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First Report on Nannoplankton of the Upper Tertiary and Quaternary of the Southern Kwanto Region, Japan

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With 4 tables, 7 text-figures and plates 1—10

Contents

Abstract

The nannoplankton population from the upper Miocene, Pliocene and Pleistocene sediments of the southern Kwanto region, Japan are described. Their stratigraphic distribution and paleoclimatic changes are discussed

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on the basis of the planktonic foraminiferal fauna. It is possible that three species i. e. *Coccolithus pelagicus* (WALLICH), *Coccolithus crassipons* BOUCHÉ and *Gephyrocapsa oceanica* KAMPTNER are sensitive with regard to the paleoclimatic environments. *Gephyrocapsa oceanica* KAMPTNER and a *Discolithina* sp. are probably useful as stratigraphic indicators. In the studied sections, discoasters are almost extinct at the lowermost Pliocene. A total of 11 genera and 19 species of nannofossils are determined. One species is proposed as new to science. One sample from the well known Pliocene type locality, Castell d'Arquato, Italy, is examined for a comparative study.

Zusammenfassung

Nannoplankton-Vergesellschaftungen aus Sedimenten des oberen Miozäns, Pliozäns und Pleistozäns der südlichen Kwanto-Region, Japan, werden beschrieben und ihre stratigraphische Verteilung und paläoklimatisch bedingten Veränderungen auf der Grundlage der Faunen planktonischer Foraminiferen diskutiert. Drei Arten, und zwar *Coccolithus pelagicus* (WALLICH), *Coccolithus crassipons* BOUCHÉ und *Gephyrocapsa oceanica* KAMPTNER sind möglicherweise empfindlich in bezug auf die paläoklimatischen Milieu-Gegebenheiten. *Gephyrocapsa oceanica* KAMPTNER und *Discolithina* sp. scheinen stratigraphisch brauchbare Leitarten zu sein. In den untersuchten Profilen sind die Discoasteriden bereits im untersten Pliozän praktisch erloschen. Es wurden insgesamt 11 Gattungen und 19 Arten von Nannofossilien bestimmt. Eine Art wird als neu vorgeschlagen. Als Vergleichsmaterial wurde eine Probe aus dem bekannten Pliozän von Castell d'Arquato, Italien, untersucht.

Resumé

Le rapport décrit la population de nanoplancton des sédiments du Miocène supérieur, du Pliocéne, et du Pleistocéne de la région du Kwanto mèridional, au Japon. La répartition stratigraphique et les modifications paléoclimatiques de cette population ont été analysées sur la base de la faune planctonique foraminifére. Il est possible que trois espèces, à savoir *Coccolithus pelagicus* (WALLICH), *Coccolithus crassipons* BOUCHÉ et *Gephyrocapsa oceanica* KAMPTNER, soient sensibles aux milieux paléoclimatiques. *Gephyrocapsa oceanica* KAMPTNER et une espèce de *Discolithina* constituent probablement des indicateurs stratigraphiques utiles. Dans les sections étudiées, les discoasters sont presque entiérement éteints au Pliocène inférieur. Au total, 11 genres et 19 espèces ont fait l'objet d'une détermination. Une espéce est proposée commenouvelle pour la science. A titre de comparaison, un échantillon provenant de Castello d'Arquato, localité bien connue du type Pliocène, a également été étudiée.

АННОТАЦИЯ

В докладе описывается наннопланктоновая популяция отложений верхнего миоцена, плиоцена и плейстоцена южного Кванто (Япония). Стратиграфическое распределение и палеоклиматические изменения этой популяции анализируются на основе планктонной фораминиферовой фауны. Возможно, что три вида, а именно *Coccolithus pelagicus* (Wallich). *Coccolithus crassipons* Bouché и *Gephyrocapsa oceanica* Kamptner чувствителъны к палеоклиматической среде. *Gephyrocapsa oceanica* Kamptner и один из видов *Discolithina* вероятно могут служить полезным стратиграфическим индикатором. В изучаемых слоях, дискоастеры почти отсутствуют в нижнем плиоцене. Всего дано определение 11-тиродов и 19-ти видов наннопланктоновых окаменелостей. Один вид предлагается, как до сих пор неизвестный науке. В целях сравнения приводится изучение одного образца из хорошо известной местности плиоценого типа, а именно Кастелло д' Арквато (Италия).

Introduction

During the past few years, there has been an enormous increase in the recognition of the value of the nannofossils as good stratigraphic index fossils. Many papers have been published on the nannofossils of the early Tertiary and Mesozoic formations. In the very recent years, BRAMLETTE & SULLIVAN (1961), STRADNER & PAPP (1961), STRADNER (1963) and BRAMLETTE & MARTINI (1964) have recorded a number of significant observations. They discussed in detail the importance of the nannofossils and found out that both coccolithophorids and discoasters can be made use of as good time-indicators of Mesozoic and lower Tertiary marine sediments. MARTINI & BRAMLETTE (1963) published a paper on the nannoplankton from the experimental Mohole drilling and reported on the nannoflora of the late Tertiary. COHEN (1964) investigated the nannofossils of the two Caribbean deep-sea cores. He tried to find stratigraphic indicators in marine Pleistocene strata and studied the relationship of certain coccolithophorids species to the sea-water paleotemperatures. WRAY & ELLIS (1965) described the pattern of extinction of discoasters found in neritic sediments of very late Tertiary age in the northern part of the Gulf of Mexico. However, at the present time the value of the nannofossils of the younger Tertiary for stratigraphic correlation is still masked by incompleteness of knowledge.

The present article is the first report on nannofossils from Japan and is undertaken largely as a basis for future work. The main purpose of the present study is to describe the nannofossil population of the uppermost Miocene to Pleistocene system in southern Kwanto region, Japan. A total of 126 samples are examined, of which 15 are recognized as suitable for the present study. Of these one sample is considered belonging to the uppermost Miocene and fourteen to Pliocene-Pleistocene. Each horizon of these samples is checked by the planktonic foraminiferal fauna.

In addition to these materials, one sample from the well known type locality at Castell d'Arquato in Italy is examined for a comparative study.

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Methods of study

The treatment of samples is much the same as outlined by STRADNER & PAPP (1961) and COHEN (1964).

For the microscopic examination, a Reichert binocular polarizing microscope "Biozet" is used. A magnification of about 1000 times with oil-immersion lens is generally made use of.

For statistical analysis two hundred coccoliths specimens and two hundred discoasters (N-6, Castell d'Arquato) are determined in each sample. Many small-sized coccoliths which show little character for satisfactory specific identification are neglected. They could probably be studied with the electron microscope.

Obitsu river region

Stratigraphy

The Pliocene-Pleistocene sediments of the central part of the Boso Peninsula are generally more than 1500 m. in thickness. The Pliocene-Pleistocene Kazusa group is one of the most important Japanese Pliocene-

Pleistocene sections and has been studied extensively. Many geological and paleontological works have been published on this region which date back to the early part of this century.

The Kazusa group overlies the Miocene Toyooka group. The relation between these two groups is a distinct clino-unconformity in the eastern part of the Boso Peninsula and nearly a disconformity in the western part. This geological setting is generally known as the Kurotaki unconformity.

The present writer studied the Pliocene-Pleistocene planktonic foraminiferal assemblages in 1961. The investigation was based on 37 samples collected from the Kazusa group exposed along the River Obitsu and River Sasa (a tributary of the River Obitsu), in the central part of the Boso Peninsula. These samples are examined for the nannofossils and only one them (sample 77) is found suitable for the present study.

The stratigraphic sequence of the upper Tertiary and Quaternary rocks of the central part of Boso Peninsula (TAKAYAMA 1961, MS.) is summarized as follows in descending order:

Stratigraphic unit — Lithologic description — Thickness in meters

Kazusa group

Kakinokidai formation

Upper part: Alternation of siltstone and fine grained sandstone with interbedded thin layers of tuff.
Middle part: Brownish grey medium grained sandstone.
Lower part: Bluish grey sandy siltstone with interbedded thin layers of tuff. 180 m.

Kokumoto formation

Bluish grey sandy siltstone with interbedded thin layers of tuff. 360 m.

Umegase formation

Alternation of sandstone and siltstone with interbedded thin layers of tuff. 460 m.

Otadai formation

Thin bedded alternation of sandstone and siltstone with interbedded thin layers of tuff. 170 m.

Kiwada formation

Bluish grey siltstone with interbedded thin layers of tuff. 90 m.

