主論文

MODERN COCCOLITHOPHORIDAE IN THE PACIFIC OCEAN

(太平洋における現世ココリソフォリデについて)

by

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Abstract

About 700 samples from the surface water, euphotic and subphotic layers were systematically collected along five sampling routes in the North and Equatorial Pacific.

Population and assemblage of coccolithophorids were biogeographically studied in detail. Each coccolithophorid species has been taxonomically examined.

Six coccolithophorid floral zones were thus established in the North and Equatorial Pacific. The northern and southern boundaries for each zone seem to be almost parallel to latitude. The formation of zones is now considered to be closely controlled by the existing ocean current systems (Fig. 8).

Coccolithophorids are densely populated in the Sub-Arctic Current. *Coccolithus huxleyi* is especially abundant in this crrent. *Rhabdosphaera stylifera* and *Discosphaera tubifera* are abundant in the North Pacific Current. *Coccolithus huxleyi* is also common in the Kuroshio Extension but less numerous than in the Sub-Arctic Current. *Umbellosphaera irregularis* is richly found both in the North Equatorial and Equatorial Counter Current.

The specific assemblage is remarkably different between norhtern and southern parts of the South Equatorial Current. In the northern part of the South Equatorial Current, the specific assemblage is further subdivided into two types. *Coccolithus huxleyi*, *Cyclococcolithus fragilis*, *Cyclococcolithus leptopolus* and *Gephyrocapsa oceanica* are commonly found,

however the relative abundances of each species are different in the two types of coccolithophorid flora. While, the southern part of the South Equatorial Current is characterized by the predominance of Umbellosphaera irregularis.

Generally speaking, coccolithophorid population of the surface layer is higher in the tropical seaway than in the sub-tropical and temperate seaways.

Coccolithophorids are classified into several groups of species in respect to the vertical distribution in the euphotic layers.

Discosphaera tubifera, Rhabdosphaera stylifera and Umbellosphaera irregularis are characteristic stenoforms of the upper euphotic layer, while Cylococcolithus fragilis and Umbellosphaera tenuis are characteristic stenoforms of the middle euphotic layer. Coccolithus huxleyi, Cyclococcolithus leptopolus and Gephyrocapsa oceanica are rather eubathic in vertical distribution ranging from the surface to middle euphotic layers. The lower euphotic layer is characterized by such coccolithophorid flora of Deutschlandia anthos, Deutschlandia sp. A and Deutschlandia sp. B.

Ninety two species of coccolithophoridae including thirty seven new species and two new varieties are recognized in all in the North and Equatorial Pacific. All these species are described in this paper, Contents

1) Introduction and acknowledgements

Many phytoplanktons are inhabited in the euphotic layer of sea waters. There are very minute phytoplanktons small enough to pass through a plankton net. They are known as "Nannoplankton". The majority of nannoplankton are belonging to coccolithophoridae.

Coccolithophorids are members of golden-brown algae belonging to biflagillata which has been classified as one of the forms of the class Haptophyceae. Their calcareous skeltal elements have been called coccoliths in general, which are commonly found in pelagic sediments. Coccoliths and shells of planktonic foraminifera are generally main constitute of sediments of warm water region.

Coccolithophorids are believed to have first appeared in the Jurrasic and flourished in the Cretaceous (Noël 1959, Fisher, Honjo and Garrison 1967).

Of the Cretaceous formation, coccoliths are found chiefly in the chalks, which are studied in detail by Black and Barnes (1959), Stradner (1961), Bramlette and Martini (1964) and Honjo (1970).

Many paleontologists, especially Bramlette and Riedel (1954), Stradner and Papp (1961) and Takayama (1967) studied on the Tertiary coccoliths, and found out many horizon indicators among them.

Coccoliths of the Pliocene and Pleistocene have been, however, comparatively less studied till now.

Reviwing all those studies above mentioned, detailed information on recent coccolithophorids seems to be very much neccessary, the author thinks, to promote paleontology on coccoliths for any geologic ages.

Indeed, Wallich (1861) already made observation on living coccolithophorids and some other European marine-biologists studied them to some extent under optical microscope (Lohmann 1902, Schiller 1925, Kamptner 1937).

In addition to this, electron microscopy has been introduced for studying of coccolithophorids since 1952. Observation of fine structure has been accordingly possible and the taxonomy of this group is now greatly advanced by this new technique (Defrandre 1952, Halldal and Markali 1954, Gaarder 1962.).

McIntyre and Bé's work (1967) on the distribution of the Atlantic coccolithophorids may be an epoch making study in this field. They compared living coccolithophorids with the fossil coccoliths found in the deep-sea cores of the Atlantic. However, distribution of coccolithophorids in the Pacific has been little known prior to the author's study, even though there were already present some works on distribution of these minute organisms made under optical microscope (Norris 1961, Hasle 1959, 1960.).

Geographical distribution, ecology and classification of coccolithophorids in the North and Equatorial Pacific, systematically sampled will be first given in the present paper.

Before stepping further into description, the author would like to acknowledge Professor Masao Minato for his continuous guidance and encouragement. He wishes to thank Dr. Susumu Honjo and Dr. Makoto Kato for their helps in various ways. He wishes to extend his cordial thanks to Dr. Tokimi Tsujita, scientific members and crews of R/V Oshoro-maru during the cruise for sampling. He is also grateful to Dr. Ryuzo Marumo, scientific members and crews of R/V Hakuho-maru for their kindness during the cruise.

2) Sampling

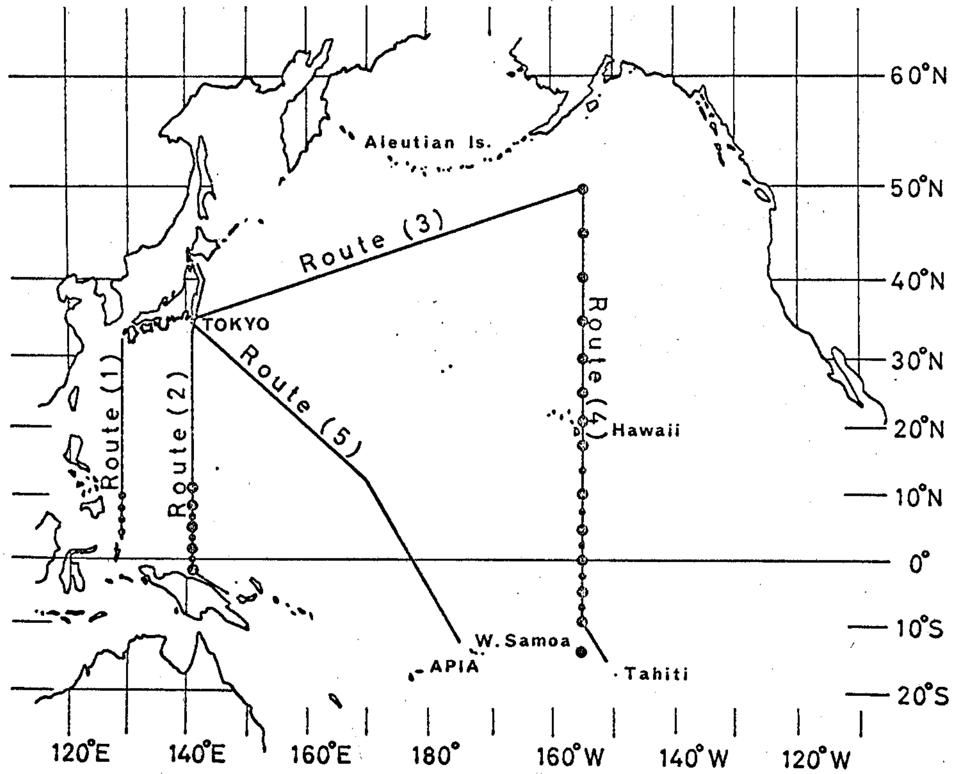
About 700 samples of water were collected along five survey routes, (1) from off Kyushu to Port Darwin along the $129^{\circ}E$ meridian, (2) from off Hokkaido to the northern waters of New Guinea along the $142^{\circ}E$ meridian, (3) diagonally from $35^{\circ}N$ to $50^{\circ}N$ along the route from Tokyo to the $50^{\circ}N$ $155^{\circ}W$ point, (4) from $50^{\circ}N$ to $16^{\circ}S$ along the $155^{\circ}W$ meridian and (5) diagonally from $35^{\circ}N$ to $13^{\circ}S$ along the Apia-Tokyo route (Fig. 1).

Samples have been systematically collected from November 1968 to January 1969 along the routes (1) and (2) by the research vessel "Oshoro-maru", Hokkaido University. A short summary on route (1) and (2) was already published by Okada and Honjo (1970).

Systematic samples along the routes (3), (4) and (5) have been collected from August to November 1969, by the research vessel "Hakuho-maru", Tokyo University. A part of the study dealt with those samples was already given by Okada (1970).

The water samples were collected from sea surface either at intervals of one degree of latitude or a half degree of latitude in the tropical region. The vertical samples of water purposely collected at nineteen stations along the route (4). Namely, every 10 or 25 meter depth from the surface untill 200 meters in depth. Sea water samples were collected in those nineteen stations above stated on the route (4). In addition to such samples of the euphotic

Fig. 1. Sampling routes and sampling stations



Large solid circles represent the major stations where vertical samples were thoroughly collected from the euphotic and subphotic layers. Small solid circles represent the minor stations where vertical samples were collected only from the euphotic layer.

layer, subphotic samples were further collected from 200 meter depth successively down to the sea bottom for fifteen stations amongst the nineteen stations in the same route (4).

Ten or two litres of water samples were pre-filtered with a brass wire filter (pore diameter; 150 microns), then put through a type AA millipore filter (pore diameter; 0.8 microns) immediately after the sampling. Salt was then removed by adequate distilled water. The sheets of the millipore filter with the residue were dried in an oven at 50°C for a few hours and delivered to the laboratory in an air tight plastic container.

3) Techniques

3a) Preparation for optical microscopy

A piece ofthe filter with residue (1cm X 1cm) was immersed by a drop of Cargile oil for study of coccolithophorid population.

Coccolithophorids on the millipore filter were counted for the whole area of a preparate under high magnification of polarized image. Based on the counted coccolithophorids, population corresponding to the unit volume (one liter) of the water was thus estimated.

3b) Preparation for electron microscopy

A piece of the filter with residue was placed directly in the vacuum evaporator (Shimadzu type SM-400G-SP) and was shadowed with Pt-Pd at 45° shadowing angle. It was then uniformly coated with carbon by the rotary shadowing apparatus.

The filter was removed by soaking in an aceton bath. The thin replica film with residue was placed in a strong oxidizing solution to remove calcareous skeletons and organic matters. The replica was then washed in distilled water, and mounted on a 150 mesh electron microscope grid (Okada and Honjo 1970).

The grids were observed in the electron microscope (Hitachi type HU-11B).

4) Surface distribution of coccolithophoridae

4a) Along the 155°W route (Route (4))

Through the study of the population and specific assemblage of coccolithophorids, six biogeographic zones were distinguished along the 155°W (Fig. 2). Each zone here designated means the seaways characterized by one or the combination of dominant forms of coccolithophorids. Therefore, it dose not involve any stratigraphical meaning.

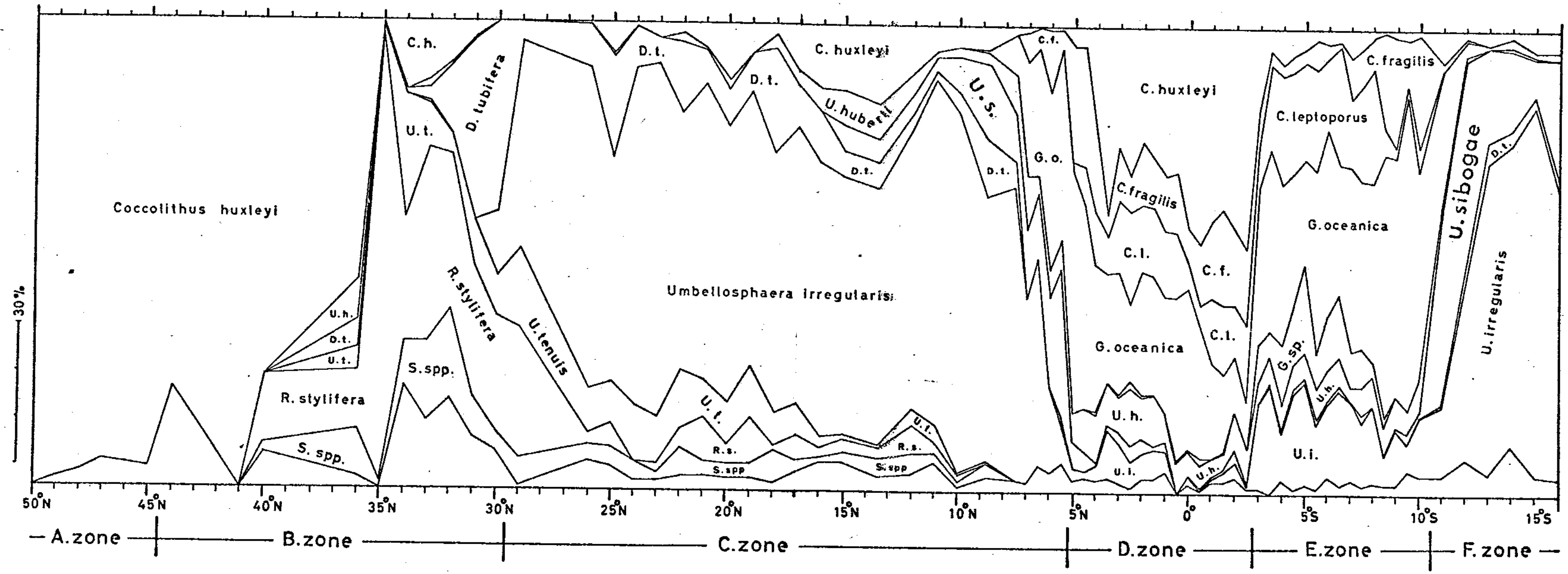
They are named as follows:

- o A zone (50°N - 45°N)
- o B zone (44°N - 30°N)
- o C zone (29°N - 5°30'N)
- o D zone (5°N - 2°30'S)
- o E zone (3°S - 10°S)
- o F zone (11°S - 16°S)

The A zone is especially rich in coccolithophorids, of which Coccolithus huxleyi is highly populated with sub-ordinate number of species belonging to the genus Syracosphaera.

