

## Late Cenozoic Micropaleontologic Events in the Equatorial Pacific Sediments

著者	Takayanagi Yokichi, Takayama Toshiaki, Sakai Toyosaburo, Oda Motoyoshi, Kato Michio
journal or publication title	The science reports of the Tohoku University. Second series, Geology = 東北大学理科報告. 地質学
volume	49
number	1
page range	71-A9
year	1979-03-31
URL	<a href="http://hdl.handle.net/10097/28834">http://hdl.handle.net/10097/28834</a>

## Late Cenozoic Micropaleontologic Events in the Equatorial Pacific Sediments

Yokichi Takayanagi\*, Toshiaki Takayama\*\*, Toyosaburo Sakai\*,  
Motoyoshi Oda\* and Michio Kato\*\*\*

### ABSTRACT

A microbiostratigraphical investigation of five deep-sea sediment cores from the equatorial Pacific was carried out by utilizing planktonic foraminifers, radiolarians and calcareous nannoplankton. Several micropaleontologic events characterized by the first occurrence of taxa were found to provide reliable datum planes for stratigraphic correlation of post-Miocene sediments. These datum planes are: The *Buccinosphaera invaginata* Datum, *Collosphaera tuberosa* Datum, *Globoquadrina conglomerata* Datum, *Pulleniatina obliquiloculata* Datum, *Gephyrocapsa oceanica* Datum, *Gephyrocapsa caribbeanica* Datum, *Anthocyrtidium angulare* Datum and *Globorotalia (G.) truncatulinoides* Datum, in downward sequence. These datum planes are related to the biostratigraphic zonations based on various microfossils, and further to the previously determined paleomagnetic stratigraphy. One new radiolarian species, *Amphiropalum praeypsilon*, is described.

### INTRODUCTION

This paper is dedicated to the late Professor Orville L. Bandy, who contributed so much toward the advancement of knowledge in the field of foraminiferal ecology and paleoecology.

With the progress of deep-sea research, numerous biostratigraphical studies have been conducted by utilizing late Cenozoic sediment cores. Although different kinds of zonations have been established by many workers on the basis of various kinds of microfossils, a relatively few investigations have been pursued in synthesizing them. In the practice of long-distance stratigraphic correlation, such a biostratigraphic zonation as the one using a single microfossil group is not fully useful, because most of the planktonic organisms are not ubiquitous in their distribution in the oceans. The purpose of the present paper is: (1) to examine stratigraphic relationship among of different micropaleontologic events based upon three microfossil groups including foraminifers, radiolarians and calcareous nannoplankton, which appear commonly in the equatorial Pacific sediment cores, (2) to select reliable datum planes for the interval from the latest Pliocene to Recent, (3) to relate these datum levels to various biostratigraphic zonations which have previously been proposed, and (4) to relate them to paleomagnetic stratigraphy.

All sediment cores examined in the present study were collected by the R/V *Hakuho Maru* during her cruises KH 68-4, KH 71-5, and KH 73-4. Their station list and location map are shown in Table 1 and Fig. 1, respectively. One of these, core C in the present study, is the same as the one studied by Kobayashi *et al.* (1971) for its magnetic and micropaleonto-

\* Institute of Geology and Paleontology, Faculty of Science, Tohoku University, Sendai

\*\* Department of Geology, College of Liberal Arts, Kanazawa University, Kanazawa

\*\*\* Department of Geology, Faculty of Integrated Arts and Science, Hiroshima University, Hiroshima

Table 1. List of core stations

Core	Station No.	Location		Water Depth (m)	Core Length (cm)	Remarks
		Latitude	Longitude			
A	KH73-4-47	2°41.3'N	164°50.2'E	4170	1115	Flow in between 1013–1115 cm depth Bottom topography: somewhat rugged slope
B	KH73-4-8	1°33.2'S	167°38.6'E	4000	1163	Flow in between 940–1163 cm depth Bottom topography: almost flat, flank of a gentle hill
C	KH68-4-18	1°59.5'N	170°00.5'W	5360	983	Non calcareous Bottom topography: almost flat slightly hilly
D	KH71-5-7	2°00.8'N	145°59.0'W	4570	1024	Bottom topography: smooth
E	KH71-5-53	8°15.3'N	112°42.1'W	3970	575	Poorly calcareous Bottom topography: inconspicuous saddle of very rugged hilly area

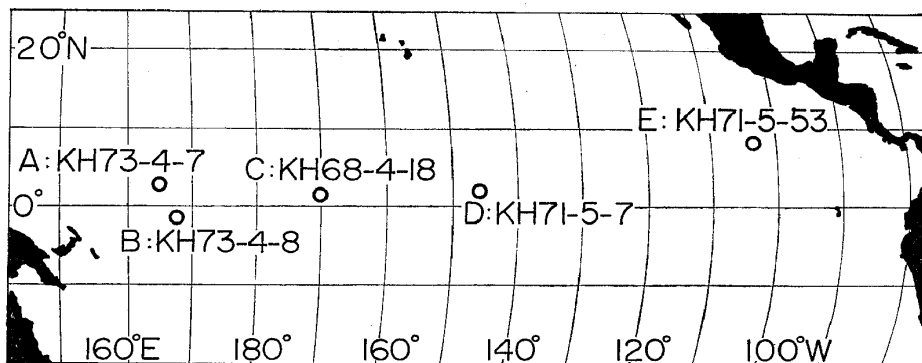


Fig. 1. Map showing locations of the studied cores.

logic characteristics. In addition, a preliminary paleomagnetic result has been obtained on cores A and B by Kobayashi, Kitazawa, Nomura and Furuta (K. Kobayashi, personal communication).

#### METHODS

Piston cores were taken by utilizing a coring tube having an inside diameter of 68 mm, except for core E whose corer had a diameter twice as large as the rest of them. Samples for study were initially taken from these cores at 50 cm intervals and one centimeter in thickness. After examination of a stratigraphic distribution of microfossils, closer sampling was made at 10 cm intervals around the estimated levels of micropaleontologic events in order to better determine stratigraphic positions of datum levels.

#### MICROPALAEONTOLOGIC DATUM PLANES

##### Introduction

As has been stated by Jenkins (1970), one of the basic aims of biostratigraphy is the development of a finer stratigraphic subdivision. Advances made in the biostratigraphy enabled us to establish finely discriminative zonations based upon various kinds of micro-

fossils. For instance, from two to four zones have been proposed for part of the Quaternary by various authors, though the number of proposed zones differs from one group to another of microfossils. At present four units seem to be almost at the upper limit of resolution power of the current biostratigraphic classification based on a single microfossil group. To improve biostratigraphic resolution, it will be necessary to combine units or horizons defined by different kind of microfossils, because "there may be all kind of vertical overlap between them" (Intern. Subcom. Stratigr. Class., 1971).

On the other hand, we encounter many difficulties during the course of biostratigraphic studies of deep-sea cores. Prevalence of calcium carbonate solution, condensation of cored section giving rise to mixing of biostratigraphic boundaries, and various kinds of floral and faunal mixing due to biological, physical and mechanical causes are all that have already been pointed out by Parker (1967).

Accordingly, zonations established by a combination of calcareous and siliceous fossil groups will be particularly useful for biostratigraphic classification of deep-sea sediments.

It is possible in theory for us to define a zone as finely discriminative as we can delimit its boundaries by fossil evidence. However, such zones are not only difficult in recognition but also unpractical for the purpose of correlation in deep-sea biostratigraphy. In the present study micropaleontologic events based upon foraminifers, radiolarians and calcareous nannoplankton are investigated, and reliable datum planes are selected, but no biostratigraphic units such as interval-zones are proposed.

The reliability of paleontologic events (of planktonic foraminifera) as datum planes in terms of chronostratigraphy have been repeatedly discussed by Jenkins (1965, 1970, 1971). He suggested the order of reliability of different categories of paleontologic events as follows: (1) initial appearance of a taxon in an evolutionary lineage, (2) abrupt extinction of a taxon, (3) initial appearance of a cryptogene, (4) gradual extinction of a taxon, (5) acme of taxon, and (6) changes in coiling direction. It is affirmable that the initial evolutionary appearance of a taxon is of prime importance. However, evolutionary lineages are hardly found among the fossil groups treated in the present study within such a short time interval as that represented by those cores examined here. As an initial step it is attempted to select of a set of horizons of the first occurrence of taxa which show the same order of succession in more than two cores. Then, the relationship between this set and horizons of changes in coiling direction of foraminiferal taxa is traced. These procedure has resulted in the recognition of reliable datum planes useful for correlation. Furthermore, horizons of the last occurrence of several taxa are found to be fairly consistent in stratigraphic relationship with the existent datum planes, and they are adopted as accessory criteria to distinguish the datum levels. Such terms as "first occurrence" or "last occurrence" in this study do not necessarily imply the initial evolutionary appearance or extinction, but are used to express stratigraphic occurrences of taxa in the studied cores.

### Mode of occurrence of microfossils

Among the five cores studied, cores A, B and D are mostly represented by a calcareous clay over the entire length. On the other hand, cores C and E consist mainly of a reddish-brown to brown clay. Calcareous microfossils are practically absent in core C (Kobayashi *et al.*, 1971), but are found throughout the remaining cores, though their mode of occurrence differs from core to core.

Both planktonic foraminifera and calcareous nannoplankton are abundant in cores A, B and D. Compared with these cores, calcareous microfossils are less abundant and poorly preserved in core E. Even in those cores rich in calcareous fossils, however, the effect of solution is easily recognizable. In the case of nannoplankton, for instance, such

strongly solution-resistant genera as *Discoaster*, *Coccolithus* and *Cyclococcolithina* (= *Cyclococcolithus*) are always abundant in the fossil populations, but such genera as *Syracosphaera*, perforate *Discolithina* and *Scyphosphaera*, all of which were once assumed to be less resistant by Bukry (1971), are very rarely found throughout all the cores examined here. Nevertheless, comparison shows that core A is the best and core D ranks second in the state of preservation of foraminifera. On the contrary, core D ranks the best in the preservation of nannoplankton. Radiolarians are abundant in cores B, C, D and E, but poor in A.

The recognition of reworked fossils among fossil populations is made more in the nannoplankton and radiolarian assemblages than in the foraminifera. Core B bears tangible evidences of reworking in the lower part as will be discussed later, and core A does show the same in some parts. There is, however, little or no evidence of reworking in cores D and E.