Kurotaki formation

Alternation of tuff and tuffaceous sandstone. 30 m.

~~~~~~~~ Kurotaki unconformity ~~~~~~~~

Toyooka group

Anno formation

Alternation of tuff, tuffaceous sandstone and siltstone.

The locations of the samples collected for the present study from the Obitsu River region are shown in text-fig. 1.

Planktonic Foraminifera

One sample (sample 77), containing nannofossils, is collected from the basal Kurotaki formation exposed along the Bokenosawa stream valley (a tributary of the Sasa River), and is at 1 m. above the Kurotaki uncon-
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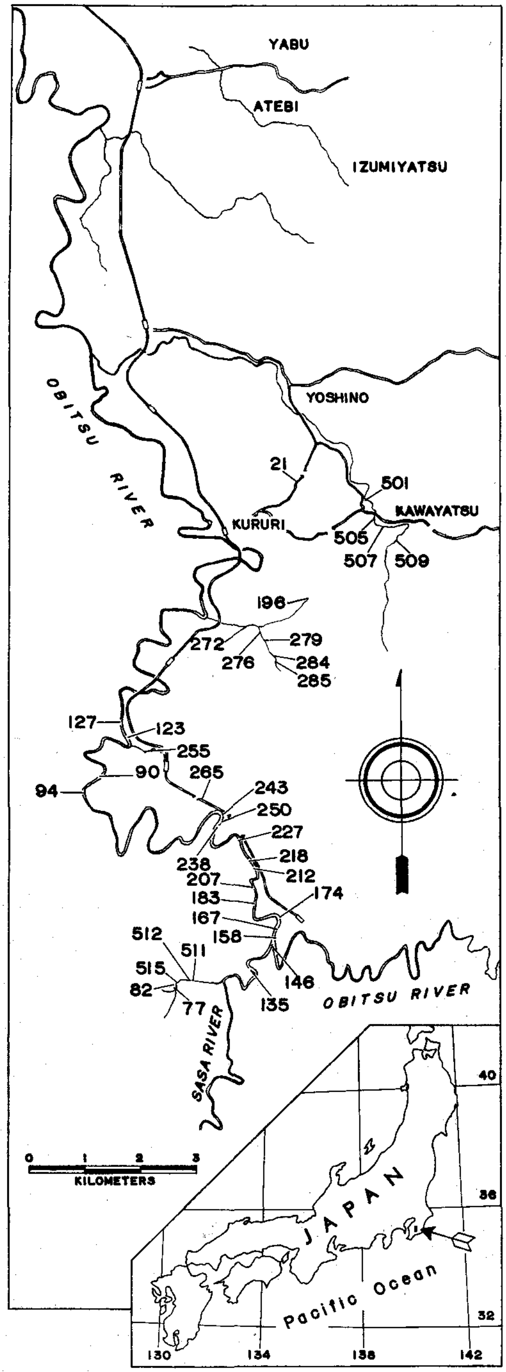

Fig. 1. The foraminiferal collection localities in the Obitsu River region.

formity. It also yielded many specimens of Foraminifera and its planktonic Foraminifera are listed in table 1.

Geological age

Many geologists regard the Kurotaki unconformity as the Miocene-Pliocene boundary in the Boso Peninsula.

BANDY (1963 a, b, 1964) selected the *Sphaeroidinella dehiscens dehiscens* datum as the Miocene-Pliocene boundary on the basis of his planktonic foraminiferal study of the deep-water conditions of the basin in southern Iloilo, Philippines. According to him, 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*. And also according to him, the planktonic foraminiferal species *Pulleniatina obliquiloculata* becomes abundant and left-coiling specimens are dominant in the basal Pliocene. They then reverse abruptly to right-coiling for the remainder of their range.

Sample 77, which is collected from the basal Kurotaki formation, has *Sphaeroidinella dehiscens dehiscens* and *Globorotalia truncatulinoides*. According to BANDY (1963 a, b, 1964), the presence of these two species places the basal Kurotaki formation in Pliocene. In this sample, *Pulleniatina obliquiloculata* is rare, but the present writer could collect 50 specimens to determine the coiling-ratio of this species, and 96% are found to coil sinistrally. To follow the change of the coiling ratios of this species in the Kurotaki formation, the writer collected twelve more samples from this formation exposed along the Bokenosawa, and picked up 20 to 50 specimens of this species at random from each sample. The result obtained from this investigation is shown in text-fig. 2. A very rapid change of the coiling-ratio from 96% sinistral to 100% dextral in *Pulleniatina obliquiloculata* is observed. This change takes place within a short stratigraphical interval in the section studied, which is less than 4 m. It is possible that the environmental changes are the cause of such sudden shifts in the coiling-ratios. The low temperatures are known to affect the reproduction in the various genera of Foraminifera. The lateral distribution of the different test-coilings may also be due to the effect of the low temperature. ERICSON (1959) studied the coiling-ratios of *Globigerina pachyderma* in the northern part of the Atlantic and reported that the coiling in this species is dominantly sinistral near the Arctic region, whereas it is dominantly dextral in the temperate area. The change of coiling-ratio of *Globigerina pachyderma* from dextral dominant to the sinistral suggests a decrease in the temperature of the seawater. Text-fig. 2 shows the change of the coiling-ratio of *Globigerina pachyderma* in the Kurotaki formation. It shows that there is no great change in the coiling-ratio of this species, and so this suggests that there is no remarkable change of the seawater temperature through the Kurotaki formation. In *Pulleniatina obliquiloculata*, the reason for the change of the coiling-ratio is not clear at the present time, but this change

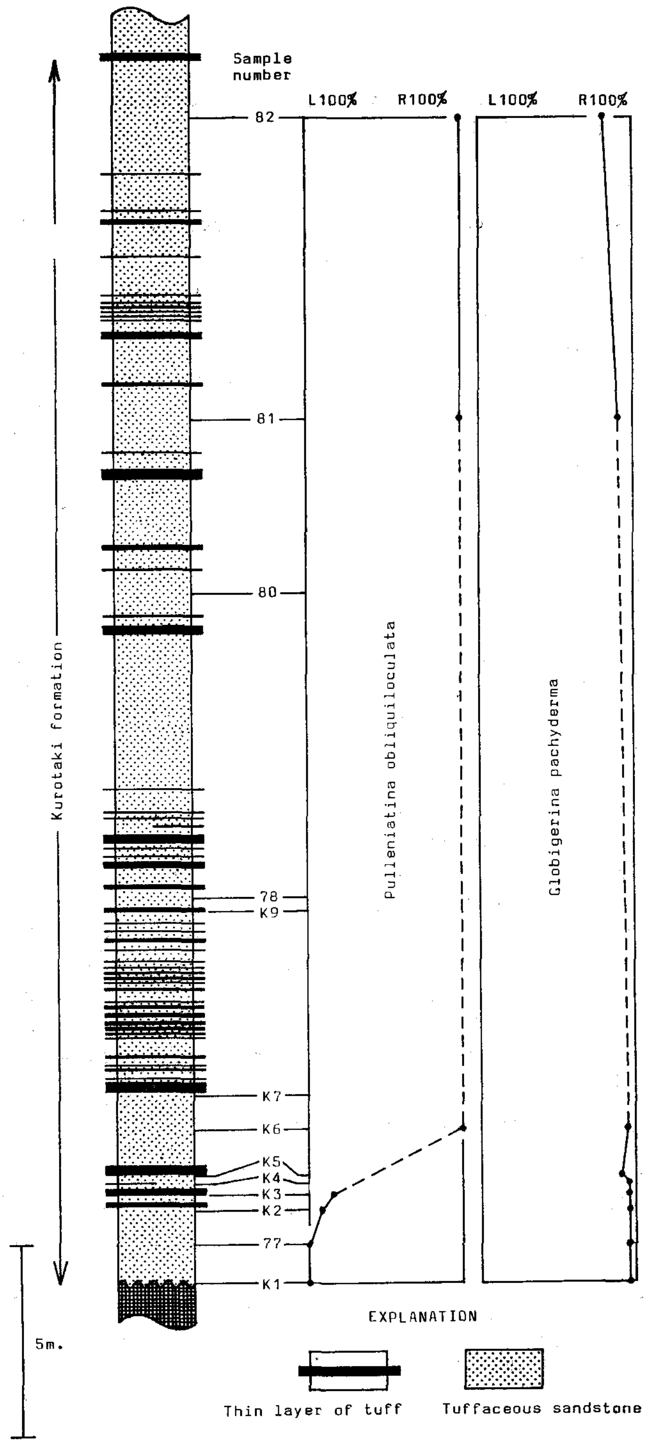

Fig. 2. The change of the coiling ratios of *Pulleniatina obliquiloculata* and *Globigerina pachyderma* in the Kurotaki Formation of the Obitsu River region.

could possibly be used as a good stratigraphic indicator which may place the basal Kurotaki formation in basal Pliocene.

N a n n o f o s s i l s

The following species of coccolithophorids are registered in sample 77.

Species	Percentage
Calcidiscus medusoides KAMPTNER	7
Calcidiscus sp.	2
Coccolithus crassipons BOUCHE	1.5
Coccolithus pelagicus (WALLICH)	7
Cyclococcolithus leptoporus (MURRAY & BLACKMAN)	35.5
Discolithina japonica n. sp.	1.5
Discolithina sp.	14
Gephyrocapsa oceanica KAMPTNER	2
Helicosphaera carteri (WALLICH)	18
Rhabdosphaera stylifer LOHMANN	0.5
Braarudosphaera bigelowi (GRAN & BRAARUD)	0.5
Thoracosphaera deflandrei KAMPTNER	3.5
Thoracosphaera heimi (LOHMANN)	2.5
Ceratolithus cristatus KAMPTNER	0.5
Miscellaneous	4

(Nannofossils smaller than 3 μ are not registered.)

In this sample the present writer found only one specimen of *Discoaster surculus* and two specimens of *Discoaster perplexus.*

Choshi region

S t r a t i g r a p h y

In Choshi region, located in the north-eastern part of the Boso Peninsula (text-fig. 3), the Pliocene-Pleistocene sediments are thinner than in the central part (generally less than 700 m. in thickness), but are well exposed with simple geological structures. Recently Y. MATOBA (1964, MS.) established the sequence and described the lithology of the stratigraphic units as follows, in descending order.

Stratigraphic unit	Lithologic description	Thickness in meters
G y o b u m i s a k i f o r m a t i o n		
	Upper and middle part: Cross-bedded medium to coarse sandstone with granule pebbles.	
	Lower part: Yellowish brown fine to medium grained loose sandstone with interbedded layers of thin siltstone and basal conglomerate.	20 m.
	Unconformity	
T o y o s a t o f o r m a t i o n		
	Upper and middle part: Massive sandy siltstone and fine grained sandstone with interbedded thin layers of pumice and fine grained tuff.	
	Lower part: Massive siltstone.	120 m.
I i o k a f o r m a t i o n		
	Massive siltstone with interbedded thin layers of pumice and fine grained tuff. Alternation of siltstone and fine to medium grained sandstone at the base of this formation.	500 m.

N a a r a i f o r m a t i o n

Pumiceous sandy tuff with interbedded thin layers of fine grained tuff. Basal conglomerate with abundant molluscan and foraminiferal fossils. Tokowa conglomerate. 100 m.

Clino-unconformity

M e t o g a h a n a f o r m a t i o n

Alternation of tuffaceous sandstone, tuffaceous siltstone and tuff with interbedded layers of basaltic and andesitic lava at the base of this formation.

Clino-unconformity

C h o s h i f o r m a t i o n

Sandstone, conglomerate and shale.

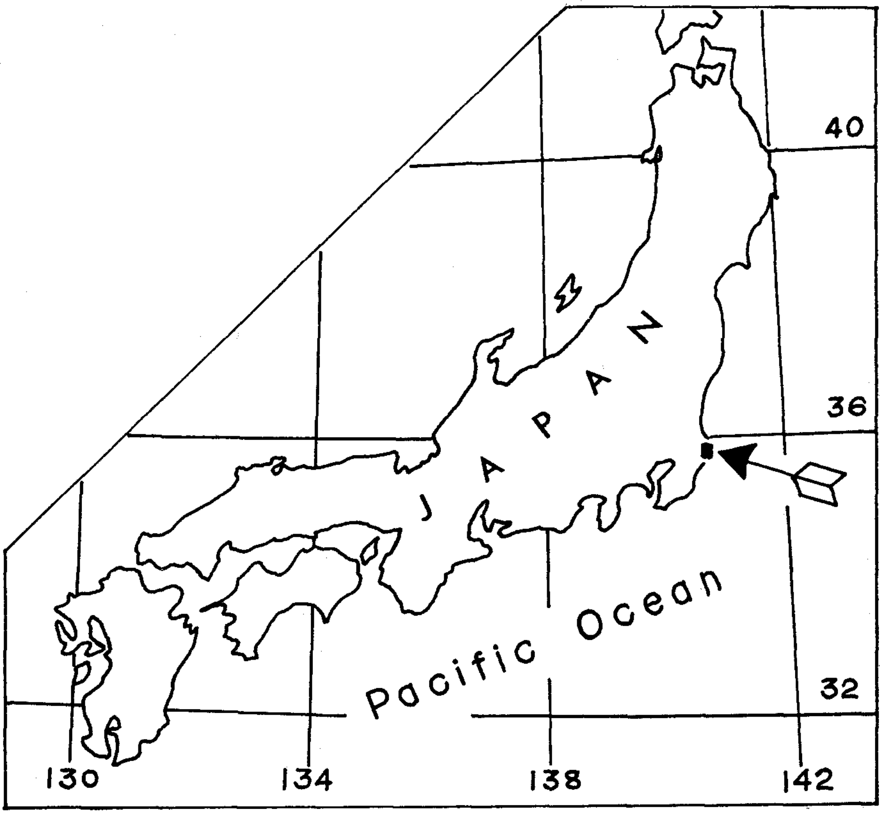

Fig. 3. Index map of the Choshi region.

P l a n k t o n i c F o r a m i n i f e r a

The Metogahana formation has Foraminifera, Radioralia, Sponge spicules and Diatoms. From this formation, Y. MATOBA reported the occurrence of only one benthonic foraminiferal species, *Martinottiella communis* D'ORBIGNY. According to him, the sample from the Tokawa conglomerate yields abundant planktonic Foraminifera such as,

Globigerina bulloides D'ORBIGNY
Globigerina falconensis BLOW
Globigerina nepenthes TODD
Globigerina pachyderma (EHRENBERG)
Globigerinoides conglobatus (BRADY)
Globigerinita glutinata (EGGER)
Globoquadrina conglomerata (SCHWAGER)
Globoquadrina dutertrei (D'ORBIGNY)
Globorotalia menardii menardii (PARKER, JONES & BRADY)
Globorotalia menardii miocenica PALMER
Globorotalia scitula scitula (BRADY)
Orbulina universa D'ORBIGNY
Sphaeroidinellopsis seminulina (SCHWAGER)

Fossil planktonic foraminiferal faunas of the Naarai, Iioka, Toyosato and Gyobumisaki formations are also studied by Y. MATOBA (1964, MS.). His results are summarized and rearranged by the present author and shown in text-fig. 4 *). According to him, the Naarai, middle and uppermost Iioka formations are characterized by the abundance of *Globigerina pachyderma, G. bulloides* and *G. quinqueloba,* which are typical cold water species. Sample C-2 and C-3 which are collected from the basal Iioka formation have dominantly sinistral *Pulleniatina obliquiloculata.*

