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Benthonic Foraminiferal Biostratigraphy of the Standard Areas of Middle Miocene in the Pacific Side Province, Central Japan

By

Isao KONDA*

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Abstract

The benthonic foraminiferal assemblages from the Tomioka and Nishiyatsushiro groups distributed in the Pacific side province, Central Japan, selected by IKEBE *et al.* (1977) as the composite stratotype of the Kaburan Stage (Middle Miocene) and subdivided by CHIJI and KONDA (1978) into two substages, the lower Kaburan and upper Fujian substages, were studied.

The following nine and four assemblage zones were recognized in ascending order, respectively.

Tomioka Group

Melonis-Stilostomella Zone
Cyclammina-Discammina compressa Zone
Cibicidoides pseudoungerianus-Stilostomella lepidula Zone

* Nara Senior High School

Martinottiella communis-Spirosigmoilinella compressa Zone
Stilostomella-Trifarina kokozuraensis Zone
Cassidulina norcrossi-Trifarina kokozuraensis Zone
Uvigerina proboscidea-Lenticulina lucida Zone
Uvigerina proboscidea-Praeglobobulimina pupoides Zone
Ammonia tochigiensis-Amphycoryna tubulata japonica Zone

Nishiyatsushiro Group

Melonis pompilioides-Ammodiscus incertus Zone
Globobulimina auriculata-Melonis nicobarensis Zone
Globobulimina auriculata-Nodosaria longiscata Zone
Melonis pompilioides-Stilostomella ketienziensis Zone

The relation between these assemblage zones of the first group and those of the latter is shown in Fig. 9, together with the horizons of the first (or last) occurrences of important planktonic foraminifera recognized in these sequences.

Judging from the stratigraphic distribution of planktonic and benthonic foraminifera, it may be concluded; (1) the sedimentary environment of the Tomioka Group was the upper bathyal zone under the influence of the warm water current from the late Early Miocene to the early Middle Miocene, but afterwards, it became shallower and changed to the outer or middle neritic zone, and a shifting of the current so as to allow the appearance of cold water species of planktonic foraminifera took place during the middle—late Middle Miocene in the area; (2) on the other hand, the sedimentary environment of the Nishiyatsushiro Group has continued to be the upper bathyal zone throughout that time under the warm water condition.

The fuanal changes of benthonic foraminifera in the *Globorotalia peripheroacuta/Globorotalia miozea* (s.s.) and *Globorotalia bykovae/Globorotalia menardii* zones reported by Maiya and Murata (1977) from the Hiki Hill and the Daigo-Omiya area of the Kanto district seem to resemble those recognized in the *Globorotalia peripheroacuta/Globigerina nepenthes* Interval-Zone of the Tomioka Group. It may be said, therefore, that the marine regression from the north and west of the Kanto district began in the middle stage of the Middle Miocene.

Besides, referring to the faunal character of benthonic foraminifera from the Middle Miocene sequences distributed not only in the Kanto district but in the adjacent areas of the Pacific side province, Central Japan, some problems which should be reinvetigated in future were discussed.

I. Introduction

During the past several years, the author has been studying the planktonic foraminiferal biostratigraphy of the Neogene sequences, especially of the Tomioka Group distributed in Tomioka City and its environs, Gunma Prefecture, and of the Nishiyatsushiro and Shizukawa groups exposed in Shimobe-cho, Yamanashi Prefecture, the Pacific side province of Central Japan.

Based on the result of this study, the Tomioka and Nishiyatsushiro groups were selected and redefined by IKEBE *et al.* (1977) as the composite stratotype of the Kaburan Stage (Middle Miocene) which was proposed by IKEBE and ASANO (1973). It was found, furthermore, that the age of the Tomioka Group is assigned from the late Early Miocene to the late Middle Miocene, and that the Nishiyatsushiro and Shizukawa groups from the middle Middle Miocene to the middle Pliocene. Subsequently, the Kaburan Stage was subdivided by CHIJI and KONDA (1978) into two substages, the lower Kaburan (s.s.) and the upper Fujian Substages.

Meanwhile, the remarkable progress in the studies of planktonic microfossils in the 1960's made possible to correlate precisely the Neogene marine sequences scattered over the Pacific coast areas of Central and Southwest Japan. Through the recent studies of these sequences by many micropaleontologists, it has revealed that the greater part of the Middle Miocene Seriese is lacking in marine sequences in many places of the Pacific side province of Southwest Japan (IKEBE *et al.*, 1973, 1977). Therefore, the Tomioka and Nishiyatsushiro groups have come to be the most important and valuable sequences to elucidate the Middle Miocene paleoenvironment of the Japanese Islands.

The purposes of the present paper are: (1) to describe in detail the faunal composition of benthonic foraminifera from the Tomioka and Nishiyatsushiro groups as the representatives of the Middle Miocene faunsa of Japan; (2) to establish the biostratigraphic zones based on the benthonic foraminiferal assemblages taken from the groups; (3) to elucidate the paleoenvironmental changes of Middle Miocene sedimentary basins in the Pacific side province, Central Japan.

The sedimentary environment of the Shizukawa Group is not referred in the present paper. Because, the age of the group is assigned from the Late Miocene to the middle Pliocene and benthonic foraminifera scarcely occur, if any, their preservation is unfavorable for the quantitative analysis, and emphasis is given, as mentioned above, to the Middle Miocene faunal character and paleoenvironment.

All of specimens used in the present study are deposited in the Osaka Museum of Natural History.

II. Acknowledgements

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III. Stratigraphy of the standard areas of Middle Miocene in the Pacific side province

Brief summaries of the lithostratigraphic and biostratigraphic units of the Tomioka and Nishiyatsushiro groups are given here in ascending order. Detailed description of these units are available from the previous papers (AKIYAMA, 1957; CHIJI and KONDA, 1978; MATSUMARU, 1967, 1977).

1. Lithostratigraphy

Tomioka Group (**Figs. 2, and 3**)

a. Ushibuse Formation; massive sandstone, adjacent to Pre-Tertiary rocks (green schist) with fault, thickness 70 m+.

b. Obata Formation; alternation of mudstone and sandstone comprising *Miogypsina* in the lower part, thickness 800 m.

c. Idozawa Formation; mudstone in the lower part with acidic tuff at the base, and alternation of mudstone and sandstone comprising *Nephrolepidina* and *Miogypsina* in the upper part, thickness 450 m.

d. Haratajino Formation; mainly mudstone, and alternation of sandstone and mudstone with acidic tuff at the base, thickness 300 m.

e. Niwaya Formation; mudstone in the lower part with acidic tuff at the base, and sandstone intercalating mudstone in the upper part, thickness 250 m.

f. Yoshii Formation; mainly mudstone with acidic tuff at the base and the Fujiki Tuff dated at 11.6±0.4 m. y. (K-Ar, on biotite, Shibata *et al.*, 1979) at the

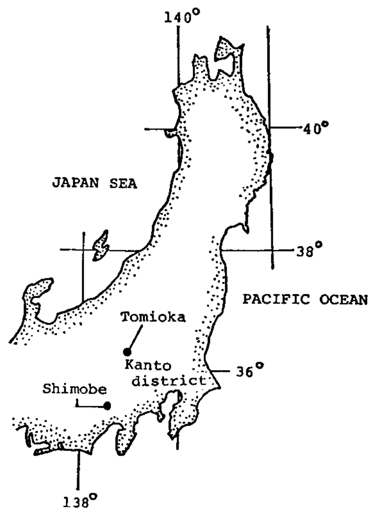

Fig. 1. Index map showing locations of the areas studied.

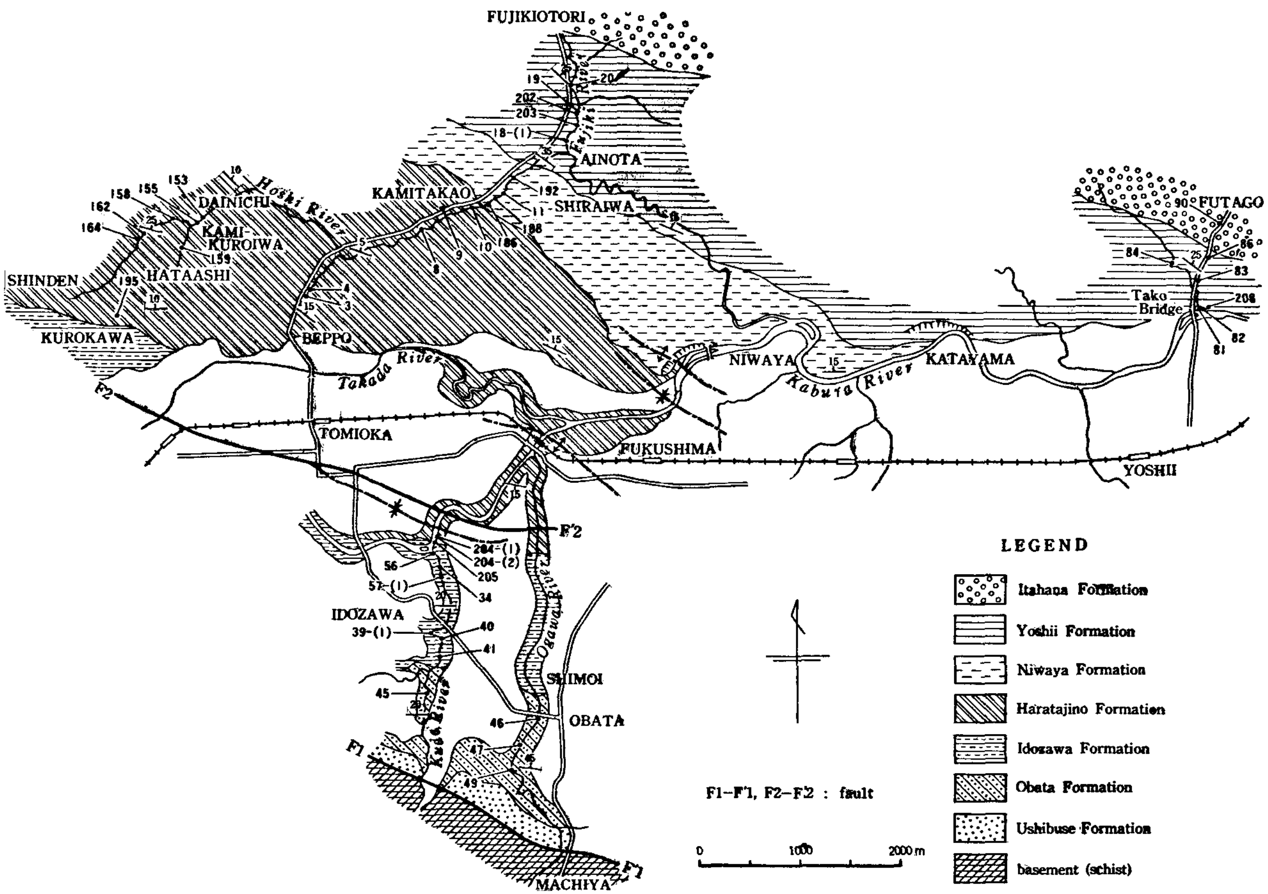

Fig. 2. Geological sketch map of the Tomioka area, Gunma Prefecture, and localities of samples collected from the Tomioka Group along the Kabura River and its tributaries.

middle level, alternation of sandstone and mudstone in the uppermost part, thickness 550 m.

g. **Itahana Formation**; alternation of conglomerate and sandstone intercalating acidic tuff, mudstone, and lignite, thickness 800 m.

Nishiyatsushiro Group (**Figs. 4–6**)

a. **Ichinose Formation**

Furusekigawa Basic Volcanic Rock; basic volcanic rock and pyroclastic rock intercalating tuffaceous sandstone and mudstone, distributed in the east of the area studied, thickness 200 m+.

Kanzaka Mudstone; mudstone intercalating tuffaceous sandstone and andestic tuff, thickness 200 m.

Wadaira Tuff; andestic tuff intercalating mudstone, thickness 500 m.

b. **Diagoyama Formation**

Kamiisshiki Volcanic Breccia; basic volcanic breccia and tuff breccia intercalating tuffaceous and brecciated mudstone-bearing sandstone and mudstone, developed as a wedge and thinning out southwards, thickness 100 m.

Deguchi Alternation of Tuffaceous Sandstone and Mudstone; mudstone in the lower part, and alternation of tuffaceous sandstone and mudstone in the middle and upper parts, thickness 200 m.

Byobuiwa Tuff; andesitic tuff intercalating alternation of tuffaceous sandstone, mudstone, and tuff, thickness 800 m.

2. Planktonic foraminiferal biostratigraphy

Tomioka Group (**Fig. 3**)

Globigerinoides scianus/Praeorbulina glomerosa Lineage-zone
Praeorbulina glomerosa/Orbulina suturalis Lineage-Zone
Globorotalia peripheroronda/Ortulina suturalis Concurrent-Zone
Globorotalia peripheroacuta/Globigerina nepenthes Interval-Zone
Globiergina nepenthes/Globorotalia acostaensis Interval-Zone

Nishiyatsushiro Group (**Fig. 6**)

Globorotalia peripheroacuta/Globigerina nepenthes Interval-Zone
Globigerina nepenthes/Globorotalia acostaensis Interval-Zone
Globorotalia acostaensis/Pulleniatina primalis Lineage-Zone
Pulleniatina primalis/Sphaeroidinella dehiscens Interval-Zone

Of these biostratigraphic zones, *Globorotalia peripheroacuta/Globigerina nepenthes* Interval-Zone common to both of the groups was subdivided by use of the *Sphaeroidinellopsis subdehiscens* Base-datum into two subzones, that is, the lower, *Globorotalia peripheroacuta/Sphaeroidinellopsis subdehiscens* Interval-Subzone, and the upper, *Sphaeroidinellopsis subdehiscens/Globigerina nepenthes* Interval-Subzone, and the *Globigerina nepen-*

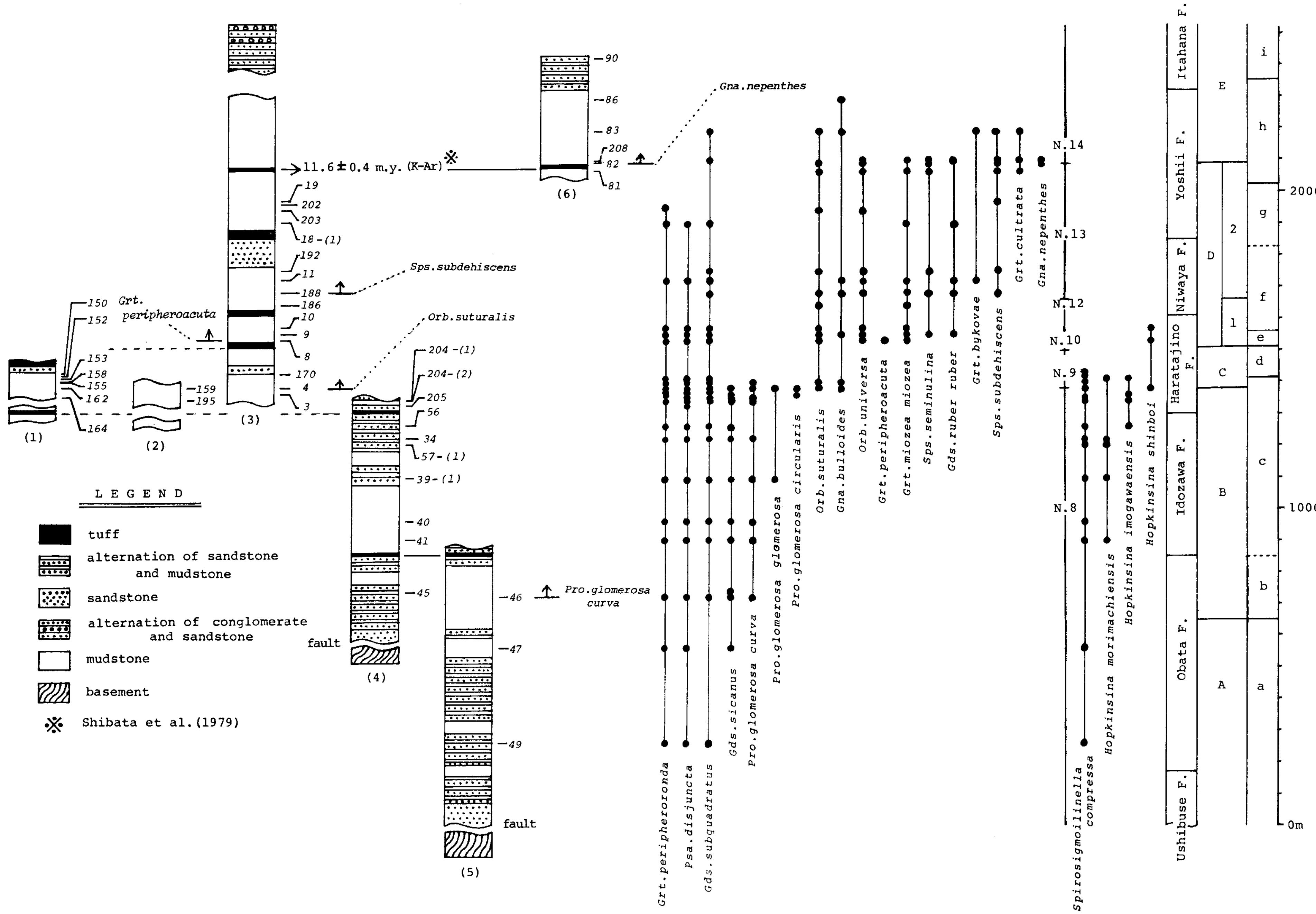

Fig. 3. Columnar sections of the Tomioka Group showing stratigraphic positions of samples and stratigraphic distribution of some selected planktonic and benthonic foraminifera.

(1) Hoshi River (Dainichi-Shinden) section (2) Hoshi River (Miyamoto-Kurokawa) section (3) Fujiki and Hoshi rivers (Fujikiotori-Beppo) section (4) Kabura and Kuda rivers (Haratajino-Kudakawa) section (5) Ogawa River (Shimoi-Machiya) section (6) Futago-Tako Bridge section

A: *Globigerinoides sicanus/Praeorbulina glomerosa* Lineage-Zone
B: *Praeorbulina glomerosa/Orbulina suturalis* Lineage-Zone
C: *Globorotalia peripheroronda/Orbulina suturalis* Concurrent-Zone
D: *Globorotalia peripheroacuta/Globigerina nepenthes* Interval-Zone
D-1: *Globorotalia peripheroacuta/Sphaeroidinellopsis subdehiscens* Interval-Subzone
D-2: *Sphaeroidinellopsis subdehiscens/Globigerina nepenthes* Interval-Subzone
E: *Globigerina nepenthes/Globorotalia acostaensis* Interval-Zone
a: *Melonis-Stilostomella* Zone
b: *Cyclammina-Discammina compressa* Zone
c: *Cibicidoides pseudoungerianus-Stilostomella lepidula* Zone
d: *Martinottiella communis-Spirosigmoilinella compressa* Zone
e: *Stilostomella-Trifarina kokozuraensis* Zone
f: *Cassidulina norcrossi-Trifarina kokozuraensis* Zone
g: *Uvigerina proboscidea-Lenticulina lucida* Zone
h: *Uvigerina proboscidea-Praeglobobulimina pupoides* Zone
i: *Ammonia tochigiensis-Amphicoryna tubulata japonica* Zone

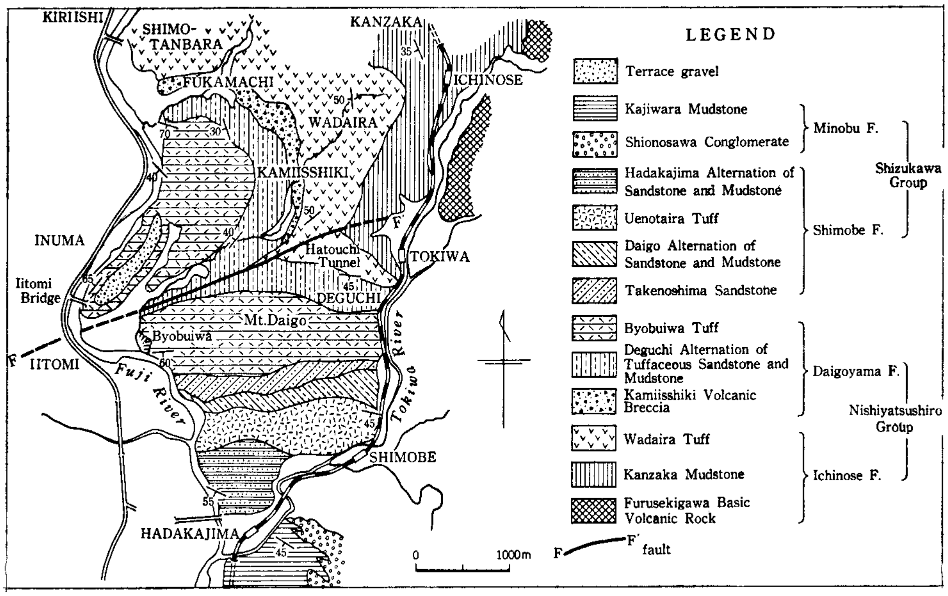

Fig. 4. Geological map of the Shimobe area, Yamanashi Prefecture (slightly modified from AKIYAMA, 1957).