### Description of datum planes

The species which are used to define datum planes and accessory criteria in this study are:

#### Foraminifera

- Globigerinoides fistulosus* (Schubert)
- Globoquadrina conglomerata* (Schwager)
- Pulleniatina obliquiloculata* Parker and Jones
- Globorotalia* (*Globorotalia*) *truncatulinoides* (d'Orbigny)

#### Radiolaria

- Collosphaera tuberosa* Haeckel
- Buccinosphaera invaginata* Haeckel
- Axoprunum angelinum* (Campbell and Clark)
- Amphirhopalum praeypsilon* Sakai, n. sp.
- Pterocanium prismatium* Riedel
- Anthocyrthidium angulare* Nigrini

#### Calcareous Nannoplankton

- Gephyrocapsa caribbeanica* Boudreaux and Hay
- Gephyrocapsa oceanica* Kamptner
- Pseudoemiliana lacunosa* (Kamptner) Gartner
- Cyclococcolithus macintyreii* Bukry and Bramlette
- Discoaster brouweri* Tan Sin Hok
- Discoaster triradiatus* Tan Sin Hok
- Ceratolithus rugosus* Bukry and Bramlette

Stratigraphic distribution of these species in respective cores is shown in Figs. 2 to 6.

Datum planes are as follows, arranged in downward sequence.

- a) *Buccinosphaera invaginata* Datum: The first occurrence of the typical form of *B. invaginata*.
- b) *Collosphaera tuberosa* Datum: The first occurrence of distinctly punctate form of *C. tuberosa*. A faintly punctate form, which is considered as a phylogenetically ancestral to this species, appeared already below this datum plane in the cores.
- c) *Globoquadrina conglomerata* Datum: The first occurrence of *G. conglomerata*. This species is not common throughout the cores, and usually constitutes only from one to two percent of the total population.
- d) *Pulleniatina obliquiloculata* Datum: A distinct sinistral-to-dextral change in the coiling direction of *Pulleniatina obliquiloculata* (s. s.) plus *P. finalis*. In order to determine the coiling ratio, counting of from 50 to 100 specimens was made of every sample in principle. As shown in Fig. 7, coiling ratios fluctuate remarkably within the lower two-thirds to

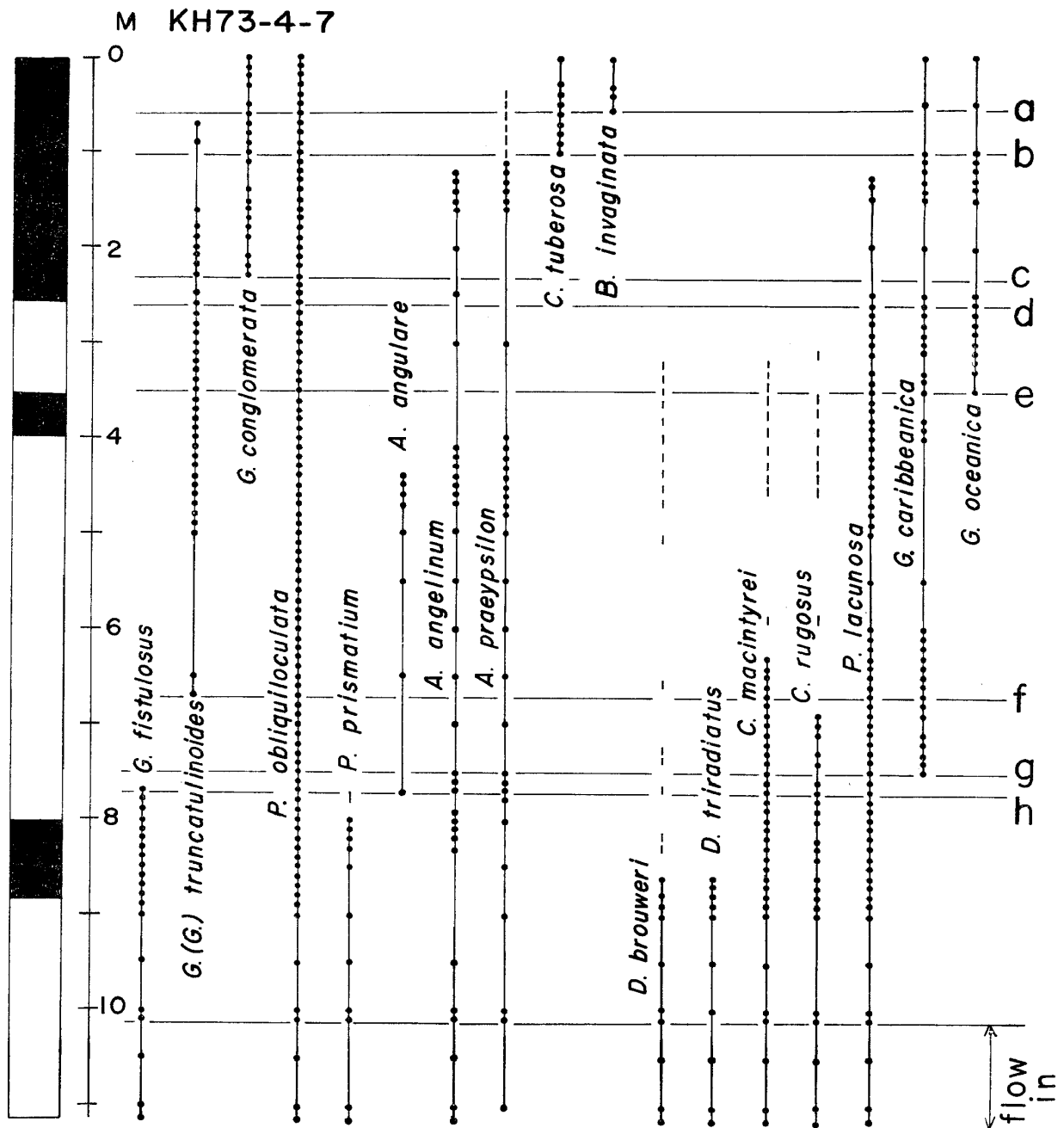


Fig. 2. Faunal, floral and magnetic stratigraphy of core A (KH73-4-7). Top of the core is assumed as normal in magnetic polarity. a:*B. invaginata* Datum, b:*C. tuberosa* Datum, c:*G. conglomerata* Datum, d:*P. obliquiloculata* Datum, e:*G. oceanica* Datum, f:*G. (G.) truncatulinoides* Datum, g:*G. caribbeanica* Datum, h:*A. angulare* Datum.

one-third of the length of the cores, even when the flow-in part is eliminated. To avoid confusion datum plane is placed at the horizon where a completely dextral population of *P. obliquiloculata* appears first. It is rather difficult to pin-point this horizon in core D, but is settled by correlating a peak at 630 cm depth in core D with the peak occurring just below the datum in cores A and B. This horizon could not be located in core E, because *Pulleniatina* occurs only in insufficient numbers in most of the samples.

e) *Gephyrocapsa oceanica* Datum: The first appearance of *G. oceanica* in abundance.

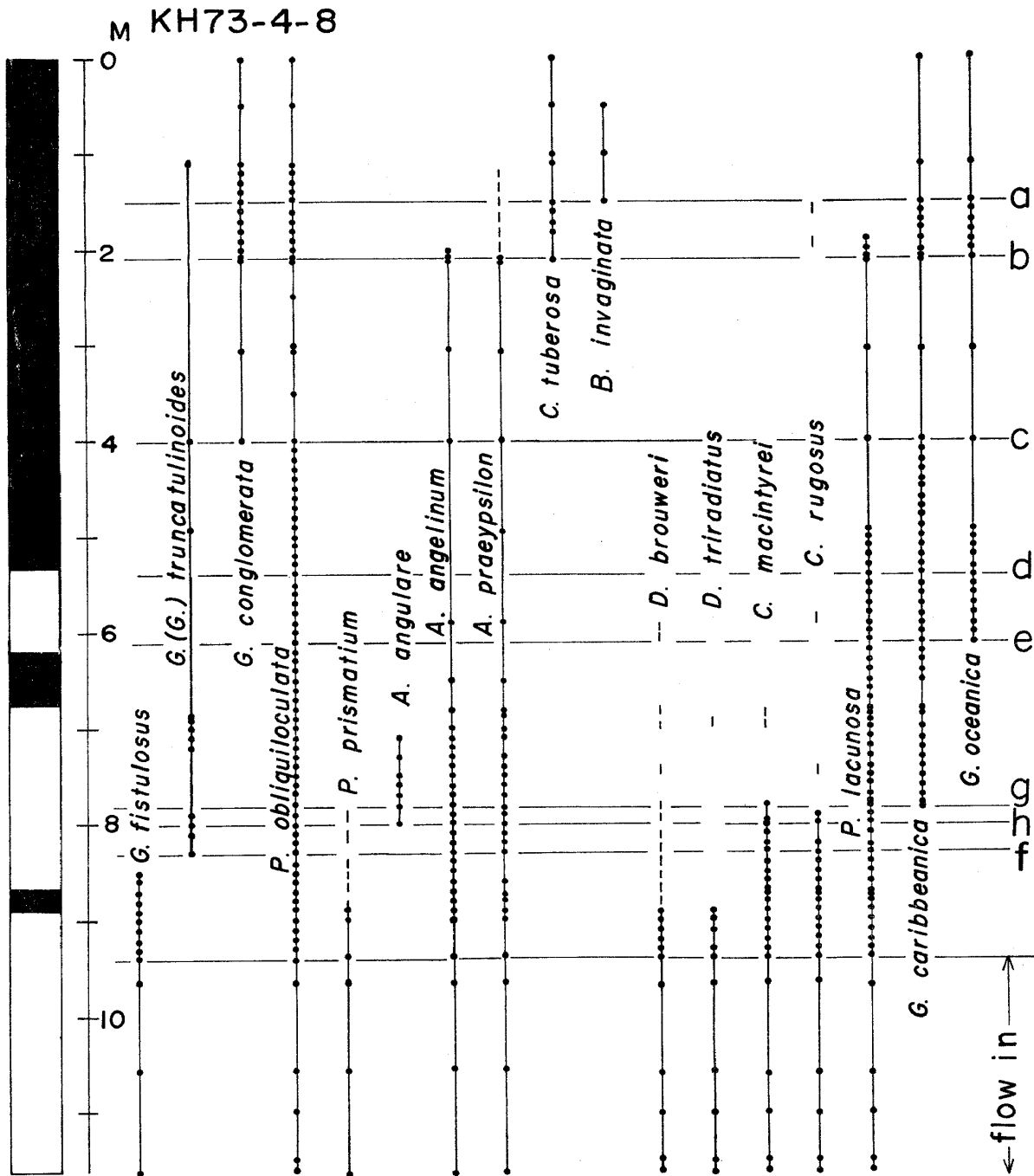


Fig. 3. Faunal, floral and magnetic stratigraphy of core B (KH73-5-8). Top of the core is assumed as normal in magnetic polarity. a:*B. invaginata* Datum, b:*C. tuberosa* Datum, c:*G. conglomerata* Datum, d:*P. obliquiloculata* Datum, e:*G. oceanica* Datum, f:*G. (G.) truncatulinoides* Datum, g:*G. caribbeanica* Datum, h:*A. angulare* Datum.