Geological age

The Choshi formation which unconformably overlies the Paleozoic formation is assigned to the Cretaceous age from the occurrence of Ammonites and Trigonias. The Metogahana formation is considered as Miocene even though no planktonic Foraminifera are found. Y. MATOBA suggested that the Tokawa conglomerate belongs to the *Globorotalia menardii menardii/Globigerina nepenthes* zone. As no guide species of planktonic Foraminifera are found in the Naarai formation except for Tokawa conglomerate, its exact geological horizon could not be determined, but the coiling-ratio of *Pulleniatina obliquiloculata* suggests that this formation may belong to the uppermost Miocene. MATOBA did not refer to the geological ages of Iioka, Toyosato, and Gyobumisaki formations. It is very difficult to draw the boundary between Pliocene and Pleistocene. ASANO et al. (1957, 1958) discussed the Pliocene-Pleistocene boundary of the Neogene sediments in the central Boso Peninsula, in consideration of the recommendations concerning the Tertiary-Quaternary boundary problem, made at the 18th International Geological Congress in London (1948). They collected many samples from the Yoro River section in the central part of the Boso Peninsula and studied the faunal change of the planktonic Foraminifera. They pointed out that the typical warm water planktonic foraminiferal species disappear at the middle horizon of the Umegase formation and they considered this horizon as the boundary between Pliocene and Pleistocene. Similar investigation was undertaken by the author at the Obitsu River section which is situated about 10 km. west of the Yoro River section (1961, MS.). The results are shown in table 1 *) and text-fig. 5 *).

*) In pocket.

He recognized the first remarkable faunal change at the middle Umegase formation and suggested that this horizon is the boundary. The following correlations of Choshi district and Obitsu River section are made: the lowermost Iioka formation with the lowermost Kurotaki formation due to the occurrence of abundant sinistral *Pulleniatina obliquiloculata;* the middle Iioka formation (sample C-5) with the middle Umegase formation (sample 227) because of the faunal changes from warm water to cold water fauna (this horizon is considered as the Pliocene-Pleistocene boundary), and the upper Iioka formation (sample C-11 and C-12) with the uppermost Kakinokidai formation by the abundant occurrence of sinistral coiling *Globigerina pachyderma.* It is considered that this horizon represents the coldest period of this section.

Nannofossils

200 specimens from each sample of the Naarai, Iioka and Toyosato formations are listed in table 2, and compiled in text-fig. 4. A sample from the Naarai formation contains such discoasters as:

Species	Percentage
Discoaster brouweri TAN SIN HOK with 6-rays	83
Discoaster pentaradiatus TAN SIN HOK with 5-rays	4
Discoaster surculus MARTINI & BRAMLETTE	1
Miscellaneous	12

The present author cannot prove the existence of any nannofossils in the sample collected from the Gyobumisaki formation. The nannoplankton assemblages from the Pliocene-Pleistocene formations at Choshi region are characterized by the absence of discoasterids except in one sample from the Iioka formation (sample C-5: *Discoaster surculus*).

Castell d'Arquato

Stratigraphy

Marine sediments, exposed at Castell d'Arquato, Italy, are one of the most important type sections of marine Pliocene in Europe. Since the beginning of the last century, many investigators studied the geology and paleontology of this region. Recently DI NAPOLI (1952) and CUSHMAN (1945) have made valuable contributions to the knowledge of the stratigraphy and foraminiferal faunas of this region.

Pliocene sediments at Castell d'Arquato start with a neritic-littoral-clastic facies, which represents a chaotic accumulation due to gravitative slumping. These are followed by sediments of clayey facies and ends with a more sandy facies showing a sharp passage into strongly littoral sediments.

Table 2. Distribution of Coccolithophorids and related nannoplankton in the Choshi section.

	N 6	C 2	C 3	C 4	C 5	C 6	C 7	C 8	C 9	C10	C11	C12	C13	C14
Calcidiscus medusoides	61	7	14	19	12	7	6	3	14	2	8		5	26
Calcidiscus sp.	29	7	16	24	12	19	32	7	7	4	12	1	1	11
Coccolithus crassipons	46	4	32	9	6	7	38	3	8	62	33	6		1
Coccolithus pelagicus	39	31	39	109	28	7	19	15	44	31	27	22	12	18
Cyclococcolithus leptoporus	5	16	15	9	25	7	21	34	3	8	4	2		5
Discolithina japonica		3	1		1	1	1			2			1	
Discolithina sp.	2	20	10	4	18	3	7	5	2	5				
Gephyrocapsa oceanica				1	2	81	14	42	56	14	68	128	137	43
Helicosphaera carteri	8	88	51	9	69	49	34	78	39	49	8	19	13	29
Braarudosphaera bigelowi		3						3	1	1				
Thoracosphaera deflandrei	2	5	15	4	9	4	1			1	1		1	2
Thoracosphaera heimi	3	15	6	8	17	15	21	10	19	15	10	19	29	63
Ceratolithus cristatus	2	1		2			1					1	1	2
Reworked specimens	3				1						4			
Miscellaneous			1	2			5		7	6	25	2		
Total	200	200	200	200	200	200	200	200	200	200	200	200	200	200

Planktonic Foraminifera

From the type section at Castell d'Arquato, the following planktonic Foraminifera are noted.

Globigerinoides adriatica (FORNASINI)
Globigerina bulloides D'ORBIGNY
Globigerinoides ruber (D'ORBIGNY)
Orbulina universa D'ORBIGNY

Nannofossils

One sample collected from this locality is examined for a comparative study. This sample is the same one from which discoasterids were studied earlier by STRADNER & PAPP (1961). From this sample the present writer ascertained the following larger nannofossils.

Species	Percentage
Arkhangelskiella cymbiformis VEKSHINA	4
Coccolithus pelagicus (WALLICH)	41.5
Crepidolithus crassus (DEFLANDRE)	3
Cribrosphaerella ehrenbergi (ARKHANGELSKY)	0.5
Cyclococcolithus leptoporus (MURRAY & BLACKMAN)	3
Deflandrius intercisus (DEFLANDRE)	1.5
Discolithina sp.	3
Eiffellithus turriseiffeli (DEFLANDRE)	1
Helicosphaera carteri (WALLICH)	17.5
Rhabdolithus angustus STRADNER	1
Rhabdosphaera stylifer LOHMANN	3
Braarudosphaera bigelowi (GRAN & BRAARUD)	1.5
Cylindralithus? gallicus (STRADNER)	0.5
Micula staurophora (GARDET)	5.5
Miscellaneous	13.5

(Nannofossils smaller than 3 μ are not registered.)

Besides these species, the present writer found a few specimens of *Zygolithus diplogrammus* DEFLANDRE, *Isthmolithus recurvus* DEFLANDRE, *Microrhabdulus decoratus* DEFLANDRE, *M.* aff. *helicoides* DEFLANDRE and *Nannoconus colomi* (DE LAPPARENT).

Discoasters from this sample are listed below, together with their frequencies.

Species	Percentage
Discoaster brouweri TAN SIN HOK with 4-rays	5
Discoaster deflandrei BRAMLETTE & RIEDEL	0.5
Discoaster barbadiensis TAN SIN HOK	1
Discoaster pentaradiatus TAN SIN HOK with 4-rays	2
Discoaster pentaradiatus TAN SIN HOK with 5-rays	54
Discoaster surculus MARTINI & BRAMLETTE with 6-rays	31
Miscellaneous	6.5

This sample contains also a few specimens of *Discoaster brouweri* TAN SIN HOK with 5- and 6-rays; *D. challengeri* BRAMLETTE & RIEDEL; *D.* cf.

currens STRADNER; *D. lodoensis* BRAMLETTE & RIEDEL and *D. surculus* MARTINI & BRAMLETTE with 3-rays.

Discussion

MARTINI & BRAMLETTE (1963) studied the nannoplankton of cores from the experimental Mohole drilling which penetrated the Pliocene and Miocene strata. According to them, *Discoaster brouweri* specimens with 5- or 6-rays are common in the middle and upper Miocene and with 3- and 4-rays are common in the lower Pliocene. *Discoaster surculus* is also particulary significant in the lower Pliocene unit. In the studied sections, 6-rayed specimens of *Discoaster brouweri* are dominant in the Naarai formation, uppermost Miocene (sample N-6). In the Pliocene-Pleistocene sediments, however, the writer cannot find any discoasters except in two samples (77 and C-5). Only two specimens of *D. perplexus* and one specimen of *D. surculus* in sample 77, and a few specimens of *D. surculus* in C-5 are found. In the sample from Castell d'Arquato, Italy, abundant *D. surculus* and 4-rayed specimens of *D. brouweri* are found. This abundant discoaster population may, however, be partly the result of reworking. An explanation to this point is given later on in this chapter.