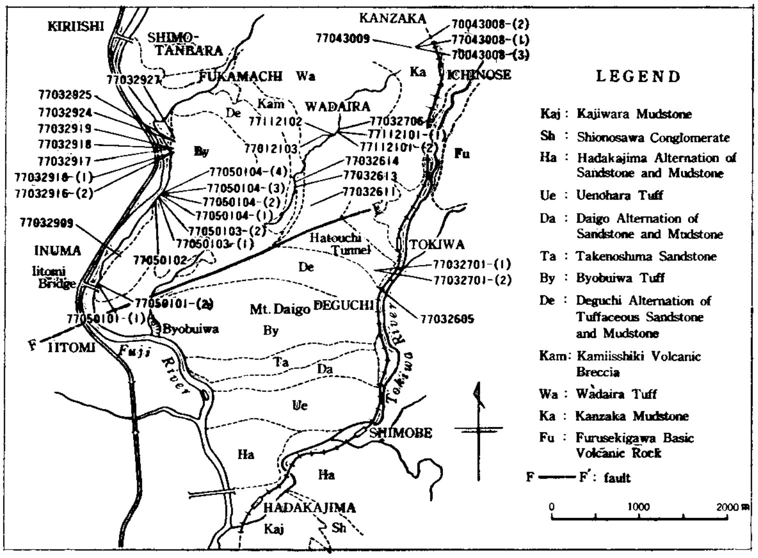

Fig. 5. Localities of samples collected from the Nishiyatsushiro Group along the upper reaches of the Fuji River and its tributaries in the Shimobe area, Yamanashi Prefecture.

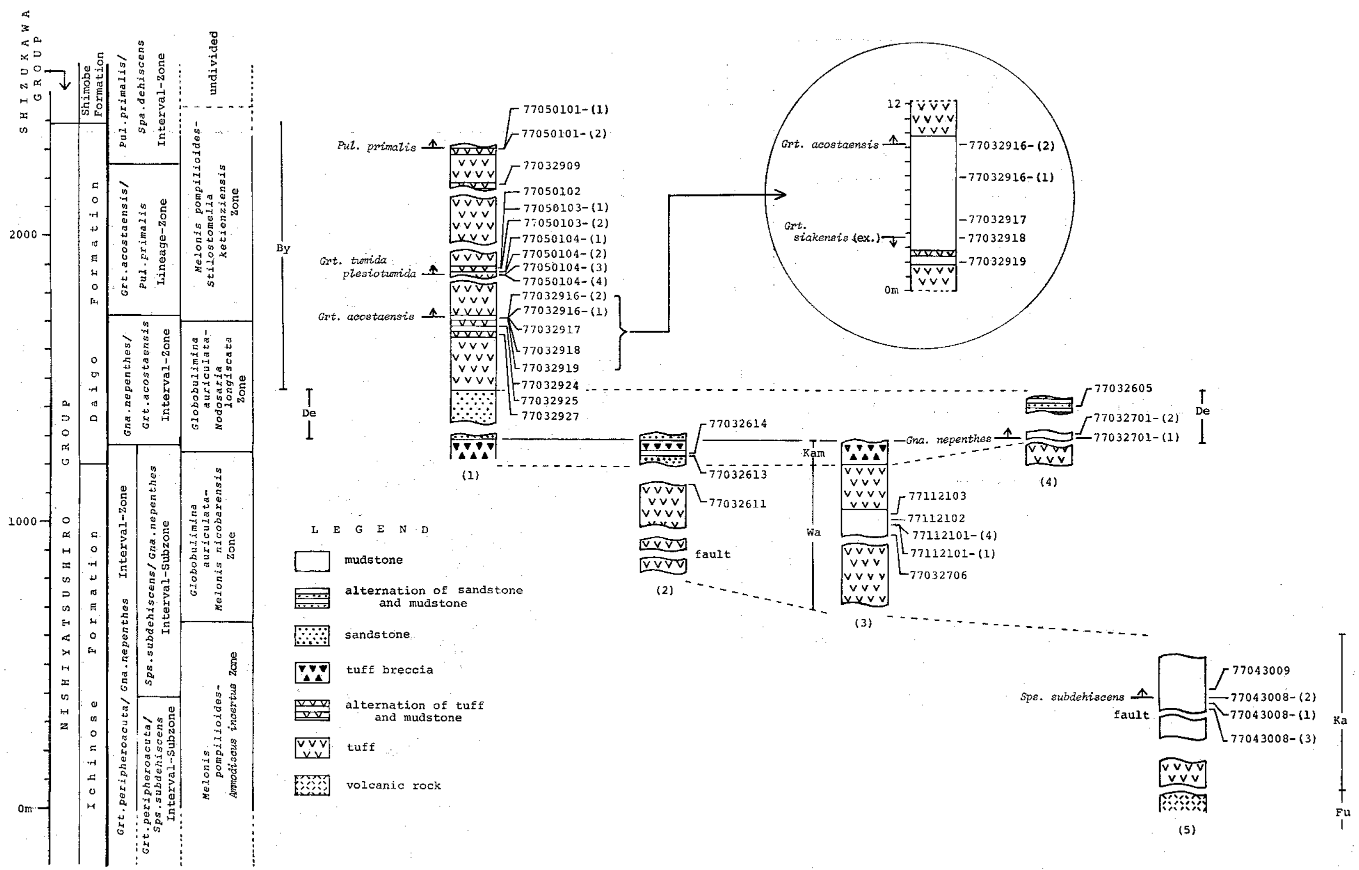

Fig. 6. Columnar section of the Nishiyatsushiro Group, showing stratigraphic positions of samples. The first occurrences of some selected planktonic foraminifera are shown on the left of each columns.
(1) Iitomi Bridge-Fukamachi section (2) Kamiisshiki-western entrance of Hatouchi Tunnel section (3) Kamiisshiki-Wadaira section (4) Deguchi-eastern entrance of Hatouchi Tunnel section (5) Kanzaka-Ichinose section By: Byobuiwa Tuff, De: Deguchi Alternation of Tuffaceous Sandstone and Mudstone, Kam: Kamiisshiki Volcanic Breccia, Wa: Wadaira Tuff, Ka: Kanzaka Mudstone, Fu: Furusekigawa Volcanic Rock

Kurihara (1974,1977)

litho unit	foraminiferal zone
It	*Grt.mayeri* Zone
Yo	*Grt.mayeri* Zone
Yo	*Grt.fohsi fohsi* Zone
Yo	*Grt. fohsi peripheroronda* Zone
Fu	*Gtl.insueta* Zone
Id	*Gtl.insueta* Zone
Id	*Cpx.unicavus* Zone
Us	*Cpx.unicavus* Zone

Maiya and Murata (1977)

litho. unit	Blow (1969)	planktonic foraminiferal Zone	benthonic foraminifera: concurrent range-zone	benthonic foraminifera: representative species
It		*Grt.bycovae/ Grt.menardii*	*Uvigerina proboscidea* *Cibicides ungerianus*	*Ammonia cf. japonica* *Uvigerina proboscidea* *Cibicides ungerianus* *Trifarina kokozuraensis*
Yo	N.10	*Grt. peripheroacuta/ Grt.miozea* s.s.	*Martinottiella communis/ Praeglobobulimina pupoides*	*Martinottiella communis* *Praeglobobulimina pupoides* *Ammonia tochigiensis* *Cyclammina* spp. *Melonis pompilioides* *Lenticulina* spp.
Yo	N.9	*Grt. peripheroronda/ Grt. quinifalcata*	*Martinottiella communis/ Praeglobobulimina pupoides*	*Martinottiella communis* *Praeglobobulimina pupoides* *Ammonia tochigiensis* *Cyclammina* spp. *Melonis pompilioides* *Lenticulina* spp.
Fu	N.8	*Gds.sicanus/ Pro.glomerosa curva*	*Hopkinsina morimachiensis/ Spirosigmoilinella compressa*	*Martinottiella communis* *Cyclammina* spp. *Gyroidina orbicularis* *Spirosigmoilinella compressa* *Hopkinsina morimachiensis* *Bulimina nipponica* *Cribrostomoides* spp.
Id	N.8	*Gds.sicanus/ Pro.glomerosa curva*	*Hopkinsina morimachiensis/ Spirosigmoilinella compressa*	*Martinottiella communis* *Cyclammina* spp. *Gyroidina orbicularis* *Spirosigmoilinella compressa* *Hopkinsina morimachiensis* *Bulimina nipponica* *Cribrostomoides* spp.
Us		Barren	Barren	

this paper

litho. unit	Blow (1969)	planktonic foraminiferal zone	benthonic foraminifera: assemblage zone	benthonic foraminifera: main accompanying species
It	N.15?	*Gna.nepenthes/ Grt.acostaensis* Interval-Zone	*Ammonia tochigiensis- Amphicoryina tubulata japonica*	*Gaudryina* sp.1 *Uvigerina proboscidea*
Yo	N.15?–N.14	*Gna.nepenthes/ Grt.acostaensis* Interval-Zone	*Uvigerina proboscidea- Praeglobobulimina pupoides*	*Amphicoryina tubulata japonica* *Gaudryina ishikiensis* *Melonis pompilioides*
Yo	N.13	*Grt. peripheroacuta/ Gna.nepenthes* Interval-Zone: *Sps.subdehiscens/ Gna nepenthes* Interval-Subzone	*Uvigerina proboscidea- Lenticulina lucida*	*Ammonia japonica* *Cibicidoides lobatulus* *Florilus grateloupi*
Ni	N.13 / N.12	*Grt. peripheroacuta/ Gna.nepenthes* Interval-Zone: *Sps.subdehiscens/ Gna nepenthes* Interval-Subzone / *Grt.peripheroacuta/ Sps.subdehiscens* Interval-Subzone	*Cassidulina norcrossi- Trifarina kokozuraensis*	*Cibicidoides aknerianus* *C. pseudoungerianus* *Melonis nicobarensis*
Ha	N.12–N.10	*Grt. peripheroacuta/ Gna.nepenthes* Interval-Zone: *Grt.peripheroacuta/ Sps.subdehiscens* Interval-Subzone	*Stilostomella- Trifarina kokozuraensis*	*Fursenkoina mexicana* *C. pseudoungerianus* *Bulimina striata*
Ha	N.9	*Grt.peripheroronda/ Orb.suturalis* Concurrent-Zone	*Martinottiella communis- Spirosigmoilinella compressa*	*Discammina compressa* *Haplophragmoides renzi*
Ha, Id	N.8	*Pro.glomerosa/ Orb.suturalis* Lineage-Zone	*Cibicidoides pseudoungerianus- Stilostomella lepidula*	*Martinottiella communis* *Spirosigmoilinella compressa* *Amphistegina radiata* *Gyroidinoides altiformis* *Hopkinsina imogawaensis* *Hopkinsina morimachiensis* *Bulimina nipponica*
Ob	N.8	*Pro.glomerosa/ Orb.suturalis* Lineage-Zone	*Cyclammina- Discammina compressa*	*Ammodiscus incertus* *Cibicidoides pseudoungerianus*
Ob	N.8	*Gds.sicanus/ Pro.glomerosa* Lineage-Zone	*Melonis-Stilostomella*	*Bulimina striata* *Praeglobobulimina pupoides* *Cibicidoides pseudoungerianus*
Us	N.7?			

Fig. 7. Comparison of lithostratigraphic and biostratigraphic subdivisions, proposed by various authors, of the Tomioka Group with special reference to the benthonic foraminiferal distribution. Thick vertical lines show the occurrence range of *Spirosigmoilinella compressa* MATSUNAGA.
Us: Ushibuse Formation, Ob: Obata F., Id: Idozawa F., Fu: Fukushima F., Ha: Haratajino F., Ni: Niwaya F., Yo: Yoshii F., It: Itahana F.

thes/Globorotalia acostaensis Interval-Zone of the latter group into two subzone, the lower, *Globigerina nepenthes/Globorotalia siakensis* Interval-Subzone, and the upper, *Globorotalia siakensis/Globorotalia acostaensis* Interval-Subzone, using the *Globorotalia siakensis* Top-datum. Then, it was mentioned that the *Sphaeroidinellopsis subdehiscens* Base-datum is recognized at the lower part of the Yoshii Formation (Sample 19) of the Tomioka Group and at the base of about 100 meters thick mudstone (Sample 77032706) which occupies the middle part of the Wadaira Tuff of the Nishiyatsushiro Group (CHIJI and KONDA, 1978). However, as a reuslt of the further eaxamination of a few additional samples from both of the groups, the *Sphaeroidinellopsis subdehiscens* Base-datum was found lying within the middle part of the Niwaya Formation (Sample 188) of the former group and within the middle part of the Kanzaka Mudstone (Sample 77043008–2) of the latter, respectively. In the present paper, therefore, the stratigraphic position of the base-datum should be corrected as shown in Figs. 3, 6, and 7. The relation among the lithostratigraphic units, planktonic foraminiferal zones, and benthonic ones described later are shown in the same figures.

IV. Benthonic Foraminiferal Zonation

1. Previous works

Hitherto, comparatively little has been known of the benthonic foraminifera except such larger foraminifera as *Nephrolepidina* and *Miogypsina* (MATSUMARU, 1967, 1973) from the Tomioka Group.

Recently, based on the extinction level of *Spirosigmoilinella compressa* MATSUNAGA which is very close to the horizon of the last occurrence of *Globorotalia fohsi fohsi* (sensu BOLLI, 1957), KURIHARA (1977) correlated the Yoshii Formation of the Tomioka Group with the lower part of the Funakawa Formation distributed in the Oga Peninsula of the Japan Sea side province, northern Japan. From the Tomioka Group, MAIYA and MURATA (1977) recognized four planktonic and three benthonic foraminiferal zones, but they enumerated only a few representative benthonic taxa from each of the latter zones. They stated, then, that the stratigraphic occurrence of *Spirosigmoilinella compressa* MATSUNAGA is limited to the Early Miocene in the Kanto district as well as the Tomioka region. These works are brought together for ready comparison in Fig. 7.

As to the Nishiyatsushiro Group, NISHIMIYA (1969, 1970, 1971) listed a number of benthonic and planktonic foraminifera collected from various localities scattered along the Fuji River and its tributaries.

In all studies mentioned above, however, the minute and precise faunal composition and/or its stratigraphic distribution were not officially announced.

2. Samples and methods

The rock samples used in the present study were collected mostly by the author from each formation of the Tomioka and Nishiyatsushiro groups along six geological sections, respectively. Some of them from the latter sequence were supplied by Dr. Manzo CHIJI, Director of the Osaka Museum of Natural History. The localities and stratigraphic positions of samples from the Tomioka Group are shown in Figs. 2 and 3, and those from the latter in Figs. 5 and 6, together with the columnar sections along the sampling routes. The stratigraphic positions of samples were correlated by use of key beds, which consist of pyroclastic sediments.

Each sample was reduced to 100 or 200 grams in dry weight, and the Naphtha-method described by MAIYA and INOUE (1973) was applied to all samples. After washing with a 200-mesh sieve (opening 74 μ), it was divided into a proper quantity so as to take 200–500 individuals of planktonic and benthonic foraminifera, respectively, and from one split part, all of both foraminifera tests were separated for the study.

3. Definition and characteristics of zones

Of about 400 benthonic taxa obtained from the Tomioka Group, selected were 100 taxa for the purpose of zoning, and of nearly 250 benthonic ones from the Nishiyatsushiro Group, selected were 70 taxa for the same purpose. Their stratigraphic occurrences and relative frequencies are shown in Fig. 10 and 11.

Based on vertical changes of the faunal composition, recognized were nine and four assemblage zones, which were defined by the International Subcommission on Stratigraphic Classification (1976) of IUGS Commission on Stratigraphy, in the Tomioka and Nishiyatsushiro groups, respectively. Each of the zones is described, in ascending order, in the following. The correlation between the zones of the Tomioka Group and those of the Nishiyatsushiro Group is shown in Fig. 9, together with the planktonic foraminiferal biozones.

(1) Tomioka Group

a. *Melonis-Stilostomella* Zone—Samples 49, 47, 46 (Ogawa River section)—

This zone is characterized by the abundant occurrences of *Melonis pompilioides* (FICHTEL and MOLL), *M. nicobarensis* (CUSHMAN), and *Stilostomella* spp., the last of which includes *S. lepidula* (SCHWAGER), *S. ketienziensis* (ISHIZAKI), and *Siphonodosaria oinomikadoi* (ISHIZAKI). *Praeglobobulimina pupoides* (D'ORBIGNY) is also common in the lowermost part of the zone. Besides, *Dentalina communis* D'ORBIGNY, *Globocassidulina subglobosa* (BRADY), *Bulimina striata* BRADY, and *Cibicidoides pseudoungerianus* (CUSHMAN) show relatively high frequencies in the middle part of this zone, though the last one of them reaches its acme in the overlying zone. The ratio of planktonic forms has high value. The fauna of this zone is of the upper bathyal zone in the temperate regoin, and this zone corresponds nearly to the *Globigerinoides sicanus/Praeorbulina glomerosa* Lineage-Zone of planktonic foraminiferal biozone, and it is recognized in the lower part of the Obata Formation exposed along the Ogawa River.

b. *Cyclammina-Discammina compressa* Zone—Sample 45 (Kuda River section)—

This zone is defined by the characteristic occurrences of *Cyclammina cancellata obesa* CUSHMAN and LAINING, *C. orbicularis* BRADY, and *Discammina compressa* (GÖES), and the former two taxa are almost confined to this zone. The ratio of planktonic forms is very low compared with the subjacent zone, and the benthonic foraminiferal number is also few. The fauna of this zone may be inferred to have lived under the deep and cold water condition. The zone corresponds to the lower part of the *Praeorbulina glomerosa/Orbulina suturalis* Lineage-Zone, and it is recognized in the upper part of the Obata Formation exposed along the Kuda River. However, additional samples need to be examined, because the zone is defined by use of only one sample.

c. *Cibicidoides pseudoungerianus-Stilostomella lepidula* Zone—Samples 41, 40, 39–(1), 34, 57–(1), 34, 56 (Kuda Rivre section); 205, 204–(1), (2) (Kabura River section); 195, 164, 3, 4, 159, 162, 155, 158, 153 (Hoshi River section)—

This zone is characterized by the relatively high frequencies of *Cibicidoides pseudoungerianus* (CUSHMAN) and *Stilostomella lepidula* (SCHWAGER) accompanied with *Martinottiella communis* (D'ORBIGNY), *Spirosigmoilinella compressa* MATSUNAGA, *Melonis pompilioides* (FICHTEL and MOLL), *M. nicobarensis* (CUSHMAN), *Pullenia bulloides* (D'-ORBIGNY), *Sphaeroidina bulloides* (D'ORBIGNY), *Siphonodosaria oinomikadoi* (ISHIZAKI), *Trifarina kokozuraensis* (ASANO), *Uvigerina akitaneis* ASANO, and *U. proboscidea* SCHWAGER. It is noticeable, moreover, that such taxa as enumerated bellow are almost confined to the zone, though the taxa marked with an asterisk are excluded from Fig. 10 on account of their scanty occurrences;

Amphistegina radiata FICHTEL and MOLL
Bolivina plicatella (CUSHMAN)
B. robusta (BRADY)
Brizalina albatrossi (CUSHMAN)
B. cochei (CUSHMAN and ADAMS)
B. alta (SEGUENZA)*
B. marginata masudai (ASANO)
B. zanzibarica (CUSHMAN)
Dentalina communis D'ORBIGNY
D. inflexa REUSS
Frondicularia foliacea SCHWAGER
Göesella schencki ASANO
Gyroidina profunda AOKI*
Gyroidinoides altiformis (R. E. and K. C. STEWART)

Gyroidinoides altiformis (R. E. and K. C. STEWART)
G. soldanii (D'ORBIGNY)*
Hopkinsina imogawaensis MATSUNAGA*
H. morimachiensis MATSUNAGA*
Nodosaria tosta SCHWAGER
Planulina nipponica ASANO
Plectofrondicularia japonica ASANO
P. miocenica CUSHMAN*
Spiroplectammina spp.*
Sphaeroidina japonica ASANO
Textularia semialata CUSHMAN
Trifarina bradyi (CUSHMAN)
T. carinata (CUSHMAN)*
Uvigerina akitaensis ASANO

Besides, *Bulimina nipponica* ASANO occurs from the above-mentioned *Melonis-Stilostomella* Zone and this zone, but the species does not extend to the overlying zones. Sample 39-(1) yields a few individuals of shallow water species, e.g., *Amphistegina radiata* FICHTEL and MOLL, which was transported from some places to become mixed, in association with deep water species of this zone. The ratio of planktonic foraminifera continues to be low from the subjacent zone except the middle part of the zone, in which it becomes relatively high. The fauna of this zone is thought to have lived in the upper bathyal zone, and the influence of cold water is indicated by such species as *Trifarina kokozuraensis* ASANO and *Uvigerina akitaensis* ASANO. This zone is recognized in the Idozawa Formation exposed along the Kuda River, and in the lower part of the Haratajino Formation exposed along the Kabura and Hoshi rivers, and it corresponds to the middle and upper parts of the *Praeorbulina glomerosa/Orbulina suturalis* Lineage-Zone and the lower part of the *Globorotalia peripheroronda/Orbulina suturalis* Concurrent-Zone. The *Orbulina suturalis* Base-datum, which is regarded as the dividing datum plane between the Early and Middle Miocene, was found from the upper part of this zone.

d. *Matinottiella communis-Spirosigmoilinella compressa* Zone—Samples 152, 170, 150 (Hoshi River section)—

This zone is outstanding in that *Martinottiella communis* (D'ORBIGNY) and *Spirosigmoilinella compressa* MATSUNAGA occur with considerable frequencies associated with *Haplophragmoides renzi* ASANO, *Discammina compressa* (GÖES), and some arenaceous forms. Calcareous forms scarcely occur in the zone throughout. The zone is recognized in the middle part of the Haratajino Formation exposed along the Hoshi River, and corresponds with the middle part of the *Globorotalia peripheroronda/Orbulina suturalis* Concurrent-Zone. However, it is noteworthy that a change of the faunal composition from the subjacent *Cibicidoides pseudoungerianus-Stilostomella lepidula* Zone happens abruptly in the consecutive muddy facies of the formation, and that the foraminiferal number is relatively small and the planktonic forms are never found in the zone.