This species is distinguished from *G. caribbeanica*, which is considered to be its immediate ancestor, by having a large central opening and a different type of crossbar alignment. It is difficult in practice, however, to draw a clear distinction between these two species because of the presence of a number of intermediate forms. Moreover, forms similar to *G. oceanica* and/or intermediate forms between *G. oceanica* and *G. caribbeanica* appear already below the present datum, although their numbers are not so large. In the present study,

only those specimens, which have a large central opening and the narrow bridge being nearly parallel to the short axis of the placoliths, was assigned to *G. oceanica*.

f) *Globorotalia (G.) truncatulinoides* Datum: The first occurrence of a typical form of *G. (G.) truncatulinoides*. Although there is some disagreement among authors with respect to the species concept, the form which develops keel around the entire peripheral margin is referred to as the typical in the present study. *Globorotalia (G.) truncatulinoides* is rare throughout the cores and usually constitutes from 0.1 to 2 percent of the total populations.

g) *Gephyrocapsa caribbeanica* Datum: The first occurrence of *G. caribbeanica*.

h) *Anthocyrtidium angulare* Datum: The first appearance of a typical form of *A. angulare*.

The levels of the last occurrence of those species which are selected in the present study to define accessory criteria are plotted against the datum planes to show discrepancy among the cores (Fig. 8). Relative positions of each datum plane are plotted following core A, because this core shows an average distributional pattern of these datum planes. Some of these criteria exhibit fairly wide stratigraphic ranges compared with others. In general, the criteria based on calcareous nannoplankton appear to show a wider range than those defined by other groups of microfossils. It may be due, at least in part, to the fact that nannoplankton is easily reworkable. Concerning these criteria a brief description is given beginning with the youngest.

*Amphirhopalum praeypsilon*: A sharp upward decrease in abundance of *A. praeypsilon*.

*Axoprunum angelinum*: A marked upward decrease in abundance of *A. angelinum*.

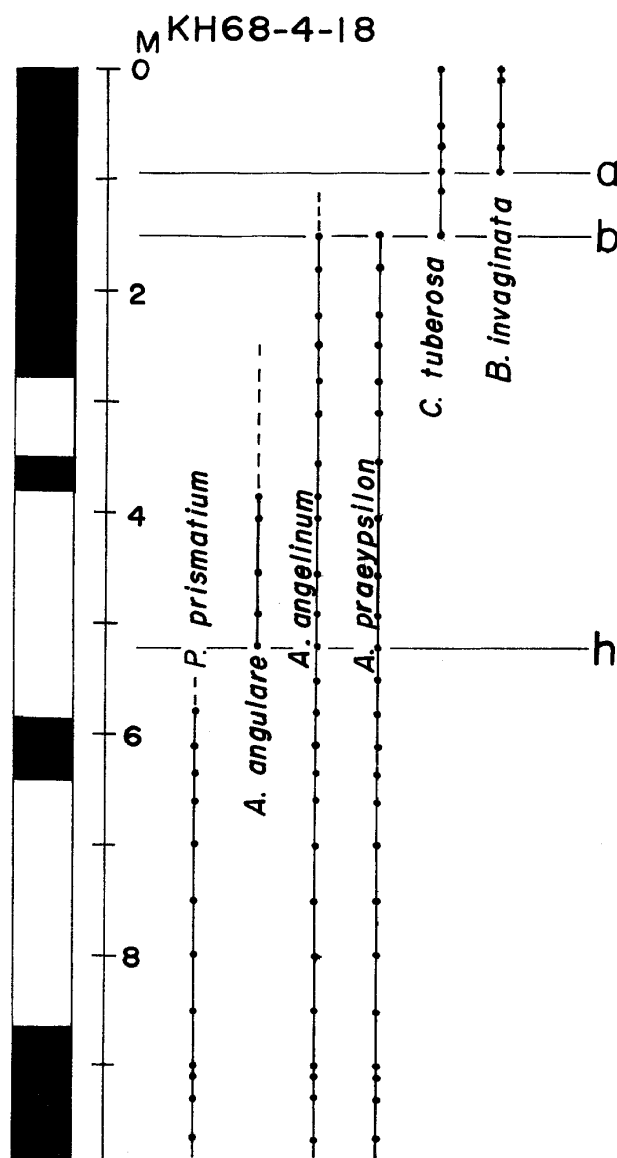
*Pseudoemiliania lacunosa*: The last occurrence of *P. lacunosa*. In cores D and E, this horizon is placed at the level where the species shows a sudden upward decrease in abundance. Although individuals of this species are also found in core sections above this horizon, its occurrence is sporadic.

*Anthocyrtidium angulare*: The last appearance of *A. angulare*.

*Cyclococcolithus macintyreii*: The last occurrence of *C. macintyreii*.

*Ceratolithus rugosus*: The last occurrence of *C. rugosus*. This species is distinguished from *C. cristatus* Kamptner, which

Fig. 4. Faunal and magnetic stratigraphy of core C (KH68-4-18): Top of the core is assumed as normal in magnetic polarity. a: *B. invaginata* Datum, b: *C. tuberosa* Datum, h: *A. angulare* Datum.





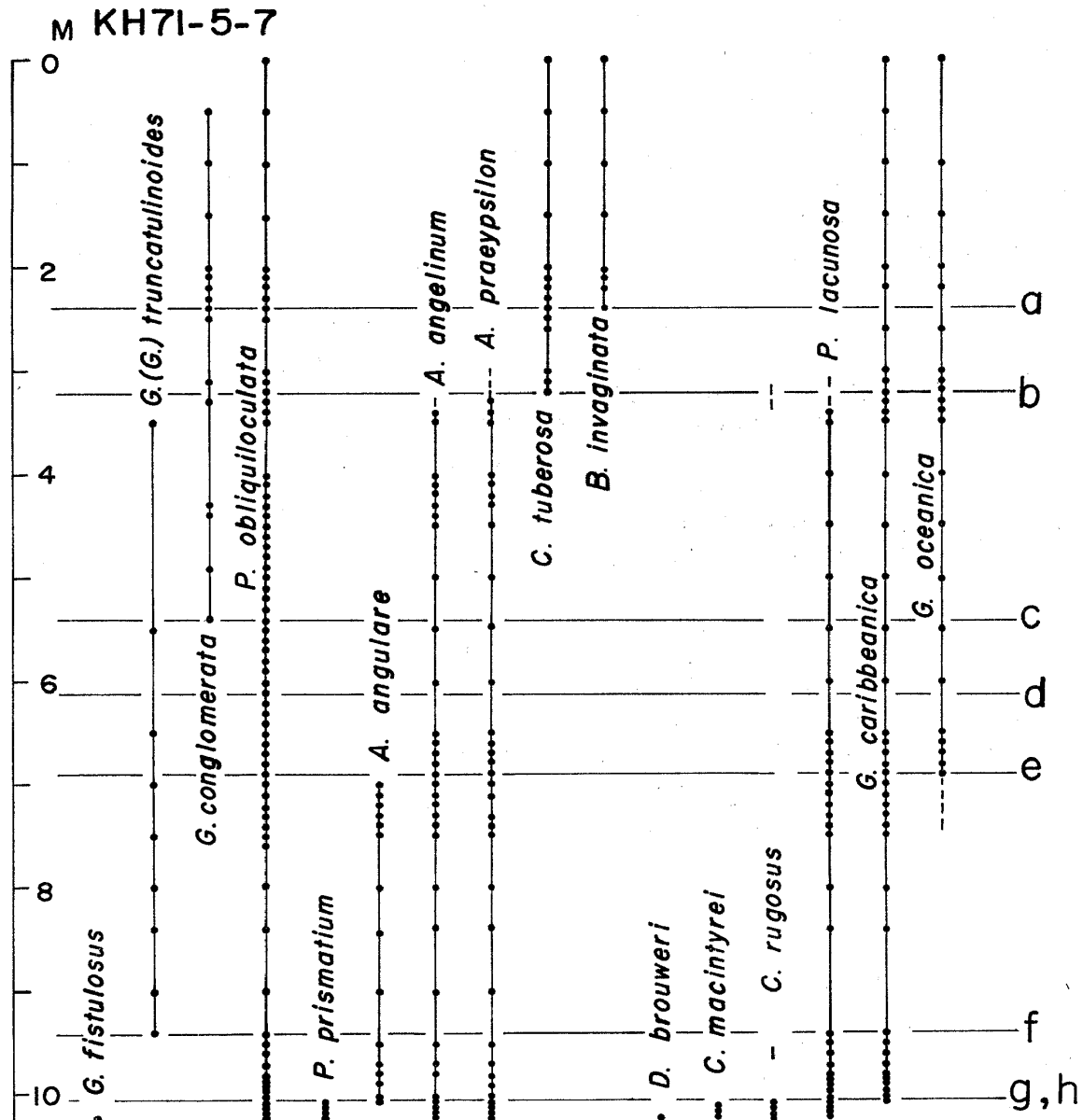


Fig. 5 Faunal and floral stratigraphy of core D (KH71-5-7). a:*B. invaginata* Datum, b:*C. tuberosa* Datum, c:*G. conglomerata* Datum, d:*P. obliquiloculata* Datum, e:*G. oceanica* Datum, f:*G. (G.) truncatulinoides* Datum, g:*G. caribbeanica* Datum, h:*A. angulare* Datum.

survives from the Pleistocene into Recent, in possessing a pronounced robust coccolith showing a rugose surface. Because of overlapping of their stratigraphic ranges and morphologic gradation between them, it is rather hard to judge the extinction level of *C. rugosus*. In search of this level, however, it will be of help that *C. rugosus* gradually acquired conspicuous teeth at the last stage of its phylogenetic development (Bukry and Bramlette, 1968). Such toothed ceratoliths are recognized among the populations occurring around the upper range of *C. rugosus* in the present cores.