The B zone is generally low in population, although it may be divisible into two sub-zones in from degree of population or the specific assemblage of coccolithophorids (Fig. 6). Coccolithus huxleyi is also fairly dominant in the northern sub-zone of this zone. While, in the southern sub-zone, Rhabdosphaera stylifera, Discosphaera tubifera and Umbellosphaera tenuis become to be increasing in population instead of

Fig. 2. Surface distribution of coccolithophoridae along the 155°W route



C.h.	Coccolithus huxleyi
C.f.	Cyclococcolithus fragilis
C.l.	Cyclococcolithus leptopolus
G.o.	Gephyrocapsa oceanica
G.sp.	Gephyrocapsa sp. A
U.h.	Umbilicosphaera hulburtiana
U.s.	Umbilicosphaera sibogae
D.t.	Discosphaera tubifera
U.i.	Umbellosphaera irregularis
U.t.	Umbellosphaera tenuis
R.s.	Rhabdosphaera stylifera
S.spp.	Syracosphaera spp.

Coccolithus huxleyi. Several species of the genus *Syracosphaera* together with holococcolithophorids are present, although not richly found.

The C zone is charactristic in low population of coccolithophorids, although it slightly changes from north to south. However, *Umbellosphaera irregularis* is a predominant species throughout the entire area of this zone. The pattern of specific assemblage is comparatively uniform throughout this zone, although relatively small changes may be recognizable at 25°N, 17°N, 10°N and 7°30'N as Fig. 2 shows.

The D zone shows large population. *Coccolithus huxleyi*, *Cyclococcolithus fragilis*, *Cyclococcolithus leptopolus*, *Gephyrocapsa oceanica* and *Umbilicosphaera hulburtiana* are common in the entire zone. The southern seaway (0°30'N) of this zone seems however to have relatively low population than the northern seaway, where *Umbellosphaera irregularis* is decreasing in number against gradual increasing of *Coccolithus huxleyi*.

The E zone is also comparatively large in population and *Cyclococcolithus fragilis*, *Cyclococcolithus leptopolus*, *Gephyrocapsa oceanica*, *Gephyrocapsa* sp. *A* and *Umbellosphaera irregularis* are commonly found. The degree of occurrence of *Cyclococcolithus leptopolus*, *Gephyrocapsa* sp. *A* and *Umbellosphaera irregularis* is, however, decreasing in the south of 8°S.

The F zone shows a comparatively small population. *Umbellosphaera irregularis* is a dominant species and *Umbilicosphaera sibogae* is rather common in this zone.

4b) Along the Apia-Tokyo route (Route (5))

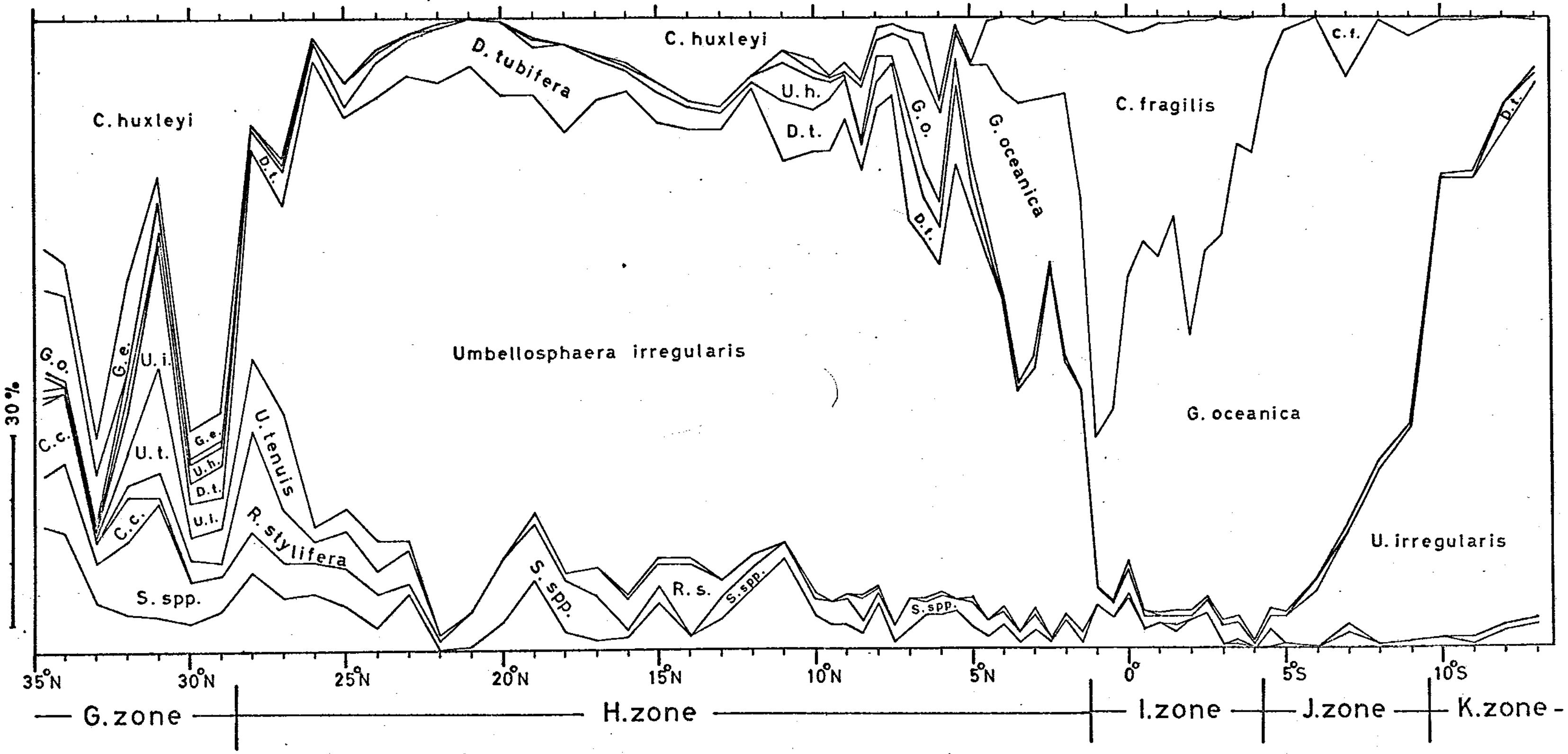
The population and specific assemblage along the Apia-Tokyo route are divided into five zones (Fig. 3). For explanation, these zones are here provisionally named as follows:

- o G zone ($34^{\circ}40'$N - 29°N)
- o H zone (28°N - $1^{\circ}30'$N)
- o I zone (1°N - 4°S)
- o J zone ($4^{\circ}30'$S - 9°S)
- o K zone (the south of 10°S)

The G zone has a large population in the northern part and the population abruptly reduces in size in its southern part. Coccolithus huxleyi is the most dominant form in this zone, and Gephyrocapsa ericsoniae, Gephyrocapsa oceanica, Umbellosphaera irregularis and Calciopuppus caudatus accompany with the former in population. Gephyrocapsa oceanica is reduced and Umbellosphaera irregularis and Umbellosphaera tenuis are increasing in number in the south of 32°N. In contrast, Calciopuppus caudatus is hardly found in the southern area beyond 30°N.

The H zone is characteristic in comparatively low population. Yet, Umbellosphaera irregularis is dominant throughout the whole area of this zone. Coccolithus huxleyi, Cyclococcolithus fragilis, Gephyrocapsa oceanica, Discosphaera tubifera and Rhabdosphaera stylifera are also commonly found. Somewhat significant changes on the specific assemblage are recognized at 21°N, 8°N and 5°N.

Fig. 5. Surface distribution of coccolithophoridae along the Apia-Tokyo route



C.f.	Cyclococcolithus fragilis	U.i.	Umbellosphaera irregularis
G.e.	Gephyrocapsa ericsoniae	U.t.	Umbellosphaera tenuis
G.o.	Gephyrocapsa oceanica	R.s.	Rhabdosphaera stylifera
U.h.	Umbilicosphaera hulburtiana	C.c.	Calciopuppus caudatus
D.t.	Discosphaera tubifera	S.spp.	Syracosphaera spp.

The I zone has a large population. Cyclococcolithus fragilis and Gephyrocapsa oceanica are especially dominant than the other species.

The J zone is also characterized by relatively low population far fewer than the H zone. Gephyrocapsa oceanica is, however, rather dominant and Umbellosphaera irregularis is also fairly rich in population than in the preceding zone.

The K zone has a low population. Umbellosphaera irregularis become rather dominant and Gephyrocapsa oceanica is decreasing in population towards south.

5) Biogeographical zones and current systems

Geographical boundaries between the zones in the both 155^{o}W route (Route 4) and Apia-Tokyo route (Route 5) mark nearly the same latitude with each other. Namely, the B zone in the 155^{o}W route corresponds to the G zone in the Apia-Tokyo route, the C zone in the 155^{o}W route to the H zone in the Apia-Tokyo route, and so on. All these boundaries stated in the preceding chapter seem to be parfectly parallel to the latitude. Accordingly, the zones established by the special assemblage and population of coccolithophorids in the present study are now supposed to have certain and intimate relationship with the current system in the Pacific.

Further, a mutual relationship is recognized among the biogeographic zones (Fig. 2, Fig. 3), the coccolithophorid population (Fig. 4, Fig. 5) and the distribution of salinity and temperature (Fig. 6, Fig. 7).

Marumo, Nakai and Hasumoto (1970) classified the current systems along the 155^{o}W meridian as follows:

50^{o}N - 45^{o}N ---- the Pacific Sub-Arctic Current
45^{o}N - 25^{o}N ---- the North Pacific Current
(45^{o}N - 35^{o}N)---- the Kuroshio Extension
25^{o}N - 10^{o}N ---- the North Equatorial Current
10^{o}N - 5^{o}N ---- the Equatorial Counter Current
south of 5^{o}N --- the South Equatorial Current

The A zone seems to be corresponding to the Sub-Arctic Current. The population of coccolithophorids is the largest

Fig. 4. Salinity and temperature in the surface layer along the 155°W route

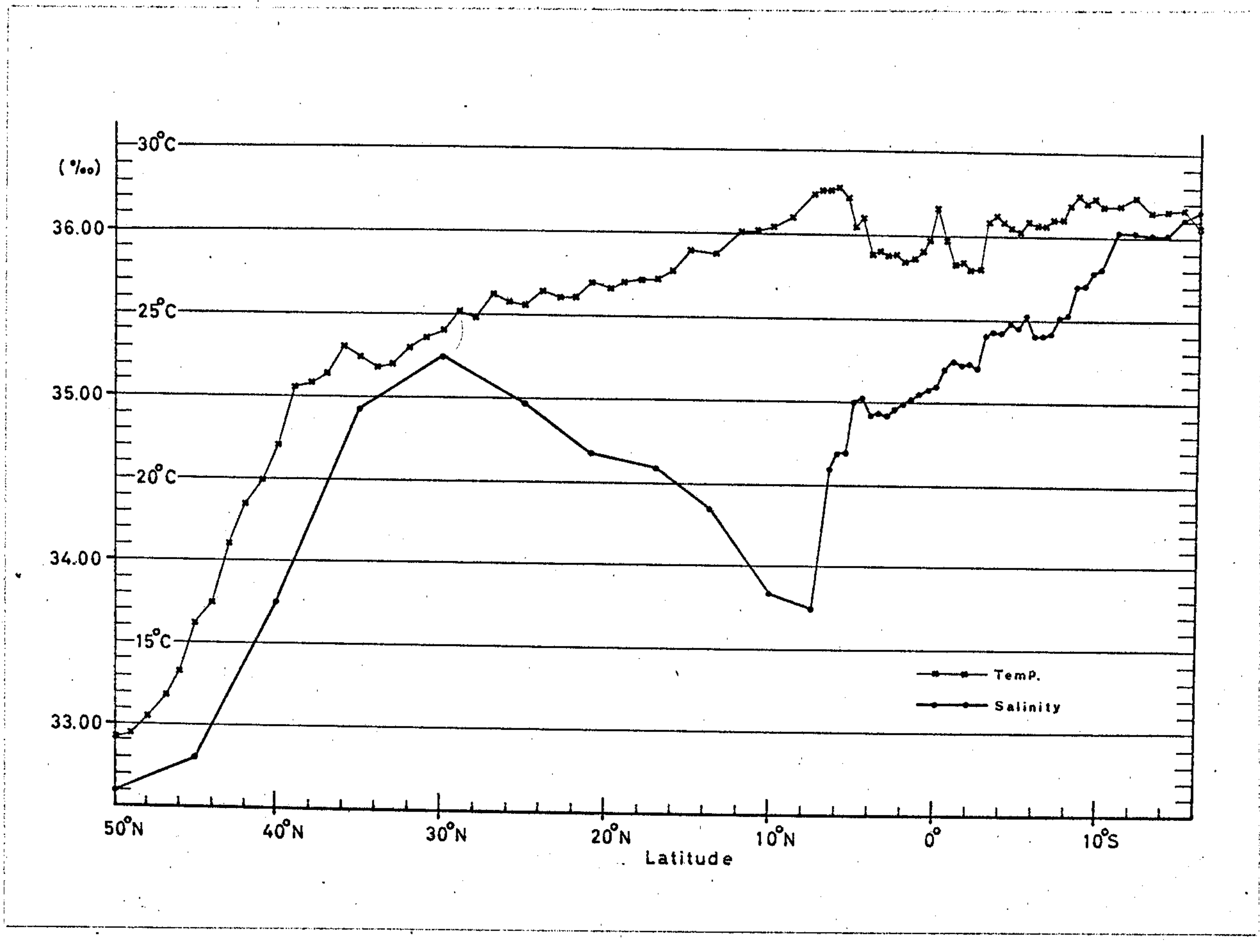


Fig. 5. Salinity and temperature in the surface layer along the Apia - Tokyo route