As for the stratigraphic distribution of *Spirosigmoilinella compressa* MATSUNAGA in the Kanto district, there have been differences of opinion among scholars. Based on the occurrence of the taxon from the Miocene Series scattered over North and Central Japan, MAIYA and MURATA (1977) divided the Miocene sedimentary basins into two major types, that is, the "Japan Sea side" and "Pacific side" types, and they stated that the taxon has the long range from the Early Miocene to the Late Miocene in the former type, but it is limited to the Early Miocene in the latter, and that the occurrence of the taxon has the close relationship with some sedimentological events and tectonic developments. On the other hand, KURIHARA (1977) stated "*Spirosigmoilinella compressa* occurs in the basal part of the Lower Miocene in the Takasaki region (=the Tomioka region of the present paper). It disappears in the middle part of the Yoshii Formation, whihc is very close to the last occurrence of *Globorotalia fohsi fohsi* (sensu BOLLI, 1957) in the same section. In the Boso Peninsula, this benthonic species occurs associated with *Globorotalia fohsi peripheroronda* and *G. fohsi fohsi* in the Amatsu Formation. *Spirosigmoilinella compressa* disappears together with the *Globorotalia fohsi* group in the section studied in the Boso Peninsula". According to a result of the present study as well, the range of the taxon extends upwards, at least, to the middle part of the *Globorotalia peripheroronda/Orbulina suturalis* Concurrent-Zone across the *Orbulina suturalis* Base-datum (Fig. 7). Therefore, it may be said that *Spirosigmoilinella compressa* MATSUNAGA had still subsisted up to the early or middle Middle Miocene in the Pacific side province of Central Japan.

Another thing to be noticed is that the zone characterized by the poor occurrence of arenaceous forms only was discovered from the Middle Miocene Series of the Pacific side province. In the adjacent Niigata area of the Japan Sea side, there can be recognized the biostratigraphic units represented by the arenaceous forms, that is, the *Haplophragmoides renzi-Plectina nipponica* and *Haplophragmoides renzi-Martinottiella communis* zonules (MATSUNAGA, 1963). These two oznules were reported from the middle part of the Nanatani Formation included within the *Globorotalia peripheroronda/Globorotalia quinifalcata* Zone of SAITO and MAIYA (1973), which corresponds to the *Globorotalia peripheroronda/Orbulina suturalis* Concurrent-Zone of the present paper. Furthermore, the zonule characterized by the poor occurrence of arenaceous forms such as *Martinottiella communis* (D'ORBIGNY) and a few other taxa is pursued throughout the lower part of the Middle Miocene deposits distributed in the Japan Sea coast region of Southwest Japan (CHIJI, 1961; NAKASEKO, 1952; TAI, 1959), and the boundary between the zonule and the subjacent one represented by the rich calcareous warm water taxa has been called the Foraminiferal Sharp Line by TAI

(1963). Meanwhile, judging from the results of sedimentoligical and paleontological studies of the Miocene sequences in the oil fields of Japan Sea coast region, such arenaceous foraminiferal assemblages as mentioned above are regarded as suggesting the presence of stagnant and anaerobic condition (IWAMOTO and SHINBO, 1964). Thus, it may be considered that the stagnant and anaerobic sedimentary environment had extended from the Japan Sea side province of Southwest Japan to the Tomioka area, the northwest margin of the Kanto district of the Pacific side province, Central Japan.

e. *Stilostomella-Trifarina kokozuraensis* Zone—Samples 8, 9 (Hoshi River section)—

This zone is characterized by the predominant occurrences of *Stilostomella* spp. and *Trifarina kokozuraensis* (ASANO), the former of which includes *Stilostomella lepidula* (SCHWAGER) and *S. ketienziensis* (ISHIZAKI), mainly associated with *Cibicidoides lobatulus* (WALKER and JACOB), *C. pseudoungerianus* (CUSHMAN), *Bulimina striata* D'ORBIGNY, *Fursenkoina mexicana* (CUSHMAN), *Melonis quadalpae* PARKER, and *Uvigerina proboscidea* SCHWAGER. Contrary to the subjacent zone, scarcely found are arenaceous forms. It is a remarkable fact, however, that a number of taxa which occur in higher or lower frequencies throughout the underlying four zones come to be never found from this zone and the overlying ones. They are as follows;

Ammodiscus incertus (D'ORBIGNY)
Discammina compresxsa (GÖES)
Göesella schencki ASANO
Spirosigmoilinella compressa MATSUNAGA
Textularia semialata CUSHMAN
Amphistegina radiata FICHTEL and MOLL
Bolivina plicatella (CUSHMAN)
Brizalina albatorossi (CUSHMAN)
B. cochei (CUSHMAN and ADAMS)
B. marginata masudai (ASANO)
Bulimina nipponica ASANO
Dentalina communis D'ORBIGNY
D. inflexa REUSS
Gyroidinoides altiformis R. E. and K. C. STEWART
Hopkinsina imogawaensis MATSUNAGA
H. morimachiensis MATSUNAGA
Planulina nipponica ASANO
Plectofrondicularia japonica ASANO
Sphaeroidina japonica ASANO
Trifarina bradyi (CUSHMAN)

Uvigerina akitaensis ASANO
U. nitidula SCHWAGER

Besides, *Brizalina pisciformis* (GALLWAY and MORREY), *Bulimina rostrata* BRADY, *Gyroidina orbicularis* (D'ORBIGNY), *Nodosaria longiscata* D' ORBIGNY, *N. tosta* SCHWAGER, and *Oolina hexagona* (WILLIAMSON) are hardly found likewise.

The number of foraminifera of this zone is relatively large, and the ratio of planktonic forms is also high. The fauna is inferred to be of the upper bathyal zone in the temperate region. This zone is recognized in the upper part of the Haratajino Formation exposed along the Hoshi River, and it corresponds to the lower part of the *Globorotalia peripheroacuta*/*Sphaeroidinellopsis subdehiscens* Interval-Subzone.

f. *Cassidulina norcrosis-Trifarina kokozuraensis* Zone—Samples 10, 186, 188, 11, 192 (Hoshi River section)—

This zone is defined by the abundant occurrences of *Cassidulina norcrossi* CUSHMAN and *Trifarina kokozuraensis* (ASANO) associated with *Cibicidoides aknerianus* (D'ORBIGNY), *C. pseudoungerianus* (CUSHMAN), *Melonis nicobarensis* (CUSHMAN), *M. quadalpae* PARKER, *Uvigerina proboscidea* SCHWAGER, and *Martinottiella communis* (D'ORBIGNY). The number of benthonic foraminifera is largest attaining the maximum of 164 per gram, and the ratio of planktonic forms is also high with the average of 55 per cent. The zone is recognized from the uppermost part of the Haratajino Formation through the Niwaya Formation exposed along the Hoshi River, and it corresponds to the middle and upper parts of the *Globorotalia peripheroacuta*/*Sphaeroidinellopsis subdehiscens* Interval-Subzone and the lower part of the *Sphaeroidinellopsis subdehiscens*/*Globigerina nepenthes* Interval-Subzone. The *Sphaeroidinellopsis subdehiscens* Base-datum are found in the nearly middle level of the zone.

Cassidulina norcrossi CUSHMAN (Figs. 8a–c) has been reported by the name of

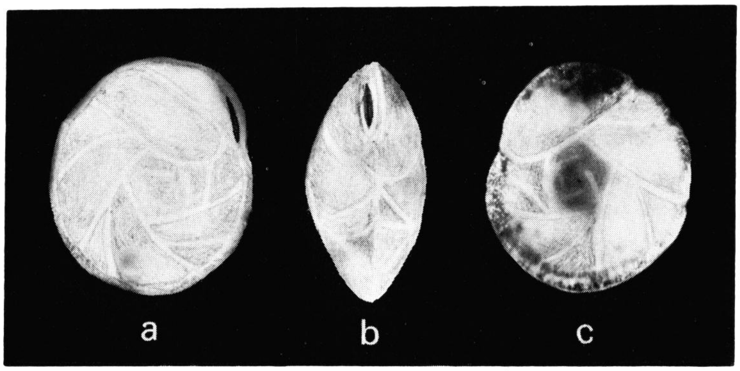

Fig. 8. *Cassidulina norcrossi* CUSHMAN ×107 OMNH Reg No. F16075F; from Sample 11 (Niwaya Formation, Tomioka Group).

Cassidulina kasiwazakiensis FUSEJIMA and MARUHASHI from the Neogene deposits distributed in the Japan Sea side provinces, but scarcely any known from the Pacific side ones. Based on the Recent distribution of the species in the sea around northern Japan (CHIJI and KONDA, 1970; IKEYA, 1970; TROITSKAJA, 1970), it is considered that the fauna of this zone has been flourished under the cold water mass ranging from the outer margin of the continental shelf to the upper bathyal zone, and that the Tomioka Basin was closely connected with Japan Sea in the Middle Miocene and was invaded by cold water mass from the Japan Sea side of northern Japan.

g. *Uvigerina proboscidea-Lenticulina lucida* Zone—Samples 18-(1), 203, 202, 19 (Fujiki River section)—

This zone is characterized by the continuous and relatively abundant occurrences of *Uvigerina proboscidea* SCHWAGER and *Lenticulina lucida* (CUSHMAN) associated with *Alveophragmium scitulum* (BRADY), *Gaudryina ishikiensis* ASANO, *Ammonia japonica* (HADA), *Amphicoryna tubulata japonica* (UCHIO), *Anomalina glabrata* CUSHMAN, *Cibicidoides lobatulus* (WALKER and JACOB), *Florilus grateloupi* (D'ORBIGNY), *Melonis nicobarensis* (CUSHMAN), and *M. pompilioides* (FICHTEL and MOLL). Each of the subordinate taxa, however, fluctuates considerably in its relative quantity and becomes occasionally dominant or recessive, and besides, a number of taxa which occur continuously or intermittently through most of the underlying zones disappear in this zone. They are as follows;

Brizalina marginata (CUSHMAN)
B. pisciformis (GALLOWAY and MORREY)
Bulimina rostrata BRADY
Cassidulina norcrossi CUSHMAN
Cibicidoides aknerianus (D'ORBIGNY)
Elphidium jenseni (CUSHMAN)
Fissurina marginata (MONTAGU)
Florilus japonicus (ASANO)
Gyroidina orbicularis (D'ORBIGNY)
Hanzawaia nipponica ASANO
Nodosaria longiscata D'ORBIGNY
N. tosta SCHWAGER
Oolina hexagona (WILLIAMSON)
Stilostomella hayasakai (ISHIZAKI)
S. lepidula (SCHWAGER)
Trifarina hughesi (GALLOWAY and WISSNER)

Instead of the taxa mentioned above, *Cyclammina japonica kaiensis* FUKUTA and SHINOKI, *Tritaxia orientale* (CUSHMAN), *Ammonia japonica* (HADA), and *A. tochigiensis* (UCHIO) first appear in the zone. The benthonic foraminiferal number and the

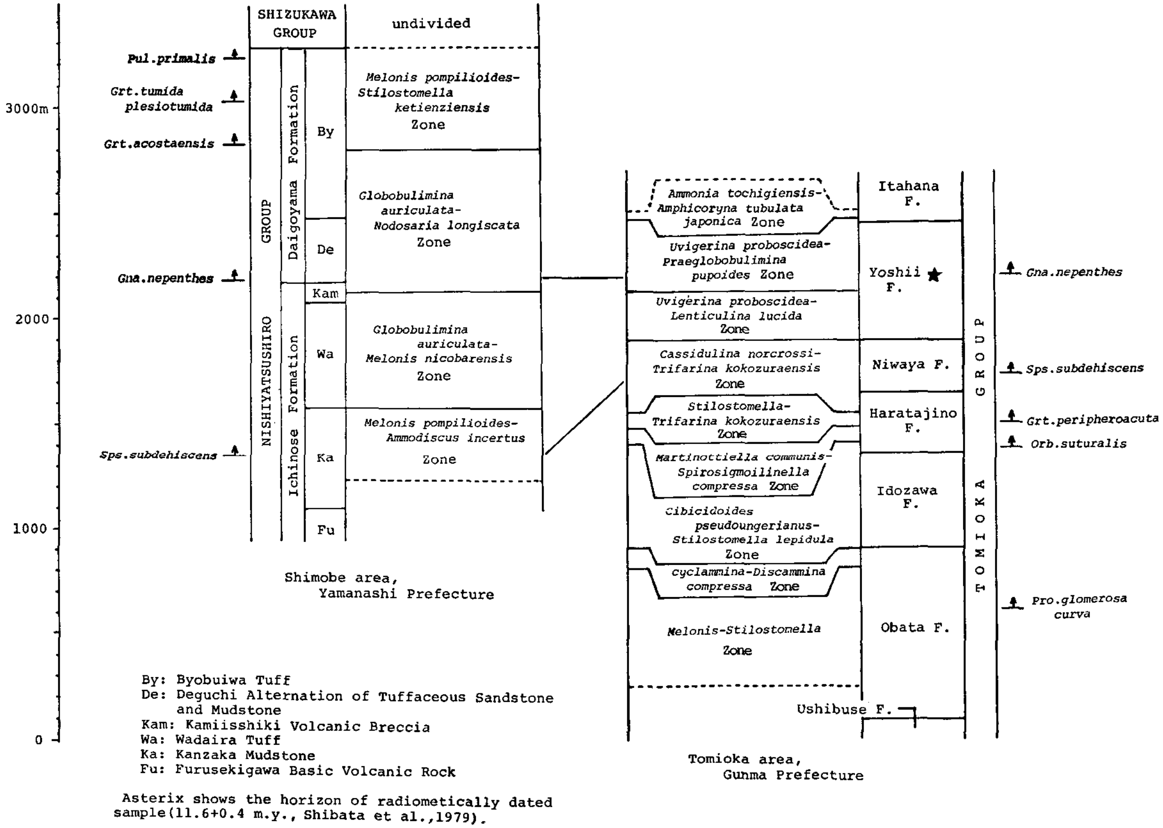

Fig. 9. Comparison between the benthonic foraminiferal zones of the Tomioka Group and those of the Nishiyatsushiro Group.

ratio of planktonic forms decrease abruptly to 4 per gram and 12 per cent on an average, respectively.

The zone is recognized in the lower half of the Yoshii Formation exposed along the Fujiki River and it corresponds to the upper half of the *Sphaeroidinellopsis subdehiscens* /*Globigerina nepenthes* Interval-Subzone. The faunal composition and its difference from those of the subjacent zone may point to the outer neritic condition of the unstable basin in the regressive stage of the late Middle Miocene.

h. *Uvigerina proboscidea-Praeglobobulimina pupoides* Zone—Samples 81, 82, 208, 83, 86 (Futago-Tako Bridge section)—

This zone is characterized by the predominance of *Uvigerina proboscidea* SCHWAGER and *Praeglobobulimina pupoides* (D'ORBIGNY) associated with *Gaudryina ishikiensis* ASANO, *Martinottiella communis* (D'ORBIGNY), *Amphicoryna tubulata japonica* (UCHIO), *Cassidulina norcrossi* CUSHMAN, *Cibicidoides lobatulus* (WALKER and JACOB), *Melonis nicobarensis* (CUSHMAN), *M. pompiloides* (FICHTEL and MOLL), *Nonionella labradorica* (DAWSON), *Trifarina kokozuraensis* (ASANO), and *Uvigerina subperegrina* CUSHMAN and KLEINPELL. However, each of the subordinate taxa considerably fluctuates in frequency as that of the subjacent zone, and both of benthonic foraminiferal number and ratio of planktonic forms are very variable. It may be inferred, therefore, that the fauna has lived in the very unstable and changeable environment under the influence of cold water ranging from the outer margin of the neritic zone to the upper bathyal one in the regressive stage. This zone is recognized in the upper half of the Yoshii Formation exposed along the Futago-Tako Bridge section, and it corresponds to the uppermost part of the *Sphaeroidinellopsis subdehiscens*/*Globigerina nepenthes* Interval-Subzone and the lower part of the succeeding *Globigerina nepenthes*/*Globorotalia acostaensis* Interval-zone. The zone, therefore, comprises the *Globigerina nepenthes* Base-datum at the lowermost part, though the *Globorotalia acostaensis* Base-datum has never been found from the Tomioka area.

i. *Ammonia tochigiensis-Amphicoryna tubulata japonica* Zone—Sample 90 (Futago-Tako Bridge section)—

This zone is outstanding in that the fauna consists of a few taxa such as *Ammonia tochigiensis* (UCHIO), *Amphicoryna tubulata japonica* (UCHIO), *Gaudryina* sp.1, *Melonis nicobarensis* (CUSHMAN), *M. pompilioides* (FICHTEL and MOLL), *Uvigerina proboscidea* SCHWAGER, and *Valvulineria sadonica* ASANO, and in that *Ammonia tochigiensis* (UCHIO) and *Amphicoryna tubulata japonica* (UCHIO) are abundant, especially the former occupies nearly half of benthonic remains. The number of the benthonic forms is very small, barely amounting to 1 per gram, and none of planktonic forms are found.

