and the Kitaura and Wakimoto Formations in the northern coast of the Oga Area. Molluscs are sparse in the silt facies, and are more abundant in the upper coarser-grained part than in the lower finer part.

(3) Sandy silt facies. The facies is lithologically rather variable and is divided into the following five lithological types. (a) Massive sandy siltstone, 35—55% in sand content, with tubulous or irregular shaped burrows of a few to ten mm in diameter. (b) Massive sandy siltstone similar to (a) but with "Houki-zuna". "Houki-zuna" (Hase and Hirayama, 1970) is a cross-laminated block in the massive sandy siltstone or fine-grained sandstone. The block is 10—30 cm wide and 10—50 cm thick. The lamination is always concave-upward. (c) Alternation of

massive sandy siltstone similar to (a) and massive siltstone of 18—30% in sand content. In the alternation, each bed lithologically merges into overlying and underlying ones and is ten to a few tens cm, rarely a few m, in thickness. (d) Alternation similar to (c) but with "Houki-zuna" in the sandy siltstone. (e) Massive sandy siltstone with tubulous burrows of 1—2 cm in diameter and 10 cm in length, which are filled with horizontally laminated very fine-grained sand and are nearly vertical to the bed.

The sandy silt facies is generally poor in current-generated sedimentary structures. It is intensively bioturbated. The facies occurs in the Machimura, Minamizawa and Terasawa Members of the Sasaoka Formation. Molluscs are widely found throughout the facies, and are more abundant in the sandy beds than in the muddy beds. Fossils also appear in the "Houki-zuna".

(4) Alternation facies. This facies is characterized by irregular alternation of fine-grained sandstone and sandy siltstone, the latter of which is coarser-grained and better sorted than the sandy siltstone of the sandy silt facies. The mud content of sandstone is 15 to 20%. A single

bed of the alternation ranges from a few tens cm to a few tens m in thickness. The facies occurs in the Tofuiwa Member. Both muddy and sandy beds often contain molluscan shells.

(5) Fine-grained sand facies. The facies is represented by massive fine-grained sandstone of 15 to 35% in mud content. The fine-grained sandstone is often intercalated by coarser-grained sandstone and conglomerate beds. The facies occurs in the upper part of the Machimura, Sodenosawa, Odai and Terasawa Members of the Sasaoka Formation. The sandy silt facies of the upper part of the Machimura Member is frequently intercalated by sandstone of this facies, which occurs as beds of a few tens cm to 10 m thick, and is overlain by the sand facies of the Sodenosawa Member. The Sodenosawa Member is represented by fine-grained sandstone with silty tubulous burrows and mud pellets in the lower part, and by fine- to medium-grained sandstone with a fossiliferous granule conglomerate bed in the middle part. The upper part of the member is composed of cross-laminated medium-grained sandstone, which is in turn overlain by alternation of non-marine pale gray clay and medium-grained sand. Molluscan shells are common in fine- and medium-grained sandstone.

(6) Volcanic sand facies. The facies corresponds to the Tomita Member of the Sasaoka Formation. The facies is composed of coarse-grained volcanic sandstone and fine- to medium-grained muddy pumiceous sandstone. The facies is contemporaneous with the middle and lower parts of the sandy silt facies. Molluscs are often found in the muddy part, while rare in the coarser-grained part.

Spatial distribution of the lithofacies:—As stated in the earlier section, the marine strata in this area are considered to have been deposited during a cycle of sedimentation, which begins with rapid transgression followed by slow regression. The six lithofacies types noted above represent the later stage of the regression. In any section in the area, the lithology becomes coarse-grained upward. In the Gojome Area, the upper strata exhibit an upward gradation

from the silt facies through the sandy silt facies, to the fine-grained sand facies in the northern part, or to the alternation facies in the southern part. In the Oga Area, the turbidite facies (the southern coast of the area) or the silt facies (the northern coast of the area) is overlain by fine-grained siltstone. The vertical gradation of lithofacies indicates the gradual shallowing of the sea. In the northern part of the Gojome Area, the fine-grained sand facies is covered with the non-marine deposits, which represent the final stage of shallowing of the basin.

Lateral gradational relationships of the lithofacies can be recognized by tracing of the marker tephra, as well as the magnetic and microfossil datum levels. Among these marker horizons, four (horizons I—IV) are widely traceable and are useful in recognizing the geographical distributions of the lithofacies (Text-figs. 5A, B).

The lithofacies becomes finer westward and finally grades into the turbidite or silt facies in the western extremity. At the horizon II along a E-W section through the northern part of the Gojome and Oga Areas (Text-fig. 5A), the following lithofacies are recognized from east to west: the sandy silt and silt facies in the Gojome Area; the silt facies in the northern coast of the Oga Area; the turbidite facies in the southern coast of the Oga Area. The horizon IV is represented by the fine-grained sand facies in the Gojome Area and thinly laminated siltstone of the turbidite facies in the Oga Area. This areal arrangement of the lithofacies suggests that during the Pliocene and early Pleistocene periods the sea became deeper westward and ended in a basinal deep.

In the southern part of the Gojome Area, the sediments are coarser-grained in any horizon than those in the northern part. For example the horizon II is represented by the alternation facies in the southern part, while it is the sandy silt facies in the northern part. The southern part of the Gojome Area was considered to be shallower than the other areas.

The lithofacies often changes in minor scale within these general tendencies. For example,

the alternation facies is composed of sandy silt beds and fine-grained sand beds both of which are thinner than 10 m thick, and the upper part of the sandy silt facies is frequently interbedded with fine-grained sandstone of 30 cm to 10 m thick. These minor variations can not be attributed to depth changes of the sea, but are interpreted as a result of local variation of hydrodynamic conditions of the sea bottom.

In the central part of the Gojome Area, fine-grained mudstone of the Onnagawa and Funakawa Formations and siltstone of the Tentokuji Formation abut against a tectonic high of the Miocene volcanics, the Odai Swell (Matsui, 1981) and fine-grained sandstone of the Sasaoka Formation directly overlies the swell (Text-fig. 5B). The swell was a submarine topographic high, on which no deposits are accumulated until the latest Pliocene. It is covered by fine-grained sandstone and sandy siltstone of the upper part of the Sasaoka Formation. The dominance of the sandy deposits around the Odai Swell suggests much supply of coarse-grained clastics from the swell and its hinterland.

Molluscan samples and modes of molluscan occurrence

Two sets of faunal samples were prepared for ecological analysis of the molluscan fauna. One is a set of about 300 assemblages from 75 localities (Text-fig. 3), which cover all fossiliferous horizons in the area studied. The "assemblage" here used means collection of individuals from stratigraphically defined interval of exposure. This set is used to establish faunal association types. Faunal compositions of the strata change in various scale. In some cases the change occurs within one meter or less in thickness. In order to detect these minor changes of composition, each assemblage is limited to include individuals of molluscs found in 10 cm to 1 m stratigraphical interval of an exposure. The other sample set is prepared to analyze a finer structure within the *Acila-Turritella* Association, the most prevailing associa-

tion in the area. This set is composed of the stratigraphically successive assemblages. Two set of successive samples were obtained from the sandy silt facies of the Sasaoka Formation (M-series and GR-series).

Megafossils abundantly occur in the bioturbated sandy silt facies and the fine-grained sand facies of the Sasaoka Formation, and are rather rare and sparse in the silt facies of the Tentokuji, Wakimoto and Kitaura Formations. The metafossil fauna in this area is composed of gastropods, bivalves and scaphopods accompanied rarely by echinoderms. Microfossils such as foraminifers, ostracods and sponge spicules are commonly found both in muddy and sandy sediments.

The bivalve shells are usually complete, although disarticulated valves are common. Their delicate surface ornamentations are well preserved. The gastropods often have the protoconchs.

In the sandy silt and silt facies, the shells are randomly oriented, sporadically disseminated in the sediments and show wide range of size. The bivalves are commonly disarticulated. The intensively bioturbated sediments with rare current stratification suggest that burrowing animals or weak current stirred the shells, so that the shells are disarticulated and have not retained their life positions. The assemblages in these facies are essentially untransported and can be called "disturbed-neighborhood assemblages" (Scott, 1974). In the muddy sediments, deep burrowing bivalves such as *Mya cuneiformis*, *Thyasira bisecta* and *Lucinoma acutilineata* are found in living position. They are articulated and their direct commissure planes are nearly perpendicular to the bedding plane.

In the fine-grained sand facies, large and thick-shelled bivalves such as *Anadara*, *Dosinia*, *Protothaca* and *Mercenaria* are usually articulated but rarely stand upright to the bedding plane. The smaller bivalves are also often articulated. The assemblages are also regarded as the disturbed-neighborhood assemblages. At loc. 24-1b, the fine-grained sand facies contains well preserved specimens of *Turritella saishuensis* and

Macoma tokyoensis below a fine-grained white tuff of a few centimeters thick. The individuals of *Macoma* are articulated, lying on the bedding plane of about 10 cm below the tuff, while the individuals of *Turritella* occur just below the tuff. Fossils are rare in the neighboring sediments of the two fossiliferous horizons. It may be concluded that the two species were contemporaneously killed by the rapid accumulation of the volcanic ash. The assemblage can be called "fossil census community" (Fagerstrom, 1964).

At loc. 6-1, a granule conglomerate bed of 1.5 m thick contains abraded and broken molluscan shells. The assemblage contains *Glycymeris yessoensis*, *Mizuhopecten poculum* and *Clinocardium fastosum* in common with the assemblages in the fine-grained sand facies, but *Cyclocardia aomoriensis* and *Peronidia* sp., which exclusively appear at the locality, are most abundant in number of individuals. This assemblage was apparently transported and is perhaps a mixture of shells from two or more different habitats.

In ecological analysis the allochthonous assemblages are excluded.

Faunal associations

In this paper, the term "association" is adopted to indicate a recurring suite of species. Six association types are recognized among 288 assemblages obtained from the Gojome-Oga Area.

The assignments of three assemblages (Locs. 5-11a, 7-7a, 7-8) to the associations are, however, not decided. In these three assemblages, molluscus sporadically occur. They are characterized by *Limopsis tokaiensis*, which never appears in the established associations. They are restricted to the lower part of the sandy silt facies. These three assemblages may represent another association, but the fossil data are too poor to establish a distinct association.

Palliolum Association:—*Palliolum peckhami* is the only constituent species of the association. The association occurs in the turbidite facies of the Kitaura Formation in the Oga Area.

The shells are densely crowded along the basal surface of tuffaceous sandstone or in thinly laminated siltstone. The shells are lying parallel to the bedding plane. In massive siltstone of the turbidite facies, it occurs very sporadically. Fragile thin shells of the species are well preserved. Conjoined valves are commonly found.

Nuculana Association:—The molluscs of this association occur sporadically in muddy sediments. The association frequently appears both in the silt facies and the lower part of the sandy silt facies, which is generally finer-grained than the upper part. It is characterized by nuculanid bivalves, buccinid and turrid gastropods, two species of *Acila*, and *Siphonodentalium* sp. A. The nuculanids are represented by eleven species (Table 1) and *Nuculana robai* is the commonest among them. The buccinid gastropods are represented by *Buccinum* cf. *rossicum*, *B.* spp., *Neptunea intersculpta*, *Clinopegma borealis* and some others. *Propebela candida* is the commonest turrid. *Cryptonatica clausa* commonly appears in the association. The faunal compositions of the association is somewhat different between the Gojome and Oga Areas. In the Gojome Area *Acila* is represented by *A. nakazimai*, while in the Oga Area *A. divaricata* occurs. *Nucula niponica*, *Portlandia toyamaensis*, *Volutomitra alaskensis* and some others appear only in the Oga Area. Minor morphological differences of *Mohnia* cf. *yanamii* are observed between the specimens of the Gojome and Oga Areas (see Systematic Notes).

The assemblages at Locs. 7-9a and 7-9b, occurred in a muddy sandstone bed inserted in the silt facies are composed of *Neptunea* sp., *Fulgoraria* sp., *Cryptonatica clausa* and some others but lack nuculanid species. Two assemblages (Locs. 17-1 and 23-3) obtained from fine-grained mudstone of the silt facies have characteristic species compositions, dominated by *Saccella onoyamai*. The assemblage Loc. 41-2, found also in fine-grained mudstone, is more peculiar in composition. It is composed of *Yoldia kikuchii*, *Acharax tokunagai*, *Periploma* cf. *besshoensis* and *Neptunea* sp.
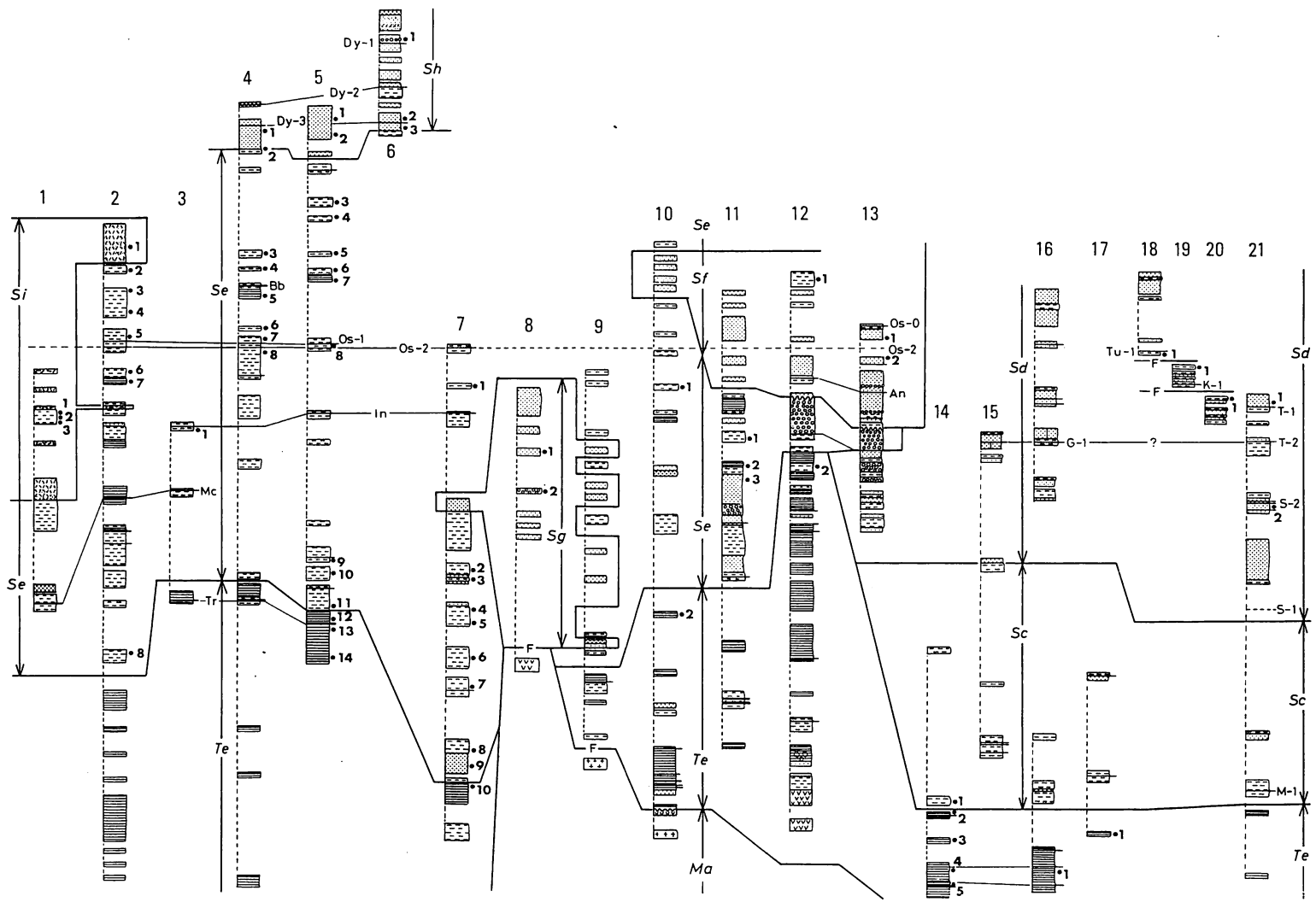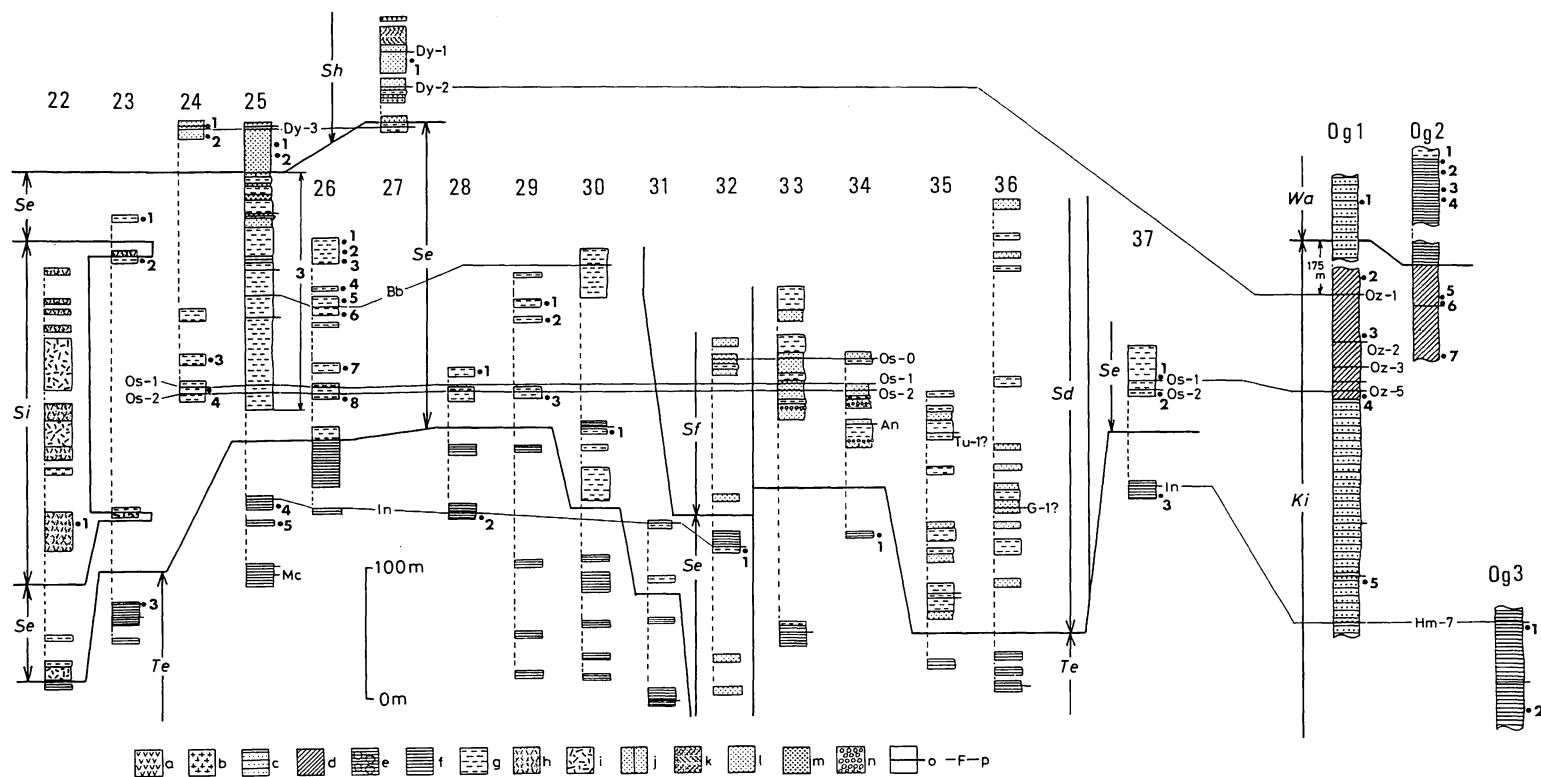
Text-fig. 3. Sections showing stratigraphic positions of the fossil localities described in the text and tables. Fossil localities are numbered 1, 2, 3, . . . in stratigraphically descending order in each section and expressed with prefixed by section number as Locs. 1-1, 1-2. At localities where two or more assemblages are obtained each assemblage is named a, b, c, . . . in stratigraphically descending order (*e.g.* the uppermost assemblage from Loc. 1-2 is denoted as 1-2a). As Loc. 25-3 contains 73 assemblages, the assemblages of the locality are expressed as 25-3-n (n = 1 − 7, 7.5, 8 − 72). The location of the sections is shown in Text-fig. 1. a: Miocene volcanics. b: Miocene diorite; c: turbidite. d: thinly laminated siltstone. e: boulders of siltstone. f: siltstone. g: sandy siltstone. h: fine-grained volcanic sandstone. i: coarse-grained volcanic sandstone. j: fine-grained sandstone interbedded with sandy siltstone. k: cross-laminated fine- to medium-grained sandstone. l: fine-grained sandstone. m: coarse-grained sandstone. n: conglomerate. o: tuff. p: fault. *Ma*: Miocene volcanics. *Te*: Tentokuji Formation. *Ki*: Kitaura Formation. *Wa*: Wakimoto Formation. *Sc-Si*: Sasaoka Formation (*Sc*: Minamizawa Sandy Siltstone. *Sd*: Tofuiwa Alternation. *Se*: Machimura Sandy Siltstone. *Sf*: Terasawa Sandstone. *Sg*: Odai Sandstone. *Sh*: Sodenosawa Sandstone. *Si*: Tomita Volcanic Sandstone).

Table 1.   List of molluscan fossils of the *Palliolum* Association (*P.* Assoc.), *Nuculana* Association and *Thyasira bisecta* Association. Lithofacies are shown by the following abbreviations. tb: turbidite facies. ls: laminated siltstone of turbidite facies. sl: silt facies. ss: sandy silt facies. vs: volcanic sand facies. fs: fine-grained sand facies. at: alternation facies.

Association / Locality / Lithofacies / Species	P. Assoc.	Nuculana Association	Thyasira bisecta Assoc.
Palliolum peckhami	• • • •		
Nucula niponica		(Nuculana Association columns)	
Acila divaricata			
Acila nakazimai			
Nuculana sadoensis			
Nuculana yokoyamai			
Nuculana robai			
Saccella onoyamai			
Portlandia hirosakiensis			
Portlandia toyamaensis			
Yoldia kikuchii			
Yoldia johanni			
Yoldia thraciaeformis			
Yoldia sp.			
Nuculanidae gen. et sp.			
Acharax tokunagai			
Limopsis sp. B			
Chlamys islandica			
Pandora sp.			
Periploma cf. *besshoensis*			
Lunatia pallida			
Cryptonatica clausa			
Fusitriton oregonensis			
Buccinum cf. *rossicum*			
Buccinum sp.			
Plicifusus sp.			
Mohnia cf. *yanamii*			
Neptunea intersculpta			
Neptunea spp.			
Clinopegma borealis			
Fulgoraria sp.			
Volutomitra alaskensis			
Admete lischkei			
Elaeocyma braunsi			
Antiplanes sanctiioannis			
Propebela candida			
Siphonodentalium sp. A			
Cyclocardia ferruginea			
Tridonta borealis			
Macoma calcarea			
Clinocardium chikagawaense			
Pandora wardiana			
Microstelma sp.			
Turritella nipponica			
Boreotrophon xestra			
Antiplanes contraria			
Turbonilla inscitula			
Striodentalium rhabdotum			
Thyasira bisecta			• • • • • • • • • • •
Lucinoma acutilineatum			• • • • • • •
Turritella saishuensis			•

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These fossils are well preserved. The bivalves are often found as conjoined valves. Some individuals of *Acila nakazimai* and *Yoldia thraciaeformis* keep their shell perpendicular to the bedding plane. The valves of smaller species such as *Nuculana* spp. are usually disarticulated, or, if not, do not seem to be preserved at their living position in most cases. Fragile protoconchs of large gastropods are often preserved.

Thyasira bisecta Association:—The association is made up of only five species. *Thyasira bisecta*, a large lucinacean bivalve, is predominant in number. *Lucinoma acutilineata* is common but less in number of individuals than *Thyasira*. In addition to them, *Acila nakazimai*, *Turritella saishuensis* and *Cryptonatica clausa* are rarely found.

The association is found from various types of lithofacies, such as the silt facies of the Tentokuji Formation, sandy silt facies and pumiceous fine-grained sandstone of the alternation facies in the lower part of the Sasaoka Formation.

Thyasira bisecta and *Lucinoma acutilineata* usually keep the valves conjoined and their commissure planes stand perpendicular or oblique to the bedding plane. They are apparently preserved at their life positions, as the occurrence is comparable to the mode of life of living lucinaceans (Stanley, 1970). In some localities individuals of *Thyasira* form a dense aggregation. In pumiceous fine-grained sandstone at Loc. 21-2, 40 individuals of *Thyasira*, two *Lucinoma* and four *Acila* are disseminated on the exposure of 2 m high and 1.5 m wide. Almost all individuals of the three species in the aggregation are conjoined. The commissure planes of most *Thyasira* and *Lucinoma* stand perpendicular to the bedding plane. This occurrence is interpreted as a result of colonial and immobile life of *Thyasira*.

Acila-Turritella Association:—The characteristic species of the association are *Acila nakazimai*, *Turritella saishuensis*, *Macoma calcarea*, *Clinocardium chikagawaense*, *Mya cuneiformis* and *Glycymeris derelicta*. They are associated by *Yoldia johanni*, *Yoldia thraciaeformis*, *Tridonta*

borealis, *Crenulilimopsis oblonga* and some others. The association is represented by 182 assemblages, about 90% of which were obtained from the upper part of the sandy silt facies. Twenty assemblages of this association occur in the fine-grained sand facies, volcanic sand facies and mudstone and sandstone beds of the alternation facies.

In the sandy silt facies, most constituent species mentioned above are found. Minor lithologic differences within this facies do not seem to give great influence to the species composition of the association. Molluscan shells are, however, less abundant in silty part than in sandy part of the sandy silt facies. The association is less diverse in the fine-grained sand facies of the Sodenosawa and Terasawa Members, and is composed only of *Macoma calcarea*, *Mya cuneiformis* and *Clinocardium chikagawaense*. The upper part of the sandy silt facies of the Machimura Member is often intercalated by sandstone beds of the fine-grained sand facies, 30 cm to 10 m thick. The intercalating sand facies also yields assemblages belonging to the association. The species found are *Turritella saishuensis*, *Mya cuneiformis* and *Macoma calcarea*, but no other representative species of the association (Text-fig. 4). The species composition in the alternation facies of the Tofuiwa Member is similar to that in the sandy silt facies, but *Crenulilimopsis oblonga*, *Nassarius siquijorensis* and some others are exclusively found here, while *Glycymeris derelicta* never appears in the facies. The assemblages both in the muddy and sandy beds of the alternation facies show no remarkable difference in species composition.

The fossils are sporadically scattered in the rock. They are often found as loose cluster but the shells do not touch each other. Protoconchs of gastropods are usually preserved. Fine sculptures of these shells are mostly preserved and fragmental shells are rare. *Mya* usually keeps the valves conjoined and is disposed perpendicular or oblique to the bedding plane with posterior ends pointing upward. *Macoma* is usually conjoined and is arranged parallel or

Table 2a. List of molluscan fossils of the *Acila-Turritella* Association. See Table 1, for abbreviations of lithofacies. (continued on Table 2b)
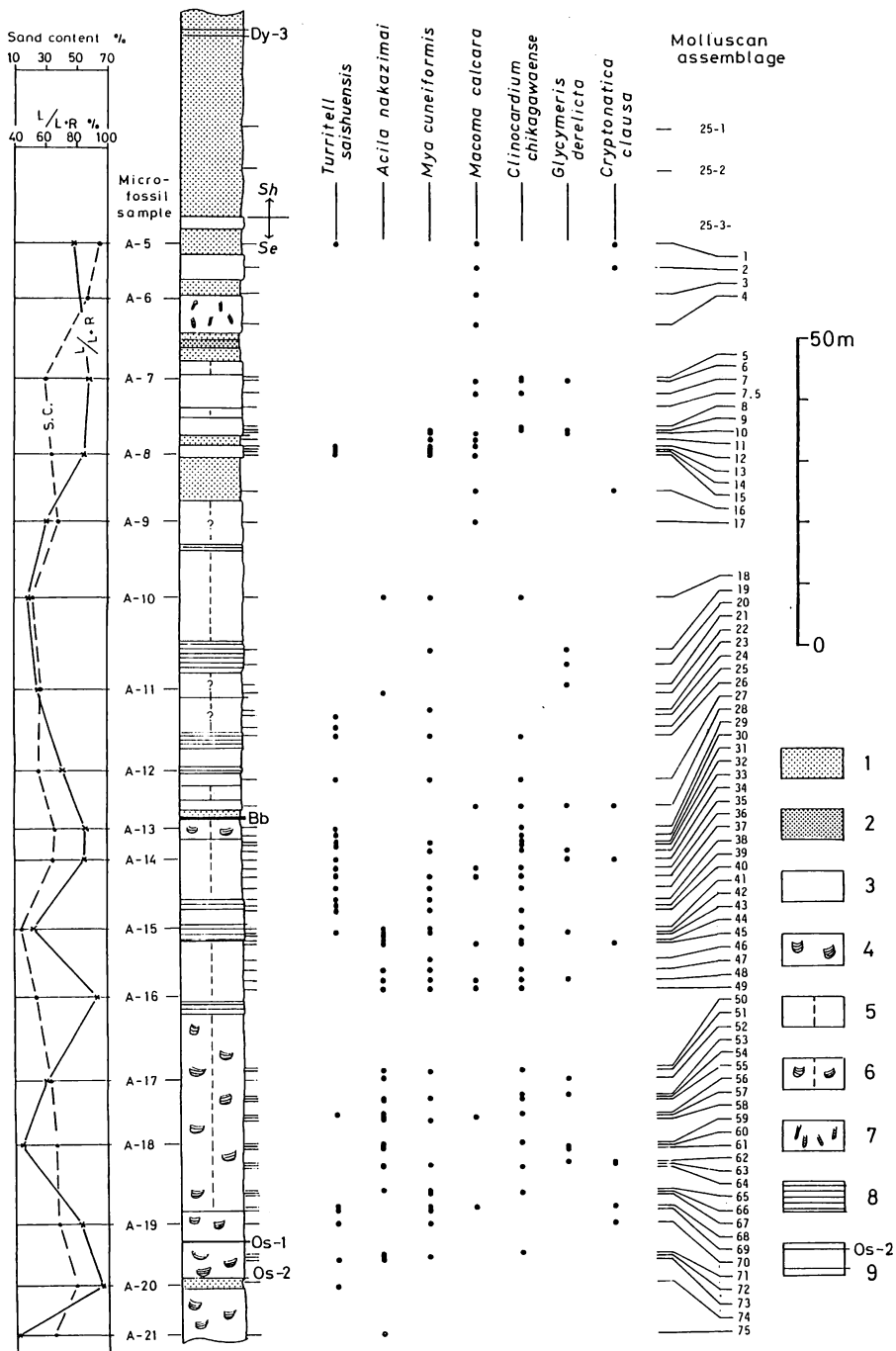
Seiichiro MATSUI

Association	Acila – Turritella Association
Locality / Lithofacies / Species	1-1, 1-2, 1-3, 2-1a, 2-1b, 2-2a, 2-2b, 2-2c, 2-2d, 2-3, 2-4, 2-5a, 2-5b, 2-5c, 2-5d, 2-6, 2-7, 4-2c, 4-2d, 4-3, 4-4, 4-5a, 4-5b, 4-5c, 4-5d, 4-5e, 4-5f, 4-5g, 4-5h, 4-6a, 4-6b, 4-7a, 4-7b, 4-7c, 4-7d, 4-8a, 4-8b, 4-8c, 5-3, 5-4, 5-5, 5-6a, 5-6b, 5-7a, 5-7b, 5-7c, 5-8a, 5-8b, 5-9, 5-10a, 5-10b, 7-2, 7-3, 7-4, 7-5, 8-1, 10-1a, 10-1b, 11-1, 11-2, 11-3
Lithofacies	vs vs vs vs vs ss ss ss ss ss ss ss ss ss ss ss ss ss ss ss ss ss ss ss ss ss ss ss ss ss ss ss ss ss ss ss ss ss ss ss ss ss ss ss ss ss ss ss ss ss ss ss ss ss ss ss ts ss ss ss ss ss

Species:

- Turritella saishuensis
- Acila nakazimai
- Mya cuneiformis
- Macoma calcarea
- Clinocardium chikagawaense
- Glycymeris derelicta
- Cryptonatica clausa
- Nuculana yokoyamai
- Nuculana sp.
- Portlandia hirosakiensis
- Yoldia johanni
- Yoldia thraciaeformis
- Anadara amicula
- Limopsis sp.A
- Solamen spectabilis
- Mizuhopecten poculum
- Lucinoma acutilineata
- Thyasira tokunagai
- Cyclocardia ferruginea
- Cyclocardia sp.
- Tridonta borealis
- Paphia sp.
- Pandora wardiana
- Myadora japonica
- Periploma plane
- Microstelma sp.
- Bittium binodulosum
- Trophonopsis kagaensis
- Boreotrophon xestra
- Plicifusus ozawai
- Admete lischkei
- Antiplanes contraria
- Suavodrillia? sp.B.
- Riuguhdrillia? sp.
- Ophiodermella pseudopannus
- Oenopota kagana
- Propebela candida
- Turbonilla inscitula
- Crenulilimopsis oblonga
- Nassarius siquijorensis
- Suavodrillia? sp.A.
- Striodentalium rhabdotum
- Siphonodentalium sp.B.

