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Stratigraphic Significance of the Planktonic Foraminifera from Japan

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ABSTRACT

The planktonic foraminiferal faunas of Japan from the Cretaceous to the end of the Miocene are described. Six planktonic foraminiferal zones are tentatively proposed for the Cretaceous sequences of Hokkaido. Planktonic foraminiferal successions in the Tertiary sequences are discussed with reference to the international zonation.

INTRODUCTION

Tertiary and Cretaceous planktonic foraminiferal faunas in Japan have been studied by several authors, since A. R. Loeblich, Jr. and his collaborators published "Studies in Foraminifera" in 1957. The wide dispersal of planktonic Foraminifera, their short life-span, and frequent occurrences in marine sediments make them useful for long distance correlation in the Cenozoic and Mesozoic stratigraphy of the world, as well as of Japan.

However, the characteristic species of planktonic Foraminifera used in the standard zonation are not always of common occurrence throughout the world. There are two groups of planktonic foraminiferal associations; tropical and boreal, in the Cenozoic and in the Cretaceous sediments. Standard divisions of zonation of the planktonic Foraminifera are based upon the characteristic sequence of the warm-water deposits, such as in the Caribbean or Mediterranean regions. When the planktonic foraminiferal associations are of boreal or cold-water type, they usually consist of monotonous species of non-carinate globorotaliids or small-sized globigerinids and lack characteristic species.

Accordingly, the warm water Tertiary deposits of southern Japan correlate well with the standard division by the characteristic planktonic species, but in northern Japan including Hokkaido, the planktonic foraminiferal association differs considerably from the the warm-water type. Even in the Cretaceous of Hokkaido, the planktonic and benthonic Foraminifera are composed of particular associations due to the special environments. Many Cenozoic basins of northern Japan were separated from the warm-water province of southern Japan after the time marked by the extinction of the *Globorotalia fohsi fohsi* Zone. Since that time northern Japan was under the influence of the cold water environment of the paleo-Japan Sea of which upper Miocene assemblage is of the boreal type. The correlation of Miocene sequences between these two areas is somewhat difficult, because of there being no diagnostic species in common.

In this report, the authors review the stratigraphic significance of the planktonic foraminiferal fauna of Japan from the viewpoint of international zonation, from the Cretaceous to the end of the Miocene.

CRETACEOUS

The first discovery of planktonic Foraminifera from the Cretaceous of Japan was made by Asano (1950a), who reported *Globotruncana canaliculata* (Reuss), *Globotruncana marginata* (Reuss) and *Globotruncana* sp. in association with several benthonic forms from a

test well at Yokouchi, south of Hisanohama-machi, Futaba-gun, Fukushima Prefecture. Since then some contributions have been made on this group from Hokkaido. However, our knowledge is still limited on those outside Hokkaido: to date, the planktonic forms have been found only from Nakaminato, Ibaragi Prefecture and Uwajima, Ehime Prefecture (Takayanagi, unpublished data), besides the Futaba area mentioned above. Under the circumstances, the present discussion is concentrated on the Cretaceous Foraminifera from Hokkaido.

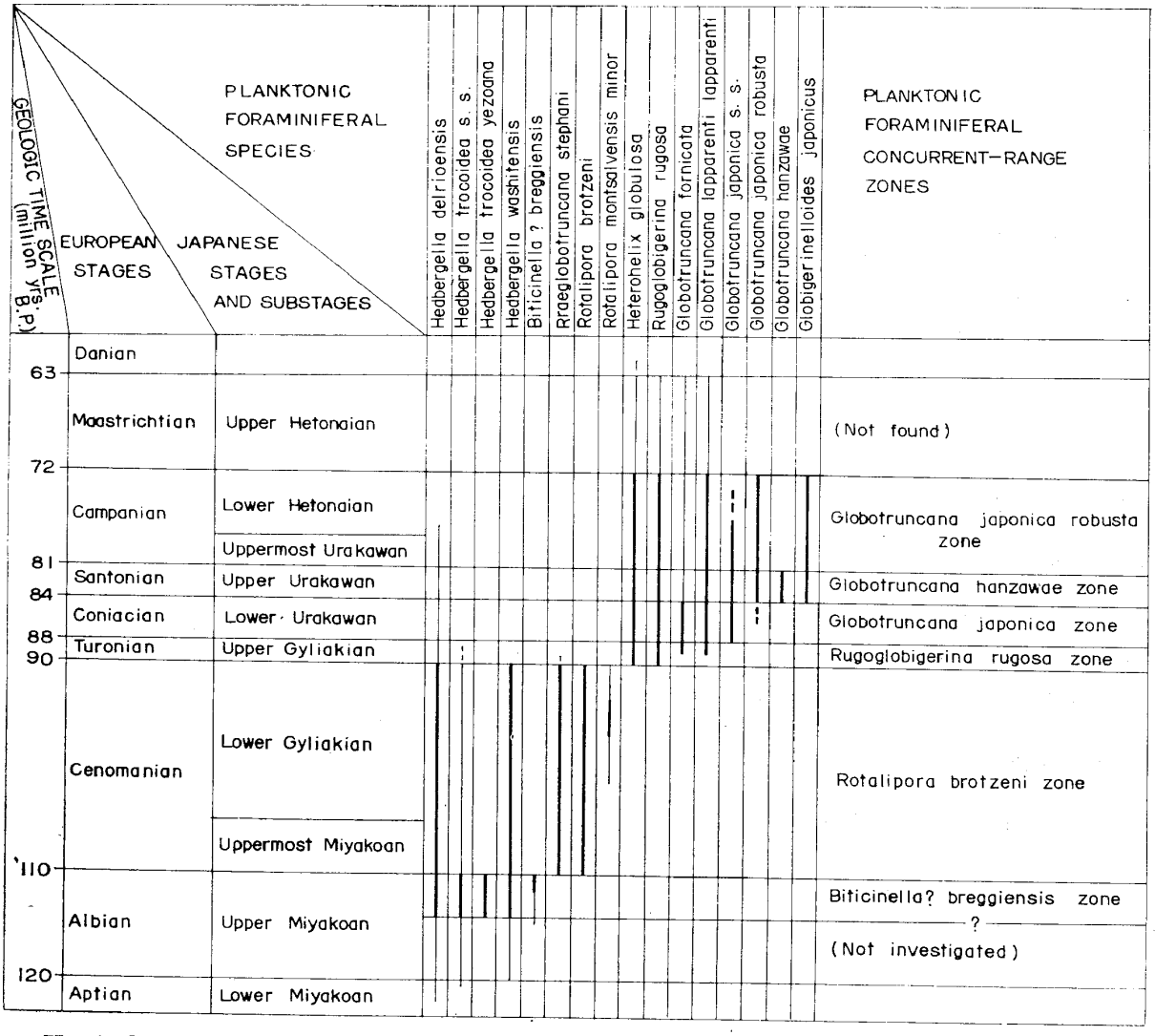
Generally speaking, the planktonic forms are quite meager in number of species and individuals compared with those from lower latitude regions such as the Gulf Coast of North America and Trinidad, where the planktonic foraminiferal zones are well established. Hitherto only 16 forms have been recognized of the genera *Heterohelix*, *Globigerinelloides*, *Biticinella*?, *Hedbergella*, *Praeglobotruncana*, *Rotalipora*, *Globotruncana* and *Rugoglobigerina*. Such paucity of the planktonic Foraminifera may have been caused by the supposed lower surface water temperature of the higher latitudes even during the Cretaceous time. However, the most remarkable features of the Cretaceous of Hokkaido are the predominance of thick clastic sediments, and the prevalence of black mudstone and shale with abundant agglutinated Foraminifera (Takayanagi, 1960). These features are considered to be indicative of a sinking basin with intense reductivity. The development of such an environment was probably related to deterioration by the circulation of the oceanic water supplying the planktonic fauna.