*Pterocanium prismatium*: A marked upward decrease in abundance of *P. prismatium*.

*Globigerinoides fistulosus*: The last occurrence of *G. fistulosus*. Although intact specimens are rare among microfossil populations in the cores, a fistulose chamber is taken to suggest

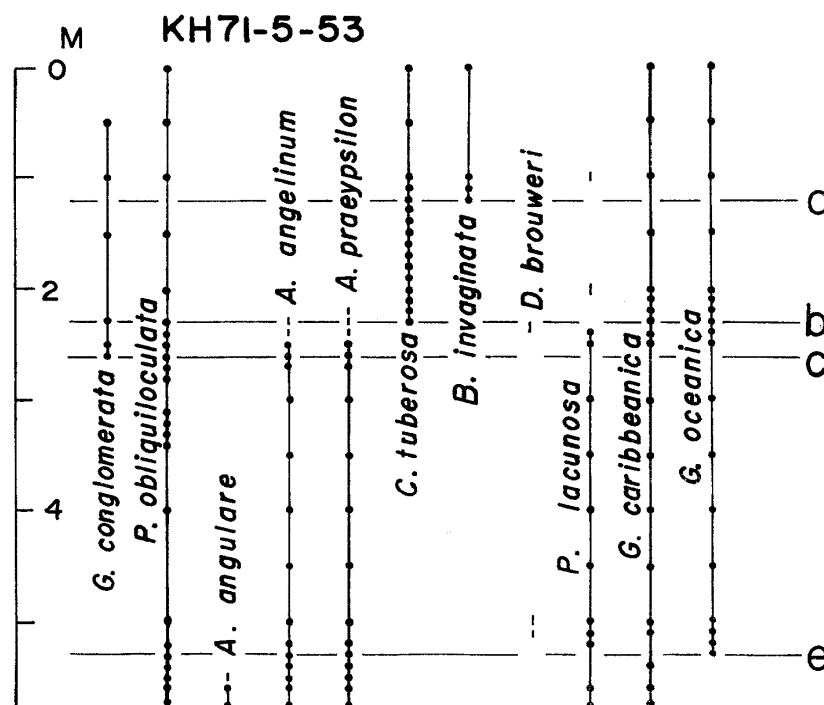


Fig. 6. Faunal and floral stratigraphy of core E (KH71-5-53): a:*B. invaginata* Datum, b:*C. tuberosa* Datum, c:*G. conglomerata* Datum, d:*P. obliquiloculata* Datum, e:*G. oceanica* Datum.

the presence of *G. fistulosus* even when specimens are poorly preserved.

**Discoasters:** The last occurrence of discoasters. Discoasters decrease both in the numbers of species and individuals toward the upper part of Pliocene, and become extinct at the Pliocene-Pleistocene boundary (Ericson *et al.*, 1963). Among the discoaster species which are gradually becoming extinct, the last survivor is *D. brouweri*. Especially the 3-rayed *D. brouweri* (= *D. triradiatus*) is dominant in the uppermost Pliocene (Wray and Ellis, 1965; Takayama, 1969). Observation of such a sequential change in the discoaster population is helpful for us to detect the extinction level. In the present cores the level of last occurrence is defined by a sharp upward decrease in abundance of discoasters or the upper limit of *D. triradiatus*. Thus the present level may be identical to the extinction level of other authors.

### Problems in core B

In the cores under study, core B, especially in its lower half, is found to be anomalous in terms of the occurrence of datum planes (see Fig. 3). Main diagnostic features appeared are: The vertical range of *Anthocyrtidium angulare* is very short; the interval between the *Gephyrocapsa oceanica* Datum and the *Gephyrocapsa caribbeanica* Datum is very short (from 610 to 780 cm in depth); the interval between the *Globorotalia (G.) truncatulinoides* Datum and the level of the last occurrence of *Globigerinoides fistulosus* is distinctly short (830 to 850 cm in depth); the last occurrence of *Pterocanium prismatium*, *Discoaster brouweri* and *D. triradiatus* are at the same horizon (890 cm in depth); and the stratigraphic relation of *Globorotalia (G.) truncatulinoides* Datum with the *Gephyrocapsa caribbeanica* Datum and the *Anthocyrtidium angulare* Datum is reversed.

Although there is no marked lithologic change within the core interval in question, various kinds of physical processes may be pregnant causes for most of these anomalous features. Looking for a clue as to its cause, frequency curves of the coiling ratio of *Pullenia-*

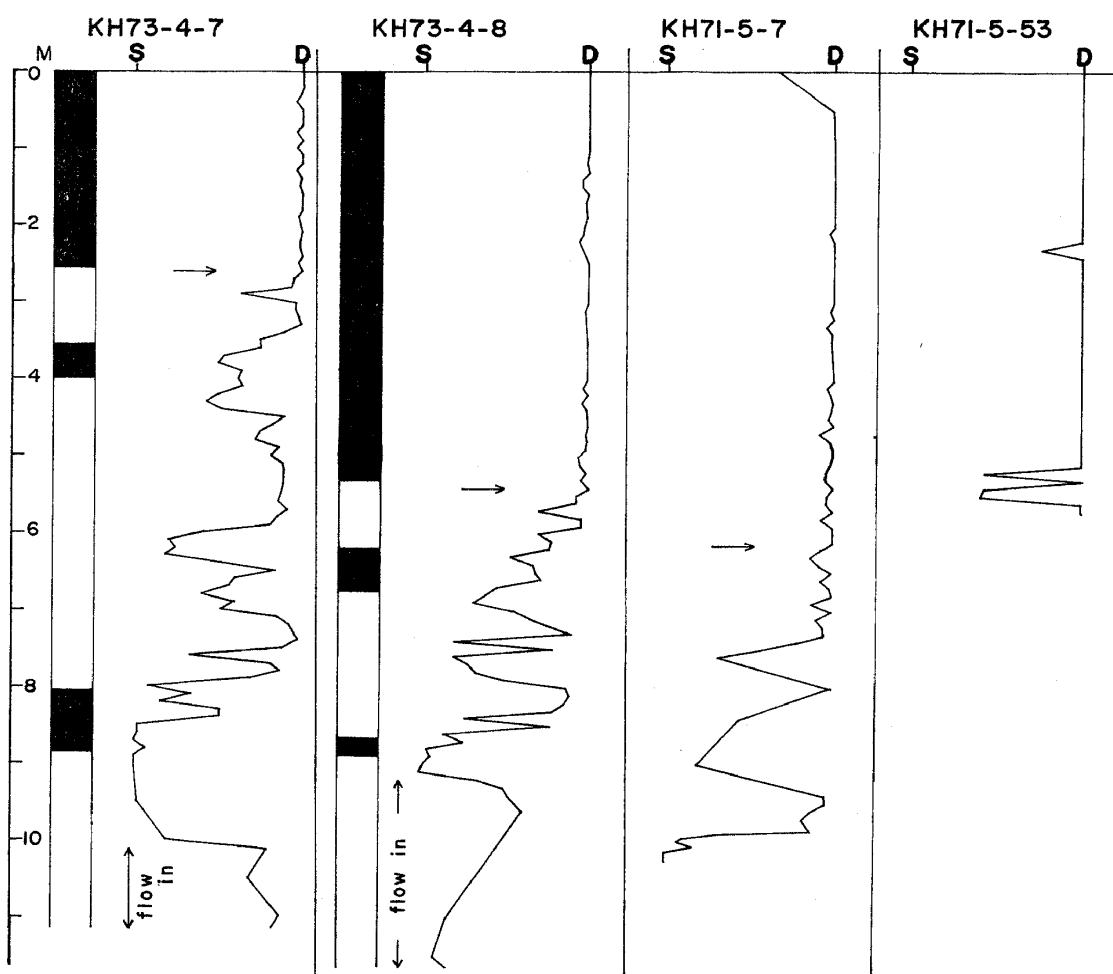


Fig. 7. Vertical changes of coiling ratio of *Pulleniatina obliquiloculata* in cores A, B, D and E.

*tina obliquiloculata* in cores A and B are compared in detail (Fig. 9). Consequently, it is estimated that parts corresponding to the intervals of 460–630 cm and 820–880 cm in core A are either missing or extremely reduced in thickness in core B. In addition, reworked nannoplankton fossils such as *Discoaster brouweri* and various coccoliths, of which ranges are limited to the interval from upper Miocene to Pliocene, are relatively common below 590 cm. Based upon the mode of occurrence as mentioned above, it may be inferred that secondary removal and agitation of bottom deposits occurred at the site of core B more than one time. A similar type of discontinuity in the sedimentary record is recognized in core D at 1006 cm depth, where the *Gephyrocapsa caribbeanica* Datum and the *Anthocyrtidium angulare* Datum occur at the same level.

As mentioned before, the datum planes are selected out of many biohorizons based upon the principle that their order of succession is the same in more than two cores. However, the stratigraphic position of the *Globorotalia (G.) truncatulinoides* Datum with respect to other datum planes in core B is apparently contradictory to those in cores A and D. In other words, this datum plane lies below the *Anthocyrtidium angulare* Datum in core B, whereas the latter occupies the lowest position in cores A and D. Since the *A. angulare* Datum followed by the *Gephyrocapsa caribbeanica* Datum is the only order of succession occurring consistently in all three cores, *G. (G.) truncatulinoides* Datum is here considered

not reliable. In addition, *G. (G.) truncatulinoides* is essentially a rare species in the equatorial region and its range to be established elsewhere. It seems that *G. (G.) truncatulinoides* appeared later than the successive appearance of *A. angulare* and *G. caribbeanica* at the core sites A and D by chance. In the present work the *G. (G.) truncatulinoides* Datum is tentatively placed below the *A. angulare* Datum as in the core B (see Fig. 10).