Table 2b. List of molluscan fossils of the *Acila-Turritella* Association. See Table 1, for abbreviations of lithofacies. (continued on Table 2c)

Association	Acila - Turritella Association
Locality / Lithofacies	12-1 (ss), 13-1 (fs), 13-2 (fs), 15-1 (fs), 15-2 (fs), 18-1 (at), 19-1 (at), 20-1a (at), 20-1b (at), 21-1 (at), 23-1 (ss), 23-2 (ss), 23-3 (ss), 24-4a (ss), 24-4b (ss), 24-4c (ss), 24-4d (ss), 25-3-1 (ss), 25-3-2 (ss), 25-3-3 (ss), 25-3-4 (ss), 25-3-5 (ss), 25-3-6 (ss), 25-3-7 (fs), 25-3-7.5 (ss), 25-3-8 (ss), 25-3-9 (ss), 25-3-10 (ss), 25-3-11 (ss), 25-3-12 (fs), 25-3-13 (ss), 25-3-14 (ss), 25-3-15 (ss), 25-3-16 (ss), 25-3-17 (fs), 25-3-18 (ss), 25-3-19 (ss), 25-3-20 (ss), 25-3-21 (ss), 25-3-22 (ss), 25-3-23 (ss), 25-3-24 (ss), 25-3-25 (ss), 25-3-26 (ss), 25-3-27 (ss), 25-3-28 (ss), 25-3-29 (ss), 25-3-30 (ss), 25-3-31 (ss), 25-3-32 (ss), 25-3-33 (ss), 25-3-34 (ss), 25-3-35 (ss), 25-3-36 (ss), 25-3-37 (ss), 25-3-38 (ss), 25-3-39 (ss), 25-3-40 (ss), 25-3-41 (ss), 25-3-42 (ss), 25-3-43 (ss)

Species:

- Turritella saishuensis
- Acila nakazimai
- Mya cuneiformis
- Macoma calcarea
- Clinocardium chikagawaense
- Glycymeris derelicta
- Cryptonatica clausa
- Nuculana yokoyamai
- Nuculana sp.
- Portlandia hirosakiensis
- Yoldia johanni
- Yoldia thraciaeformis
- Anadara amicula
- Limopsis sp. A
- Solamen spectabilis
- Mizuhopecten poculum
- Lucinoma acutilineata
- Thyasira tokunagai
- Cyclocardia ferruginea
- Cyclocardia sp.
- Tridonta borealis
- Paphia sp.
- Pandora wardiana
- Myadora japonica
- Periploma plane
- Microstelma sp.
- Bittium binodulosum
- Trophonopsis kagaensis
- Boreotrophon xestra
- Plicifusus ozawai
- Admete lischkei
- Antiplanes contraria
- Suavodrillia? sp. B.
- Riuguhdrillia? sp.
- Ophiodermella pseudopannus
- Oenopota kagana
- Propebela candida
- Turbonilla inscitula
- Crenulilimopsis oblonga
- Nassarius siquijorensis
- Suavodrillia? sp. A.
- Striodentalium rhabdotum
- Siphonodentalium sp. B.

Table 2c. List of molluscan fossils of the *Acila-Turritella* Association. See Table 1, for abbreviations of lithofacies.

Association	Acila – Turritella Association
Locality / Lithofacies / Species	25-3-44, 25-3-45, 25-3-46, 25-3-47, 25-3-48, 25-3-49, 25-3-50, 25-3-51, 25-3-52, 25-3-53, 25-3-54, 25-3-55, 25-3-56, 25-3-57, 25-3-58, 25-3-59, 25-3-60, 25-3-61, 25-3-62, 25-3-63, 25-3-64, 25-3-65, 25-3-66, 25-3-67, 25-3-68, 25-3-69, 25-3-70, 25-3-71, 25-3-72, 25-3-73, 25-3-74, 25-3-75, 26-1, 26-2a, 26-2c, 26-3, 26-4, 26-5a, 26-5b, 26-5c, 26-5d, 26-5e, 26-5f, 26-5g, 26-6a, 26-6b, 26-7a, 26-7b, 26-7c, 26-7d, 28-1a, 28-1b, 29-2, 29-3, 30-1, 32-1, 37-1, 37-2, 42

Lithofacies abbreviations (per column): ss (most), ts (26-1), at (42)

Species:

- Turritella saishuensis
- Acila nakazimai
- Mya cuneiformis
- Macoma calcarea
- Clinocardium chikagawaense
- Glycymeris derelicta
- Cryptonatica clausa
- Nuculana yokoyamai
- Nuculana sp.
- Portlandia hirosakiensis
- Yoldia johanni
- Yoldia thraciaeformis
- Anadara amicula
- Limopsis sp. A
- Solamen spectabilis
- Mizuhopecten poculum
- Lucinoma acutilineata
- Thyasira tokunagai
- Cyclocardia ferruginea
- Cyclocardia sp.
- Tridonta borealis
- Paphia sp.
- Pandora wardiana
- Myadora japonica
- Periploma plane
- Microstelma sp.
- Bittium binodulosum
- Trophonopsis kagana
- Boreotrophon xestra
- Plicifusus ozawai
- Admete lischkei
- Antiplanes contraria
- Suavodrillia? sp. B.
- Riuguhdrillia? sp.
- Ophiodermella pseudopannus
- Oenopota kagaensis
- Propebela candida
- Turbonilla inscitula
- Crenulilimopsis oblonga
- Nassarius siquijorensis
- Suavodrillia? sp. A.
- Striodentalium rhabdotum
- Siphonodentalium sp. B.

Text-fig. 4. Stratigraphical sequence at Machimura, the northern part of the Gojome Area, showing the distribution of common constituent species of the *Acila-Turritella* Association, sand contents (break line in the left column) and the ratio of the left coiling forms of *Neogloboquadrina pachyderma* (solid line in the left column). 1: fine-grained sandstone, 2: coarse-grained sandstone, 3: massive sandy siltstone, 4: massive sandy siltstone with "Houki-zuna", 5: alternation of sandy siltstone and siltstone, 6: alternation of sandy siltstone and siltstone with "Houki-zuna", 7: sandy siltstone with tubulous burrows, 8: siltstone, 9: tuff, *Sh*: Sodeno-sawa Sandstone, *Se*: Machimura Sandy Siltstone.

slightly oblique to the bedding plane. Almost all individuals of *Acila* are randomly oriented and a half of them are conjoined. The occurrence of *Glycymeris* is similar to that of *Acila*. *Clinocardium* usually occurs as single valve.

Different preservation of the bivalves seems to reflect their different life habits, especially different depth of burrowing. *Mya cuneiformis* can be regarded as a very deep burrower, judging from the life habit of *Mya arenaria*, a living analogue of *M. cuneiformis*. *Macoma calcarea* is also probably deep burrower. Such deep burrowers generally keep their shells conjoined, and the orientation of the shells to the bedding plane probably shows their life positions. On the other hand, *Acila*, *Clinocardium*, and *Glycymeris* are shallow burrowers. *Clinocardium* possesses short siphons and *Glycymeris* is non-siphonate bivalve. Both of them probably exposed their posterior end above the bottom surface. These three species are often found as single valve, and the valves are randomly directed. Dominance of single valve and random orientation of these three species may be due to reworking of dead shells by weak current and/or burrowing animals. Molluscan shells within the "Houki-zuna" in the sandy silt facies are disposed along laminae, and are usually composed of shallow burrowers such as *Acila*, *Glycymeris*, *Clinocardium* and *Turritella*.

Macoma tokyoensis Association:—The association is characterized by dominant occurrence of *Macoma tokyoensis*. *Macoma* is frequently accompanied by *Turritella saishuensis*, and small gastropods and bivalves (*e.g. Ophiodermella pseudopannus*, *Axinopsida subquadrata*) are often found. *Macoma calcarea* coexists with *M. tokyoensis* at Locs. 4-1h, 4-2a, 4-2b, 5-1a.

This association is confined to the fine-grained sand facies. Some assemblages of the *Acila-Turritella* Association are similar to the *Macoma* Association in species composition but do not contain *Macoma tokyoensis*. For example, the assemblage of Loc. 4-2b in the fine-grained sand facies contains *M. tokyoensis*, *M. calcarea*, and *Turritella*, and is included in the *Macoma tokyoensis* Association. On the other hand, sandy

siltstone at Loc. 4-2c, situated at 1.4 m below 4-2b contains *M. calcarea* and *Mya cuneiformis* without *M. tokyoensis*, being considered to belong to the *Acila-Turritella* Association.

The shells are well preserved. Two species of *Macoma* are usually disposed parallel or oblique at low angle to the bedding plane.

Prothothaca Association:—This association is characterized by large and thick shelled bivalves such as *Prothothaca adamsi*, *Anadara amicula*, *Glycymeris yessoensis*, *Dosinia japonica*, *Mercenaria stimpsoni* and smaller bivalves *Felaniella usta*. It is contained in the fine-grained sand facies.

The association occupies horizons stratigraphically very close to those of the *Macoma tokyoensis* Association in the fine-grained sand facies. The sand containing these two associations seems to have no difference in lithology, although there are few common species between the two associations.

The large bivalves are mostly well preserved, articulated and randomly oriented. Shells are usually sporadically disseminated in the sand. *Anadara amicula* is often crowded in a bed of 10 cm or less in thickness. The other species are also contained in the *Anadara* beds. *Felaniella usta* is also associated with the large bivalves, although it forms a dense aggregation of shells in some cases.

Relationships between association types and environments

Vertical and horizontal distributions of the associations are shown on a stratigraphical profile (Text-figs. 5A—B). There is rather loose correlation between the association types and the lithofacies types, as follows:

Palliolum Association — The turbidite facies.

Nuculana Association — The silt facies and lower part of the sandy silt facies.

Acila-Turritella Association — The upper part of the sandy silt facies, alternation facies and fine-grained sand facies.

Macoma tokyoensis Association — The fine-grained sand facies.

Table 3. List of molluscan fossils of the *Macoma tokyoensis* Association and *Prototheca* Association. See Table 1, for abbreviations of lithofacies.

Association	Macoma tokyoensis Association																								Prototheca Association														
Lithofacies / Species	fs 4-1h	fs 4-2a	fs 4-2b	fs 5-1a	fs 5-1b	fs 5-1f	fs 5-1h	fs 5-1j	fs 5-1k	fs 5-2a	fs 5-2d	fs 5-2e	fs 5-2f	fs 5-2g	fs 5-2h	fs 5-2i	fs 5-2j	fs 5-2k	fs 6-2	fs 24-1a	fs 24-1b	fs 24-2a	fs 24-2b	fs 25-2	fs 4-1a	fs 4-1b	fs 4-1c	fs 4-1d	fs 4-1e	fs 4-1f	fs 4-1g	fs 5-1c	fs 5-1d	fs 5-1e	fs 5-1g	fs 5-1i	fs 5-2a	fs 24-2c	fs 25-1
Turritella saishuensis	•	•	•								•			•		•	•	•																					
Macoma calcarea	•	•	•	•																					•	•													
Yoldia johanni				•																						•	•	•											
Plicifusus ozawai				•																																			
Antiplanes contraria				•																																			
Ophiodermella pseudopannus		•	•																			•			•	•	•	•											•
Oenopota kagana				•																																			
Macoma tokyoensis	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•					•							•				
Acila sp.	•	•	•																			•																	
Mizuhopecten poculum		•	•																																				
Axinopsida subquadrata	•	•																																•					
Clinocardium fastosum																																							
Thracia kakumana						•																																	
Homalopoma amussitatum			•																																				
Trophonopsis kagaensis	•													•		•									•														
Boreotrophon xestra																																							
Reticunassa cf. spurca																•									•														
Paradrillia cf. dainichiensis					•																																		
Epitonium echigonum	•															•																							
Anadara amicula	•																					•	•		•	•	•		•						•	•		•	•
Glycymeris yessoensis																									•	•	•	•				•				•			•
Felaniella usta	•																								•	•	•	•	•							•		•	
Fulvia mutica																									•														
Dosinia japonica																												•				•	•						
Mercenaria stimpsoni																•	•									•	•								•			•	•
Protothaca adamsi																									•		•	•											
Cryptonatica clausa												•										•			•		•	•											
Neverita didyma																												•											

Protothaca Association — The fine-grained sand facies.

Thyasira bisecta Association — The silt facies, sandy silt facies and alternation facies.

Lithological variations within the major lithofacies types, which occur within 10 m or less stratigraphical interval, however, seem to give little influence to the distributions of the associations.

As discussed before, the vertical and lateral
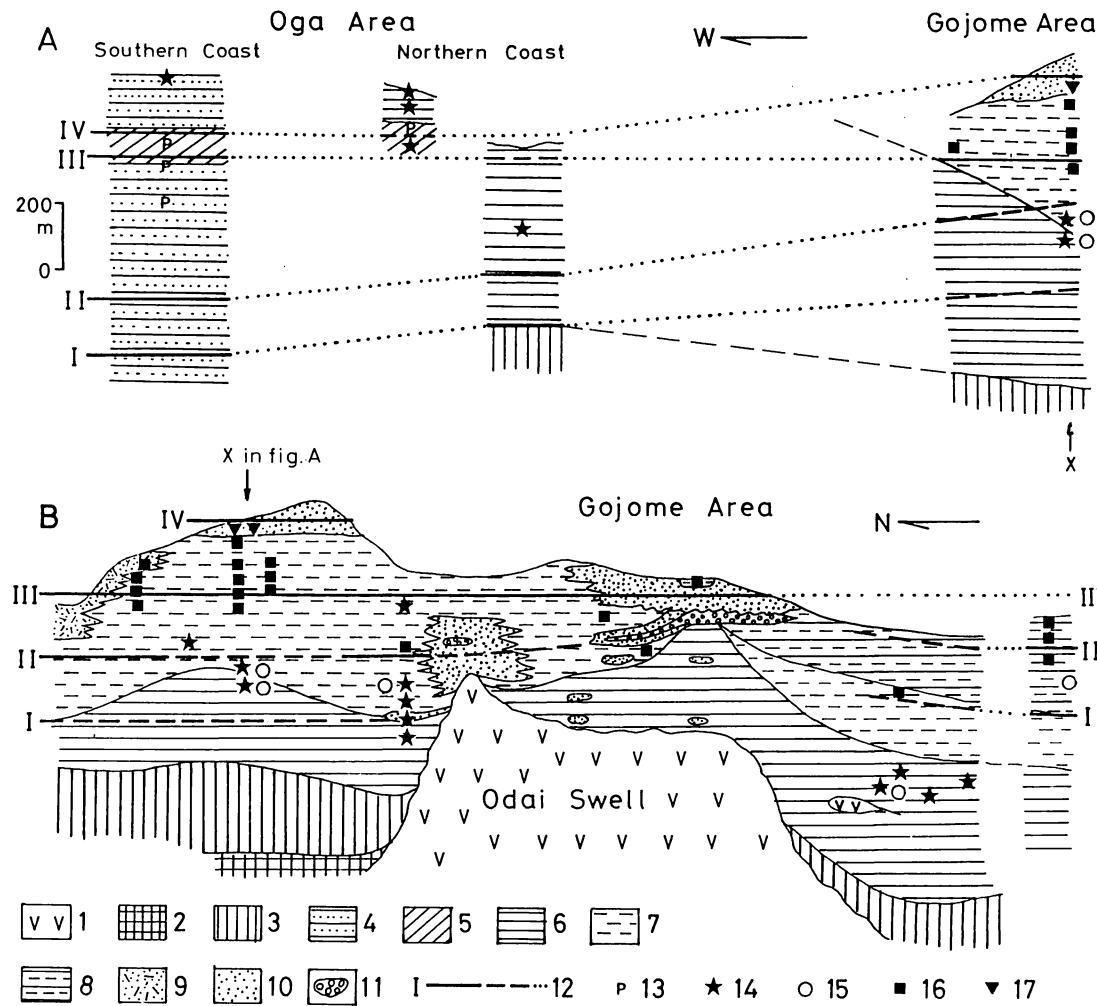
Text-fig. 5.   Stratigraphic distribution of the associations. A: E-W section from the northern part of the Gojome Area to the Oga Area. B: N-S section along the eastern margin of the Gojome Area. 1: Miocene volcanics. 2: Onnagawa Formation. 3: Funakawa Formation. 4: turbidite facies. 5: thinly laminated siltstone of turbidite facies. 6: silt facies. 7: sandy silt facies. 8: alternation facies. 9: volcanic sand facies. 10: fine-grained sand facies. 11: conglomerate. 12: marker horizons I — IV. 13: *Palliolum* Association. 14: *Nuculana* Association. 15: *Thyasira bisecta* Association. 16: *Acila-Turritella* Association. 17: *Macoma tokyoensis* Association and *Protothaca* Association.

changes of the lithofacies may be controlled by the regressive shallowing of the sea and by areal differences of water depth, while lithological variations within a lithofacies type are probably due to local differences of hydrodynamic conditions of the bottom. This suggests that the distribution of the associations is primarily controlled by water depth. For example, the *Palliolum* Association probably occupied

the deepest part of the area, the *Acila-Turritella* Association was living in the area shallower than the former, and the *Macoma tokyoensis* and the *Protothaca* Associations occupied the most near-shore and shallowest environments. The variations of lithology within a lithofacies type are, however, often correlated with compositional variations within the associations. The major cause of the compositional variations
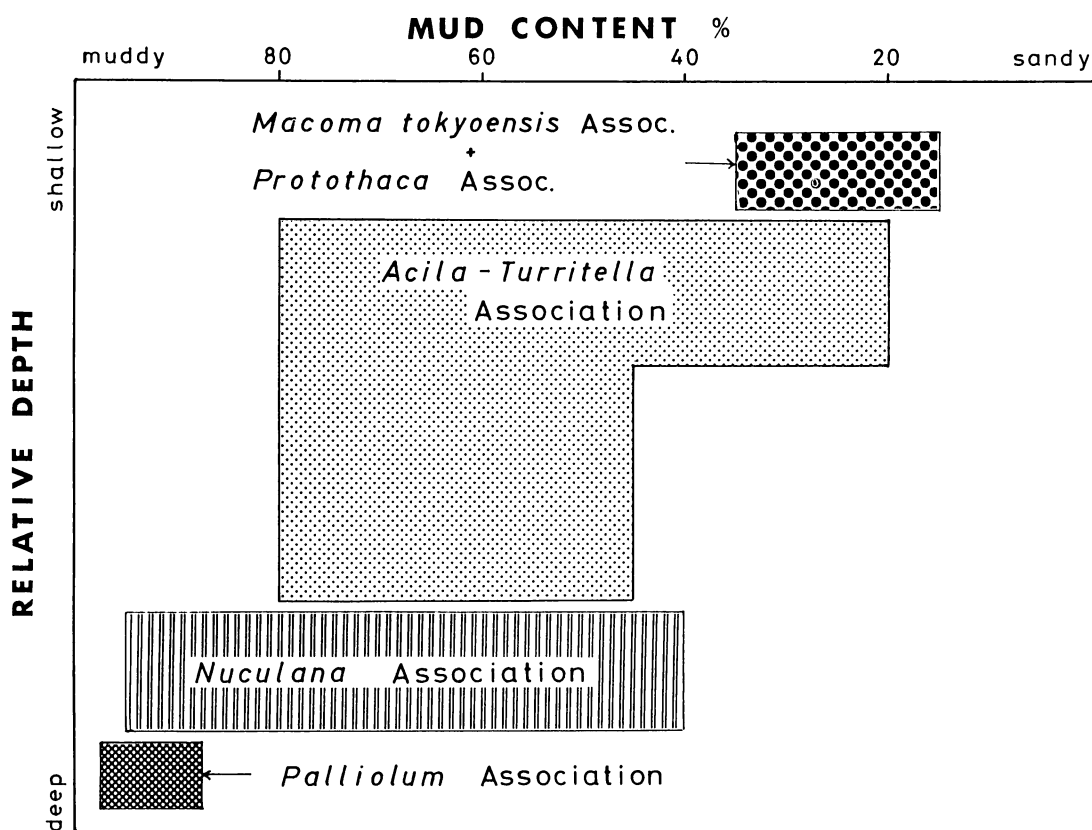
MUD CONTENT %

Text-fig. 6. Relationship between the associations and environmental conditions expressed in terms of water depth and mud content of the sediments.

associated with the minor lithological variations may be ascribable to difference of the substrata.

Facies- and depth-related distribution of the associations is summarized in Text-fig. 6.

The *Palliolum* Association is confined to the turbidite facies and to the westernmost part of the area studied. Accordingly it is thought to represent the deepest biofacies of the area. The *Nuculana* Association occurs in muddy deposits and occupies deep environments but shallower than the *Palliolum* Association. Some assemblages of the *Nuculana* Association (Locs. 7-9a, 7-9b) are found in a muddy sand bed (sand content 63%) interbedded in the silt facies. The two assemblages found in the sandy sediments contain *Neptunea* or *Fulgoraria*, which are characteristic in the association, but lack nuculanid bivalves. This fact suggests that the prevalence of deposit-feeding nuculanid and

nuculid is probably due to high contents of mud fraction in the substrata. Absence of the deposit feeding bivalves at Locs. 7-9a and 7-9b is interpreted as a modification of composition dependent on lithology. Sanders (1958) showed that concentration of clay fraction is positively correlated with the distribution of deposit-feeders in a bay environment.

The *Acila-Turritella* Association is widely distributed in the sandy silt facies. The association in this facies is relatively stable in species composition, although a minor variation independent of lithology is observed. The variation is probably due to minor fluctuations of water depth, as discussed in the next section. The association modifies its composition in the fine-grained sand facies, and *Glycymeris derelicta* is absent, while *Mya* and *Macoma calcarea* are prevalent. The association in the alternation

facies of the Tofuiwa Member have similar composition to that in the sandy silt facies, but is modified by the abundant occurrence of *Crenulilimopsis oblonga* and *Nassarius siquijorensis* and by absence of *Glycymeris derelicta*. *Crenulilimopsis* and *Nassarius* are warm water molluscs, which are rare in other horizons in this area. The living form of *Nassarius siquijorensis* is restricted to shelf environment under the warm Kuroshio water and is distributed from subtropical to equatorial Pacific region. The Tofuiwa Member is older than the other horizons yielding the *Acila-Turritella* Association, and is latest Pliocene to earliest Pleistocene in age (Matsui, 1981). This horizon is assigned to be in "pre-glacial Pleistocene" time, when the Japan Sea coast of Honshu including this area was considered to be affected by the warm surface water, based on faunal analysis of planktonic foraminifers (Maiya *et al.*, 1976). These warm water molluscs were conveyed by the influx of warm waters from the Pacific regions.

The *Macoma tokyoensis* Association and the *Protothaca* Association are found in the uppermost part of the marine sediments and are distributed in the eastern part of the area. The two associations are considered to be the shallowest inhabitants among others. They are closely accompanied by each other, and the enclosing rocks of the two associations show little lithological difference.

The *Thyasira bisecta* Association appears in three lithofacies types, the silt facies, sandy silt facies and fine-grained sandstone of the alternation facies. In the Taihei Area, southeast of the Gojome Area the association occurs in pebbly fine-grained sandstone of the Sasaoka Formation (Matsui, 1977). The *Thyasira bisecta* Association seems to have wide tolerance to sediment types. The association is characterized by common occurrence of two lucinacean species, *Thyasira* and *Lucinoma acutilineata*. Allen (1958) stated that the anatomical features of the Lucinacea show their successful adaptation to environments unsuitable for other infaunal species, where the supply of oxygen and foods is suppressed. This fact is probably related

to the absence of *Thyasira* and *Lucinoma* in the other associations and their low selectivity to sediment type.

Fine structure of *Acila-Turritella* Association in the sandy silt facies

As discussed before, the *Acila-Turritella* Association is heterogeneous in species composition, and some of these variations in composition are interpreted as a result of the difference of lithology and invasion of warm surface water.

In the sandy silt facies, the association shows a minor compositional variation independent of lithology. The fine compositional variation of the association in the sandy silt facies is analyzed in relation to lithology and planktonic foraminiferal assemblages. Stratigraphical distribution of constituent species of the association at an exposure in the northern part of the Gojome Area is shown in Text-fig. 4 with the changes of lithology, sand content and coiling ratio of a planktonic foraminiferal species *Neogloboquadrina pachyderma*.

Acila nakazimai and *Turritella saishuensis*, which are characteristic species of the association, rarely coexist at one assemblage. The two species respectively occupy the limited stratigraphical intervals and alternatively occur in this section. Other characteristic species of the association seem to be distributed more evenly than *Acila* and *Turritella*.

In order to examine the details of the alternative occurrence, molluscs of two sections in the northern part of the Gojome Area were successively sampled. The sampling of molluscs was made semi-quantitatively (Text-fig. 7). Molluscs on the exposures are counted and whole individuals of the surface of 2 m wide and 50 cm thick (*i.e.*, 1 m^2) are treated as an assemblage. In case that exposure is narrower than 2 m by a cover or thinner than 50 cm by a insertion of tuff, the number of individuals counted is converted to number per one square meter of the exposure. Sand contents of the enclosing rocks are measured at about 1 m
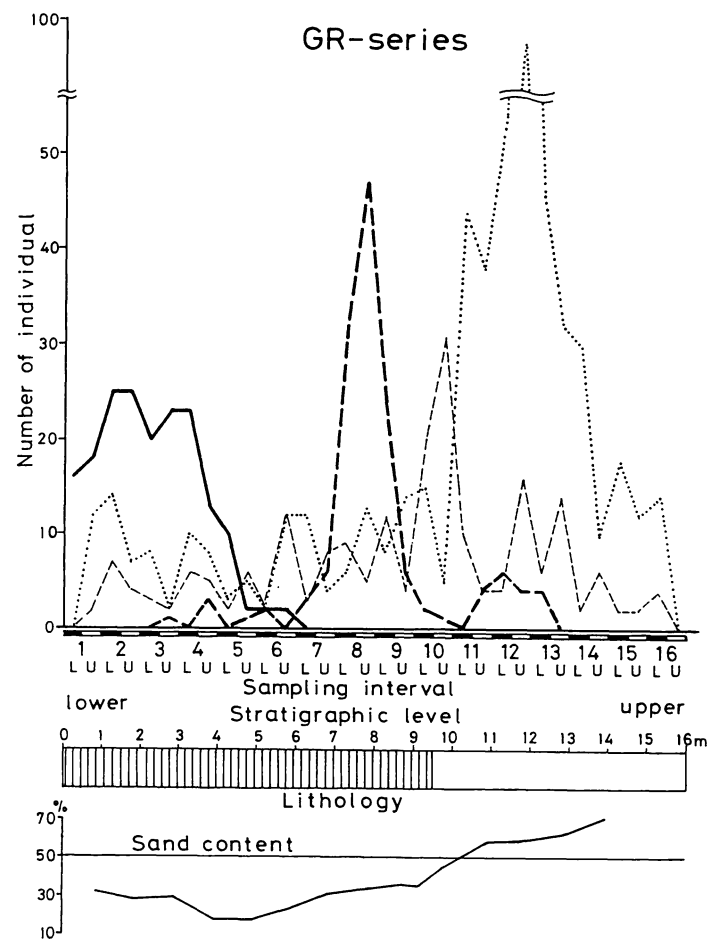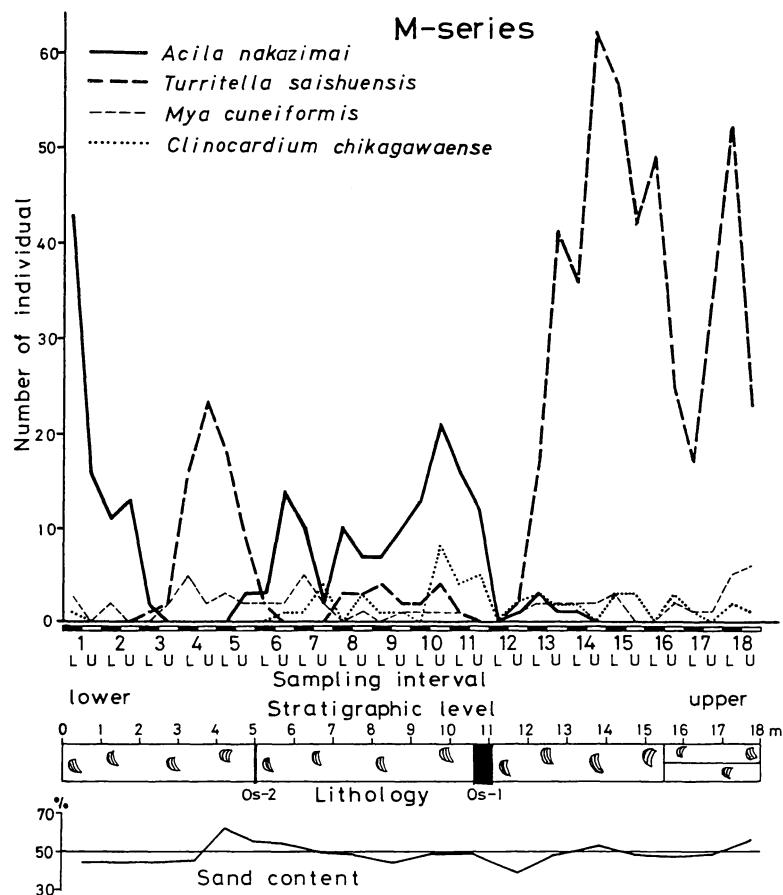
Text-fig. 7.   Stratigraphic distribtuion of the abundance of characteristic elements of the *Acila-Turritella* Association in two sections. M-series covers the assemblages of 25-3-68 to 25-3-75. Columnar section of M-series is shown in Text-fig. 4. GR-series covers the assemblages of 4-5a to 4-5h. Symbols of lithofacies are noted in Text-fig. 4.

interval. Stratigraphically successive samples of such assemblages are obtained from two sections. The two serial samples are called M-series and GR-series.

The alternative occurrence of *Acila* and *Turritella* is evident in Text-fig. 7. In the two sections, the two species are not completely exclusive from each other, but in horizons dominated by one species, the other is very rare or absent. The alternative occurrence of the two species is hardly explained by change of lithology. In the M-series, the two species attain their maximum individual numbers in the sandy silt containing sand fraction of about 50%, below and above the tuff Os-1. In the GR-series, both species are most abundant in the silt of about 30% in sand content.