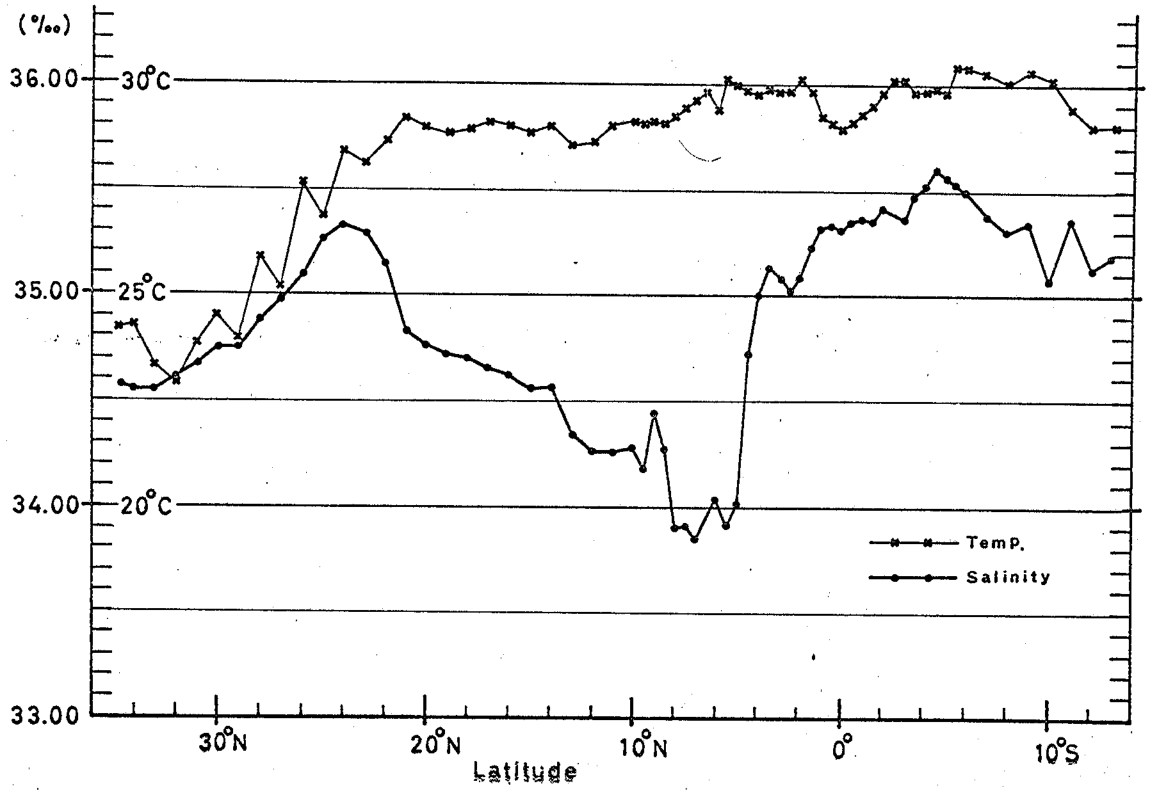


Fig. 6. Coccolithophorid population in the surface layer along the 155°W route

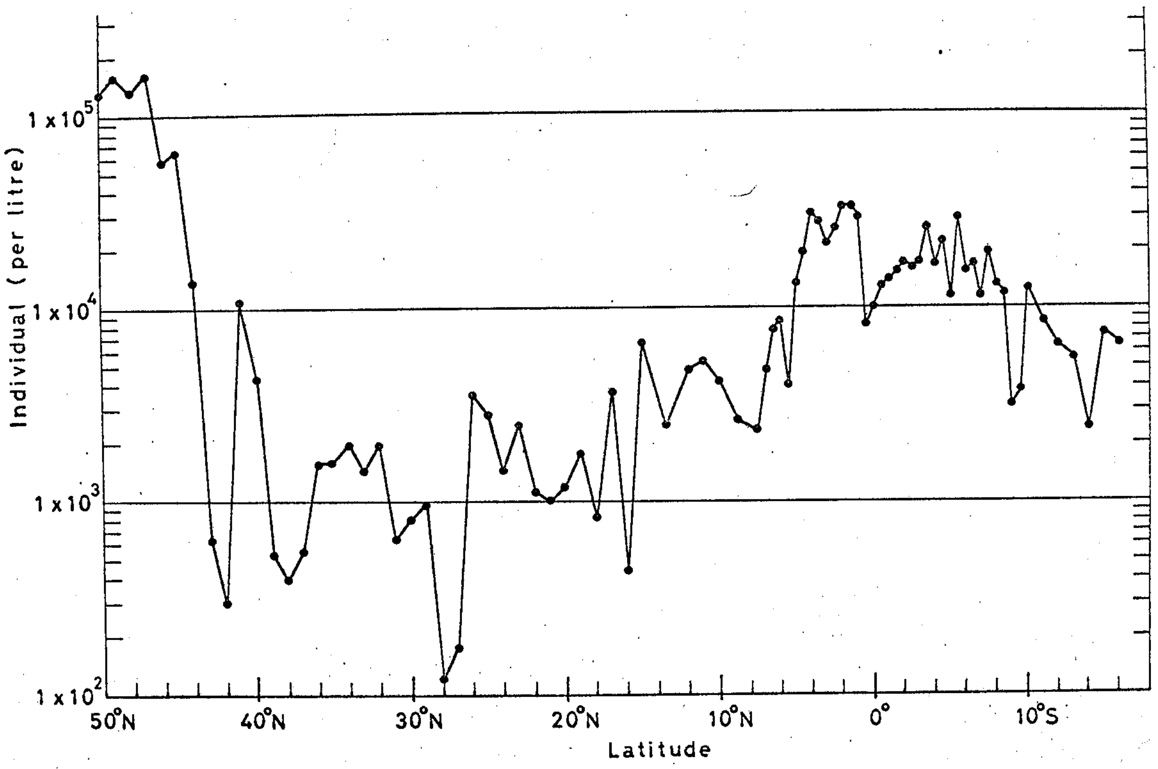
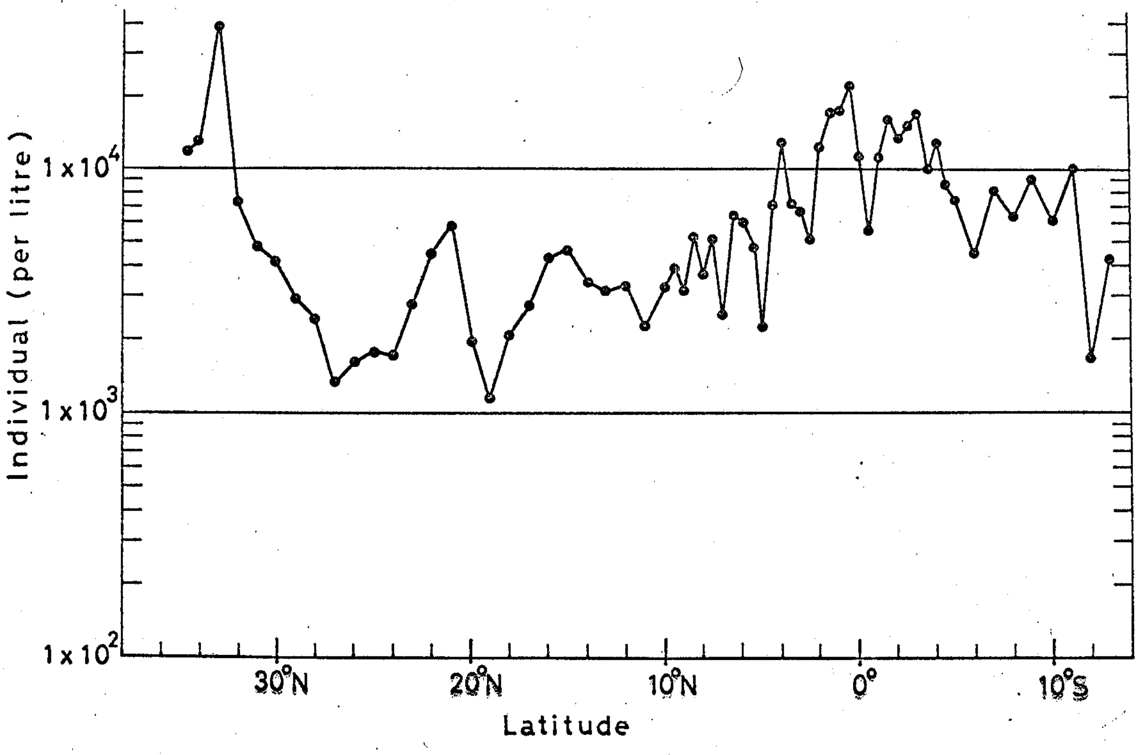


Fig. 7. Coccolithophorid population in the surface layer along the Apia - Tokyo route



and the salinity and temperature are low in this current.

In the B zone, a significant change is recognized at 35°N along the 155°W route in specific assemblage, which definitely shows the southern boundary of the Kuroshio Extension. The northern sub-zone is characterized by the dominance of *Coccolithus huxleyi*, and the similar specific assemblage is also observed in the Kuroshio area along the Apia-Tokyo route.

The C zone characterized by the predominance of *Umbellosphaera irregularis* corresponds to the area characterized by both the North Equatorial Current and the Equatorial Counter Current. Although the area, north to 25°N also belongs to the North Pacific Current; this area may be considered as the transitional zone between the B zone and C zone.

The H zone is doubtlessly corresponding to the C zone from the floral assemblage. The degree of predominance of *Umbellosphaera irregularis* is, however, a little larger in the H zone than in the C zone. The area between 10°N and 5°N in the C zone corresponds to the Equatorial Counter Current and should be distinguished from the North Equatorial Current. However, the significant difference cannot be recognized between these two currents in the specific assemblage. The area extending from 7°30'N to 5°N in the C zone characterized by the mixed floral assemblage extends in the area of the South Equatorial Current and the Equatorial Counter Current. This is also found in the area from 5°N to 1°30'N in the H zone. The specific assemblage remarkably changes in this mixed zone. The salinity and temperature also abruptly change in these mixed zones and the change of water mass is clearly recognized.

The area south to 5°N along the 155°W route almost wholly corresponds to the South Equatorial Current, the specific assemblage varies in this current from north to south. The D zone and E zone along the 155°W route are considered to belong to the same biogeographical zones of the I zone and J zone along the Apia-Tokyo route respectively. *Cyclococcolithus fragilis* and *Gephyrocapsa oceanica* play an important role in the specific assemblage in the I zone, while the specific assemblage is more complex in the D zone.

In the D zone, *Coccolithus huxleyi* and *Gephyrocapsa oceanica* are predominant species and *Cyclococcolithus fragilis*, *Cyclococcolithus leptopolus*, *Umbilicosphaera hulburtiana* and *Umbellosphaera irregularis* are commonly found. The population is high in both zones. However, it abruptly decreases in the area near the Equator. The salinity and temperature show a resembled pattern in these two zones; the temperature shows low in degree while the salinity shows high in degree.

The E zone and J zone show a similar pattern of the specific assemblage that *Gephyrocapsa oceanica* is predominant and *Umbellosphaera irregularis* is abundant. These two species form the majority of the specific assemblage in the J zone, but *Cyclococcolithus fragilis*, *Cyclococcolithus leptopolus*, *Gephyrocapsa* sp. *A* and *Umbellosphaera hulburtiana* are fairly common in the E zone besides the two species above mentioned. The population is higher in the E zone than in the J zone.

The temperature is generally higher along the Apia-Tokyo route than in the 155°W route. The surface temperature of the J zone is approximately 2°C higher than in the D zone. The salinity in these two zones shows a reverse in condition viz., it is higher in the southern area of the E zone and lower in the southern area of the J zone.

The F zone and K zone are considered to be the same biogeographic zone. Umbellosphaera irregularis is predominant in these zones. This species is also predominant in the C zone and H zone. Umbilicosphaera sibogae is abundant in the F zone, while rarely found in the J zone. Gephyrocapsa oceanica is fewer in the F zone, while greater in the J zone in population. Although the entire population of coccolithophorids shows a similar pattern in both the F and J zones, the salinity of seawater is remarkably different in these zones. The salinity is high in the southern area of the F zone, while it is low in the southern area of the J zone.

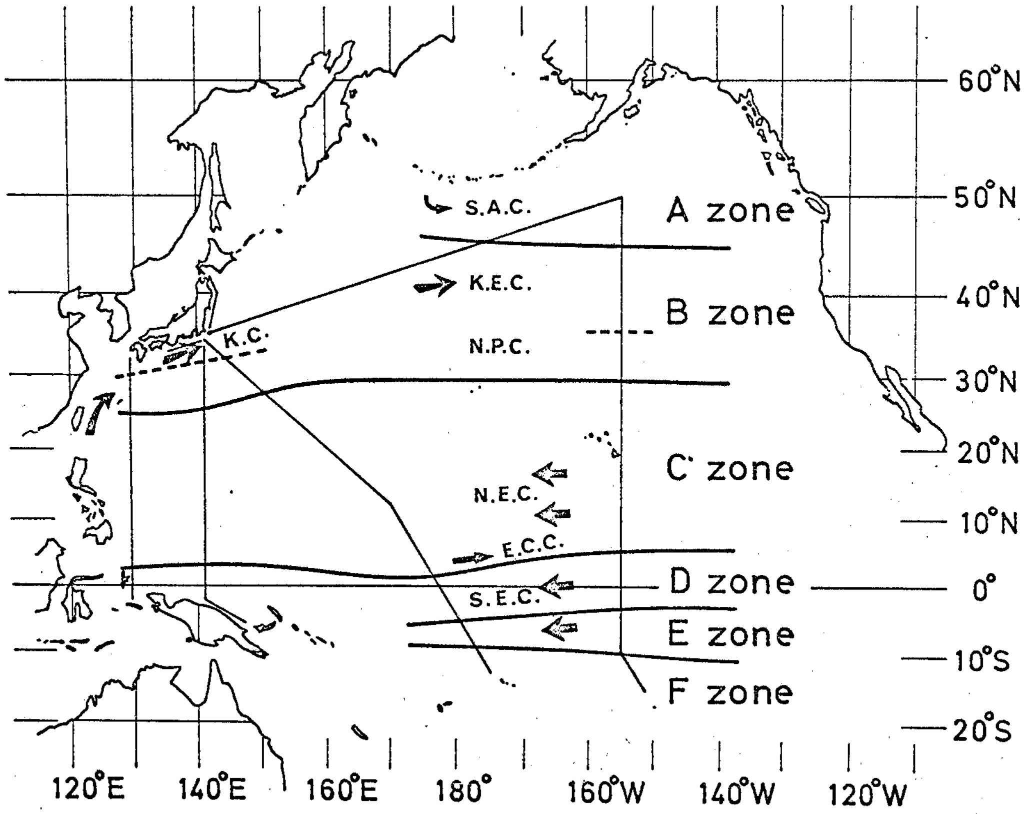
Accordingly, the biogeographical zones so far described in this paper are now well established. Surface distribution of the Pacific coccolithophorids is well demonstrated by the present study. The boundaries between biogeographic zones of coccolithophorids may be concluded as shown in Fig. 8.