## CORRELATION

### Correlation with biostratigraphic zonations

In order to relate the datum planes to the previously proposed biostratigraphic zonations, the zonations based on planktonic foraminifera (Blow, 1969), radiolarians (Nigrini, 1971), and calcareous nannoplankton (Martini, 1971; Bukry, 1973; Takayama, 1973) are checked with the core sections under study. Because most of the authors use the same kind of microfossil criteria as those used for establishing the present datum planes, there is not much difficulty in correlating with each other (Fig. 10).

Blow (1969) defined the base of his Zone N. 22 (= *Globorotalia (G.) truncatulinoides truncatulinoides* Partial-range zone) by the first evolutionary appearance of the zone marker species from its immediate ancestor, *G. (Turborotalia) tosaensis* Takayanagi and Saito. In the core sections under study, however, the evolutionary transition of *G. (T.) tosaensis* to *G. (G.) truncatulinoides* is not worked out, because of the lack of *G. (T.) tosaensis*. Thus, some uncertainty is attached in correlating the *G. (G.) truncatulinoides* Datum with the base of the Zone N. 22. In addition, the relation between the top boundary of the zone with the datum planes is not determinable, since no species diagnostic of the overlying Zone N. 23 occurs in the core sections.

Working on Swedish Deep-Sea cores from the equatorial Pacific, Nigrini (1971) proposed four zones for the Quaternary sequence overlying the "Pliocene". The top of her *Anthocyrtidium angulare* Concurrent Range Zone (Zone 4), the basal zone, is defined by the last occurrence of *A. angulare*, and its base by the last occurrence of *Pterocanium prismatium*. As already described, these levels of the last occurrence vary somewhat between the examined cores. Therefore, their positions are settled at the midpoint of the respective ranges of each species for convenience (compare Fig. 10 with Fig. 8). The same procedure will be followed in the rest of the cases. Thus, Nigrini's Zone 4 is thus placed between the *G. (G.) truncatulinoides* Datum and the *A. angulare* Datum, and the top lies at a midway between the *Gephyrocapsa caribbeanica* Datum and the *G. oceanica* Datum. On the other hand, Nigrini's *Collosphaera tuberosa* Concurrent Range Zone is defined as the interval between the first appearance of *C. tuberosa* occurring at the base and that of *Buccinosphaera invaginata* marking its top. Since the area covered by the present study is almost the same as that of Nigrini, these zonal boundaries should coincide with the *C. tuberosa* Datum and *T. invaginata* Datum, respectively.

Among the calcareous nannoplankton zonations previously published for the late

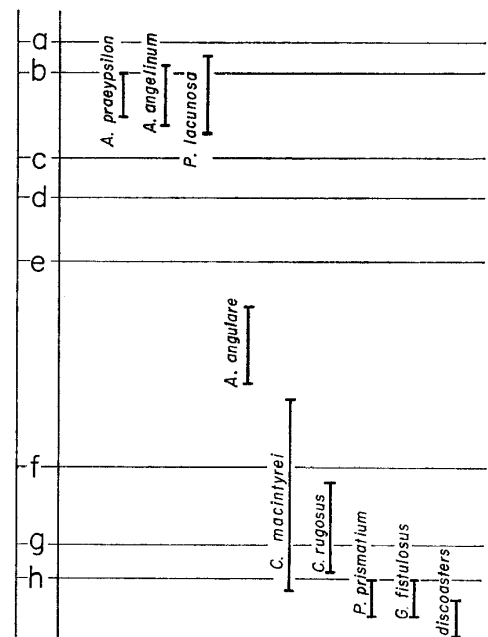


Fig. 8 Ranges of the last occurrence levels of the selected species among cores plotted against the datum planes.

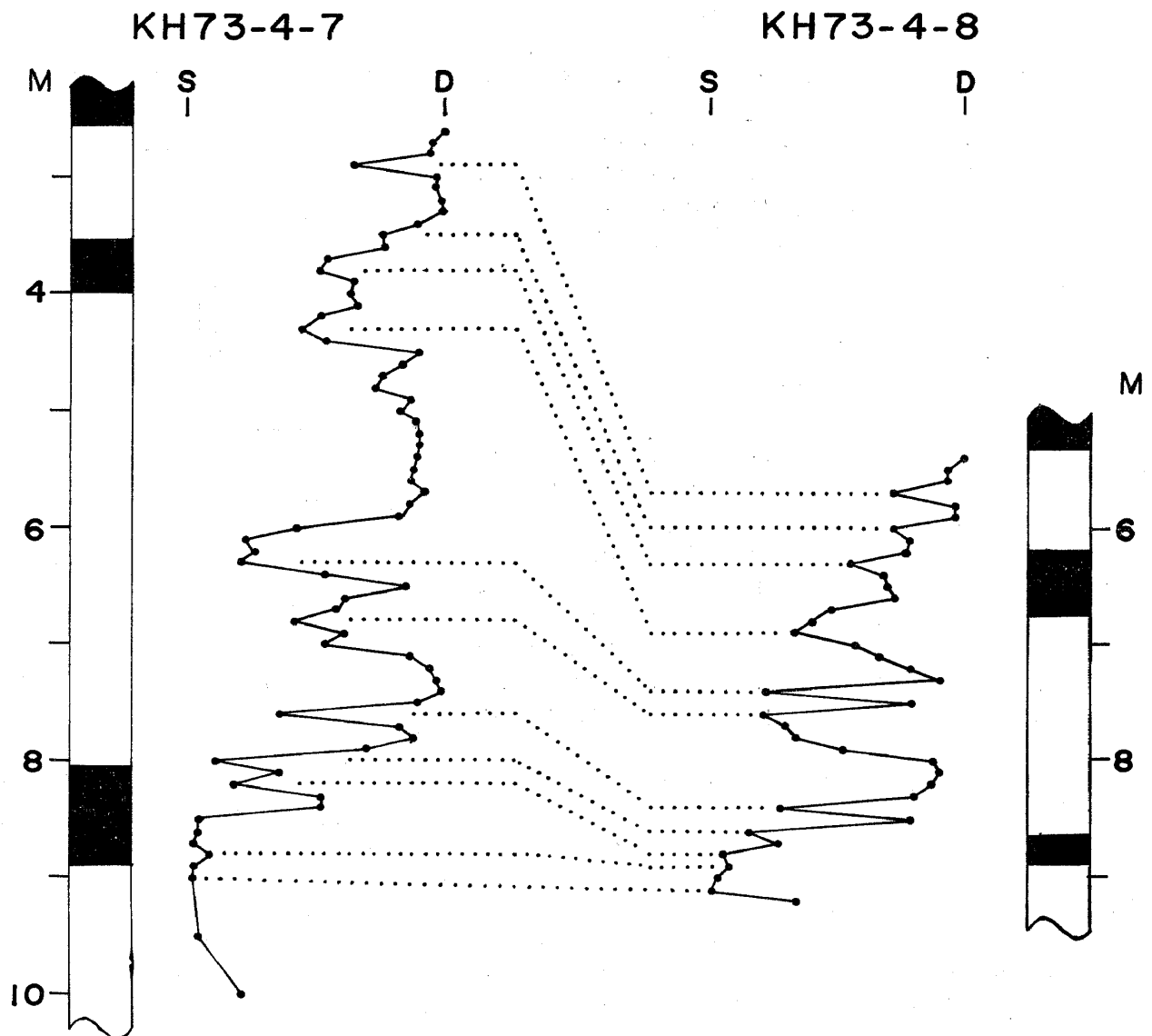


Fig. 9. Comparison of vertical changes in coiling ratio of *Pulleniatina obliquiloculata* and magnetic stratigraphy between cores A and B.

Cenozoic works by Martini (1971) and Bukry (1973) are considered as the principal contributions. They employed different kinds of criteria in defining their zones. Martini's *Discoaster brouweri* Zone (NN 18) is delimited at its top by the extinction of *D. brouweri*, which level is estimated to be somewhat lower than the *Globorotalia (G.) truncatulinoides* Datum. The last occurrence of *Pseudoemiliana lacunosa* marks the upper limit of the *P. lacunosa* Zone (NN 19), and this level is estimated to occur a little below the *C. tuberosa* Datum. The boundary between the *Gephyrocapsa oceanica* Zone (NN 20) and the *Emiliana huxleyi* (NN 21) is not determined in the present cores, because of the absence of zone index species.

The top of Bukry's *Discoaster brouweri* Zone is identical with that of Martini's zone of the same name by definition. Bukry defined the bottom of the *Gephyrocapsa caribbeanica* Subzone of the *G. daronicoides* Zone by the first appearance of *G. caribbeanica* and the top by the first appearance of *G. oceanica*. These boundary horizons correspond to the *G.*

DATUM	FORAMINIFERA	RADIOLARIA	CALCAREOUS NANNOPLANKTON				
	BLOW (1969)	NIGRINI (1971)	MARTINI (1971)	BUKRY (1973)	TAKAYAMA (1973)		
a	N.23: <i>Globigerina calida calida</i> / <i>Sphaeroidinella dehiscentes excavata</i> Assemblage zone	1: <i>Buccinosphaera invaginata</i> Range Zone	NN21: <i>Emiliana huxleyi</i> Zone	<i>Emiliana huxleyi</i> Zone	<i>Emiliana huxleyi</i> Zone <i>Umbellosphaera irregularis</i> Zone <i>Gephyrocapsa oceanica</i> Zone		
b		2: <i>Collosphaera tuberosa</i> Concurrent Range Zone	NN20: <i>Gephyrocapsa oceanica</i> Zone				
c		Assemblage zone	3: <i>Amphirhopalum ypsilon</i> Assemblage Zone	NN19: <i>Pseudoemiliana lacunosa</i> Zone	<i>Gephyrocapsa oceanica</i> Zone	<i>Pseudoemiliana lacunosa</i> Zone	
d							
e	N.22: <i>Globorotalia (G.) truncatulinoides truncatulinoides</i> Partial-range zone	4: <i>Anthocyrtidium angulare</i> Concurrent Range Zone	NN18: <i>Discoaster brouweri</i> Zone	<i>Gephyrocapsa caribbeanica</i> Subzone	<i>Discoaster brouweri</i> Zone		
g	Assemblage zone	'Pliocene'				<i>Gephyrocapsa caribbeanica</i> Subzone	<i>Emiliana annula</i> Subzone
h							
f	N.21: <i>Globorotalia (T.) lasaensis tenuithecata</i> Consecutive -range zone			<i>Cyclococcolithina macintyreii</i> Subzone	<i>Discoaster brouweri trithallus</i> Zone		

Fig. 10 Comparison of datum planes and five latest Pliocene to Holocene microbiostratigraphical zonations.