The areal distributions of *Acila* and *Turritella* along the marker tuff Os-1 and Os-2 are shown in Text-fig. 8. In the localities A to G, the stratigraphical distribution of the two species are similar to each other, for example, *Acila* is abundant below Os-1, and *Turritella* takes over the place above Os-1 in most localities. In the locality H, however, *Acila* appears at two horizons, above Os-1 and below Os-2 where *Turritella* occurs in other localities. As the sea at that time was considered to become deeper at the locality H than the localities A to G, the distribution of the two species implies that *Acila* have inhabited in a deeper sea bottom than *Turritella*. This interpretation is consistent with the fact that *Acila* occurs in the *Nuculana* Association, but *Turritella* is not associated with it.

The stratigraphic distribution of the ratio of left-coiling forms of *Neogloboquadrina pachyderma* has a positive correlation with the occur-
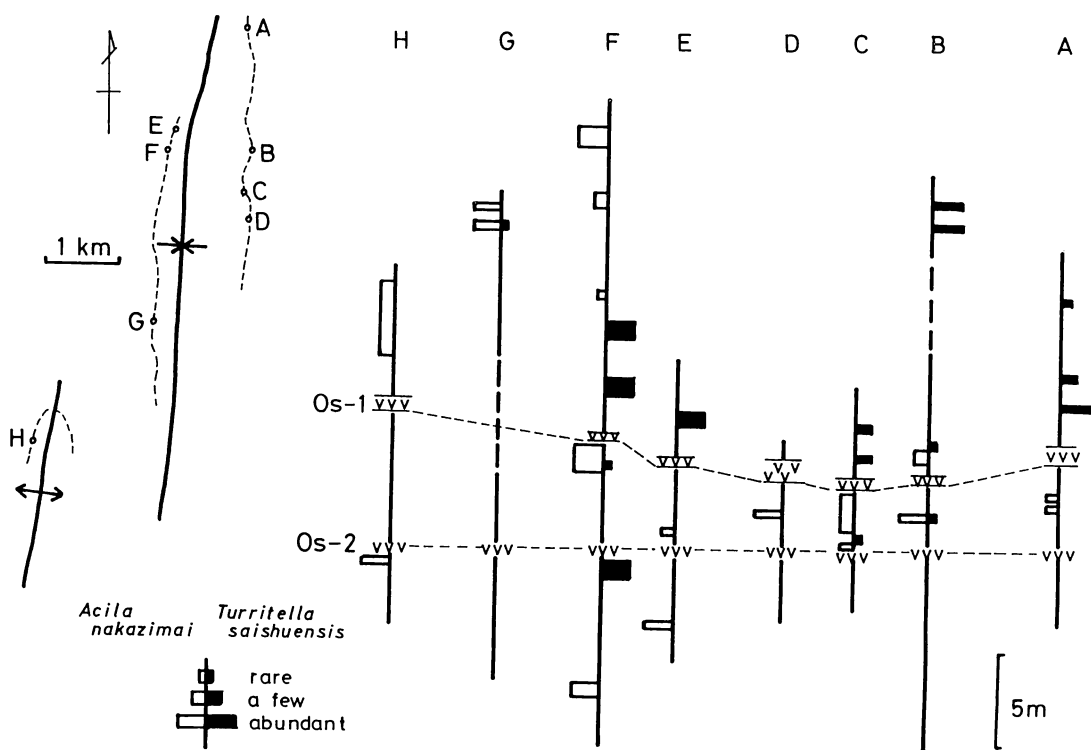
Text-fig. 8.   Areal and stratigraphic distribution of *Turritella saishuensis* and *Acila nakazimai* along the marker tuff Os-1 and Os-2 in the northern part of the Gojome Area. Sections of A to G correspond respectively to the following sections of Text-fig. 1. A: 2. B: 4. C: not shown in Text-fig. 1. D: 5. E: 24. F: 25. G: 28.

rence of *Turritella* (Text-figs. 4 and 9). In Text-fig. 9, the occurrence of *Acila* and *Turritella* within 1 m from the sampling horizons of microfossils is plotted against percentage of the left-coiling *N. pachyderma*. *Turritella* occurs in horizons only where the ratio is more than 78.5%, while *Acila* occurs in horizons of the ratio less than 61%.
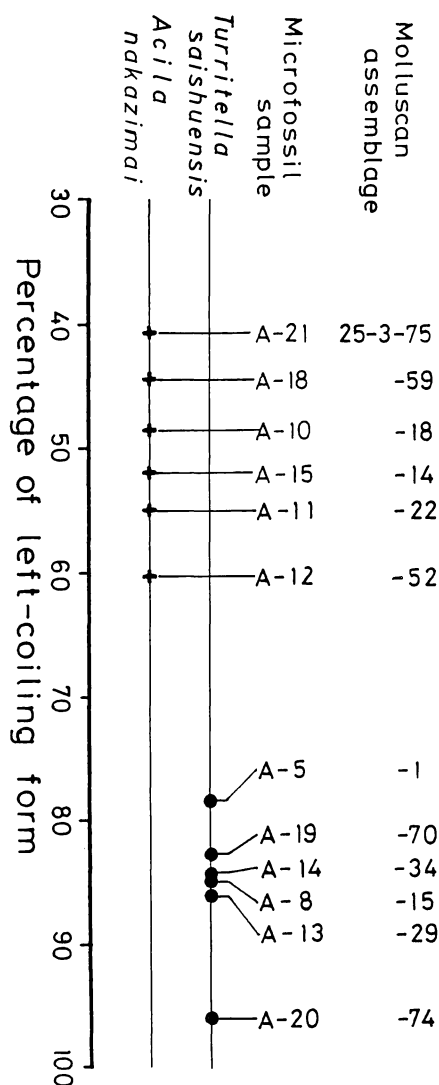
The left-coiling forms of *N. pachyderma* inhabit in the colder surface water, and the fluctuation of the coiling ratio is probably caused by the fluctuation of the surface water temperature (*e.g.* Ericson, 1959). The change of paleooceanographic condition in this area was thought to be linked with the glacial climatic changes (Maiya *et al.*, 1976). The cooling of climate resulted the development of ice sheet and eustatic lowering of the sea level. Therefore the dominance of the left-coiling forms may indicate the horizons of lowered sea level, and *Turritella* is found in these horizons. The occurrence of *Turritella* in the horizons of high ratio of left-coiling *N. pachyderma* coincides with the assumption that *Turritella* occupied shallower bottom than *Acila*.

Systematic notes

All speciemens examined are deposited in the collection of the University Museum, University of Tokyo (UMUT). Registration numbers of UMUT are given in parentheses after locality number. Localities of M-series and GR-series are expressed by combination of series name (M or GR), number of sampling level and a letter of A or B. The numbers of sampling levels are shown in Text-fig. 7. The letters of A or B are code for identification of two sampling quadrates from the same sampling level, which are not shown in Text-fig. 7.

Homalopoma amussitatum (Gould, 1861)

Pl. 22, Fig. 1.

Homalopoma amussitatum (Gould). Habe, 1958b, p. 5, pl. 1, fig. 13; Kuroda, Habe and Oyama, 1971, p. 51, pl. 15, fig. 6.

Locality: 4-2b (CM16223).

Alvania sp.

Pl. 22, Fig. 2.

Description:—Shell small in size, elongated-conical. Protoconch one and a half turns, depressed, surface smooth, homeostrophic, 0.4—

Text-fig. 9. Relationship between the occurrence of *Turritella saishuensis* and *Acila nakazimai* and the ratio of left coiling form of *Neogloboquadrina pachyderma*.

Microfossil sample	Molluscan assemblage
A-21	25-3-75
A-18	-59
A-10	-18
A-15	-14
A-11	-22
A-12	-52
A-5	-1
A-19	-70
A-14	-34
A-8	-15
A-13	-29
A-20	-74

0.45 mm in maximum diameter. Teleoconch four whorls, ornamented by axial ribs and spiral grooves. The first one turn ornamented by round-topped fifteen to seventeen axial ribs, and by four or five fine spiral grooves, being apparent only on the interspace of the axial ribs. Penultimate whorl has nineteen or twenty axial ribs and four or five spiral grooves. The axial ribs on the body whorl become low and irregular. The surface of the body whorl lower than the periphery has five or six narrow spiral grooves and no axial ribs. Suture is very narrowly canaliculate. Peristome continuous. Aperture circular, and umbilicus not open.

They are somewhat similar to *Alvania asura* (Yokoyama, 1926), but they have stronger spiral grooves and less inflated whorl than *asura*.

Locality: M1B (CM16224, CM16225).

Microstelma sp.

Pl. 22, Fig. 3.

Description:—Shell small, solid, suboval in outline with abutting whorl. Protoconch one and a half turns, globose, smooth, homeostrophic, 0.45—0.55 mm in maximum diameter. Teleoconch three and a half whorls. The first one ornamented by round-topped, orthoclinal axial ribs numbering 14 or 15, and by two or three spiral cords, which are weaker than the axial ribs. On the later whorls, the spiral cords become weaker or almost disappear. Axial ribs 17 to 19 on the body whorl, 15 on the penultimate whorl. On the body whorl, the axial ribs abapically disappear below the periphery, and become low on the last quarter of whorl. There are three or four very weak and flat spiral cords, which are equal to or wider than the interspace, below the periphery. Aperture circular, and outer lip slightly thickened. Umbilicus narrowly opened.

These specimens are similar to *Microstelma daedala* A. Adams, 1863 and *M. flava* Okutani, 1964, but *daedala* has angulate shoulder, and *flava* has more arcuate whorl and only weak spiral lirae on the earlier whorls.

Locality: 12-2 (CM16226); 25-3-45 (CM 16227); 25-3-59 (CM16228).

Turritella (Neohaustator) saishuensis Yokoyama, 1923

Pl. 22, Figs. 4—6.

Turritella saishuensis Yokoyama, 1923a, p. 3, pl. 1, fig. 2.
Turritella (Neohaustator) saishuensis Yokoyama, Kotaka, 1959, pp. 76—78, pl. 3, fig. 9, pl. 6, figs. 2—4, 6, 7, pl. 12, fig. 9, pl. 14, fig. 7, pl. 15, fig. 7.

More than seventy specimens of turritellid gastropods are examined. They are divided into three morphologically different types, which are distinguished by differences in spiral cords, but are very similar to each other with respect to the other morphological characters. These three types are morphologically comparable respectively with *T. saishuensis* Yokoyama, *T. motidukii* Otuka, 1935 and *T. nipponica* Yokoyama, 1920. Here these types are called as *saishuensis*-type, *motidukii*-type and *nipponica*-type. The *motidukii*-type is numerically the most abundant, and ubiquitously occurs from the Sasaoka Formation. The *saishuensis*- and *nipponica*-types are rarer than the *motidukii*-type, and are usually associated with the *motidukii*-type. The following associations of the types can be recognized; the distribution in the Sasaoka Formation are shown in parentheses.

"*motidukii*" only (lower and middle)
"*motidukii*" + "*saishuensis*" (middle)
"*motidukii*" + "*nipponica*" (middle and upper)
"*nipponica*" (lowermost)

Kotaka (1959) examined ontogenetic change of the spiral cords and regarded the *motidukii*- and *saishuensis*-types as morphological variation within a species. The species composed of the two types are called as *saishuensis* in this paper. The *nipponica*-type associated with the *motidukii*-type perhaps represents a phenon in the species of *saishuensis*.

Locality: 2-1b (CM16229); 2-2a (CM16230); 2-5b (CM16231); 2-5d (CM16232); 4-2a (CM

16233); 4-2b (CM16234); 4-5a (CM16235); 4-5d (CM16236); 4-5f (CM16237); 11-2 (CM16238); 20-1a (CM16239); 20-1b (CM16240); 21-1 (CM 16241); 23-1 (CM16242); 24-1a (CM16243); 25-3-14 (CM16244); 25-3-34 (CM16245, CM16246); 25-3-38 (CM16247); 26-5c (CM16248); 26-5g (CM16249); 26-7c (CM16250); M13A (CM 16251).

Turritella (Neohaustator) nipponica Yokoyama, 1920
Pl. 22, Fig. 7.

Turritella nipponica Yokoyama, 1920, pp. 71, 72, pl. 4, figs. 16—19.

The taxonomic status of the samples composed only of the *nipponica*-type can not be concluded, because these samples contain only a few and poorly preserved specimens. They are tentatively called *nipponica.*

Locality: 7-8 (CM16252, CM16253).

Bittium binodulosum Yokoyama, 1920
Pl. 22, Fig. 8.

Bittium binodulosum Yokoyama, 1920, p. 68, pl. 4, fig. 8.
?Bittium yokoyamai Otuka. Sawada, 1962, pp. 46, 47, pl. 2, figs. 10, 11.
?Bittium cf. *yokoyamai* Otuka. Ogasawara, 1977, pl. 22, figs. 15, 16.

The specimens have two nodular spiral cords on the lower half of whorl and weaker two or three spirals on the upper half. These spiral cords become low and flat on the later whorls. The axial ribs are prominent and about 11 on the body whorl. The outline of the shell is somewhat cyrtoconoidal. The apical angle is about 22 degree, and the mean spire angle is about 15 degree. They well agree with the type specimen of *Bittium binodulosum.* The type specimen of the species from the Pleistocene Koshiba Formation perhaps represents an immature form.

Locality: 25-3-35 (CM16254); 26-5g (CM 16255).

Lunatia pallida (Broderip and Sowerby, 1829)
Pl. 22, Fig. 9.

Polinices pallida (Broderip and Sowerby). Oldroyd, 1927, p. 728, pl. 97, fig. 9.
Lunatia pallida (Broderip and Sowerby). Shuto, 1964, pp. 288, 289, pl. 42, fig. 12, pl. 43, figs. 4, 6—8, 11, 13.
Polinices (Euspira) pallidus (Broderip and Sowerby). Marincovich, 1977, pp. 278—281, pl. 25, figs. 1—6, 8.

Locality: Og2-3 (CM16256).

Nevertita (Glossaulax) didyma (Röding, 1798)
Pl. 22, Fig. 11.

Neverita (Glossaulax) didyma (Röding). Habe and Ito, 1965, pp. 32, 33, pl. 9, figs. 1, 2.
Glossaulax didyma (Röding). Kuroda, Habe and Oyama, 1971, p. 121, pl. 18, fig. 2.

Locality: 4-1e (CM16257).

Cryptonatica clausa (Broderip and Sowerby, 1829)
Pl. 22, Fig. 10.

Tectonatica clausa (Broderip and Sowerby). Habe and Ito, 1965, p. 30, pl. 8, fig. 4.
Natica (Cryptonatica) clausa (Broderip and Sowerby). Marincovich, 1977, pp. 410—418, pl. 41, figs. 7—10, pl. 42, figs. 1—6.

Locality: 1-2 (CM16258); 2-1a (CM16259); 2-5a (CM16260; 2-8 (CM16261); 4-1a (CM 16262); 4-1c (CM16263); 4-1e (CM16264); 4-2c (CM16265); 5-11b (CM16266); 7-6a (CM16267); 7-6e (CM16268); 7-6f (CM16269); 7-9a (CM 16270); 12-2 (CM16271); 14-2 (CM16272); 15-3 (CM16273); 16-1 (CM16274); 20-1b (CM 16275); 24-1a (CM16276); 25-2 (CM16277); 25-3-7.5 (CM16278); 25-3-34 (CM16279); 25-3-63 (CM16280); 25-3-70 (CM16281, CM 16282); 26-5c (CM16283); 26-7c (CM16284); 28-2 (CM16285); 34-1 (CM16286); Og2-1 (CM 16287); Og2-4 (CM16288).

Fusitriton oregonensis (Redfield, 1848)

Pl. 22, Fig. 12.

Fusitriton oregonensis (Redfield). Takayasu, 1962, pl. 1, figs. 26a-b; Habe and Ito, 1965, pp. 33, 34, pl. 9, figs. 5, 6.

Locality: Og2-2a (CM16289).

Trophonopsis kagaensis
(Hatai and Nisiyama, 1939)

Pl. 22, Fig. 13.

Trophon kagaensis Hatai and Nisiyama, 1939, p. 153, pl. 9, figs. 8, 9, 13, 14; Ogasawara, 1977, pl. 21, figs. 5a-b.
Trophonopsis kagaensis Hatai and Nisiyama. Kaseno and Matsuura, 1965, pl. 3, fig. 3.

Locality: 4-1b (CM16290); 4-2a (CM16291); 5-2j (CM16292); 24-1a (CM16293); 25-3-7.5 (CM16294).

Boreotrophon xestra Dall, 1918

Pl. 22, Fig. 14.

Boreotrophon xestra Dall, 1918, p. 232; Kosuge, 1972, pl. 7, fig. 6.

Locality: 5-1a (CM16295); 23-2 (CM16296); 25-3-69 (CM16297); Og2-4 (CM16298, CM 16299).

Buccinum cf. *rossicum* Dall, 1907

Pl. 23, Figs. 1, 7.

cf. *Buccinum rossicum* Dall, 1907, pp. 150, 151; Dall, 1925, p. 8, pl. 31, fig. 5; Kosuge, 1972, pl. 18, fig. 1.

Six poorly preserved specimens are examined. They are characterized by rather thin shell, inflated whorls, fine spiral grooves on the shell surface, a wide and shallow channel in front of the suture, and a weak spiral cord on the shoulder. They are very similar to *Buccinum rossicum* Dall.

Locality: 5-12b (CM16300); 7-6d (CM16301); 7-6h (CM16302); 7-10a (CM16303); 14-1 (CM 16304); 14-5b (CM16305); 34-1 (CM16306).

Plicifusus ozawai (Yokoyama, 1927)

Pl. 23, Fig. 2.

Raphitoma ozawai Yokoyama, 1927c, pp. 172, 173, pl. 47, figs. 3, 4.
?*Lora yanamii tenuis* Hatai and Nisiyama, 1939, p. 152, pl. 9, figs. 15, 16.

Locality: 4-2b (CM16307); 4-5c (CM16308).

Mohnia cf. *yanamii* (Yokoyama, 1926)

Pl. 23, Figs. 3—5.

cf. *Bela yanamii* Yokoyama, 1926b, p. 261, pl. 32, fig. 11.
Lora yanamii (Yokoyama). Nomura and Hatai, 1935, pp. 123, 124, pl. 13, fig. 2.
cf. *Mohnia* sp. Chinzei, 1959, p. 116, pl. 10, figs. 19, 20.
Mohnia yanamii (Yokoyama). Hatai, Masuda and Suzuki, 1961, pl. 3, figs. 7a-b; Takayasu, 1962, pl. 1, figs. 19a-b; Sakagami *et al.*, 1966, pl. 2, fig. 12; Honda, 1978, pl. 2, figs. 1a, b.

Twenty-six specimens were collected from four localities. Two living specimens from sandy bottom 200 m deep of Toyama Bay, the Sea of Japan are also examined for comparison.

In general outline, eight specimens from the Gojome Area (Locs. 3-1, 12-1, 34-1) agree with Yokoyama's description of *Mohnia yanamii*, but they are somewhat different from *yanamii* in number and shape of axial ribs and in prominence of spiral furrows. The specimens figured by Yokoyama (UMUT CM23085) has eighteen axial ribs on the body whorl, and three others not figured (CM23086) have 21, 20 and 17 axial ribs on the body whorl respectively. The number of the axial ribs of the specimens from the Gojome Area is about 12 on the average, ranging from 11 to 14. The Gojome specimens have more round-topped axial ribs, more obscure spiral furrows and anteriorly less narrowed siphonal canal than the typical *Mohnia yanamii*. Eighteen specimens from the Wakimoto Formation (Loc. Og2-4) also differ in number of axial ribs and in shape of the siphonal canal from the typical *yanamii*, but the other features well agree with Yokoyama's description. The number of the axial ribs of these specimens is

about 13, ranging from 12 to 15. The Wakimoto specimens have more slender axial ribs and more prominent spiral furrows than the Gojome specimens. Two living specimens from Toyama Bay (UMUT RM16654, RM16655) are very similar to the specimens from the Wakimoto Formation, but they have more slender outline than the latter. Some of the living and fossil specimens preserve protoconch. The first one turn is smooth and depressed. The succeeding half turn has smooth surface and angulate shoulder. The next one turn is ornamented by two prominent spiral cords, which are situated on the shoulder and on the periphery respectively. The axial ribs appear on the next whorl.

Locality: 3-1 (CM16309); 12-2 (CM16310); 34-1 (CM16311, CM16312); Og2-4 (CM16313, CM16314).

Neptunea intersculpta (Sowerby, 1899)

Pl. 23, Fig. 6.

Neptunea intersculpta (Sowerby). Habe and Ito, 1965, pp. 69, 70, pl. 25, fig. 4; Shikama and Masujima, 1969, pl. 5, fig. 31.

Locality: 2-8 (CM16315); 5-13a (CM16316).

Clinopegma borealis Tiba, 1969

Pl. 23, Figs. 8a, 8b.

Clinopegma borealis Tiba, 1969, pp. 135, 136, pl. 7, figs. 1—5; Tiba and Kosuge, 1982, pp. 11, 12, figs. 1—6.

Shell has an angulate shoulder forming a channel in front of suture. Siphonal canal short and twisted. Surface of the shell ornamented with very weak spiral threads and with very weak and irregular growth lines. They well coincide with *Clinopegma borealis* from Sea of Okhotsk, although they have somewhat lower spire than the living species.

Locality: 5-13a (CM16317, CM16318); 5-13c (CM16319); 14-4a (CM16320).

Nassarius (Zeuxis) siquijorensis
(A. Adams, 1852)

Pl. 22, Fig. 15.

Zeuxis caelatus (A. Adams). Kira, 1959, p. 73, pl. 28, fig. 16.
Zeuxis siquijorensis (A. Adams). Kuroda, Habe and Oyama, 1971, pp. 177, 178, pl. 48, figs. 9, 10.

Locality: 20-1a (CM16321, CM16322); 20-1b (CM16323).

Reticunassa cf. *spurca* (Gould, 1860)

Pl. 22, Figs. 16a, 16b.

Nassarius (Hinia) aff. *dominulus* (Tapparona-Canefri). Kanehara, 1940a, pl. 12, figs. 11, 12.
cf. *Reticunassa acutidentata* (Smith). Kira, 1959, p. 73, pl. 28, fig. 12.
cf. *Reticunassa spurca* (Gould). Kuroda, Habe and Oyama, 1971, pp. 175, 176, pl. 47, figs. 17—19.

The two specimens agree with *Reticunassa spurca* (Gould) in general outline, but they have somewhat smaller shell and less number of axial and spiral ribs than *spurca*. The measurement is as follows.

Specimen	1 (Loc. 4-1a)	2 (Loc. 24-1a)
Height (mm)	6.65	7.85
Maximum diameter (mm)	3.8	4.65
Spiral cords on body whorl	7	8
Spiral cords on penultimate	3	3
Axial ribs on body whorl	12	14

Locality: 4-1a (CM16324); 24-1a (CM16325).

Volutomitra alaskana Dall, 1902

Pl. 22, Fig. 17.

Volutomitra alaskana Dall. Dall, 1921, p. 87, pl. 11, fig. 3; Sakagami *et al.*, 1966, pl. 1, fig. 28; Tiba and Kosuge, 1980, pp. 3—5, figs. 1—5.
Mitra kurakiensis Hatai and Nisiyama. Takayasu, 1962, pl. 1, figs. 18a—b.

Locality: Og2-4 (CM16326, CM16327).

Admete lischkei (Yokoyama, 1926)

Pl. 22, Figs. 18a, 18b.

Cancellaria lischkei Yokoyama, 1926b, pp. 264, 265, pl. 32, figs. 16, 17.
Admete lischkei (Yokoyama). Chinzei, 1959, p. 116, pl. 10, figs. 5—7.

Locality: 12-2 (CM16328); 25-3-69 (CM 16329); 26-5g (CM16330).

Elaeocyma (Splendrillia) braunsi
(Yokoyama, 1920)

Pl. 22, Figs. 19a, 19b.

Pleurotoma (Drillia) braunsi Yokoyama, 1920, pp. 40, 41, pl. 1, figs. 25a—c.
Elaeocyma (Splendrillia) braunsi (Yokoyama). Kuroda, Habe and Oyama, 1971, p. 206,

pl. 55, fig. 10.

The specimens have opisthoclinal prominent axial ribs, which are 12 in number on the penultimate whorl, and have J-shaped distinct sinus. The first two turns are polished and somewhat heterostrophic. They are very similar to the syntype specimens of the species (UMUT CM20078—20080), although the axial ribs of the present specimens are abapically extended than the Yokoyama's specimens.
Locality: Og2-4 (CM16331, CM16332).

Paradrillia cf. *dainichiensis* (Yokoyama, 1923)

Pl. 22, Fig. 20.

cf. *Drillia dainichiensis* Yokoyama, 1923b, p. 6,

Explanation of Plate 22

Fig. 1. *Homalopoma amussitatum* (Gould), ×3, Loc. 4-2b (CM16223).

Fig. 2. *Alvania* sp., ×8, Loc. M1B (CM16224).

Fig. 3. *Microstelma* sp., ×8, Loc. 25-3-45 (CM16227).

Figs. 4—6. *Turritella (Neohaustator) saishuensis* (Yokoyama), ×1, fig. 4, "*saishuensis*"-type, Loc. 25-3-38 (CM16247); fig. 5, "*nipponica*"-type, Loc. M13A (CM16251); fig. 6, "*motidukii*"-type, Loc. 25-3-34 (CM16245).

Fig. 7. *Turritella (Neohaustator) nipponica* Yokoyama, ×1, Loc. 7-8 (CM16252).

Fig. 8. *Bittium binodulosum* Yokoyama, ×2, Loc. 25-3-35 (CM16254).

Fig. 9. *Lunatia pallida* (Broderip and Sowerby), ×1, Loc. Og2-3 (CM16256).

Fig. 10. *Cryptonatica clausa* (Broderip and Sowerby), ×1, Loc. 25-3-70 (CM16281).

Fig. 11. *Neverita (Glossaulax) didyma* (Röding), ×2, Loc. 4-1e (CM16257).

Fig. 12. *Fusitriton oregonensis* (Redfield), ×1, Loc. Og2-2a (CM16289).

Fig. 13. *Trophonopsis kagaensis* (Hatai and Nisiyama), ×1, Loc. 4-2a (CM16291).

Fig. 14. *Boreotrophon xestra* Dall, ×1, Loc. Og2-4 (CM16298).

Fig. 15. *Nassarius (Zeuxis) siquijorensis* (A. Adams), ×1.5, Loc. 20-1a (CM16321).

Figs. 16a, 16b. *Reticunassa* cf. *spurca* (Gould), ×3, Loc. 24-1a (CM16325).

Fig. 17. *Volutomitra alaskana* Dall, ×2, Loc. Og2-4 (CM16326).

Figs. 18a, 18b. *Admete lischkei* (Yokoyama), ×3, Loc. 25-3-69 (CM16329).

Figs. 19a, 19b. *Elaeocyma (Splendrillia) braunsi* (Yokoyama), ×2, Loc. Og2-4 (CM16331).

Fig. 20. *Paradrillia* cf. *dainichiensis* (Yokoyama), ×2, Loc. 5-1b (CM16333).

Fig. 21. *Antiplanes contraria* (Yokoyama), ×1.5, Loc. 25-3-38 (CM16337).

Fig. 22. *Antiplanes (Rectiplanes) sanctiioannis* (Smith), ×1, Loc. Og2-4 (CM16340).

Fig. 23. *Suavodrillia*? sp. A, ×1, Loc. 20-1a (CM16342).

Fig. 24. *Suavodrillia*? sp. B, ×3, Loc. 2-5d (CM16343).

Figs. 25, 26. *Ophiodermella pseudopannus* (Yokoyama), fig. 25, ×1.5, Loc. 25-3-35 (CM16355); fig. 26, ×3, Loc. 4-1e (CM16349).

Fig. 27. *Oenopota kagana* (Yokoyama), ×1.5, Loc. 2-1b (CM16356).

Fig. 28. *Propebela candida* (Yokoyama), ×3, Loc. 12-2 (CM16360).

Fig. 29. *Epitonium (Boreoscala) echigonum* Kanehara, ×1.5, Loc. 5-2j (CM16369).

Fig. 30. *Turbonilla (Ptycheulimella) inscitula* Yokoyama, ×3, Loc. 25-4 (CM16373).
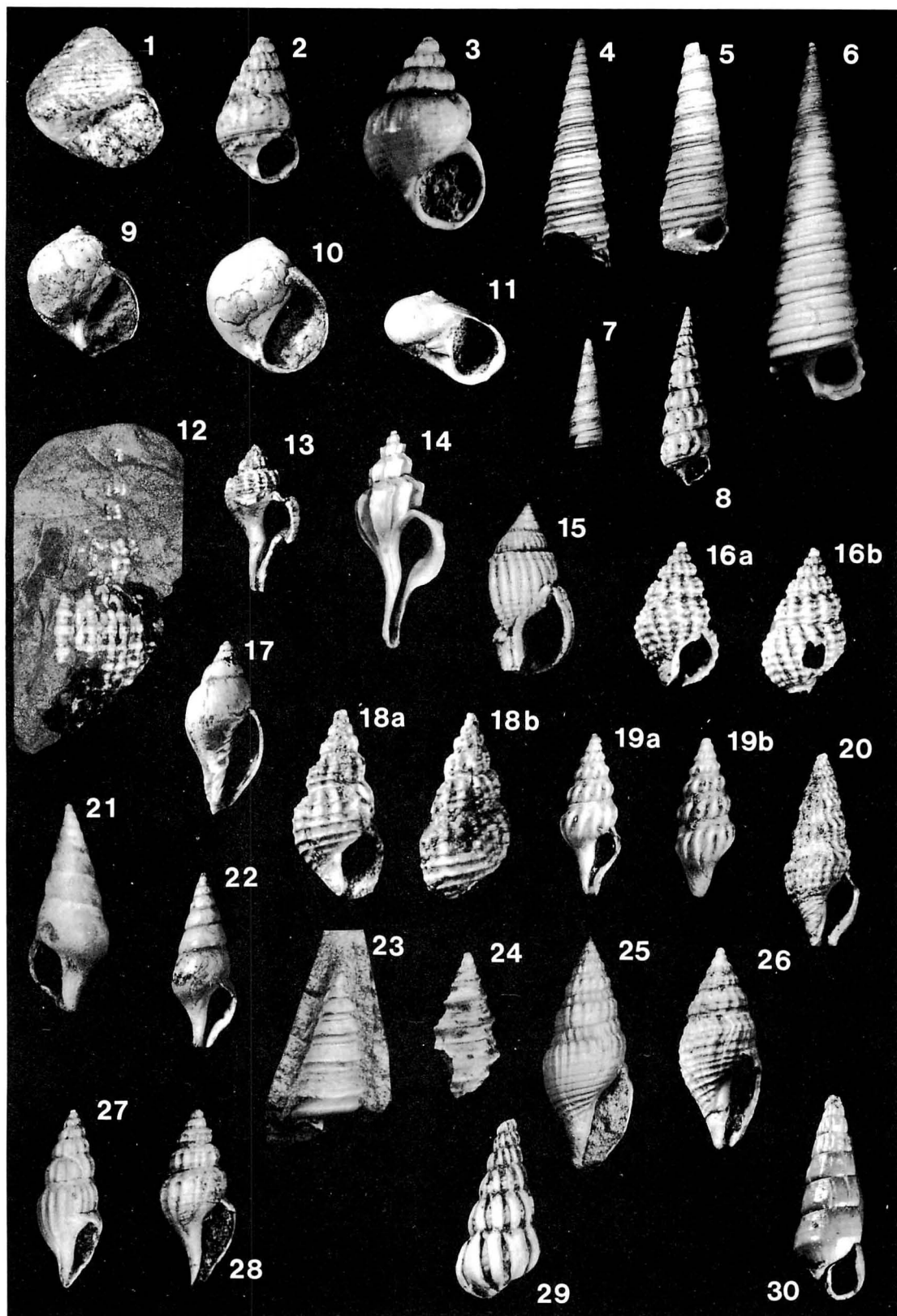
pl. 1, fig. 2.

cf. *Clavatula patruelis dainichiensis* (Yokoyama). Makiyama, 1927, pp. 102, 103, pl. 4, figs. 14, 15.

Clavatula dainichiensis (Yokoyama). Kanehara, 1940a, pp. 131—133, pl. 12, figs. 1—10.

cf. *Clavatula (Paradrillia) dainichiensis* (Yokoyama). Makiyama, 1940, pp. 133, 134.