The composite chart (Table 1) showing the vertical distribution of all recorded planktonic forms of Japan is based on the formerly proposed chronostratigraphic classification in Japan. In addition to the acutual stratigraphic range of the respective forms, their total ranges compiled from the previous records are also given. The correlation of the Japanese stages with the European standard is according to Matsumoto (1959), who used the Ammonites and Inocerami for the purpose. The ages deduced from the planktonic Foraminifera agree well with those assigned by the Ammonites and Inocerami. Based upon Kulp's time scale (1961), the time duration of each stage is indicated on the left side of the table. The planktonic foraminiferal zones proposed are tentative because further research will require more fine cut divisions. These zones are to be placed in the category of the concurrent-range zone defined in the Code of Stratigraphic Nomenclature (1961). In the following lines they are discussed in a concise manner.

Lower Cretaceous

Biticinella? *breggiensis* zone: – This is the lowest of the planktonic foraminiferal zones in Hokkaido, and includes the lower part of the Middle Yezo Group distributed in the Ikushumbetsu, Miruto and Hatonosu areas, Ishikari Province. From this zone, *Biticinella*? *breggiensis* (Gandolfi), *Hedbergella delrioensis* (Carsey), *Hedbergella trocoidea* (Gandolfi), *Hedbergella trocoidea yezoana* Takayanagi and Iwamoto, and *Hedbergella washitensis* (Carsey) were discriminated (Takayanagi and Iwamoto, 1962). As discussed in the previous paper (*op. cit.*) the successive occurrence of these forms in the Middle Yezo Group is analogous with the foraminiferal sequence in the early Cretaceous of Madagascar (Sigal, 1956), and the assemblage is correlated with the upper Albian of Europe, Africa, America and their adjacent regions without contradiction. Lately *Biticinella* was regarded as a synonym of *Globigerinelloides* by some authors, but the present writers hold the genera distinct, because the initial trochosprial stage is supposedly present in *Biticinella* (for further discussion, see Takayanagi and Iwamoto, *op. cit.*). *Biticinella*? *breggienis* is restricted to the upper Albian. Although the lower limit of this zone has not yet been defined because of the necessity of further study, it probably represents the upper part of the Upper Miyakoan in Hokkaido.

Table 1. Chronostratigraphic classification and tentative biostratigraphic [zonation of the Cretaceous of Hokkaido by means of planktonic Foraminifera, with distribution of planktonic Foraminifera in the Cretaceous of Hokkaido.



Vertical range in the Cretaceous of Hokkaido
Vertical range in the Cretaceous of various regions compiled from the previous records

Upper Cretaceous

In spite of the extensive studies on the Upper Cretaceous Foraminifera from Hokkaido by Asano (1950b, 1962), Fukuta (1957), Takayanagi (1960), and Yoshida (1958, 1963), very little is known of the planktonic Foraminifera outside the meridional zone of Hokkaido. The zoning of the Upper Cretaceous rests on the basis of the result of Takayanagi's investigation (1960, *op. cit.*).

Rotalipora brotzeni zone: – This is characterized by the first appearances of *Praeglobotruncana stephani* (Gandolfi), *Rotalipora brotzeni* (Sigal) and *Rotalipora montsalvensis minor* Mornod, and last appearances of *Hedbergella delrioenis* and *Hebdergella washitensis*. This zone is well represented in the Hikagezawa, Nakafutamata and Takinosawa Formations of the Middle Yezo Group of the Oyubari area, Ishikari Province and the unit Myl of the Middle Yezo

Group of the Monbetsu area, Hidaka Province. Although *Hedbergella delrioensis* is known to range up to the lower Campanian in North America, it has not been found in strata younger than the Lower Gyliakian in Hokkaido. So far as the previous records are concerned, the last occurrence of *Hedbergella washitensis* is within the Cenomanian, and both forms of *Rotalipora* mentioned above are known only from the Cenomanian. Thus the *Rotalipora brotzeni* zone, which involves the Uppermost Miyakoan and Lower Gyliakian, can be correlated with the Cenomanian. Owing to its scarcity, the exact distribution of *Rotalipora montsalvensis minor* in Hokkaido is still uncertain. It is possible, however, to subdivide the *Rotalipora brotzeni* zone into two subzones by applciation of the range zone of the present form because it is known only from the upper Cenomanian.