ERICSON, EWING & WOLLIN (1963) defined the Pliocene-Pleistocene boundary in deep-sea cores from the Atlantic and Indian Oceans on micropaleontological evidences — the extinction of discoasters and the evolutionary changes of certain planktonic Foraminifera. According to them, this boundary is marked by the following faunal changes: at this level all discoaster species disappear; the planktonic foraminiferal species *Globorotalia truncatulinoides* appears and becomes abundant; below this level the planktonic foraminiferal species *Globorotalia menardii* exhibits two types of the test, above this level it shows only one type. The coiling-ratio of *Globorotalia menardii* also changes abruptly from 95% right-coiling to 95% left-coiling and the diameter of the test of this species increases suddenly at this boundary. This horizon which is first proposed by ERICSON et al. (1963) was subsequently discussed by RIEDEL, BRAMLETTE & PARKER (1963), BANDY (1963 b), JENKINS (1964) and WRAY & ELLIS (1965). According to BANDY (1963 b), this abrupt extinction of discoasters in Atlantic and Indian Oceans deep-sea cores may be due to an unconformity betwee nMiocene and Pleistocene sediments. WRAY & ELLIS (1965) studied the pattern of extinction of discoasters found in the neritic sediments of late Tertiary age in the northern part of the Gulf of Mexico and considered the zone of extinction of discoasters as approximating to the Pliocene-Pleistocene boundary. According to them, the zone of extinction of discoasters is marked by two separate discoasterid horizons. The lower one of the two horizons is characterized by the last occurence of *Discoaster exilis, D. hamatus, D. pentaradiatus, D. surculus, D. variabilis* and *D. brouweri.* Above this lower horizon, only *D. brouweri* extends into younger sediments, and the ultimate occurrence of this species defines the upper horizon.

In the Obitsu River section, *Globorotalia truncatulinoides* is already present at the base of Kurotaki formation which is generally regarded as lowermost Pliocene by many geologists. Throughout this section, the author recognized only one type of *G. menardii* which is dominantly left-coiling. The increase of the size of *G. menardii* is also recognized at the Kurotaki unconformity. In the studied sections, discoasters are almost extinct at the lowermost Pliocene. This is not in agreement with the observation of ERICSON et al. (1963), RIEDEL et al. (1963) and WRAY & ELLIS (1965).

The present author finds no remarkable change in the composition of coccolithophorid species throughout the studied sections and cannot recognize any changes at the Miocene-Pliocene and Pliocene-Pleistocene boundaries. Some species, however, show restricted ranges. *Gephyrocapsa oceanica* appears in basal Pliocene (sample 77) and suddenly becomes dominant at the middle Iioka formation (sample C-6). The autor assigns this horizon to the lower Pleistocene. It corresponds to the period after the first glaciation. *Discolithina* sp. disappears at the upper Iioka formation (sample C-11). This horizon corresponds to the coldest period in these sections. Therefore these two species are probably useful as stratigraphic indicators.

The reworking and redistribution of the nannofossils have already been discussed in detail by COHEN (1964). As mentioned above, the Pliocene sample from Castell d'Arquato has an abundant nannofossil population but it is partly the result of reworking. Many species which are shown in table 3 and 4 are considered to be derived from older sediments. The stratigraphical ranges of these species are also shown in these tables (based on STRADNER & PAPP, 1961, and STRADNER 1963). From these tables, it is clear that a part of the assemblage of Castell d'Arquato is reworked from the sediments of at least six different geological horizons of Pliensbachian-Bajocian, Hauterivian-Barremian, Cenomanian-Turonian, Maastrichtian, middle Eocene and upper Eocene.

The following derived forms are also recognized in the studied sections of the Kwanto region, Japan.

Sample N-6: *Arkhangelskiella* sp.
Cylindralithus? gallicus (STRADNER)
Sample C-5: *Cylindralithus? gallicus* (STRADNER)
Sample C-11: *Arkhangelskiella* sp.
Cylindralithus? gallicus (STRADNER)

The horizons of C-5 and C-11 correspond to the cold climate periods. As mentioned by COHEN (1964), it is possible that this phenomenon is due to a lower sea level and the intensification of currents and wave action during the cold glacial periods.

COHEN (1964) used the Caribbean deep-sea cores which have already been analyzed by the O^{18}/O^{16} paleotemperature method and dated by the Pa^{231}/Th^{230} method. The present author determined the geological ages and the paleotemperature by the planktonic foraminiferal assemblages.

Recently many papers have been published on the areal distribution of the planktonic Foraminifera. BRADSHAW (1959) investigated the distribution of the planktonic Foraminifera in the northern and equatorial Pacific Ocean and recognized four assemblages, namely sub-arctic fauna (cold), transitio-

	Discolithina crassa	Nannoconus colomi	Zygolithus diplogrammus	Braarudosphaera bigelowi	Rhabdolithus angustus	Rhabdolithus? turriseiffeli	Cribrosphaerella ehrenbergi	Deflandrius intercisus	Microrhabdulus decoratus	Micula staurophora	Microrhabdulus aff. helicoides	Arkhangelskiella cymbiformis	Cylindralithus? gallicus
Danian				x						x			
Maastrichtian				x		x	x	x	x	x	x	x	x
Campanian			x	x		x	x	x	x	x	x		
Santonian			x	x		x	x	x	x	x			
Coniacian			x	x		x	x	x	x	x			
Turonian			x	x	x	x							
Cenomanian			x	x	x	x							
Albian			x	x									
Aptian			x										
Barremian		x	x										
Hauterivian		x	x										
Valendisian													
Purbeckian													
Portlandian													
Kimmeridgian													
Oxfordian													
Callovian													
Bathonian													
Bajocian	x												
Aalenian	x												
Toarcian	x												
Pliensbachian	x												
Sinemurian													
Hettangian													

Table 3. Stratigraphic range chart of the reworked species which were found from the locality of Castell d'Arquato, Italy.

nal fauna, central fauna (warm) and equatorial west central fauna (warm). According to him, *Globigerina pachyderma* belongs to the sub-arctic fauna, and *Pulleniatina obliquiloculata* and *Sphaeroidinella dehiscens dehiscens* belong to the typical equatorial west central fauna. He also reported that

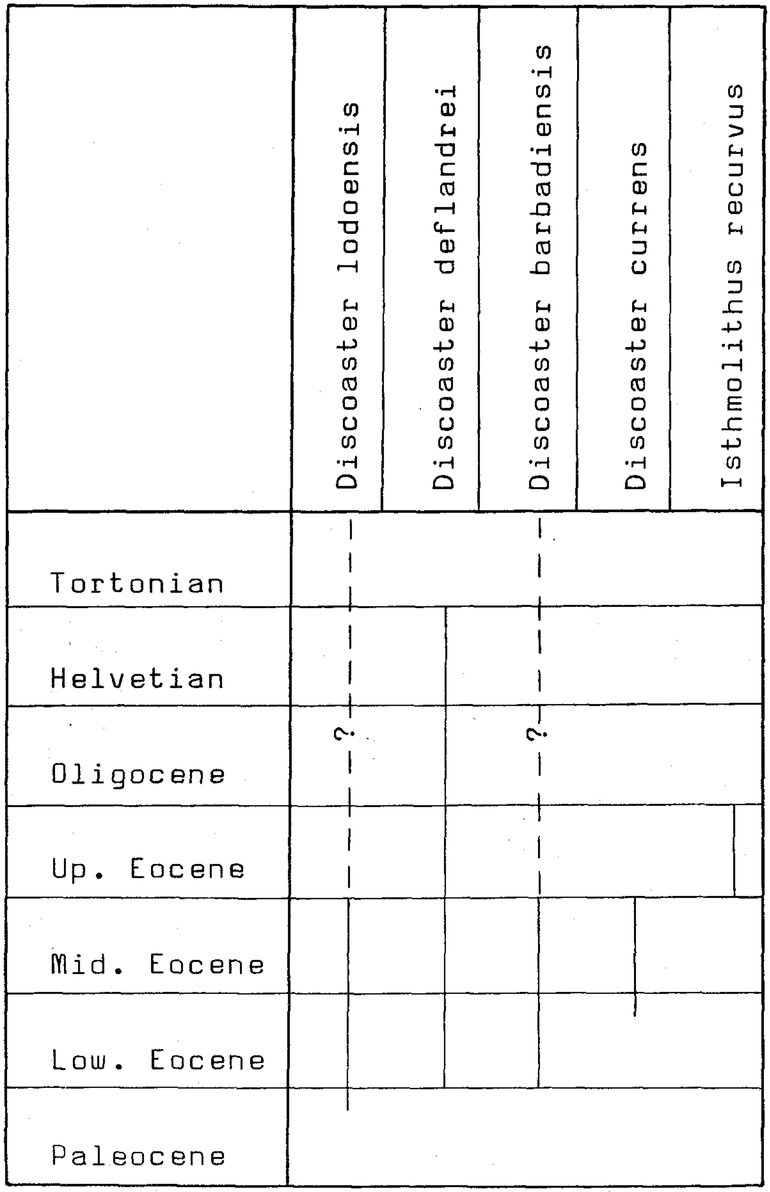

Table 4. Stratigraphic range chart of the reworked species which were found from the locality of Castell d'Arquato, Italy.

Globigerina quinqueloba and *G. bulloides* are cold water species and *Globorotalia tumida*, *Globigerinoides conglobatus*, *Globorotalia menardii* and *Globigerinoides sacculifer* are warm-water species. PHLEGER (1952) and UCHIO (1960) reported the occurrence of *Globigerina pachyderma* and *G. bulloides* from the arctic and antarctic regions. ASANO (1957) studied many bottom samples collected from the adjacent seas of Japan and reported that *Pulleniatina obliquiloculata* and *Globorotalia menardii* were carried by the warm-water current and *Globigerina pachyderma* by the cold-water current. Similar investigations by SCHOTT (1935), WISEMAN & OVEY (1950), PHLEGER (1954), STONE (1956), BÉ (1959) in the Atlantic Ocean, PARKER (1962), SMITH (1963) in the Pacific Ocean and POLSKI (1959) in the East China Sea gave similar results. According to them, *Globigerina pachyderma* and *G. quinqueloba* are cold-water species and *Sphaeroidinella dehiscens dehiscens*, *Pulleniatina obliquiloculata*, *Globigerinoides conglobatus*, *Globorotalia menardii*, *G. truncatulinoides*, *Globigerinoides sacculifer* are warm-water species. These cold- and warm-water species show a tendency to increase or decrease in abundance in the studied sections of the Kwanto region. From these faunal changes, the writer considers that the upper Umegase, lower Kokumoto and uppermost Kakinokidai formations correspond to the cold periods in Obitsu river section. According to MATOBA's study (1964, MS.), the middle Iioka (sample C-5) and uppermost Iioka formation (sample C-11) correspond to the cold periods in Choshi section. It is the writer's opinion that the uppermost Kakinokidai formation in Obitsu River section and uppermost Iioka formation (sample C-11) in Choshi section represent the coldest period of these sections. This is based on the investigation of the coiling-ratio of *Globigerina pachyderma* as mentioned earlier.