Clavatula (Paradrillia) dainichiensis (Yokoyama). Hatai, Masuda and Suzuki, 1961, pl. 3, figs. 4a—b.

Paradrillia dainichiensis (Yokoyama). Kaseno and Matsuura, 1965, pl. 5, fig. 4.

cf. *Paradrillia dainichiensis* (Yokoyama). Powell, 1969, p. 316, pl. 244, figs. 1—3.

The specimen is very similar to *Paradrillia dainichiensis* (Yokoyama), although some minor differences are found in surface sculptures. The syntype specimens of *dainichiensis* (UMUT CM21736, 21737) have thirteen to fifteen nodes on the shoulder of the penultimate whorl, and axial ribs below the shoulder are twice as many as the nodes. On the penultimate whorl of the present specimen both the nodes and ribs are fifteen in number. Some authors applied the name of *dainichiensis* to Plio-Pleistocene specimens from northeast Japan. They are identical with the present specimen. A living specimen from Sagami Bay (Powell, 1969, pl. 244, fig. 3) is typical *dainichiensis*.

Locality: 5-1b (CM16333).

Antiplanes contraria (Yokoyama, 1926)

Pl. 22, Fig. 21.

Pleurotoma contraria Yokoyama, 1926c, p. 383, pl. 44, figs. 2a—b.

Antiplanes contraria (Yokoyama). Itoigawa, 1958, pl. 2, fig. 15; Habe and Ito, 1965, p. 83, pl. 30, fig. 26.

Locality: 2-2b (CM16334); 4-2b (CM16335); 8-1 (CM16336); 25-3-38 (CM16337); Og2-4 (CM16338).

Antiplanes (Rectiplanes) sanctiioannis (Smith, 1875)

Pl. 22, Fig. 22.

Pleurotoma (_____?) Sancti-Ioannis Smith, 1875, pp. 416, 417.

Pleurotoma sadoensis Yokoyama, 1926b, p. 259, pl. 32, fig. 3.

Antiplanes (Rectiplanes) sadoensis (Yokoyama). Chinzei, 1959, pp. 117, 118, pl. 9, figs. 6, 7.

Rectiplanes sanctioannis [sic] (Smith). Takayasu, 1962, pl. 1, figs. 23a—b.

Rectiplanes sanctaioannis [sic] (Smith). Habe and Ito, 1965, p. 83, pl. 30, fig. 28.

Locality: 7-6b (CM16339); Og2-4 (CM16340, CM16341).

Suavodrillia? sp. A

Pl. 22, Fig. 23.

A specimen without body whorl was examined. It has high spire, a strong carina, one or more strong spiral cords below the carina and two very low and wide spiral cords between the upper suture and carina. It is somewhat similar to *Suavodrillia declivis*, but it has stronger carina and spiral cords than the species.

Locality: 20-1a (CM16342).

Suavodrillia? sp. B

Pl. 22, Fig. 24.

Two broken specimens were examined. They are characterized by a strong carina being more prominent than that of *Suavodrillia* sp. A. There are a spiral cord above the carina and strong two or more cords below the carina. They are similar to *S. kennicottii* (Dall, 1871) and *S. oyamai* Chinzei, 1959, but they have the stronger spiral cords above the carina than the two species.

Locality: 2-5d (CM16343); 4-5g (CM16344).

Ophiodermella pseudopannus (Yokoyama, 1922)

Pl. 22, Figs. 25, 26.

Genotia pseudopannus Yokoyama, 1922, pp. 37, 38, pl. 1, figs. 27, 28; Yokoyama, 1926b, p. 260, pl. 32, fig. 2.

The specimens are ornamented with two spiral grooves narrower than the interspace between the shoulder and lower suture, and by very

fine numerous spiral cords above the shoulder. Axial ribs are about 20 on the penultimate whorl, and become obscure on the later whorls of the larger specimens. They well agree with Yokoyama's description. Some of the specimens show variation of the spiral ornamentation and shell outline. Three specimens from Locs. 4-1e; 21-1; 25-2 have spiral grooves wider than the interspace (Pl. 22, fig. 26). Five specimens from Loc. 4-1b show variation of the spiral orna-mentation, ranging from fine grooves to grooves wider than the interspace. The other specimen from Loc. 21-1 has spiral grooves narrower than the interspaces, which are secondary grooved. Height of spire and shape of body whorl also varies. Pl. 22, fig. 25 shows typical outline, and Pl. 22, fig. 26 exhibits lower spire, less inflated whorl and less narrowed siphonal canal anteriorly.

Locality: 2-1a (CM16345); 4-1b (CM16346); 4-1c (CM16347); 4-1d (CM16348); 4-1e (CM16349); 4-2a (CM16350); 4-2b (CM16351); 21-1 (CM16352); 25-1 (CM16353); 25-2 (CM16354); 25-3-35 (CM16355).

Oenopota kagana (Yokoyama, 1927)

Pl. 22, Fig. 27.

Bela kagana Yokoyama, 1927c, p. 172, pl. 47, fig. 2.

Locality: 2-1b (CM16356); 4-2b (CM16357).

Propebela candida (Yokoyama, 1926)

Pl. 22, Fig. 28.

Bela candida Yokoyama, 1926b, pp. 261, 262, pl. 34, fig. 1.
Bela candida var. *angulata* Yokoyama, 1926b, p. 262, pl. 34, fig. 2.

Locality: 2-1a (CM16358); 5-13b (CM16359); 12-2 (CM16360, CM16361); 14-4c (CM16362); 16-1 (CM16363); 25-3-30 (CM16364); 26-5g (CM16365); 28-1a (CM16366); 34-1 (CM16367).

Epitonium (Boreoscala) echigonum Kanehara, 1940

Pl. 22, Fig. 29.

Epitonium (Boreoscala) yabei echigonum Kane-hara [MS], 1940a, pl. 12, figs. 13—16, (March 31, 1940).
Epitonium (Boreoscala) yabei var. *echigonum* Kanehara, 1940b, pp. 14—16, pl. 4, figs. 6a—b (October 5, 1940).
Epittonium [sic] *(Boreoscala) yabei echigonum* Kanehara. Kaseno and Matsuura, 1965, pl. 2, fig. 6.

Locality: 4-2a (CM16368); 5-2j (CM16369).

Turbonilla (Ptycheulimella) inscitula Yokoyama, 1927

Pl. 22, Fig. 30.

Turbonilla (Ptycheulimella) inscitula Yokoyama, 1927c, p. 176, pl. 47, figs. 15, 16.

Locality: 4-5g (CM16370); 23-2 (CM16371); 25-3-65 (CM16372); 25-4 (CM16373).

Striodentalium rhabdotum (Pilsbry, 1905)

Explanation of Plate 23

Figs. 1, 7. *Buccinum* cf. *rossicum* Dall, x1, fig. 1, Loc. 34-1 (CM16306); fig. 7, Loc. 7-6h (CM16302).

Fig. 2. *Plicifusus ozawai* (Yokoyama), x1.5, Loc. 4-5c (CM16308).

Figs. 3, 4, 5. *Mohnia* cf. *yanamii* (Yokoyama), x1.5, fig. 3, Loc. 34-1 (CM16311); fig. 4, Loc. Og2-4 (CM16313); fig. 5, Toyama Bay, KT-79-5, St. I-15D (RM16654).

Fig. 6. *Neptunea intersculpta* (Sowerby), x1, Loc. 5-13a (CM16316).

Figs. 8a, 8b. *Clinopegma borealis* Tiba, x1, Loc. 5-13a (CM16317).

Fig. 9. *Striodentalium rhabdotum* (Pilsbry), x2, Loc. Og2-4 (CM16376).

Fig. 10. *Siphonodentalium* sp. A, x4, Loc. 34-1 (CM16386).

Fig. 11. *Siphonodentalium* sp. B, x2, Loc. 20-1b (CM16389).

Plate 23
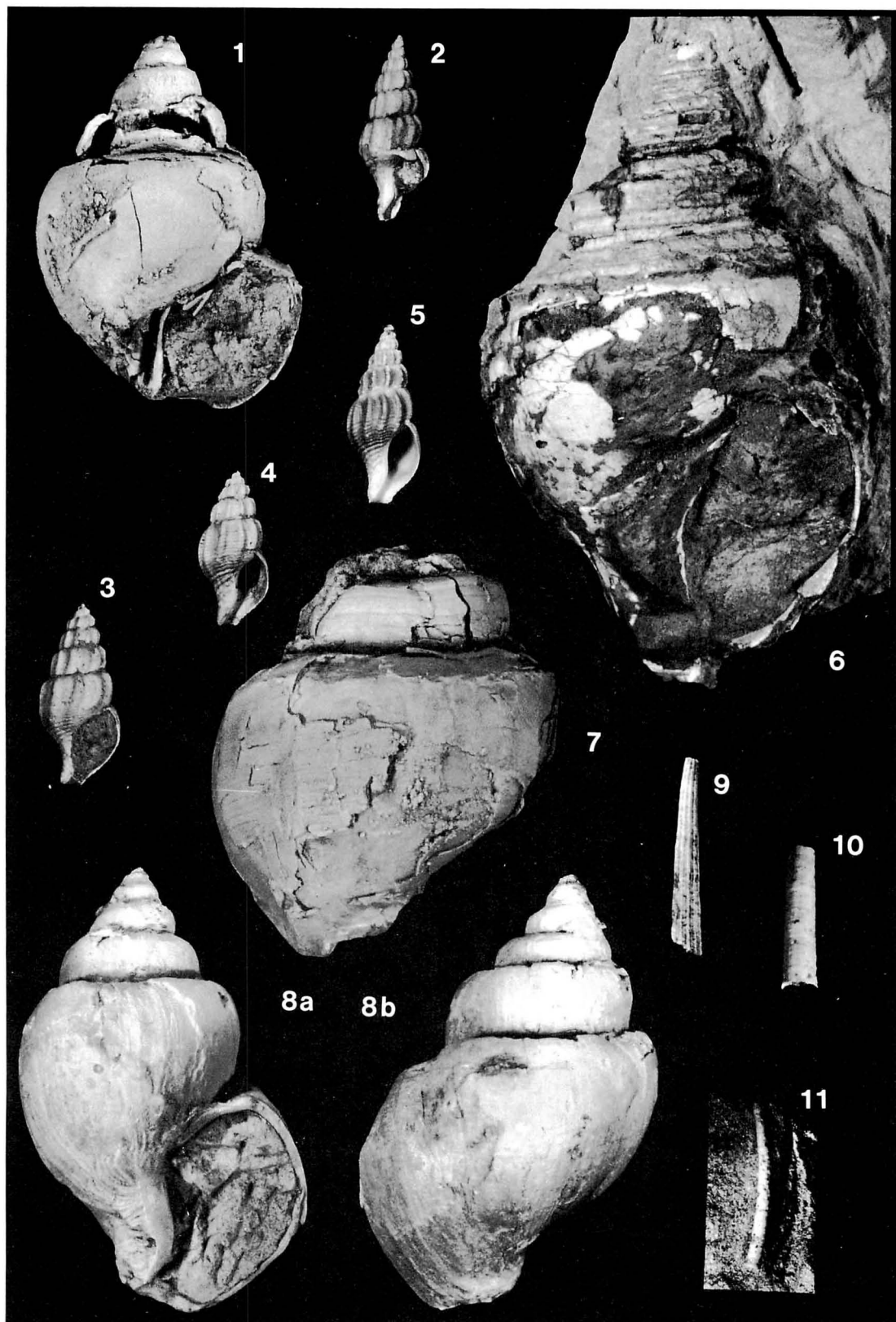
Pl. 23, Fig. 9.

Striodentalium rhabdotum (Pilsbry). Habe, 1964, p. 22, pl. 2, figs. 17, 18.

Locality: 20-1a (CM16374); 20-1b(CM16375); Og2-4 (CM16376, CM16377).

Siphonodentalium sp. A

Pl. 23, Fig. 10.

Many broken specimens are examined. Shell curved, slightly tapering to apex, circular in section. The apex seems simple, although poor preservation of the apical part prevents the precise decision. Surface ornamented with growth lines and one to three longitudinal weak and fine grooves. The growth lines curve to the apex around the ventral side.

Locality: 5-13c (CM16378); 7-1 (CM16379); 14-1 (CM16380); 14-5b (CM16381); 17-1 (CM16382); 23-3 (CM16383); 25-4 (CM16384); 28-2 (CM16385); 34-1 (CM16386, CM16387); Og2-2a (CM16388).

Siphonodentalium sp. B

Pl. 23, Fig. 11.

A few fragmental materials are examined. They are similar to *Siphonodentalium* sp. A, but the growth lines do not curved to the apex around the ventral margin.

Locality: 20-1b (CM16389, CM16390).

Akita 秋田　　Funakawa 船川　　Gojome 五城目　　Hokkaido 北海道　　Kakegawa 掛川
Kitaura 北浦　　Machimura 町村　　Manganji 万願寺　　Minamizawa 南沢　　Nishikurosawa
西黒沢　　Odai 大台　　Oga 男鹿　　Omma 大桑　　Onnagawa 女川　　Sasaoka 笹岡　　Sodeno-
sawa 袖ノ沢　　Tatsunokuchi 竜ノ口　　Tentokuji 天徳寺　　Terasawa 寺沢　　Tofuiwa 豆腐岩
Tomita 富田　　Wakimoto 脇本

　　五城目―男鹿地域の大桑―万願寺動物群の貝化石群集：秋田市北方の五城目―男鹿地域に
分布する鮮新―下部更新統中の貝化石の分布が，どのような環境要因に規制されているかを検
討した。貝化石の多くは自生～準自生と考えられるもので，それらは6つの群集に分けられる。
各群集は地層中で層序的，岩相的に異なった部分にあらわれ，水深及び底質と次のような関連
をもって分布していたと推定される。すなわち *Palliolum* 群集は最も深いタービダイトの堆
積するような海盆の底にあらわれ，*Nuculana* 群集は次に深いシルト質の部分を占めていた。
Acila-Turritella 群集は *Nuculana* 群集より浅く，またより粗粒なシルト～細粒砂底に生息
した。*Macoma tokyoensis* 群集と *Protothaca* 群集は密接に伴なってあらわれ，共に最も浅
い細粒砂の部分を占めていた。*Thyasira bisecta* 群集は様々な層準と岩相に出現し，広い環
境耐性をもっていたらしい。*Acila-Turritella* 群集のなかで *Acila nakazimai* と *Turritella
saishuensis* は稀にしか共存せず，層序的に交互に産出する。この2種の産状と浮遊性有孔虫
の *Neogloboquadrina pachyderma* の巻き方向には関連があり，2種の交互の出現は気候変
化による海水準変動に規制されていたらしい。32種の腹足類と3種の掘足類を記載した。
　　　　　　　　　　　　　　　　　　　　　　　　　　　　　　　　　　　　松居誠一郎

[to be continued]

800. PLIOCENE FRESHWATER GASTROPODS FROM THE IGA FORMATION OF THE KOBIWAKO GROUP, MIE PREFECTURE, CENTRAL JAPAN

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Abstract.   The Pliocene Iga Formation of the Kobiwako Group of the Ueno Basin and the Ayama Hills in Mie Prefecture, central Japan contains abundant remains of viviparid and pleurocerid gastropods. Taxonomic examination of these gastropods results in recognition of one new genus and four species including three new species. *Igapaludina stricta* (Araki), n. gen., *Bellamya suzukii*, n. sp., *Tulotomoides sanaguensis*, n. sp., and *Semisulcospira (Biwamelania) praemultigranosa*, n. sp. are described herein. The subgeneric name *Biwamelania* is redefined.

Introduction

The Pliocene Iga Formation is the lower part of the Kobiwako Group, and is distributed mainly over the Ueno Basin and the Ayama Hills in Mie Prefecture, central Japan. This formation consists of lacustrine and fluvial sediments deposited in the ancient lake, Paleo-lake Iga (Okuyama, 1981c) and its marginal area, and contains an abundant and diversified molluscan fauna associated with diatoms, sponges, fish, tortoises, and crocodiles.

Since Nakamura (1925) first reported the occurrence of fossil molluscs in the Iga Formation, the molluscan remains have been treated geologically and paleontologically in several publications (Nakagawa, 1948; Takaya, 1963; Kondo, 1968; Yokoyama, 1969; Okuyama, 1981a, b, 1983, 1984; Matsuoka, 1983a; Tamura et al., 1984), but no attempt has been made to describe them in detail.

Molluscs collected from the Iga Formation are well preserved and show high diversity compared with molluscan fossils from other

known Pliocene freshwater deposits of Japan. These molluscs seem to constitute a representative of the Pliocene non-marine fauna of Japan, and moreover they are good material to fill a large gap in knowledge of the freshwater molluscan fauna between the Miocene and the Recent. Large collections of molluscs were made at five localities shown in Text-fig. 1.

The purpose of the present study is to describe four species including three new species and one new genus from the Ohyamada area and the Sanagu area where the Iga Formation is widely distributed: *Igapaludina stricta* (Araki), n. gen., *Bellamya suzukii*, n. sp., *Tulotomoides sanaguensis*, n. sp., and *Semisulcospira (Biwamelania) praemultigranosa*, n. sp.

This is one of the series of papers describing invertebrate fossils from the Kobiwako Group.

Stratigraphy and occurrence

Stratigraphic studies on the Pliocene Iga Formation have been made by Takaya (1963), Kondo (1968), Yokoyama (1969), Yokoyama et al. (1980, 1982), Kawabe (1981), and Okuyama (1981c). The Iga Formation unconform-
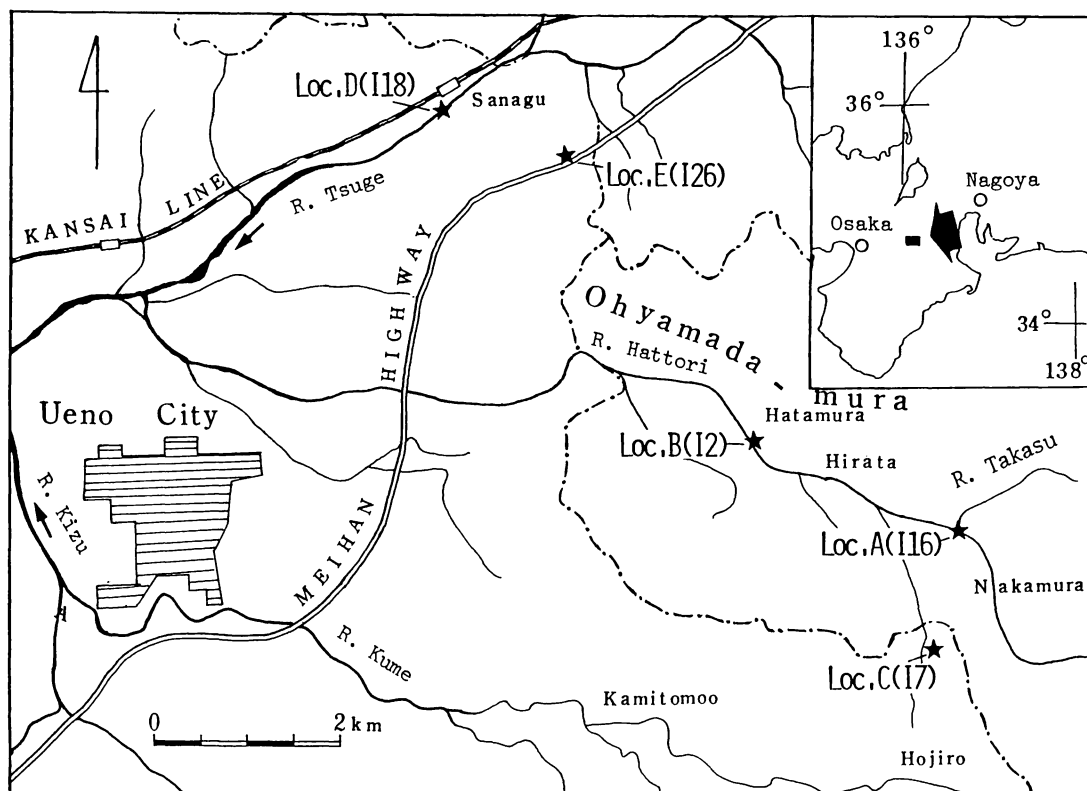
Text-fig. 1. Index map of sample localities in the Ueno Basin and Ayama Hills.

ably rests on the basement of the Ryoke metamorphic rocks and is overlain conformably by the Koka Formation or unconformably by Quaternay terrace depposits. The stratigraphy of the Ohyamada and Sanagu areas, eastern and northeastern parts of the Iga tectonic basin (Kondo, 1968), was studied in full by Yokoyama *et al.* (1980). They divided the Iga Formation into three lithological units, Ohyamada clays, Kashikimura sands, and Aitagawa alternations, in ascending order, and it has a total thickness of about 300 meters. Among the several volcanic ash layers intercalated in the Ohyamada clays, the Hattorigawa (abbr., Hattori) II volcanic ash layer was dated to be 4.6 Ma B.P. by the fission track method (Yokoyama *et al.*, 1980). The common occurrence of the elements of the *Metasequoia* and *Pinus trifolia* floras, such as *Glyptostrobus, Sequoia, Fagus, Liquidambar, Nyssa,* and *Carya,* has been reported from the Ohyamada area by Miki (1948)

and Shimakura (1966). The occurrence of *Stegodon* cf. *elephantoides* (Clift) has been known from the two localities of the Iga Formation (Yokoyama *et al.,* 1980; Kawaguchi, 1984). Paleontological evidences mentioned above give support to the fission track age which suggests an Early Pliocene age.

The columnar sections at the localities A to E from which molluscan specimens were collected are shown in Text-fig. 2.

Locality A(I16): Blueish gray and massive-bedded silts exposed on the confluence of the Hattori and Takasu Rivers, Hirata, Ohyamada, Ayama-gun, Mie Prefecture (lat. $34°45'34''$ N, long. $136°13'30''$ E).

The fossiliferous silts exposed at this locality are stratigraphically situated over the horizon of the Nakamura volcanic ash layer (Yokoyama *et al.,* 1980) intercalated in the lower part of the Ohyamada clays. Fossils are abundant on the bedding, but are sparse within the bed. Molluscs
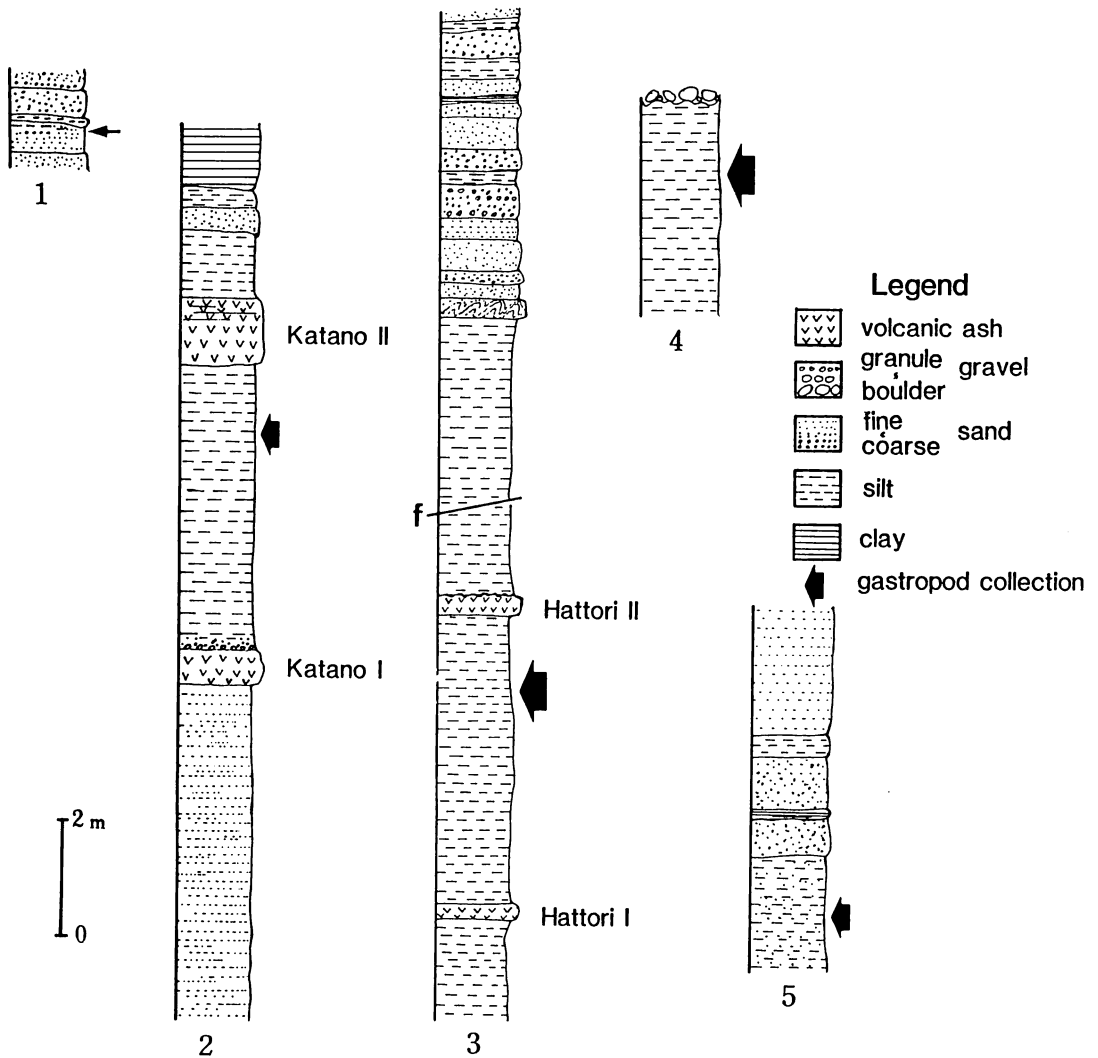
Text-fig. 2. Columnar sections at the fossiliferous exposures in the Ueno Basin and Ayama Hills.
1: Loc. D(I18), 2: Loc. E(I26). 3: Loc. B(I2), 4: Loc. A(I16), 5: Loc. C(I7), f: fault.

collected is composed of *Igapaludina stricta*, *Semisulcospira* (*Biwamelania*) *praemultigranosa*, *Unio* (*Nodularia*) sp., *Cuneopsis* sp., *Lamprotula* sp., and *Anodonta* sp. This molluscan assemblage includes numerous and excellently preserved juvenile to adult forms of *Igapaludina stricta*, and other species are present in small numbers. Many unionid bivalves are preserved with a disarticulated valve or a broken shell. Other fossils are cyprinid pharyngeal teeth, bones

and spines, and spongillid sponges adhering to the surface of molluscs.

Locality B(I2): Blueish gray silt on the north side of the Hattori River at Hatamura, Ohyamada-mura, Ayama-gun, Mie Prefecture (lat. 34°46′ N, long. 136°12′7″ E).

At this locality, light gray silts of the Oh-yamada clays are exposed on the north side of the Hattori River, and the fossiliferous sediments rest conformably on the Hattorigawa I volcanic

ash layer and in turn are conformably overlain by the Hattorigawa II volcanic ash layer. The present beds yielded the following species of molluscs, *Igapaludina stricta, Bellamya suzukii, Semisulcospira (Biwamelania) praemultigranosa, Inversidens* spp., *Cuneopsis* sp. 1, *Cuneopsis* sp. 2, *Unio (Nodularia)* sp. 1, *Psilunio* sp., *Unionetta* sp., and *Anodonta* sp. in addition to some cyprinid fishes as spines, pharyngeal teeth, scales and bones, imperfectly preserved plant leaves, and sponges. This molluscan assemblage is characterized by *Igapaludina stricta* that is smaller in size than that from the Locality A(I16). The shells are represented entirely by molds and casts, and are compressed by pressure in the process of fossilization.

From this locality, Okuyama (1981a, b; 1983; 1984) photographically illustrated fossil plant remains, cyprinid pharyngeal teeth, scales, spines and bones, molluscs, trionychid turtles, and crocodilian teeth.

Yokoyama *et al.* (1980) noted the occurrence of *Stegodon* cf. *elephantoides* nearby the pond of Midoro approximately 750 meters southsouthwest of the present locality.

Locality C(I7): Small exposure approximately two kilometes north of Hojiro, Ueno City, Mie Prefecture (lat. 34°44'50″ N, long. 136°13'20″ E).

Fossil molluscs were collected from ill-sorted silty sands including mica fragments near the base of the section. The fossil-bearing bed is of the Takayama bed (Yokoyama *et al.*, 1980) which is equivalent to a marginal facies of the Ohyamada clays. The molluscan assemblage is characterized by *Bellamya suzukii* and a few *Semisulcospira (Biwamelania)* sp. and *"Unio"* sp. are also present. The calcareous matter of the molluscan shell was partly replaced by ferriferous material, but most of the remains are imperfectly preserved and are more or less deformed by postmortem compression. Other fossils diatoms, spongillid sponges, pharyngeal teeth and bones of cyprinid fishes, *"Xenocypris"* sp. and *Carassius* sp. are included.

Tanaka and Matsuoka (1983) reported the freshwater diatoms of 10 taxa from the present locality. Also they stated that the silty sands including diatoms contain marine silicoflagellate fossils derived from the Miocene strata.

Locality D(I18): Southwest side of the Tsuge River, 150 meters downstream of the Toyama-bashi, Toyama, Sanagu-cho, Ueno City, Mie Prefecture (lat. 34°47'53″ N, long. 136°9' 53″ E).

This locality may be younger or about the same age as the locality E(I26), and is the stratigraphic position is the upper part of the Kashikimura sands. The poorly sorted silty sands which contain plant fragments, sponges attaching to *Tulotomoides sanaguensis*, pharyngeal teeth of *Carassius* are probably of fluvial origin. The molluscan assemblage is rich in *Tulotomoides sanaguensis*, and is common or rare in *Semisulcospira (Biwamelania)* sp., *Inversidens* sp., *Anodonta* sp., and *Corbicula* sp. The shells are in a poor state of preservation, like McAlester's (1962) "composite mold", and were distorted by pressure in the process of fossilization. The fossiliferous ill-sorted sands are overlain by the yellowish gray colored and coarse to medium grained sands about 50 centimeters thick, which yield unionid bivalves, *Anodonta* sp., *"Inversidens"* sp., and plant leaves.

Locality E(I26): Cliff to the south of Goyo Paper Co. Ltd., Sanagu-cho, Ueno City, Mie Prefecture (lat. 34°47'39″N, long. 136°10'45″ E).

At this locality, the Kashikimura sands are composed chiefly of well-sorted fine grained sands, two volcanic ash layers, namely lower Katano I and upper Katano II, and blackish gray colored massive silts with quartz grains. The stratigraphic position yielding fossil molluscs is about one meter below the Katano II volcanic ash layer. This molluscan assemblage is predominantly of *Tulotomoides sanaguensis*. These viviparid specimens were much deformed by post-mortem compression, and are now in poor state of preservation. Among other fossils are plant fragments and spongillid sponges attaching to the shell surface of *T. sanaguensis*.

Systematic paleontology

Specimens used for this study are deposited in the molluscan collections of the Department of Earth Sciences, Nagoya University (ESN) and of the Mizunami Fossil Museum, Mizunami City, Gifu Prefecture (MFM).

Class Gastropoda

Order Mesogastropoda

Family Viviparidae Gray, 1847

Subfamily Bellaminae Rohrbach, 1937

Genus *Igapaludina*, nov. gen.

Type species:—*Viviparus stricta* Araki, by present designation. Pliocene Wakebe Formation of the Agé Group, Kambe, Tsu City, Mie Prefecture, central Japan.

Derivation of name:—From Iga, the old place-name of the Ueno City area and *paludina* (Latin), feminine.

Diagnosis:—Shell medium to large, broadly conic, with elevated spire. In the early stage of growth, the shell subglobose, with rounded periphery; the embryonic shell somewhat depressed but the first whorl submammillated. The embryonic shell marked by two or more spiral ridges with their intercostal fine spiral lines and faint growth ones, but at late stage of growth, the shell generally sculptured by only growth lines. The later whorls having wide shoulder with step-like ramp anterior to the suture, rounded periphery, and whorl side almost flat or slightly concave.