The Correspondence between each biogeographic zone of coccolithophorids and the current system may be enumerated:

A zone ---- the Sub-Arctic Current

B zone ---- the North Pacific Current (partly the Kuroshio Extension)

Fig. 8. The biogeographic zones of coccolithophorids and ocean current systems.



S.A.C. ---- the Sub-Arctic Current

K.C. ---- the Kuroshio

K.E.C. ---- the Kuroshio Extension

N.P.C. ---- the North Pacific Current

N.E.C. ---- the North Equatorial Current

E.C.C. ---- the Equatorial Counter Current

S.E.C. ---- the South Equatorial Current

C zone ---- the North Equatorial Current and the Equatorial Counter Current

D zone ---- the northern part of the South Equatorial Current

E zone ---- the central part of the South Equatorial Current

F zone ---- the southern part of the South Equatorial Current

6) Vertical distribution of coccolithophoridae

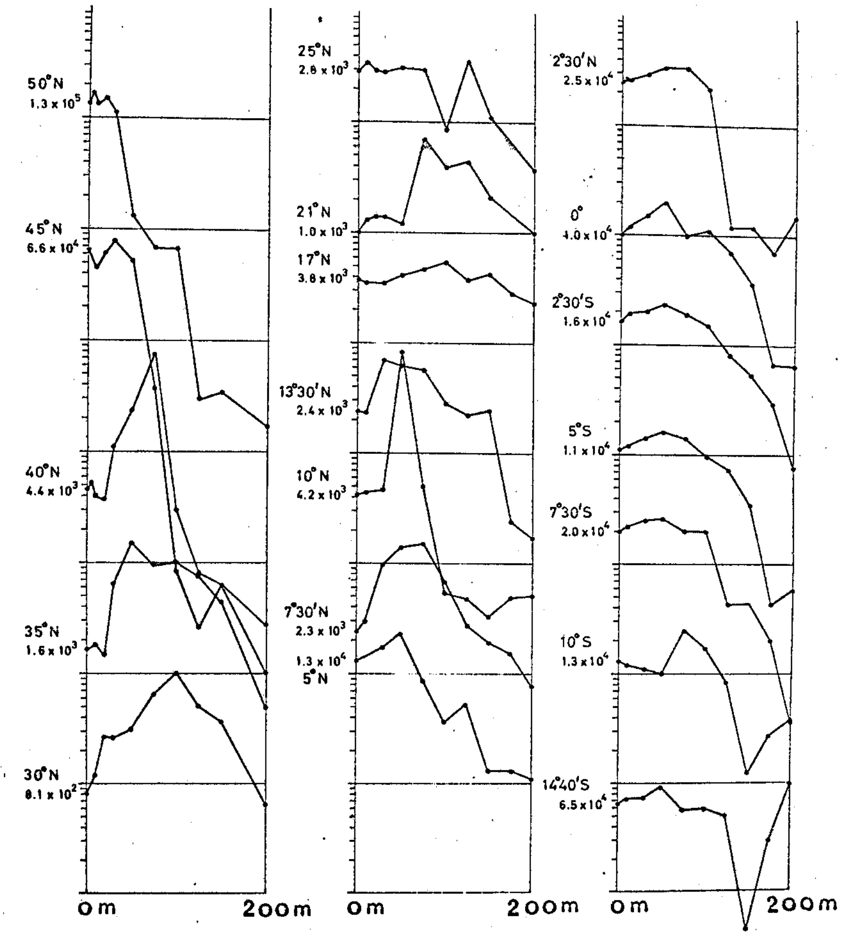
6a) Vertical change of population

A series of samples was systematicaly collected from the various layers of the euphotic zone at the nineteen stations which were set up along the 155°W route. The vertical change of population of coccolithophorids in these stations is shown in Fig. 9.

At the two stations, 50°N and 45°N respectively, belonging to the A zone, temperature of seawater is nearly the same with each other and the population is high through the upper euphotic layer. Below 50m in depth, temperature suddenly falls down, and population number also abruptly decreases in both middle and lower euphotic layers.

At the three stations (40°N, 35°N, 30°N) belonging to the B zone, population is rather small in the surface layer, but it is remarkably increasing in the middle euphotic layer. The latter is ten times larger than the former. The population is generally lower in the southern station than in the northern station. At the 40°N station which is situated at the Kuroshio Extension, the tendency of population in the middle and lower euphotic layers resembles the two stations of 50°N and 45°N, both belonging to the A zone. The decreasing ratio, viz., population gradually decreasing from the middle to lower euphotic layer is especially remarkable in the two stations (35°N, 30°N) belonging to the North Pacific Current.

Fig. 9. Vertical change of coccolithophorid population in the euphotic layers along the 155°W route



At six stations (25°N - 7°30'N) belonging to the C zone, population is the largest in the middle euphotic layer although the variation of population is small through the entire layers. The particular pattern of population is recognized at the 10°N station. There, the population is abnormally large in the 50m deep layer while it is small in the upper layer. This peculiar pattern may be due to the existence of the cold under current. (see Fig. 17)

At the four stations (5°N - 2°30'S) belonging to the D zone, population shows an especially high level for the whole layers and the degree of decreasing in population from the middle to lower euphotic layers tends to be less remarkable in the southern stations.

At the three stations (5°S - 10°S) belonging to the E zone, population is observed to be again increasing in the lower euphotic layer deeper than 150m, although it is decreasing in the middle-lower euphotic layer.

At the 14°40'S station belonging to the F zone, population is rather constant in the upper and middle euphotic layers shallower than 125m, but the population falls down remarkably in the 150m deep layer. Further, it again increases in the lower layer below 175m and the population reaches the maximum in the 200m deep layer. This abnormaly high population in the lower euphotic layers may be due to the predominance of the particuler coccolithophorid group. The minimum population at the 150m deep layer just coincides with the boundary between the deep and shallow flora. Both eurybathic and stenobathic species will be later mentioned some in detail.

6b) Specific assemblages in the euphotic layer

The specific assemblages in the euphotic layer are studied at the nineteen stations along the 155°W route. The results are shown in Table to .

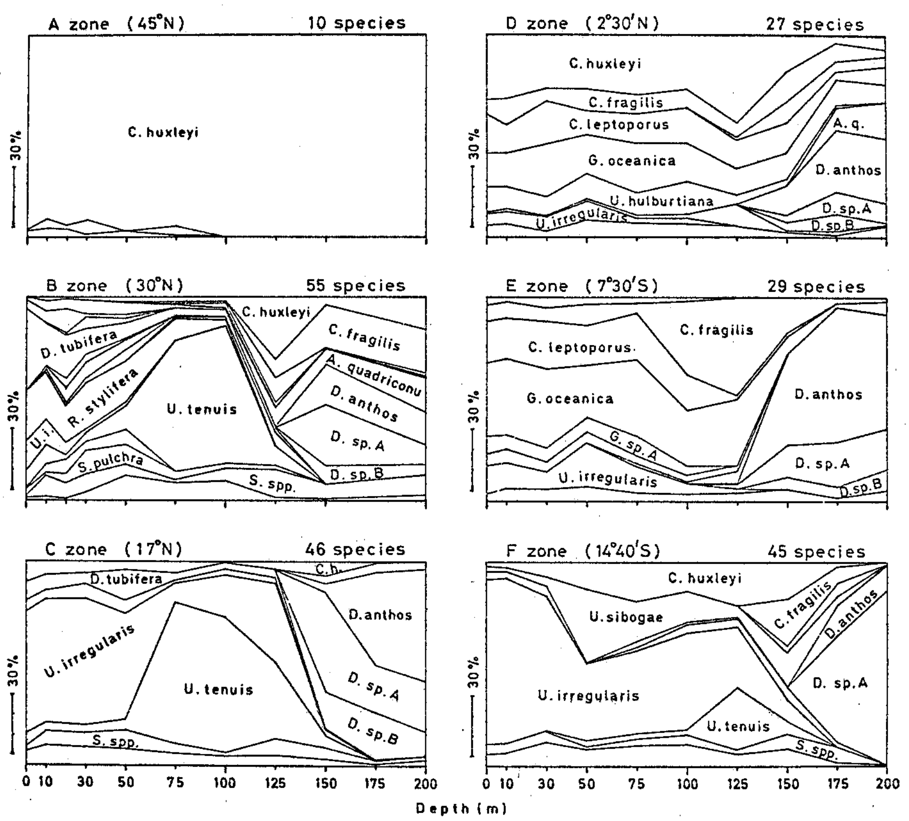
Through these table, six zones [illegible] originally established by the surface distribution of coccolithophorids may be quite significant units even for the middle and lower euphotic layers. Although, the transitional tendency is present in each marginal part of neighboring zones, in respect to the vertical distribution of coccolithophorids, definite and proper pattern in population and assemblage characterizing each zone can be still recognized throughout entire euphotic layers.(Fig. [illegible]).

The representative stations are chosen from each of the six zones and their typical patterns of the vertical specific assemblages are shown in Fig. 10.

In the A zone, Coccolithus huxleyi is predominantly found in the whole layers of the euphotic zone. Acanthoica acanthifera is common in the upper layer and Calciopuppus caudatus is also commonly found in the middle euphotic layer. The number of species is so small and only ten species are detected at the 45°N station.

In the B zone, Discosphaera tubifera and Rhabdosphaera stylifera are abundantly found, Acanthoica quatrospina, Caliptrosphaera oblonga, Umbellosphaera irregularis, Umbellosphaera

Fig. 10. Vertical distribution of coccolithophoridae in the euphotic layers at each representative station



C.h.	Coccolithus hucleyi
G.sp.A	Gephyrocapsa sp. A
A.q.	Anthosphaera quadriconu
D.sp.A	Deutschlandia sp. A
D.sp.B	Deutschlandia sp. B
U.i.	Umbellosphaera irregularis
S.spp.	Syracosphaera spp.

tenuis, *Syracosphaera mediterania* and *Syracosphaera pulchra* are commonly found in the upper euphotic layer. *Umbellosphaera tenuis* is predominant and the other species are rarely found in the middle euphotic layer. *Coccolithus huxleyi*, *Cyclococcolithus fragilis*, *Anthosphaera quadriconu*, *Deutschlandia* sp. *A* and *Deutschlandia* sp. *B* are richly found in the lower euphotic layer. The number of species significantly varies in the southern area and fifty-five species are found at the 30°N station.

In the C zone, *Umbellosphaera irregularis* is a leading form, while *Coccolithus huxleyi*, *Discosphaera tubifera* and *Rhabdosphaera stylifera* also fairly abundant in the upper euphotic layer. *Umbellosphaera tenuis* is the most predominant species, and *Umbellosphaera irregularis* and *Coccolithus huxleyi* are richly present in the middle euphotic layer. While, *Deutschlandia anthos*, *Deutschlandia* sp. *A* and *Deutschlandia* sp. *B* take an important role in the specific assemblage of the lower euphotic layer. The number of species tends to be reducing and forty-six species are observed at the 17°N station.

In the D zone, the specific assemblage is uniform in the upper and middle euphotic layers, *Coccolithus huxleyi*, *Cyclococcolithus fragilis*, *Cyclococcolithus leptopolus*, *Gephyrocapsa oceanica*, *Umbilicosphaera hulburtiana* and *Umbellosphaera irregularis* are commonly found. While, *Anthosphaera quadriconu*, *Deutschlandia anthos*, *Deutschlandia* sp. *A*, *Deutschlandia* sp. *B* and *Cyclococcolithus fragilis* var. *A* are leading forms in the lower euphotic layer. The number of species is small and twenty-seven species are recognized at the 2°30'N station.

In the E zone, Cyclococcolithus fragilis, Cyclococcolithus leptopolus, Gephyrocapsa oceanica, Gephyrocapsa sp. A and Umbellosphaera irregularis are especially flowrishing in the upper euphotic layer, while Cyclococcolithus fragilis and Gephyrocapsa oceanica are predominant in the middle euphotic layer. Deutschlandia anthos, Deutschlandia sp. A and Deutschlandia sp. B occupy the greater part of the specific assemblage in the lower euphotic layer. The number of species is small and twenty-nine species are counted at the 7°30'S station.

In the F zone, Umbellosphaera irregularis is predominantly found in the upper euphotic layer, while Umbellosphaera irregularis, Umbilicosphaera sibogae, Coccolithus huxleyi, Cyclococcolithus fragilis and Umbellosphaera tenuis are common in the middle euphotic layer. Further, Deutschlandia anthos and Deutschlandia sp. A are fairly common in the lower euphotic layer. Species greatly increase in number and forty-five species are found at the 14°40'S station.

7) Species preference in surface and vertical distribution

7a) Species preference in surface distribution

The surface distribution of each species is considered to be mostly regulated by a physico-chemical environment such as chemical composition and temperature of sea water.

The relative abundance of the more important species along the 155°W route and the Apia-Tokyo route is shown in Fig. 11 and 12.

The six floral zones mentioned above are corresponding to the climate conditions as follows:

Tropical area	------	D zone and E zone
Sub-Tropical area	------	C zone and F zone
Temperate area	------	B zone
Sub-Arctic area	------	A zone

The preference of water temperature was already studied for certain species of the Atlantic coccolithophorids (McIntyre and Bé 1967).

