Bull. Natn. Sci. Mus., Ser. C (Geol.), 2 (4), December 22, 1976

Lithology and Planktonic Foraminifera of the Sea of Japan Piston Cores

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Introduction

The Sea of Japan enclosed by an arc of the Japanese Islands may be a most attractive target of scientific study of international interest, because it is one of the typical marginal seas which may offer some clues to solve the oceanization of the earth crust and a touchstone to polish up the "Plate Techtonics" theory. At the same time, the nation-wide interesting must be focused on the Sea, since its presence influences not only physiography of Japan but also the nationality of the Japanese people.

The Sea of Japan, however, has not been investigated comprehensively by scientists, particularly of geological sciences. Although the sea bottom sediments are inexhaustible sources of knowledge about the geologic history, almost all the papers hitherto published dealt with a single or a few cores of the sediments. Our previous report (UJIIÉ and ICHIKURA, 1973) on planktonic Foraminifera also treated just a piston core taken from off San'in district, western Japan, even though our result was expected to be applicable to some extent throughout the Sea. For the present study we chose twenty-six piston cores among forty-four which were collected from various parts of the Sea of Japan by the research vessels of the Lamont-Doherty Geological Observatory of Columbia University. We described thoroughly their lithology including some biofacies, and analysed their planktonic Foraminifera.

The main purpose of this paper was to describe these core samples, but some facts revealed in the course of the work have enabled us to infer certain environmental changes of the Sea of Japan through geologic times, particularly during the latest period of Cenozoic.

Brief Note on the Physiography of the Sea of Japan

It is remarkable that the Sea of Japan is separated from the Pacific Ocean by the Japanese Islands Arc, leaving four narrow and very shallow straits, such as Mamiya

(Tartar) (average water depth 12 m), Soya (55 m), Tsugaru (130 m) and Tsushima (130 m) from north to south. Therefore, the greater part of oceanic currents which might flow into the Sea would be prevented by these sills. In fact, the Tsushima Current, a branch of the Kuroshio Warm Current, diminishes its influence quickly after it enters the Sea, passing through the Tsushima Strait between the Korean Peninsula and Kyushu, western Japan, and becomes less extensive so that its main route is restricted just along the coasts of the Japanese Islands.

The cold water current prevalent for the whole region has its origin mostly attributed to the self-generation within the Sea. The oxygen-rich surface water off the continental coast of the Sea is chilled with the Siberian Air Mass developed in winter, and then the chilled and heavier water mass migrates southward and, at the same

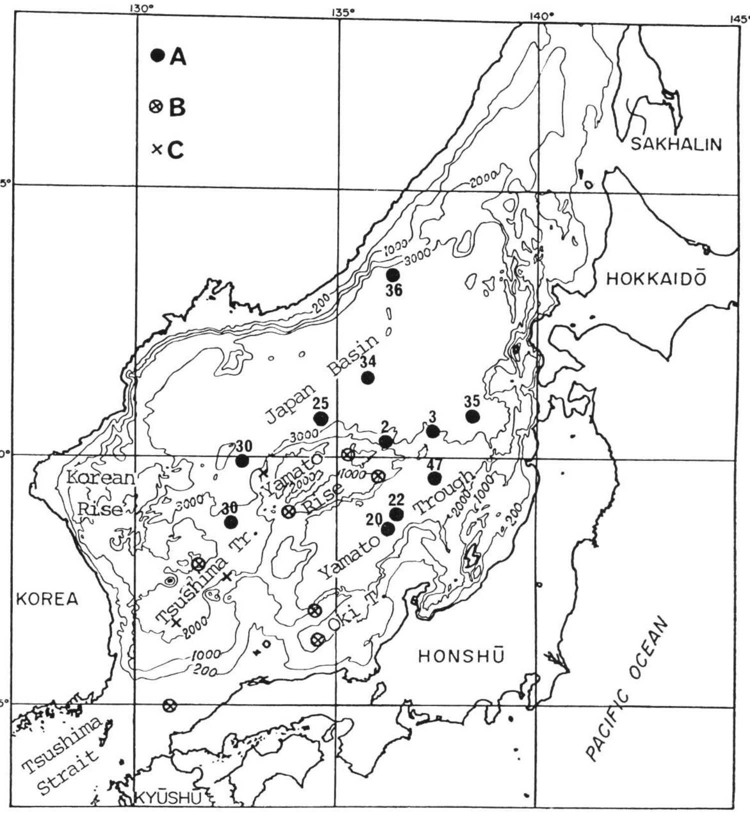

Fig. 1. Showing topographic divisions of the Sea of Japan, and two lithologic characters of the examined cores.

Tr. or T.: Trough, A: Cores with "brown clay" at the top, thickness of which is shown by bold-faced numeral, indicating oxidized condition of bottom water, B: Cores with common planktonic Foraminifera due to the water depth above the CCD, C: Cores probably below the CCD but under not so much oxidized condition.

time, sinks deeper. Because its southern exits are shut out by the Japanese Islands Arc and its shallow straits, the cold and heavy water mass cannot flow away out of the Sea, so it accumulates within year after year, which accounts for the unique character of biocoenoses, particularly deep water ones, and of the Recent sediments. For example, probably due to the bottom water oversaturated in soluble oxygen, the calcium carbonate compensation depth (CCD) is very shallow, being around 2300 m, compared with ordinary oceanic cases as suggested before (UJIIÉ and ICHIKURA, 1973).