*caribbeanica* Datum and *G. oceanica* Datum of the present study, respectively. The boundary between the *G. oceanica* Zone and the *Emiliana huxleyi* Zone is indeterminable for the same reason as stated before.

Takayama (1973) proposed eight zones for the late Cenozoic sequence of Japan, based on paleontologic criteria similar to the former studies (Bukry, 1971; Martini, 1971; etc.). His *Pseudoemiliana lacunosa* Zone is defined by the same criteria employed for Martini's zone NN 19. For the lack of data, however, it is not possible to correlate the boundaries of three zones above the *P. lacunosa* Zone with the present datum planes.

**Correlation with paleomagnetic stratigraphy**

Paleomagnetic polarity records of cores A and B were determined by Kobayashi *et al.* (personal communication) as shown in Figs. 2 and 3.

The relationship of various floral and faunal datum planes to the geomagnetic polarity time-scale has been demonstrated in numerous deep-sea cores from the equatorial Pacific, Antarctic and Atlantic by Opdyke *et al.* (1966), Hays and Opdyke (1967), Berggren *et al.* (1967), Glass *et al.* (1967), Phillips *et al.*

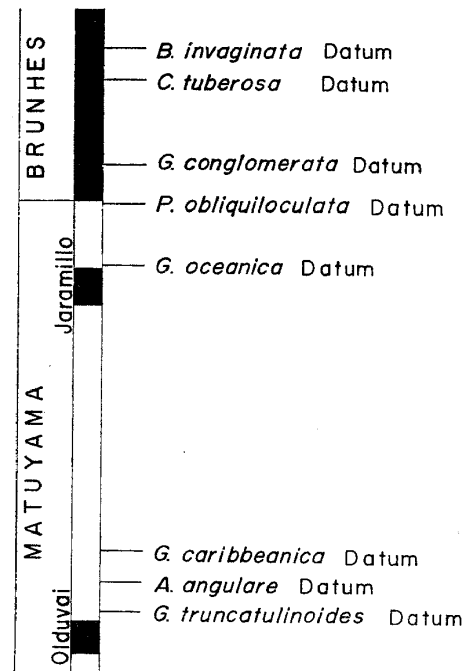


Fig. 11. The relationship between magnetic stratigraphy and datum planes proposed in the present study.

(1968), Hays *et al.* (1969), Hays (1970, 1971), Hays and Berggren (1971), Berggren (1973), and Gartner (1973), among others. They have established some micropaleontologic events based on planktonic foraminifera, Radiolaria and calcareous nannoplankton in relation to the paleomagnetic polarity record.

The upper limit of *Globigerinoides fistulosus* lies near the top of the Olduvai normal event (Hays *et al.*, 1969). The first evolutionary appearance of *Globorotalia (G.) truncatulinoides* is within the Olduvai event (Berggren *et al.*, 1967; Hays *et al.*, 1969). A radiolarian species, *Pterocanium prismatium* has its upper limit just above the Olduvai event (Hays *et al.*, 1969; Hays, 1971). Moreover, *Axoprunum angelinum* and *Pseudoemiliana lacunosa* have their last occurrences within the middle part of the Brunhes normal epoch (Hays and Opdyke, 1967; Hays *et al.*, 1969; Hays, 1970, 1971; Gartner, 1973). The extinction of *Discoaster brouweri* has been recognized within the Olduvai event by several authors (Berggren *et al.*, 1967; Glass *et al.*, 1967; Phillips *et al.*, 1968). Hays *et al.* (1969) subsequently reaffirmed the detailed relationship between them and made it clear that discoasters are sharply reduced in number just above the base of the Olduvai event. According to Gartner (1973), the last occurrence of *D. brouweri* is observed within and near the top of the Olduvai event.

The paleomagnetic polarity records of cores A and B are interpreted on the basis of those paleontological evidences mentioned above and the following paleomagnetic stratigraphy is established. In core A, the interval of normal polarity (0 cm to 254 cm in depth), where *A. angelinum* and *P. lacunosa* have their upper limits, can only be correlated with the Brunhes normal epoch; the short normal event (804 to 883 cm depth) is correlatable with the Olduvai normal event, because *D. brouweri* becomes extinct within this interval and the last occurrences of *G. fistulosus* and *P. prismatium* take place just above it. Consequently the short normal event between 355 cm and 400 cm depth is interpreted to be the Jaramillo normal event of the Matuyama reversed epoch. In this core, the level of the first appearance of *G. (G.) truncatulinoides* is higher than the previous records. In core B, the interval of normal polarity between the top and 532 cm depth can be correlated to the Brunhes epoch. This interpretation is borne out by the fact that the last occurrences of *A. angelinum* and *P. lacunosa* occur at 200 cm and 180 cm of core levels, respectively. The short normal polarity event between 867 cm and 886 cm depth is probably of the Olduvai event, though it is represented by only two samples. The reason is that *G. fistulosus*, *P. prismatium* and *D. brouweri* have their last occurrences and *G. (G.) truncatulinoides* has its first occurrence around this core level. Therefore, the normal event between 622 cm and 674 cm depth is interpreted to be that of the Jaramillo event.

Paleomagnetic and radiolarian investigations of core C were carried out by Kobayashi *et al.* (1971). According to them, *P. prismatium* has its upper limit just above the Olduvai event. In reviewing vertical distributions of selected radiolarian species in the present study it is demonstrated that *A. angelinum* becomes extinct at the middle of the Brunhes epoch. These features agree well with the results obtained from cores A and B.

Based upon the general agreement of the relationships between paleomagnetic records and distributional patterns of the selected microfossil species in cores A, B and C, we can make the following correlation between paleomagnetic stratigraphy and paleontologic datum planes proposed in the present paper (Fig. 11). In the Brunhes normal epoch, there are three datum planes, *i.e.* *B. invaginata*, *B. tuberosa* and *G. conglomerata* datums in downward sequence. The former two datum planes occur in the middle part and the latter in the lower part of the Brunhes epoch. The *P. obliquiloculata* Datum is situated just below the Matuyama reversed epoch/Brunhes normal epoch boundary. Just above the Jaramillo normal event of the Matuyama reversed epoch, *G. oceanica* Datum is located.

Both *G. caribbeanica* and *A. angulare* datums are above, but comparatively close to, the Olduvai normal event; the former is higher than the latter. The *G. (G.) truncatulinoides* Datum, the basal one, is placed immediately above the Oludvai event.

DESCRIPTION OF NEW SPECIES

Phylum PROTOZOA Goldfuss, 1818

Class ACTINOPODA Calkins, 1909

Subclass RADIOLARIA Müller, 1858

Superorder POLYCYSTINA Ehrenberg, 1840; *sensu emend.* Riedel, 1967

Suborder SPUMELLARIA Ehrenberg, 1875

Family SPONGODISCIDAE Haeckel, 1862; *sensu emend.* Riedel, 1967

Genus *Amphirhopalum* Haeckel, 1867; *sensu emend.* Nigrini, 1967

*Amphirhopalum praeypilon* Sakai, n. sp.

Plate 9, figure 11; plate 10, figures 1, 2

*Amphirhopalum ypsilon* Haeckel. Nigrini, 1971 (part), p. 447, pl. 34.1, figs. 7b and 7c (not fig. 7a).

*Amphirhopalum wirchowii* Haeckel. Dumitrica, 1973 (part), p. 835, pl. 21, figs. 11 and 13 (not pl. 9, figs. 2 and 4; pl. 11, fig. 6; pl. 30, figs. 2 to 10 and 12).

*Description:* – Shell consists of a central disc and two chambered arms. One of the arms is bifurcated distally. Arms arise from the central disc. The disc contains two spherical shells in its innermost part, an outer oblate shell and the outermost ring of mesh. All of them are connected by numerous discontinuous radial beams. The shorter axis of the oblate is perpendicular to the arms and outer ring. Arms are elliptical in cross section and their broader surfaces are aligned with the equatorial plane of the oblate shell. The unforked arm, consisting of 4–9, distally convex chambers, is narrow at the proximal end, expand distally reaching the maximum breadth at about two-thirds of the way along its length, and then tapers off with a blunt termination. The forked arm consists of 2–3 chambers before bifurcation and 3–6 chambers thereafter. In some specimens, the distal ends of the arms become spongy. A patagium is present around the central disc and the arms.

*Dimensions:* – Based on 30 specimens from cores KH73–4–7 (300–301 cm), KH73–4–8 (350–351 cm and 590–591 cm), KH71–5–7 (349–350 cm, 450–451 cm, 840–841 cm, 990–991 cm and 1023–1024 cm) and KH71–5–53 (550–551 cm), sizes are measured. Total length 210–310  $\mu$ ; maximum breadth of simple arm 60–100  $\mu$ ; maximum breadth of branch of forked arm 50–90  $\mu$ .

*Remarks:* – This species differs from *A. ypsilon* Haeckel in having fewer chambers in the forked arm before bifurcation, and from *A. wirchowii* (Haeckel) in more number of these chambers. The new species described here has been included within the range of morphological variation of *A. ypsilon* by Nigrini (1971). The present study reveals, however, that there is a marked difference in stratigraphic distribution between these two forms. They are distinguished from each other by the number of chambers before bifurcation of the forked arm. One form having 4–6 chambers first appears between the *Gephyrocapsa oceanica* Datum and the *Pulleniatina obliquiloculata* Datum and survives to the top of the cores, while the other form with 2–3 chambers exists already below the *Globorotalia (G.) truncatulinoides* Datum and has its last occurrence near the *Collosphaera tuberosa* Datum. Accordingly, these two forms are reasonably separated from each other in terms of their



morphology as well as in their stratigraphic distribution. Retaining the former form as *A. ypsilon* s.s., the latter is herein described as *A. praeypsilon*, n. sp.

*Types*:—Holotype (IGPS coll. cat. no. 75029; slide no. KH71-5-7, 349-350 cm, K31/4) from core KH71-5-7, 349-350 cm; paratype (IGPS coll. cat. no. 75030; KH71-5-7, 1023-1024 cm; D33/2) from core KH71-5-7, 1023-1024 cm; paratype (IGPS coll. cat. no. 75031) from core KH71-5-7, 990-991 cm.