Discussion:—The viviparid genera which appear to be related to the new genus *Igapaludina* are as follows:
Heterogen Annandale, *Idiopoma* Pilsbry, *Tulotomoides* Wenz, and *Tulotoma* Haldeman.

Heterogen is separable from the genus *Igapaludina* by some differences, namely that it has flattened whorl side oblique to the shell axis and the embryonic shell is subcylindrical, with a spiral rib anterior to the suture, and with a subangular periphery. In *Igapaludina*, the whorl side is flat or slightly concave, being subparallel to the shell axis, and the embryonic

shell is subglobose, with a rounded periphery. The shape of the embryonic shell of *Idiopoma* has an obtuse angle at the apex, and the whorl side is rounded as in *Igapaludina*. This new genus can be distinguished from *Idiopoma* by having the larger shell and wide shoulder in front of the suture. The Recent species belonging to *Tulotoma* Haldeman have a solid shell with nodulous spiral ridges. Their distribution is restricted to the Alabama River and its tributaries in North America. The fossil forms from eastern Europe and Asia Minor, however, do not have tuberculated sculptures, therefore the fossil *Tulotoma* resembles *Igapaludina* in shell-shape, especially in that of the body whorl. *Igapaludina* is similar to the extinct genus *Tulotomoides*, which has an elongately to broadly conic shell with shouldered whorl, and with whorl side nearly vertical below the shoulder. It is distinguished from *Tulotomoides* by possessing a larger embryonic shell, the absence of spiral lines on the whorl surface and a spiral ridge anterior to the suture.

Igapaludina stricta (Araki)

Pl. 24, Figs. 1, 2; Pl. 25, Figs. 1a—15b;
Pl. 26, Figs. 1—5b.

Viviparus strictus Araki, 1960, *Bull. Lib. Arts Dep., Mie Univ., Spec. Vol.*, no. 1, p. 106—107, pl. 9, fig. 8. (holotype), type lost (personal communication, Y. Araki).

Type locality:—Road side cliff in eastern part of Kambe, Tsu City, Mie Prefecture, central Japan (lat. 34°42'21"N, long. 136°29'12"E). Wakebe Formation, Agé Group. Pliocene.

Original description (Araki, 1960):—"Many specimens which are preserved as moulds and casts are in the collection from the lake deposits of the Agé Group. These specimens all have well defined sutures, rather straight whorl profile, more or less orbicular aperture, their whorls are rather sharply defined from the basal part by an obscure angularity marking the lower part of the body whorl above the base. The columella is almost straight but slightly curved. The shell sculpture consists of obscure, slightly oblique,

longitudinal striae becoming more or less sigmoidal near their shoulders which is rather buldging before passing into the defined suture separating the respective whorls from one another. The younger whorls are missing in all of the specimens probably due to decollation.

The present specimens have been compared with the fossil fresh-water gastropods hitherto reported from the Tertiary deposits of Japan, but they all differ and therefore are considered to represent a new species, for which the name of *Viviparus strictus* Araki, n. sp., is proposed, the name indicating that the specimens are strict in their shape."

Material studied:—There are 66 specimens from Hirata (Loc. A(I16)) and 5 from Hatamura (Loc. B(I2)). ESN 40029—40031, 40034, 40040, 40042, 40057, 40058, 40060; MFM 110010, 110012, 110013, 111014, 111017, 111022, 111023, 111031, 111034, 111035, 111056—58.

Diagnosis:—Shell medium to large, broadly conic in outline, having an elevated spire. The embryonic shell subglobose, with an inflated whorl. The postembryonic shell having wide shoulder on the whorl with advancing growth stage, and the whorl side almost flat, nearly vertical below the shoulder.

Supplementary description:—Shell medium to large, up to about 44 mm long, moderately thick, broadly conic; the spire elevated consisting of about four whorls, comprising about two-fifths of the height in a little corroded specimens; the apical angle 40 to 50 degrees. The embryonic shell subglobose, 2.5 to 3.0 whorls, low spire with rounded periphery, and being not sharply separated from the postembryonic shell; the first whorl, small, submammilated. The surface of the test smooth, but having several microscopic spiral lines and faint growth striae. The microscopic ornamentation sometimes increasing in prominence. The embryonic shell and early whorls of the spire generally corroded. The postembryonic shell increasing in size regularly; the whorl side flat or slightly concave, and having a wide shoulder anterior to the suture. At adult stage of growth, the shoulder of the body whorl 3 to 3.5 mm in

width, and the upper surface undulated near the groove of rest marks. The surface of the postembryonic shell ornamented by fine growth lines and their rest marks at irregular intervals. The rest marks more strongly impressed than the growth lines. In younger specimens, weak spiral carinae occasionally present on the whorls. Suture narrow, distinctly impressed, but sometimes becoming wide like groove. Aperture pyriform, broadly rounded anteriorly and narrowed posteriorly. Outer lip thin, Columellar lip oblique, completely sealing the umbilicus. Operculum corneous, thin, concentric, pyriform; the outer margin curved through a greater arc, and terminating at the posterior edge, the outer and inner margins forming approximately 80 degrees; the inner edge situated at about two-fifths of the operculum length; the basal margin well-rounded. The exterior surface slightly concave, with irregularly concentric lines; the nucleus apparently amorphous, situated about half of the distance from the base to the summit and drown near the inner margin.

Discussion:—The fossil viviparid gastropod has been known to occur abundantly in Ohyamada-mura, Ayama-gun, Mie Prefecture. The viviparid gastropod has been assigned to *Viviparus* sp., *Sinotaia* sp., and *Heterogen longispira* (Smith) by Nakagawa (1948), Takaya (1963), Kondo (1968), Yokoyama (1969), and Yokoyama *et al.* (1980). Certainly, the wide shoulder and flattened whorl side of *Heterogen longispira*, an endemic species in Lake Biwa, has a similarity to *Igapaludina stricta* from the Iga Formation. This species differs from it in having slender body whorl, flat and vertical whorl side, rounded periphery, and subglobose embryonic shell. *Tulotoma abchasica* from the Pliocene of Abhazu, south U.S.S.R., originally assigned to *Viviparus* by Taboyakova (1964) and *Viviparus argesiensis* from the Pliocene (Daz stage) in Rumania by Wenz (1942), resemble *Igapaludina stricta* in having smooth surface except for growth lines, wide shoulder, and round periphery. It differs from the latter in possessing a smaller embryonic shell, lower spire and perforate

umbilicus. *Igapaludina stricta* shows particularly close resemblance to *Viviparus margaryaeformis* from the Pliocene of Mongtze, Yunnan in China, (Mansuy, 1918). *V. margaryaeformis* has a broader shell outline, rounded convex whorls, and ill-defined shoulder (personal communication, Pan Huayhang), but *Igapaludina stricta* has a slender shell, flattened whorl side, and wide shoulder on the whorls. Yen (1943a) mentioned that *V. margaryaeformis* appears to be closely related to the form of *Bellamya quadrata* (Benson). Mansuy's *margaryaeformis* has hitherto been referred to the genus *Viviparus* or "*Viviparus*" (Yen, 1943b; Yü *et al.*, 1963), but it can be assigned to this new genus. *Margarya melanioides obsoleta* from the Pleistocene of Yunnan (Dautzenberg and Fischer, 1905) resembles *Igapaludina stricta* in having shouldered whorls, and almost flattened whorl side, but it differs from the latter by the presence of a more turreted spire and subconic embryonic shell. *Igapaludina stricta* resembles *Idiopoma chutsingensis* and *I. tingi* from the Pliocene of Yunnan (Yen, 1935) in outline of the embryonic shell, but differs from the latter two in having the wide shoulder and flattened whorl side.

Measurements (in mm):

	H	W	BH	AH	AA
ESN 40029	38.7	24.4	26.1	18.0	50°
ESN 40030	37.7	21.9	25.7	18.0	40°
ESN 40031	38.6	20.2	25.7	17.4	41°
ESN 40032	41.6	23.8	28.8	20.5	49°
ESN 40033	35.8	21.2	24.8	17.7	44°
ESN 40034	40.0	24.4	28.5	18.0	46°
MFM 110009	38.0	22.0	27.6	18.0	48°
MFM 110010	34.3	20.2	25.0	17.2	47°
MFM 110011	40.2	25.2	29.5	20.3	51°
MFM 111006	31.0	19.5	22.2	15.5	53°
MFM 111007	36.1	20.2	24.8	18.0	46°
MFM 111009	35.9	22.8	27.3	18.0	47°
ESN 40036	29.2	18.0	22.0	15.9	45°

H = height; W = width; BH = height of body whorl; AH = height of aperture; AA = apical angle.

Genus *Bellamya* Jousseaume, 1886

Type species:—*Bellamya bellamya* Jousseaume, by original designation. Recent. Senegal, west Africa.

Geologic range:—Jurassic to Recent.

Discussion:—The genus *Bellamya* is inhabited widely in rivers and lakes of central and west Africa, and Southeast Asia. The shell characterized by medium, ovately conic, with rounded or convex whorl; the body whorl enlarged, with a rounded or subangular periphery; the umbilicus narrowly perforate; the aperture is ovate, and the outer lip is thin, with rounded margin.

Among the Tertiary viviparid gastropods from Japan, *Viviparus uryuensis* Yokoyama from the Oligocene Uryu Group, *V. mabutii* Suzuki from the Oligocene Ishikari Group, and *V. kosasanus* Ueji from the Miocene Nojima Group may belong to *Bellamya*. Oyama *et al.* (1960) placed *V. uryuensis* and *V. mabutii* in *Bellamya* (*Sinotaia*). The subgenus *Sinotaia* was established for the Recent Chinese species which is characterized by elongate conic, solid shell with thick columellar lip, and conspicuous carinae on whorls at the young and adult stages. The type species is *Paludina quadrata* Benson. Some of the Recent Chinese species and Prashad's (1928) *Vivipari dissimiles* group have been assigned to *Bellamya* by Yen (1943b), and *Sinotaia* has been regarded as a junior synonym of *Bellamya*. Brandt (1974), Pace (1973) and Popova (1980), however, considered *Sinotaia* to be a separate genus, including the fossil species of U.S.S.R. and the living species of Thailand and Formosa, with which I do not agree.

Bellamya suzukii, nov. sp.

Pl. 26, Figs. 6a—14b.

Type locality:—Hojiro (Locality C(I7)), Ueno City, Mie Prefecture, central Japan.

Derivation of name:—The species is named in honor of the late Dr. K. Suzuki, who studied fossil non-marine molluscs of the Japanese

Islands and north China.

Material studied:—18 specimens. Figured specimens, ESN 40026—40064, 40067, MFM 110014, 110015, 111036, 111042.

Diagnosis:—Shell medium, ovately conical; the spire about 3/10 of the shell height; the apical angle 50 to 60 degrees. The whorl side rounded, with weakly carinate spirals in younger stage of growth. The body whorl large with well-rounded periphery.

Description:—Shell medium for genus, up to 25 mm long, thin to moderately thick, ovately conical; the spire moderately elevated, comprising about 3/10 of the shell height; the apical angle usually 50 to 60 degrees. The early whorls including the embryonic shell corroded. The spire generally preserved four whorls, the whorl side rather convex, increasing in size rapidly. The periphery rounded near the center of the body whorl; the basal parts slightly convex or flat. The later whorls having a very narrow or ill-defined shoulder. Suture shallow, but distinctly impressed. Shell surface covered with delicate growth lines and their rest marks. The growth lines slightly opisthocline below the suture. The rest marks being darker in color and more remarkable than impression of the growth lines. The body whorl sometimes sculptured by a few axial costae with rounded top. At juvenile stage, the surface of the spire covered with weakly carinate spirals. Aperture ovate, broadly rounded, somewhat extend to the front, and subangular behind. Outer lip thin, gently rounded. Columellar lip thin, smooth, oblique, with thick parietal callus. Umbilicus narrowly perforate.

Discussion:—*Bellamya kosasana* from the Middle Miocene Nojima Group of the Nojima Island, Saga Prefecture, Kyushu is closely related to *Bellamya suzukii*, but is assigned to the genus *Viviparus* in the original description. Moreover, this Miocene species has been reported from the Koura Formation in the Shimane Peninsula in Shimane Prefecture (Suzuki, 1949) and the Suzuka Group at the southern foot of the Suzuka Mountains in Mie Prefecture (Suzuki and Oyama, 1948). It may be distin-

guished from *B. kosasana* by having a slenderer shell outline with inflated whorls, round periphery, and higher shell (20 to 25 mm). The specimens figured by Kanno (1954) as *Viviparus (Sinotaia) uryuensis* from the Early Miocene Osawa Formation in Fukushima Prefecture resemble the present specimens, but the former differs from the latter in having more conspicuous shoulder with a step-like form, apical angle 70 to 75 degrees, and obtusely angulated on the anterior two-thirds of the body whorl. *Bellamya suzukii* is close to *Sinotaia (Sinotaia) deviatkini* described by Popova et al. (1970) from the Eopleistocene Kyzylgir Formation of Altay Highalnd, U.S.S.R., but it is distinguished from *S. deviatkini* in having a smaller shell size and shallower suture.

Suzuki and Oyama (1948) and Akamine et al. (1951) have reported *Viviparus (Sinotaia) uryuensis kosasanus* from the Plio-Pleistocene Agé Group about 20 kilometers east of the type locality of *B. suzukii*. They, however, are probably assigned to *B. suzukii*.

Measurements (in mm):

	H	W	BH	AH
ESN 40062 (holotype)	21.3	15.0	15.3	9.5
ESN 40063 (paratype 1)	23 +	17.5	—	—
ESN 40067	21.3	15.7	16.2	11.2
MFM 110014 (paratype 2)	17.3	13.5	13.5	10.1
MFM 110015 (paratype 3)	20.5	14.4	15.4	10.8
MFM 111042	20.1	13.9	15.8	11.2

Genus *Tulotomoides* Wenz, 1939

Type species:—*Tulotoma kwangsiensis* Hsü, by original designation. Eocene Yongning Formation. Kuanghsi Province, China.

Geologic range:—(Middle Jurassic?) Eocene to Pliocene.

Discussion:—This species of the genus *Tulotomoides* first reported from Japan is *Tuloto-*

moides japonicus from the Gamo Formation of Kobiwako Group (Habe and Tomoda, 1980). The species of the genus *Tulotomoides* hitherto known from China and U.S.S.R. are as follows:

Tulotomoides? antiqua Pan. Zhanghe and Huopingyao Formations (Middle Jurassic). Lufeng and Yangbi, Yunnan Province, China (Pan, 1977).

T.? talatzensis Suzuki. Middle Shale Formation, Talatzu Group (Early Cretaceous). Sanlaikou, Jilin Province, China (Suzuki, 1941).

T. kwangsiensis (Hsü), *T. lii* (Hsü) and *T. lii parva* (Hsü). Yongning Formation (Eocene). Cienyang, Kuanghsi Province, China (Hsü, 1935).

T. terrassa Youluo. Shahejia Formation (Early Oligocene). Kenli, Shantung Province and Panshan, Liaoning Province, China (Inst. Petrol. Pros. and Develop. Plan and Nanking Inst. Geol. and Palaeont., 1978).

T. aspericarinata Youluo. Shaheji Formation (Early Oligocene). Penhsien and Kenli, Shantung Province, China (*op. cit.*).

T. spiralicostata Youluo. Shahejia Formation (Early Oligocene). Kenli, Shantung Province, China (*op. cit.*).

T. rehetaiensis Youluo. Shahejia Formation (Early Oligocene). Panshan, Liaoning Province, China (*op. cit.*).

T. pagodaeformis (Martinson). Tanhoi Formation (Oligo-Miocene). Near Lake Baikal, U.S.S.R. (Popova, 1981).

T. cf. tulotomoides (Yen). *Ditto.*

T. tulotomoides (Yen). Sijian Formation (Late Pliocene). Qujing, Yunnan Province, China (Yen, 1935).

Tulotomoides sanaguensis, nov. sp.

Pl. 27, Figs. 1—8; Text-fig. 3.

Type locality:—Toyama (Locality D(I18)), Sanagu-cho, Ueno City, Mie Prefecture, central

Text-fig. 3.   Reconstruction of *Tulotomoides sanaguensis*, n. sp., apertural view.(× 3).

Japan.

Derivation of name:—This name is formed after the name of place, Sanagu-cho, from which the type specimens were collected.

Material studied:—14 specimens. Figured specimens, ESN 40074—40078, 40080, MFM 110016, 111049, 111051.

Diagnosis:—Shell medium for the genus, elongately conic in outline. The embryonic shell and early whorls subglobose, smooth, and rounded. The later whorls having a flattened shoulder. The shoulder being ridge-like spiral rib. The surface irregular and undulatory. The whorl side flat and vertical.

Description:—Shell medium for genus, commonly 20 to 26 mm long, probably thin, elongately conic. Spire moderately elevated, more than half of the height; the apical angle about 30 degrees. The early whorls including the embryonic shell, less than 5 mm in width, subglobose, smooth and rounded. The spire consisting of about four whorls, cylindrical, with obliquely flattened sutural shelf, increasing

Explanation of Plate 24

Figs. 1, 2.   *Igapaludina stricta* (Araki) from the Ohyamada clays, Locality A(I16).
      1, A swarmed specimen of mature individuals, MFM 111035, ×1.
      2, A swarmed specimen of juvenile individuals, MFM 111034, ×1.
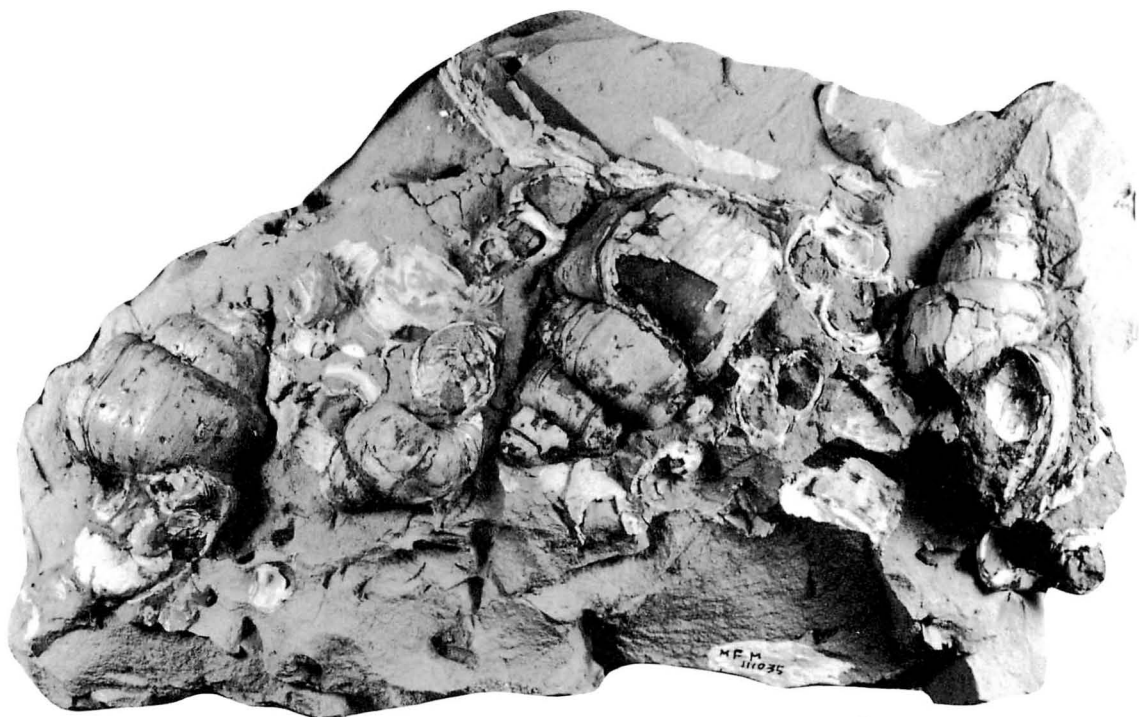
1

2

in size slowly. The whorl side flat and vertical. The shoulder being ridge-like spiral rib with the irregularly undulated surface which gradually becoming prominent with advancing years, and just below the shoulder slightly concave. The periphery rounded, and the basal part slightly convex or flat. The suture shallow, but distinctly impressed. Shell surface covered with fine growth lines and with irregularly spaced rest marks. The gr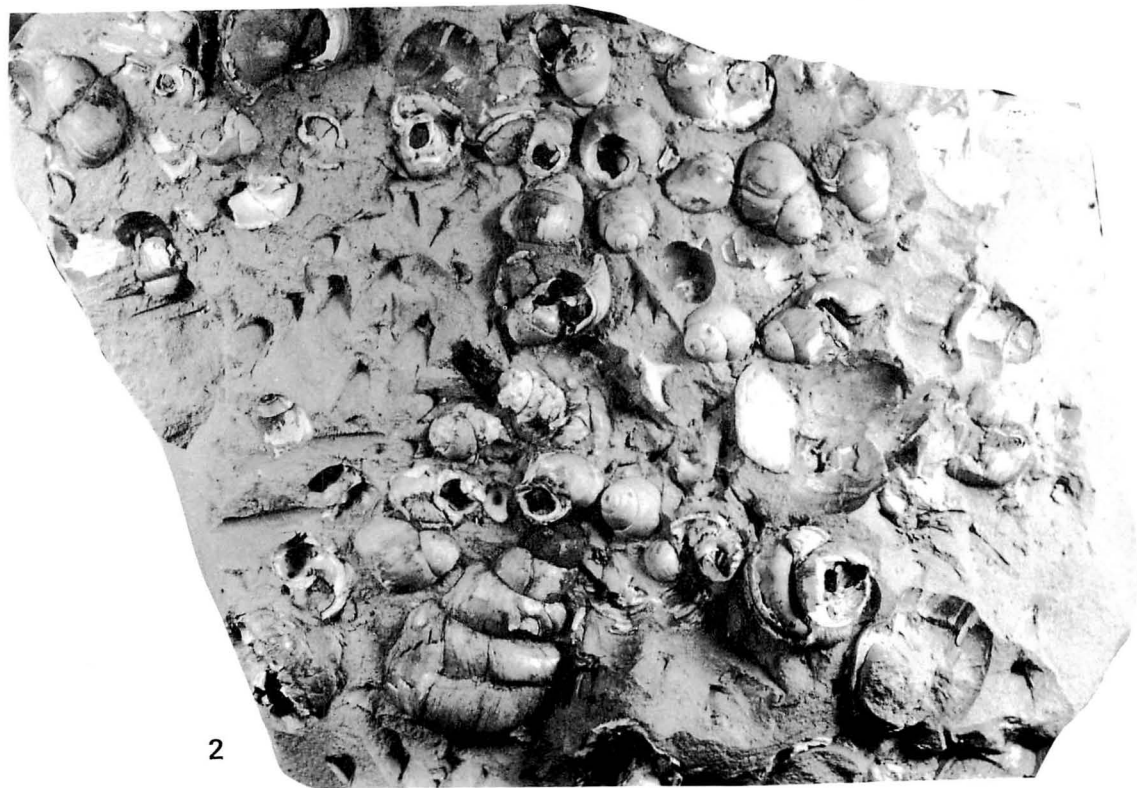owth lines anteriorly curved near the shoulder. The rest marks sometimes becoming like longitudinal rib. Aperture elongate ovate, oblique, with continuous rounded margin in front. Outer lip thin, with moderately rounded margin. Columellar lip curved, its axial side concave, not perforate.

Discussion:—All specimens from the type locality occur as McAlester's (1962) "composite mold", and have been deformed by post-mortem compression. This new species is most closely related to *T. japonicus* from the Gamo Formation of Kobiwako Group, at Mikumo, Shiga Prefecture. It differs from *T. japonicus* by a slender shell with narrower sutural shelf and with obtusely rounded early whorls. The shells from the Gamo Formation are large, 33 mm height in maximum, and have wider sutural shelf, and distinct shoulder until the younger shell of 3.2 mm in width. In the Kobiwako Group, *T. sanaguensis* occurs in strata older than those containing *T. japonicus*. *T. sanaguensis* may therefore be the direct ancestor of *T. japonicus*. *T. lii* from the Eocene of Chienyang, Kuanghsi Province of China resembles this new species in having a rounded whorl side and smooth surface except for growth lines at younger stages of growth, but is distinguished by the presence of three spiral ridges on each whorl. The slender and elevated spire of *T. sanaguensis* also resembles *T. spiralicostata* from the Shahejia Formation of Shantung Province in China, but is distinguished by the possession of an obtuse apex, and flat and vertical whorl side.

Measurements (in mm):

	H	W	BH	S/H
ESN 40074 (holotype)	21.8	12.9	15.7	0.28
ESN 40075 (paratype 1)	20.2	15.1	15.5	0.23
ESN 40076	22.4	14.8	14.7	0.34
ESN 40077	24.7	15.0	18.2	0.26
MFM 110016 (paratype 2)	21.2	17.0	16.1	0.24

S/H = height of spire/height

Family Pleuroceridae Fischer, 1885

Genus *Semisulcospira* Boettger, 1886

Type species:—*Melania libertina* Gould, by subsequent designation, Annandale and Prashad (1924). Recent.

Geologic range:—(Cretaceous?) Eocene to Recent.

Discussion:—Boettger (1886) established this genus as a section of the genus *Sulcospira* Troschel, which includes *Semisulcospira libertina* (Gould), *S. spadicea* (Reeve), *S. japonica* (Reeve), and so on. This genus is restricted to East Asia — Amur Basin, Korean Peninsula, China, Formosa, and Japanese Islands.

Subgenus *Biwamelania* Matsuoka and Nakamura, 1981, redefined

Discussion:—The generic name *Biwamelania* was first used for species which are endemic in Lake Biwa, and the Seta and Uji Rivers by Habe (1978), but descriptions necessary for the establishment of a new taxon have not been made. Matsuoka and Nakamura (1981) have subdivided the genus *Semisulcospira* into two subgenera; *Semisulcospira* and *Biwamelania*, and the two subgenera were correlated with Davis' (1969) *Semisulcospira libertina* group and *S. niponica* group, respectively. All species of *Semisulcospira* from the Katata Formation of the upper part of the Kobiwako Group belong to the subgenus *Biwamelania*. *S. niponica* group consists of species which have chromosome numbers n = 7 to 14, and their adult shells are conic to elongate conic in outline, possess-

ing the prominent nodes on the axial ribs, and two to six basal cords. The embryonic shell is larger and fewer than that of the *Semisulcospira libertina* group in size and number. The subgenus *Biwamelania* is revised here to contain some Recent species, *S. decipiens* (Westerlund), *S. multigranosa* (Boettger), *S. habei* Davis, *S. habei yamaguchi* Davis, *S. reticulata* Kajiyama et Habe, *S. niponica* (Smith), and *S. nakasekoae* Kuroda. The type of this subgenus placed in this paper is *S. decipiens* (Westerlund) which lives in Lake Biwa. The species of the *Semisulcospira cancellata* group (Kuroda, 1947) which are distributed over the Amur Basin, Korean Peninsula, and China presumably belong to this subgenus *Biwamelania*. The fossil species which may be assigned to the subgenus *Biwamelania* are *Semisulcospira* spp. from the Kobiwako, Agé and Tokoname Groups (Matsuoka and Nakamura, 1981; Matsuoka, 1983b, 1985), *S. napoensis* from the Eocene Yungning Formation of Guangxizhuangzu (Hsü, 1935), and *S. aubryana* var. *cancellata*, *S. aubryana* var. *spiralis*, *S. aubryana* var. *costellata*, and *S. aubryana* var. *obsoleta* from the Pliocene Cijian Formation in Yunnan, China (Mansuy, 1912).

Semisulcospira (Biwamelania)
praemultigranosa, nov. sp.

Pl. 27, Figs. 9—18.

Type locality:—Hirata (Locality A(I16)), Ohyamada-mura, Ayama-gun, Mie Prefecture, central Japan.

Derivation of name:—This species is named from *prae*-(Latin, prefix meaning before) and the specific name of *Semisulcospira multigranosa*, feminine.

Material studied:—13 specimens. Figured specimens, ESN 40023—40026, 40070, 40072, 40073, MFM 110008, 111044, 111048.

Diagnosis:—Shell medium, elongate-conic, six or more whorls; five prominent nodes on the axial ribs on the penultimate whorl, but the most anterior node imperfect, sealing suture. The basal cords distinct, two to three in number.

Description:—Shell medium for genus, moderately thick, elongate conical. Spire high turreted, approximately one-fourth the height of the shell, and always lacking the embryonic shell and early postembryonic one; apical angle 18 to 20 degrees. Whorls preserved four to six in number, increasing in size regularly; whorl profile flat or slightly convex. Suture shallowly impressed, undulatory. Sculpture of the spire consisting of four to five nodes, more or less regularly spaced, on axial ribs with rounded or somewhat carinated top, crossed by moderately raised lirae and feeble spiral lines. The body

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Explanation of Plate 25

Figs. 1a—15b. *Igapaludina stricta* (Araki) from the Ohyamada clays, Locality A(I16).
    1a, apertural view; 1b, abapertural view. ESN 40029, mature specimen, ×1.
    2a, apertural view; 2b, abapertural view. ESN 40042, juvenile specimen, ×1.
    3a, apertural view; 3b, abapertural view. MFM 110010, mature specimen, ×1.
    4a, apertural view; 4b, abapertural view. ESN 40031, mature specimen, elongate type, ×1.
    5a, apertural view; 5b, abapertural view. ESN 40040, juvenile specimen, ×1.
    6a, apertural view; 6b, abapertural view. ESN 40034, mature specimen, ×1.
    7a, apertural view; 7b, abapertural view. ESN 40030, mature specimen, ×1.
    8a, apertural view; 8b, abapertural view. MFM 111014, juvenile specimen, ×1.
    9a, apertural view; 9b, abapertural view. MFM 111017, juvenile specimen, ×1.
    10a, apertural view; 10b, abapertural view. ESN 40057, juvenile specimen, ×1.5.
    11a, apertural view; 11b, abapertural view. ESN 40058, more juvenile specimen, ×2.
    12a, apertural view; 12b, abapertural view. MFM 111022, more juvenile specimen, ×2.
    13a, apertural view; 13b, abapertural view. MFM 111031, more juvenile specimen, ×2.
    14a, apertural view; 14b, abapertural view. MFM 111023, more juvenile specimen, ×2.
    15a, apertural view; 15b, abapertural view. ESN 40060, more juvenile specimen, ×2.
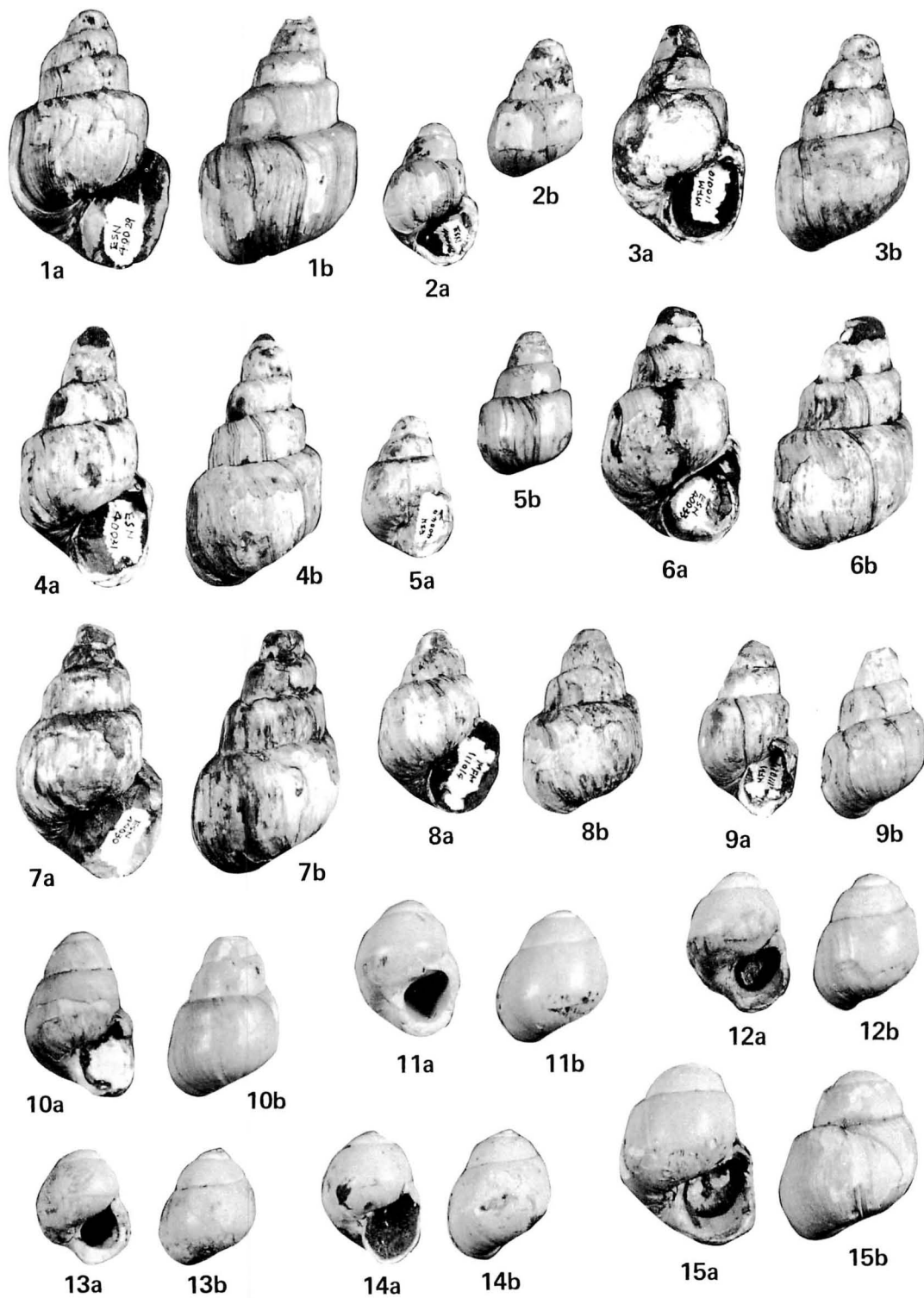
whorl with rounded periphery, the width about two-fifths of the height, the spiral cords six, prominent, more widely spaced than the interspaces, the basal cords strong, two to three, with rounded or weakly carinated top. Axial ribs on the penultimate whorl 17 to 19, almost equal to the width of intercostal spaces, orthocline to weakly opisthocline and with five nodes; the nodes immediately above the suture imperfect, and the other nodes equal or the uppermost one slightly small. Growth lines irregularly spaced, very fine, and opisthocline. Aperture elongate-ovate, oblique with narrowly rounded basal lip, and angular in posterior. Outer lip thin. Columellar lip smooth, parietal callus not thicken, completely sealing the umbilicus. In the juvenile specimen, the early whorls of the spire narrowly conic, 10.3 mm in height, and 3.8 mm in width. The shell sculptured by regularly spaced axial ribs with nodes and crossed by fine spiral cords, and two basal cords. The width of the axial ribs occupying one-third to one-fifth of the interspaces. The embryonic shell about 1.7 mm in maximum width, and having the axial ribs and spiral cords with carinated top.