The more important species of the Pacific coccolithophorids may be enumerated in decending order in population within respective climate area, together with the Atlantic forms of coccolithophorids:

	Pacific Ocean	Atlantic Ocean
Tropical area	*G. oceanica*	*U. irregularis*
	C. fragilis	*C. annulus*
	C. leptopolus	*C. fragilis*
	C. huxleyi	*U. tenuis*
	U. irregularis	*D. tubifera*
	Gephyrocapsa sp. *A*	*R. stylifera*
	U. hulburtiana	*H. carteri*
	U. sibogae	*G. oceanica*
		C. huxleyi
		C. leptopolus

Fig. 11. Relative abundance of important coccolithophorid species in the surface layer along the 155°W route

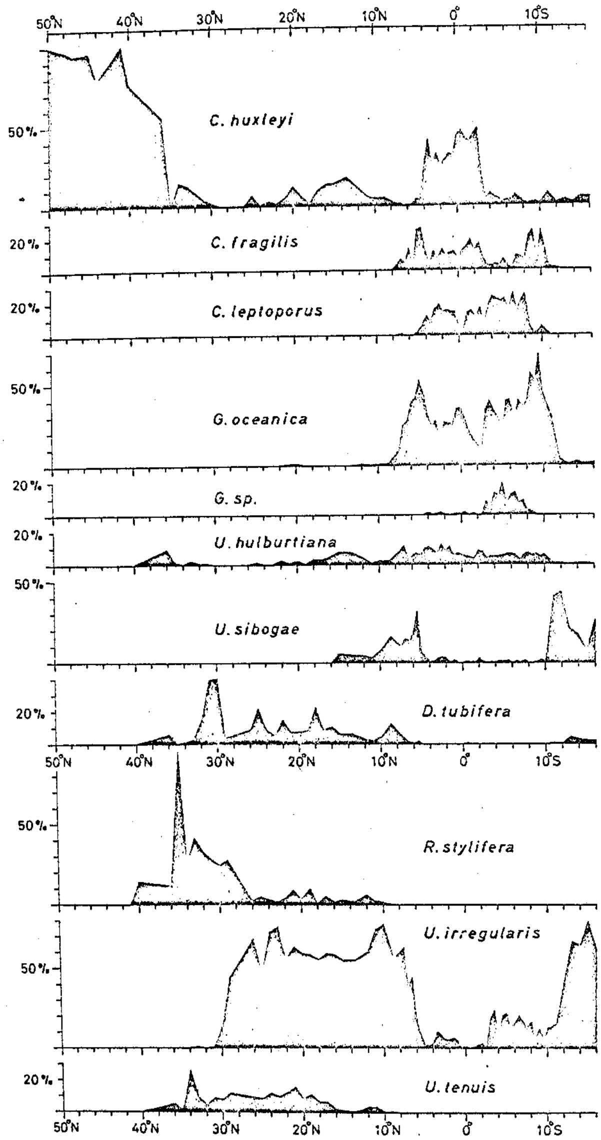
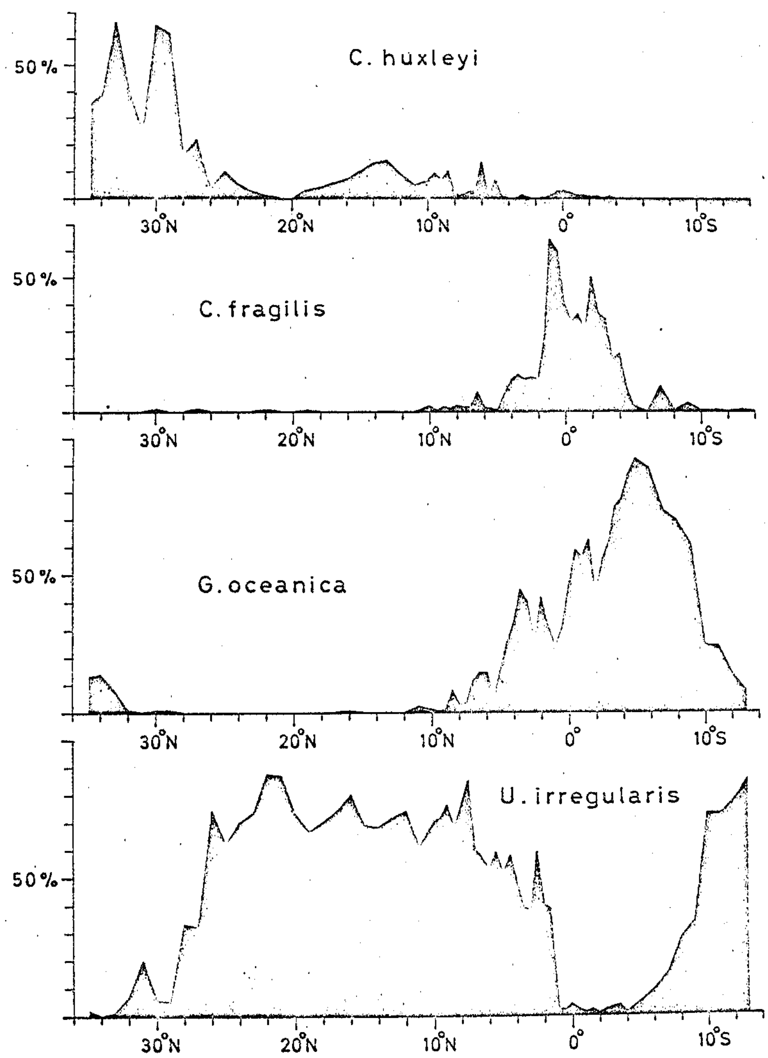


Fig. 12. Relative abundance of important coccolithophorid species in the surface layer along the Apia-Tokyo route



Sub-Tropical area	*U. irregularis*	*U. tenuis*
	C. huxleyi	*R. stylifera*
	D. tubifera	*D. tubifera*
	U. tenuis	*C. annulus*
	U. sibogae	*G. oceanica*
	R. stylifera	*U. mirabilis*
	U. hulburtiana	*H. carteri*
	G. oceanica	*C. leptopolus*
		C. fragilis
		C. huxleyi
Temperate area	*C. huxleyi*	*C. huxleyi*
	R. stylifera	*C. leptopolus*
	D. tubifera	*G. ericsoniae*
	U. tenuis	*R. stylifera*
		G. oceanica
		U. tenuis
		C. pelagicus
Sub-Arctic area	*C. huxleyi*	*C. pelagicus*
	C. caudatus	*C. huxleyi*
		C. leptopolus

Certain difference in horizontal distribution regarding to the climatic condition is observed between the present authers result of the Pacific and the Atlantic reported by McIntyre and Bé (1967).

The auther's data are however based on only from the collection of autumn; seasonal fluctuation of floral distribution has been not yet checked at all, in contrast to the case of study in the Atlantic. Further study should be required in purpose to settle the relationship between the ecological condition and horizontal distribution of each predominant species in both oceans.

7b) Species preference in vertical distribution

The relative abundance of important species in the entire euphotic layers along the 155°W route is shown in Figs. 13 to 16.

Coccolithus huxleyi is widely distributed from the subarctic to tropical area but remarkably fluctuate in population from latitude to latitude. This species predominates in the whole layers of the euphotic zone and especially in the middle euphotic layer of the tropical to temperate area. It is observed that the relative abundance of this species again increases in the lower euphotic layer of the certain temperate are.

Cyclococcolithus fragilis shows two different groups of tribution. This species is common in the middle-lower hotic layer of the temperate area, while it is uniformly tributed in the entire layers of the tropical euphotic .e, although it is a little increasing in the middle layer .ı its population.

Gephyrocapsa oceanica is selectively distributed in the tropical seaway. It is especially abundant in the upper and middle euphotic layers, although it is not seldom found even in the lower euphotic layer.

Cyclococcolithus leptopolus again shows two distinct groups of distribution. In the temperate seaway, it is rather reichly found in the middle and lower euphotic layers, while in the tropical seaway, it is more or less commonly found

Fig. 13. Relative abundance of important coccolithophorid species in the euphotic layers along the 155°W route

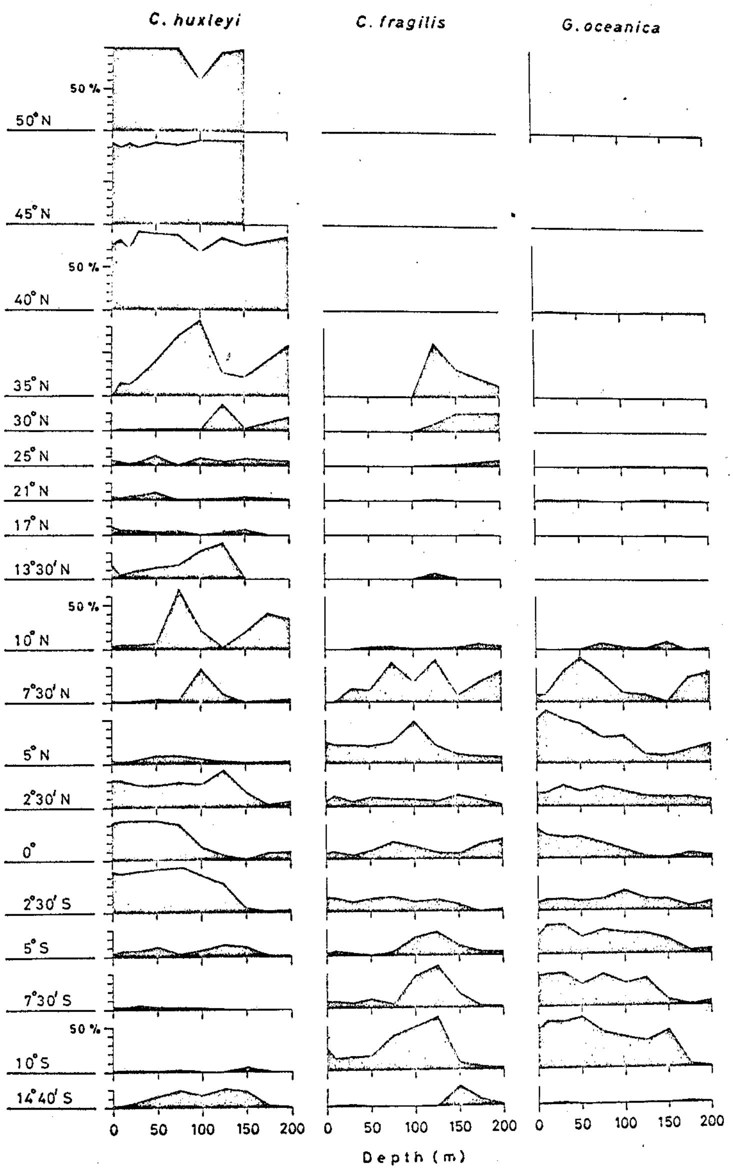


Fig. 14. Relative abundance of important coccolithophorid species in the euphotic layers along the 155°W route

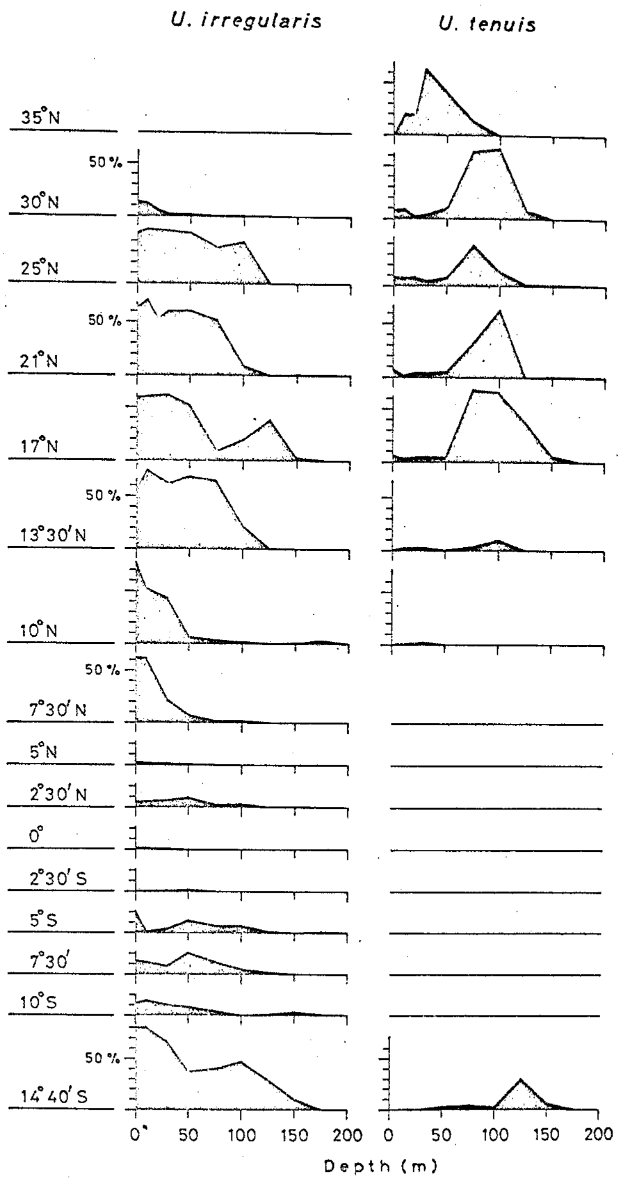


Fig. 15. Relative abundance of important coccolithophorid species in the euphotic layers along the 155°W route