The author also examined the effects of temperature on nannofossil distribution (text-fig. 4). *Coccolithus pelagicus* and *C. crassipons* are more abundant in "warm" samples. *Gephyrocapsa oceanica* also seems to be more abundant in "warm" samples. This fact is already indicated by KAMPTNER (1943). According to COHEN (1964), this species could have been temporarily reduced in abundance during the cooler periods in the two Caribbean deep-sea cores.

Systematic paleontology

Family COCCOLITHOPHORIDAE LOHMANN

Genus *Calcidiscus* KAMPTNER, 1950

Calcidiscus medusoides KAMPTNER

(Plate 1, figure 9)

1954 *Calcidiscus medusoides* KAMPTNER, Arch.Protistenk., vol 100, no. 1, p. 26, figs. 24, 34.
1963 *Calcidiscus medusoides* KAMPTNER, MARTINI & BRAMLETTE, Jour. Paleont., vol. 37, no. 4, p. 849, pl. 102, figs. 1—2.

R e m a r k s: Japanese specimens have two types of this species. The larger one has a large central opening and striae are distinct. The smaller one has a small central opening and indistinct striae. Both types show only faint extinction, especially the latter one.

Distribution: The larger type is rare to common in the Pliocene-Pleistocene section but the smaller type is abundant in the Naarai formation, upper Miocene. This species is common in the Quaternary and the late Tertiary in many regions of the world.

Calcidiscus sp.

(Plate 1, figure 12)

Remarks: The present specimens are similar to *C. medusoides* in the general outline and side view. But this form is usually small, less than 5 μ, and has a small central opening. The striae are more straight and the extinction cross is distinct.

Distribution: Rare to common in the studied sections.

Genus *Coccolithus* SCHWARZ, 1894

Coccolithus crassipons BOUCHÉ

(Plate 2, figure 6—10)

1962 *Coccalithus crassipons* BOUCHE, Revue de Micropaléontologie, vol. 5, no. 2, p. 83, pl. 1, fig. 14, text-fig. 3.

Remarks: This species is characterized by the existence of the central bridge, crossing the centrally located opening. This bridge can be recognized easily in polarized light between crossed nicols. It shows three stages of growth. In the first stage, the bridge starts to grow from two small knob-like spines at opposite sides of the elliptical central area. In this stage, the top view gives the impression that knobs are present. These two knob-like spines tend to grow and in the final stage they touch each other and form a single bridge structure.

Distribution: Abundant throughout the studied sections. This species may show a greater abundance in "warm" samples.

Coccolithus pelagicus (WALLICH)

(Plate 1, figure 10, 11)

1877 *Coccosphaera pelagica* WALLICH, Ann. Mag. Nat. Hist., ser. 4, vol. 19, p. 348, pl. 17, figs. 1—2, 5, 11—12.

1930 *Coccolithus pelagicus* (WALLICH); SCHILLER, in RABENHORST, Krypt.-Flora, Akad. Verl. Leipzig, vol. 10, p. 246.

1963 *Coccolithus pelagicus* (WALLICH); MARTINI & BRAMLETTE, Jour. Paleont., vol. 37, no. 4, pp. 849—850.

Remarks: The present specimens have no bar across the central opening and some specimens have distinctly curved striae. The extinction cross at the outer rim is obscure.

Distribution: Abundant throughout the sequence. This species is common in the Recent and the late Tertiary sediments of many regions. According to STRADNER (1963), this species starts from Callovian.

Genus *Cyclococcolithus* KAMPTNER, 1954

Cyclococcolithus leptoporus (MURRAY and BLACKMAN)

(Plate 2, figure 1—5)

1898 *Coccosphaera leptopora* MURRAY & BLACKMAN, Roy. Soc. London, Philos. Trans., vol. 190, ser. B, p. 430, pl. 15, figs. 1—7.

1930 *Coccolitus leptoporus* (MURRAY & BLACKMAN); SCHILLER, in RABENHORST, Krypt.-Flora, vol. 10, p. 245, text-fig. 10.

1954 *Cyclococcolithus leptoporus* (MURRAY & BLACKMAN); KAMPTNER, Arch. Protistenk., vol. 100, p. 23, fig. 20.

1961 *Coccolithus leptoporus* (MURRAY & BLACKMAN), BLACK & BARNES, Roy. Micr. Soc. Jour., vol. 80, pt. 2, p. 143, pl. 24, figs. 3—4.

1963 *Cyclococcolithus leptoporus* (MURRAY & BLACKMAN); MARTINI & BRAMLETTE, Jour. Paleont., vol. 37, no. 4, p. 850, pl. 102, figs. 4—5.

1964 *Cyclococcolithus leptoporus* (MURRAY & BLACKMAN); COHEN, Micropaleont., vol. 10, no. 2, p. 237, pl. 1, figs. 6 a—e; pl. 2, figs. 4 a—b.

Remarks: This species shows a wide variation in size and forms. Japanese specimens have four types of this species. One of these is the typical *C. leptoporus*, which shows a faint extinction cross, especially in the outer margin. The second type shows ery strong birefringence and the extinction cross is therefore remarkable. The rays are straight and the central area is broad. The third type is very small, shows very weak birefringence, and faint extinction cross, striae not distinct, central area broad. The last one has a very small central area, strongly curved striae and an almost obscure extinction cross.

Distribution: Rare to common in the studied sections. The third type is abundant in middle Iioka formation and the fourth type is found only in sample C-8.

Genus *Discolithina* LOEBLICH & TAPPAN, 1963

Discolithina japonica TAKAYAMA n. sp.

(Plate 9; 10, figure 1, 2 a—d; Text-figure 7)

Name: *japonica* (lat.), Japanese.

Holotypes: IGPS coll. cat. no. 75144 (slide) and no. 2600/65 (Electron micrograph), from sample C-10, upper Iioka formation.

D e s c r i p t i o n: Discoliths consisting of a single thin elliptical plate, with the proximal side concave and the distal side convex. The central area is perforated with numerous pores in arrangement of so-called quincunx (text-fig. 6). The diameter of the pores is about 0.1 μ and the distance between the pores about 0.1—0.2 μ. The rim is broad, about one fourth of the shorter diameter of the plate. The central area is bisected by a longitudinal slit. Length: 10.5 μ.

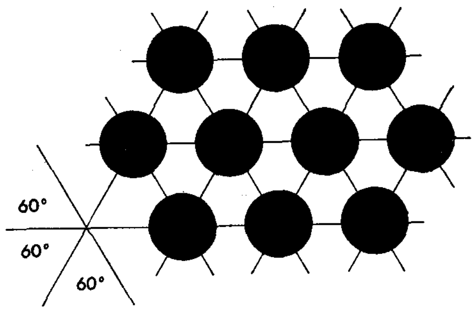

Fig. 6. Quincunx arrangement.

R e m a r k s: The carbon replica shows that the central area of the plate is perforated by many tiny pores. These pores are too small to be recognized clearly under the normal microscope. Under the normal microscope, this species has an appearance of a thin elliptical plate without pores but with a longitudinal slit line. The central part of a well preserved specimen looks thinner than its outer margin, especially under negative phase contrast. This species differs from COHEN's (1964) *Discolithus crassus* in having a broad rim and the regular arrangement of the penetrating holes.

D i s t r i b u t i o n: Locally present in the studied sections.

D e p o s i t i o n o f t h e t y p e s p e c i m e n: Slides are deposited in the Institute of Geology and Paleontologiy, Faculty of Science, Tohoku University, Sendai, Japan. The electronmicrographs were taken at the Elektronenmikroskopisches Laboratorium of the Medical Clinic of the University for Veterinary Medicine at Vienna by H. Stradner.

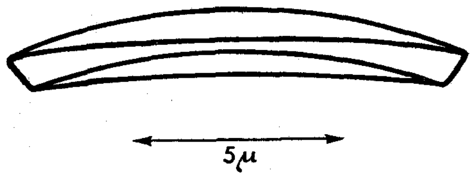

Fig. 7. Side view of *Discolithina japonica* Takayama n. sp.

Discolithina sp.

(Plate 1, figure 7 a, b; Plate 3, figure 1—19)