The zone is recognized at a level of the lower part of the Itahana Formation exposed at the northeast margin of the Futago-Tako Bridge section, and it may

Chronostratigraphic Unit	TOZAWAN																KABURAN																									
																	KABURAN (s. s.)																					FUJIAN				
Lithologic Unit	TOMIOKA GROUP																																									Itahana F.
	Obata F.				Idozawa F.						Haratajino Formation																		Niwaya F.				Yoshii Formation									Itahana F.
Planktonic Foraminiferal Zone	A		B														C									D												E				
																										D-1				D-2												
Benthonic Foraminiferal Zone	a			b	c																		d			e		f					g				h					i
Species / Sample Number	49	47	46	45	41	40	39-(1)	57-(1)	34	56	205	204-(1)	204-(2)	195	164	3	4	159	162	155	158	153	152	170	150	8	9	10	186	188	11	192	18-(1)	203	202	19	81	82	208	83	86	90
Alveophragmium scitulum (Brady)					R													VR		VR														C						VR		
Ammodiscus incertus (d'Orbigny)	R	VR		R			R																																			
Cyclammina cancellata obesa Cushman and Laiming				C																		VR											VR									
C. ezoensis Asano																		VR	VR														R		VR				R	VR		
C. incisa (Stache)															VR										F																	
C. japonica Asano																				R													R									
C. japonica kaiensis Fukuta and Shinoki																																		VR	R			VR	R	VR		
C. orbicularis Brady				C															VR																							
Discammina compressa (Goës)				C											VR		R		R						F																	
Gaudryina ishikiensis Asano												VR																				VR		R	F	F	R		VR	C		
G. sp. 1																																			VR	R	R			R		F
Goësella schencki Asano					VR		R											VR	VR	VR			R																			
Haplophragmoides renzi Asano															VR										C								VR	VR		VR		VR				
Martinottiella communis (d'Orbigny)					VR	R	R	A	VR	F	R			R	VR	F	R	VR	R	R	R	R	VA	A	VA	VR	VR	R	VR	R	R	F	VR	VR			C					
Sigmoilopsis schlumbergeri (Silvestri)													VR									VR	R									R								VR		
Spirosigmoilinella compressa Matsunaga	R	R			VR	R	R	C	VR	R	R			F	R		R	VR	VR		VR		A	VA	A																	
Textularia semialata Cushman					VR	R			R																																	
Tritaxia orientale (Cushman)																																		R	R							
Trochammina sp.	R			R																R																						
Ammonia beccarii (Linnaeus) forma A		VR		R							R	R	VR																					VR								
A. japonica (Hada)																																			F	R				R		
A. ketienziensis (Ishizaki)													VR					R	F															F			VR		R			
A. tochigiensis (Uchio)																																		VR							R	VA
Amphicoryina pauciloculata (Cushman)					VR				VR		R		VR	VR				VR									VR	VR	VR	VR	VR		VR	VR	VR	R		R	VR	R		
A. proxima (Silvestri)					VR							VR																VR	VR	VR	VR		R		VR	F		VR	R		VR	
A. tubulata japonica (Uchio)					VR															VR														VR	R	C			VR	F	VR	C
Amphistegina radiata Fichtel and Moll							R												VR																							
Anomalina glabrata Cushman		VR			VR				VR	VR		VR	VR				VR										VR	VR	VR	VR	VR			VR	F	VR	VR	R		R		
Bolivina plicatella (Cushman)					VR				F			F	R	R				F	R	R	F																					
B. robusta (Brady)					VR	R	R		VR						R			VR	VR							VR																
Brizalina acerosa pacifica (Cushman and McCulloch)					VR	R			VR	VR		VR		VR		VR		R			R	VR							VR	VR		R		R			VR					
B. albatrossi (Cushman)					VR				VR		R	VR								R		VR																				
B. cochei (Cushman and Adams)					VR										R		VR			R																						
B. marginata (Cushman)		VR							VR			VR			R		R	R	VR	F	R						VR			VR		VR										
B. marginata masudai (Asano)															VR		VR	R	R	R	R	VR																				
B. pisciformis (Galloway and Morrey)		R			VR							VR						R	R	VR	R											VR										
Bulimina nipponica Asano	R		R		VR		VR	R	VR	R		VR	VR	R		R	VR	VR	VR	R	VR	VR																				
B. rostrata Brady		VR				R				VR					VR			VR	R	VR	VR	VR									VR											
B. striata d'Orbigny		F		VR	R	R	F			R	R			F	VR		R	R	R	R		R				F																
Cassidulina norcrossi Cushman							VR		VR			VR	VR		VR			VR									VR	C	F	F	C	A								F		
C. sagamiensis Asano					VR		F		R	VR		VR						VR	VR		VR						VR	R	R	R		VR										
Cibicidoides aknerianus (d'Orbigny)									VR			VR						VR			VR	R				R	R	R		VR	C	R										
C. lobatulus (Walker and Jacob)				VR	R		R		R											VR	R	VR				F	R	VR	R	R	VR	R		F	C	A	F	R	VR	C		
C. pseudoungerianus (Cushman)		F		F	C	C	A	R	A	C	F	C	C	C	C			F	F	C	F	F				F	F	C	C	C	F	F	VR	R	R		VR	R	VR	VR		
C. sp.			F		VR				VR																	VR	VR	VR			VR	VR										
Dentalina communis d'Orbigny	F				VR				VR		R	VR			R				R	R	R																					
D. inflexa Reuss		VR			VR			R		R					R					VR	R	VR																				
Elphidium advena (Cushman)																											VR	VR	VR	R		VR	VR									
E. jensei (Cushman)												VR	VR													R		VR	VR	VR		VR						VR				
Fissurina marginata (Montagu)					VR				VR	VR			VR				VR	VR	VR							VR	R	R	R	VR	R	VR										

Fig. 10. Stratigraphic distribution of benthonic foraminifera in the Tomioka Group. The frequency in each of the samples is expressed in the following grades: VA; more than 46%, A; 46–22%, C; 22–10%, F; 10–4%, R; 4–1%, VR; less than 1%. Species of less than 1% frequencies in all of the samples are excluded from the list.

A: *Globigerinoides sicanus*/*Praeorbulina glomerosa* Lineage-Zone, B: *Praeorbulina glomerosa*/*Orbulina suturalis* Lineage-Zone, C: *Globorolia peripheroronda*/*Orbulina suturalis* Concurrent-Zone, D: *Globorotalia peripheroacuta*/*Globigerina nepenthes* Interval-Zone, D-1: *Globorotalia peripheroacuta*/*Sphaeroidinellopsis subdehiscens* Interval-Subzone, D-2: *Sphaeroidinellopsis subdehiscens*/*Globigerina nepenthes* Interval-Subzone, E: *Globigerina nepenthes*/*Globorotalia acostaensis* Interval-Zone. a; *Melonis-Stilostomella* Zone, b: *Cyclammina-Discammina compressa* Zone, c: *Cibicidoides pseudoungerianus-Stilostomella lepidula* Zone, d: *Martinottiella communis-Spirosigmoilinella compressa* Zone, e: *Stilostonella-Trifarina kokozuraensis* Zone, f: *Cassidulina norcrossi-Trifarina kokozuranesis* Zone, g: *Uvigerina proboscdea-Lenticulina lucida* Zone, h: *Uvigerina probsocidea-Praeglobobulimina pupoides* Zone, i: *Ammonia tochigiensis-Amphicoryna tubulata japonica* Zone.

Species / Sample Number	49	47	46	45	41	40	39 -(1)	57 -(1)	34	56	205	204 -(1)	204 -(2)	195	164	3	4	159	162	155	158	153	152	170	150	8	9	10	186	188	11	192	18 -(1)	203	202	19	81	82	208	83	86	90
F. orbignyana (Seguenza)					VR		VR		VR			VR	VR	VR				VR				VR				VR	R	R	VR	R	VR	R	VR	VR				R	VR			
Florilus grateloupi (d'Orbigny)		VR										VR	VR					VR	VR															F	F	VR		VR	R		F	
F. japonicus (Asano)					VR						R					R			VR												VR								VR			
F. sp.																																	F	R				R			R	
Frondicularia foliacea Schwager					VR							R		VR	R	F		VR	VR																							
Fursenkoina mexicana (Cushman)					F					VR		VR			R	VR		VR	VR							VR	C	R				VR							VR		VR	
Globocassidulina subglobosa (Brady)		F		VR	VR		R		VR	R		R	R	F	R	VR	F	R	R	F						VR	VR	VR	R	VR	R			VR								
Gyroidina orbicularis (d'Orbigny)					VR		R	R		R			R				R	R								VR				VR												
Gyroidinoides altiformis R. E. and K. C. Stewart									VR					VR	F			VR	R	F																						
Hanzawaia nipponica Asano		VR			VR				VR					R				VR	VR		VR					VR	R	VR			VR											
Hopkinsina imogawaensis Matsunaga										VR			VR	R		F						VR																				
Lagena semilineata Wright										VR																	VR	VR				VR	R	VR		R		R		R		
L. striata (d'Orbigny)	R	VR				R													VR			VR				VR	VR		VR	VR					R			VR		VR		
L. substriata Williamson												VR	R														VR	VR				VR	R	R								
Lenticulina lucida (Cushman)		VR			VR		VR	VR	VR						R	VR	R	VR		R		VR				VR	VR			VR	VR	VR	R	F	F	C	VR	R	R	R		
Melonis nicobarensis (Cushman)	C	R	C		VR	R	VR		VR	F	F	VR	VR	R	R		C	R	F	VR	VR	VR				R	R	R	VR	R	R	F	VR	A	F		VR	VR	F	VR		R
M. pompilioides (Fichtel and Moll)	C	R	C		R	F	R	F	R	F	F	VR	R	F	VR		R	F	R	F	R	R				R	R			VR		VR		F	F	F	F		A	R	R	R
M. quadalupae Parker					VR				VR		R	VR	R	VR	VR			R		R	VR	R					F	VR	R	R	F						VR					
Nodosaria longiscata d'Orbigny	R		R		VR		R	VR	VR	R		VR		R	F	C				F		F			R	VR				VR	VR											
N. tosta Schwager					R	R	R		VR	R	F					R						R								VR												
Nonion japonicum Asano		VR																R								VR													R	VR		
N. pacificum (Cushman)									VR					VR	VR		R	VR								VR	VR		VR						VR		R	R	VR		VR	
N. subturgidum (Cushman)																			VR												VR			VR	R		R	VR		R		
Nonionellina labradorica (Dawson)		VR													VR	R		VR	VR							VR	VR				R	VR	VR			R	R	VR		F	VR	
Oolina costata (Williamson)		VR			R	R	VR		VR			VR	VR		VR	R		VR	VR	VR	R	VR				R	VR	R	R	VR	VR	VR	VR	VR					VR			
O. hexagona (Williamson)					VR						R		VR					VR		R												VR										
O. melo d'Orbigny			R		VR				VR		R			VR				VR	VR		VR	VR				VR	VR		VR	VR	VR	VR	VR					VR				
Planulina nipponica Asano																R	R		VR	R																						
Plectofrondicularia japonica Asano								VR	VR						R		R	VR	VR	R	VR																					
Porosorotalia sp.				R	VR	R	VR																			VR																
Praeglobobulimina pupoides (d'Orbigny)	C	R	F		F	R	R		VR	F				F	VR			R	VR	VR						R		VR			VR							C	F	R	R	
Pullenia bulloides (d'Orbigny)	R	VR			VR	R		R	VR	R	R			R	VR		R	VR			VR	VR				VR	R		VR	VR	VR	VR							VR			
P. subcarinata (d'Orbigny)					R		VR		VR					VR			R			VR		VR				VR	VR		VR	VR	VR	VR	VR		R			VR	R	R		
Pyrgo murrhina (Schwager)	F								VR		R																															
Siphonodosaria oinomikadoi (Ishizaki)		F	C		F	R			VR		VR	R	F	VR	R	VR	VR	R	R	R	VR	VR				R							VR									
Stilostomella hayasakai (Ishizaki)	F	F		VR	VR	F	VR			R		VR	R					VR			VR								R	R	VR											
S. ketienziensis (Ishizaki)	F	VR					R			R		VR		R	R	F		VR									F												VR			
S. lepidula (Schwager)	C	F		VR	F	F	F	R	R	R	C	F	F	R	VR		R	F	F	F	C	C				C	VR				VR	VR										
Sphaeroidina bulloides (d'Orbigny)		VR	R		VR	R	VR		VR	R		VR	VR		VR			VR	VR		VR											R		VR								
S. japonica Asano					VR	R	R		VR									R																								
Trifarina bradyi (Cushman)							VR		VR												F	VR																				
T. hughesi (Galloway and Wissner)							VR		VR			VR	VR	R				R	VR			VR				R	VR		R	VR	VR	VR										
T. kokozuraensis (Aseno)		R			F	C	R		F	R	F	F	F	R			R	C	F	R	R	R				F	F	F	C	C	C	F		R	VR	VR		F	R	VR		
Uvigerina akitaensis Asano				VR	VR	R						VR			R			VR	R																							
U. nitidula Schwager									R					R				VR	VR									VR														
U. proboscidea Schwager			R	R	R	F	R	R	R	F	F	F	F	R	VR		R	R	F	R	R	R				F	VR	VR		VR	F	R	VA	R	F	R	A	A	F	R	VA	F
U. subperegrina Cushman and Kleinpell					VR	R			VR				VR	R				R	R		VR					VR		R		R		VR	VR				F	R	R			
Valvulineria glabra Cushman					VR		VR			R	R						R	R	VR		VR					VR	VR					VR									VR	
V. sadonica Asano					VR				VR		R			R		VR	R	VR	VR		VR					VR						R									VR	R
Benthonic Foraminiferal Number per Gram	1	2	1	6	28	24	29	2	101	10	1	8	3	11	25	18	13	85	70	18	41	66	4	2	4	72	20	123	54	101	110	164	3	5	5	2	16	7	1	5	36	1
Ratio of Planktonic Foraminifera (%)	82	69	69	3.4	9.2	4.2	2.7	5.0	1.7	13	18	19	32	9.3	62	35	20	14	6.0	11	4.4	0.5	0	0	0	49	84	86	39	32	82	10	24	10	9.6	8.9	7.4	27	64	26	0.6	0

Fig. 10 (continued)

Species \ Sample Number	77043008-(3)	77043008-(1)	77043008-(2)	77043009	77032706	77112101-(1)	77112101-(4)	77112102	77112103	77112611	77032613	77032614	77032701-(1)	77032701-(2)	77032605	77032927	77032925	77032924	77032918	77032917	77032916-(1)	77032916-(2)	77050104-(4)	77050104-(3)	77050104-(2)	77050104-(1)	77050103-(2)	77050103-(1)	77050102	77032909	77050101-(2)	77050101-(1)
Chronostratigraphic Unit	K A B U R A N																					Y U I A N										
	K A B U R A N (s. s.)												F U J I A N																			
Lithologic Unit	N I S H I Y A T S U S H I R O G R O U P																															
	Ichinose Formation										Daigoyama Formation																					
	Kanzaka Ms				Wadaira Tuff						Kam*		Deg**			Byobuiwa Tuff																
Planktonic Foraminiferal Zone	A												B									C									D	
	A-1		A-2										B-1						B-2													
Benthonic Foraminiferal Zone	a				b							c							d													
Alveophragmium scitulum (Brady)			VR	R																				VR								
Ammodiscus incertum (d'Orbigny)	F	F	F	A	R				R	VR		VR	VR		VR													VR	VR	VR		
A. incertum (d'Orbigny) var.			R	VR																		R										
Cyclammina sp. 1	R			VR																									VR			
C. spp.	VR	VR	R	R	VR				VR	R	VR	VR	VR			R			VR	VR	VR	VR	VR				VR			VR		VR
Marsipella elongata Norman																R																
Martinottiella communis (d'Orbigny)					VR		VR		VR	R	VR	VR	R	R	VR	R	VR	VR	R	R	R	R	VR		VR	VR	VR		R	VR		VR
M. communis hosoyaensis Asano					VR		VR	VR			VR			VR		VR	VR	R		VR			R	VR			VR	R		VR		
Psammosphaera fusca Schulze															R			R														
Reophax compressa (Cushman and McCulloch)																							R									
R. pilulifer Brady	VR				VR				VR				VR	VR	R								VR		VR		VR			VR		VR
Rhabdammina abyssorum M. Sars									R	C															VR	VR					R	VR
Saccammina sphaerica M. Sars												VR			R								VR				R		VR		R	
Saccoriza ramosa (Brady)																	VR						R				VR					
Sigmoilina sigmoidea (Brady)								VR			VR	R				R								VR								
Sigmoilopsis schlumbergeri (Silvestri)					VR		VR		VR				VR	VR	VR					R	R	VR	VR	VR		R	VR	VR	VR		R	VR
Trochammina sp.																										R						
Biloculinella natukawa (Matui and Nakamura)					R						VR																					
Bolivina robusta Brady										VR		R				VR									VR			VR				
Bulimina rostrata Brady	VR		VR			VR	VR	VR	VR	VR		R				VR	R	R		R	VR		VR	R	VR	R	VR		VR	VR	VR	VR
Chilostomella oolina Schwager											VR						VR							VR					R	VR		
Cibicidoides pseudoungerianus (Cushman)		VR	VR				VR				VR	R		VR																	VR	
C. sp. 1	VR	R	R			VR	VR		VR	R	R	R	R	VR				VR							VR		VR			VR		
C. spp.			VR		R	R	VR	R	R	R	R		R	R			VR				VR		VR			VR	VR					
Cyclogyra involvens (Reuss)		R				VR	VR						VR	VR	VR																	
Dentalina subsoluta (Cushman)	R																												VR			
D. spp.	F	R	F	F		R	R	R	R		VR	VR	R	VR		R	VR		R	VR	VR			VR		VR	VR	R	VR	VR		VR
Fissurina spp.	VR	R	VR		VR	VR	R	VR	VR		R	VR	R	VR	VR		VR		VR	VR			VR	VR	VR	VR						
Globobulimina auriculata (Bailey)	F	R	F	R	F	C	F	C	C	A	A	R	F	F	A	C	C	F	F	F	R	F	R	R	F	VR	F	C	F	R	F	R
G. perversa (Cushman)						R										R																
Globocassidulina subglobosa (Brady)			VR				VR	VR		R		VR																				
Gyroidina sp. 1							VR	VR	VR							VR	VR						VR				R	R	VR	VR	VR	VR
Gyroidinoides altiformis (Roscoe and Stewart)	VR					VR	VR			VR	VR		VR	VR		R	R	R	R	R	R		R		R	VR			VR		R	R
G. komatsui (Aoki)	VR	F	F				VR	VR		R	VR	VR	R	R		VR			VR					VR					VR			R
G. nipponicus (Ishizaki)		VR	VR				VR			R																			VR			
G. soldanii (d'Orbigny)						VR								VR					VR				R			VR	R	R			R	
Hanzawaia nipponica Asano	VR	VR						VR	VR		R	VR			VR	R	R		VR		R	R	VR		VR		R	VR	VR		R	VR
Lagena flatulenta Loeblich and Tappan	VR						VR	VR	VR		VR		VR	VR		R		VR			VR			VR		VR					R	
L. spp.	R	R	VR	VR	VR	VR	VR	VR	VR	VR	VR	R	VR	VR	VR	R	VR		VR	VR	VR	VR	VR	R	R	VR	VR	VR	VR	VR	VR	VR
Lenticulina lucida (Cushman)					R					VR			VR	VR																		
Melonis nicobarensis (Cushman)		VR			F	F	F	F	F	R	C		R	VR	VR	R	VR	VR					VR	VR	VR	R	R	VR	R	R	R	R
M. pompilioides (Fichtel and Moll)	C	A	C	C	R	F	R	C				F		R	R	R	R	F	C	C	C	C	F	C	C	C	R	R	R		C	C
M. quadalupae Parker	VR	R																				VR				VR					VR	VR
Nodosalia longiscata d'Orbigny	R	R	R	R	VR	R	R	R	F	C		VR	R	F	F	F	F	F	VR	R	R	VR	R	F	VR	R	R	R	VR	VR	R	R
N. tosta Schwager					VR				VR								VR		VR	VR									R			R
N. spp.	F	R	R	R	F	R	R	R	VR	VR	VR	VR	R	VR	VR	R	R	R	R	R	R	R	R	F	VR	VR	R	F	R	R	R	R
Nonionella miocenica Cushman																							VR						VR	R		
Oridosalis umbonatus (Reuss)	VR				VR	VR	VR	R		VR	VR	VR	VR	R				VR					R		VR	VR	VR	VR		VR		VR
Parafissurina ovalis Todd					VR	VR	VR	VR		VR	VR			VR	VR							R				VR			VR	VR		
Planulina wuelerstorfi (Schwager)			VR		VR		VR			VR	R	R	VR					R	R	R	R		R	F	R				R	R		R
Plectofrondicularia advena (Cushman)											VR								R	R	R			R	R	R					VR	VR
Pleurostomella brevis Schwager	VR				VR		VR					R	VR	VR			VR	VR	VR				R		VR	VR	VR	VR	VR	R		VR
P. elliptica Galloway and Heminway		R	VR			VR	R				VR	VR	VR			R	VR			VR				VR			R	VR	VR	VR	VR	VR
Praeglobobulimina hanzawai Asano					VR	VR					VR					R			VR			VR		VR								
Pullenia bulloides (d'Orbigny)	R					VR		R	VR		R	VR	R	R		R			VR	VR	VR	R	VR		VR	R	VR	R	VR		VR	VR
Pyrgo depressa (d'Orbigny)		VR			VR	VR	VR	VR				VR		VR		R	R	VR		VR	VR		VR				R		R			
P. murrhina (Schwager)					R	R	R	VR	VR	R	R	R	VR	R		VR		R	VR	R	R	R		R	VR		R	R	VR			VR
P. vespertilio (Schlumberger)											VR			VR	R					VR							VR					
Quinqueloculina sawanensis Asano			VR		VR		VR		VR				VR		R	VR																
Siphonodosalia cf. *abyssorum* (Brady)										R																						
S. cf. *consobrina* (d'Orbigny)		R			VR	VR	R	VR	R	R		VR	VR	VR	VR	R	R	R			VR	VR			R		VR		VR	VR		VR
Sphaeroidina bulloides (d'Orbigny)		VR				VR	R	R			VR	R																				
Stilostomella fistuca (Schwager)		VR			F	R	R	R			R	R	R	VR	VR	VR	R	R	R		F	R	VR	R	F	R		R	VR	R	R	R
S. ketienziensis (Ishizaki)	VR		R		R	R	F	F	R		R	F	F	F		F	F	F	F	F	C	C	F	R	F	C	F	F	F	F	C	F
S. lepidula (Schwager)	VR	VR			VR		VR	VR	VR				R	VR					VR	VR											VR	VR
Tosaia hanzawai Takayanagi	VR				VR		VR	VR			R	VR	VR	VR	VR	R	VR	R	VR		R		VR		R		R	R	VR	R	VR	VR
Trifarina kokozuraensis (Asano)					VR	R	VR	VR	VR		R	VR		VR			VR						VR		VR	VR			VR	VR		VR
T. occidentalis (Cushman)	VR				VR	R	F	VR	R				VR	R					VR				VR									
Uvigerina peregrina dirupta Todd						VR	R		VR																							
U. proboscidea Schwager		VR	VR		R	VR	VR		VR		VR	R						VR			VR	R	R	R	R	R	F	R	R	R	R	F
U. subperegrina Cushman and Kleinpell											VR	R	VR																			
Foraminiferal Number per Gram	5	3	7	2	18	11	24	17	8	9	18	37	19	20	6	14	9	8	9	4	11	6	9	7	10	6	10	6	15	15	10	13
Ratio of Planktonic Foraminifera (%)	60	67	71	50	83	36	75	71	50	67	50	60	63	65	33	36	33	63	44	4.8	64	67	44	57	50	17	60	67	53	60	50	31

*Kamiisshiki Volcanic Breccia   **Deguchi Alternation of Tuffaceous Sandstone and Mudstone

Fig. 11. Stratigraphic distribution of benthonic foraminifera in the Nishiyatsushiro Group. VA; more than 46%, A; 46–22%, C; 22–10%, F; 10–4%, R; 4–1%, VR; less than 1%. Species of less than 1% frequencies in all of the samples are excluded from the list.
A: *Globorotalia peripheroacuta*/*Globigerina nepenthes* Interval-Zone, A-1: *Globorotalia peripheroacuta*/*Sphaeroidinellopsis subdehiscens* Interval-Subzone, A-2: *Sphaeroidinellopsis subdehiscens*/*Globigerina nepenthes* Interval-Subzone, B: *Globigerina nepenthes*/*Globorotalia acostaensis* Interval-Zone, B-1: *Globigerina nepenthes*/*Globorotalia siakensis* Interval-Subzone, B-2: *Globorotalia siakensis*/*Globorotalia acostaensis* Interval-Subzone, C: *Globorotalia acostaensis*/*Pulleniatina primalis* Lineage-Zone, D: *Pulleniatina primalis*/*Sphaeroidinella dehiscens* Interval-Zone. a: *Melonis pompilioides*-*Ammodiscus incertus* Zone, b: *Globobulimina auriculata*-*Melonis nicobarensis* Zone, c: *Globobulimina auriculata*-*Nodosaria longiscata* Zone, d: *Melonis pompilioides*-*Stilostomella ketienziensis* Zone.

occupy probably a part of the *Globigerina nepenthes/Globorotalia acostaensis* Interval-Zone, and the fauna indicates an environment ranging from the middle to outer neritic zone under the influence of cold water.