Discussion:—In the adult stage of development, this new species resembles the following three species, *Semisulcospira (Biwamelania) multigranosa* (Boettger), *S. (B.) decipiens* (Westerlund), *S. (B.) habei yamaguchi* Davis, which are found sympatrically in the littoral zone of Lake Biwa. *S. (B.) multigranosa* shows close resemblance to *S. (B.) praemultigranosa*. It is distinguished from *S. (B.) praemultigranosa* by having seven to eight numbers of nodes on the ribs and 23 ribs per penultimate whorl. Ribs of *S. (B.) decipiens* are more slender and delicate than those of this new species and has seven to eight nodes on them. *S. (B.) habei yamaguchi* shows the closest resemblance to the new species. *S. (B.) habei yamaguchi* differs from *S. (B.) praemultigranosa* in having the large apical angle and generally conspicuous six nodes on each rib of the whorl in the adult stage. The similarity in shell morphology suggests that *S. (B.) habei yamaguchi* may have derived

from this new species.

The fossil specimens reported from the Agé Group, under the name of *S.* cf. *multigranosa* (Suzuki and Oyama, 1948; Akamine *et al.*, 1951) are probably identical with *S. (B.) praemultigranosa*.

Measurements (in mm):

|	H	W	BH	AH	BC
ESN 40023 (holotype)	35.6	12.8	20.3	10.2	3
ESN 40024 (paratype 1)	30.2	12.2	17.7	—	3
ESN 40025 (paratype 2)	35.0	12.8	17.6	—	—
MFM 110007 (paratype 3)	31.6	15.0	—	—	3
MFM 110008 (paratype 4)	32.9	13.1	19.1	—	3
ESN 40070	29.1	10.3	11.7	—	2
MFM 111044	28.0	10.4	13.9	—	3

BC = basal cord

Acknowledgments

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Explanation of Plate 26

Figs. 1, 2.   Opercula of *Igapaludina stricta* (Araki) from the Ohyamada clays, Locality B(I2).
 1, MFM 110012, ×1.5, collected by S. Okuyama.
 2, MFM 110013, ×2, collected by S. Okuyama.
Figs. 3—5b.   *Igapaludina stricta* (Araki) from the Ohyamada clays, Locality B(I2).
 3, apertural view, MFM 111053, ×1.
 4, apertural view, MFM 111057, ×1.
 5a, apertural view; 5b, abapertural view, MFM 111056, ×1.
Figs. 6a—b, 8, 9.   *Bellamya suzukii*, n. sp. from the Ohyamada clays, Locality B(I2).
 6a, apertural view; 6b, abapertural view. ESN 40062 (holotype), ×1.
 8, abapertural view, ESN 40063 (paratype 1), ×1.
 9, abapertural view, ESN 40064, ×1.3.
Figs. 7, 10a—14b.   *Bellamya suzukii*, n. sp. from the Takayama bed, Locality C(I7).
 7, apertural view, ESN 40067, ×1.
 10a, apertural view; 10b, abapertural view. MFM 110015 (paratype 3), ×1.5.
 11a, apertural view; 11b, abapertural view. MFM 110014 (paratype 2), ×1.5.
 12, apertural view. MFM 111043, ×1.5.
 13a, apertural view; 13b, abapertural view. MFM 111042, ×1.5.
 14a, apertural view; 14b, abapertural view. MFM 111036, ×1.5.

1

2

3

4

5a

5b

6a

6b

7

8

9

10a

10b

11a

11b

12

13a

13b

14a

14b
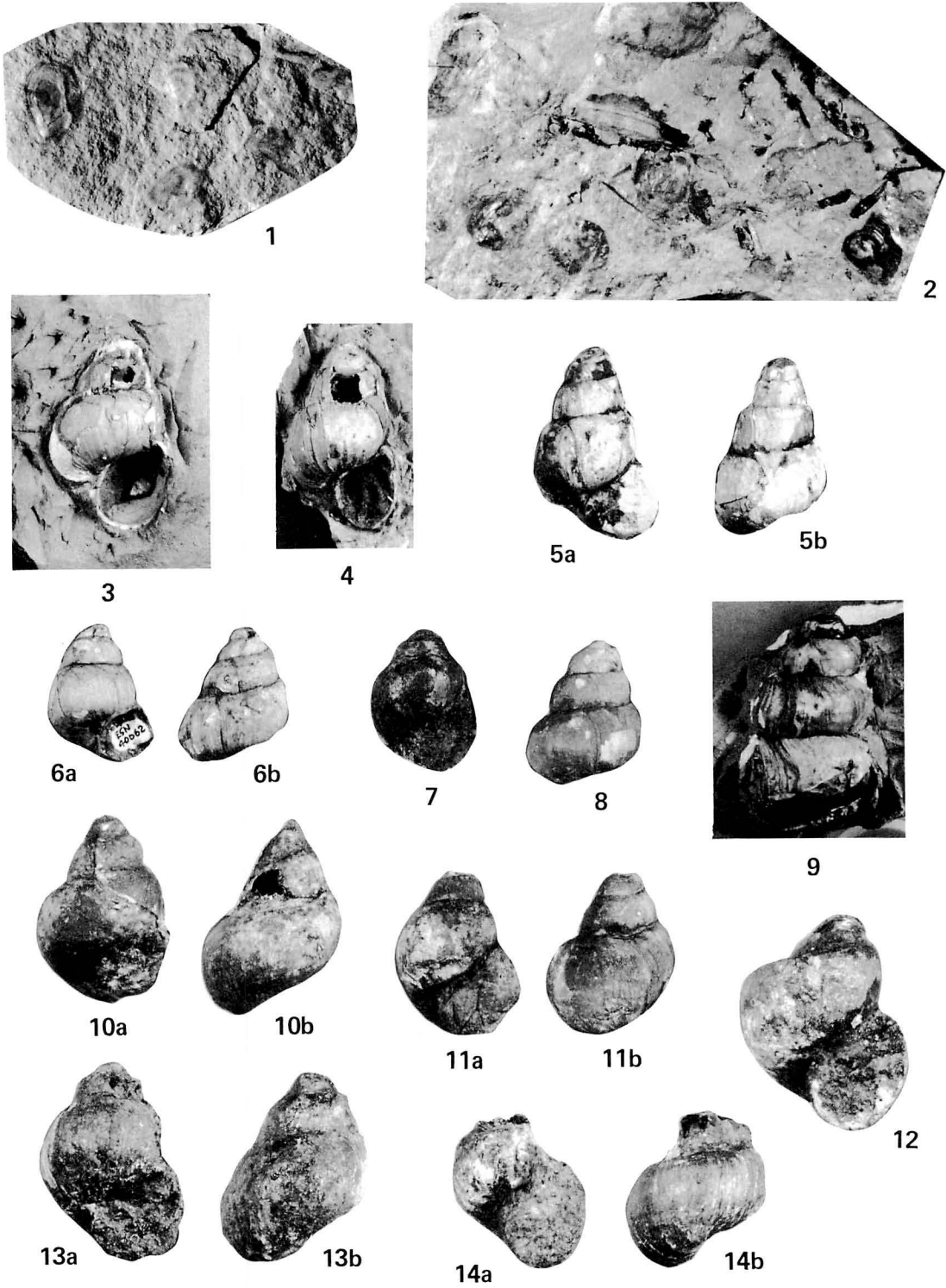
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Explanation of Plate 27

Figs. 1—8. *Tulotomoides sanaguensis*, n. sp. from the Kashikimura sands, Locality D(I18).
   1, abapertural view. ESN 40074 (holotype), ×1.
   2, abapertural view. ESN 40076, ×1.
   3, apertural view. ESN 40080, ×1.
   4, abapertural view. ESN 40075 (paratype 1), ×1.
   5, abapertural view. MFM 111049, ×1.
   6, abapertural view. MFM 110016 (paratype 2), ×1.
   7, abapertural view. MFM 111051, ×1.
   8, abapertural view. ESN 40078, ×1.

Figs. 9, 10, 17, 18. *Semisulcospira (Biwamelania) praemultigranosa*, n. sp. from the Ohyamada clays, Locality B(I2).
   9, abapertural view. MFM 111044, ×1.
   10, abapertural view. ESN 40070, ×1.
   17, abapertural view. ESN 40073, more juvenile specimen, ×2.
   18, abapertural view. ESN 40072, juvenile specimen, ×1.

Figs. 11—16b. *Semisulcospira (Biwamelania) praemultigranosa*, n. sp. from the Ohyamada clays, Locality A(I16).
   11, abapertural view. ESN 40026, ×1.1.
   12, abapertural view. MFM 111048, ×1.2.
   13, apertural view. ESN 40025 (paratype 2), ×1.
   14a, apertural view; 14b, abapertural view. ESN 40023 (holotype), ×1.
   15a, apertural view; 15b, abapertural view. MFM 110008 (paratype 4), ×1.
   16a, apertural view; 16b, abapertural view. ESN 40024 (paratype 1), ×1.
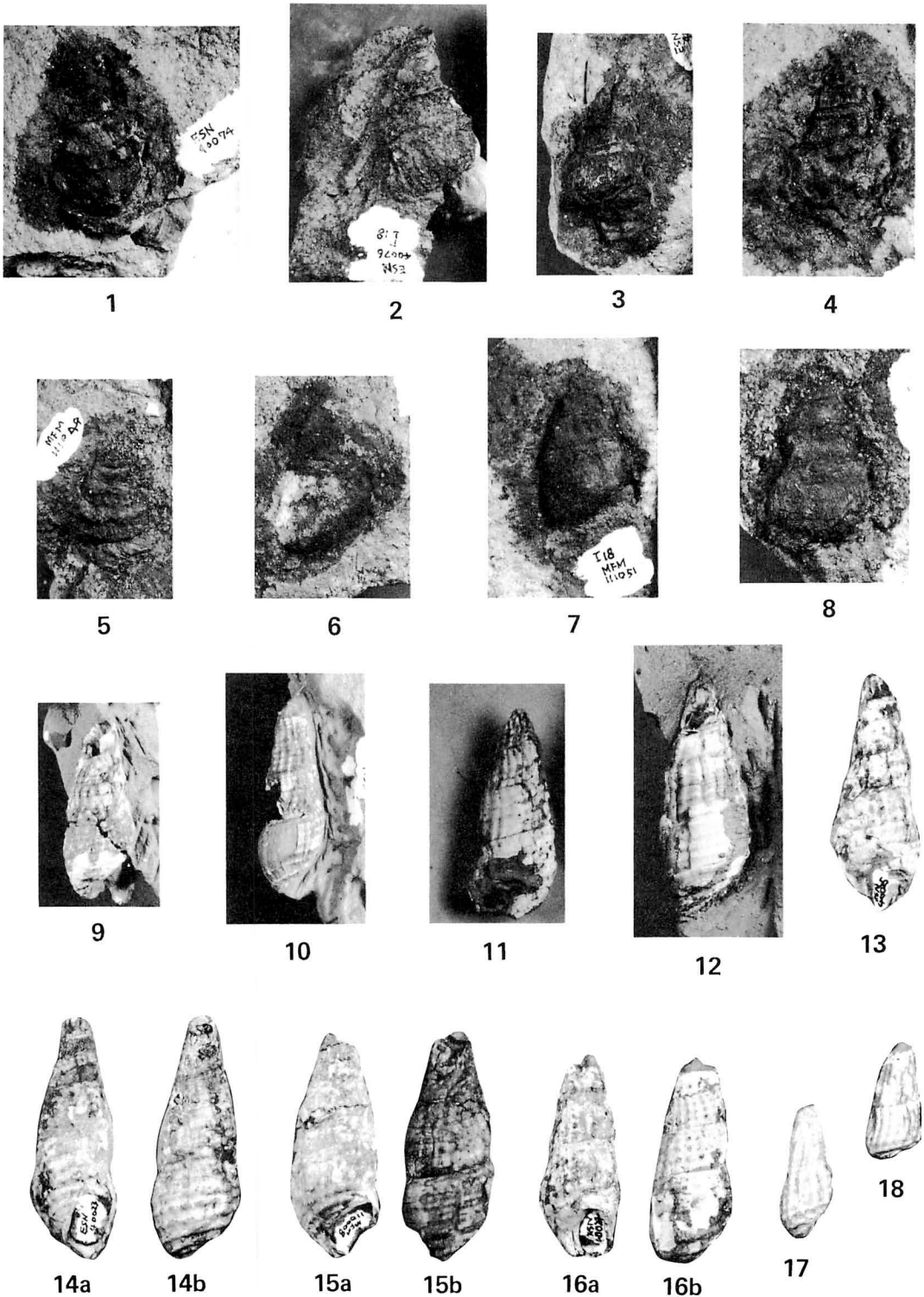
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Agé 奄芸　Aitagawa 愛田川　Ayama 阿山　Hatamura 畑村　Hattori 服部　Hirata 平田　Hojiro＝Hohziro 喰代　Katano？甲野 (Kouno)，Iga 伊賀　Kambe 神戸　Kashikimura 炊村　Nakamura 中村　Ohyamada 大山田　Sanagu 佐那具　Takasu 高砂　Takayama 高山　Toyama 外山　Tsuge 拓植　Wakebe 分部

古琵琶湖層群伊賀累層の鮮新世淡水生腹足類：三重県上野盆地と阿山丘陵には，湖沼河川成堆積物からなる古琵琶湖層群下部の伊賀累層が分布している。伊賀累層は，日本非海成鮮新統の中では保存良好な淡水生物化石（珪藻，海綿，貝類，魚類，爬虫類）や陸上生物化石（大型植物，哺乳類）を産出する。貝類化石はタニシ類，イシガイ類が古くから知られていたが，詳細な分類学的研究はなく，琵琶湖固有種などの現生種に同定されることが多かった。今回，大山田・佐那具地域の伊賀累層からイシガイ科の二枚貝類と共産した腹足類化石を検討した結果，次の4属（内1新属）4種（内3新種）を識別し，記載を行い新属 *Igapaludina* および亜属 *Biwamelania* を各々創設および再定義した：*Igapaludina stricta* (Araki)，*Bellamya suzukii* (nov. sp.)，*Tulotomoides sanaguensis* (nov. sp.)，*Semisulcospira* (*Biwamelania*) *praemultigranosa* (nov. sp.).　*Bellamya* 属はアフリカ，東南アジア，東アジアに，*Semisulcospira* 属は東アジアに分布する。*Igapaludina* と *Tulotomoides* は絶滅属である。これらの腹足類は，日本の鮮新世腹足類の構成内容及び中新世以降の淡水生腹足類の変遷，系統を解明する上で極めて重要な資料である。　　　　　　　　　　　　松岡敬二

801. NEW DATA ON URANIUM-SERIES AGES OF HERMATYPIC CORALS FROM THE PLEISTOCENE LIMESTONE ON KIKAI, RYUKYU ISLANDS*

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Abstract. Twenty-one Pleistocene corals newly collected at fourteen localities on the island of Kikai were dated by the uranium-series ^{230}Th/^{234}U method. One of the most salient observations is that a part of the Pleistocene limestone on the island was dated to be Middle Pleistocene in age, which may be correlative with two stages of the high sea stand. The one is corresponding to the stage 7 of the marine oxygen isotopic record (Emiliani and Shackleton, 1974), approximately 200,000 years B.P., and the other may be correlative to the stage 9 (or older one), 250,000 years or more B.P. From the distribution of corals assigned to more than 250,000 years and the lithology of limestone including those corals, the very shallow environment where hermatypic corals could grow up is inferred to have spread at that time over the area having a diameter of at least 6.5 km. Namely, the initial coral reef settled directly onto the Pliocene basement (Somachi Formation; Nakagawa, 1969) might be a fairly extensive table reef and the limestone deposited as such a reef is nowadays composed the basal part of Late Pleistocene limestone. The other new uranium-series dates also are shown in the present paper.

We point out, based on these new ^{230}Th/^{234}U dates, that the geologic history itemized by Konishi et al. (1970) should be modified, although it is not necessarily required to change principally the articles concerning the history since the past 130,000 years.

Introduction

The Pleistocene limestone (Riukiu Limestone of Hanzawa, 1935) on the island of Kikai has been chronologically studied in some detail mainly by employing the uranium-series dating technique (Komura and Sakanoue, 1967; Konishi et al., 1970, 1974; Omura, 1983). So far, the ^{230}Th/^{234}U and ^{231}Pa/^{235}U coral dates number between forty and fifty. In addition to them, the ESR (electron spin resonance) dating also has been applied to some corals on this island (e.g., Ikeya and Ohmura, 1983). The number of radiometric dates, however, is not necessarily

enough to discuss exhaustively the geologic history of the island and to correlate the Pleistocene limestone on Kikai with the counterparts in other areas.

The present paper deals with ^{230}Th/^{234}U ages for hermatypic corals collected at new localities, from most of which no radiometric date has been reported. In this study, we try to examine the following two problems which remain still equivocal. (1) Since when has the coral reef been settled in the place where Kikai is at present? How was the scale of such an initial reef? It is the chief concern of ours to examine whether the dates assigned to 200,000 years or more can be obtained for corals from the Pleistocene limestone on Kikai. Although they were verified from two islands in the Ryukyu Islands, Hateruma (Konishi, 1980; Omura, 1984) and Toku (Omura, 1982), yet no uranium-series dates indicative of Middle Pleistocene have been reported from this island. (2) When and how was the uppermost terrace formed? Konishi *et al.* (1970, 1974) inferred that the oldest part of the Pleistocene limestone distributing in the highest area of the island was deposited at the time of the highest sea stand through the last interglacial from three uranium-series ages (122,000 ± 2,000 to 128,000 ± 3,000 years) of corals collected at the height of 170 m. They defined such a stratigraphic unit of reefy limestone as the Older Member of Riukiu Limestone. The height of the shoreline at that time of formation of the Older Member was thought to be more than 200 m in present altitude. In order to inspect their estimation, we devoted special attention to collect the datable coral samples from the localities of the height of 200 m or more.

Samples

Radiochemical analyses were carried out on twenty-one hermatypic coral samples including seven genera of *Favia, Goniastrea, Porites, Montipora, Favites, Galaxea* and *Montastrea*. Among them, five genera except *Galaxea* and *Montastrea* are most representative of corals

occurred in the Pleistocene limestone on Kikai. Table 1 lists numbers, taxonomy and elevation for all samples examined. The localities of them are plotted in Text-fig. 1 together with those of both hermatypic and ahermatypic solitary corals dated previously to be Late Pleistocene in age (see the papers of Konish *et al.*, 1974, and Omura, 1983, for details).

Fossil corals found at the outcrops of Pleistocene limestone were examined very carefully on their mode of occurrence and mineralogy. The samples for dating purpose were selected during the field survey owing to their original position of growth and to nature of neither pore-filling nor recrystallization. Three samples (OA053, AO089 and AO152) listed in Table 1 were apparently not in situ.

Prior to the isotopic analysis, the X-ray powder diffraction method of Davies and Hooper (1963) was used for each sample in order to check the existence of the secondary calcite and the calcite/aragonite ratio. As the results, more than 5% of calcite were detected in four samples (AO091, AO173, AO085 and AO175). Particularly, AO085 and AO175 samples were composed of the high percent (25 and 40%, respectively) of the secondary calcite. The other seventeen samples were free from calcite or consisted of more than 95% of the original aragonite.

Results and discussion

Table 2 summarizes analytical results and ^{230}Th/^{234}U ages calculated from the following equation;

$$^{230}\text{Th} = {}^{238}\text{U}[1 - \exp(-\lambda_0 t)] + ({}^{234}\text{U} - {}^{238}\text{U})$$
$$[\lambda_0/(\lambda_0 - \lambda_4)][1 - \exp(\lambda_4 t - \lambda_0 t)]$$

where λ_0 and λ_4 are decay constant of ^{230}Th and ^{234}U, respectively.

Known quantities of ^{232}U and ^{228}Th were used as yield tracers in the analyses of the radioisotopes listed in the table. The quoted errors (one standard deviation) are based on the counting statistical fluctionations only. In calculation of the ages, we assumed that ^{230}Th was initially absent or present in negligible amounts and

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Table 1. List of the dated coral samples from the Pleistocene limestone on the island of Kikai.

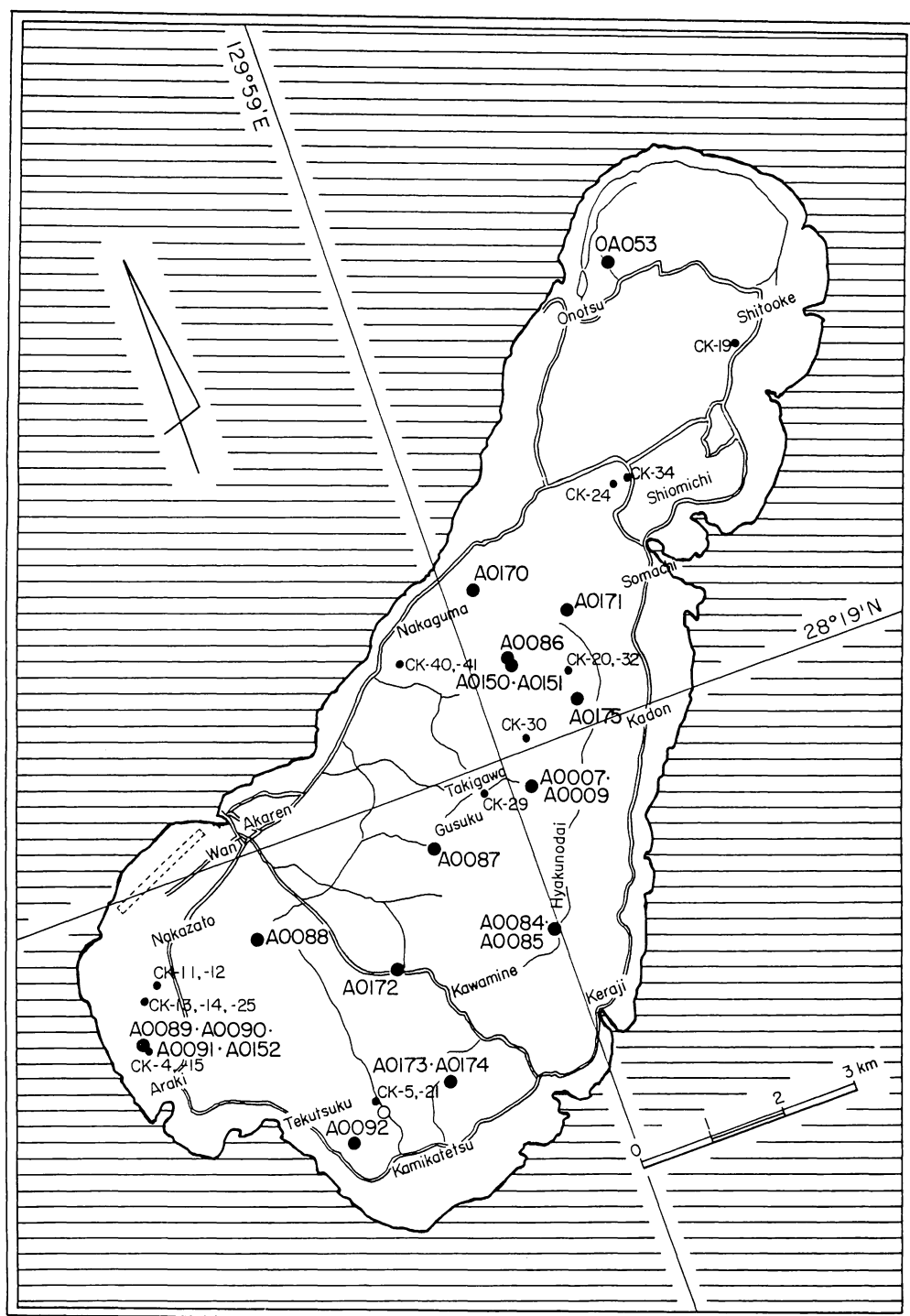| Code Number	Sample Number	Genera	Elevation	Calcite / Aragonite
OA053	CK–23	*Favites*	40 m	< 0.05
AO007	75–4–1–3A	*Goniastrea*	170	0
AO009	75–4–1–3B	*Goniastrea*	170	0
AO084	K–C–11	*Porites*	210	< 0.01
AO085	K–C–4	*Porit̄es*	210	0.25
AO086	K–C–10	*Montipora*	120	< 0.01
AO087	K–C–5	*Favites*	110	< 0.02
AO088	K–C–3	*Montipora*	25	< 0.01
AO089	K–C–12	*Porites*	25	< 0.01
AO090	K–C–13	*Montipora*	25	0
AO091	K–C–14	*Goniastrea*	25	0.08
AO092	K–C–18	*Galaxea*	20	< 0.05
AO150	K–C–26	*Porites*	140	0
AO151	K–C–27	*Porites*	140	0
AO152	K–C–28	*Montastrea*	25	< 0.01
AO170	K–C–29	*Favia*	33	< 0.05
AO171	K–C–30	*Favia*	135	< 0.05
AO172	K–C–31	*Montipora*	62	0
AO173	K–C–32	*Montipora*	72	0.08
AO174	K–C–33	*Montipora*	72	< 0.05
AO175	K–C–34	*Favites*	175	0.40

that samples acted as a closed system after incorporation of the radioisotopes. The half-life values used for ^{230}Th and ^{234}U are 75,200 years and 248,000 years, respectively.

Uranium content in AO175 sample, in which the high percentage (40%) of calcite was detected, differs significantly from those in the contemporary corals in the same area (Omura, 1976). This fact is thought to be dependent either on the scantiness of uranium in the calcite crystallized secondarily or the elution of uranium from the original aragonitic skeleton during the time of recrystallization, and/or on the joint effect of both factors. In any case, the reliable uranium-series age cannot be expected from a sample, of which uranium has been reduced the quantity through the diagenetic history.

In the case of AO085, the another sample composed of the high percentage (25%) of calcite, it cannot be asserted from the apparent isotopic composition that the sample has not been preserved as a closed system. Because uranium content is almost equal to those in the present-day corals and ^{230}Th/^{232}Th activity ratio is very much higher (156 ± 11) than those (1 to 3) in natural waters or sediments. The existence of the secondary calcite, however, means that this sample does not fulfill one of the most important criteria for reliable age determination (Veeh and Burnett, 1982). For these reasons, the dates of both AO175 and AO085 samples are rejected from the following discussion.

The others, seventeen samples except AO091 and AO173, can be interpreted to satisfy all of the criteria for reliable dating from both the

129°59'E

OA053

Onotsu Shitooke

CK-19

CK-34
CK-24 Shiomichi

AOI70
Nakaguma AOI7I
Somachi
AO086
CK-40,-41 CK-20,-32
AOI50·AOI5I
CK-30 AOI75 Kadon
28°19'N
Takigawa AO007·
Gusuku CK-29 AO009
Akaren
Wan AO087
Hyakunodai
Nakazato AO084·
AO088 AO085
CK-11,-12
CK-13,-14,-25 AOI72 Kawamine Keraji
AO089·AO090·
AO091·AOI52
CK-4,-15 AOI73·AOI74
Araki CK-5,-21
Tekutsuku AO092
Kamikatetsu

3 km
2
0

Text-fig. 1.   Map showing the localities of dated corals from the Pleistocene limestone on the island of Kikai.

(Bigger and smaller black circles show the localities of hermatypic coral samples dated in this study and reported by Konishi *et al.*, 1974, respectively: open small circle, the locality of ahermatypic solitary corals by Omura, 1983).

Table 2. Uranium and thorium isotopic composition and estimated ^{230}Th/^{234}U ages of fossil corals from the Pleistocene limestone on the island of Kikai.