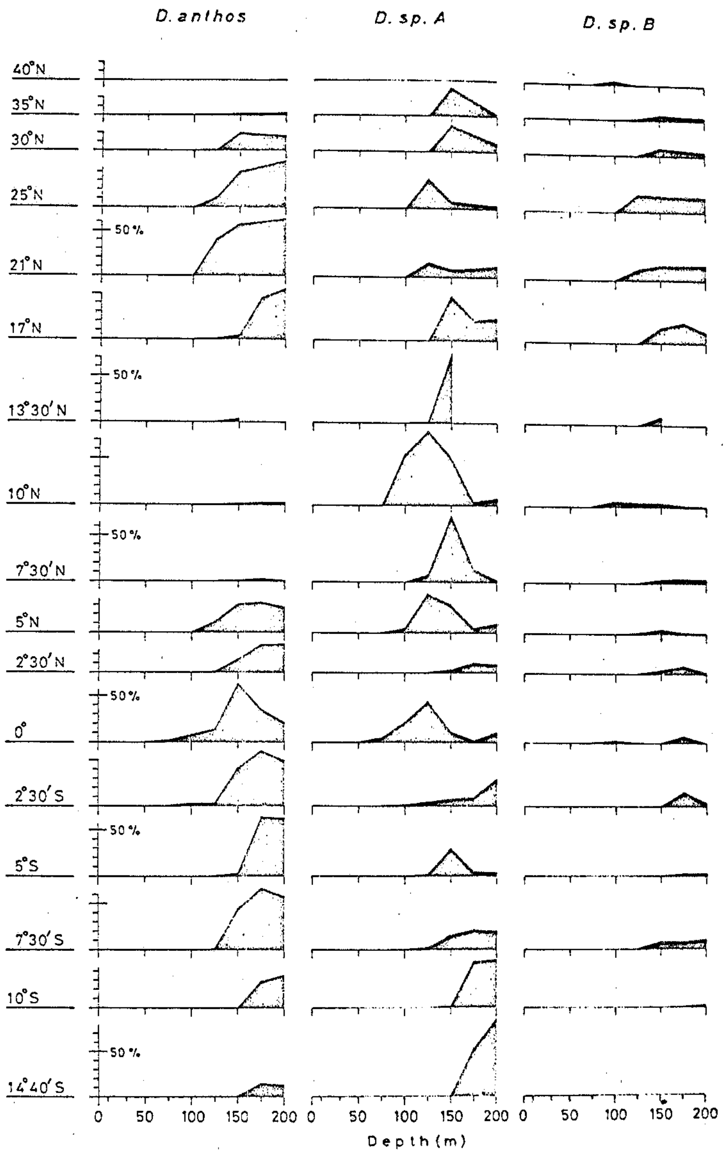
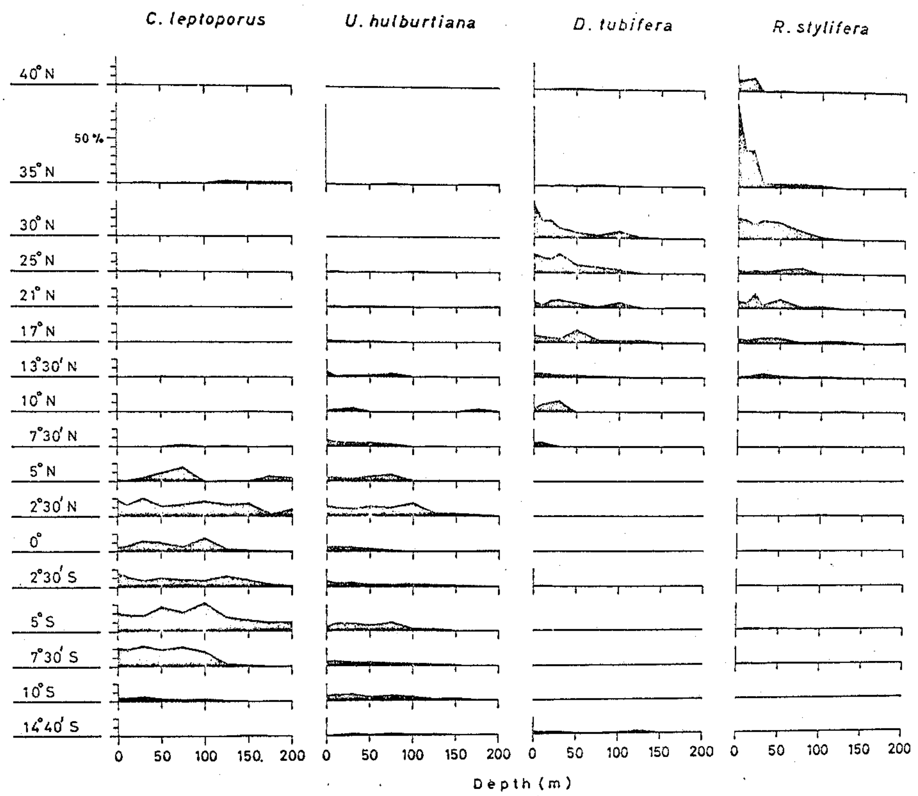


Fig. 16. Relative abundance of important coccolithophorid species in the euphotic layers along the 155°W route



in the upper and middle euphotic layers.

The distribution of Umbilicosphaera hulburtiana ranges from the temperate to tropical area. This species is abundantly found in the upper euphotic layer, is common in the middle euphotic layer and is rarely found in the lower euphotic layer.

Discosphaera tubifera is distributed in the temperate and sub-tropical area. This species is abundant in the upper euphotic layer, is rarely in the middle euphotic layer and is seldom found in the lower euphotic layer.

Rhabdosphaera stylifera is distributed in the temperate and sub-tropical area. The distribution of this species is rather limitted in north, compered with Discosphaera tubifera. This species is dominant in the upper euphotic layer, rarely found in the middle euphotic layer and is almost unobserved in the lower euphotic layer.

Umbellosphaera irregularis is distributed from the temperate to tropical area and is especially rich in the sub-tropical seaway. This species predominates in the surface and upper euphotic layers and is only occasionally found in the lower euphotic layer.

Umbellosphaera tenuis is distributed in the temperate and sub-tropical area. This species is commonly found in the upper euphotic layer and is abundantly found in the middle euphotic layer.

Deutschlandia anthos is confined in the lower euphotic layer in general, but it is richly distributed in two areas like temperate and tropical seas. In between the above two areas, it is almost lacking. This species is rarely found in the middle euphotic layer but is never found in the upper euphotic layer.

Deutschlandia sp. A is widely distributed in the entire area from the temperate to tropical. This species is especially rich in the middle-lower layer of the tropical seaway. Generally speaking, this species seems to prefer a layer a little above the preference "niveau" of Deutschlandia anthos.

Deutschlandia sp. B is also distributed from the temperate to tropical seaway. The feature of vertical distribution resembles that of Deutschlandia anthos and Deutschlandia sp. A, while the relative abundance is smaller than the other two species. This species is also never found in the upper euphotic layer.

In summary, the species preference in vertical distribution may be grouped as follows:

Upper euphotic layer species

Umbellosphaera irregularis
Discosphaera tubifera
Rhabdosphaera stylifera
Acanthoica quatrospina
Caliptrosphaera oblonga
Umbilicosphaera hulburtiana
Gephyrocasa sp. A

Middle euphotic layer species

Cyclococcolithus fragilis
Umbellosphaera tenuis

Upper and middle euphotic layer species

Coccolithus huxleyi
Gephyrocapsa oceanica
Cyclococcolithus leptopolus

Lower euphotic layer species

Deutschlandia anthos
Deutschlandia sp. *A*
Deutschlandia sp. *B*
Anthosphaera quadriconu
Cyclococcolithus fragilis var. *A*
Syracosphaera spp. (double layer stage)

8) Relationship between phytoplankton distribution and physico-chemical environment in the euphotic layer

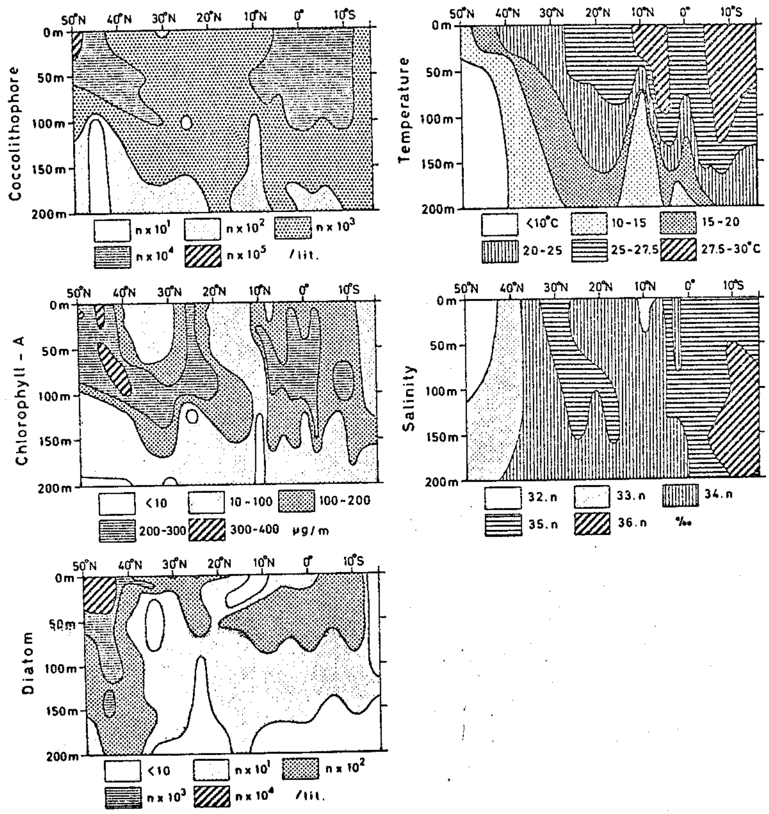
The distribution of coccolithophorids, diatoms, chlorophyll-A, temperature and salinity in the euphotic layer along the 155°E route are shown in Fig. 17.

Coccolithophorids and diatoms are considered to be important members for primary production. These two lives generally have similar pattern of distribution. However, coccolithophorid is one order higher than diatom in population throughout the whole area and vertical layers, excepting in the middle and lower layers of the high latitude area. Especially, the population of coccolithophorid is approximately two order higher than the diatom's in the tropical seaway.

Therefore it is, considered that coccolithophorid play the most important part on the primary production in the tropical area.

The relationship among the distribution of coccolithophorid, salinity and temperature is not well setteled yet. Nevertheless, in the area close to 10°N and 0°, the distribution of coccolithophorid and chlorophyll-A is observed to be greatly influenced by the existence of the cold under current.

Fig. 17. Distribution of coccolithophorid, diatom, chlorophyll-a, temperature and salinity in the euphotic layer along the 155°W route



Data on diatom population are after O. Asaoka (Ms.)

9) Distribution of free coccolith in subphotic layer

When a coccolithophorid dies, the organism is immediately decomposed by certain bacteria and the coccosphere may be disintegrated into free coccoliths.

When a coccolithophorid is eaten by a zooplankton, coccoliths are excreate as a fecal pellet and the greater part of them are also decomposed by bacteria into coccoliths.

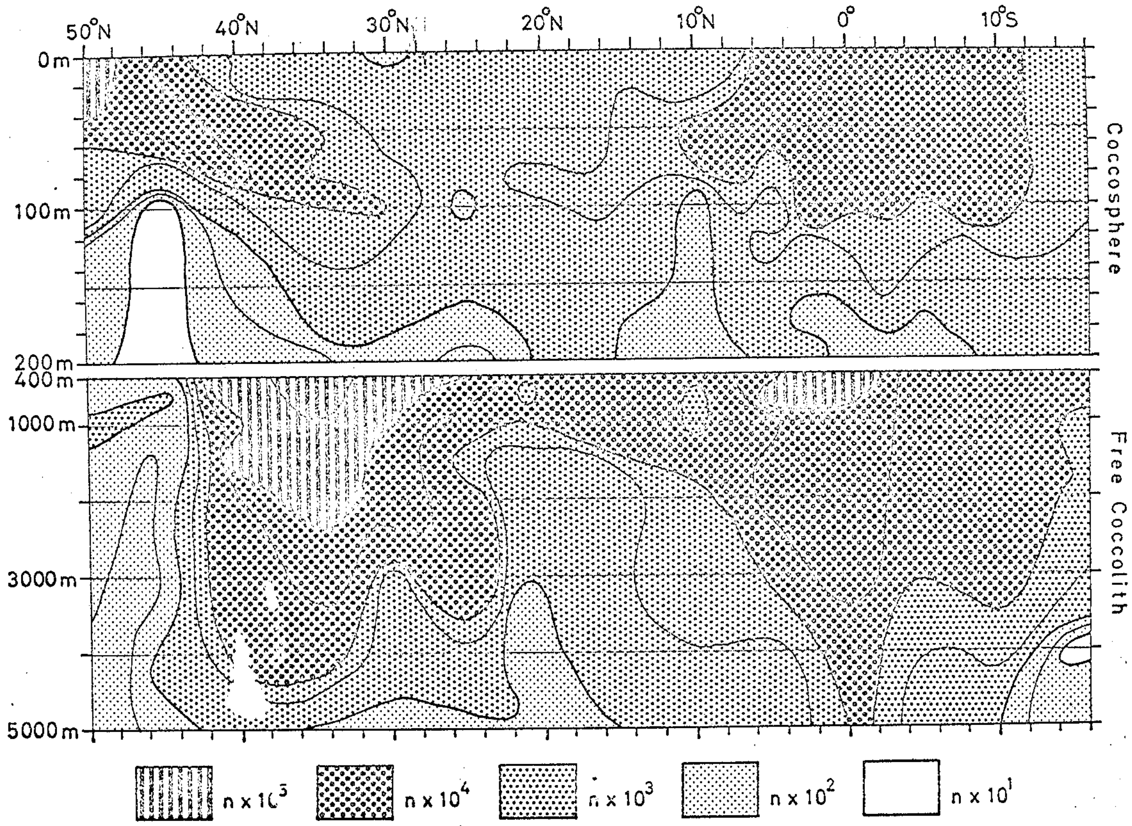
Finally, the free coccoliths are slowly precipitate in the subphotic layer to the sea bottom.

The distribution of free coccoliths in the subphotic layer along the 155°W route is shown in Fig. 18.

In the high latitude area belonging to the A zone, the coccolithophorid population in the euphotic layer is very large and the coccolith population in the subphotic layer is quite small. The predominant coccolithus huxleyi has the irregularly formed and weakly crystallized coccoliths in this area. Accordingly, the coccoliths are immediately dissolved by the severe environment which is influenced by the acid water caused by the low temperature. As a matter of fact, the free coccoliths found in this subphotic layer are mostly belonging to the species Coccolithus pelagicus and Cyclococcolithus leptopolus, while coccoliths belonging to Coccolithus huxleyi is hardly detectable. It may be evident proof that Coccolithus huxleyi has so fragile coccoliths in this area.

In the area belonging to the B zone, the coccolithophorid

Fig. 18. Coccolithophorid population in the euphotic zone and coccolith population in the subphotic zone along the 155°W



(per a litter of sea water)

population in the euphotic layer and the coccolith population in the subphotic layer are both large. As in the previous descriptions, *Coccolithus huxleyi* is predominantly found in the Kuroshio Extension. This species, however, has the regularly formed and solidly crystallized coccoliths in this area. But, in the lower subphotic layer of this area, the free coccoliths are eroded away and its population is rapidly decreased.

In the area belonging to the C zone, the coccolithophorid population in the euphotic layer and the coccolith population in the subphotic layer are both small. Predominantly observed *Umbellosphaera irregularis* in this area is so fragile in skeletal elements that its coccoliths are hardly found in the subphotic zone.

In the area belonging to the D zone and E zone, the coccolithophorid population in the euphotic layer is large and the free coccoliths are also abundantly preserved throughout the layers of the subphotic zone. Especially, in the subphotic layer of the equator, the largest population of free coccolith is observed and approximately 4.2×10^4 pieces of the coccolith are detected from a liter of the water at the 4,000m deep layer.

In the area belonging to the F zone, the coccolith population in the subphotic layer is small and its feature quite resembles that of the C zone. It is because of the predominance of Umbellosphaera irregularis and the small population of coccolithophorids in the euphotic layer.