This zone is defined by only one sample and it may be not proper to apply the term zone here. But, the collection of additional samples can be hardly expected, because the Itahana Formation is composed mainly of thick-bedded sandstone and conglomerate, showing a coarsening-upward tendency.

(2) **Nishiyatsushiro Group** (Fig. 11)

a. *Melonis pompilioides-Ammodiscus incertus* Zone—Samples 77043008-(3), -(1), -(2), 77043009 (Kanzaka-Ichinose section)—

This zone is characterized by the abundance of *Melonis pompilioides* (FICHTEL and MOLL) and *Ammodiscus incertus* (D'ORBIGNY) accompanied with *Dentalina* spp., *Globobulimina auriculata* (BAILEY), *Gyroidinoides komatsui* (AOKI), *Nodosaria longiscata* D'ORBIGNY, and *N.* spp. The benthonic foraminiferal number is rather small, amounting to 2–7 individuals per gram, but the ratio of planktonic forms is as high as 50–71 per cent. The fauna of this zone is inferred to have lived in the upper bathyal zone of the temperate region.

The zone is recognized in the middle part of the Kanzaka Mudstone of the Ichinose Formation exposed along the Kanzaka-Ichinose section, though the assemblages from the lower and upper part of the mudstone are unknown due to the conspicuous weathering and the dissolution of calcareous microfossils. But, the *Sphaeroidinellopsis subdehiscens* Base-datum was confirmed at the middle level of the zone. Therefore, the zone corresponds to the uppermost part of the *Globorotalia peripheroacuta/Sphaeroidinellopsis subdehiscens* Interval-Subzone and the basal part of the succeeding *Sphaeroidinellopsis subdehiscens/Globigerina nepenthes* Interval-Subzone.

b. *Globobulimina auriculata-Melonis nicobarensis* Zone—Samples 77032706, 7711-2101 (1), -(4), 77112102, 77112103 (Kamiisshiki-Wadaira section); 77032611, 77032613 (Kamiisshiki-western entrance of Hatouchi Tunnel section)—

This zone is defined by the predominance of *Globobulimina auriculata* (BAILEY) and *Melonis nicobarensis* (CUSHMAN) accompanied mainly with *Melonis pompilioides* (FICHTEL and MOLL), *Stilostomella fistuca* (SCHWAGER), *S. ketienziensis* (ISHIZAKI), *Nodosaria longiscata* D'ORBIGNY, *N.* spp., and *Trifarina occidentalis* (CUSHMAN). *Melonis pompilioides* (FICHTEL and MOLL) is relatively dominant in the lower part of the zone, but it is overwhelmed by the increase of *Nodosaria longiscata* D'ORBIGNY in the upper part, and numerous fragments referable to *Rhabdammina abyssorum* M. SARS are found from a few restricted levels of the upper part. Many taxa first appear in this zone, and most of them are found from the overlying two zones as well. They are as follows;

Martinottiella communis (D'ORBIGNY)
M. communis hosoyaensis ASANO
Sigmoilopsis schlumbergeri (SILVESTRI)
Bolivina robusta BRADY
Chilostomella oolina SCHWAGER
Gyroidina sp. 1
Gyroidinoides soldanni (D'ORBIGNY)
Parafissurina ovalis TODD
Plectofrondicularia advena (CUSHMAN)
Pyrgo murrhina (SCHWAGER)
P. vespertilio (SCHLUMBERGER)
Sigmoilina sigmoidea (BRADY)
Trifarina kokozuraensis (ASANO)

However, *Biloculina natsukawa* (MATUI and NAKAMURA), *Siphonodosaria* cf. *abyssorum* (BRADY), and *Uvigerina peregrina dirupta* TODD occur only from this zone, and *Globobulimina perversa* (CUSHMAN), *Lenticulina lucida* (CUSHMAN), and *Uvigerina subperegrina* CUSHMAN and KLEINPELL are restricted to the zone and to the next younger zone.

The benthonic foraminiferal number is relatively large, attainig 15 per gram on an average, and the ratio of planktonic forms is as high as in the subjacent zone with the average ratio of 62 per cent. The fauna of this zone may be of the upper bathyal zone of the temperate region.

This zone is recognized; (1) in the mudstone of about 100 meters in thickness which occupies the middle part of the Wadaira Tuff of the Ichinose Formation along the Kamiisshiki-Wadaira section; (2) in the mudstone intercalated in the upper part of the Wadaira Tuff along the Kamiisshiki-western entrance of Hatouchi Tunnel. It occupies the middle part of the *Sphaeroidinellopsis subdehiscens/Glogigerina nepenthes* Intervai-Subzone.

c. *Globobulimina auriculata-Nodosaria longiscata* Zone—Samples 77032614 (Kamiisshiki-western entrance of Hatouchi Tunnel section); 77032701–(1), –(2), 77032605 (Deguchi-eastern entrance of Hatouchi Tunnel section); 77032927, 77032925, 77032924 (Iitomi Bridge-Fukamachi section)—

This zone is characterized by the predominant occurrences of *Globobulimina auriculata* (BAILEY) and *Nodosaria longiscata* D'ORBIGNY, accompanied by *Martinottiella communis* (D'ORBIGNY), *Gyroidinoides altiformis* (R. E. and K. C. STEWART), *Melonis pompilioides* (FICHTEL and MOLL), *Nodosaria* spp., *Pullenia bulloides* (D'ORBIGNY), *Pyrgo murrhina* (SCHWAGER), *Siphonodosaria* cf. *consobrina* (D'ORBIGNY), *Stilostomella fistuca* (SCHWAGER), and *S. ketienziensis* (ISHIZAKI), the last of which has constant occurrence with relatively high frequency. *Marsipella elongata* NORMAN and *Psammosphaera fusca*

SCHULZE are confined to this zone, and some species such as *Cyclogyra involvens* (REUSS), *Globobulimina perversa* (CUSHMAN), *Globocassidulina subglobosa* (BRADY), *lenticulina lucida* (CUSHMAN), *Quinqueloculina sawanensis* ASANO, *Sphaeroidina bulloides* (D'ORBIGNY), and *Uvigerina subperegrina* CUSHMAN and KLEINPELL disappear in the middle or upper part of the zone.

The benthonic foraminiferal number is large, amounting to the maximum of 37 individuals per gram in the lower part of this zone, where the ratio of planktonic forms is constant with 60–65 per cent in succession to the subjacent zone. But, the former decreases to 6–14 per gram, and the latter also becomes low with the average of 40 per cent in the upper part. The fauna is inferred to have lived in the upper bathyal zone of the temperate region.

This zone is recognized: (1) in the uppermost part of the Wadaira Tuff of the Ichinose Formation along the Kamiisshiki-western entrance of Hatouchi Tunnel section; (2) in the Deguchi Alternation of Tuffaceous Sandstone and Mudstone of the Daigoyama Formation along the Deguchi-eastern entrance of Hatouchi Tunnel section; (3) in the lower part of the Byobuiwa Tuff of the Daigoyama Formation along the Iitomi Bridge-Fukamachi section. *Globigerina nepenthes* Base-datum was found from the basal part of the Deguchi Alternation of Tuffaceous Sandstone and Mudstone, and the *Globorotalia siakensis* Top-datum was confirmed at a level in the middle part of the Byobuiwa Tuff. Therefore, this zone ranges from the uppermost part of the *Sphaeroidinellopsis subdehiscens/Globigerina nepenthes* Interval-Subzone to the major part of the next younger *Globigerina nepenthes/Globorotalia siakensis* Concurrent-Subzone.

d. *Melonis pompilioides-Stilostomella ketienziensis* Zone—Samples 77032918, 77032917, 77032916–(1), –(2), 77050104–(4), –(3), –(2), –(1), 77050103–(2), –(1), 77050102, 77032909, 77050101–(2), –(1) (Iitomi Bridge-Fukamachi section)—

On the whole, this zone is characterized by the abundant occurrences of *Melonis pompilioides* (FICHTEL and MOLL) and *Stilostomella ketienziensis* (ISHIZAKI). It is noticeable that *Globobulimina auriculata* (BAILEY), *Nodosaria longiscata* D'ORBIGNY, *N.* spp., and *Stilostomella fistuca* (SCHWAGER) are found successively with relatively high frequency. There are a few levels where *Melonis pompilioides* (FICHTEL and MOLL) is overwhelmed by the increase of *Globobulimina auriculata* (BAILEY). Besides, *Melonis nicobarensis* (CUSHMAN) and *Uvigerina proboscidea* SCHWAGER have a tendency to increase upwards, and *Nonionella miocenica* CUSHMAN first appears in the zone. The other accompanying taxa are as follows;

Martinottiella communis (D'ORBIGNY)
Sigmoilopsis schlumbergeri (SILVETRI)
Bulimina rostrata BRADY
Gyroidinoides altiformis (R. E. and K. C. STEWART)

Hanzawaia nipponica ASANO
Lagena spp.
Planulina wuelerstorfi (SCHWAGER)
Plectofrondicularia advena (CUSHMAN)
Pleurostomella brevis SCHWAGER
P. elliptica GALLOWAY and HEMINWAY
Pullenia bulloides (D'ORBIGNY)
Pyrgo murrhina (SCHWAGER)

The benthonic foraminiferal number is rather few, amounting to 4–15 per gram. The ratio of planktonic forms is very variable ranging from 5 to 67 per cent in the lower part of the zone, and fairly constant with 54 per cent on an average in the middle and upper parts. The fauna may indicate a slightly unstable environment of the upper bathyal zone of the temperate region.

The zone is recognized in the middle and upper parts of the Byobuiwa Tuff of the Daigoyama Formation along the Iitomi Bridge-Fukamachi section. The *Globorotalia siakensis* Top-datum and the next younger *Globorotalia acostaensis* Base-datum were found from the basal part of the zone, and the *Pulleniatina primalis* Base-datum from the uppermost part. Therefore, this zone corresponds to the four biozones of planktonic foraminifera, that is, the uppermost part of the *Globigerina nepenthes/Globorotalia siakensis* Concurrent-Subzone, the *Globorotalia siakensis/Globorotalia acostaensis* Interval-Subzone, the *Globorotalia acostaensis/Pulleniatina primalis* Lineage-Zone, and the lowermost part of the *Pulleniatina primalis/Sphaeroidinella dehiscens* Interval-Zone.

4. Comparison of benthonic faunas and sedimentary environments between the Tomioka and Nishiyatsushiro groups

Based on the planktonic foraminiferal datum planes, the *Sphaeroidinellopsis subdehiscens* Base-datum and *Globigerina nepenthes* Base-datum, common to the Tomioka and Nishiyatsushiro groups, the benthonic foraminiferal zones of both groups can be correlated with each other as shown in Fig. 9.

In comparison of the benthonic foraminifera from the synchronous zones between the groups, there are considerable differences in their faunal composition. Excepting some taxa whose occurrences are very rare, the number of taxa common to the both groups is only twelve, and they are as follows;

Alveophragmium scitulum (BRADY)
Martinottiella communis (D'ORBIGNY)
Sigmoilopsis schlumbergeri (SILVESTRI)
Cibicidoides pseudoungerianus (CUSHMAN)
Globocassidulina subglobosa (BRADY)
Lenticulina lucida (CUSHMAN)
Melonis nicobarensis (CUSHMAN)

M. pompilioides (FICHTEL and MOLL)
M. quadalpae PARKER
Sphaeroidina bulloides (D'ORBIGNY)
Trifarina kokozuraensis (ASANO)
Uvigerina subperegrina CUSHMAN and KLEINPELL

The number of taxa which are present in the Tomioka Group but not in the Nishiyatsushiro Group is about thirty. The important taxa are as follows;

Cyclammina ezoensis ASANO
Gaudryina ishikiensis ASANO
Ammonia japonica (HADA)
A. ketienziensis (ISHIZAKI)
A. tochigiensis (UCHIO)
Amphicoryna proxima (SILVESTRI)
A. tubulata japonica (UCHIO)
Anomalina glabrata CUSHMAN
Cassidulina norcrossi CUSHMAN
Cibicidoides aknerianus (D'ORBIGNY)
C. lobatulus (WALKER and JACOB)
Elphidium advena (CUSHMAN)
E. jenseni (CUSHMAN)
Florilus grateloupi (D'ORBIGNY)
Nonion japonicum ASANO
N. pacificum (CUSHMAN)
Nonionellina labradorica (DAWSON)
Praeglobobulimina pupoides (D'ORBIGNY)

The number of characteristic taxa found from the Nishiyatsushiro Group only is also about thirty. The next taxa are significant;

Ammodiscus incertus (D'ORBIGNY)
Marsipella elongata NORMAN
Psammosphaera fusca SCHULZE
Reophax pilulifer BRADY
Rhabdammina abyssorum M. SARS
Saccammina sphaerica M. SARS
Globobulimina auriculata (BAILEY)
Gyroidinoides komatsui (AOKI)
G. nipponicus (ISHIZAKI)
Oridosalis umbonatus (REUSS)
Pleurostomella brevis SCHWAGER
P. elliptica GALLOWAY and HEMINWAY

Pyrgo spp.
Siphonodosaria cf. *consobrina* (D'ORBIGNY)
Stilostomella fistuca (SCHWAGER)
Tosaia hanzawai TAKAYANAGI
Trifarina occidentalis (CUSHMAN)

Another thing to be noticed is that there is an appreciable difference in the planktonic foraminiferal assemblages as well between the above-mentioned synchronous zones. The charateristic taxa of the Tomioka Group are *Globigerina bulloides bulloides* D'ORBIGNY, *G. pachyderma* (EHRENBERG), and *Globorotalia bykovae* (AISENSTAT), and the assemblages of the group are monotonous in composition, consisting predominantly of several taxa of *Globigerina*, except ones from the lower part of the *Sphaeroidinellopsis subdehiscens/Globigerina nepenthes* Interval-Subzone. Both species of carinate and non-carinate *Globorotalia* scarcely occur, and *Globigerinoides ruber ruber* (D'ORBIGNY) and *Globigerina nepenthes* TODD are found in very low frequencies. Therefore, the planktonic foraminiferal assemblages from the upper part of the Tomioka Group are characteristic of the "Miocene boreal fauna" called tentatively by SAITO (1963).

From the Nishiyatsushiro Group, on the other hand, tropical and subtropical taxa such as *Globoquadrina altispira* (CUSHMAN and JAVIS), *G. dehiscens* (CHAPMAN, PARR, and COLLINS), *Globorotalia lenguaensis* BOLLI, *G. peripheroacuta* BLOW and BANNER, *G. praefohsi* BLOW and BANNER, *Hastigerina siphonifera praesiphonifera* BLOW, *H. siphonifera siphonifera* (D'ORBIGNY), and *Globigerina nepenthes* TODD etc. are found in fairly high frequencies.

After all, it is apparent that the sedimentary environment of the Tomioka Group and that of the Nishiyatsushiro Group were quite differnet during the late Middle Miocene, and that the Tomioka area has changed from the upper bathyal condition to the neritic one under the influence of cold water, but the Shimobe area has continued to subside so as to permit the subsistence of the upper bathyal fauna under the warm water current during that time.

V. Middle Miocene benthonic faunas from the other regions of the Kanto and its adjacent districts

Last of all, it is necessary to compare the Middle Miocene foraminiferal faunas of the Tomioka and Nishiyatsushiro groups with those reported from various places of the Kanto and its adjacent districts.

From the Hiki Hill, Saitama Prefecture and the Daigo-Omiya area, Ibaragi Prefecture, three planktonic foraminiferal zones were reported. They are the *Globorotalia peripheroronda/Globorotalia quinifalcata, Globorotalia peripheroacuta/Globorotalia miozea* (s.s.), and *Globorotalia bykovae/Globorotalia menardii* zones, in ascending order,

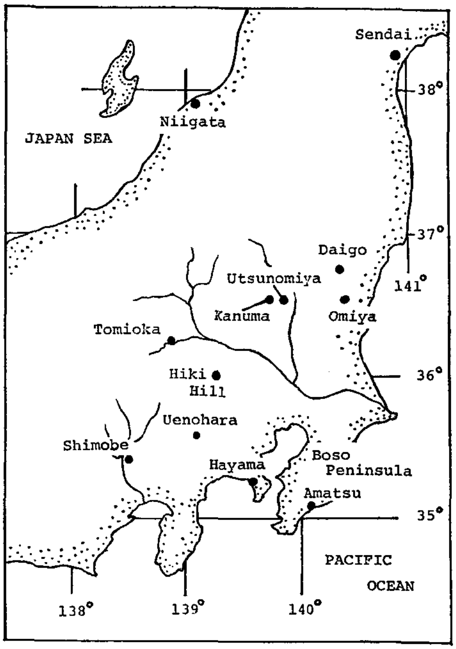

Fig. 12. Map showing locations of the Kanto district and its environs from which Middle Miocene foraminiferal faunas were discussed in the present paper.

and the representative benthonic foraminifera from each of the zones were also referred (MAIYA and MURATA, 1977). On the whole, the faunal changes of benthonic foraminifera in the latter two zones seem to resemble those known from the *Globorotalia peripheroacuta/Globigerina nepenthes* Interval-Zone of the Tomioka Group. It may be said, therefore, that the marine regression from the north and west of the Kanto district began in the middle or late Middle Miocene.

In the Boso Peninsula, Chiba Prefecture, the Amatsu Formation was ascertained by ODA (1977) to have been deposited during the Middle Miocene based on the stratigraphic distribution of planktonic foraminifera. However, it is a matter for regret that the benthonic foraminiferal distribution in the formation remain unknown. Only a few taxa such as *Stilostomella* spp., *Planulina wuelerstorfi* (SCHWAGER), and *Nodosaria* spp. were reported by MAIYA and MURATA (op. cit.) from the basal part of the formation. Therefore, benthonic fauna can not be compared with those of the Tomioka and Nishiyatsushiro groups. Further investigation of paleoenvironment based on the faunal character of benthonic forms and its vertical changes are necessary.

Besides, two benthonic faunas were described by UCHIO (1950) from Tochigi

Prefecture. One of them was found from the Momiyama Sandstone of the Kanuma Formation exposed in Kanuma City and was assumed to be the Middle Miocene in age, and the other from a fine sandstone of the Terayama Group distributed in

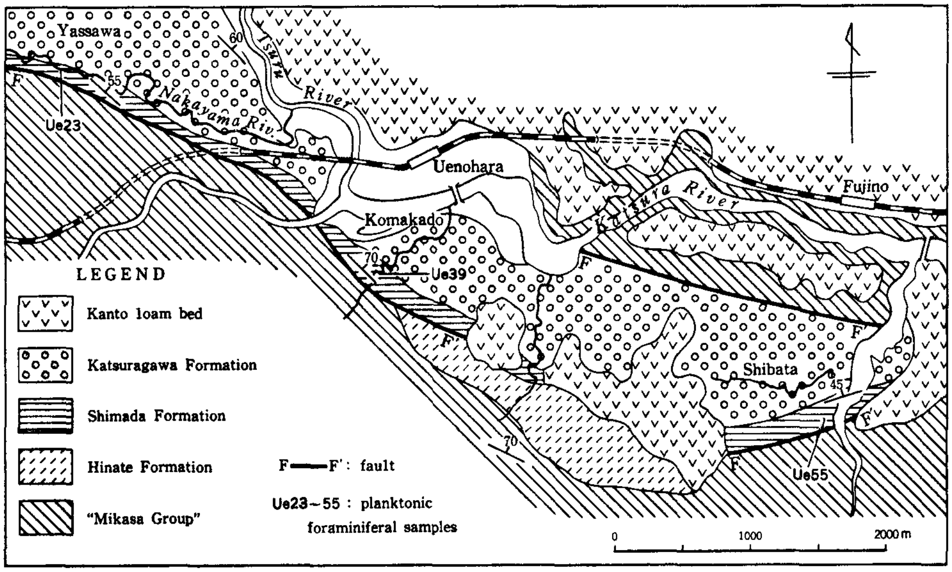

Fig. 13. Geological map of the Uenohara-cho and its environs, Kitakatsura-gun, Yamanashi Prefecture, and locations of samples collected from the Shimada Formation of the Nishikatsura Group.