Rugoglobigerina rugosa zone: – Among the planktonic foraminiferal zones in Hokkaido, this zone may have the least number of specific constituents, but it is characteristic in the absence of the species mentioned above and the others which are diagnostic to the subjacent zone, and by the first appearance of *Rugoglobigerina rugosa* (Plummer), *Globotruncana fornicata* Plummer and *Globotruncana lapparenti lapparenti* Brotzen. As to the stratigraphic range of the genera *Rugoglobigerina* and *Globotruncana* there are some discrepancies among authors, but it is adequate to regard that their first appearance is in the Turonian (Takayanagi, 1965, p. 169). According to the previous records, *Rugoglobigerina rugosa* ranges from the lower Turonian to Maastrichtian, and the two forms of *Globotruncana* mentioned above extends from the upper Turonian to Maastrichtian. The time lag in the appearance of the *Globotruncana* species in contrast with that of *R. rugosa* is recognized in the Upper Gyliakian, but the few planktonic forms make subdivision of the present zone inadvisable. Thus, the *Rugoglobigerina rugosa* zone as a whole is correlated with the Turonian. The Shirokinzawa Formation of the Middle Yezo Group in the Oyubari area, Ishikari Province is taken as the type for this zone.

Globotruncana japonica zone: – This includes the Lower Urakawan and is characterized by the first appearance of *Globotruncana japonica japonica* Takayanagi and *Globotruncana japonica robusta* Takayanagi, though the latter subspecies is rather rare. Besides the two forms just mentioned, *Globotruncana fornicata, Globotruncana lapparenti lapparenti* and *Rugoglobigerina rugosa* occur continuously from the underlying zone. *Heterohelix globulosa* (Ehrenberg) makes its first appearance in this zone. Its distribution is rather restricted. The present zone is typically represented in the unit Uyl of the Upper Yezo Group of the Mombetsu area, Hidaka Province.

Globotruncana hanzawae zone: – This corresponds to the Upper Urakawan, and is characterized by the first appearance of *Globotruncana hanzawae* Takayanagi and *Globigerinelloides japonicus* (Takayanagi), and by the common occurrence of the other globotruncanids which had appeared in the subjacent zones. The range zone of *Globotruncana hanzawae* may be restricted to the present zone. Although *Globotruncana fornicata* is known to range from the upper Turonian to Maastrichtian in various regions, it has not been found in the Upper Urakawan and younger strata in Hokkaido. Compared with the under- and overlying zones, the planktonic Foraminifera are most abundant in this zone. The unit Uy2 of the Upper Yezo Group in the Mombetsu area, Hidaka Province is taken as the type for the present zone.

Globotruncana japonica robusta zone: – This zone includes the Uppermost Urakawan and Lower Hetonaian, and is distinguished from the underlying *Globotruncana hanzawae* zone by the absence of *G. hanzawae*. *Globotruncana japonica* s.s. tends to diminish upwards and disappears within the Lower Hetonaian. The unit Uh-k of the Upper Yezo Group in the Obira area, Teshio Province is taken as the type for this zone. Since planktonic Foraminifera are not known from the superjacent Upper Hetonaian of the meridional zone as well as the eastern part of Hokkaido, this zone is practically the highest in the Cretaceous of Hokkaido.

Concerning the upper three planktonic foraminiferal zones, the stratigraphic data is insufficient for valid evidences for their inter-regional correlation. Nevertheless, the correlation by the benthonic components in association with the planktonic species in the respective zones is in good agreement with that based on the established molluscan zones: namely, the *Globotruncana japonica* zone is correlated with the Coniacian; the *Globotruncana hanzawae* zone with the Santonian; and the *Globotruncana japonica robusta* zone with the Campanian.

TERTIARY

Paleocene

There have been many discussions concerning whether the Danian is Cretaceous or Paleocene. The problems are not discussed or documented in this report, but the modern tendency is to place the Danian at the base of the Paleogene because of the distinct faunal break — disappearance of the Cretaceous globotruncanids and appearance of Tertiary globigerinids — at the base of the Danian.

A Danian planktonic foraminiferal assemblage was first found in the "Cretaceous" formation of Nemuro, eastern Hokkaido. Asano (1960) reported on the occurrence of *Globigerina* cf. *triloculinoides* Plummer, *G. pseudobulloides* Plummer, *G. daubjergensis* Bronnimann, and *G. compressa* Plummer associated with many benthonic Foraminifera from the Choboshi Formation at Ochiishi, Nemuro, which had been considered to be Upper Cretaceous from the megafossils. Yoshida (1960), who studied the Cretaceous Foraminifera from Urahoro, Tokachi Province, stated that the foraminiferal assemblage from the so-called Cretaceous formation near the provincial boundary between Tokachi and Kushiro Provinces may be correlated with that of the Paleocene of Venezuela. Subsequently Iwamoto found *Globorotalia pseudomenardii* Bolli, a typical Palaeocene planktonic Foraminifera, from the Chippomanai Formation, south of Akkeshi, Kushiro Province, which had been regarded as the Upper Cretaceous.

Another type of Paleocene *Globorotalia* was found in the limestone of the Setogawa Group, Shizuoka Prefecture by Saito (1960). Such evidences suggest that Paleocene (including Danian) deposits are distributed in Japan, though limited at present. These deposits may be correlated with those of the Paleocene distributed along the northern Pacific region.

Eocene

Well defined Eocene formations are developed in many coal fields of Hokkaido, Kyushu and Honshu, but they are considered to be mostly deltaic deposits, comprising marine, brackish and fresh-water deposits. Consequently the occurrence of planktonic Foraminifera is rather limited and the fauna an improverished one. But in Kyushu, typical transgressive marine sediments were deposited on the erosion surface of the Cretaceous and older rocks and they yielded many planktonic species.

Since the establishment of the Paleogene stratigraphy of Kyushu by Nagao (1928), many authors have contributed to the geology of the area. These authors consider that the stratigraphy of the Amakusa Islands is a standard of the Eocene Series of Japan. In the lowest formation, Akashimisaki (=Fukami Sandstone of some authors), which lies with unconformity on the Cretaceous shale, *Nummulites*, *Discocyclina* and *Globigerina* cf. *linaperta* Finlay were found and considered to be Cuisian (or in part of lower Lutetian) in age. The Nummulitic Shiratake Sandstone in Kamishima, Amakusa Islands is said to pass laterally into non-marine red beds called the Akasaki Formation.