Remarks: Consisting of a single thin elliptical plate, with the proximal side concave and the distal side convex and with a thin marginal rim on the distal side. The platte is regularly perforated by conspicuous pores and with a longitudinal line. This species shows a wide variation in size and form. The largest diameter of this species ranges from 14 μ to 7 μ, averaging 10 μ. Generally this species has a very thin plate which is regularly perforated by numerous conspicuous pores, however, some small specimens are irregularly perforated by only few differently sized pores. In the side view the shape of the rim also shows a wide variation, but the author cannot find any relationship between the shape and the size of this rim and the arrangement of the pores. The author checked many specimens and recognized that these variations are gradually changing into each other. Therefore the author considers that all these variants must be included in one species. This species differs from *D. numerosa* in lacking the striae on the rim; from *D. distinctus* in having a lower and thinner rim and thinner basal plate; from *D. punctosus* in having a rim and from *D. vescus* in having a pronounced rim. KAMPTNER (1948, 1955) described many kinds of similar forms of this species. But the basal plates of these species are very thick. The ratios of the thickness to the length of these species are about 0.152 (1.4 μ/9.2 μ: *C. anisotrema),* 0.220 (2 μ/9.1 μ: *C. pachymorphus),* and 0.145 (1.2 μ/8.3 μ: *C. deflandrei),* whereas the ratio of the present species is about 0.05. This species differs from *C. anisotrema, C. pachymorphus, C. deflandrei, C. martini. D. vigintiforatus and D. multiporus* in having a thinner basal plate; from *C. trematotes* in having a concave lower side of the plate; from *C. attenuatus* and *D. sparsiforatus* in having a lower rim. This species shows a wide variation in size and forms as mentioned earlier. But these variants have a much thinner basal plate than the above discussed species of KAMPTNER. The full interpretation of the relation of this species to *Discolithina japonica* n. sp. must await a more detailed study under the electron microscope.

Distribution: Rare to common in the studied sections. But this species disappears at the upper Iioka formation. Many larger sized specimens of this species are recorded from the Pliocene sample at Castell d'Arquato.

Genus *Gephyrocapsa* KAMPTNER, 1943

Gephyrocapsa oceanica KAMPTNER

(Plate 1, figure 8)

1902 *Pontosphaera huxleyi* LOHMANN, (part), Arch. Protistenk., vol. 1, p. 130, pl. 4, figs. 1—9.

1943 *Gephyrocapsa oceanica* KAMPTNER, Akad. Wiss. Wien, Anz., vol. 80, pp. 43—49.

1956 *Gephyrocapsa oceanica* KAMPTNER var. typica; KAMPTNER, Arch. Protistenk., vol. 101, no. 2, p. 179, pl. 16, figs. 4—5.

1961 *Gephyrocapsa oceanica* KAMPTNER; BLACK & BARNES, Roy. Micr. Soc., Jour., vol. 80, pt. 2, p. 143, pl. 25, figs. 1—2.
1964 *Gephyrocapsa oceanica* KAMPTNER; COHEN, Micropaleont., vol. 10, no. 2, p. 240 pl. 3, figs. 3 a—c; pl. 4, figs. 3 a—b.

Remarks: The detailed morphology and micro-structure of this species have been shown by KAMPTNER (1956) and COHEN (1964). The present specimens are delicate forms and very difficult to see with transmitted light. But in polarized light the transverse bar (bridge) shows the peculiar extinction which is characteristic of this species.

Distribution: In the studied sections, this species appears to start in basal Pliocene (sample 77) and becomes dominant at the basal Pleistocene (sample C-11). This species has been reported from Recent sediments in the Pacific and the South Atlantic. The living specimens are found in the Gulf Stream and the Mediterranean. According to KAMPTNER (1943) and COHEN (1964), this species is more abundant in "warm" samples.

Genus *Helicosphaera* KAMPTNER, 1954

Helicosphaera carteri (WALLICH)

(Plate 1, figure 5)

1877 *Coccosphaera carteri* WALLICH, Ann. Mag. Nat. Hist., ser. 4, vol. 19, p. 348, pl. 17, figs. 3—4.
1902 *Coccolithophora pelagica* (WALLICH); LOHMANN, (part), Arch. Protistenk., vol. 1, p. 138, pl. 5, figs. 58 a, c.
1954 *Helicosphaera carteri* (WALLICH); KAMPTNER, Arch. Protistenk., vol. 100, no. 1, p. 21, text-figs. 17—19.
1961 *Helicosphaera carteri* (WALLICH); BLACK & BARNES, Roy. Micr. Soc., Jour., vol. 80, pt. 2, pp. 139—140, pls. 22—23.
1964 *Helicosphaera carteri* (WALLICH); COHEN, Micropaleont., vol. 10, no. 2, pp. 238—240, pl. 3, figs. 2 a—f; pl. 4, figs. 1 a—c.

Remarks: This species is characterized by an asymmetrical plate appearing as a helicoid form. In the elliptical central shield, two conspicuous slit-like holes along the long axis are distinctive. Detailed descriptions and electron microscopic photographs are given by BLACK and BARNES (1961) and COHEN (1964).

Distribution: Abundant throughout the studied sections. Similar forms have been reported from the early Tertiary. The species common in Recent deep-sea sediments from the South Atlantic. Living forms have been observed in all oceans (COHEN, 1964).

Genus *Rhabdosphaera* HAECKEL, 1894

Rhabdosphaera stylifer LOHMANN

(Plate 1, figure 6)

1902 *Rhabdosphaera stylifer* LOHMANN, Arch. Protistenk., vol. 1, p. 143, pl. 5, fig. 65.
1937 *Rhabdosphaera stylifer* LOHMANN; KAMPTNER, Arch. Protistenk., vol. 89, p. 313, pl. 17, figs. 43—45.

1941 *Rhabdosphaera stylifer* LOHMANN; KAMPTNER, Ann. Naturhistor. Mus. Wien, vol. 51, p. 96, 115, pl. 15, fig. 149.
1955 *Rhabdosphaera stylifer* LOHMANN; KAMPTNER, K. Nedrl. Akad. Wetensch., Verh., ser. 2, vol. 50, no. 2, p. 37—38, fig. 106.

Distribution: Present in sample 77 from the basal Kurotaki formation.

Family BRAARUDOSPHAERIDAE DEFLANDRE

Genus *Braarudosphaera* DEFLANDRE, 1947

Braarudosphaera bigelowi (GRAN & BRAARUD)

(Plate 1, figure 1)

1935 *Pontosphaera bigelowi* GRAN & BRAARUD, Jour. Biol. Board Canada, vol. 1, p. 389, text-fig. 67.
1947 *Braarudosphaera bigelowi* (GRAN & BRAARUD); DEFLANDRE, C. R. Acad. Sci., vol. 225, p. 439, text-figs. 1—5.

Remarks: The pentaliths of this species range greatly in diameter from 6 μ to 23 μ.

Distribution: It is rare throughout the studied sections. Widely distributed from the upper Cretaceous to Holocene.

Family THORACOSPHAERIDAE KAMPTNER

Genus *Thoracosphaera* KAMPTNER, 1927

Thoracosphaera deflandrei KAMPTNER

1956 *Thoracosphaera deflandrei* KAMPTNER, Österr. Bot. Z., vol. 103, no. 4, pp. 448—456, figs. 1—4.
1961 *Thoracosphaera deflandrei* KAMPTNER; STRADNER, Erdoel-Zeitschrift., vol. 77, no. 3, p. 84, fig. 74.

Distribution: Few in the Pliocene; rare in the Pleistocene. According to STRADNER (1963), this species ranges from the Albian to early Tertiary. Therefore it is considered that specimens of this species in the studied sections are reworked ones.

Thoracosphaera heimi (LOHMANN)

1927 *Thoracosphaera pelagica* KAMPTNER, Arch. Protistenk., vol. 58, no. 1, p. 180.
1954 *Thoracosphaera Heimi* (LOHMANN); KAMPTNER, Arch. Protistenk., vol. 100, no. 1, p. 40—42, figs. 41—42.
1961 *Thoracosphaera heimi* KAMPTNER; STRADNER, Erdoel-Zeitschrift., vol. 77, no. 3, p. 84, fig. 75.

Distribution: Rare to common in the studied sections.

Family DISCOASTERIDAE TAN SIN HOK

Genus *Discoaster* TAN SIN HOK, 1927

Discoaster brouweri TAN SIN HOK

(Plate 4, figure 1—4; Plate 6, figure 1—5)

1927 *Discoaster brouweri* "Type" TAN SIN HOK, Jaarb. Mijnwezen Ned. Oost-Indie, p. 120, text-figs. 2 (8 a—b).
1954 *Discoaster brouweri* TAN sens. emend. BRAMLETTE & RIEDEL, Jour. Paleont., vol. 28, no. 4, p. 402, pl. 39, fig. 12, text-figs. 3 a—b.
1963 *Discoaster brouweri* TAN SIN HOK; MARTINI & BRAMLETTE, Jour. Paleont., vol. 37, no. 4, p. 851, pl. 102, figs. 9—10.

Distribution: Six-rayed specimens of this species are dominant in the uppermost Miocene, Naarai formation (sample N-6). Four-rayed specimens are common in Castell d'Arquato, Italy (Pliocene).

Discoaster challengeri BRAMLETTE & RIEDEL