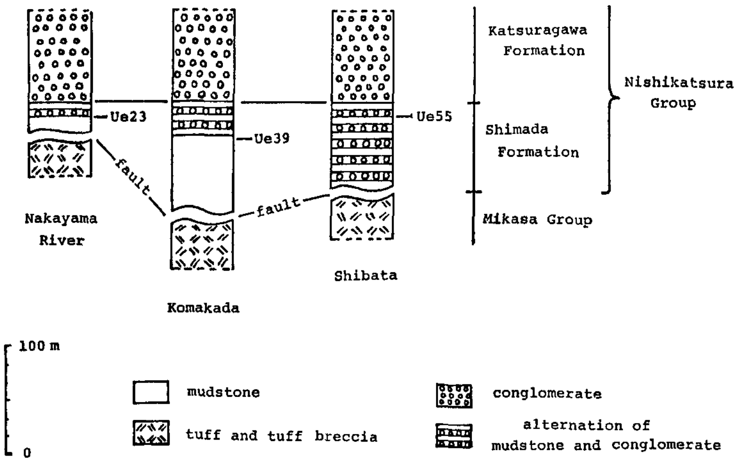

Fig. 14. Columnar section of the Shimada and Katsura formations of the Nishikatsura Group, showing the stratigraphic positions of samples.

Utsunomiya City and was assumed to be of the Upper Miocene. The former comprises about thirty taxa, and is characteried by abundant *Vaginulina otukai* UCHIO and *Hanzawaia nipponica* ASANO associated with *Ammonia tochigiensis* (UCHIO), *Elphidium momiyamaensis* UCHIO, *Celanthus craticulatum* (FICHTEL and MOLL), and *Miogypsina kotoi* HANZAWA etc. The latter consists of nearly fifty taxa and is characterized by abundant *Melonis pompilioides* (FICHTEL and MOLL), *Ammonia ketienziensis* (ISHIZAKI), and *Elphidium subgranulosum* ASANO. Planktonic forms such as *Globigerina bulloides* D'ORBIGNY, *G. bilobata* D'ORBIGNY, *Globorotali tumida* (BRADY), *G. crassa* (D'ORBIGNY), and *Orbulina universa* D'ORBIGNY were also reported. However, reexamination of planktonic foraminifera based on the updated taxonomy is necessary, and age determination of these faunas should be settled first. Comparison of the faunas with those of

Species \ Samples	Ue23	Ue39	Ue55
Globigerina angustiumbilicata Bolli		+	+
G. bradyi Wiesner		+	
G. bulbosa LeRoy			+
G. decoraperta Takayanagi & Saito		+	
G. falconensis Blow	+		
G. foliata Bolli			+
G. nepenthes Todd	+	+	
G. pachyderma (Ehrenberg)		+	
G. parabulloides Blow	+		
G. praebulloides Blow	+		
G. spp.	+	+	
Globigerinita incrusta Akers	+	+	+
G.? sp.		+	
Globigerinoides obliquus obliquus Bolli			+
G. quadrilobatus immatulus LeRoy			+
G. quadrilobatus trilobus (Reuss)			+
G. subquadratus Brönnimann		+	+
G. spp.		+	+
Globoquadrina dehiscens (Chapman, Parr & Collins)	+	+	+
G. venezuelana (Hedberg)		+	
Globorotalia (Turborotalia) cf. *adamantea* Saito		+	
G. (T.) continuosa Blow		+	
G. (G.) menardii (d'Orbigny)	+	+	
G. (G.) cf. *menardii* (d'Orbigny)	+		
Hastigerina sp.	+		
Sphaeroidinellopsis seminulina seminulina (Schwager)	+		+
S. subdehiscens subdehiscens (Blow)	+	+	

Fig. 15. Planktonic foraminifera from the Shimada formation of the Nishikatsura Group.

the Tomioka and Nishiyatsushiro groups is a subject of the future investigation.

In the other adjacent regions, FUKUTA and SHINOKI (1952) studied benthonic foraminiferal fauna from the Shimada Formation distributed from the south of Uenohara-cho, Kitakatsura-gun, Yamanashi Prefecture to the southwest of the Lake Sagami, Tsukui-gun, Kanagawa Prefecture. The fauna comprises very abundant arenaceous forms such as *Martinottiella communis* (D'ORBIGNY), *Haplophragmoides scitulum* (BRADY), and *Göesella schencki* ASANO in association with *Cyclammina incisa* (STACHE), *C. japonica kaiensis* FUKUTA and SHINOKI, *Nonion soldanni* (D'ORBIGNY), *N. pacificum* CUSHMAN, and some others. FUKUTA and SHINOKI (op. cit.) came to a conclusion that the Shimada Formation was deposited in rather cold water condition. Recently, the author studied planktonic foraminifera collected from the formation (Figs. 13 and 14). Most of them are in poor preservation and unfavorable for the quantitative analysis of faunal composition, but about thirty taxa including *Globigerina nepenthes* TODD, *Globigerinoides subquadratus* BRÖNNIMANN, *Globorotalia menardii* (D'ORBIGNY), and *G. continuosa* BLOW were found (Fig. 15). It is inferred, therefore, that the formation

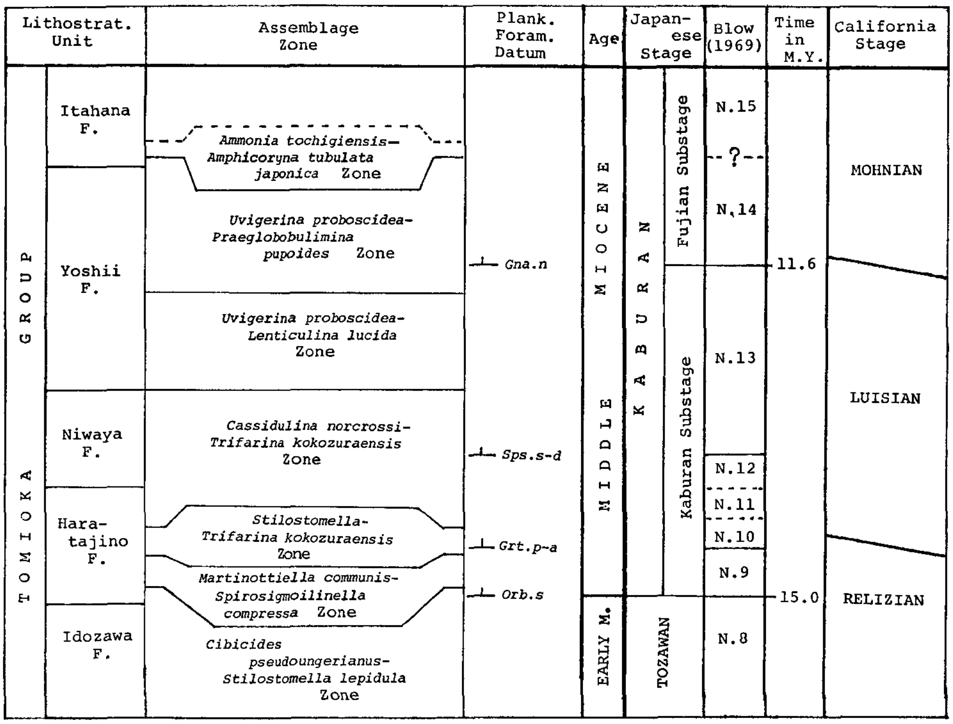

Fig. 16. Relation among the Japanese chronostratigraphic units, the benthonic foraminiferal zones in the Tomioka area, and California stages based on benthonic foraminiferal distribution.
Gna.n: Globigerina nepenthes, Sps.s-d: Sphaeroidinellopsis subdehiscens, Grt.p-a: Globorotalia peripheroacuta, Orb.s: Orbulina suturalis.

is included within the *Globigerina nepenthes/Globorotalia acostaensis* Interval-Zone, and that the temperature of surface water was rather warm at the deposition of the formation. Judging from the faunal composition of benthonic and planktonic foraminifera it is considered that the formation was deposited in the upper bathyal zone under the influence of the warm water current in the late Middle Miocene.

VI. Summary and conclusion

(1) It was revealed that the *Sphaeroidinellopsis subdehiscens* Base-datum exists in a level somewhat lower than that reported previously (CHIJI and KONDA, 1978) through the examination of additional samples. The stratigraphic position of the base-datum should be altered as follows. The base-datum exists in the middle part of the Niwaya Formation of the Tomioka Group and in the same part of the Kanzaka Mudstone of the Nishiyatsushiro Group.

(2) Based on the stratigraphic distribution of benthonic foraminifera, the Tomioka and Nishiyatsushiro groups are divided into nine and four biozones, respectively. They are as follows, in ascending order.

Tomioka Group—*Melonis-Stilostomella* Zone, *Cyclammina-Discammina compressa* Zone, *Cibicidoides pseudoungerianus-Stilostomella lepidula* Zone, *Martinottiella communis-Spirosigmoilinella compressa* Zone, *Stilostomella-Trifarina kokozuraensis* Zone, *Cassidulina norcrossi-Trifarina kokozuraensis* Zone, *Uvigerina proboscidea-Lenticulina lucida* Zone, *Uvigerina proboscidea-Praeglobobulimina pupoides* Zone, and *Ammonia tochigiensis-Amphicoryina tubulata japonica* Zone.

Nishiyatsushiro Group—*Melonis pompilioides-Ammodiscus incertus* Zone, *Globobulimina auriculata-Melonis nicobarensis* Zone, *Globobulimina auriculata-Nodosaria longiscata* Zone, and *Melonis pompilioides-Stilostomella ketienziensis* Zone.

(3) The lower half of the Tomioka Group was deposited in the upper bathyal zone under the warm water condition during the late Early Miocene. However, just above the *Orbulina suturalis* Base-datum of the group, the *Martinottiella communis -Spirosigmoilinella compressa* Zone characterized by the poor occurrence of arenaceous forms such as *Cyclammina incisa* (STACHE), *Discammina compressa* (GÖES), *Göesella schencki* ASANO, *Haplophragmoides renzi* ASANO, *Martinottiella communis* (D'ORBIGNY), and *Spirosigmoilinella compressa* MATSUNAGA was recognized, though it is several tens of meters thick. The faunal change from the subjacent *Cibicidoides pseudoungerianus-Stilostomella lepidula* Zone characterized by the rich warm water species of calcareous forms happens abruptly in the consecutive muddy facies of the Haratajino Formation, and the planktonic forms are never found in the zone. Such a biozone seems to indicate the stagnant and anaerobic condition of the basin, and it has been pursued from the Japan Sea side province of Southwest Japan through the adjacent Niigata basin in

the early Middle Miocene. Accordingly, it may be considered that the Tomioka basin had been connected with the sedimentary basin of Japan Sea side since that time, and that the boundary between this zone and the subjacent one corresponds to the Foraminiferal Sharp Line of TAI (1963).

(4) In the middle Middle Miocene, the Tomioka basin was significantly affected by the cold water mass which invaded the Kanto district from the northward, and subsequently, it became shallower and changed from the uppermost bathyal zone to the outer or middle neritic zone.

(5) By means of the *Sphaeroidinellopsis subdehiscens* Base-datum and the next younger *Globigerina nepenthes* Base-datum, the benthonic foraminiferal zones of the Tomioka Group and those of the Nishiyatsushiro Group are correlated with each other as shown in Fig. 9. As to the Nishiyatsushiro Group distributed in the Shimobe area, there is no indication for the appreciable depth change throughout the time of deposition. All the benthonic foraminiferal assemblages are of the upper bathyal zone, and many tropical and subtropical taxa of planktonic forms were abundantly and consistently found from the whole section of the group. Contrary to the Tomioka area, the Shimobe area has continued to submerge under the warm water condition during the middle and late Middle Miocene, and there accumulated the marine sequence intercalating very thick volcanic detritus. On the other hand, the Uenohara area of the eastern margin of Yamanashi Prefecture situated near to the Kanto district was deposited under a deep water condition in a transitional region of the warm and cold water currents.

(6) There are many points of resemblance in the faunal character and its vertical changes between the Middle Miocene benthonic faunas reported from Saitama and Ibaragi prefectures and those found from the Tomioka Group. It can be said, therefore, that the marine regression from the north and west of the Kanto district began in the middle Middle Miocene. As far as the southern part of the district is concerned, the Middle Miocene benthonic fauna remains unknown. It is necessary to investigate the stratigraphic distribution of benthonic foraminifera from the Amatsu Formation distributed in the Boso Peninsula.

VII. Discussion

The present study has revealed that the Tomioka area was affected significantly by the cold deep water during the middle Middle Miocene time, and changed to the neritic zone after that time.

As a whole, the Middle Miocene was a remarkable regressive stage in the Japanese region. In many places, as mentioned afore, the greater part of the Middle Miocene Series is lacking in marine sequences, especially on the Pacific side of the

Japanese Islands*. Change of depositional condition of the Tomioka area is presumably not a local phenomenon in the Kanto district, Central Japan, but a event related to upheaval of the Japanese region during the Middle Miocene time.

Furthermore, it is noteceable that a subarctic bathyal fauna including abundant *Cassidulina norcrossi* CUSHMAN and *Trifarina kokozuraensis* (ASANO) was found in the lower part of the *Globorotalia peripheroacuta/Globigerina nepenthes* Interval Zone corresponding approximately to the middle Middle Miocene. With regard to this, some discussion may be necessary.

Judging from available data of biostratigraphic and paleontological studies on the middle latitudes along the marginal North Pacific region, appearance of the subarctic deep water type fauna in the Tomioka Group can be convincingly attributed to the worldwide temperature change in the Middle Miocene.

In recent years, intercontinental correlation of California mid-Cenozoic stages defined by KLEINPELL (1938) based on stratigraphic distribution of benthonic foraminifera became possible through the progress of studies of planktonic microfossils and radiometric dating (BANDY and INGLE, 1970; BANDY, 1972; INGLE, 1977; LIPPS, 1964, 1967, 1968; TURNER, 1970; WILCOXON, 1969), and then, all, the upper part of Relizian, Luisian, and lower half of Mohnian stages of KLEINPELL (op. cit.) in ascending order, have been considered to be equivalent to the Middle Miocene (Fig. 16).

The Luisian Stage corresponding approximately to the middle Middle Miocene was essentially regressive. It is absent at some localities in California. The early Luisian is represented by warm to temperate water type fauna of medium depth (bathyal zone) including abundant *Siphogeneria* under the open sea condition, but the later stage by shallow (neritic) and current-sheltered warm water type, and paleotemperature became successively cooler toward the latest stage. In the following lower Mohnian Stage corresponding to the late Middle Miocene, benthonic fauna characteristic of the neritic zone became common. The warm water elements have disappeared in the middle Mohnian and there is a remarkable increase of cold water forms such as *Cassidulina, Nonion pizarensis*, and *Uvigerina*. The faunal change observable between the Luisian and Mohnian is the most pronounced change recognized in the California Miocene (KLEINPELL, 1938).

Therefore, general trends of paleoenvironmental changes are similar to each other between the Pacific side of the Japanese Islands and California coast during the Middle Miocene time. This is also supported by the data on oxygen isotope analyses of bathyal foraminiferal tests from the DSDP cores in the Pacific Ocean.

Recently, oxygen isotopic compositions of multispecies assemblages of bathyal

* The Shimobe area is an exception, because the area is situated in the Fossa Magna region where subsidence and sedimentation occurred largely following intense volcanism and faulting movements during the Middle and Late Miocene.

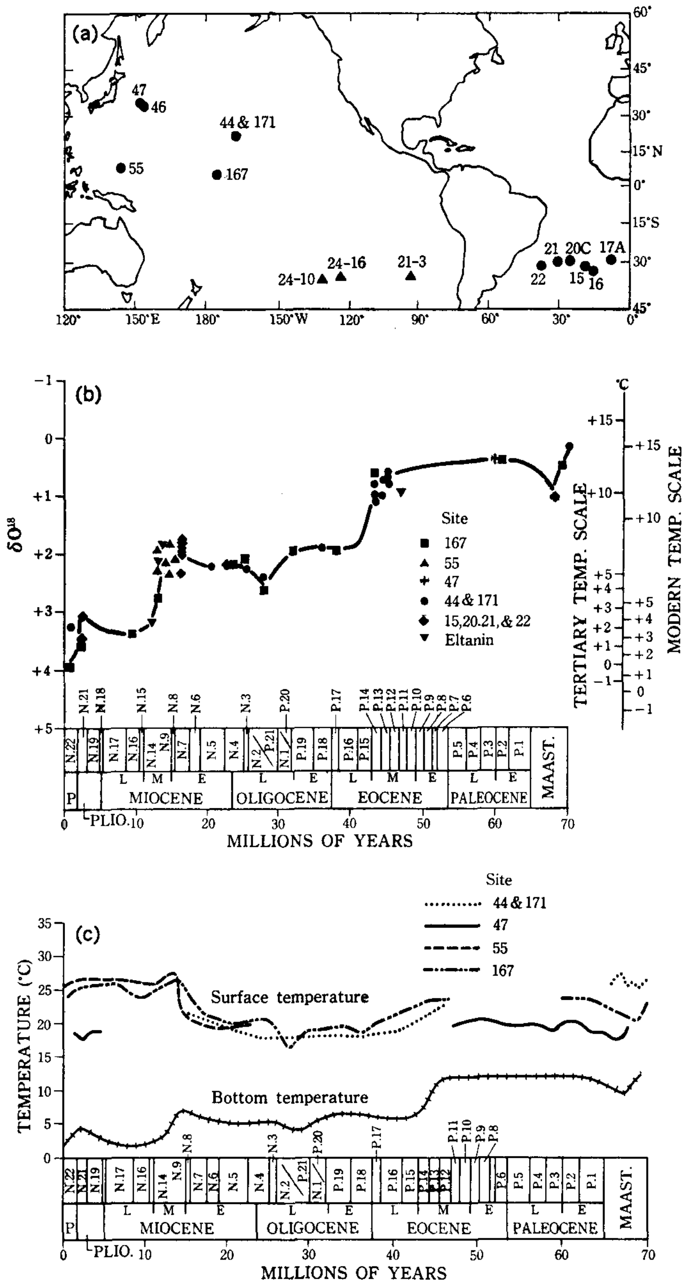
(a)
47
46
44 & 171
55
167
24-16
21-3
24-10
21 20C 17A
22
15 16
(b)
δO18
Site
167
55
47
44 & 171
15,20.21,& 22
Eltanin
TERTIARY TEMP. SCALE
MODERN TEMP. SCALE
MIOCENE
OLIGOCENE
EOCENE
PALEOCENE
MAAST.
PLIO.
MILLIONS OF YEARS
(c)
Site
44 & 171
47
55
167
Surface temperature
Bottom temperature
TEMPERATURE (°C)
MIOCENE
OLIGOCENE
EOCENE
PALEOCENE
MAAST.
PLIO.
MILLIONS OF YEARS

Fig 17.

foraminifera from many sampling sites in the North and South Pacific have been plotted as a function of time (DOUGLAS and SAVIN, 1973; SAVIN *et al.*, 1975; SAITO, 1977). In these data, all points concentrate on a single curve without any exception, and the most dramatic cooling of bottom waters is shown in the Middle Miocene. Also, in general Tertiery paleotemperature deduced from isotope analyses of planktonic and benthonic foraminifera of five DSDP cores (sites 44, 47, 55, 167, and 171) in the North Pacific (SAVIN *et al.*, 1975), the fluctuation of the planktonic and benthonic foraminiferal curves are parallel until the early Middle Miocene, and thereafter the benthonic curve shows a temperature decline, while the low latitude planktonic temperature curve shows relatively constant temperatures (Fig. 17). Since deep

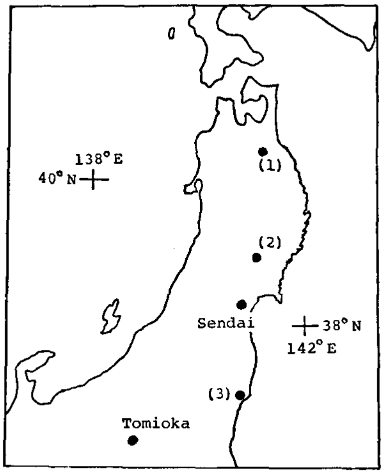

Fig. 18. Map showing the locations of the Kadonosawa-Sannohe (1), Ichinoseki (2), and Joban (3) areas, northern Japan.

bottom water temperatures throughout the world's oceans today closely approximate surface temperatures in their source region at polar latitudes, the oxygen isotopic record in deep sea sediments may in turn suggests high latitude surface temperatures of the geologic past. In addition, because the thermal conditions (temperatures and

Fig. 17. General Tertiary paleotemperatures deduced from oxygen isotope analyses of planktonic and benthonic foraminifera from several DSDP cores in the North and South Pacific and South Atlantic oceans:
(a) locations of cores studied. Circles=DSDP sites. Triangles=USNS Eltanin sampling sites. (b) Oxygen isotopic compositions of multispecies assemblages of benthonic foraminifera. The Tertiary temperature scale applies to samples older than Middle Miocene. Modern temperature scale is applicable to present-day oceans. Temperature scales for Middle and Late Miocene and Pliocene lie between two scales shown. (c) Surface temperature of five low latitude North Pacific DSDP sampling sites estimated from isotopic data. Also shown are bottom temperature (or high latitude surface temperatures) from (b). Quoted from SAVIN *et al.* (1975).

volume of ice) of high latitudes are the primary factor controlling the δO^{18} values in the tests of bathyal foraminifera (SCHACKLETON, 1967; SCHACKLETON and OPDYKE, 1976), the δO^{18} record in deep open ocean sediments is globally synchronous.