The next younger Eocene sediments, the Kyoragi Formation, yielded a rich globiger-

inids faunule (Asano, 1962) throughout the shale member of the formation. Its characteristic species are: *Globorotalia bullbrooki* Bolli, *Globorotalia centralis* Cushman and Bermudez, *Globorotalia pseudomayeri* Bolli, *Globorotalia spinuloinflata* (Bandy), *Globorotalia bonairensis* Pijpers, *Globigerina linaperta* Finlay, *Globigerina kyushuensis* Asano, *Globigerina ariakensis* Asano, *Globigerina boweri* Bolli, *Globigerina yeguaensis* Weinzierl and Applin, and *Globoquadrina venezuelana* Hedberg. This assemblage is correlated with the *Hantkenina aragonensis* and *Globigerapsis kugleri* Zones of Trinidad (lower Lutetian), though the representative species are different. The Kyoragi Formation is superposed with conformity by the Toishi Formation, from which no characteristic fossils have been recorded. But it may be middle Lutetian in age, because the overlying Eocene sediments of the Sakasegawa Group (Asano, 1962) are characterized by such Lutetian or Priabonian planktonic Foraminifera as *Globigerina ampliapertura* Bolli, *Globigerina linaperta* Finlay, *Globigerina ouachitaensis senilis* Bandy, *Globigerina pera* Todd, *Globigerina isahayaensis* Asano, *Catapsydrax dissimilis* (Cushman and Bermudez), etc.

The benthonic Foraminifera from the Sakasegawa Group were divided into two assemblages by R. Saito (1958): the upper *Plectofrondicularia packardi* zone and the lower *Plectian pronaiensis* zone, based upon the boring cores in the Miike coal field drilled through the Manda Group, which is correlated with the Sakasegawa Group of the Amakusa Islands. This foraminiferal sequence was subdivided into four zones in the type section of the Sakasegawa Group by Murata (1961), but there is no change in the order of the foraminiferal succession.

Other Eocene sediments are exposed in the coal fields of Miike, Takashima, Yagami, Fukuoka and Chikuho in northern Kyushu. Many formational names have been proposed for the different sedimentary facies of these coal fields (Matsushita, 1949). They are mostly non-marine in origin, but with several intercalations of marine sediments. These Eocene sediments are considered to be marginal, shallow or terrestrial representatives of the Eocene transgression of Kyushu which extended from the Amakusa Islands to northern Kyushu. This transgressive course is traced from Ushibuka to Sasebo through the eastern margin of the Ariake Sea or from Kumamoto to Ube through the Miike and Asakura coal fields.

The Eocene of Honshu is found locally in the coal fields of Joban (Fukushima Prefecture) and Ube (Yamaguchi Prefecture), while along the Pacific coast of Japan, geosynclinal deposits such as the Oigawa, Kinan, Murotohanto (Shikoku) and Nichian (Kyushu) Groups occur, forming a zonal structure in which are often incorporated the undifferentiated Mesozoic strata.

The ages of these Eocene rocks are mainly determined by megafossils as mammals or plant remains, but in the Setogawa district, Shizuoka Prefecture, Saito (1960) confirmed that the Oigawa Group ranges from Eocene to early Oligocene in age. From the occurrence of diagnostic species of planktonic Foraminifera, the upper part of the Oigawa Group, Horai Formation, can be correlated with the *Globigerina ampliapertura* Zone.

In the Ogasawara (Bonin) Islands, south of Honshu, it has been known that abundant specimens of *Nummulites boninensis* Hanzawa were yielded from the limestone of Haha-jima, whose geological horizon was confirmed to be correlative with the *Porticulasphaera mexicana* Zone (upper Lutetian) by the occurrence of the following characteristic species which were found associated with *Nummulites: Hantkenina dumblei* Weinzierl and Applin, *Globigerinatheka barri* Bronnimann, *Porticulasphaera mexicana* (Cushman), *Globorotalia lehneri* Cushman and Jarvis, etc. (Saito, 1962).

In Shikoku, the lower part of the Kuma Group of the Ishizuchi Mountains is characterized by Lutetian Foraminifera, such as *Discocyclina* and *Fabiania*. The Kuma Group covers the Median tectonic line of Southwest Japan and was separated from the

Paleogene sediments of the Pacific coast of Shikoku, mentioned above, by the eroded pre-Tertiary mountains. This is a very important fact relating to the genesis of the Median line and the paleogeography of the Lutetian sea extending from Amakusa to Ube as already stated.

In Hokkaido, the Eocene sediments are represented by the Ishikari Group and Poronai Shale, which were deposited in the Ishikari coal field. Regarding these sediments, Asano (1953, 1958, 1963) discussed repeatedly the genesis of the Paleo-Ishikari Sea and the direction of the transgression of that time. Successions of detailed foraminiferal zones were made at several sections through the Pronai and Ishikari Groups. However, planktonic Foraminifera are very rare, owing to the particular environment, though many benthonic forms of the Poronai Shale are the same as those commonly found in the Eocene formations of Kyushu. *Globigerina linaperta* and *Globorotaloides suteri* Bolli are the only planktonic species which were first recorded by Ujiie and Watanabe (1960) from the Ashibets district, Ishikari coal field. The former species was successively found from the boring core of the Yufutsu area in the southern part of Ishikari. This indicates that the Poronai, together with the Ishikari are Eocene in age. Other Eocene strata in Hokkaido are called the Urahoro Group in the Kushiro coal field and Uryu Group in the Uryu coal field, but no planktonic form has been recorded.