Code Number	Isotope Concentration				Activity Ratio			Estimated Age (ka)
	^{238}U (ppm)	^{234}U (dpm/g)	^{232}Th (ppm)	^{230}Th (dpm/g)	^{234}U/^{238}U	^{230}Th/^{232}Th	^{230}Th/^{234}U	
AO092	3.26 ± 0.04	2.73 ± 0.04	< 0.02	0.866 ± 0.016	1.12 ± 0.01		0.317 ± 0.022	41 ± 4
AO090	4.16 ± 0.07	3.47 ± 0.06	< 0.02	1.20 ± 0.03	1.12 ± 0.02		0.346 ± 0.032	46 ± 5
AO088	4.17 ± 0.03	3.53 ± 0.03	< 0.02	1.33 ± 0.02	1.13 ± 0.01		0.376 ± 0.020	51 ± 3
AO091	3.24 ± 0.05	2.70 ± 0.04	< 0.02	1.02 ± 0.02	1.12 ± 0.01		0.376 ± 0.023	51 ± 4
AO152	3.32 ± 0.03	2.73 ± 0.03	0.0544±0.0063	1.09 ± 0.02	1.10 ± 0.01	83.9 ± 9.7	0.401 ± 0.007	55 ± 2
AO007	3.19 ± 0.10	2.66 ± 0.08	0.0245±0.0068	1.60 ± 0.04	1.12 ± 0.03	273 ± 76	0.602 ± 0.039	99 ± 9
AO009	3.23 ± 0.07	2.61 ± 0.06	< 0.02	1.62 ± 0.05	1.08 ± 0.02		0.621 ± 0.038	104 +11 −10
OA053	3.10 ± 0.09	2.38 ± 0.07	0.0361±0.0021	2.03 ± 0.04	1.03 ± 0.04	234 ± 14	0.853 ± 0.030	204 +23 −19
AO086	3.80 ± 0.04	2.86 ± 0.03	< 0.02	2.61 ± 0.03	1.01 ± 0.01		0.911 ± 0.015	259 +19 −17
AO089	2.71 ± 0.03	2.08 ± 0.03	< 0.02	2.02 ± 0.02	1.03 ± 0.01		0.973 ± 0.017	360 +64 −40
AO170	3.44 ± 0.04	2.62 ± 0.03	0.162±0.011	2.54 ± 0.03	1.02 ± 0.01	65.6 ± 4.4	0.973 ± 0.016	369 +69 −42
AO084	2.71 ± 0.03	2.05 ± 0.03	< 0.02	2.01 ± 0.02	1.01 ± 0.01		0.981 ± 0.016	409 +120 −55
AO151	3.13 ± 0.03	2.39 ± 0.03	0.0242±0.0044	2.42 ± 0.03	1.02 ± 0.01	417 ± 76	1.01 ± 0.02	> 450
AO172	4.66 ± 0.05	3.53 ± 0.04	0.0233±0.0041	3.55 ± 0.04	1.02 ± 0.01	634 ± 111	1.01 ± 0.02	> 450
AO173	4.16 ± 0.05	3.11 ± 0.04	0.0210±0.0038	3.13 ± 0.04	1.00 ± 0.01	620 ± 112	1.01 ± 0.02	> 450
AO171	3.02 ± 0.04	2.32 ± 0.03	0.0284±0.0038	2.37 ± 0.02	1.03 ± 0.01	348 ± 46	1.02 ± 0.02	∞
AO087	3.08 ± 0.03	2.36 ± 0.02	< 0.02	2.42 ± 0.02	1.03 ± 0.01		1.03 ± 0.01	∞
AO174	3.75 ± 0.05	2.83 ± 0.04	0.0304±0.0049	2.93 ± 0.04	1.01 ± 0.01	401 ± 65	1.04 ± 0.02	∞
AO150	2.87 ± 0.03	2.23 ± 0.03	0.0278±0.0040	2.37 ± 0.03	1.04 ± 0.01	354 ± 51	1.06 ± 0.02	∞
AO085	4.55 ± 0.05	3.47 ± 0.04	0.0235±0.0016	3.66 ± 0.03	1.02 ± 0.01	156 ± 11	1.05 ± 0.01	(∞)
AO175	1.41 ± 0.02	1.08 ± 0.02	0.0636±0.0082	1.08 ± 0.02	1.03 ± 0.02	71.1 ± 9.2	1.00 ± 0.03	(> 450)

mineralogical nature and the isotopic composition of each sample. In other words, the assumptions used in calculating the ages are certainly supported in these samples by the observations listed in Tables 1 and 2 (see the paper of Veeh and Burnett, 1982, for detail and concrete discussion).

The ^{230}Th/^{234}U dates reported here involve some useful pieces of information to understand the geologic history of Kikai. They are as the followings:

The estimated ages of twelve samples, from OA053 through AO150 in Table 2, are 200,000 years or more, and moreover the ESR dates of 403,000 ± 21,000 to 536,000 ± 37,000 years have been obtained from ten samples except OA053 and AO170. We may, therefore, reasonably say that a part of the Pleistocene limestone on Kikai is Middle Pleistocene in age. Such ^{230}Th/^{234}U dates are likely to be divided into two groups. The one is approximately 200,000 years from one sample (OA053) and the other is more than 250,000 years. The former is almost equivalent to the age of the penultimate interglacial which is corresponding to the stage 7 of the marine oxygen isotope record (Emiliani and Shackleton, 1974). In the Ryukyu Islands, the same dates have been previously reported from the island of Hateruma by Konishi (1980) and Omura (1984). Namely, a part of the Pleistocene limestone on this island may be correlative with the Hateruma I of Ota *et al.* (1982). The extent of distribution and the litho- and biofacies of the limestone deposited at this stage, however, are not clear on Kikai as of now.

The value of the latter is thought to be near or beyond the limitation of the ^{230}Th/^{234}U method for dating, although the ages can be numerically calculated as shown in Table 2. It can be conclusively said from the ^{234}U/^{238}U ratios close to the unity that these corals are too old for the uranium-series method to be applicable. The value of the ^{234}U/^{238}U activity ratios of the samples averages $1.01_9 \pm 0.01_1$. Assuming that the initial ^{234}U/^{238}U ratio was 1.14 (Ku *et al.*, 1977), the mean age is estimated from such an average value of ^{234}U/^{238}U ratio

to be $645,000^{+284,000}_{-103,000}$ years. These facts suggest that the oldest limestone on Kikai may be correlative to the deep-sea core stage 9 or the preceding warm stage. So far, in the Ryukyu Islands the same extent of ^{230}Th/^{234}U age has been obtained from the Kametsu Formation (Nakagawa, 1967), a part of the Riukiu Limestone of Hanzawa (1935), on the island of Toku (Omura, 1982).

The localities of the samples assigned to more than 250,000 years are scattered in a extensive area on the island (Text-fig. 1). Such an area is likely to cover the distribution area of the Younger, Middle and Older Members of Riukiu Limestone of Konishi *et al.* (1974). The distance in a straight line between the localities of AO170 and AO174 samples is about 6.5 km. Tsuji (1979) mapped geologically the southwestern part of Kikai and concluded that the oldest limestone on this island occurs fairly extensively in this area and is unconformably overlain even with the Araki Limestone which is thought to be the uppermost unit of the Pleistocene limestone on this island and to have been deposited 35,000 − 45,000 years ago by Konish (1967) and Konish *et al.* (1970, 1974). The very shallow environment where hermatypic corals could grow up is thus inferred to have spread at that time over the area having a diameter of at least 6.5 km. On the whole, the limestone including corals indicative of the age of Middle Pleistocene is not typical bindstone or framestone of Embry and Klovan (1971). However, it is sure that a considerable number of hermatypic corals are preserved in the state of their original position of growth and that the binding structure made of flat-shaped colonies of hermatypic corals and crustose coralline algea is observed in some places. These facts suggest that the initial coral reef developed directly onto the Pliocene basement (Somachi Formation; Nakagawa, 1969) might be a fairly extensive table reef. And then, the limestone deposited as such a reef is considered to constitute the basal part of the Pleistocene limestone on the island.

Two (AO007 and AO009) samples were dated to be approximately 100,000 years,

which fits in the time of an interstadial phase and almost equals the age of the Barbados II terrace of Mesolella *et al.* (1969) on Barbados, West Indies, and the age of the Reef Complex VI on the Huon Peninsula in New Guinea (Bloom *et al.*, 1974). Both $^{230}Th/^{234}U$ and $^{231}Pa/^{235}U$ ages of about 100,000 years have been previously reported for a coral sample (CK-30) collected on the island by Konish *et al.* (1974). This date corresponds with the age of the Hateruma IV (Omura, 1984).

As shown in Table 1, the elevation of both AO007 and AO009 samples is 170 m and is 30 m higher than that of CK-30 sample of Konish *et al.* (1974). Based on the elevation and the mode of occurrence of these samples, there is very little doubt that the sea level of about 100,000 years ago was 170 m or more in present altitude. It is generally known that the sea level, through the period of the last interglacial, has attained to the maximum (say 6 m higher than present) 120,000 to 130,000 years before. Comparing with it, the sea level during the interstadial of about 100,000 years ago seems to have been roughly 20 m lower, from the data for the uplifted coral reefs on the island of Barbados and the Huon Peninsula (Broecker *et al.*, 1968; Bloom *et al.*, 1974).

Supposing the depositional depth ("Ld" value of Konishi, 1967) of 0 − 10 m, we can infer from the present elevation (as a first approximation, regarded as "Le" value) of the sample dated that the sea level was 170 − 180 m in present altitude. The limestone, from which both AO007 and AO009 were sampled, consists of large hermatypic coral heads in growth position and of encrusting coralline algae and foraminifera. For this observation, we suppose that this limestone was formed as the reef-wall facies and that its depth was 0 to 10 m. Because the differences ("ΔSL" value) between sea level at the time of deposition and sea level at present is −14 m, the amount of vertical displacement ("ΔV" value) due to tectonic uplift is calculated to be 184 − 194 m by the equation of Konish (1967). If the displacement is continuous rather than episodic, the rate of displacement ("ΔV/

ΔT" value) is estimated to be 1.84 − 1.94 mm/y. This ΔV/ΔT value is consistent with that estimated for the Araki Limestone and the Younger Member of Riukiu Limestone by Konish *et al.* (1970). By assuming that such a value of ΔV/ΔT is also valied for the limestone deposited at the time of 120,000 − 130,000 years ago, then we can calculate that the sea level at that time reaches to the present elevation of 227 − 239 m to 245 − 258 m. This means that the highest point of 224 m in Hyakunodai has been submerged during the time of last interglacial as pointed out by Konish *et al.* (1970, 1974).

In order to vindicate the inference as stated above, it is the best way to date the appropriate coral samples occurred in the limestone unit which makes of the terrace deposit of Hyakunodai, attaining a height of more than 200 m. Among the samples treated in this study, only two samples (AO084 and AO085) are collected at the locality of higher than 200 m. The apparent date of AO085 sample, however, cannot be used here for above-mentioned reason. Thus, for the present, we can hardly avoid the conclusion that the limestone of the highest terrace is Middle Pleistocene in age. It is necessary in the further study to search and date the coral samples occurred in the portion close to the surface of the terrace.

The date of a coral sample (AO092) was 41,000 ± 4,000 years (Table 2), which is corresponding to the age of the Araki Limestone of Konish *et al.* (1970, 1974). This limestone unit was originally divided as an independent lithostratigraphic unit from the Riukiu Limestone of Hanzawa (1935) by Schlanger and Konishi (1966) who remained the name of "Riukiu Limestone" adopted by Hanzawa (1935) and divided the other part into two, Younger and Older Members of Riukiu Limestone. The Araki Limestone is composed mainly of well-sorted and slightly cemented calcarenite. Main components of this unit are tests of *Calcarina*, *Amphistegina*, *Marginopora* and *Baculogypsina*, and disarticulated fragments of *Amphiroa*, *Corallina* and *Halimeda* (Konishi *et al.*, 1970). A few hermatypic corals in growth position are

present at the basal part of the formation. The age of the Araki Limestone is thought based on $^{230}Th/^{234}U$ and $^{231}Pa/^{235}U$ dates of total numbers of fifteen to be 35,000 − 45,000 years B.P. (Konishi *et al.*, 1974). Tsuji (1979) who examined the litho- and bio-facies in more detail made clear that this limestone unit is sporadically distributed in the southwestern part of the island. The locality of AO092 sample is situated approximately 800 m northwest of Kamikatetsu at a height of 20 m, and is included in the area of the Araki Limestone seen in the geologic map of Tsuji (1979). These facts support, therefore, his conclusion as to the distribution of the Araki Limestone.

A date of 55,000 ± 2,000 years was obtained for a coral (AO152) collected at the type locality of the Araki Limestone. This date is correlative to the age of the Younger Member of Riukiu Limestone of Konishi *et al.* (1974). It may, therefore, be said that some corals in the Araki Limestone are detrital in origin, even though they appeared to be kept in their original position of growth. An another sample (AO091) from the same location also may be of detrital origin, depending on its date (51,000 ± 4,000 years) close to the age of the Younger Member of Riukiu Limestone.

As stated above, we reported in this paper some additional uranium-series dates of corals from the Pleistocene limestone on the island of Kikai. Such dates do not require to change largely the geologic history since the last interglacial of this island, which was itemized by Konishi *et al.* (1970), although the dates assigned to probably two stages during the time of Middle Pleistocene were newly obtained. In order to generalize the geologic history of Kikai, we propose here to add at least two articles described below between the first (A) and the second (B) among the seven items seen in the paper of Konishi *et al.* (1970).

(i) Development of a fairly extensive coral reef (probably, table reef) onto the basement, Pliocene Somachi Formation (Nakagawa, 1969), more than 250,000 years B.P.

(ii) Formation of a small-sized reef (fringing reef?), during the time of the penultimate interglacial stage, approximately 200,000 years B.P.

Summary

(1) A part of the Pleistocene limestone on the island of Kikai is Middle Pleistocene in age and is thought to have been deposited during two stages of high sea stand. The one is approximately 200,000 years B.P. and the other is more than 250,000 years B.P.

(2) The former can be correlative with the Hateruma I on Hateruma Island (Omura, 1984). The latter is almost near or beyond the limitation of the $^{230}Th/^{234}U$ dating method but is thought from the $^{234}U/^{238}U$ activity ratio to be correlative with the Kametsu Formation (Nakagawa, 1967) on the island of Toku.

(3) The distribution of corals assigned to more than 250,000 years denotes that the very shallow environment where hermatypic corals could grow up has spread at that time over the area having a diameter of at least 6.5 km. The initial coral reef settled directly onto the Pliocene basement (Somachi Formation; Nakagawa, 1969) might be a fairly extensive table reef.

(4) The limestone deposited approximately 100,000 years ago is traced up to a height of 170 m. Assuming that the displacement is continuous, the amount and the rate of vertical displacement since the past 100,000 years are estimated to be 184 − 194 m and 1.84 − 1.94 mm/y, respectively. Moreover, it is very strong possibility that the most elevated point of 224 m on this island has been submerged at the time of the last interglacial, 120,000 − 130,000 years ago.

(5) The date correlative to the age of the Araki Limestone (Konishi *et al.*, 1974) was obtained for a coral which was sampled at the other spot than the type locality of it. This fact supports the conclusion of Tsuji (1979) that the Araki Limestone is sporadically distributed in the southwestern part of the island.

(6) Some corals in the Araki Limestone may be detrital in origin, even though they are ap-

parently in their original position of growth.

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喜界島に分布する更新統石灰岩産サンゴのウラン系列年代に関する新資料：琉球列島喜界島に分布する更新統石灰岩 (Hanzawa, 1935, の Riukiu Limestone) から，新しく ^{230}Th/^{234}U 法によって放射年代を求めた。ここで報告する年代値は，ほとんどが，これまで放射年代が知られていない地点で採集した7属 (*Favia, Goniastrea, Porites, Montipora, Favites, Galaxea, Montastrea*)・合計21個の礁性サンゴ化石から得たものである。その結果として，喜界島の更新統の一部は，更新世中期における2回の高海水準期に形成されたことが明らかになった。一つは，おおよそ20万年前の Emiliani and Shackleton (1974) の oxygen isotopic stage 7 にあたり，他の一つは，25万年以上前の stage 9 (あるいは，より以前の温暖期) に相当する。後者の年代値は，島の各所で採集した試料から得られたが，それら採集地点の広がりとそれらサンゴ化石を含む石灰岩の岩相などから，当時，礁性サンゴの生育が可能な極浅海環境が，一つの直径が少なくとも6.5 km ある範囲に広がっていたと思われる。すなわち，基盤 (上部鮮新統早町層；中川，1969) 上に，はじめて形成されたサンゴ礁は，かなりの広がりをもった卓礁であった可能性もあり，当時の礁を形成していた石灰岩は，現在，Konishi *et al.* (1974) ほかの琉球石灰岩古・中および新期部層の基底部を構成していると考えられる。

今回新たに得られた ^{230}Th/^{234}U サンゴ年代から，以前 Konishi *et al.* (1970) によって箇条書きにして述べられた本島の地史を，過去13万年間の部分は基本的に変更の必要はないものの，一部修正しなければならないことを指摘する。

大村明雄・辻　喜弘・大村一夫・桜本勇治

802. ADDITIONAL SILURIAN TRILOBITES TO THE YOKOKURA-YAMA FAUNA FROM SHIKOKU, JAPAN

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Abstract.   A new trilobite collection by Sakō contains 12 species including 11 new species three of which were already described in the advance report and the remainder is included in this paper. *Pseudocheirurus* and *Staurocephalus* are two new genera for the Silurian fauna of Yokokura-yama. The former indicates the faunal connection from Japan to Bohemia through the Mongolian geosyncline. Some species of *Encrinurus* on the other hand are related to the Australian ones.

In 1974 the authors described a copious fauna of Mt. Yokokura comprizing 26 species in 14 genera and seven families of trilobites. Recently a new collection made therefrom by Sakō was placed by Katto at the authors' disposal for study. Most trilobites in this collection were obtained at the Gomi quarry and its vicinity and some others found at loc. D among drifts which are presumably derived from the same quarry.

As shown in fossil list, the collection contains 12 species beside a few exactly indeterminable forms, among which three species of *Bumastus* (*agmakros, kattoi, sakoi*) have been already described in the advance report (Kobayashi and Hamada, 1984). The remainder is dealt with in this article. As genera, *Pseudo-*

cheirurus and *Staurocephalus* are new to the fauna, although *Staurocephalus* (?) sp. was already found. *Staurocephalus* as a genus appeared in the Middle Ordovician in Norway, spread widely from Europe to North America on one side and to Australia through Central Asia on the other, being especially extensive in the Wenlockian rocks. Among the Silurian species *Staurocephalus trichochin* looks similar to *S. struszi* from the Wenlockian of Australia.

A pygidium is identifiable with *Proetus sugiharensis*. This find confirms that the *Encrinurus tosensis* horizon at Sugihara shrine is near the fossil beds of Gomi quarry, as considered before. Among 8 new species *Dindymene* (?) *megacranidia* belongs probably to an unnamed genus. *Japonoscutellum* and *Apolichas* are two endemic genera.

As noted already (Kobayashi and Hamada, 1974), *Pseudocheirurus beyrichi* (Barrande) occurs in the lower Ludlovian Kopanina Forma-

tion (Horný and Bastl, 1970). It is the type species of *Pseudocheirurus* to which *Pseudocheirurus gomiensis* appears most similar. Among the Asiatic cheirurids this species is very similar to Nan's *Cheirurus strabo* from the Upper Silurian of Inner Mongolia (1960), instead of Lower Devonian *Cheirurus strabo* Weber, 1932 of Ferghana. These two species suggest that the Yokokura fauna was connected with the Bohemian one through the Mongolian geosyncline in the early Ludlovian age.

Encrinurus subtrigonalis is an aberrant species of the genus resembling *Encrinuroides uncatus* in certain aspects of the cheek. A pygidium referred to this species is similar to *Encrinurus nodai. Encrinurus similis* is represented by another pygidium distinct from that of *E. subtrigonalis*, but they agree with each other so close that the differences may reveal sexual dimorphism. *Encrinurus stenorhachis* is closely related to *E. tosensis*. Combined with *E. yoko-*

kurensis, E. mamelon, E. ishii and *E. fimbriatus* these two species *i.e. similis* and *subtrigonalis* show an intimate relationship with *E. mitchelli* and its allies in Australia through *Encrinurus konghsaensis* in Burma, as pointed out already (Kobayashi and Hamada, 1974).

In adding new elements it can be concluded with more certainty that the Silurian fauna of Mt. Yokokura indicates the faunal connection to Australia through Burma on one side and to Bohemia or Europe on the other through the Mongolian geosyncline.

All of the type specimens of new species were donated by the collector to the Kochi University where they are kept. Before entering into description of trilobites, the authors wish to record their sincere thanks to Professor Emeritus Jiro Katto of the Kōchi University and Mr. Yukio Sakō, ardent fossil collector, for the privilege of describing these interesting trilobites.

Trilobites \ Localities	A	B	C	D
Japonoscutellum geniculatum, sp. nov.	x			
Bumastus agmakros Kobayashi and Hamada	x			
Bumastus kattoi Kobayashi and Hamada	x			
Bumastus sakoi Kobayashi and Hamada	x			
Illaenoid (?) gen. et sp. indet.	x			
Proetus (*Gerastos*) *sugiharensis* Kobayashi and Hamada				x
Pseudocheirurus gomiensis, sp. nov.	x			
Encrinurus subtrigonalis, sp. nov.	x			
Encrinurus similis, sp. nov.	x			
Encrinurus stenorhachis, sp. nov.			x	
Dindymene (?) *megacranidia*, sp. nov.	x			
Staurocephalus trichochin, sp. nov.				x
Phacopid (?) gen. et sp. indet.	x			
Apolichas perconuexus, sp. nov.		x		
Lichid (?) hypostoma, gen. et sp. indet.	x			

Fossil list of additional Silurian trilobites to the Yokokura-yama Fauna
A. Gomi quarry
B. Boulder found near Gomi quarry
C. About 1 km east of Gomi quarry
D. Boulders found between Gomi and Ichiyama villages

Description of trilobites

Family Scutelluidae R. and E. Richter, 1955

Genus *Japonoscutellum* Přibyl and Vaněk, 1971

Japonoscutellum geniculatum
Kobayashi and Hamada, sp. nov.

Pl. 28, Figs. 2a—c.

Description:—Pygidium semiparabolic in outline, about three-fourths as long as wide, flat in inner part, but slanting to depressed margin in outer part. Axial lobe small, elevated above pleural lobes, subtrigonal, tripartite, half as long as wide and a quarter as wide as straight anterior margin which indicates maximum breadth of pygidium; median lobe of axis a little higher than its lateral lobes, crossed by five or six transverse lirae with regular intervals, articulating half-ring stout, isolated from axial lobe by a profound furrow. First pleural rib straight anteriorly, regularly thickening laterally, more prominent than others and isolated from them by a strong pleural furrow well broadened laterally; succeeding furrows narrower than the above rib, anterior ones of which extend as far as lateral margin, but posterior ones die out shortly inside of the margin; median rib much broader than these lateral ribs, most distinctly geniculated, more or less depressed mesially behind the geniculation, but the depression is by no means so distinct as pleural furrows; geniculation becomes insignificant laterally; many weak subconcentric lirae recognizable on all of these ribs, but they become obscure proximally from margin. Test smooth except for such fine lirae.

Comparison:—This species is represented by a single, but almost complete, well preserved pygidium. Its dorsal carapace is exfoliated in the left anterior part where it is seen that the doublure extends at least to the geniculation.

It agrees nicely with the pygidium of *Japonoscutellum japonicum* (Kobayashi and Hamada, 1965), in the outline, texture and some other aspects. It is, however, specifically distinct from that species in regard of the distinct geniculation most emphasized a little behind the mid-length of the broad median rib, shallow mesial depression in its posterior part and the distinct tripartition of the axial lobe with several transverse lirae on its median lobe.

Such geniculation is seen in some genera, *Platyscutellum, Bojoscutellum* and *Planiscutellum*, for example. In the first and second genera, both Lower Devonian in age, the pygidium is respectively pentagonal and elliptical in outline. In Silurian *Kosovopeltis* the median rib is typically simple.

Family Proetidae Salter, 1864

Subfamily Proetinae Salter, 1864

Genus *Proetus* Steininger, 1831

Subgenus *Gerastos* Goldfuss, 1843

Proetus (Gerastos) sugiharensis
Kobayashi and Hamada, 1974

Pl. 29, Figs. 1a—c.

1974. *Proetus (Geratos) sugiharensis* Kobayashi and Hamada, p. 116, pl. 12, figs. 5—6, text-fig. 8C.

Beside an incomplete pygidium this species was founded on the complete pygidium (holotype). The third specimen before hand is also a well preserved pygidium which coincides with the holotype in detail. In this specimen anterior seven ribs, instead of five, are clearly defined. Eight ribs are countable on the right pleural lobe among which the second to fifth ribs are distinctly divided into two bands by insertion of an interpleural rib from their lateral margin.

Family Cheiruridae Salter, 1864

Subfamily Cheirurinae Salter, 1864

Genus *Pseudocheirurus* Prantl and Přibyl, 1947

Pseudocheirurus gomienesis
Kobayashi and Hamada, sp. nov.

Pl. 28, Figs. 1a—c.

1984. *Pseudocheirurus* sp. Kobayashi and Hamada, p. 253, pl. 5, figs. 5a—b.

Description:—Cheirurid cranidium with two

anterior lateral furrows gently curving backward and extending laterally as far as one-third of glabella; preoccipital furrow diagonal and confluent with occipital furrow which is in turn bent forward in its median part. Frontal lobe of glabella nearly as long as two anterior lateral lobes; preoccipital lobe trigonal. Neck ring expanded in median part twice as thick as its lateral terminus. Axial furrows profound and slightly divergent forward. Fixed cheek narrow and ornamented with irregular anastomozing lirae; eye small, located far anteriorly and close to axial furrow. Glabella and marginal borders smooth.

Observation and comparison:—In the frontal view of the cranidium it is seen in the basal part of the frontal lobe of the glabella that there are a pair of linear furrows which are disconnected in the median part.

The principal distinction of the subgenus *Pseudocheirurus* from *Cheirurus* s. str. lies in the seven lobate pygidium of the former. In the cephalon it is noteworthy that the preoccipital furrow is subrectangular and the preoccipital lobe is subquadrate in typical *Cheirurus*. In the diagonal preoccipital furrow and its confluence with the forwardly bent occipital furrow, this subgenus agrees better with *Cheirurus (Crotalocephalus)*, but in the latter the two pairs of anterior lateral furrows are united into two transversal furrows. By this distinction *Crotalocephalus* is separated now from *Cheirurus* generically.

The chief distinction of this species from *Cerauroides orientalis* and *Cerauroides elongatus* in the Yokokura fauna lies in the confluence of its preoccipital furrow with the forwardly bent occipital furrow. The glabella is more expanded anteriorly in *C. orientalis*. The expansion is particularly emphasized at the frontal lobe in *C. elongatus*. Additional differences are the median tubercle on the occipital ring and the relatively broad cheek in *Cerauroides orientalis*.

Didrepanon Lane, 1971 and *Hadromeros* Lane, 1971 have similar glabellae, but their cheeks are broader and their eyes placed more posteriorly.

Nan's *Cheirurus strabo* from the Upper Silurian of Inner Mongolia (Nan, 1976) looks very similar to this species. *Cheirurus strabo* Weber, 1932, is however, a Lower Devonian trilobite of Ferghana, Turkestan.

Family Encrinuridae Angelin, 1854

Subfamily Encrinurinae Angelin, 1854

Evitt and Tripp (1977) included in this subfamily the following twelve genera.

Encrinurus Emmrich, 1844
Cromus Barrande, 1852
Frammia Holtedahl, 1914
Coronocephalus Grabau, 1924
Encrinuroides Reed, 1931
Fragiscutum Whittington and Campbell, 1967
Encrinuraspis Webby, Moors and McLean, 1970
Erratencrinurus Kruger, 1971
Senticuculus Xia in Chang, 1974
Kailia Chang, 1974
Celtencrinurus Evitt and Tripp, 1977
Physemataspis Evitt and Tripp, 1977

Then Wu Hong-ji (1979) splitted *Coronocephalus* and *Kailia* each into two subgenera as follows:

Coronocephalus (Coronocephalus) Grabau, 1924
Coronocephalus (Coronocephalina) Wu, 1979
Kailia (Kailia) Chang, 1974
Kailia (Parakailia) Wu, 1979

Strusz (1980) synonymized *Encrinuraspis* with *Cromus* on one hand and on the other he added *Paraencrinurus* Antelo, 1973 and *Batocara*, gen. nov. whose type species is *Encrinurus bowningi* Foerste, 1888. An additional genus is *Balizoma* Holloway, which is founded on *Calymene variolaris* Brongniart, 1822.

Genus *Encrinurus* Emmrich, 1844

According to Strusz (1980), *Cryptonymus* Eichwald, 1840, *Michellaspis* Henningsmoen in Moore, 1959, *Mitchellia* Vogdes, 1917, non de Koninck, 1877 and *Calcachia, Paracalcachia,*

Aristobeggia, Letichia and *Trippia* Lamont, 1978 are all synonymous with *Encrinurus*. He recognized in this genus three species plexi as follows:

1. *Encrinurus variolaris* plexus
2. *Encrinurus punctatus* plexus
3. *Encrinurus mitchelli* plexus

Holloway (1980) on the contrary proposed *Balizoma* for members of the *variolaris* species group listed by Tripp, Temple and Gass (1977) except *E. diabolus* and *E. anticostiensis* which were both considered to belong to *Fragiscutum*, but it includes *E. nereus* Hall, 1867, *E. indianensis* Kindle and Bregger, 1904, *E. tuberculifrons* Weller, 1907 and *E. hyperborea* Thomas in Thomas and Narbonne, 1979. Strusz on the other hand referred the following species to his *Encrinurus variolaris* plexus.

Cromus transiens Barrande, 1852
Encrinurus poloeckensis von Gaertner, 1930
Encrinurus kiltsiensis Rosenstein, 1941
Encrinurus pilisyverensis Rosenstein, 1941
Encrinurus rumbatensis Rosenstein, 1941
Encrinurus brevispinosus Haas, 1968
Encrinurus schmidti Männel, 1968

in addition to *E. diabolus, E. anticostiensis, E. indianensis, E. rosensteinae* and some others.

The *Encrinurus mitchelli* plexus most flourished in eastern Australia where occur *Encrinurus mitchelli* Foerste, 1888.

Encrinurus etheridgei Mitchell in Etheridge and Mitchell, 1916
Encrinurus rothwellae Etheridge and Mitchell, 1916
Encrinurus silverdalensis Etheridge and Mitchell, 1916
Encrinurus borenorensis Fletcher, 1950
Encrinurus civica Strusz, 1980

Strusz (1980, p. 53) is of opinion that the existence of intermediate species precludes the recognition of the three plexi as distinct genera or even subgenera.

As to the Japanese species of *Encrinurus, E. yokokurensis, E. mamelon, E. tosensis, E. ishii, E. fimbriatus* and *Encrinurus stenorhachis*, sp. nov. are comparable with *Encrinurus borenorensis, E. mitchelli, E. rothwellae* (i.e. *E. incertus*)

or/and *E. silverdalensis* in one or other characteristic. They are, as a whole, considered by Strusz to belong probably to the *mitchelli* plexus. As pointed out by the authors *Encrinurus yokokurensis* may be nearest to *Encrinurus konghsaensis* Reed, 1906 from Burma which is in turn referred also to the *mitchelli* plexus. Therefore the *Encrinurus mitchelli* plexus must be a characteristic trilobite group for the western Pacific fauna in the Silurian period.

Encrinurus nodai is probably better placed in the *variolaris* plexus or *Encrinurus (Balisoma)* rather than the *punctatus* plexus or *Encrinurus (Encrinurus)*. *Encrinurus subtrigonalis*, sp. nov. which resembles *Encrinuroides uncatus* Evitt and Tripp, 1977 is quite distinct from most species of *Encrinurus*, although it is not an *Encrinuroides*.

Among six species of *Encrinuroides* described by Chang (1974) from the Silurian of Southwest China *E. meitanensis* Chang and *E. meijiangensis* Chang were referred to *Encrinurus* or the *E. variolaris* plexus by Strusz (1980). The former has long genal spines. Both of them have non-mucronate triangular pygidia with median tubercles on the axes like *Encrinurus fimbriatus*, but the median smooth band is apparently absent or undeveloped in them.

<center>

Encrinurus subtrigonalis
Kobayashi and Hamada, sp. nov.

Pl. 28, Figs. 4a—e; Pl. 29, Figs. 2a—d.

</center>

1984. *Encrinurus* sp., Kobayashi and Hamada, p. 254, pl. 5, figs. 5a—b.