On the Japan Sea side of northern Japan, tropical species of planktonic foraminifera, such as *Globorotalia praemenardii praemenardii* CUSHMAN and STAINFORTH, *Globorotalia miozea* (s.l.) FINLAY, *Globoquadrina altispira altispira* (CUSHMAN and JAVIS), and *Globoquadrina dehiscens* (CHAPMAN, PARR and COLLINS), disappear at the top of the *Globorotalia peripheroacuta/Globorotalia miozea* (s.l.) Zone corresponding approximately to BLOW's (1969) Zone N.10–N.11 (IKEBE *et al.*, 1977; MAIYA, 1978). In the Tomikao area, on the other hand, tropical taxa mentioned above subsisted until the top of the *Globorotalia peripheroacuta/Globigerina nepenthes* Interval-Zone corresponding to Zone N.10–N.13 (CHIJI and KONDA, 1978), and then it should be emphasized that prior to the extinction of tropical planktonic foraminifera a remarkable faunal change of benthonic foraminifera occurred in the bathyal zone; namely, a subarctic cold water type fauna such as the *Cassidulina norcrossi-Trifarina kokozuraensis* Assbmelage invaded the Tomioka basin, replacing the warm to temperate water type fauna. Therefore, it is considered that the cold deep waters derived from the surface waters in the high latitude regions had underlain the warm surface current during the middle Middle Miocene. Accordingly, the faunal composition change of bathyal foraminifera in the land section is not inconsistent with the δO^{18} record in deep sea sediments mentioned above.

In California as well, planktonic and benthonic foraminiferal occurrences show a similar trend in the Luisian Stage; some tropical indices of planktonic foraminifera still survived into the close of the stage, suggesting that the major isotherms has shifted northward at this time, and all of them disappear in the following Lower Mohnian Stage (BANDY, 1972; INGLE, 1967; LIPPS, 1964; PARKER, 1964). On the other hand, benthonic foraminiferal faunal change in the Luisian Stage shows already a tendency of gradual cooling of the Pacific bottom waters (KLEINPELL, 1938).

There are not enough data, however, on benthonic foraminifera to explain Middle Miocene events in the marginal North Pacific region. On the Pacific side of northern Japan, only a Middle Miocene benthonic fauna has been known from the Hatatate Formation distributed in the southwest of Sendai (ASANO, 1937; TAKAYANAGI, 1952), and the age of the formation was assigned by ODA and SAKAI (1977) to be the early Middle Miocene to the early Late Miocene based on planktonic foraminifera and radiolaria. TAKAYANAGI (op. cit.) classified sedimentary environment of the formation into two phases, the earlier one of a shallow sea in an unstable area and the later one of a deeper in a more stable condition, but it seems for the author that there is no apparent evidence of the temperature decline of deep waters in the faunal composition of the later phase.

Besides, some Middle Miocene marine sequences have been reported through the recent studies of planktonic microfossils from the Kadonosawa-Sannohe, Ichinoseki, and Joban areas, the Pacific side of northern Japan [SAMATA, 1976; TAKAYANAGI *et al.*, 1976; TUSCHI *et al.*, 1979; (Fig. 18)]. Neverthless, benthonic foraminiferal research on these sequences has not been carried out until now. In connection with the author's work, it is necessary to confirm benthonic foraminiferal compositions in these sequences.

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Explanation of Plates I-V

Plate I

Fig. 1: *Martinottiella communis* (D'ORBIGNY) ×50 OMNH Reg. No. F13871F; from Sample 57-(1) (Idozawa Formation, Tomioka Group).
Fig. 2: *Martinottiella communis* (D'ORBIGNY) ×72 OMNH Reg. No. F13872F; from Sample 57-(1) (Idozawa Formation, Tomioka Group).
Figs. 3a, b: *Spirosigmoilinella compressa* MATSUNAGA ×66 OMNH Reg. No. F13903F; from Sample 4 (Haratajino Formation, Tomioka Group).
Fig. 4: *Spirosigmoilinella compressa* MATSUNAGA ×60 OMNH Reg. No. F13904F; from Sample 57-(1) (Idozawa Formation, Tomioka Group).
Figs. 5a, b: *Discammina compressa* (GÖES) ×24 OMNH Reg. No. F13858F; from Sample 162 (Haratajino Formation, Tomioka Group).
Figs. 6a, b: *Discammina compressa* (GÖES) ×22 OMNH Reg. No. F13857F; from Sample 152 (Haratajino Formation, Tomioka Group).
Fig. 7: *Ammodiscus incertus* (D'ORBIGNY) ×6 OMNH Reg. No. F13912F; from Sample 7704-3008-(2) (Kanzaka Mudstone, Ichinose Formation, Nishiyatsushiro Group).
Fig. 8: *Ammodiscus incertus* (D'ORBIGNY) var. ×6 OMNH Reg. No. F13913F; from Sample 41 (Idozawa Formation, Tomioka Group).
Fig. 9: *Marsipella elongata* NORMAN ×14 OMNH Reg. No. F13914F; from Sample 77043008-(2) (Kanzaka Mudstone, Ichinose Formation, Nishiyatsushiro Group).
Figs. 10a, b: *Göesella schencki* ASANO ×26 OMNH Reg. No. F13836F; from Sample 150 (Haratajino Formation, Tomioka Group).
Figs. 11a, b: *Gyroidinoides altiformis* (R. E. and K. C. STEWART) ×50 OMNH Reg. No. F13837F; from Sample 77032613 (Wadaira Tuff, Ichinose Formation, Nishiyatsushiro Group).
Fig. 12: *Fursenkoina mexicana* (CUSHJAN) ×60 OMNH Reg. No. F13834F; from Sample 41 (Idozawa Formation, Tomioka Group).
Fig. 13: *Fursenkoina mexicana* (CUSHMAN) ×60 OMNH Reg. No. F13835F; from Sample 4 (Haratajino Formation, Tomoika Group).
Figs. 14a, b, c: *Gyroidinoides altiformis* (R. E. and K. T. STEWART) ×56 OMNH Reg. No. F13-839F; from Sample 162 (Haratajino Formation, Tomioka Group).
Figs. 15a, b: *Cyclammina orbicularis* (D'ORBIGNY) ×18 OMNH Reg. No. F13856F; from Sample 45 (Obata Formation, Tomioka Group).
Figs. 16a, b, c: *Gyoridina orbicularis* (D'ORBIGNY) ×70 OMNH Reg. No. F13838F; from Sample 41 (Idozawa Formation, Tomioka Group).
Figs. 17a, b, c: *Gyroidinoides soldanni* (D'ORBIGNY) ×54 OMNH Reg. No. F13841F; from Sample 77112101-(1) (Wadaira Tuff, Ichinose Formation, Nishiyatsushiro Group).

Plate II

Fig. 1: *Stilostomella fistuca* (SCHWAGER) ×46 OMNH Reg. No. F13906F; from Sample 7711-2101-(1) (Wadaira Tuff, Ichinose Formation, Nishiyatsushiro Group).
Fig. 2: *Stilostomella fistuca* (SCHWAGER) ×50 OMNH Reg. No. F13907F; from Sample 77032909 (Byobuiwa Tuff, Daigoyama Formation, Nishiyatsushiro Group).
Fig. 3: *Stilostomella ketienziensis* (ISHIZAKI) ×54 OMNH Reg. No. F13908F; from Sample 77050102 (Byobuiwa Tuff, Daigoyama Formation, Nishiyatsushiro Group).

Fig. 4: *Stilostomella ketienziensis* (ISHIZAKI) ×40 OMNH Reg. No. F13909F; from Sample 77050102 (Byobuiwa Tuff, Daigoyama Formation, Nishiyatsushiro Group).

Fig. 5: *Stilostomella lepidula* (SCHWAGER) ×50 OMNH Reg. No. F13910F; from Sample 39–(1) (Idozawa Formation, Tomioka Group).

Fig. 6: *Stilostomella lepidula* (SCHWAGER) ×46 OMNH Reg. No. F13911F; from Sample 162 (Haratajino Formation, Tomioka Group).

Fig. 7: *Stilostomella lepidula* (SCHWAGER) ×46 OMNH Reg. No. F13915F; from Sample 8 (Haratajino Formation, Tomioka Group).

Fig. 8: *Stilostomella hayasakai* (ISHIZAKI) ×50 OMNH Reg. No. F13916F; from Sample 186 (Niwaya Formation, Tomioka Group).

Fig. 9: *Siphonodosaria oinomikadoi* (ISHIZAKI) ×60 OMNH Reg. No. F13895F; from Sample 41 (Idozawa Formation, Tomioka Group)

Fig. 10: *Stilostomella consobrina* (D'ORBIGNY) ×30 OMNH Reg. No. F13905F; from Sample 77112101–(1) (Wadaira Tuff, Ichinose Formation, Nishiyatsushiro Group).

Fig. 11: *Nodosaria longiscata* D'ORBIGNY ×10 OMNH Reg. No. F13917F; from Sample 77032706 (Wadaira Tuff, Ichinose Formation, Nishiyatsushiro Group).

Fig. 12: *Nodosaria longiscata* D'ORBIGNY ×12 OMNH Reg. No. F13918F; from Sample 77032706 (Wadaira Tuff, Ichinose Formation, Nishiyatsushiro Group).

Fig. 13: *Nodosaria tosta* SCHWAGER ×40 OMNH Reg. No. F13879F; from Sample 77050101–(1) (Byobuiwa Tuff, Daigoyama Formation, Nishiyatsushiro Group).

Fig. 14: *Nodosaria tosta* SCHWAGER ×50 OMNH Reg. No. F13880F; from Sample 77050101–(1) (Byobuiwa Tuff, Daigoyama Formation, Nishiyatsushiro Group).

Figs. 15a, b: *Plectofrondicularia japonica* ASANO ×36 OMNH Reg. No. F13887F; from Sample 158 (Haratajino Formation, Tomioka Group).

Fig. 16: *Plectofrondicularia advena* (CUSHMAN) ×28 OMNH Reg. No. F13885F; from Sample 77032613 (Deguchi Alternation of Tuffaceous Sandstone and Mudstone, Daigoyama Formation, Nishiyatsushiro Group).

Figs. 17a, b: *Pleurostomella alternans* SCHWAGER ×56 OMNH Reg. No. F13888F; from Sample 77050104–(2) (Byobuiwa Tuff, Daigoyama Formation, Nishiyatsushiro Group).

Figs. 18a, b: *Nonionellina labradorica* (DAWSON) ×66 OMNH Reg. No. F13878F; from Sample 3 (Haratajino Formation, Tomioka Group).

Fig. 19: *Praeglobobulimina pupoides* (D'ORBIGNY) ×34 OMNH Reg. No. F13928F; from Sample 56 (Idozawa Formation, Tomioka Group).

Fig. 20: *Praeglobobulimina pupoides* (D'ORBIGNY) ×54 OMNH Reg. No. F13927F; from Sample 195 (Haratajino Formation, Tomioka Group).

Fig. 21: *Pleurostomella brevis* SCHWAGER ×36 OMNH Reg. No. F13889F; from Sample 77050104–(4) (Byobuiwa Tuff, Daigoyama Formation, Nishiyatsushiro Group).

Fig. 22: *Pleurostomella brevis* SCHWAGER ×28 OMNH Reg. No. F13890F; from Sample 77032613 (Wadaira Tuff, Ichinose Formation, Nishiyatsushiro Group).

Figs. 23a, b: *Sphaeroidina japonica* ASANO ×70 OMNH Reg. No. F13898F; from Sample 159 (Haratajino Formation, Tomioka Group).

Fig. 24: *Globobulimina auriculata* (BAILEY) ×44 OMNH Reg. No. F13925F; from Sample 770-50102 (Byobuiwa Tuff, Daigoyama Formation, Nishiyatsushiro Group).

Fig. 25: *Globobulimina auriculata* (BAILEY) ×40 OMNH Reg. No. F13926F; from Sample 770-32613 (Wadaira Tuff, Ichinose Formation, Nishiyatsushiro Group).

Figs. 26a, b: *Sphaeroidina austriaca* D'ORBIGNY ×50 OMNH Reg. No. F13896F; from Sample 153 (Haratajino Formation, Tomioka Group).

Figs. 27a, b: *Sphaeroidina bulloides* D'ORBIGNY ×60 OMNH Reg. No. F13877F; from Sample 34 (Idozawa Formation, Tomioka Group).

Fig. 28: *Plectofrondicularia miocenica* CUSHMAN ×46 OMNH Reg. No. F13886F; from Sample 155 (Haratajino Formation, Tomioka Group).

Fig. 29: *Frondicularia foliacea* SCHWAGER ×46 OMNH Reg. No. F13842F; from Sample 162 (Haratajino Formation).

Plate III

Fig. 1: *Amphicoryna tubulata japonica* (UCHIO) ×50 OMNH Reg. No. F13845F; from Sample 83 (Yoshii Formation, Tomioka Group).

Fig. 2: *Amphicoryna tubulata japonica* (UCHIO) ×56 OMNH Reg. No. F13844F; from Sample 83 (Yoshii Formation).

Fig. 3: *Brizalina pisciformis* (GALLOWAY and MORREY) ×54 OMNH Reg. No. F13932F; from Sample 77050102 (Byobuiwa Tuff, Daigoyama Formation, Nishiyatsushiro Group).

Fig. 4: *Amphicoryna proxima* (SILVESTRI) ×60 OMNH Reg. No. F13846F; from Sample 83 (Yoshii Formation, Tomioka Group).

Figs. 5a, b: *Fissurina fukamiensis* (ASANO) ×44 OMNH Reg. No. F13859F; from Sample 77112102 (Wadaira Tuff, Ichinose Formation, Nishiyatsushiro Group).

Figs. 6a, b: *Fissurina exculpta* (BRADY) ×60 OMNH Reg. No. F13860F; from Sample 153 (Haratajino Formation, Tomioka Group).

Fig. 7: *Oolina melo* D'ORBIGNY ×74 OMNH Reg. No. F13883F; from Sample 188 (Niwaya Formation, Tomioka Group).

Fig. 8: *Oolina hexagona* (WILLIAMSON) ×100 OMNH Reg. No. F13882F; from Sample 158 (Haratajino Formation, Tomioka Group).

Fig. 9: *Oolina costata* (WILLIAMSON) ×86 OMNH Reg. No. F13881F; from Sample 82 (Yoshii Formation, Tomioka Group).

Fig. 10: *Lagena parri* LOEBLICH and TAPPAN ×74 OMNH Reg. No. F13867F; from Sample 77043008-(1) (Kanzaka Mudstone, Ichinose Fo'mation, Nishiyatsushiro Group).

Fig. 11: *Lagena flatulenta* LOEBLICH and TAPPAN ×66 OMNH Reg. No. F13865F; from Sample 77050104-(3) (Byobuiwa Tuff, Daigoyama Formation, Nishiyatsushiro Group).

Figs. 12a, b: *Alveophragmium scitulum* (BRADY) ×16 OMNH Reg. No. F13847F; from Sample 203 (Yoshii Formation, Tomioka Group).

Fig. 13: *Lagena semilineata* WRIGHT ×90 OMNH Reg. No. F13868F; from Sample 192 (Niwaya Formation, Tomioka Group).

Figs. 14a, b: *Tritaxia orientale* (CUSHMAN) ×40 OMNH Reg. No. F13919F; from Sample 19 (Yoshii Formation, Tomioka Group).

Figs. 15a, b, c: *Ammonia ketienziensis* (ISHIZAKI) ×40 OMNH Reg. No. F13848F; from Sample 162 (Haratajino Formation, Tomioka Group).

Fig. 16: *Lagena striata* (D'ORBIGNY) ×66 OMNH Reg. No. F13869F; from Sample 202 (Yoshii Formation, Tomioka Group).

Fig. 17: *Lagena substriata* WILLIAJSON ×100 OMNH Reg. No. F13870F; from Sample 203 (Yoshii Formation, Tomioka Group).

Fig. 18: *Lagena laevis* (MONTAGU) ×84 OMNH Reg. No. F13866F; from Sample 77032614 (Wadaira Tuff, Ichinose Formation, Nishiyatsushiro Group).

Fig. 19: *Gaudryina ishikiensis* ASANO ×30 OMNH Reg. No. F13840F; from Sample 202 (Yoshii Formation, Tomioka Group).

Figs. 20a, b, c: *Ammonia tochigiensis* (UCHIO) ×46 OMNH Reg. No. F13849F; from Sample 90 (Itahana Formation, Tomioka Group)

Plate IV

Figs. 1a, b: *Melonis nicobarensis* (CUSHMAN) ×80 OMNH Reg. No. F13873F; from Sample 9 (Haratajino Formation, Tomioka Group).

Figs. 2a, b: *Melonis pompilioides* (FICHTEL and MOLL) ×46 OMNH Reg. No. F13874F; from Sample 77050101-(1) (Byobuiwa Tuff, Daigoyama Formation, Nishiyatsushiro Group).

Figs. 3a, b: *Melonis pompilioides* (FICHTEL and MOLL) ×60 OMNH Reg. No. F138745F; from Sample 202 (Yoshii Formation, Tomioka Group).

Figs. 4a, b: *Pullenia bulloides* (D'ORBIGNY) ×70 OMNH Reg. No. F13891F; from Sample 4 (Haratajino Formation, Tomioka Group).

Figs. 5a, b: *Pullenia bulloides* (D'ORBIGNY) ×60 OMNH Reg. No. F13892F; from Sample 4 (Haratajino Formation, Tomioka Group).

Figs. 6a, b: *Melonis quadalpae* PARKER ×66 OMNH Reg. No. F13876F; from Sample 77050104-(1) (Byobuiwa Tuff, Daigoyama Formation, Nishiyatsushiro Group).

Figs. 7a, b: *Melonis quadalpae* PARKER ×80 OMNH Reg. No. F13877F; from Sample 192 (Niwaya Formation, Tomioka Group).

Figs. 8a, b: *Pullenia subcarinata* (D'ORBIGNY) ×54 OMNH Reg. No. F13893F; from Sample 192 (Niwaya Formation, Tomioka Group).

Figs. 9a, b, c: *Cibicidoides pseudoungerianus* (CUSHMAN) ×50 OMNH Reg. No. F13855F; from Sample 188 (Niwaya Formation, Tomioka Group).

Figs. 10a, b: *Pyrgo vespertilio* (SCHLUMBERGER) ×34 OMNH Reg. No. F13894F; from Sample 77032613 (Wadaira Tuff, Ichinose Formation, Nishiyatsushiro Group).

Figs. 11a, b, c: *Planulina nipponica* ASANO ×26 OMNH Reg. No. F13884F; from Sample 162 (Haratajino Formation, Tomioka Group).

Figs. 12a, b: *Haplophragmoides renzi* ASANO ×20 OMNH Reg. No. F13861F; from Sample 150 (Haratajino Formation, Tomioka Group).

Plate V

Fig. 1: *Bulimina nipponica* ASANO ×84 OMNH Reg. No. F13851F; from Sample 41 (Idozawa Formation, Tomioka Group).

Fig. 2: *Bulimina striata* D'ORBIGNY ×80 OMNH Reg. No. F13852F; from Sample 8 (Haratajino Formation, Tomioka Group).

Fig. 3: *Bulimina striata* D'ORBIGNY ×100 OMNH Reg. No. F13853F; from Sample 8 (Haratajino Formation, Tomioka Group).

Fig. 4: *Uvigerina proboscidea* SCHWAGER ×74 OMNH Reg. No. F13923F; from Sample 82 (Yoshii Formation, Tomioka Group).

Fig. 5: *Uvigerina proboscidea* SCHWAGER ×70 OMNH Reg. No. F13931F; from Sample 202 (Yoshii Formation, Tomioka Group).

Fig. 6: *Bulimina rostrata* BRADY ×56 OMNH Reg. No. F13854F; from Sample 77052917 (Byobuiwa Tuff, Daigoyama Formation, Nishiyatsushiro Group).

Figs. 7a, b: *Uvigerina subperegrina* CUSHMAN and KLEINPELL ×80 OMNH Reg. No. F13922F; from Sample 81 (Yoshii Formation, Tomioka Group).

Figs. 8a, b: *Uvigerina akitaensis* ASANO ×70 OMNH Reg. No. F13920F; from Sample 41 (Idozawa Formation, Tomioka Group).

Figs. 9a, b: *Hopkinsina morimachiensis* MATSUNAGA ×50 OMNH Reg. No. F13863F; from Sample 153 (Haratajino Formation, Tomioka Group).