Oligocene

In March, 1962, Asano described a new Oligocene *Globigerina*, named *G. sakitoensis*, from the Nakado Formation (Oligocene) at Sakito-machi, Nishisonogi-gun, Nagasaki Prefecture. Later, but in the same year, Blow and Banner described *Globigerina oligocaenica*, a typical Lattorfian to Rupelian species, from the Lindi area, East Africa. According to Blow and Banner, this is a very important species and marks the *Globigerina oligocaenica*

Table 2. Palaeogene correlation of Hokkaido. (ASANO, 1962)

AREA / AGE	KUSHIRO - NEMURO	ISHIKARI		YUFUTSU	URYU
		SORACHI	YUBARI		
OLIGOCENE	×			(DEEP BORINGS)	×
	×				×
	×	×	×	×	×
	×	×	×	×	×
	×	×	×	×	×
	×	×	×	×	
	×	×	×	×	TAPPU
	×	×	MOMIJIYAMA	×	SHIMOKINE
EOCENE	OMBETSU G.	PORONAI	PORONAI	↑ "PORONAI"	URYU G.
	URAHORO G.	ISHIKARI G. ASHIBETSU HIRAGISHI IKUSHUNBETSU AKABIRA	IKUSHUMBETSU		
		BIBAI WAKKANABE	WAKKANABE	↓ 4000m	
	×	YUBARI HOROKABETSU NOBORIKAWA	YUBARI HOROKABETSU NOBORIKAWA	- - - ? - - -	×
	×				×
	×				×
	×				×
	×	×	×		×
		×	×		×
PALAEOCENE INCLUDING DANIAN	"CHIPPOMANAI"	×	×		×
	"CHOBOSHI"	×	×		×
CRETACEOUS	NEMURO G.	HAKOBUCHI G.	HAKOBUCHI G.	CRETA.?	YEZO G.

Table 3. Palaeogene correlation of Honshu and Shikoku. (ASANO, 1962)

AGE \ AREA	SETOGAWA	JOBAN	CHICHIBU	UBE	KUJI	KII	SHIKOKU: ISHIZUCHI	SHIKOKU: KOCHI
MIOCENE	TOWATA	YUNAGAYA G.	NENOKAMI					
AQUITANIAN	AMAKATA	×	USHIKUBI-TŌGE					
	×	×	×					
	×	×	×					
	×	×	×					—?—
OLIGOCENE	×	—?—	×					SUKUMO G.
	OIGAWA G.	SHIRA-MIZU G.	×					—?—
LATTORFIAN	HORAI	SHIRASAKA ASAGAI IWAKI	×					
PRIABONIAN			×	UBE G.	NODA G.	KINAN G.	KUMA G. MYOJIN	MUROTO-HANTO G.
	SETO	×	×			—?—		
	×	×	×	×	×		NIMYO	—?—
EOCENE	×	×	×	×	×		×	
	×	×	×	×	×		×	
	×	×	×	×	×		×	
PALAEOCENE	SETOGAWA	×	×	×	×			
CRETACEOUS	G.	FUTABA G.	×	×	KUJI G.	CRETA.	IZUMI G. ×	ARIOKA

Table 4. Palaeogene correlation of Kyushu. (ASANO, 1962)

AGE \ AREA	AMAKUSA	MIIKE	TAKASHIMA	SAKITO-MATSUSHIMA	KARATSU	CHIKUHO
MIOCENE AQUITANIAN	×	×	×	NISHISONOGI G.	KISHIMA G.	ASHIYA G.
	×	×	×	×	×	×
	×	×	×	×	×	×
OLIGOCENE	×	×	×	×	×	×
	×	×	×	×	×	×
	×	×	IOJIMA	SAKITO NAKADO	OCHI G.	OTSUJI G.
LATTORFIAN	×	×		×		
EOCENE PRIABONIAN	SAKASEGAWA G. ONIIKE		×	×	×	
	FUTAE	MANDA G.		×	×	NOGATA G.
LUTETIAN	SAKASEGAWA		OKINOSHIMA	×	×	
	ITCHODA			×	×	
(CUISIAN)	SHIMOSHIMA G. TOISHI	OMUTA G.	TAKASHIMA G.	×	×	×
	KYORAGI			×	×	×
YPRESIAN	AKASHIMISAKI	×	×	×	×	×
PRE-TERTIARY	HIMENOURA G.	SCHISTS & GRANITE	SCHISTS	GRANITE	SCHISTS & GRANITE	SCHISTS GRANITE &C.

Zone, corresponding to Lattorfian-Rupelian. They note that the morphological characters of this species show considerable variation in the rate of enlargement of the later chambers, affecting the shape of the test so that some specimens may be more globose whilst others may be more quadrate than the holotype. The specimens from Kyushu as already described and figured are quite similar to *G. oligocaenica*, and considered to be synonymous with *G. sakitoensis*. In the Iojima Island, Kyushu, the Iojima Formation overlies with unconformity the Eocene Okinoshima Formation. Asano (1962) reported *Globigerina ampliapertura*, *Globoquadrina dehiscens* (Chapman, Parr and Collins) and *Globigerinoides subquadratus* Bronnimann from the lower part of the Iojima Formation just above the Dezaki conglomerate. This assemblage, just as in Australia (Jenkins, 1960), should be correlated with the *Globigerina ampliapertura* Zone of Trinidad. Blow and Banner (1962) placed the zone at the base of the "Aquitanian", but later Berggren (1963) criticized their opinions and placed the zone at the lower part of Oligocene (Lattorfian-Rupelian).

The benthonic Foraminifera from the Iojima Formation are very similar to those of the Shimokine Formation in the Uryu coal field, Hokkaido, or the Asagai Formation in the Joban coal field, Fukushima Prefecture. Therefore, these formations may represent the Oligocene of Japan. It is noteworthy that the upper half of the Oligocene is missing in almost every part of the Japanese Islands, as shown in Tables 2–4. This interval is represented by the Pre-Kishima (Pre-Aquitanian) crustal deformation of R. Saito (1957), and the movement is traced from Japan to the Philippines via Taiwan.

Lower Miocene — Aquitanian

Debates that the Aquitanian should be included in the base of the Miocene were reviewed by Berggren (1963). From the viewpoint of planktonic foraminiferal assemblages, the Aquitanian is bounded by two important evolutionary horizons (Bandy, 1964), (1) the base of the Aquitanian is marked by the *Globigerinoides triloba* datum (first appearance in geologic time), and (2) the Aquitanian-Burdigalian boundary is the *Orbulina* datum.

In Japan, Saito (1963) divided the strata correlative with the Aquitanian into the following planktonic foraminiferal zones:

Globigerinatella insueta Zone
G. insueta/Globigerinoides bisphericus Subzone
G. insueta/Globigerinoides trilobus Subzone
Globigerinita unicava Zone

These planktonic zones and associated subzones are well defined in the type area of the Kakegawa district, Shizuoka Prefecture.