It is accordingly doubtless that coccoliths are most richly preserved in the deep sea sediments of tropical seas as fossils. Calcareous ooze including a large number of coccoliths are most commonly distributed in the floor of the tropical sea.

References

Bartolini, C. (1970): Coccoliths from sediments of the Western Mediteranean. Micropaleont., vol. 16, pp. 129-154.

Bé, A. W. H. and McIntyre, A. (1965): Recent coccoliths of the Atlantic Ocean. Spec. Pap. Geol. Soc. Aner., vol. 82, p. 8.

Bernard, F. (1939): Coccolithophorids nouveaux ou peu connus observés à Monaco en 1938. Arch. Zool. Expér. et Gén., vol. 81, pp. 33-44.

Black, M. (1963): The fine structure of the mineral parts of the Coccolithophoridae. Proc. Linn. Soc. London, vol. 174, pp. 41-46.

Black, M. (1965): Coccoliths. Endeavour, vol. 24, no. 93, pp. 131-137.

Black, M. and Barnes, B. (1959): The structure of coccoliths from the English Chalk. Geol. Mag., vol. 96, pp. 321-328.

Black, M. and Barnes, B. (1961): Coccoliths and discoasters from the floor of the South Atlantic Ocean. Jour. Roy. Micr. Soc. (London), ser. 3, vol. 80, pp. 137-147.

Brrarud, T. (1954): Coccolith morphology and taxonomic position of Hymenomonas roseola Stein and Syracosphaera carterae Brrarud and Fegerland. Nytt.Mag. Bot., vol. 3, pp. 1-4.

Brrarud, T. Defrandre, G. Halldal, P. and Kamptner, E. (1955): Terminology, nomenclature, and systematics of the Coccolithophoridae. Micropaleont., vol. 1, no. 2, pp. 157-159.

Brrarud, T. and Nordli, E. (1952): Coccoliths of Coccolithus huxleyi seen in an electron microscope. Nature, vol. 170, pp. 361-362.

Bramlette, M. N. (1958): Significance of coccolithophorids in calcium-carbonate deposition. Bull. Geol. Soc. Amer., vol. 69, pp. 121-126.

Bramlette, M. N. and Martini, E. (1964): The great change in calcareous nannoplankton fossils between the Maestrichtian and Danian. Micropaleont., vol. 10, 231-250.

Bramlette, M. N. and Riedel, W. R. (1954): Stratigraphic value of discoasters and some other microfossils related to Recent coccolithophores. Jour. Paleont., vol. 28, pp. 385-403.

Cohen, C. L. D. (1964): Coccolithophorids from two Caribbean deep-sea cores. Micropaleont., vol. 10, pp. 231-250.

Defrandre, G. (1936): Les Flagellés fossiles. Actual. Scient. Ind., no. 335, pp. 1-98.

Defrandre, G. (1952): Classe des Coccolithophoridés. In: Traité de Zoologie, P. P. Grassé, editor vol. 1, no. 1, pp. 439-470.

Defrandre, G. and Fert, C. (1952): Sur la structure fine de quelque coccolithes fossiles observés au microscope électronique signification morphorogénétique et application à la systématique. C. R. Acad. Sci. (Paris), vol. 234, pp. 2100-2102.

Defrandre, G. and Fert, C. (1954): Observations sur les coccolithophoridés actuals et fossiles en microscopie ordinaire et électronique. Ann. Paléont., vol. 40, pp. 115-176.

Dixon, H. H. (1900): On the structure of coccospheres and the origin of coccoliths. Proc. Roy. Soc. London, vol. 66, pp. 305-315.

Fischer, A. G. Honjo, S. and Garrison, R. E. (1967): Electron micrographs of limestone. Princeton Univ. Press, Princeton, 141 pp.

Gaarder, K. R. (1962): Electron microscope studies on holococcolithophorids. Nytt Mag. Bot., vol. 10, pp. 35-51.

Gaarder, K. R. (1967): Observations on the genus Ophiaster Gran (Coccolithineae). Sarsia, vol. 29, pp. 183-192.

Gaarder, K. R. (1970): Three new taxa of Coccolithineae. Nytt Mag. Bot., vol. 17, pp. 113-126.

Gaarder, K. R. and Markali, J. (1959): On the coccolithophorid Crystallolithus hyalinus n. gen., n. sp. Nytt Mag. Bot., vol. 5, pp. 1-5.

Gaarder, K. R. and Ramsfjell, E. (1954): A new coccolithophorid from northern waters. Calciopappus caudatus n. gen. n. sp. Nytt Mag. Bot., vol. 2, pp. 155-156.

Halldal, P. (1953): Phytoplankton investigations from Weather ship M in the Norwegian Sea, 1948-1949. Norske Vid.-Akad. Oslo, vol. 38, pp. 1-91.

Halldal, P. and Markali, J. (1954a): Morphorogy and micro-structure of coccoliths studied in the electron microscope. Observations on Anthosphaera robusta and Calyptrosphaera papillifera. Nytt Mag. Bot., vol. 2, pp. 117-119.

Halldal, P. and Markali, J. (1954b): Observations on coccoliths of Syracosphaera mediteranea Lohm., S. pulchra Lohm., and S. molischi Schill. in the electron microscope. Cons. Int. Explor. Mer. Jour. Cons., vol. 19, pp. 329-336.

Halldal, P. and Markali, J. (1955): Electron microscope studies on coccolithophorids from the Norwegian Sea, the Gulf Stream and the Mediterranean. Avh. Norske Vid.-Akad. Oslo, Mat.-Naturv. Kl., 1955 no. 1, pp. 1-30.

Hasle, G. R. (1959): A quantitative study of phytoplankton from the Equatorial Pacific. Deep-Sea Res., vol. 6, pp. 38-59.

Hasle, G. R. (1960): Plankton coccolithophorids from the subantarctic and equatorial Pacific. Nytt Mag. Bot., vol. 8, pp. 77-88.

Hay, W. W. and Towe, K. M. (1962): Electronmicroscopic examination of some coccoliths from Donzacq (France). Eclog. Geol. Helvet., vol. 55, pp. 497-517.

Hay, W. W. Mohler, H. and Wade, M. E. (1966): Calcareous nannofossils from Nal'chik (Northwest Caucasus). Eclog. Geol. Helvet., vol. 59, pp. 379-399.

Honjo, S. (1970): Study of fine grained carbonate matrix: Sedimentation and Diagenesis of "Micrite". in Litho- and Biofacies of carbonate sediments. Matumoto ed. Paleont. Soc. Jap., special papers, no. 14, pp. 220-264.

Honjo, S. and Fischer, A. G. (1964): Fossil coccoliths in limestone examined by electron microscope. Science, vol. 144, no. 1620, pp. 837-839.

Honjo, S. and Minoura, N. (1968): Discoaster barbadiensis Tan Sin Hok and the geologic age of Setogawa Group. Proc. Jap. Acad., vol. 44, pp. 165-169.

Honjo, S. Minoura, N. and Okada, H. (1967): Study of nannofossils by the scanning electron microscope. Jour. Fac. Sci. Hokkaido Univ., ser. 4, vol. 13, pp. 427-431.

Honjo, S., Minoura, N, Okada, H. and Minato, M. (1967): Present status of nannofossil study by electron microscope in Japan. Proc. Jap. Acad., vol. 43, pp. 138-142.

Hulburt, E. M. and Rodman, J. (1963): Distribution of phytoplankton species with respect to salinity between the coast of southern New England and Bermuda. Limnol. Oceanogr., vol. 8, pp. 263-269.

Hulburt, E. M. Ryther, J. H. and Guillard, R. L. (1960): The phytoplankton of the Sargasso Sea off Bermuda. Cons. Int. Explor. Mer. Jour. Cons., vol. 25, pp. 115-128.

Isenberg, H. D. et al. (1963): Calcification in marine coccolithophorid. Ann. N. Y. Acad. Sci., vol. 109, pp. 49-64.

Kamptner, E. (1927): Beitrag zur Kenntnis adriatischer Coccolithophoriden. Arch. Protistenk., vol. 58, pp. 173-184.

Kamptner, E. (1928): Über das System und die phylogenie der Kalkflagellaten. Ibid., vol. 64, pp. 19-43.

Kamptner, E. (1937): Neue und bermerkenswerte Coccolithineen aus dem Mittelmeer. Ibid., vol. 89, pp. 279-316.

Kamptner, E. (1956): Das Kalkskelett von Coccolithus Huxleyi (Lohm) Kpt. und Gephyrocapsa oceanica Kpt. (Coccolithineae). Ibid., vol. 101, pp. 171-202.

Kamptner, E. (1958): Betrachtungen zur Systematik der Kalkflagellaten, nebst Versuch einer neuen Gruppierung der Chrysomonadales. Ibid., vol. 103, pp. 54-116.

Kamptner, E. (1963): Coccolithineen-Skelettreste aus Tiefseeablagerungen des Pazifischen Ozeans. Ann. Naturh. Mus. Wien, vol. 66, pp. 139-204.

Lecal (Lecal-Schlauder), Juliette (1954): De I'instérét de quelques stations du détroit de Gibraltar. Vie et Milieu, vol. 4, pp. 177-186.

Lecal (Lecal-Schlauder), Juliette (1964): Structure et biologie de quelques Coccolithophoridés après observations au microscope électronique. Bull. Soc. Hist. Nat. Toulouse, vol. 99, pp. 450-458.

Lecal (Lecal-Schlauder), Juliette (1965): Navisolenia n. g. aprili n. sp., nouveau genre de Calciosoleniâés. Bull. Soc. Hist. Nat. Toulouse, vol. 100, pp. 422-426.

Loeblich, A. R. Jr. and Tappan, H. (1963): Type fixation and validation of certain calcareous nannoplankton genera. Proc. Biol. Soc. Wash., vol. 76, pp. 191-196.

Loeblich, A. R. Jr. and Tappan, H. (1966): Annotated index and bibiography of the calcareous nannoplankton. Phycologia, vol. 5, pp. 81-216.

Loeblich, A. R. Jr. and Tappan, H. (1968): Annotated index and bibiography of the calcareous nannoplankton 2. Jour. Paleont., vol. 42, pp. 584-598.

Lohmann, H. (1902): Die Coccolithophoridae, eine Monographie der Coccolithen bildenden Flagellaten, zugleich ein Beitrag zur Kenntnis des Mittelmeerauftriebs. Arch. Protistenk., vol. 1, pp. 89-165.

Lohmann, H. (1913): Über Coccolithophoriden. Verh. Deutsch. Zool. Ges., vol. 23, pp. 143-164.

Manton, I. and Leedale, G. F. (1963): Observations on the micro-anatomy of Crystallolithus Gaarder and Markali. Arch. Microbiol., vol. 47, pp. 115-136.

Markali, J. and Paasche, E. (1955): On two species of Umbellosphaera, a new marine coccolithophorid genus. Nytt Mag. Bot., vol. 4, pp. 95-100.

Marshall, H. G. (1966): Observation on the vertical distributiom of coccolithophorids in the Northwestern Sargasso Sea. Limnol. Oceanogr., vol. 11, no. 3, pp. 432-435.

Martini, E. and Bramlette, M. N. (1963): Calcareous nannoplankton from the experimental Mohole driling. Jour. Paleont., vol. 37, pp. 845-856.

Marumo, R. Nakai, T. and Hasumoto, H. (1970): Water masses, current systems and phytoplankton communities along 155°W. R. Marumo ed. Preliminary Report of The Hakuho Maru Cruise KH-69-4, pp. 11-12.

McIntyre, A. and Bé, A. W. H. (1966): Coccolithophorids as ecologic indicators in oceanic sediments. Amer. Assoc. Petrol. Geol., Abstr. vol. 50, pp. 624-625.

McIntyre, A. and Bé, A. W. H. (1967): Modern coccolithophoridae of the Atlantic Ocean -1. Placoliths and Cyrtoliths. Deep-Sea Res., vol. 14, pp. 561-597.

McIntyre, A. Bé, A. W. H. and Preikstak, R. (1967): Coccoliths and the Pliocene-Pleistocene boundary. Prog. Oceanogr., vol. 4, pp. 3-24.

Murray, G. and Blackman, V. H. (1897): Coccospheres and Rhabdospheres. Nature, vol. 55, pp. 510-511.

Noël, D. (1959): Étude de coccolithes du Jurassique et du Crétacé inférieur. Publ. Serv. Carte Géol. Algérie, ser. 2, Bull. 20, pp. 155-196.

Norris, R. E. (1961): Observation on phytoplankton organisms collected on the N. Z. O. I. Pacific Cruise, September 1958. New Zealand Jour. Sci., vol. 4, pp. 162-188.

Norris, R. E. (1965): Living cells of Ceratolithus cristatus (Coccolithophorineae). Arch. Protistenk., vol. 108, pp. 19-24.

Okada, H. (1970): Surface distribution of coccolithophore in the North and Equatorial Pacific. Jour. Geol. Soc. Japan, vol. 76, pp. 539-547. (in Japanese)

Okada, H. and Honjo, S. (1970): Coccolithophoridae distributed in Southwest Pacific. Pacific Geol., no. 2, pp. 11-21.

Ostenfeld, C. H. (1910): Thoroshaera, eine neue Gattung der Coccolithophoriden. Ber. Deutsch. Bot. Ges., vol. 28, pp. 397-400.

Paasche, E. (1962): Coccolith formation. Nature, vol. 193, pp. 397-400.

Parke, M. and Adams, I. (1960): The motile (Crystallolithus hyalinus Gaarder and Markali) and non-motile phases in the life history of Coccolithus pelagicus (Wallich) Schiller. Jour. Mar. Biol. Assoc. U. K., vol. 39, pp. 263-274.

Parke, M. and Dixon, P. S. (1964): A revised check-list of British marine algae. Ibid., vol. 44, pp. 499-542.

Schiller, J. (1916): Der derzeitige Stand unserer Kenntnis der Coccolithophoriden. Naturwiss., vol. 4, pp. 277-283.

Schiller, J. (1925): Die planktonischen Vegetationen des adriatischen Meeres. A. Die Coccolithophoriden-Vegetation in den Jahren 1911-14. Arch. Protistenk., vol. 51, pp. 1-130.

Schiller, J. (1926): Über Fortpflanzung, geissellose Gattungen und die Nomenklatur der Coccolithophoraceen nebst Mitteilung über Copulation bei Dinobryon. Ibid., vol. 53, pp. 326-342.

Stradner, H. (1961): Vorkonmen von Nannofosilien im Mesozoikum und Alttertiär. 2 Teil. Erdoel-Z., vol. 77, pp. 77-88.