Figs. 10a, b: *Hopkinsina imogawaensis* MATSUNAGA ×36 OMNH Reg. No. F13862F; from Sample 3 (Haratajino Formation, Tomioka Group).

Fig. 11: *Trifarina hughesi* (GALLOWAY and WISSLER) ×120 OMNH Reg. No. F13900F; from Sample 153 (Haratajino Formation, Tomioka Group).

Fig. 12: *Uvigerina akitaensis* ASANO ×70 OMNH Reg. No. F13924F; from Sample 41 (Idozawa Formation, Tomioka Group).

Fig. 13: *Trifarina kokozuraensis* (ASANO) ×84 OMNH Reg. No. F13929F; from Sample 162 (Haratajino Formation, Tomioka Group).

Fig. 14: *Uvigerina subperegrina* CUSHMAN and KLEINPELL ×74 OMNH Reg. No. F13921F; from Sample 77032614 (Wadaira Tuff, Ichinose Formation, Nishiyatsushiro Group).

Fig. 15: *Trifarina bradyi* (CUSHMAN) ×66 OMNH Reg. No. F13899F; from Sample 158 (Haratajino Formation, Tomioka Group).

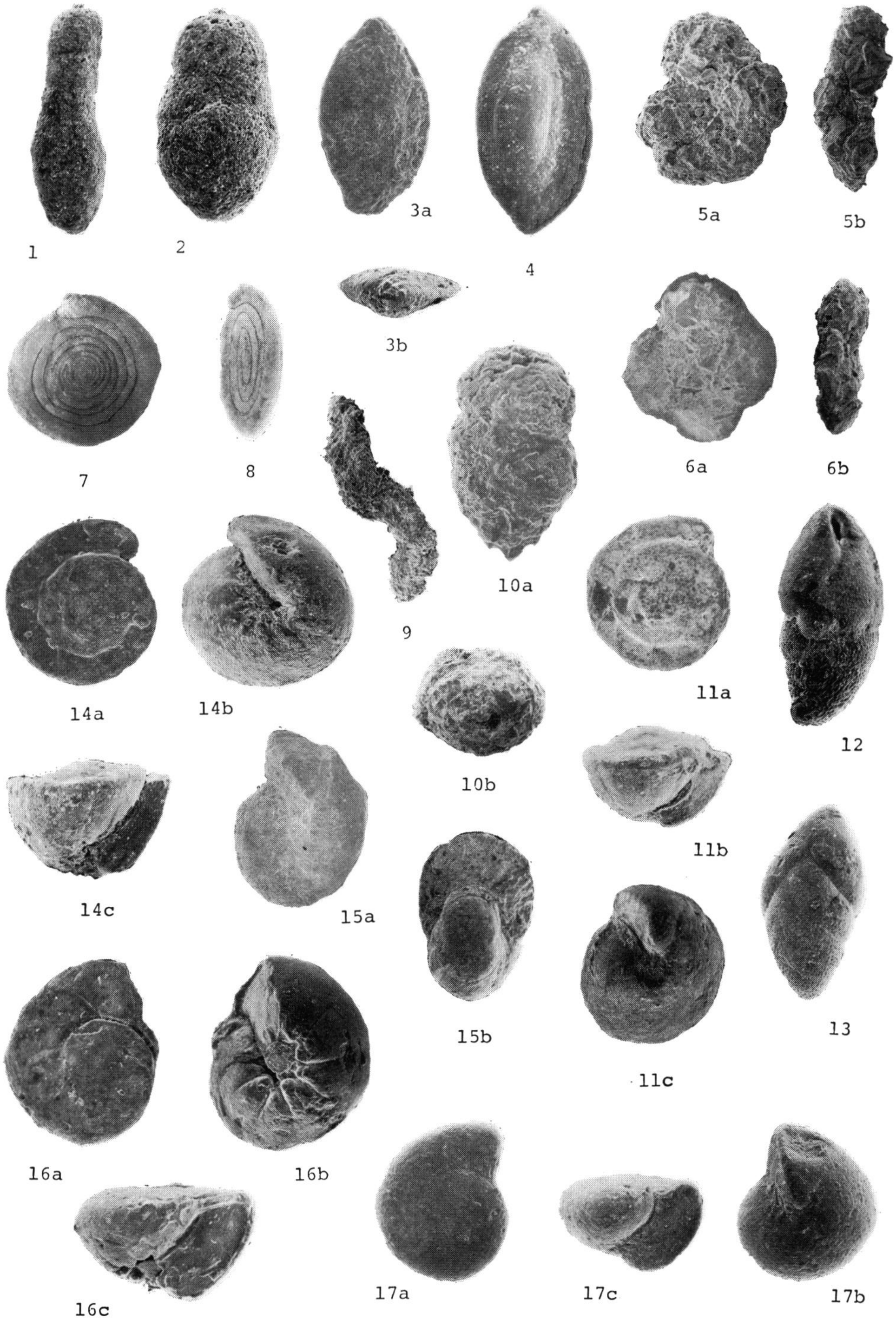
Fig. 16: *Trifarina kokozuraensis* (ASANO) ×76 OMNH Reg. No. F13930F; from Sample 162 (Haratajino Formation, Tomioka Group).

Figs. 17a, b: *Hopkinsina shinboi* MATSUNAGA ×60 OMNH Reg. No. F13864F; from Sample 8 (Haratajino Formation, Tomioka Group).

Fig. 18: *Trifarina occidentalis* (CUSHMAN) ×66 OMNH Reg. No. F13901F; from Sample 771-12101-(4) (Wadaira Tuff, Ichinose Formation, Nishiyatsushiro Group).

Fig. 19: *Trifarina occidentalis* (CUSHMAN) ×66 OMNH Reg. No. F13902F; from Sample 771-12101-(4) (Wadaira Tuff, Ichinose Formation, Nishiyatsushiro Group).

Figs. 20a, b: *Bolivina zanzibarica* CUSHMAN ×84 OMNH Reg. No. F13850F; from Sample 56 (Idozawa Formation, Tomioka Group).



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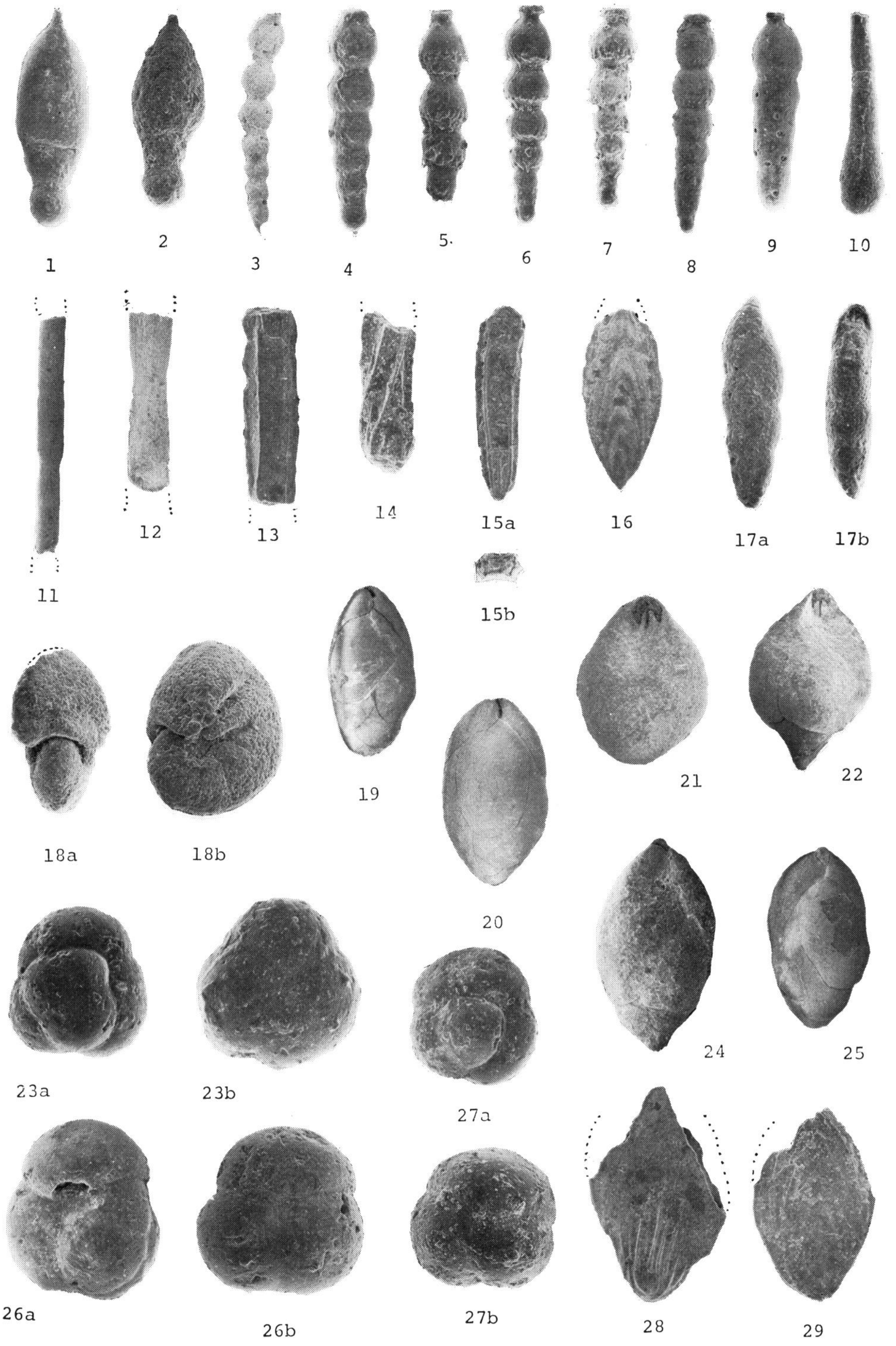

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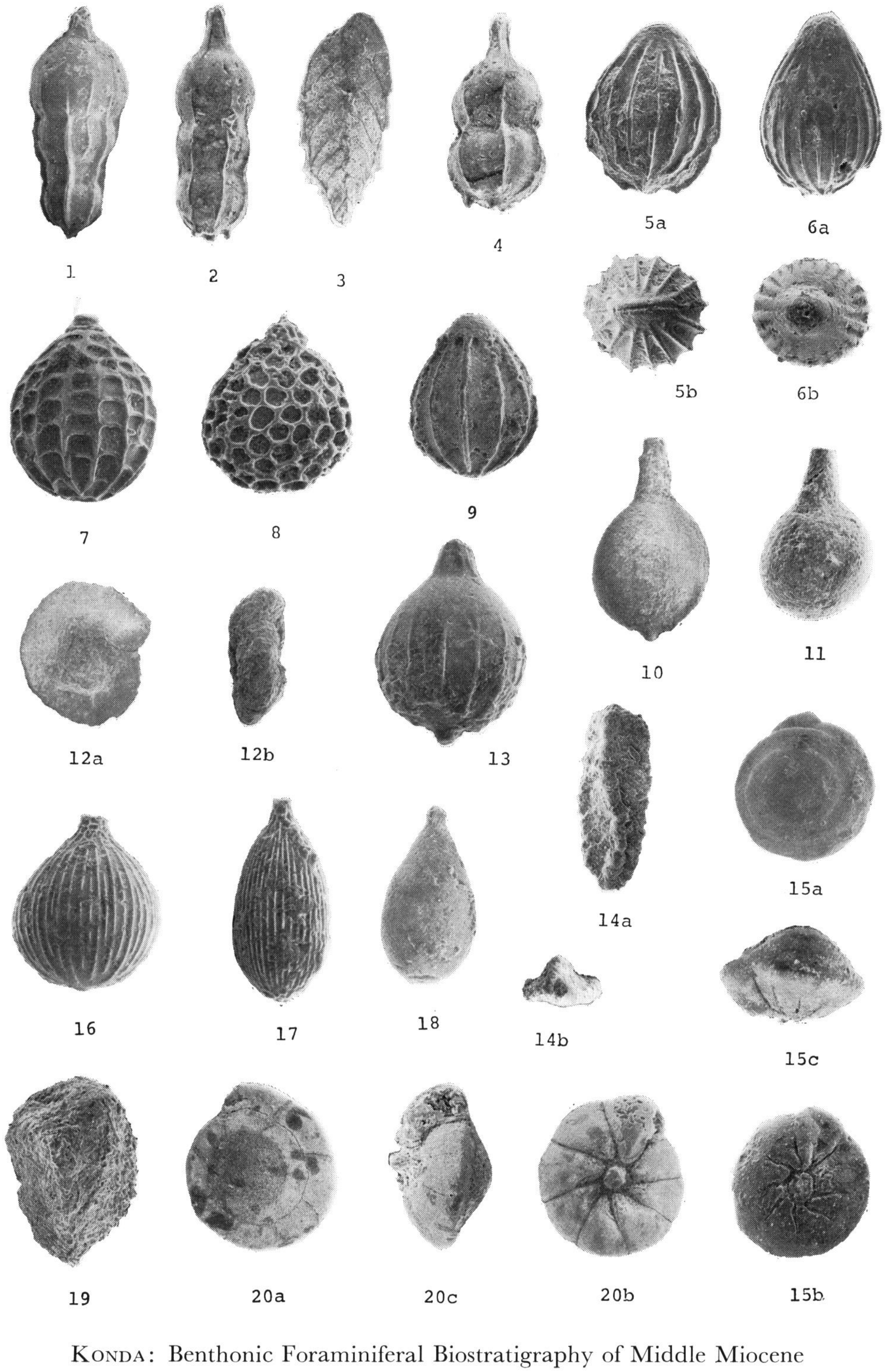
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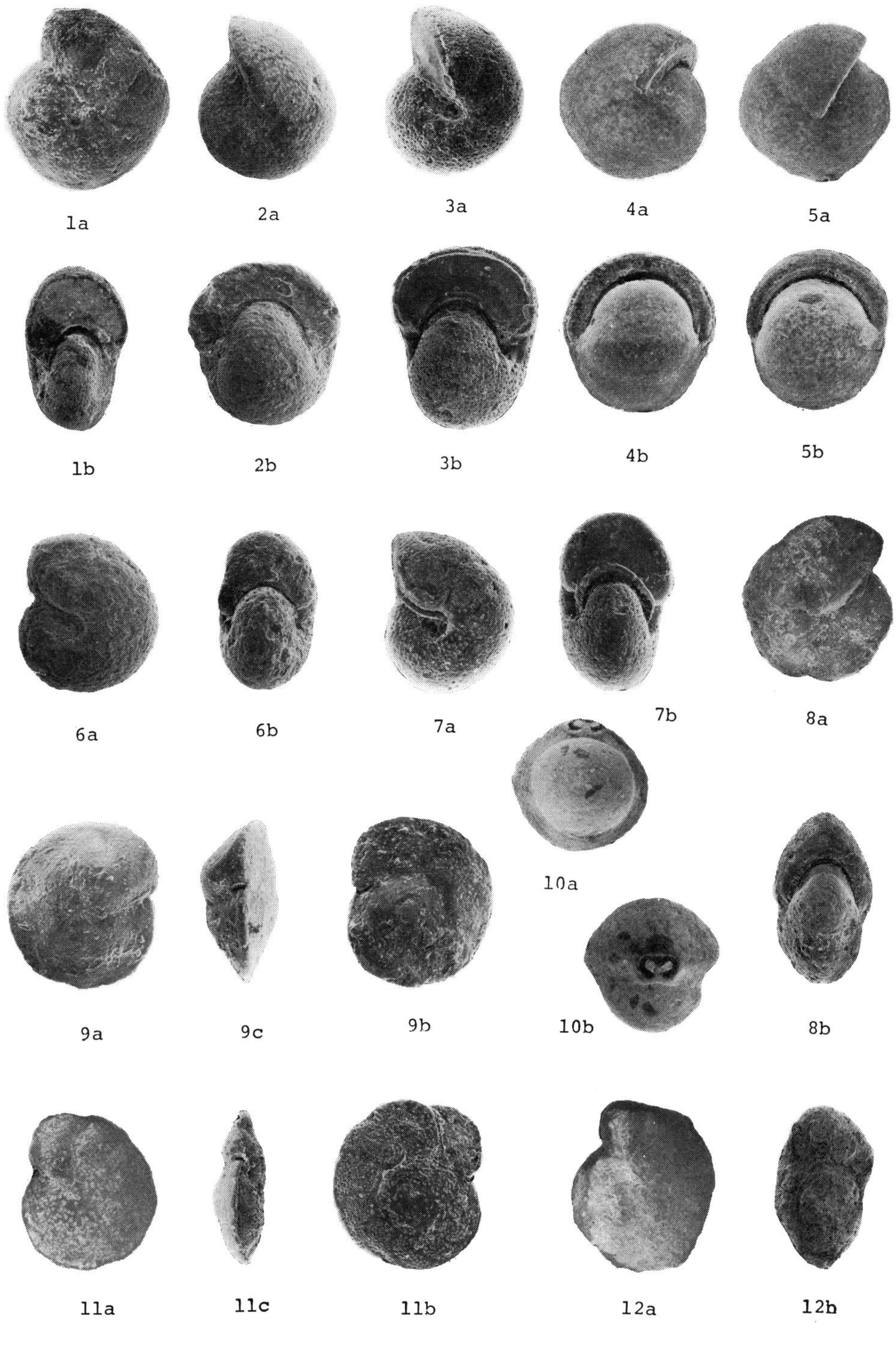

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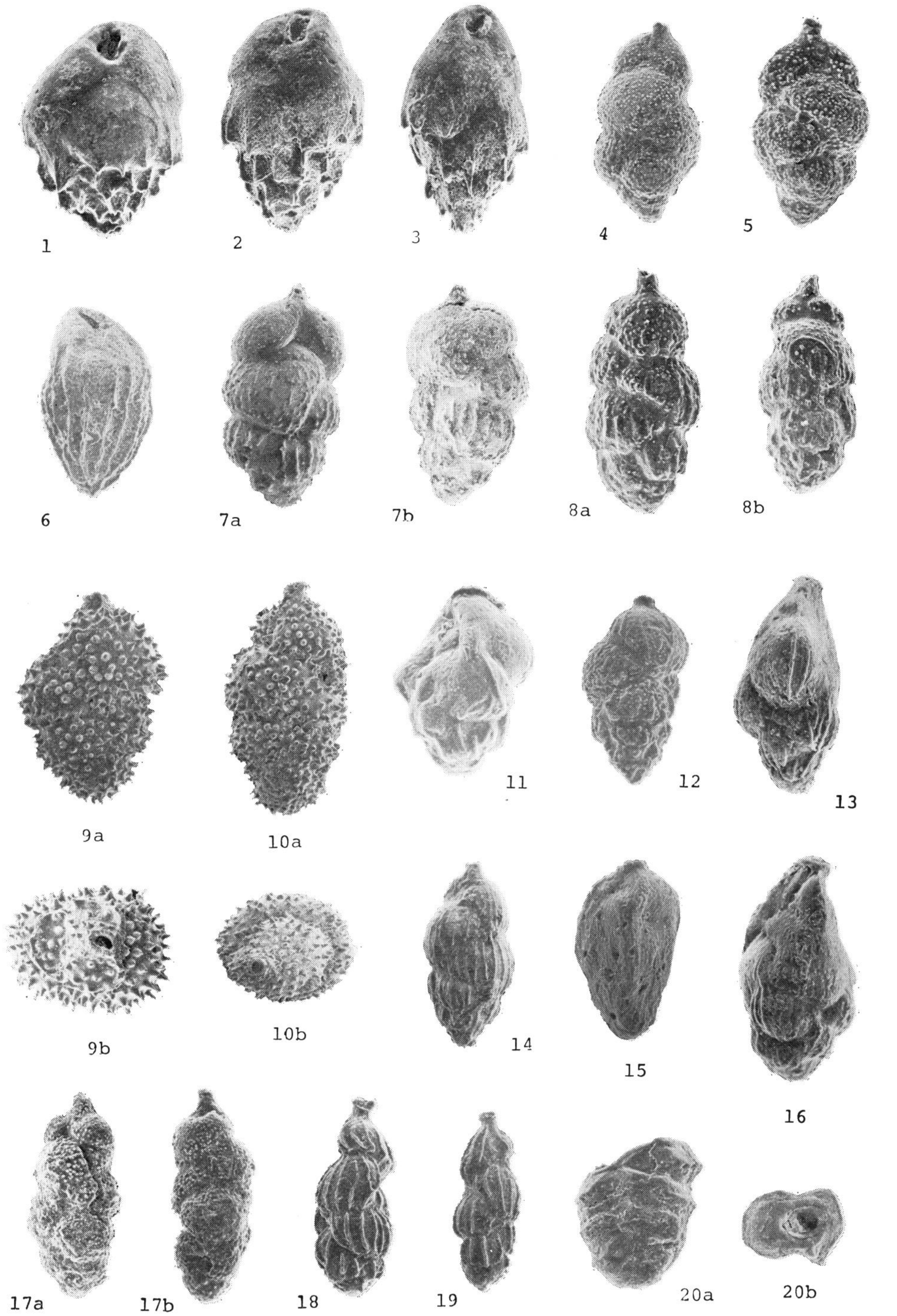

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