Globigerinita unicava Zone includes the Amakata, Towata and lower part of Matsuba Formations of the Kakegawa district, and is defined by the occurrence of *Globigerina dissimilis* Cushman and Bermudez and *Globigerinita unicava* (Bolli, Loeblich and Tappan). *Globoquadrina praedehiscens* Blow and Banner occurs only in the lower part of this zone. *Globorotalia fohsi barisanensis* LeRoy, *Globigerinoides trilobus* (Reuss), *Globigerinoides immaturus* LeRoy and *Globigerinatella insueta* Cushman and Stainforth appear within this zone.

The lower part of the Hikokubo Group in the Chichibu basin, Saitama Prefecture (Ujiie, 1959; Saito, 1963) and the Kishima Formation of the basal part of the Ashiya Group, Karatsu coal-field, Kyushu can be correlated with this zone by the common occurrence of *G. dissimilis*.

Globigerinatella insueta Zone includes the Matsuba (upper part) and Saigo Formations of the Kakegawa district, and is characterized by *Globigerinatella insueta* Cushman and Stainforth, and by the absence of *Globigerinita dissimilis* and *Globigerinita unicava*. *Globoquadrina obesa* Akers first appears in the lower part of this Zone. By the new entry of

Globigerinodies bisphericus Todd in the upper part of this Zone, two subdivisions are recognized in Japan. Among them, *Globigerinatella insueta/Globigerinoides bisphericus* Subzone is distinguished by the joint occurrence of *G. insueta* and *G. bisphericus*. *Sphaeroidinella seminulina* (Schwager) and *Globorotalia praemenardii* Cushman and Bermudez first appear within this subzone. Most of the *Lepidocyclina* (*Nephrolepidina*) *japonica* Yabe and *Miogypsina kotoi* Hanzawa assemblages in Japan fall within the range of this subzone, on the basis of associated planktonic foraminiferal evidences. The present subzone is widely distributed in Japan as shown in Fig. 1 and Table 5. Most formations belonging to this subzone are transgressive facies with a distinct unconformable relationship with the older rocks, except in the areas of Kakegawa, Chichibu and Takasaki basins. According to Hanzawa (1950), the *Lepidocyclina* horizon in Japan is considered to indicate the Burdigalian age in the European standard. However, planktonic foraminiferal evidences associated in the same *Lepidocyclina* bearing rocks show that they should be referred to the *Globigerinatella insueta/Gleobigerinoides bisphericus* Sugzone of the Aquitanian age. But there is one exception of the horizon of *Lepidocyclina* bearing in Japan, as already noted by Saito. It is the Shimoshiraiwa calcareous sandstone of the Izu Peninsula. Its planktonic assemblage associated with *Lepidocyclina nipponica* from the Shimoshiraiwa should be referred to the *Globorotalia mayeri/Globigerina nepenthes* Zone which is Helvetian in age. Morishima (1949) described *Lepidocyclina makiyamai* from the Shinzaike Formation of the Kakegawa district and referred it to the Vindobonian in age, but Saito found planktonic Foraminifera which should be referred to the *Globigerinatella insueta/G. bisphericus* Subzone from the type locality of the Shinzaike Formation, accompanying *Lepidocyclina makiyamai*. Accordingly, the horizon of *L. makiyamai* is closely correlative with the type horizon of *L. japonica* Yabe in the Takasaki region and of *L. nipponica* Hanzawa assemblage in the Megami Limestone where the same planktonic foraminiferal assemblage has been found. Hanzawa now considers *L. makiyamai* and *L. nipponica* as junior synonyms of *L. japonica* Yabe.

Middle Miocene — Burdigalian

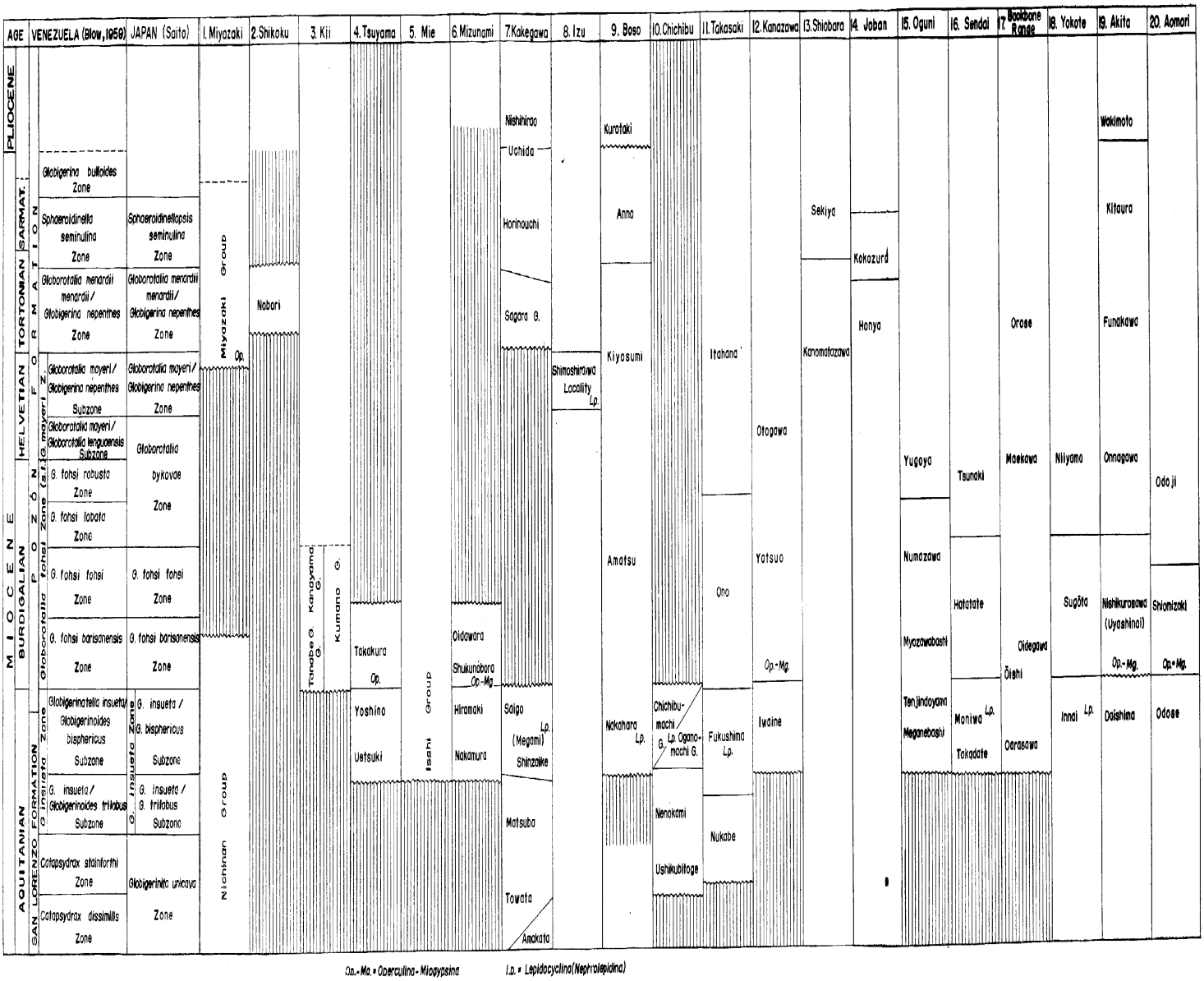
Many stratigraphers place the Burdigalian in the Lower Miocene, but most modern micropaleontologists prefer to place the Burdigalian in the middle Miocene from the evolutional change of the characteristic planktonic Foraminifera. Bandy (1964) defined the Burdigalian by the *Orbulina* datum as the lower boundary and by the *Globorotalia menardii* datum as its upper boundary. Thus, the Burdigalian was a time during which the *Globorotalia fohsi* group evolved from *barisanensis* to *robusta*.