#### ACKNOWLEDGMENTS

The writers wish to thank Prof. Tsunemasa Saito of the Yamagata University for his critical reading the manuscript. The paleomagnetic reversal records of the studied cores were supplied by Prof. Kazuo Kobayashi of the Ocean Research Institute, University of Tokyo. The writers are deeply grateful to Prof. Kobayashi, Dr. Kazuhiro Kitazawa, and Messrs. Masashi Nomura and Toshio Furuta, who made the paleomagnetic study. One of the writers (Oda) was supported during the present study by a Postdoctoral Fellowship of the Japan Society for the Promotion of Science.

#### REFERENCES

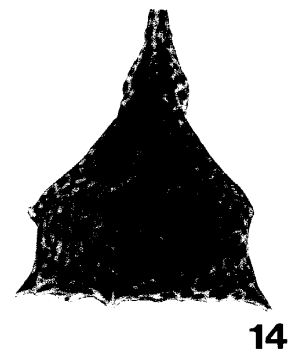
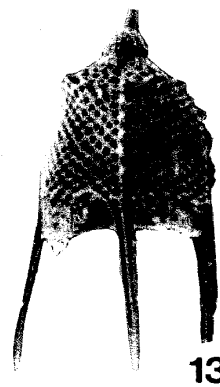
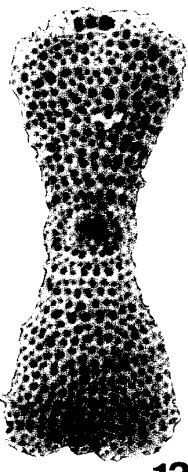
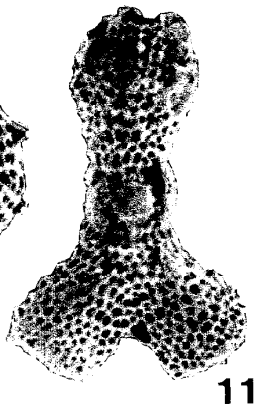
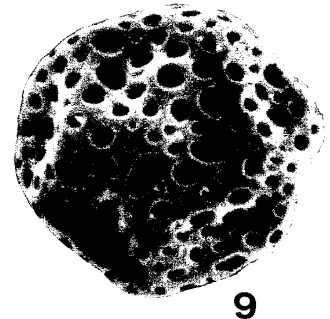
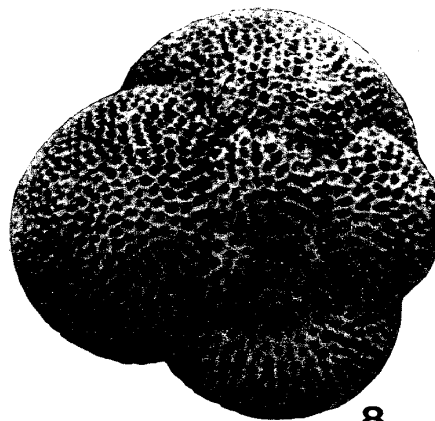
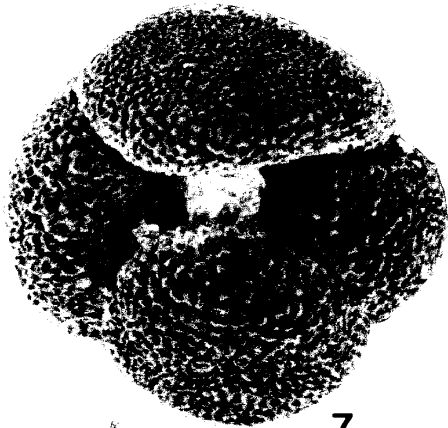
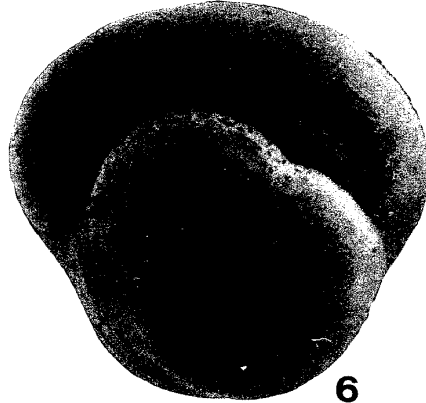
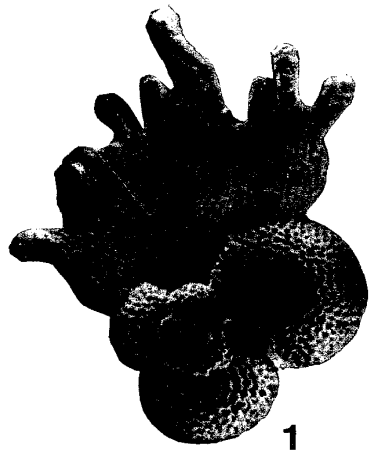
- Berggren, W.A., 1973, The Pliocene time scale: Calibration of planktonic foraminiferal and calcareous nannoplankton zones. *Nature*, v. 243, no. 5407, p. 391-397, 1 fig., tabs. 1-5.
- , Phillips, J.D., Bertels, A. and Wall, D., 1967, Late Pliocene-Pleistocene stratigraphy in deep-sea cores from the south central North Atlantic. *Nature*, v. 216, no. 5112, p. 253-255, figs. 1-2.
- Blow, W.H., 1969, Late Middle Eocene to Recent planktonic foraminiferal biostratigraphy. In *Proceedings of the First International Conference on Planktonic Microfossils, Geneva, 1967*, edited by Brönnimann, P. and Renz, H.H., v. 1, p. 199-421, figs. 1-43, pls. 1-54, E.J. Brill, Leiden.
- Bukry, D., 1971, Cenozoic calcareous nannofossils from the Pacific Ocean. *San Diego Soc. Nat. Hist., Trans.*, v. 16, no. 14, p. 303-328, tabs. 1-3, pls. 1-7.
- , 1973, Low-latitude coccolith biostratigraphic zonation. In Edgar, N.T., Saunders, J.B., et al., *Initial Reports of the Deep Sea Drilling Project*, v. XV, p. 685-730, figs. 1, 2, 1 tab., U.S. Government Printing Office, Washington.
- and Bramelitte, M.N., 1968, Stratigraphic significance of two genera of Tertiary calcareous nannofossils. *Tulane Stud. Geol.*, v. 6, no. 4, p. 149-155, pls. 1, 2.
- Dumitrica, P., 1973, Cretaceous and Quaternary Radiolaria in deep-sea sediments from the north-west Atlantic Ocean and Mediterranean Sea. In Ryan, W.B., Hsü, K.J., et al., *Initial Reports of the Deep Sea Drilling Project*, v. XIII, part 2, p. 829-981, tabs. 1-3, pls. 1-28, U.S. Government Printing Office, Washington.
- Ericson, D.B., Ewing, M. and Wollin, G., 1963, Pliocene-Pleistocene boundary in deep-sea sediments. *Science*, v. 139, no. 3556, p. 727-737, figs. 1-14.
- Gartner, S., 1973, Absolute chronology of the Late Neogene calcareous nannofossils succession in the Equatorial Pacific. *Geol. Soc. Amer., Bull.*, v. 84, no. 6, p. 2021-2034, figs. 1-6, 1 tab.
- Glass, B., Ericson D.B., Heezen, B.C., Opdyke, N.D. and Glass, J.A., 1967, Geomagnetic reversals and Pleistocene chronology. *Nature*, v. 216, no. 5114, p. 437-442, figs. 1-6, 1 tab.
- Hays, J.D., 1970, The stratigraphy and evolutionary trend of Radiolaria in North Pacific deep-sea sediments. *Geol. Soc. Amer., Mem.* 126, p. 185-218, figs. 1-10, tabs. 1, 2, pl. 1.
- , 1971, Faunal extinctions and reversals of the earth's magnetic field. *Geol. Soc. Amer., Bull.*, v. 82, no. 9, p. 2433-2447, figs. 1-11, tabs. 1-4.
- and Berggren, W.A., 1971, Quaternary boundary and correlations. In *The Micropaleontology of Oceans*, edited by Funnell, B.M. and Riedel, W.R., p. 669-691, figs. 1-9, 1 tab., Cambridge Univ. Press, Cambridge.
- and Opdyke, N.D., 1967, Antarctic Radiolaria, magnetic reversals, and climatic change. *Science*, v. 158, no. 3804, p. 1001-1011, figs. 1-10, tabs. 1-4.
- , Saito, T., Opdyke, N.D. and Burckle, L.H., 1969, Pliocene-Pleistocene sediments of