(Plate 4, figure 7)

1954 *Discoaster challengeri* BRAMLETTE & RIEDEL, Jour. Paleont., vol. 28, no. 4, p. 401, pl. 39, fig. 10.
1959 *Discoaster challengeri* BRAMLETTE & RIEDEL; STRADNER, 5th World Petr. Congr. Sect. I, Paper 60, p. 1088, fig. 26.
1963 *Discoaster challengeri* BRAMLETTE & RIEDEL; MARTINI & BRAMLETTE, Jour. Paleont., vol. 37, no. 4, p. 851, pl. 103, figs. 11—12.

Distribution: Only one specimen in the Naarai formation. This species has been recorded from late Tertiary in many localities of the world.

Discoaster pentaradiatus TAN SIN HOK

(Plate 4, figure 5, 8; Plate 7, figure 1—4)

1927 *Discoaster pentaradiatus* TAN SIN HOK, Jaarb. Mijnwezen Ned. Oost-Indie, 1926, p. 120, text-figures 2 (14).
1954 *Discoaster pentaradiatus* TAN sens emend. BRAMLETTE & RIEDEL, Jour. Paleont., vol. 28, p. 401, pl. 39, fig. 11, text-figs. 2 a, b.
1959 *Discoaster pentaradiatus* TAN SIN HOK; STRADNER, Erdoel-Zeitschrift.,- vol. 75, no. 12, p. 480, pl. 3, figs. 46, 48.
1961 *Discoaster pentaradiatus* TAN sens emend. BRAMLETTE & RIEDEL; STRADNER & PAPP, Jb. Geol. Bundesanst. Spec. Vol., no. 7, pp. 87—88, pl. 21, figs. 1—4.
1963 *Discoaster pentaradiatus* TAN SIN HOK; MARTINI & BRAMLETTE, Jour. Paleont., vol. 37, no. 4, p. 853, pl. 105, fig. 5.

Remarks: Asteroliths are five-rayed in the Naarai formation and also occasionally four-rayed in the Pliocene of Castell d'Arquato (plate 7, figs. 4 a, b). The rays show a slight umbrella-like bending, which is also characteristic of *D. brouweri*.

D i s t r i b u t i o n: They are rare in the Naarai formation but common in the Pliocene of Castell d'Arquato. This species is widespread in the Miocene strata and typical forms have been recorded from the Lengua formation of Trinidad, Suva formation of Fiji, the Tagpochau limestone of Saipan and many other localities. According to MARTINI & BRAMLETTE (1963), they are rare in the upper part of the Miocene of the Mohole sequence but common in the lower Pliocene. The lower and upper limit of this species is still unknown. No specimens have been recorded from the lower Miocene and Recent sediments.

Discoaster perplexus BRAMLETTE & RIEDEL

(Plate 4, figure 9)

1954 *Discoaster perplexus* BRAMLETTE & RIEDEL, Jour. Paleont., vol. 28, no. 4, pp. 400—401, pl. 39, fig. 9.

1961 *Discoaster perplexus* BRAMLETTE & RIEDEL; STRADNER & PAPP, Jb. Geol. Bundesanst., Spec. Vol., no. 7, p. 100, pl. 30, figs. 1—7.

1961 *Discoaster perplexus* BRAMLETTE & RIEDEL; BLACK & BARNES, Roy. Micr. Soc., Jour., vol. 80, pt. 2, pp. 144—145, pl. 24, fig. 1.

1964 *Discoaster perplexus* BRAMLETTE & RIEDEL; COHEN, Micropaleont., vol. 10, no. 2, pp. 246—248, pl. 5, figs. 4 a—c; pl. 6, figs. 4 a—b.

D i s t r i b u t i o n: Found in the lowermost Kurotaki formation. It is recorded from the upper Oligocene sediments of Trinidad and from Recent deep-sea sediments of the Pacific, South Atlantic and Mediterranean.

Discoaster surculus MARTINI & BRAMLETTE

(Plate 4, figure 6, 10; Plate 5, figure 1—4)

1961 *Discoaster brouweri* TAN SIN HOK; STRADNER & PAPP, Jb. Geol. Bundesanst., Spec. Vol., no. 7, pp. 85—87, pl. 20, figs. 2—3, 6.

1963 *Discoaster surculus* MARTINI & BRAMLETTE, Jour. Paleont., vol. 37, no. 4, p. 854, pl. 104, figs. 10—12.

R e m a r k s: Asteroliths usually with 6-rays and rarely with 3-rays in the sample from Castell d'Arquato (plate 5, figure 4 a, b).

D i s t r i b u t i o n: A single specimen of this species has been found in the Naarai formation and only one specimen is found in the basal Kurotaki formation, but they are in abundance in Pliocene sample from Castell d'Arquato in Italy. STRADNER (1961) reported the occurrence of this species from the Pliocene sediments at Castell d'Arquato and from deep-sea sediments of the Mediterranean. According to MARTINI & BRAMLETTE (1963), this species occurs only in the Pliocene section of the Mohole sequence and the lower limit of this species seems to extend into the latest Miocene.

INCERTAE SEDIS

Genus *Ceratolithus* KAMPTNER, 1954

Ceratolithus cristatus KAMPTNER

(Plate 1, figure 2—4)

1954 *Ceratolithus cristatus* KAMPTNER, Arch. Protistenk., vol. 100, p. 43, text-figs. 44—45.
1954 *Ceratolithus* cf. *C. cristatus* (KAMPTNER); BRAMLETTE & RIEDEL, Jour. Paleont., vol. 28, no. 4, p. 394, pl. 38, fig. 9.
1963 *Ceratolithus* aff. *C. cristatus* KAMPTNER; MARTINI & BRAMLETTE, Jour. Paleont., vol. 37, no. 4, p. 854.
1964 *Ceratolithus cristatus* KAMPTNER; COHEN, Micropaleont., vol. 10, no. 2, p. 246, pl. 5, figs. 5 a—d; pl. 6, fig. 5.

Distribution: Rare throughout the sequence. This species has been reported from the Miocene deposits and is common in Recent sediments.

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Plates 1—10

PLATE 1

Braarudosphaera bigelowi (GRAN & BRAARUD)
Figure 1
Distal view; sample 77, Kurotaki formation.
Ceratolithus cristatus KAMPTNER
Figure 2
Plan view; sample N-6, Naarai formation.
Ceratolithus cristatus KAMPTNER
Figure 3
Plan view; sample N-6, Naarai formation.
Ceratolithus cristatus KAMPTNER
Figure 4
Plan view; sample 77, Kurotaki formation.
Helicosphaera carteri (WALLICH)
Figure 5
Distal view; sample 77, Kurotaki formation.
Rhabdosphaera stylifer LOHMANN
Figure 6
Side view; sample 77, Kurotaki formation.
Discolithina sp.
Figure 7
a, distal view; b, side view; sample 77, Kurotaki formation.
Gephyrocapsa oceanica KAMPTNER
Figure 8
Distal view; sample C-5, Iioka formation.
Calcidiscus medusoides KAMPTNER
Figure 9
Distal view; sample N-6, Naarai formation.
Coccolithus pelagicus (WALLICH)
Figure 10
Proximal view; sample N-6, Naarai formation.
Coccolithus pelagicus (WALLICH)
Figure 11
Proximal view; sample N-6, Naarai formation.
Calcidiscus sp.
Figure 12
Distal view; sample C-7, Iioka formation.

(Miocene-Pleistocene of Kwanto region, Japan.)

PLATE 1

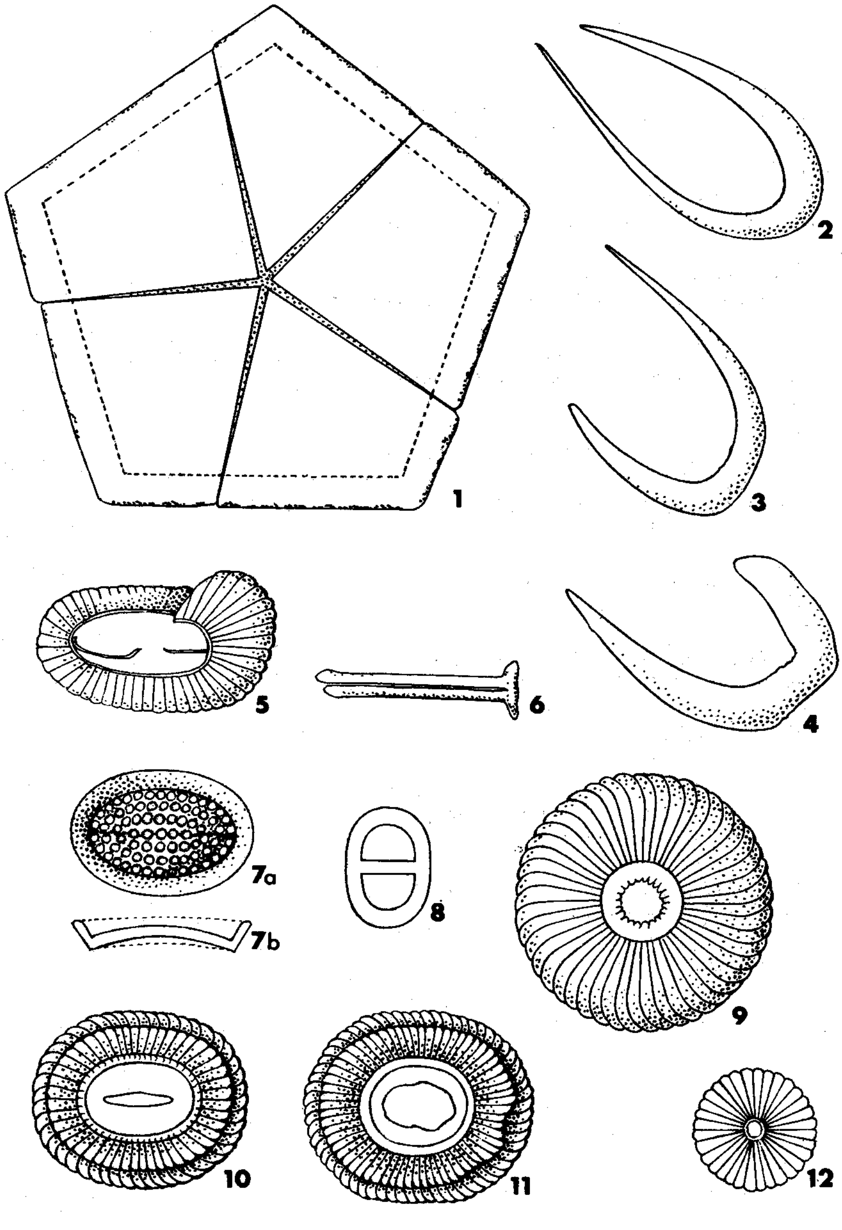


PLATE 2

Cyclococcolithus leptoporus (MURRAY & BLACKMAN)
Figure 1
Distal view; sample C-8, Iioka formation.
Cyclococcolithus leptoporus (MURRAY & BLACKMAN)
Figure 2
Distal view; sample N-6, Naarai formation.
Cyclococcolithus leptoporus (MURRAY & BLACKMAN)
Figure 3
Proximal view; sample 77, Kurotaki formation.
Cyclococcolithus leptoporus (MURRAY & BLACKMAN)
Figure 4
Distal view; sample 77, Kurotaki formation.
Cyclococcolithus leptoporus (MURRAY & BLACKMAN)
Figure 5
Distal view; sample C-7, Iioka formation.
Coccolithus crassipons BOUCHÉ
Figure 6
Distal view; sample 77, Kurotaki formation.
Coccolithus crassipons BOUCHÉ
Figure 7
Proximal view; sample N-6, Naarai formation.
Coccolithus crassipons BOUCHÉ
Figure 8
Proximal view; sample N-6, Naarai formation.
Coccolithus crassipons BOUCHÉ
Figure 9
Distal view; sample N-6, Naarai formation.
Coccolithus crassipons BOUCHÉ
Figure 10
Proximal view; sample N-6, Naarai formation.
Discolithina japonica TAKAYAMA, n. sp.
Figure 11
Distal view; sample C-2, Iioka formation.

(Miocene-Pleistocene of Kwanto region, Japan.)

PLATE 2

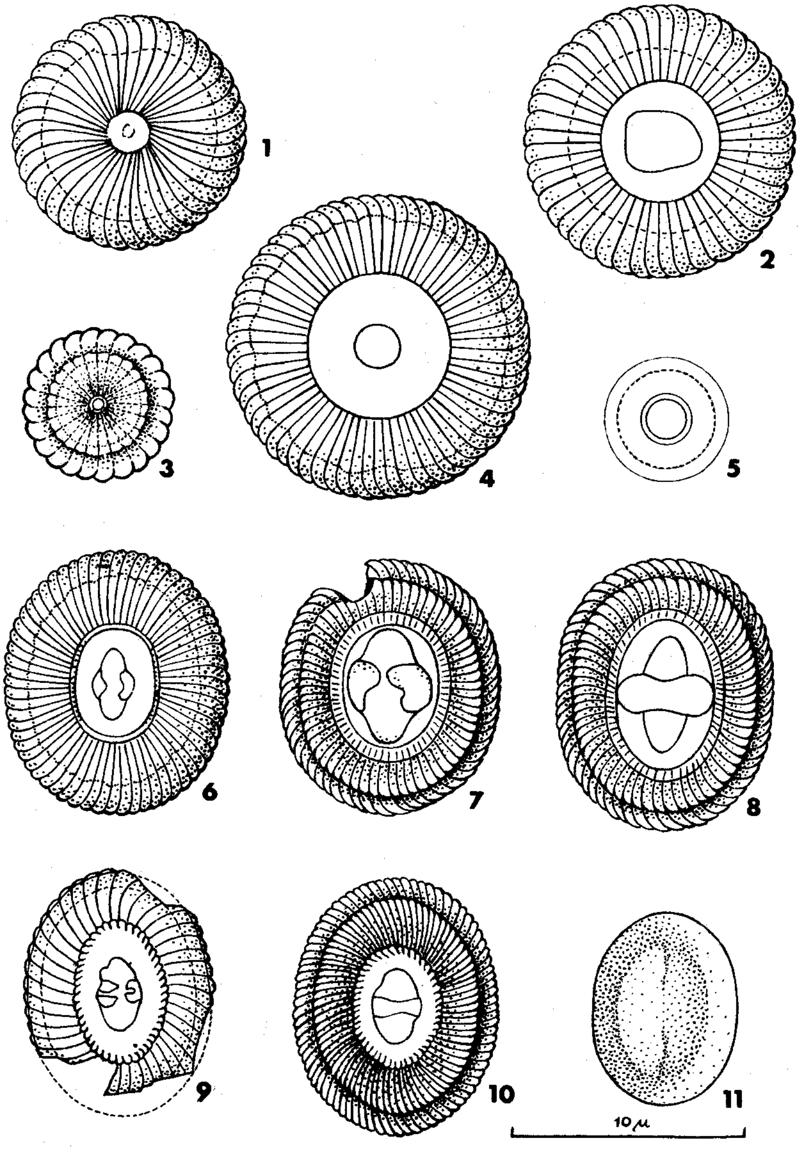


PLATE 3

Discolithina sp.
Figure 1—19
Distal view:
3, 4, 7, 8, 12; sample 77, Kurotaki formation.
14, 15; sample N-6, Naarai formation.
1; sample C-5, Iioka formation.
2; sample C-9, Iioka formation.
(Miocene-Pleistocene of Kwanto region, Japan.)
5, 6, 9, 10, 11, 13, 16, 17, 18, 19; Castell d'Arquato.
(Pliocene of Castell d'Arquato, Italy.)

PLATE 3

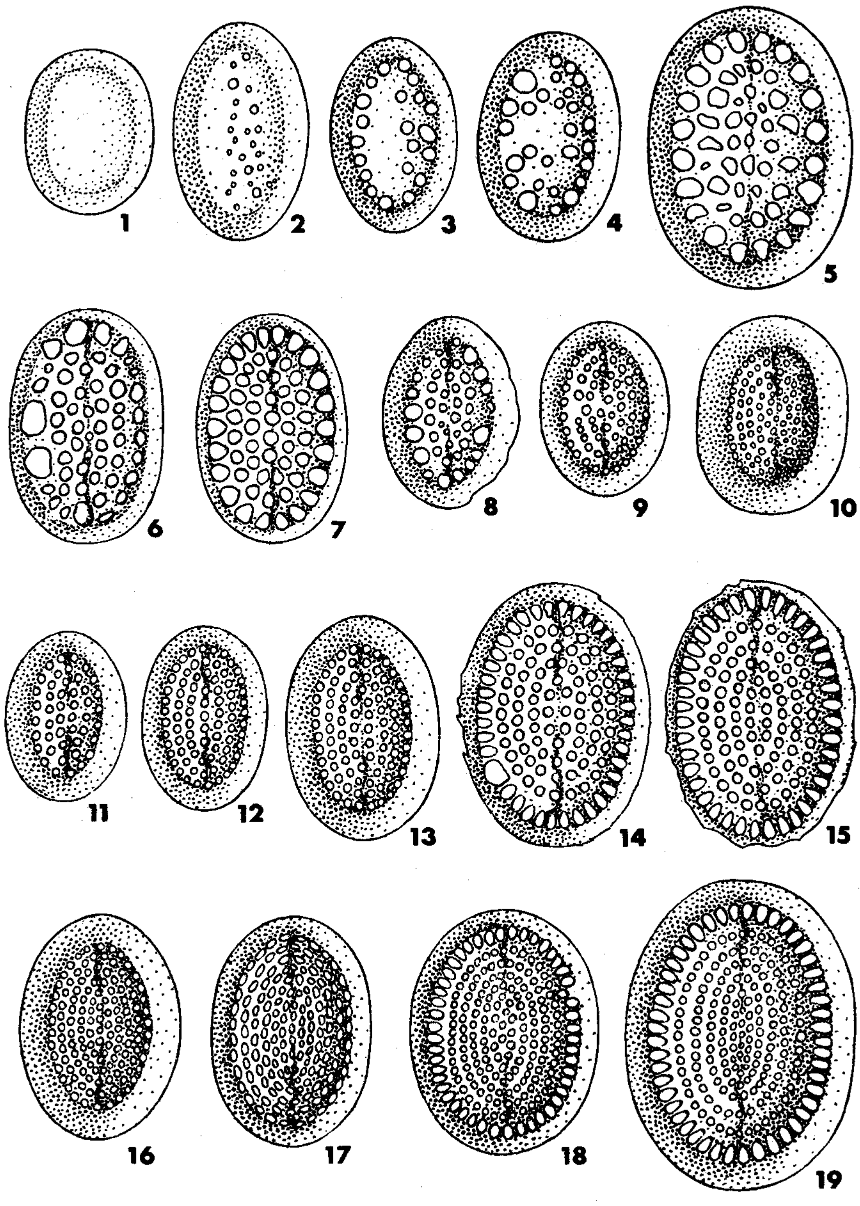


PLATE 4

Discoaster brouweri Tan Sin Hok
Figure 1
Plan view; sample N-6, Naarai formation.

Discoaster brouweri Tan Sin Hok
Figure 2
Oblique view; sample N-6, Naarai formation.

Discoaster brouweri Tan Sin Hok
Figure 3
Side view; sample N-6, Naarai formation.

Discoaster brouweri Tan Sin Hok
Figure 4
Plan view; sample N-6, Naarai formation.

Discoaster pentaradiatus Tan Sin Hok
Figure 5
Plan view; sample N-6, Naarai formation.

Discoaster surculus Martini & Bramlette
Figure 6
Plan view; sample N-6, Naarai formation.

Discoaster challengeri Bramlette & Riedel
Figure 7