Stradner, H. and Papp, A. (1961): Tertiäre Discoasteriden aus Österreich und deren stratigraphischen Bedeutung mit Hinweisen auf Mexico, Rumänien und Italien. Jahrb. Geol. Bundesanst., (Wien), Sonderband 7, 159 pp.

Takayama, T. (1967): First report on nannoplankton from the upper Tertiary and Quaternary of the Southern Kwanto region, Japan. Ibid., no. 110, pp. 169-198.

Wallich, G. C. (1861): Remarks on some novel phases of organic life, and on the boring poweres of minute annelids, at great depth in the sea. Ann. Mag. Nat. Hist., ser. 3, vol. 8, pp. 52-58.

Wallich, G. C. (1868): Coccoliths and coccospheres. Ibid., ser. 4, vol. 2, pp. 317-319.

Wallich, G. C. (1877): Observations on the coccosphere. Ibid., vol. 19, pp. 342-350.

Watabe, N. and Wilber, K. M. (1966): Effect of temperature on growth, calcification, and coccolith from in Coccolithus huxleyi (Coccolithineae). Limnol. Oceanogr. vol. 11, pp. 567-575.

A list of coccolithophorid species

Coccolithus huxleyi (Lohmann) Kamptner
Coccolithus huxleyi (Lohmann) Kamptner var. A
Coccolithus sp. A
Coccolithus sp. B
Coccolithus sp. C
Cyclococcolithus fragilis (Lohmann) Defrandre
Cyclococcolithus fragilis (Lohmann) Defrandre var. A
Cyclococcolithus leptopolus (Murray and Blackman) Kamptner
Gephyrocapsa ericsoniae McIntyre and Bé
Gephyrocapsa oceanica Kamptner
Gephyrocapsa sp. A
Gephyrocapsa sp. B
Gephyrocapsa sp. C
Helicosphaera carteri (Wallich) Kamptner
Helicosphaera hyalina Gaarder
Helicosphaera sp. A
Umbilicosphaera hulburtiana Gaarder
Umbilicosphaera mirabilis Lohmann
Umbilicosphaera sibogae (Weber-von Bosse) Gaarder

Acanthoica acanthifera Lohmann
Acanthoica quatrospina Lohmann
Brrarudosphaera bigelowi (Gran and Brrarud) Defrandre
Calciopuppus caudatus Gaarder and Ramsfjell
Calciosolenia sinuosa Schlauder
Ceratolithus cristatus Kamptner
Ceratolithus telesmus Norris
Cyclolithella annulus (Cohen) McIntyre and Bé
Deutschlandia anthos Lohmann
Deutschlandia sp. A
Deutschlandia sp. B
Discoaster perplexus Bramlette and Riedel
Discolithus anistrema Kamptner

Discolithus sp. *A*

Discolithus sp. *B*

Discosphaera tubifera (Murray and Blackmann) Lohmann

Michaelsarsia elegans Gran

Ophiaster hydroideus Schiller

Ophiaster sp. *A*

Rhabdosphaera stylifera Lohmann

Scyphosphaera apsteini Lohmann

Umbellosphaera irregularis Paasche

Umbellosphaera tenuis (Kamptner) Paasche

Umbellosphaera sp. *A*

Anthosphaera quadriconu Lecal-Schlauder

Anthosphaera robusta (Lohmann) Kamptner

Calyptrosphaera catillifera (Kamptner) Gaarder

Calyptrosphaera oblonga Lohmann

Calyptrosphaera papillifera Halldal

Calyptrosphaera sp. *A*

Calyptrosphaera sp. *B*

Corisphaera arethusae Kamptner

Corisphaera strigilis Gaarder

Helladosphaera aurisinae Kamptner

Helladosphaera cornifera (Schiller) Kamptner

Homozygosphaera dalmatica (Kamptner) Okada

Homozygosphaera tholifera (Kamptner) Halldal and Markali

Homozygosphaera triarcha Halldal and Markali

Homozygosphaera quadriperforata (Kamptner) Gaarder

Homozygosphaera wettsteini (Kamptner) Halldal and Markali

Homozygosphaera sp. *A*

Homozygosphaera sp. *B*

Homozygosphaera sp. *C*

Homozygosphaera sp. *D*

Homozygosphaera sp. *E*

Homozygosphaera sp. *F*

Periphyrophora mirabilis (Schiller) Kamptner

Zygosphaera divergens (Schiller) Kamptner

Zygosphaera sp. *A*

Syracolithus sp. *A*

Syracosphaera binodata Kamptner

Syracosphaera confusa Halldal and Markali

Syracosphaera mediteranea Lohmann

Syracosphaera molischi Schiller

Syracosphaera nanna (Kamptner) Okada

Syracosphaera nodosa Kamptner

Syracosphaera pilus Halldal and Markali

Syracosphaera pulchra Lohmann

Syracosphaera tuberculata Kamptner

Syracosphaera sp. *A*

Syracosphaera sp. *B*

Syracosphaera sp. *C*

Syracosphaera sp. *D*

Syracosphaera sp. *E*

Syracosphaera sp. *F*

Syracosphaera sp. *G*

Syracosphaera sp. *H*

Syracosphaera sp. *I*

Syracosphaera sp. *J*

Syracosphaera sp. *K*

Syracosphaera sp. *L*

Syracosphaera sp. *M*

Syracosphaera sp. *N*

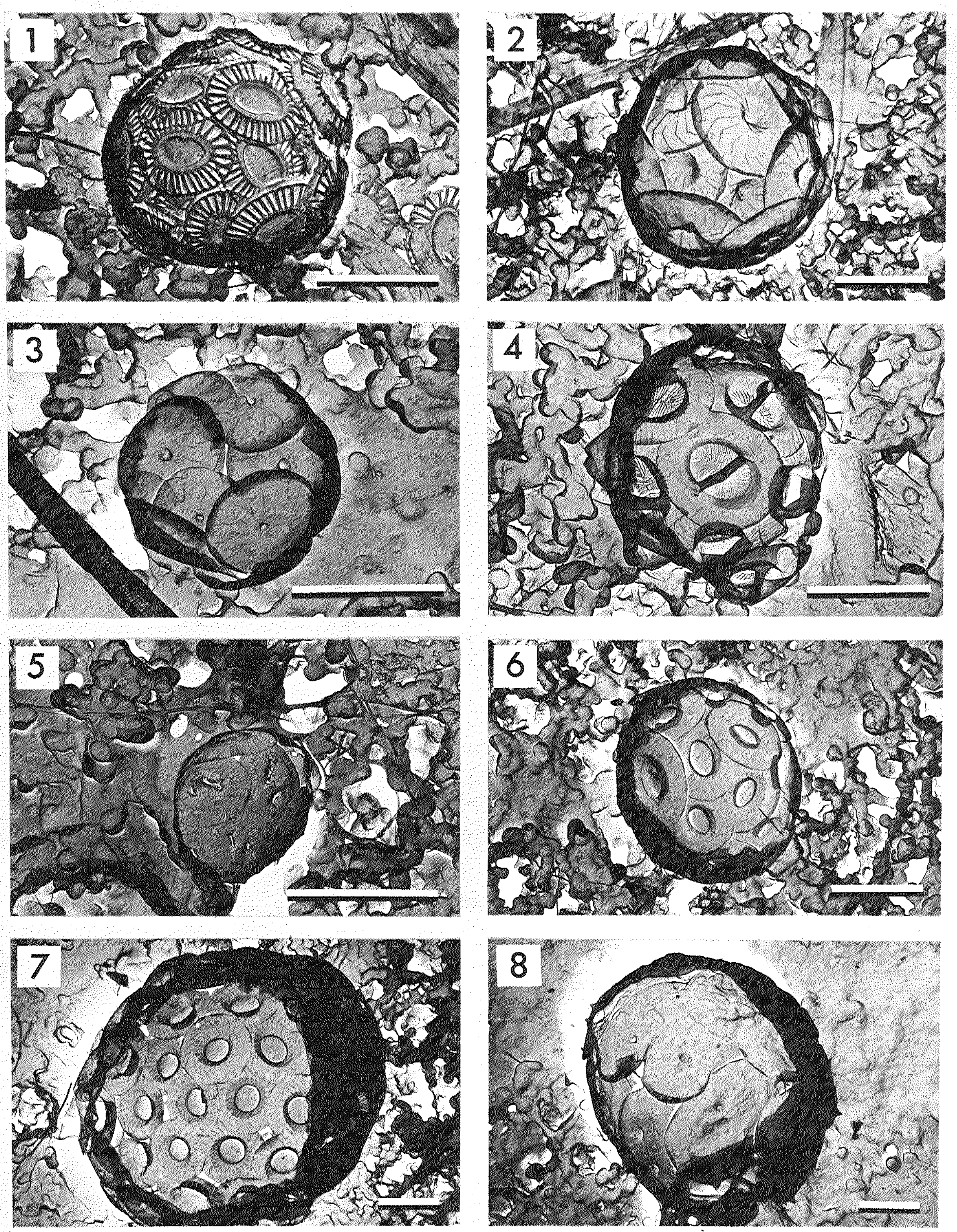
Explanation of plate 1

Fig. 1. <u>Coccolithus huxleyi</u> (Lohmann) Kamptner
Fig. 2. <u>Cyclococcolithus leptopolus</u> (Murray and Blackman) Kamptner
Fig. 3. <u>Cyclococcolithus fragilis</u> (Lohmann) Defrandre
Fig. 4. <u>Gephyrocapsa oceanica</u> Kamptner
Fig. 5. <u>Gephyrocapsa</u> sp. <u>A</u>
Fig. 6. <u>Umbilicosphaera hulburtiana</u> Gaarder
Fig. 7. <u>Umbilicosphaera sibogae</u> (Weber-von Bosse) Gaarder
Fig. 8. <u>Helicosphaera cateri</u> (Wallich) Kamptner

Explanation of plate 2

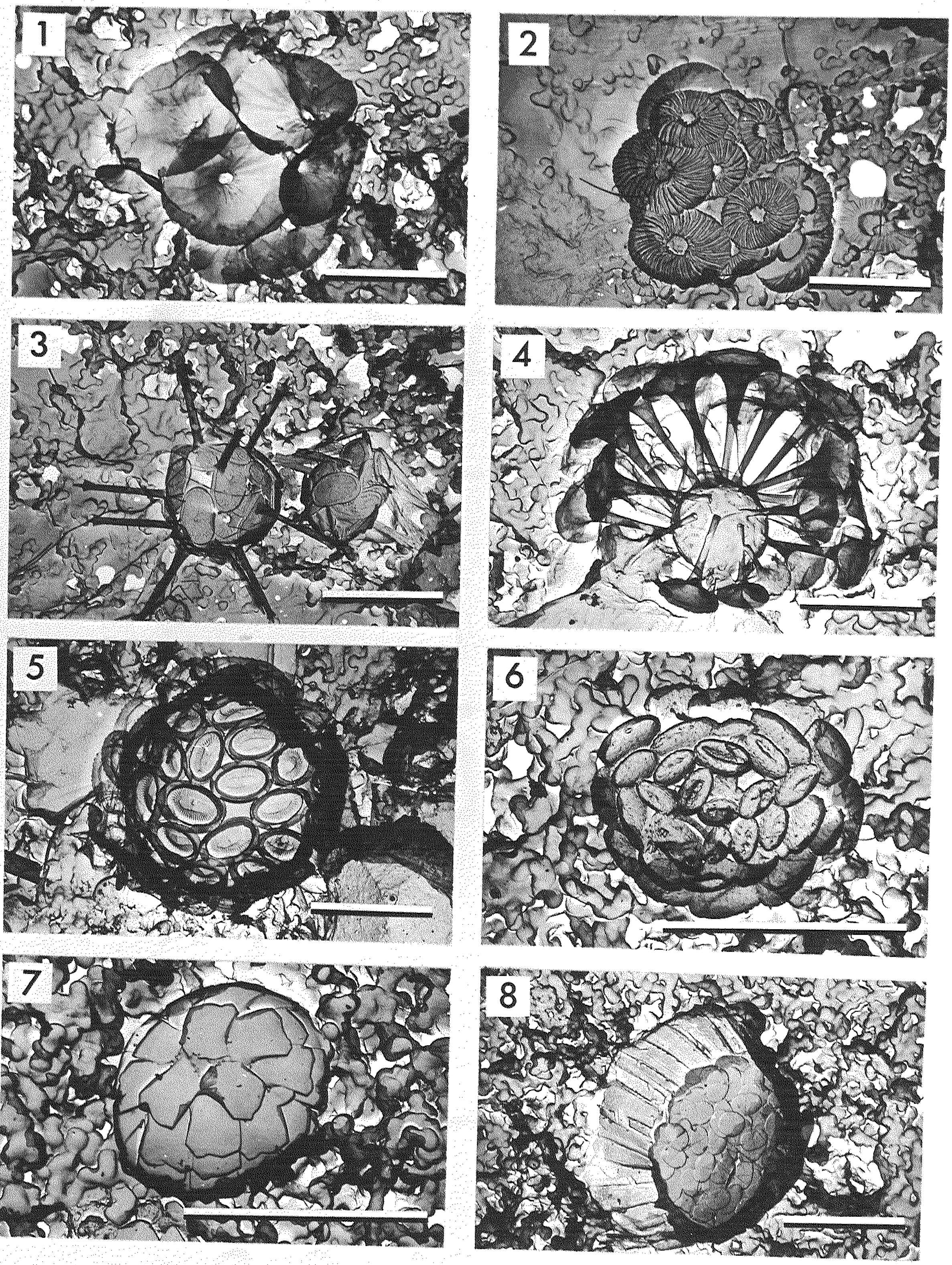
Fig. 1. <u>Umbellosphaera irregularis</u> Paasche
Fig. 2. <u>Umbellosphaera tenuis</u> (Kamptner) Paasche
Fig. 3. <u>Rhabdosphaera stylifera</u> Lohmann
Fig. 4. <u>Discosphaera tubifera</u> (Murray and Blackman) Lohmann
Fig. 5. <u>Syracosphaera tuberculata</u> Kamptner
Fig. 6. <u>Anthosphaera quadriconu</u> Lecal-Schlauder
Fig. 7. <u>Deutschlandia</u> sp. <u>A</u>
Fig. 8. <u>Deutschlandia anthos</u> Lohmann

Plate 1



Bar Length = 5μ

Plate 2



Bar Length = 10 μ