In Japan, Saito (1963) recognized the following zones in the strata corresponding to the Burdigalian:

Globorotalia bykovae Zone (lower part)
Globorotalia fohsi fohsi Zone
Globorotalia fohsi barisanensis Zone

The *Globorotalia fohsi barisanensis* Zone is represented by the upper part of the Isobe Formation and the basal part of the Ono Formation in the Takasaki region, Gunma Prefecture. This zone is characterized by the occurrence of *Globorotalia fohsi barisanensis* LeRoy, *Orbulina universa* d'Orbigny, and *O. suturalis* Bronnimann. *Globigerinoides bisphericus* Todd has not yet been found within the present zone of Japan. Fig. 2 shows the paleogoeography at the time of this zone. The *Miogypsina~Operculina* assemblage in Japan belongs to this zone. *Globorotalia fohsi fohsi* Zone is distinguished by the first appearance of *G. fohsi fohsi* Cushman and Ellisor. *Globorotalia scitula scitula* (Brady) becomes common at the base of this zone, though it is recognized in the subjacent zone. However, in general, at the close of the present zone time, the sea began to retreat twoards the Pacific Ocean and/

Table 5. Neogene correlation of Honshu by means of planktonic Foraminifera zonation (after T. Saito, 1963)



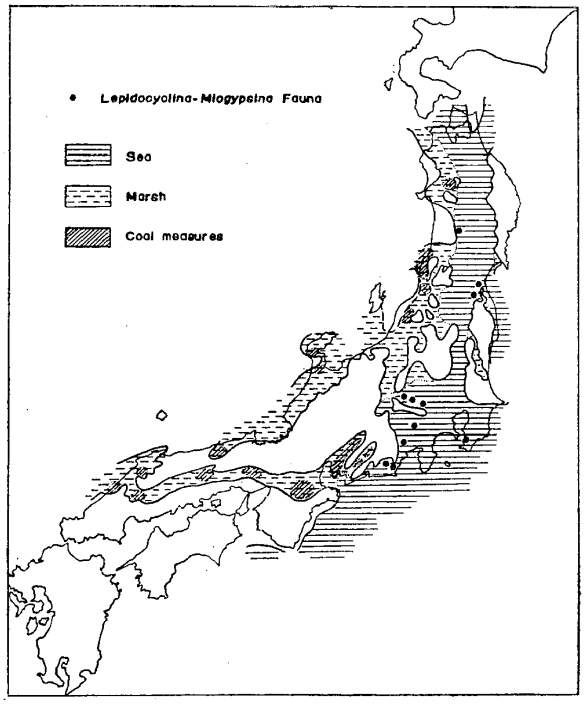


Fig. 1.

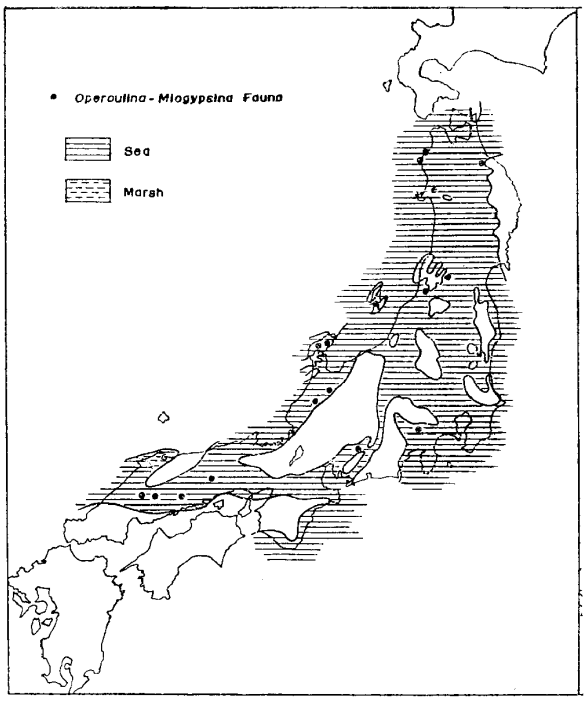


Fig. 2.

Fig. 1 Paleogeographic map of *Globigerinatella insueta / Globigerinoides bisphericus* Subzone in Honshu (After Saito, 1963)

Fig. 2 Paleogeographic map of *Globorotalia fohsi barisanensis* Zone in Honshu (After Saito, 1963)

or the Japan Sea. Consequently, the strata yielding *G. fohsi fohsi* became replaced upwards by coarse grained sediments or pyroclastics void of planktonic Foraminifera.