Plan view; sample N-6, Naarai formation.

Discoaster pentaradiatus Tan Sin Hok
Figure 8
Plan view; sample N-6, Naarai formation.

Discoaster perplexus Bramlette & Riedel
Figure 9
Plan view; sample 77, Kurotaki formation.

Discoaster surculus Martini & Bramlette
Figure 10
Plan view; sample N-6, Naarai formation.

(Miocene-Pleistocene of Kwanto region, Japan.)

PLATE 4

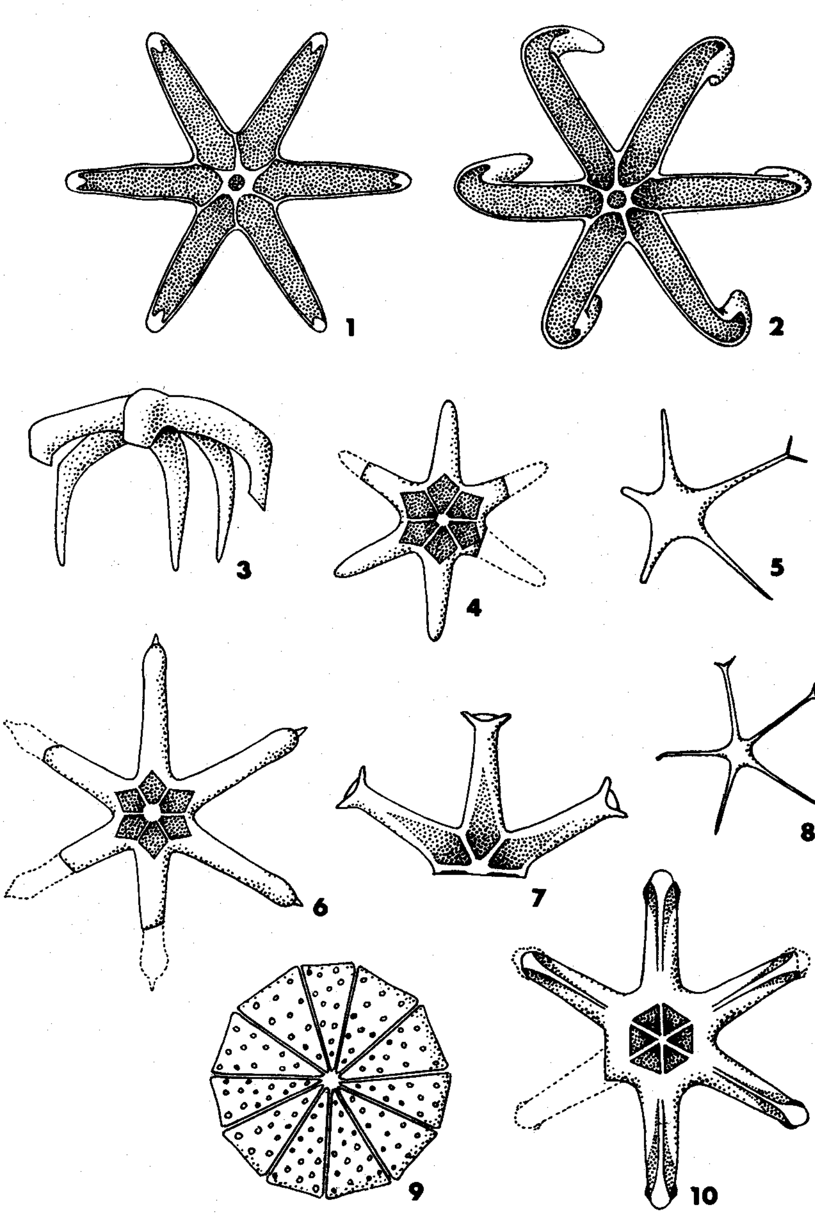


PLATE 5

Discoaster surculus MARTINI & BRAMLETTE
Figure 1
1 a, Superior side.
1 b, Inferior side.
Discoaster surculus MARTINI & BRAMLETTE
Figure 2
2 a, Superior side.
2 b, Inferior side.
Discoaster surculus MARTINI & BRAMLETTE
Figure 3
3 a, Superior side.
3 b, Inferior side.
Discoaster surculus MARTINI & BRAMLETTE
Figure 4
4 a, Superior side.
4 b, Inferior side.

(Pliocene of Castell d'Arquato, Italy.)

PLATE 5

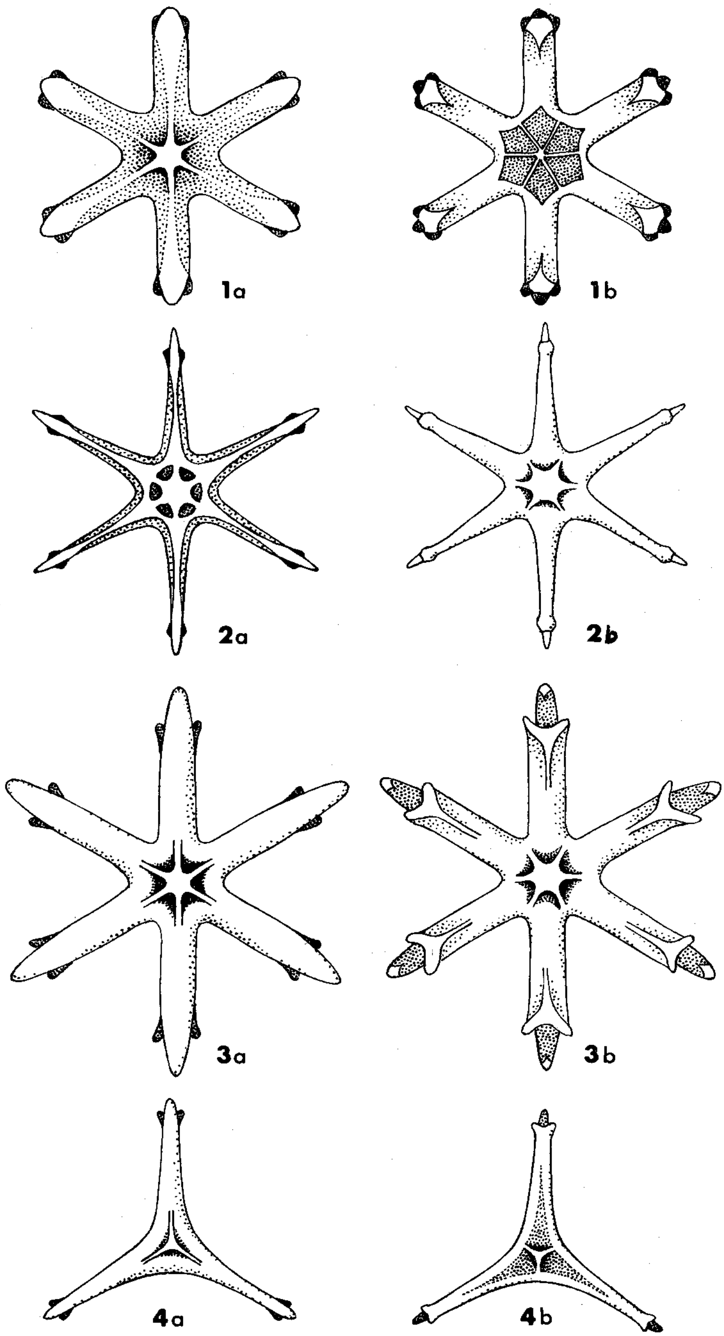


PLATE 6

Discoaster brouweri TAN SIN HOK
Figure 1
1 a, Superior side.
1 b, Inferior side.
Discoaster brouweri TAN SIN HOK
Figure 2
2 a, Superior side.
2 b, Inferior side.
Discoaster brouweri TAN SIN HOK
Figure 3
3 a, Superior side.
3 b, Inferior side.
Discoaster brouweri TAN SIN HOK
Figure 4
4 a, Superior side.
4 b, Inferior side.
Discoaster brouweri TAN SIN HOK
Figure 5
5 a, Superior side.
5 b, Inferior side.

(Pliocene of Castell d'Arquato, Italy.)

PLATE 6

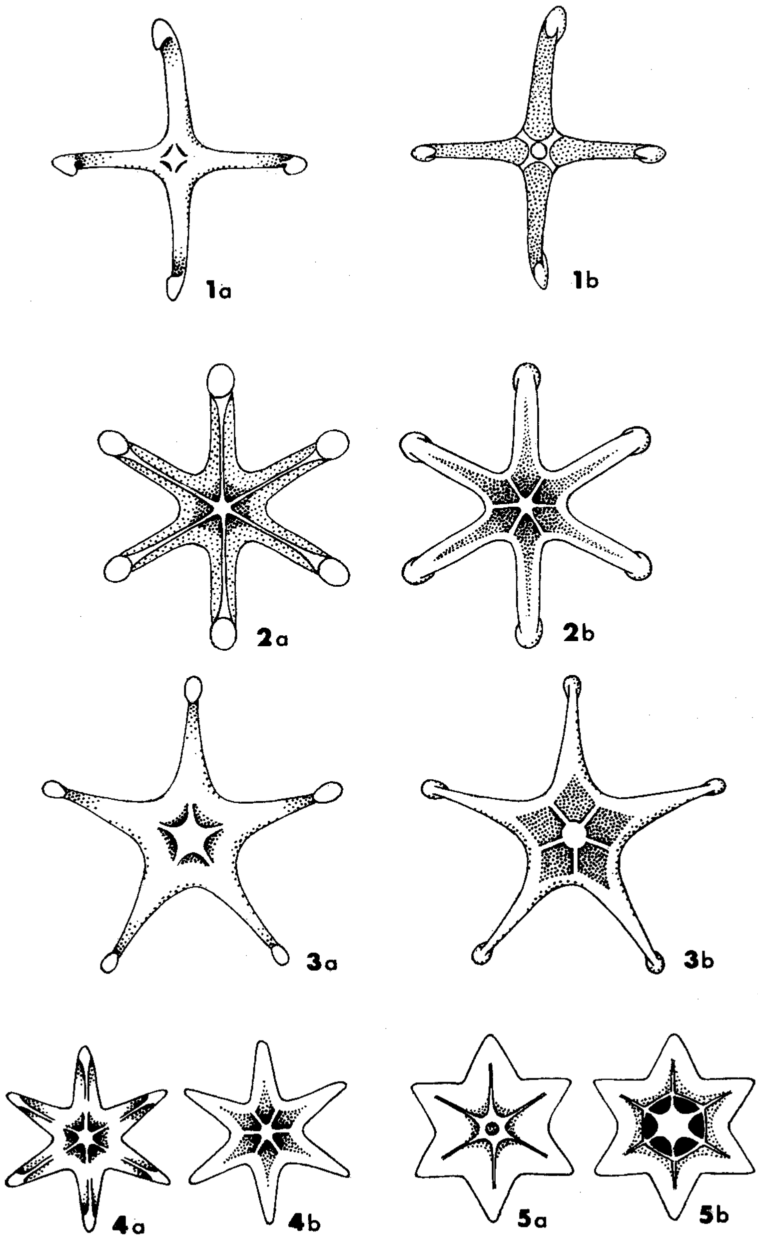


PLATE 7

Discoaster pentaradiatus TAN SIN HOK
Figure 1
1 a, Superior side.
1 b, Inferior side.
Discoaster pentaradiatus TAN SIN HOK
Figure 2
2 a, Superior side.
2 b, Inferior side.
Discoaster pentaradiatus TAN SIN HOK
Figure 3
3 a, Superior side.
3 b, Inferior side.
Discoaster pentaradiatus TAN SIN HOK
Figure 4
4 a, Superior side.
4 b, Inferior side.
Discoaster sp.
Figure 5
5 a, Superior side.
5 b, Inferior side.

(Pliocene of Castell d'Arquato, Italy.)

PLATE 7

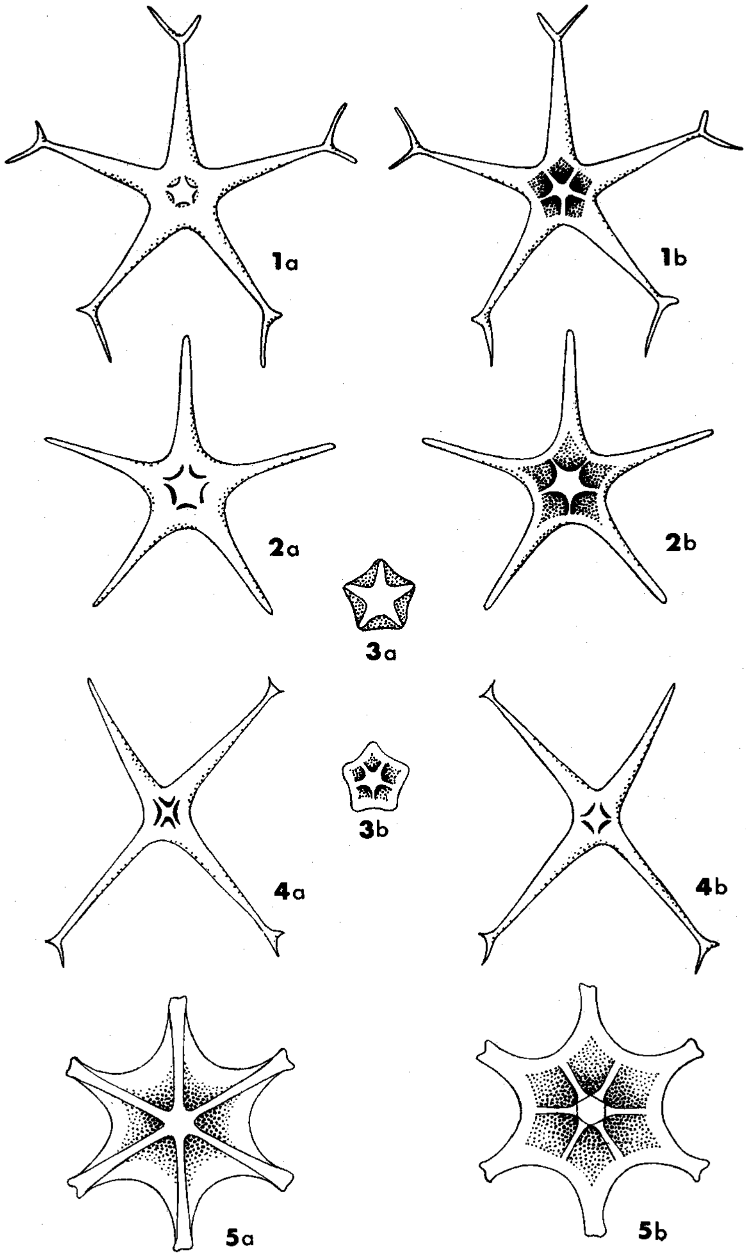


PLATE 8

Discoaster sp.
Figure 1
1 a, Superior side.
1 b, Inferior side.
Discoaster deflandrei Bramlette & Riedel
Figure 2
2 a, Superior side.
2 b, Inferior side.
Discoaster barbadiensis Tan Sin Hok
Figure 3
3 a, Superior side.
3 b, Inferior side.
Discoaster lodoensis Bramlette & Riedel
Figure 4
4 a, Superior side.
4 b, Inferior side.

(Pliocene of Castell d'Arquato, Italy.)

PLATE 8

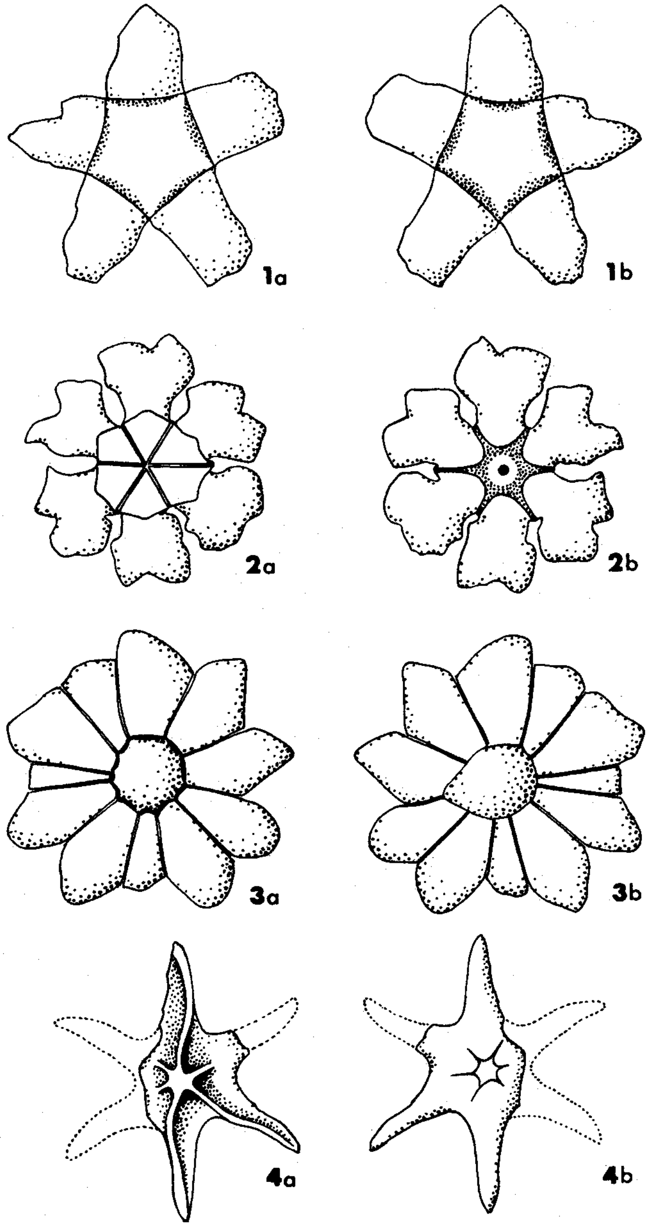


PLATE 9

Discolithina japonica TAKAYAMA n. sp.
Holotype, no. 2600/65.
Plan view; carbon replica; sample C-10, Iioka formation.

(Miocene-Pleistocene of Kwanto region, Japan.)

PLATE 9

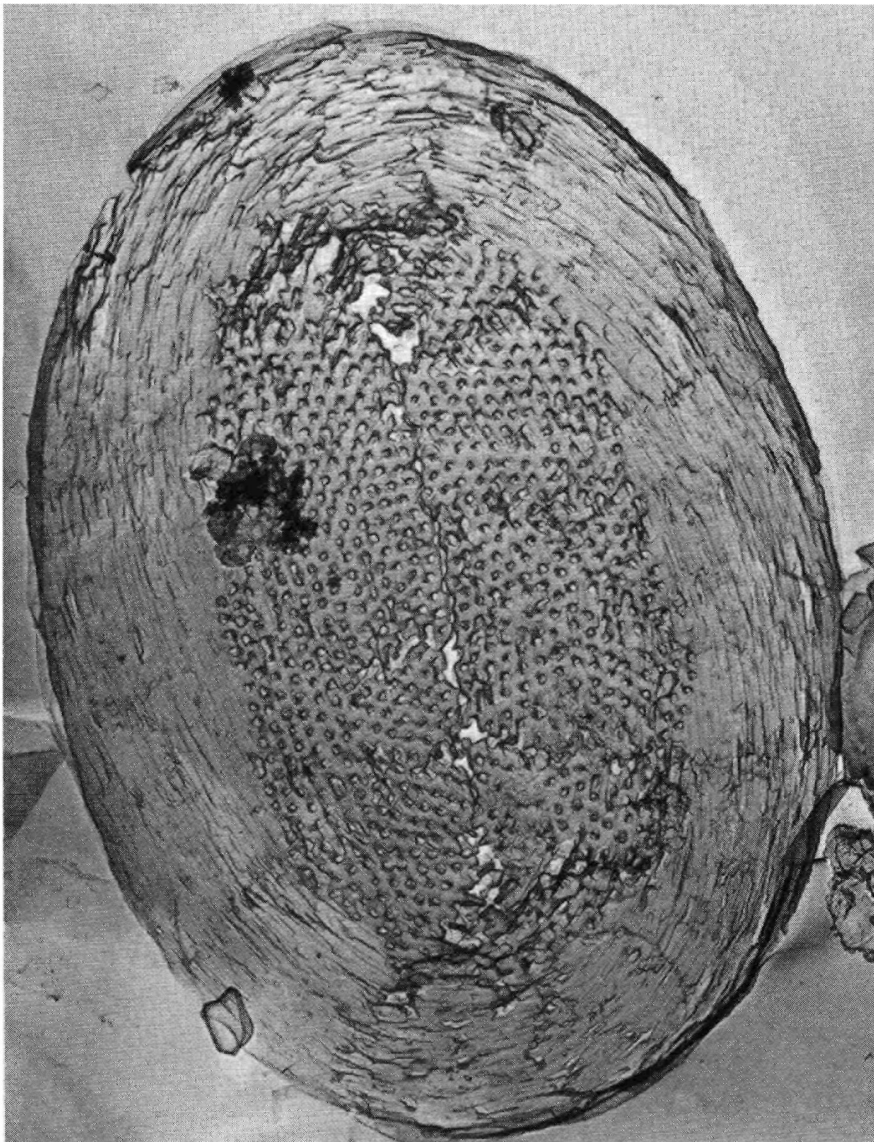
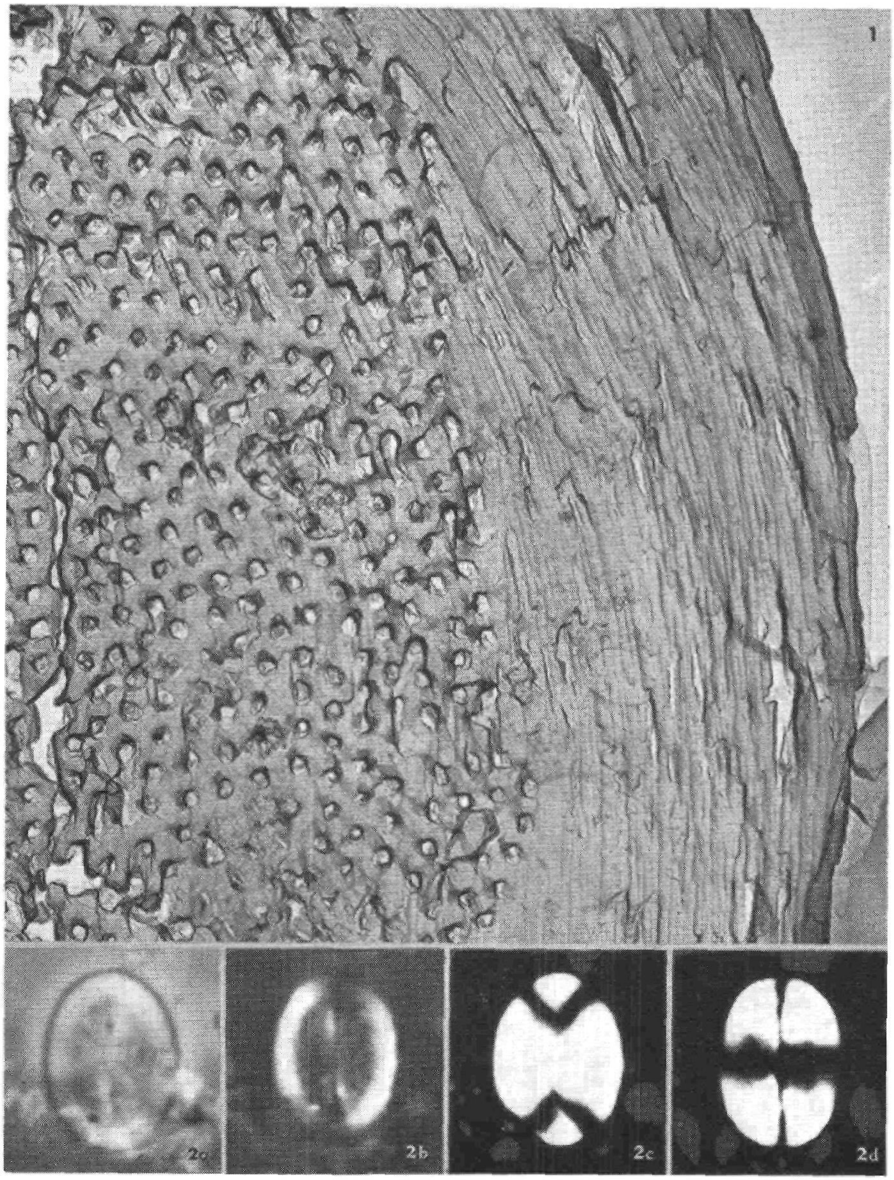


PLATE 10

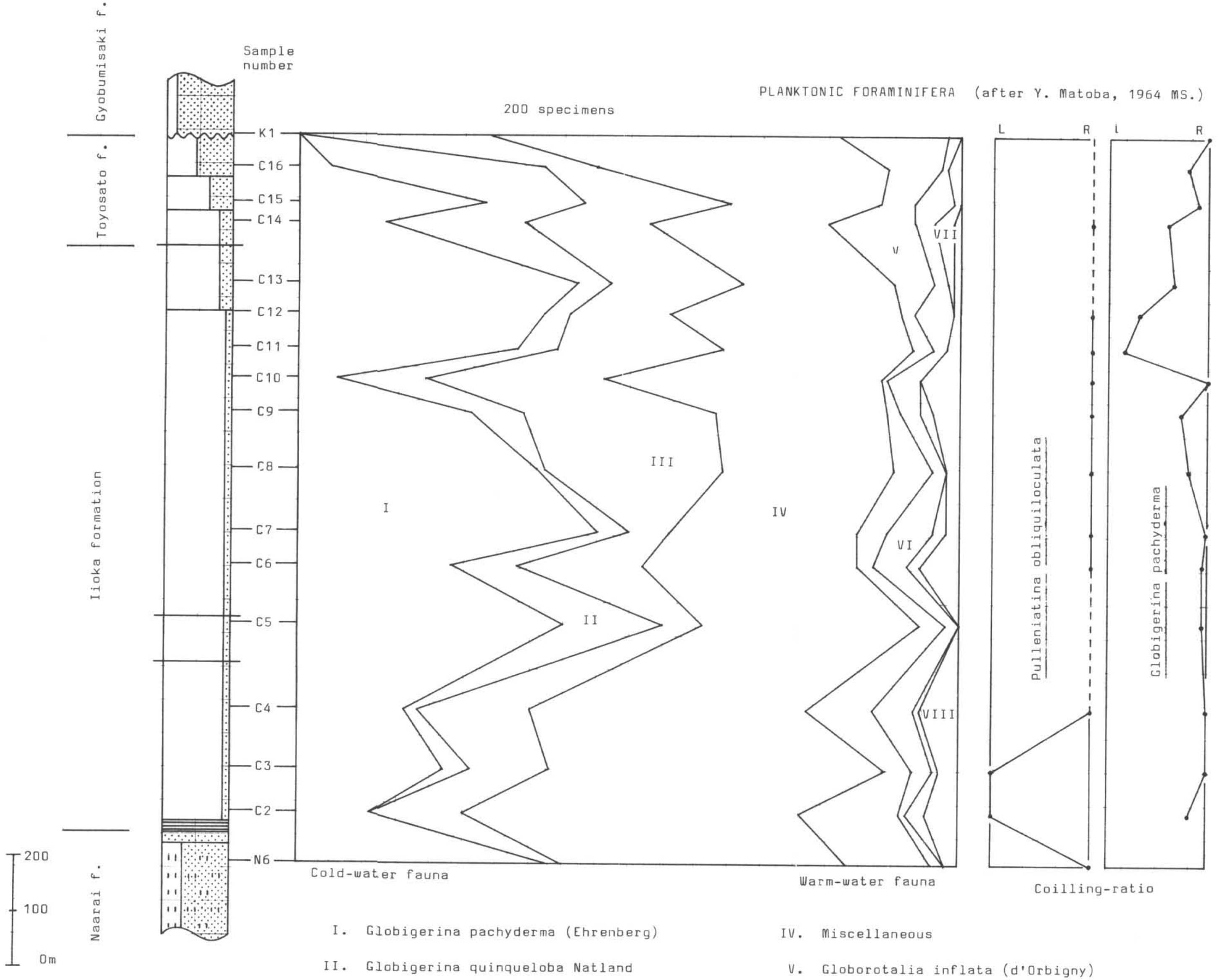
Discolithina japonica TAKAYAMA n. sp.
Figure 1
Detail of plate 9.
Discolithina japonica TAKAYAMA n. sp.
Figure 2
Holotype IGPS coll cat. no. 75144; sample C-10, Iioka formation.
2 a, Positive phase contrast.
2 b, Anoptral contrast (Reichert).
2 c, Crossed nicols, 0°—90°.
2 d, Crossed nicols, 45°—135°.

(Miocene-Pleistocene of Kwanto region, Japan.)

PLATE 10



TAKAYAMA: Figure 4. Planktonic Foraminifera and nannofossils from the Choshi region.



I. Globigerina pachyderma (Ehrenberg)

II. Globigerina quinqueloba Natland

III. Globigerina bulloides d'Orbigny

Globigerina falconensis Blow

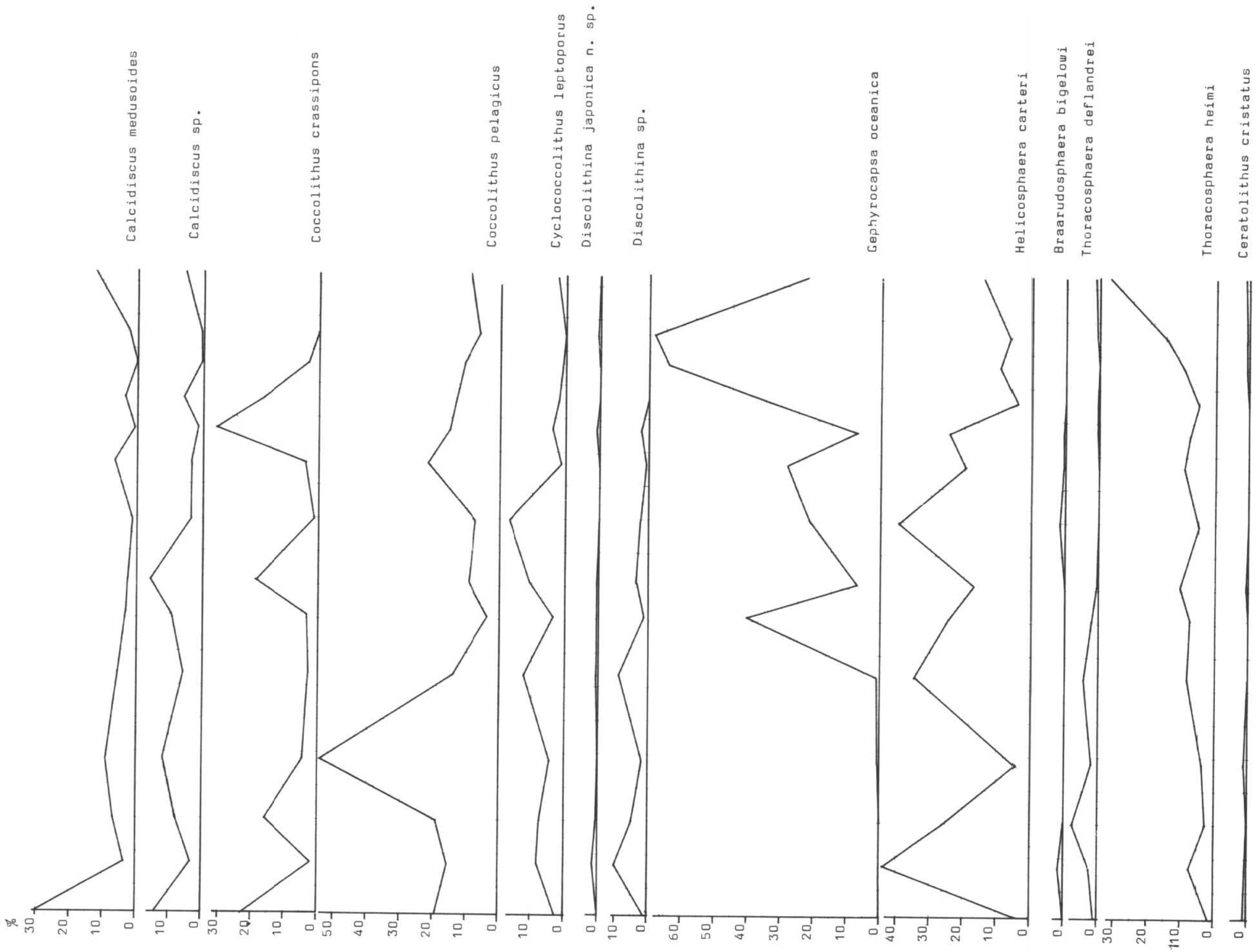
Globigerina rubescens Hofker

IV. Miscellaneous

V. Globorotalia inflata (d'Orbigny)

VI. Globigerinoides ruber cyclostomus (Galloway and Wissler)

Globigerinoides ruber ruber (d'Orbigny)



VII. Globorotalia truncatulinoides (d'Orbigny)

Globigerinella siphonifera (d'Orbigny)

Globigerinoides conglobatus (Brady)

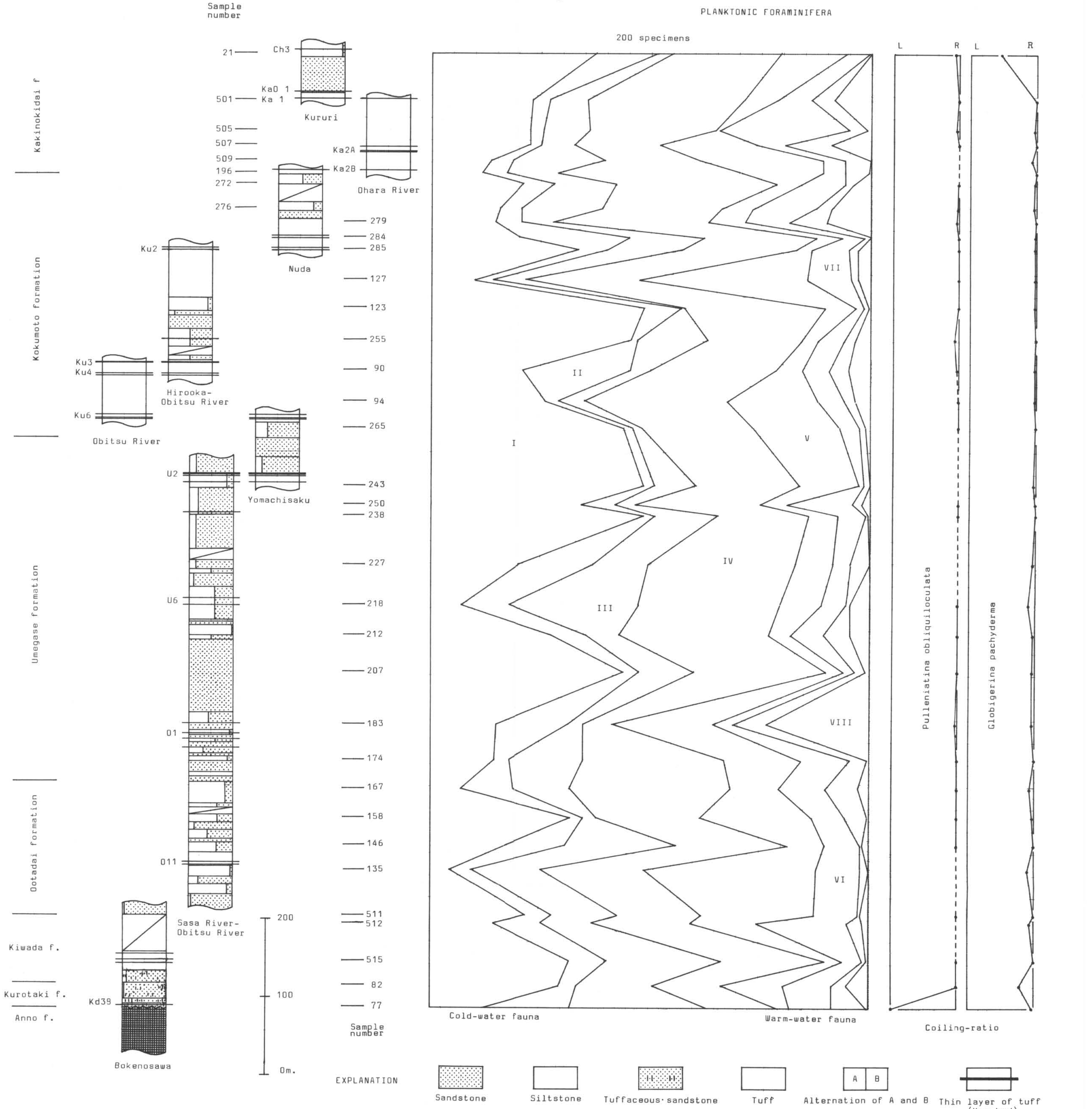
Globigerinoides sacculifer (Brady)

VIII. Globorotalia menardii (d'Orbigny)

Pulleniatina obliquiloculata (Parker and Jones)

Sphaeroidinella dehiscens dehiscens (Parker and Jones)

TAKAYAMA: Figure 5. Planktonic foraminiferal assemblage from the Kazusa group in the Obitsu River region.



EXPLANATION: Sandstone; Siltstone; Tuffaceous-sandstone; Tuff; Alternation of A and B; Thin layer of tuff (Key bed)

I. Globigerina pachyderma (Ehrenberg)
Globigerina quinqueloba Natland

II. Globigerina bulloides d'Orbigny

III. Globigerina falconensis Blow

IV. Miscellaneous

V. Globorotalia inflata (d'Orbigny)

VI. Globigerinoides elongatus (d'Orbigny)
Globigerinoides obliquus Bolli
Globigerinoides ruber cyclostomus (Galloway and Wissler)
Globigerinoides ruber ruber (d'Orbigny)

VII. Globorotalia truncatulinoides (d'Orbigny)
Globigerinoides immaturus LeRoy
Globigerinoides sacculifer (Brady)
Globigerinoides trilobus (Reuss)

VIII. Globorotalia menardii (d'Orbigny)
Globigerinoides conglobatus (Brady)
Pulleniatina obliquiloculata (Parker and Jones)
Sphaeroidinella dehiscens dehiscens (Parker and Jones)

TAKAYAMA: Planktonic Foraminifera from the Kazusa group in the Obitsu River region.

Table 1

Sample	77	82	515	512	511	135	146	158	167	174	183	207	212	218	227	238	250	243	265	94	90	255	123	127	285	284	279	276	272	196	509	507	505	501	21
Globorotalia crassaformis (Galloway and Wissler)		1	3	19	10	10		6	14	11		1	19	11	3	3	9		4	8	7	3	12	8	9	4	20	30	26	36	15	3	16	9	7
Globorotalia hirsuta (d'Orbigny)							2								2																				
Globorotalia inflata (d'Orbigny)	5	28	8	29	60	78	17	51	22	35	46	8	10	18	17	13	12	27	39	41	12	7	14	76	7	12	17	14	11	37	56	44	2	15	30
Globorotalia menardii (d'Orbigny)		3		3	2		1		3		2						1		1	1	1			1	1		1	4	1	1		3		1	
Globorotalia scitula scitula (Brady)	1		1							3		2			1		1																		
Globorotalia truncatulinoides (d'Orbigny)	4		2	2				1	8	2	6	1	2						1	1		1		1			3			1	2	3	2	2	
Globigerina bulloides d'Orbigny	40	8	17	7	12	10	28	6	24	7	33	7	16	22	34	5	15	5	4	6	49	3	17	8	13	50	12	10	14	11	10	5	6	8	28
Globigerina falconensis Blow	63	35	52	28	30	32	50	6	26	34	7	25	15	59	24	29	9	19	4	12	9	32	1	15	34	34	15	37	28	24	42	15	21	17	7
Globigerina glutinata Egger	2	3	11	11	2	3	18	9	2	2	2	15	1	8	17	4	3	3	2	6	2	5	2			1	1	1	2	1	2	2		2	8
Globigerina pachyderma (Ehrenberg)	24	51	63	29	44	9	34	64	14	29	30	84	55	11	39	97	69	97	87	49	42	91	97	20	67	40	29	31	42	23	26	34	35	36	75
Globigerina quinqueloba Natland		8	1									4		3	1				1	3											1	1			
Globigerinella siphonifera (d'Orbigny)									1		1					1	1	1	2		2			2		1	1		1	1	2		1	1	2
Globoquadrina conglomerata (Schwager)	6	2		1	1				1		1	2	7	1		1	1			2			1		3	2	3	2	1	3		1		5	2
Globoquadrina dutertrei (d'Orbigny)	4	10		3	1	9	3	8	14	33	4	4	3	6	9	9	18	14	16	24	16	9	8	20	7	7	6	2	3	13	3	13	22	6	4
Globoquadrina cf. dutertrei (d'Orbigny)	18	2		11		4	13	15	20	13	1	16	12	1	14	11	7	11	1	5	8	8	36	7	7	11	6	5	10	21	10	23	12	52	10
Globoquadrina hexagona (Natland)						4						1																4							
Globigerinoides conglobatus (Brady)					1																2														
Globigerinoides elongatus (d'Orbigny)	3		2	1	2		1	2	3	8	5	2			1	2	4		1	4	2	1	1	4	3		2	1	1	4	1	3	5	4	2
Globigerinoides immaturus LeRoy		1		1	1	1	1	5	2	3	2	2	2		3		1	2	2	1		3		1	2		8	1	4		7	8	4	5	1
Globigerinoides obliquus Bolli		3				2			4				2				1					1													
Globigerinoides ruber cyclostomus (Galloway and Wissler)	16	9	7	26	3	14	8	8	10	8	2		8	11	5	9	20	1	4	4	7	10	2	13	6	7	7	24	16	4	9	10	25	9	6
Globigerinoides ruber ruber (d'Orbigny)		10		14	5	4	7	5	4	6	2	3	5		2	2	5	1	4	4	3		1	3	8	3	11	4	3	2			17	3	2
Globigerinoides sacculifer (Brady)						1		3	1		2			1	1		1			2	2										1	1			
Globigerinoides tenellus Parker				2																													4		
Globigerinoides trilobus (Reuss)	12	6	2	6		2		1	4	3	5	2	8	1	5	1	2	1		1	7	1	2	1	2	3	6	6		10	2	9	2	3	
Pulleniatina obliquiloculata (Parker and Jones)		7	1		1		2	1	2	1	45	2	9	9		1	3		1	6	7	7	1	5	5		19	14	7			15	2	16	
Sphaeroidinella dehiscens dehiscens (Parker and Jones)	1																																		
Orbulina universa d'Orbigny					2		1				2	1		1	4	2	3	3	1	2	3			1	12	1	4	2	9	3		1			1
Miscellaneous	1	13	30	7	23	17	14	9	21	2	2	18	26	37	18	10	14	15	25	18	19	18	5	14	14	24	29	8	21	5	11	6	24	6	15
Total	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200