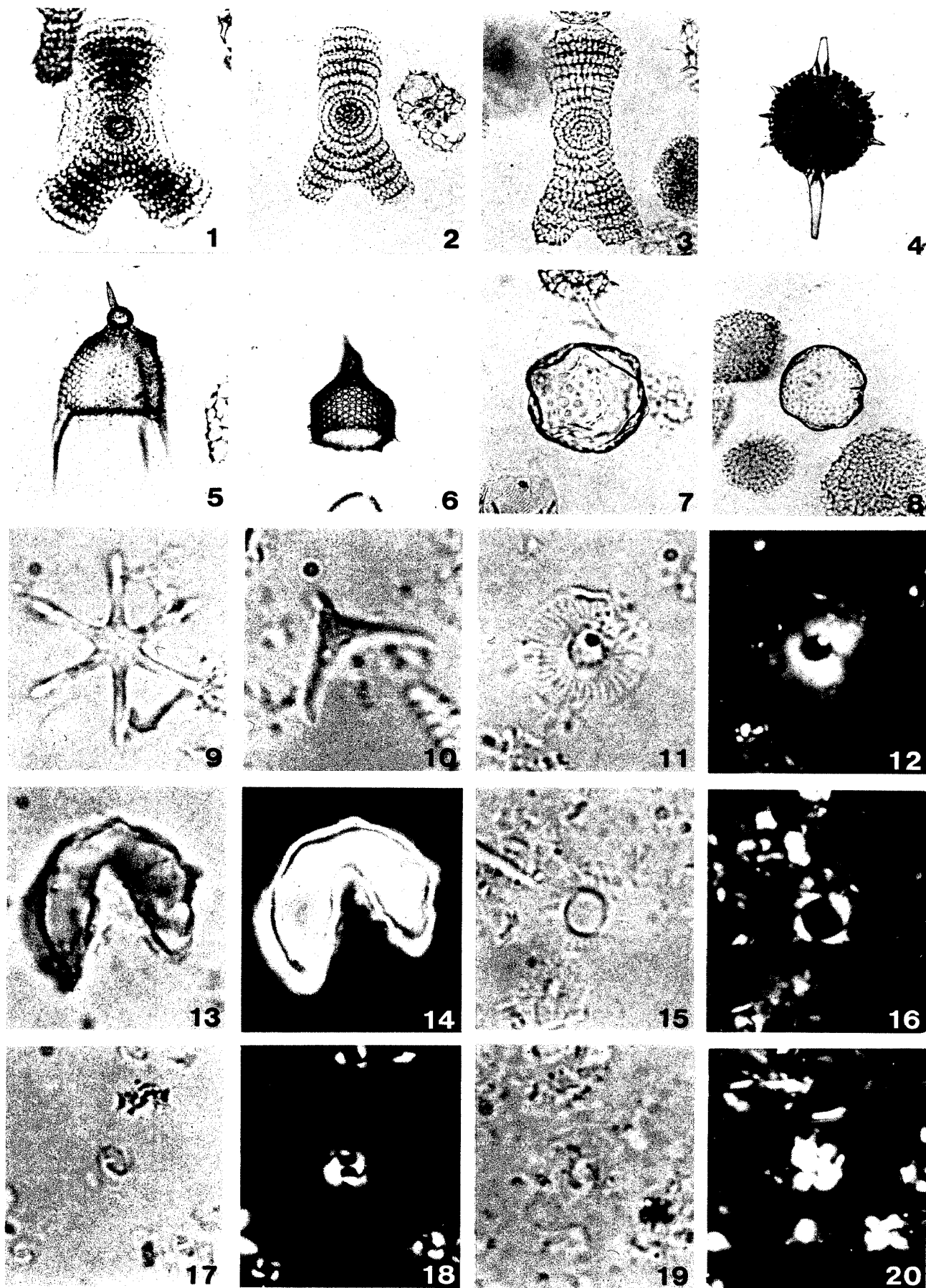
- equatorial Pacific: Their paleomagnetic, biostratigraphic and climatic record. *Geol. Soc. Amer., Bull.*, v. 80, no. 8, p. 1481-1514, figs. 1-16, pl. 1.
- International Subcommission on Stratigraphic Classification, 1971, Preliminary report on biostratigraphic units. *Internat. Subcom. Stratigr. Class., Rep.*, no. 5, vii+50 p., figs. 1-4.
- Jenkins, D.G., 1965, Planktonic foraminifera and Tertiary international correlations. *Micropaleontology*, v. 11, no. 3, p. 265-277, figs. 1, 2, pls. 1-2.
- , 1970, Foraminifera and New Zealand Tertiary biostratigraphy. *Rev. Espanola Micropal.*, v. 2, no. 1, p. 13-26, tabs. 1-3.
- , 1971, The reliability of some Cenozoic planktonic foraminiferal "datum-planes" used in biostratigraphic correlation. *Jour. Foram. Res.*, v. 1, no. 2, p. 82-86.
- Kobayashi, K., Kitazawa, K., Kanaya, T. and Sakai, T., 1971, Magnetic and micropaleontological study of deep-sea sediments from the west-central equatorial Pacific. *Deep-Sea Res.*, v. 18, no. 11, p. 1045-1062, figs. 1-6, 1 tab.
- Martini, E., 1971, Standard Tertiary and Quaternary calcareous nannoplankton zonation. In Proceedings of the II Planktonic Conference Roma 1970, edited by Farinacci, A., p. 739-785, tabs. 1-6, pls. 1-., *Edizioni Tecnoscienza*, Rome.
- Nigrini, C.A., 1967, Radiolaria in pelagic sediments from the Indian and Atlantic Oceans. *Scripps Inst. Oceanogr., Univ. Calif., Bull.*, v. 11, p. 1-106, figs. 1-48, pls. 1-9.
- , 1971, Radiolarian zones in the Quaternary of the equatorial Pacific Ocean. In The Micropaleontology of Oceans, edited by Funnell, B.M. and Riedel, W.R., p. 443-461, figs. 1, 2, tabs. 1-23, pl. 1, *Cambridge Univ. Press*, Cambridge.
- Opdyke, N.D., Glass, B., Hays, J.D. and Foster, J.H., 1966, Paleomagnetic study of Antarctic deep-sea cores. *Science*, v. 154, no. 3784, p. 394-357, figs. 1-7, tabs. 1, 2.
- Parker, F.L., 1967, Late Tertiary biostratigraphy (planktonic foraminifera) of tropical Indo-Pacific deep-sea cores. *Bull. Amer. Pal.*, v. 52, no. 235, p. 115-203, figs. 1-5, tabs. 1-4, pls. 17-32.
- Phillips, J.D., Berggren W.A., Bertels, A. and Wall, D., 1968, Paleomagnetic stratigraphy and micropaleontology of three deep-sea cores from the south-central North Atlantic. *Earth and Planet. Sci. Letters*, v. 4, no. 2, p. 118-130, figs. 1-5, 1 tab.
- Takayama, T., 1969, Discoasters from the Lamont Core V21-98 (preliminary reports of the Philippine Sea cores. part 2). *Nat. Sci. Mus. Tokyo, Bull.*, v. 12, no. 2, p. 431-450, figs. 1-8.
- , 1973, On the distribution of calcareous nannoplankton in the youngest Cenozoic of Japan. *Geol. Soc. Japan, Mem.*, no. 8, p. 45-63, figs. 1-11 (in Japanese with English abstract).
- Wray, J.L. and Ellis, C.H., 1965, Discoaster extinction in neritic sediments, northern Gulf of Mexico. *Amer. Assoc. Petrol. Geol., Bull.*, v. 49, no. 1, p. 98-99, 1 fig.

**POSTSCRIPT:** This paper was initially submitted to the planned Prof. O. L. Bandy memorial volume, but it is included in the Science Reports of Tohoku University because of the long publication delay of the Prof. Bandy Volume. Consequently, this paper was already in a manuscript form in 1974. In the meantime, there appeared several contributions relating to the subject discussed in the present paper. They are, however, not included in the above references.

Plate 1

- 1, 2 *Globigerinoides fistulosus* (Schubert)  
1, sample KH73-4-8, 870-871 cm; 2, sample KH71-4-7, 870-871 cm; ×42.
- 3, 4 *Globorotalia (Globorotalia) truncatulinoidea* (d'Orbigny)  
Sample KH73-4-8, 100-101 cm; ×42.
- 5, 6 *Pulleniatina obliquiloculata* (Parker and Jones)  
Sample KH71-5-7, 230-231 cm; ×42.
- 7, 8 *Globoquadrina conglomerata* (Schwager)  
Sample KH71-5-7, 230-231 cm; ×42.
- 9 *Collosphaera tuberosa* Haeckel  
Sample KH68-4-18, 0-1 cm; ×140.
- 10 *Axoprunum angelinum* (Campbell and Clark)  
Sample KH68-4-18, 405-406 cm; ×140.
- 11 *Amphirhopalum praeypsilon* Sakai, n. sp.  
Paratype (IGPS coll. cat. no. 75031), sample KH71-5-7, 909-991 cm; ×94.
- 12 *Amphirhopalum ypsilon* Haeckel  
Sample KH71-5-53, 250-251 cm; ×94.
- 13 *Pterocanium prismatium* Riedel  
Sample KH68-4-18, 610-611 cm; ×94.
- 14 *Anthocyrtidium angulare* Nigrini  
Sample KH68-4-18, 405-406 cm; ×140.





## Plate 2

- 1, 2 *Amphirhopalum praeypsilon* Sakai, n. sp.  
1, holotype (IGPS\* coll. cat. no. 75029), sample KH71-5-7, 349-350 cm, K31/4\*\*; 2, paratype (IGPS coll. cat. no. 75030), sample KH71-5-7, 1023-1024 cm, D33/2;  $\times 90$ .
- 3 *Amphirhopalum ypsilon* Haeckel  
Sample KH71-5-53, 150-151 cm, T39/2;  $\times 90$ .
- 4 *Axoprunum angelinum* (Campbell and Clark)  
Sample KH71-5-7, 1018-1019 cm, C40/2;  $\times 90$ .
- 5 *Pterocanium prismatium* Riedel  
Sample KH71-5-7, 1023-1024 cm, F25/0;  $\times 90$ .
- 6 *Anthocyrtdium angulare* Nigrini  
Sample KH71-5-7, 1000-1001 cm, L29/3;  $\times 90$ .
- 7 *Collosphaera tuberosa* Haeckel  
Sample KH71-5-53, 50-51 cm, F36/0;  $\times 90$ .
- 8 *Buccinosphaera invaginata* Haeckel  
Sample KH71-5-7, 200-201 cm, H24/0;  $\times 90$ .
- 9 *Discoaster brouweri* Tan Sin Hok  
Sample KH73-4-8, 966-967 cm;  $\times 1300$ .
- 10 *Discoaster triradiatus* Tan Sin Hok  
Sample KH73-4-7, 1050-1051 cm;  $\times 1300$ .
- 11, 12 *Cyclococcolithus macintyreii* Bukry and Bramlette  
11, without nicols; 12, crossed nicols; sample KH73-4-7, 950-951 cm;  $\times 1300$ .
- 13, 14 *Ceratolithus rugosus* Bukry and Bramlette  
13, without nicols; 14, crossed nicols; sample KH73-4-7, 1050-1051 cm;  $\times 1300$ .
- 15, 16 *Pseudoemiliana lacunosa* (Kamptner) Gratner  
15, without nicols; 16, crossed nicols; sample KH73-4-7, 140-141 cm;  $\times 1300$ .
- 17, 18 *Gephyrocapsa oceanica* Kamptner  
17, without nicols; 18, crossed nicols; sample KH73-4-8, 130-131 cm;  $\times 1300$ .
- 19, 20 *Gephyrocapsa caribbeanica* Boudreaux and Hay  
19, without nicols; 20, crossed nicols; sample KH73-4-8, 780-781 cm;  $\times 1300$ .

\* Abbreviation for Institute of Geology and Paleontology, Sendai    \*\* England Finder coordinate