Description:—Cephalon subtriangular with broadly rounded genal angles and strongly inflated, highest in frontal part of glabella and densely covered by granules of different sizes. Glabella very large, strongly convex, expanding forward, shortly projected beyond frontal border and drooping; granules of various sizes distributed densely on surface; three pairs of large nodose lobes clearly defined by deep but short lateral furrows in posterior part of glabella; three granules or nodes of medium

size aligned on antero-lateral margins and twelve granules on anterior margin; median interspace a little broader than other intergranular space, but not depressed in form of a furrow; small and large granules scattered on glabella irregularly besides medium sized ones in smaller number; most granules pitted at center. Occipital furrow very deep; a pair of narrow preoccipital lateral ridges present; neck ring a little broader than glabellar base, but bent up mesially with straight posterior and gently arcuate anterior margins; axial furrow as strong as occipital one continuing to shallow marginal furrow on one side and deep lateral marginal furrow on the other side at the most expanded point of glabella. Fixed and free cheeks well united and globular, but truncated by axial furrow, densely granulated and pitted at each interspace; three large granules disposed alternately with nodose lateral lobes of glabella on two sides of axial furrow; eyes located a little behind cheek center and prominent. Frontal marginal rim indicated by a row of granulation, 12 to 14 in number. Lateral border embracing cheek, very wide, ornamented with two rows of granules, coarser on the inner side than the other and arranged more or less alternately; these granules pitted at center; outer margin of lateral border edged and provided with numerous minute granules. Posterior cheek border, occipital ring and all furrows non-granulate.

Pygidium subtrigonal, a little wider than long and strongly convex; anterior margin arcuate, longer than lateral margin, and distinctly bent postero-laterally from middle part of first pleural rib. Axial lobe highly elevated above pleural lobes, composed of about 14 tuberculate axial rings and a terminal piece whose segmentation is obscure; first axial ring particularly large and prominent, separated from smooth articulating half-ring by profound furrow; anterior two ring furrows transversal, but succeeding ones are interrupted by flat median band with which ring furrows are confluent; anterior two axial rings with five tubercles, median one of which is somewhat larger than others; large tubercles present in median band, particularly large at

third and sixth rings; succeeding tubercles may be aggregates of two or three small tubercles. Pleural lobe rising up gently from axial furrow, then strongly arching down to lateral margin; pleural ribs nine in number, separated by deep furrows, truncated at their termini and carrying tubercles, countable five on second rib and three on seventh rib; such tubercles aligned subparallel to axial furrow or lateral margin, forming five rows among which third and fourth rows are persistent through all ribs.

Observation:—The granules on the glabella vary in size, and their distribution is so disordered to find no definite pattern. The minute pits are seen on many granules. As stated above, the median anterior space is a little broader than lateral ones along the frontal marginal furrow, but it is by no means a distinct median furrow.

The position of the eye can be ascertained by its scar or eye-socle which is a little elevated above the general cheek surface. It is probable that the eye in question is shortly stalked. The intergranular pits are distributed regularly on the cheek. The facial suture runs from the eye to the lateral expansion of the marginal border. Its anterior branch is obscure. The granules aligned on the outer edge of the lateral border are numerous, small and close-set. The posterior cheek border and occipital ring are not granulate, but they are rectangularly cut with some interspaces. This aspect, however, looks secondary rather than primary. The granulate and pitted texture of the cheek, the very broad lateral cheek border, its two rows of granules and its prominent peripheral edge are important characteristics of this species.

The collection contains two pygidia of similar outline between which the one having tuberculate pleural ribs are provisionally selected for this species. In the antero-ventral view the two lateral borders of the cephalon form an angle of about 80 degrees in front of the glabella which fits in the subtrigonal pygidium in rolling. The long and short rows of the tubercles through the ribs are very distinctive of this pygidium. These characteristics of the cephalon as well

as the pygidium easily distinguish this species from other species of *Encrinurus*. Like *Encrinurus nodai* this pygidium is paucisegmented and its axis is broad and provided with median tubercles, but it has one more pleural rib than *E. nodai* and the median band is well developed in this species.

In the tuberculation and punctuation of the cheek and its very thick lateral border this species closely resembles *Encrinuroides uncatus* Evitt and Tripp, 1977 (pl. 6, figs. 7a—b). In this cephalon, however, the genal angle is well rounded without spines. Furthermore, the antero-median glabellar furrow is absent and the preoccipital ridge present. The narrow preglabellar area as seen in *Encrinuroides sexcostatus* (Salter) (in Whittington, 1950) and other species is also absent in this cephalon. The pygidum is subtriangular in this species.

Encrinurus similis Kobayashi and
Hamada, sp. nov.

Pl. 29, Figs. 4a—d.

This pygidium is very similar to the preceding in the outline and convexity of the carapace, proportional size between the axial and pleural lobes, number of their segmentation and the possession of the median band and tubercles on the axial lobe, but the tuberculation is less developed in this pygidium. The postero-lateral bent of the anterior margin on its two sides is more distinct and the arching down of the

pleural lobe in its abaxial part is more emphasized in this pygidium. The pleural ribs number nine or ten in that pygidium, but seven or eight in this pygidium.

In this axial lobe the anterior three axial rings, instead of two in that pygidium, are defined by two transverse ring furrows. Accordingly the smooth median band extends backward from the fourth ring. The large tubercles on the band are at the fifth, eighth (scar), twelfth and sixteenth rings, while they are at the third, sixth, eighth, ninth and eleventh rings in the preceding pygidium, although such a distribution may vary within a species to some extent. Small tubercles occur on the lateral part near the median band at a few rings. The most important distinction from the preceding pygidium lies in the absence of large tubercles on the pleural ribs in this pygidium. In the exfoliate part it is clearly seen that the post-axial ridge is embraced by the last pair of pleural ribs.

This pygidium is so similar to the preceding that they may reveal sexual dimorphism.

Among the other species of *Encrinurus* in Japan it is very similar to *E. tosensis* and *E. ishii*, but less segmented in this species.
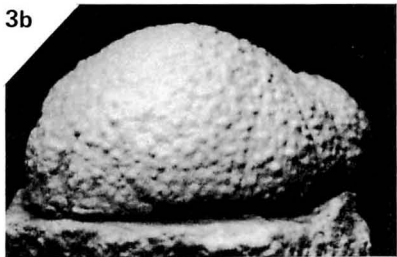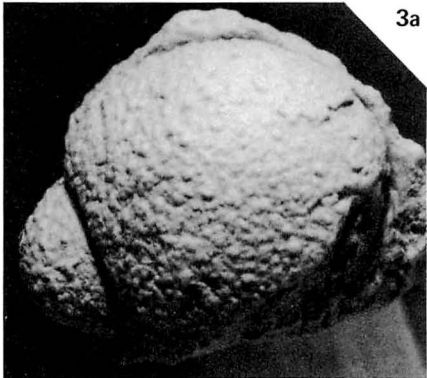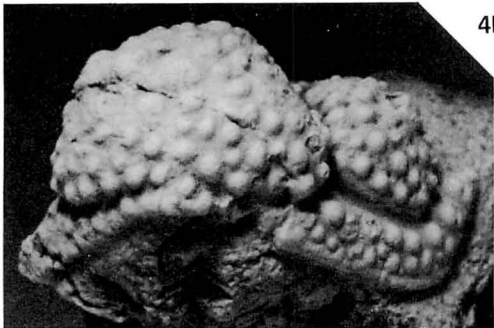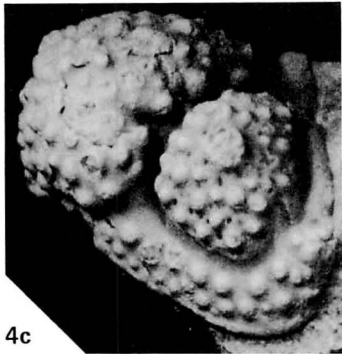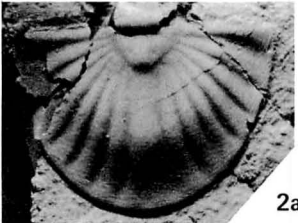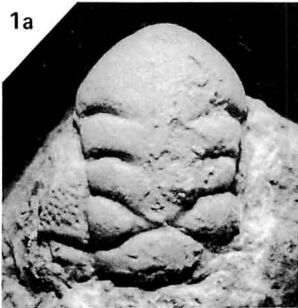
Encrinurus stenorhachis
Kobayashi and Hamada, sp. nov.

Pl. 29, Figs. 3a—c.

1974. *Encrinurus* A-2 type pygidium, Kobayashi and Hamada, p. 98, pl. 10, figs.

Explanation of Plate 28

9a—c, text-fig. J.

This is a subtrigonal pygidium having a narrow axial lobe without median tubercles. It is an internal cast whose outline and convexity are somewhat modified secondarily by lateral compression.

The axial lobe is narrow and tapers back rather abruptly in anterior, but gradually in the middle and posterior parts and rounding off at the terminus at a short distance from the posterior margin of the pygidium. It is divided into about 22 axial rings by ring furrows which are not exactly countable in the posterior part. The post-axial area is ill-preserved. The lobe is one-fifth or less as wide as the pygidium in its middle part, strongly arching down near the posterior end. It is a little elevated above the pleural lobes and flattopped. The median smooth band is not well developed.

Separated from the axis by strong axial furrows, the pleural lobes are divided into about nine ribs by pleural furrows which are broader than the ribs on the cast. In the lateral half the lobe is distinctly sloping down to the margin.

Compared to another pygidium of the A-2 type subgroup the axial lobe looks somewhat broader in this by deformation. There are also some differences on the posterior terminal part which is not well preserved in these pygidia. Nevertheless, these two pygidia agree with each other in most other characteristics. *Encrinurus tosensis* is similar to this species in the outline of the pygidium and its ribbing, but the axial lobe is broader and penetrated by a median smooth band in that species.

Subfamily Dindymeninae Kielan, 1959

Genus *Dindymene* Hawle and Corda, 1847

Dindymene (?) *megacranidia*
Kobayashi and Hamada, sp. nov.

Pl. 28, Figs. 3a—c.

Description:—Cephalon strongly vaulted toward its center, globular but truncated by posterior margin, widest through mid-length of cheeks, and trisected by nearly straight axial furrows into very large glabella and relatively small cheeks. Glabella with a pair of linear longitudinal furrows of moderate length incised into anterior part of glabella near its lateral ends, but no distinct lateral furrows are present. Marginal rim narrower than marginal furrow. Test densely granulate.

Observation:—The occipital ring is unpreserved and the posterior outline of the cephalon unknown. The glabella exclusive of the ring as long as 0.7 of the cephalic breadth and as wide as 0.6 of the breadth in posterior, but expanded to 0.7 in anterior. The cheek occupies only 0.17 of the cephalic breadth.

One or two rudimentary lateral furrows may be present on the left side of this glabella, but they are so obscure that their being furrows cannot be convinced. On the left cheek an elliptical more or less smooth area is seen on its antero-lateral side, but it is not clearly outlined and a few granules are found also in this area. Therefore it is probably not an eye-scar and this is most probably blind.

Comparison:—Compared to *Dindymene* the cephalon is quite narrow and the cheek very small, if compared to the glabella. This cephalon lacks the distinct preoccipital lobe typical of *Sphaerexochus.*

Family Staurocephalidae
Prantl and Přibyl, 1948

Besides *Staurocephalus* this family included *Oedicybele* Whittington, 1938 in Moore's Treatise, 1959. Evitt and Tripp (1977) added *Liberella* Hu, 1971 to them and suggested that *Rongxiella* Chang, 1974 may be still another genus of the family.

Genus *Staurocephalus* Barrande, 1846

Staurocephalus appeared in the Middle Ordovician age in Norway, spread widely in Europe from Britain to Poland and further to Kazakhstan and widest in the Silurian period, particularly in Wenlockian, occurring not only in Eurasia but also in Australia and North

America (Kielan, 1957).

In describing *Staurocephalus susanae*, sp. nov. from the Wenlockian of Dudley, England, Thomas (1981) enumerated nine other species of the genus as follows:

Staurocephalus murchisoni Barrande, 1846, Wenlock, Ludlow; Bohemia

S. obsoletus Weller, 1907, Niagaran; Illinois

S. elegantus Freyburg, 1923, Llandeilian; Germany

S. struszi Chatterton and Campbell, 1980, Wenlockian, Canberra

S. mitchelli Chatterton and Campbell, 1980, Ludlow; New South Wales

S. pilafrons Owen and Bruton, 1980, Caradoc-Ashgill, Oslo

S. lagena Holloway, 1980, Wenlockian, Arkansas

S. otarion Holloway, 1980, ditto.

The eleventh species is *Staurocephalus trichochin* here described.

Staurocephalus sp. and *Staurocephalus* (?) sp. were reported from Upper Ordovician and *Staurocephalus murchisoni* from Silurian all in Turkestan by Weber (1948, 1951). The second is represented by a glabella and the two others by cranidia whose frontal lobes of glabellae are protruded far from their cheeks which are relatively large and not so convex as in *S. trichochin*.

Staurocephalus trichochin Kobayashi and Hamada, sp. nov.

Pl. 30, Figs. 2a—e.

1984. *Staurocephalus* sp., Kobayashi and Hamada, p. 254, pl. 5, figs. 6a—b.

Description:—Cephalon a little longer than broad and strongly inflated. Glabella composed of a very large frontal lobe and a comparatively small posterior lobe; frontal lobe three-fourths as long as cephalon, sphaerical, elevated highly toward its center; posterior lobe exclusive of neck ring nearly half as long as frontal lobe, truncato-conical in outline; lateral furrows indistinct; occipital and axial furrows deep. Cheek suboval, more or less elongate, highly swelling up, but its top is slightly lower than posterior glabellar lobe, much smaller than frontal lobe of glabella; eyes small, located at top near cheek-center. Marginal border not indented, describing semicircle and running below frontal glabellar lobe behind its mid-length; lateral marginal border flat and depressed, lacking furrow on its inner side. Small tubercles widely distributed on whole surface except for furrows.

Observation:—Neither distinct furrow nor pit is seen on the lateral side of the glabella. The position of the eye is indicated on the specimen by its scar. The genal angle is obtuse; genal spine apparently absent.

Explanation of Plate 29
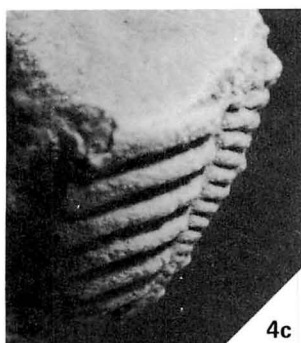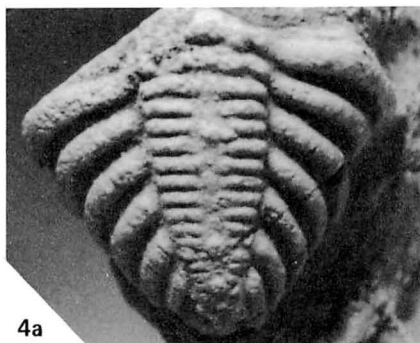
Comparison:—The extraordinarily large and strongly convex frontal lobe of the glabella, its long forward protrusion far beyond the frontal border, obsolete lateral furrows on the glabella, the comparatively small cheeks and non-indented marginal border are very distinctive from other species of this genus. Compared to *Staurocephalus murchisoni* (Horný and Bastl, 1970, pl. 15, fig. 7) the frontal lobe of the glabella is larger, but less projected forward and the posterior lobe is very small, if compared with the cheeks as well as the frontal lobe.

Among several forms described by Kielan (1957, 1959) this species closely resembles *Staurocephalus* sp. b (pl. 3, figs. a—c, 1957) and also *Staurocephalus clavifrons* (pl. 26, fig. 9, 1959) from the Upper Ordovician of Sweden and Poland respectively. In this species, however, the frontal lobe of the glabella is much larger in comparison with cephalon and cheeks. This species is similar to *Staurocephalus struszi* in the glabellar aspect, but it has a very thick margianl border. In this species the border is narrow and short margianl spines and long genal spines are apparently absent.

Staurocephalus (?) sp. indet. described by the authors (1974) from the Yokokura-yama limestone at Gomi is quite distinct from this species in the frontal glabellar lobe not so long and provided with a narrow granulate belt along its posterior margin.

Family Lichidae Hawle and Corda, 1874

Subfamily Homolichinae Phleger, 1936

Genus *Apolichas* Kobayashi and Hamada, 1974

Apolichas perconvexus
Kobayashi and Hamada, sp. nov.

Pl. 30, Figs. 3a—d.

Cephalon semi-elliptical, as long as strongly vaulted; its height corresponding to three-fourths of its length; median lobe separated from tricomposite lateral lobes by nearly straight longitudinal furrows; lateral lobe half as wide as median lobe; marginal border narrow and de-pressed.

This cephalon differs from *Apolichas truncatus* in the much longer outline and greater convexity of the cephalon and the shape of the main glabellar lobe limited by straight longitudinal furrows.

The cheeks are not preserved in the specimen.

Lichid (?) hypostoma, gen. and sp. indet.

Pl. 30, Fig. 4.

The main body of this hypostoma is sub-quadrate, much broader than long, broadly arcuate anteriorly and narrowing backward; posterior margin straight; at about one-third the length of the body; a pair of profound furrows cutting into the body from lateral sides for about a quarter of the breadth and pitted at the termini. Lateral and posterior furrows strong; lateral border more or less crescentic and depressed; a pair of large flat spines extending postero-laterally from main body.

This hypostoma is similar to that referred to *Apolichas truncatus* in the subquadrate main body provided with the flat and depressed lateral and posterior borders. It is, however, quite different from that hypostoma in the possession of the crescentic lateral border and the large and flat posterior spines.

The posterior part of the hypostoma is commonly produced backward from its lateral sides in the Lichinae, Homolichinae and Tetralichinae (Tripp, 1957, text-fig. 4), but the posterior projections are not so far prolonged into such posterior spines.

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Explanation of Plate 30

Bumastus sakoi Kobayashi and Hamada .... Page 207
      Figs. 1a—e. Dorsal, posterior, frontal, left-lateral and right-lateral views of the holotype cranidium. ×3.3 KGS 3529.

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      Figs. 2a—e. Dorsal, anterior, posterior, right-lateral and left-lateral views of the holotype cephalon. ×3.4 KGS 3631.

Apolichas perconvexus, sp. nov. .... Page 215
      Figs. 3a—d. Dorsal, frontal, left-lateral and right-lateral views of the holotype cephalon. ×2.1 KGS 3632.

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      Fig. 4.   A ventral view. ×3.6.

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      Figs. 5a—c. Dorsal, frontal and right-lateral views of the holotype cranidium. ×3.7 KGS 3590.

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      Fig. 6.   A dorsal view of the holotype pygidium. ×2 KGS 3588.
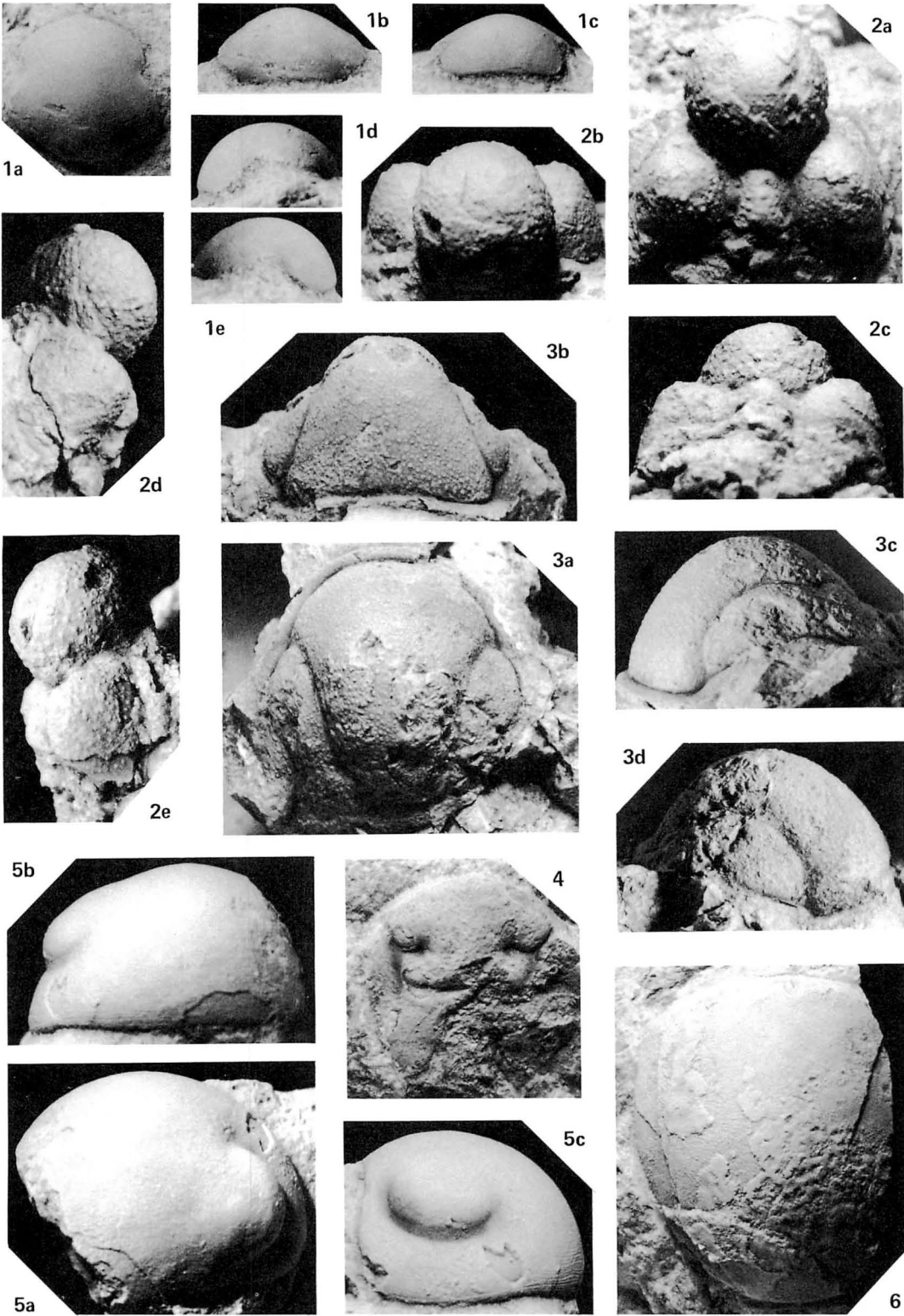
allied species, with notes on *Frammia*. *Ibid.* v. 20, no. 4, p. 847—867.

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四国の横倉山フォーナに追加するシルル紀三葉虫：甲藤次郎氏の好意で左向コレクションを研究し化石表に示す通りの鑑定結果に達した。1既知種の外に11新種がありその3種は最近高知大学の紀要に記載した。残余の8新種中 *Pseudocheirurus* と *Staurocephalus* とは属としてもこのフォーナに新しいものである。*Pseudocheirurus gomiensis* は Ludlow 前期にこのフォーナが蒙古地向斜を経てボヘミアのものと繋っていたことを示す。他方で *Encrinurus* の諸種はビルマを通じてオーストラリア東部のフォーナとの類縁がある。　小林貞一・浜田隆士

803.   DISCOVERY OF A MIDDLE JURASSIC AMMONITE *KEPPLERITES* FROM THE MINO BELT, CENTRAL JAPAN*

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Abstract.   A Middle Jurassic *Keppleritis* (*Seymourites*) was discovered from the olistostrome bed exposed on the Nagaragawa River bed, NW of Gujo-Hachiman. Because this genus is known to occur in the boreal realm in Upper Bathonian to Lower Callovian, the occurrence of this genus from the Mino Belt bears particularly important meaning in the paleogeographical reconstruction of Jurassic Japan.

A Middle Jurassic ammonite, *Kepplerites*, was discovered from fine-grained sandstone exposed on the river bed of the Nagaragawa River near Tokunaga in Yamato-mura of Gifu Prefecture. The location is about 10 km NW of Gujo-Hachiman, between two junctions of the Nagaragawa River with its tributaries Oomamigawa and Kurisugawa Rivers ($35°48'15''$N and $136°54'10''$E) (Text-fig. 1).

Mr. K. Kijima, inhabitant at Tokunaga, while fishing at the site, noticed the occurrence of this ammonite, and communicated to Mr. H. Tanaka, member of the Editorial Committee of the Village History. Mr. Tanaka collected the specimen in collaboration with Kasahara. A resin mould was taken in situ, and sent to Sato for identification. Wakita studied the geology of the fossil locality.

The ammonite was preserved in sandy siltstone exposed on the river bed of the middle reaches of the Nagaragawa River. This is a part of the sequence of slump facies A of Wakita and Okamura (1982), composed mostly of massive sandstone and alternation of mudstone-sandstone with allochthonous blocks and slabs of chert and greenstone, zonally distributed in NW-SE direction along the main stream of the Nagaragawa River. This has been hitherto classified in Upper Paleozoic, but the Jurassic age is recently proved by the discoveries of radiolarians (Wakita and Okamura, *op. cit.*).
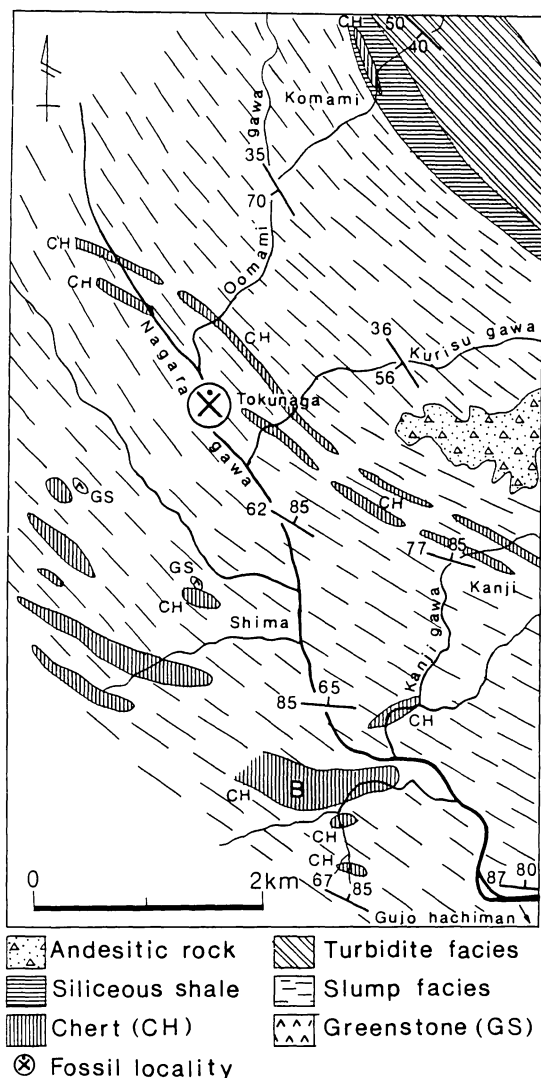
Text-fig. 1. Location of the occurrence of *Kepplerites*. Base map adopted from Wakita and Okamura, 1982.

Description of species

Kepplerites (*Seymourites*) sp.

Text-fig. 2.

cf. *Kepplerites* (*Seymourites*) *acuticostum* Kobayashi, 1947, p. 28, pl. 7, fig. 2.

Material:—An outer cast impressed on the sandy siltstone. Very fragmentary, only a part around the umbilicus is preserved. Observable maximum size is 7 cm.

Description:—The whorl in the inner stage is very involute but later suddenly becoming evolute, giving rise to an eccentric volution. The section of the whorl is unknown but in the preserved part, the umbilical wall is rounded and the flank is slightly convex. The ventral region is not observed.

The ribs are sharp and closely spaced. Strong and clearly concave primary ribs, numbering about 34 per one volution, are bi- or tri-furcated at the inner 1/3 height of the flank. Secondary ribs are distinctly finer, and somewhat sinuous in general. Free intercalatory ribs are frequent beside the bi- or tri-furcated secondary ribs. A small but well definable tubercles are superimposed on the points of bifurcation.

No suture line is visible.

Remarks:—The specific determination is impossible because the specimen is very fragmentary. However, the strongly eccentric coiling with sudden widenning of the umbilicus and the sharp, closely spaced and bi- or tri-furcated ribbing are all indicative of *Kepplerites* (*Seymourites*).

Among already known species of this genus, the Japanese specimen of *K.* (*S.*) *acuticostum* described from the Kuzuryu area resembles considerably the present specimen, in view of its closely spaced, and sharp ribbing. Unfortunately, lack of other characteristics in the present specimen does not allow the identification with that species.

Age:—Even if the species is undeterminable, the present ammonite shows undoubtedly late Middle Jurassic age.

The genus *Kepplerites* has been generally thought to be a Lower Callovian indicator, and is chosen as a representative of the *Kepplerites* zone in NE Pacific. This was also adopted in the Jurassic biochronology proposed in the Kuzuryu area. However, its time range is now considered to extend into Upper Bathonian, as indicated in British Columbia by the coexistence with *Iniskinites* where an independent zone was established in Upper Bathonian (Frebold, 1978).

Text-fig. 2.   Side view of *Kepplerites* (*Seymourites*) sp. Natural size.
Photograph was taken from the resine mould. Original is an impression.

This is also true in the Western Interior of the United States, where this genus occurs with *Cobbanites, Parareineckeia* or *Cadoceras* (Imlay, 1981).

In Japan, in particular in the Kuzuryu area, *Kepplerites* (*Seymourites*) forms an assemblage zone in association with *Grossouvreia* and *Lilloettia* which were assigned to Lower Callovian (Sato, 1962). There are coexisting genera known from the Bathonian, such as *Lilloettia*, but their identifications are not very reliable, because the specimens are all fragmentary. It is therefore concluded that the present specimen of *Kepplerites* (*Seymourites*) indicates a range from Upper Bathonian to Lower Callovian, but most probably Lowest Callovian.

Discussion

The occurrence of *Kepplerites* (*Seymourites*) in the Mino Belt bears an important meaning. Firstly, it gives the firm basis for the correlation with the Middle Jurassic, besides the radiolarians. Secondly, this is an ammonite indicative of the "boreal" faunal province in Middle Jurassic (*e.g.* Enay, 1980) and the southern limit of the distribution of this genus in the Circum-Pacific region lies as south as Western Interior U.S.A. and central Japan (*e.g.* Westermann, 1980). It was further discussed that Japan was situated at the locus of encounter of cold and warm oceanic currents in Jurassic (Sato, 1960). In fact, *Kepplerites* (*Seymourites*) is, known from Kuzuryu and southern Kitakami (Kobayashi, 1947) in addition to the occurrences of *Kepplerites* (*Gowericeras*), though different subgenerically, from southern Kitakami (Takahashi, 1969).

The discovery of the "boreal" ammonite genus from the Mino Belt tells as a matter of consequence that the belt was in the realm of the "boreal" biogeographic province. Whether the climate of this province was actually cold or not is of little importance, but it should

be emphasized that the province encompassed the northern part of the present Northern Hemisphere. The restoration of the paleocontinent does not alter much the situation (Owen, 1983). The claim that the Mino Belt was located down south from the paleomagnetic requirement (*e.g.* Hattori, 1982) cannot be easily admitted, from the paleobiogeographic point of view.

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Gujo-Hachiman 郡上八幡　　Kanji 神路　　Kanjigawa River 神路川　　Komami 小間見　　Kurisu-gawa River 栗巣川　　Nagaragawa River 長良川　　Oomami 大間見　　Oomamigawa River 大間見川　　Shima 島　　Tokunaga 徳永　　Yamato-mura 大和村

中部日本美濃帯から中期ジュラ紀アンモナイト *Kepplerites* の産出。郡上八幡北西方約 10 km の長良川河床の露頭から，中期ジュラ紀のアンモナイト *Kepplerites* (*Seymourites*) sp. が発見された。これは，Bathonian 後期から Callovian 初期にかけて生存し，この時期に明瞭に識別される北極区に特有なアンモナイトである。九頭龍・北上からも同じ属の産出が知られているが，これは当時の日本の古地理を考える上で重要な資料となろう。

佐藤　正・笠原芳雄・脇田裕二

PROCEEDINGS OF THE PALAEONTOLOGICAL SOCIETY OF JAPAN

日本古生物学会第 134 回例会

日本古生物学会第 134 回例会が1985年 6 月15・16日に大阪市立大学理学部を会場として開備された。

シンポジウム「化石放散虫の分類・古生物地理・生層序——最近の研究成果より」

シンポジウムをもつにあたって................
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行 事 予 定

	開 催 地	開 催 日	講演申込締切
1986年 年会・総会	東北大学・他	1986年1月31日～2月2日	1985年11月30日

講演申込先：113 東京都文京区弥生 2-4-16　日本学会事務センター　日本古生物学会　行事係

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