After the time marked by the flourishment of *G. fohsi fohsi*, a remarkable faunal change happened among the planktonic Foraminifera in Japan. The *Globorotalia bykovae* Zone of Saito represents this interval, and is characterized by monotonous planktonic fauna consisting mainly of long-ranging globigerinids. *Globorotalia bykovae* (Aisenstat), the zonal index species, was originally described from the Bogorodchanskaya Formation (middle Miocene), Pred-Carpathia, U.S.S.R. At the time of proposal of the *Globorotalia bykovae* Zone, this species had been recognized only from some isolated localities in northern Japan, and was considered to range from the present zone to the *Sphaerodinellopsis seminulina* Zone. Later investigations, however, have revealed that its range should be extended downwards to the *Globorotalia fohsi barisanensis* Zone (unpublished data in the Geology and Paleontology, Tohoku University). Thus the inter-regional correlation of this zone is quite difficult, because of lacking such diagnostic species as *Globorotoalia fohsi lobata* Bermudez and *Globorotalia fohsi robusta* Bolli.

In the larger part of southeastern Japan, the strata corresponding to the present zone are almost missing. On the other hand, in northern Japan where continuous deposition of both marine and fresh-water environment took place, the cooler water fauna dominated with the close of the flourishing of *G. fohsi fohsi* assemblage. But in the Boso Peninsula, recently Asano found *Globorotalia fohsi lobata* from the boring materials at the Osawa-well, Chiba Prefecture drilled by the Geological Survey of Japan. Although the *Globorotalia fohsi lobata* Zone has not yet been detected in the surface sections of the Boso Peninsula, it is noteworthy that the strata containing *G. fohsi lobata* is also distributed in some areas of Japan.

Upper Miocene

According to Bandy (1964), the upper Miocene including Helvetian, Tortonian, Sarmatian and Pontian is marked by the *Globorotalia menardii* datum as its lower boundary and by the *Sphaeroidinella dehiscens* datum as its upper boundary. Four assemblage zones within the upper Miocene were proposed by him as the standard division of the deep water facies. However, in Japan, the planktonic foraminiferal assemblages are more similar to those of the Caribbean region than those of Bandy.

In the upper Miocene strata of Japan, Saito (1963) distinguished the following zones in descending order:

Sphaerodinellopsis seminulina Zone
Globorotalia menardii menardii/Globigerina nepenthes Zone
Globorotalia mayeri/Globigerina nepenthes Zone
Globorotalia bykovae Zone (upper part)

As mentioned above, there is no distinct species diagnostic for the *Globorotalia bykovae* Zone, and its upper boundary has not been defined. Although Saito correlated the zone with the *Globorotoalia fohsi lobata* Zone, *Globorotalia fohsi robusta* Zone and lower part of the *Globorotalia mayeri* Zone (*Globorotalia mayeri/Globorotalia lenguaensis* Subzone) of the Caribbean region as a whole, it is a matter of urgency to refine the zonation for this part of Japan.

Globorotalia mayeri/Globigerina nepenthes Zone is represented in the Shimoshiraiwa calcareous sandstone of the Yugashima Group, in the Izu Peninsula, and the basal part of the Miyazaki Group in Kyushu. On the other hand, this zone is not clearly discriminated in northern Japan, because its characteristic species, *Globorotalia mayeri* Cushman and Ellisor and *Globigerina nepenthes* Todd, are lacking in cold-water facies.

Globorotalia menardii/Globigerina nepenthes Zone is represented in the Sagara Group and the lower part of the Kakegawa Group in the Kakegawa district, Shizuoka Prefecture, and is distributed in some parts of southern Japan. It is characterized by the continued occurrence of *Globigerina nepenthes* after the extinction of *Globorotalia mayeri*. The planktonic fauna from the strata corresponding to the present zone in northern Japan is composed of monotonous, small-sized species of cold-water type, such as *Globigerina bulloides* d'Orbigny and *Globigerina pachyderma* (Ehrenberg). It is difficult to correlate the Miocene sequence between southern and northern Japan by means of index species of this zone.

The *Sphaeroidinellopsis seminulina* Zone is distinguished by the continued occurrence of *Sphaerodinellopsis seminulina* (Schwager) and *Sphaerodinellopsis subdehiscens* (Blow) after the disappearance of *Globigerina nepenthes*. It is also typically represented in the middle part of the Kakegawa district.

Bandy (1964) defined the *Sphaerodinella dehiscens dehiscens* datum as the Miocene-Pliocene boundary, on the basis of a study of the deep-water conditions of the basin in southern Iloilo, Philippines. He states that this level marks the upper limit of the *Globoquadrina altispira globosa-Globoquadrina dehiscens dehiscens* assemblage and the beginning or basal occurrence of *Sphaeroidinella dehiscens dehiscens* and *Globorotalia truncatulinoides*. He also remarks that *Pulleniatina obliquiloculata* (Parker and Jones) is relatively rare in the upper Miocene but becomes abundant and dominantly left-coiling in the basal Pliocene and then reverses abruptly to right-coiling for the remainder of its range.

However, *Sphaeriodinella dehiscens dehiscens* (Parker and Jones) was found in association with *Globoquadrina altispria globosa* Bolli in the Nobori Formation in Shikoku, which was correlated with the *Globorotalia menardii menardii/Globigerina nepenthes* Zone by Takayanagi and Saito (1962). Therefore it is not acceptable to regard the *Sphaeroidinella dehiscens dehiscens* datum as the Miocene-Pliocene boundary in Japan.

On the other hand, the same tendency in the direction of coiling of *Pulleniatina obliquiloculata* has subsequently been observed in the Miocene-Pliocene sequence of some areas in the Boso Peninsula, Chiba Prefecture (Takayama, unpublished data; Matoba, 1964, MS.). Although the unconformable relationships are often recognized between the Miocene and Pliocene deposits in various parts of Japan, the coiling ratio of *Pulleniatina* as well as the rest of the planktonic species is now under investigation.

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