Aside from the oceanic current problem, no larger river like the Amur River or the Hwang River pours into the Sea from the Asiatic Continent so that river waters have little effect on the above-mentioned hydrographic character as a whole.

In addition to the hydrography, submarine topography is another important factor to characterize the sea-bottom sediments (Fig. 1). The northern half of the Sea of Japan, called the Japan Basin, is rather flat and deep, the average depth attaining to more than 3000 m, as if it is an abyssal plain of the ocean, and likewise it has the oceanic type of crust underneath (*e.g.* MURAUCHI, 1966). In contrast to the north, the southern half is provided with complicated relief and with the continental type of crust as a whole, especially beneath the Yamato Rise and the Korean Continental Rise. The Yamato Rise consists of two parallel ridges running from northeast to southwest around the center of the Sea of Japan, and its water depth measures about 1000 m on average. The Korean Rise in the eastern offing of the Korean Peninsula shows much irregular bottom configuration. Between the Yamato Rise and Honshu, main land of the Japanese Islands, the Yamato Trough extends from the Japan Basin southwestward, branching off the Oki Trough at the west of the Noto Peninsula and the Toyama Submarine Canyon at the east; the Canyon runs for about 500 km and terminates near the southern margin of the Japan Basin. Also extending from the Basin between the Yamato and Korean Rises, the Tsushima Trough reaches the shelf edge of the Tsushima Strait. Twenty-six piston-cores examined here will be described or discussed under the topographic divisions; *.i.e*, Tsushima Strait, Tsushima Trough, Yamato Trough including Oki Trough, Yamato Rise and Japan Basin regions.

Summarized Descriptions of the Core Lithology

Research vessels of the Lamont-Doherty Geological Observatory have surveyed three times across the whole area of the Sea of Japan in three cruises and obtained many cores as shown in location map (Fig. 2). The three cruises are the 12th cruise of R/V Robert Conrad (abbreviated as RC12 or merely R in Fig. 2 and in the following paragraphs) from June to July, 1969, the 12th of R/V Vema (V28 or V) from June to July, 1971, and the 32nd of R/V Vema (V32) in July, 1975.

The following descriptions and columnar sections of the RC12-cores are based on our compilation of the descriptions made on half-cut sections of the cores by S. GREGORI at the Lamont and of their photographs. Those of the V28-cores are also of the compilation of descriptions by Norio FUJI of Kanazawa University and J.

Table 1. Data on the piston cores examind

Region	Core	Latitude	Longitude	Water Depth (m)	Core Length (cm)
Tsushima Strait	RC12–373	34°57′N	130°52′E	129	300
Tsushima Trough	RC12–374	36°39′N	130°58′E	2111	1161
	RC12–376	37°50′N	131°39′E	1426	1759
	RC12–377	37°35′N	132°15′E	2226	1486
	V28–267	38°37.5′N	132°24′E	2831	1403
Yamato Trough	V28–265	36°17′N	134°34′E	1218	920
	RC12–378	36°57′N	134°32.5′E	1401	1110
	RC12–379	36°53.5′N	134°33′E	1010	1227
	V28–268	38°37′N	136°20′E	2692	1524
	RC12–389	38°54.5′N	136°30′E	2650	1245
	V28–274	39°38′N	137°28′E	2677	520
	RC12–397	39°46.5′N	137°36′E	2840	153
Yamato Rise	RC12–398	40°30.5′N	137°31.2′E	2664	664
	RC12–394	40°19′N	136°13.5′E	2338	601
	RC12–390	39°42′N	136°01.5′E	1103	785
	RC12–387	40°05.7′N	135°12′E	838	706
	RC12–381	38°55′N	133°48′E	1437	681
	RC12–383	39°42.7′N	133°07′E	2113	977
Japan Basin	RC12–382	39°55.1′N	132°40′E	3027	1225
	RC12–386	40°48′N	134°36′E	3497	1517
	V28–273	41°29′N	135°43′E	3533	777
	V28–271	40°45′N	138°27′E	3382	791
	V28–281	43°25′N	136°21′E	3588	1047
	V32–146	41°10′N	136°17.4′E	3367	783
	V32–154	41°49′N	133°15′E	3420	1169
	V32–156	44°18′N	138°53′E	3338	1270

RIGAUD both at the Lamont and of their photographs. These compilations were made referring to the result of our own detailed examination of the materials at the laboratory of the National Science Museum, Tokyo. Although we have not yet obtained the descriptive data of V32-cores, we could examine planktonic Foraminifera in the shipboard samples of their three important cores taken from the Japan Basin. These were offered us by the courtesy of Kenji KURIHARA of St. Paul University who participated in the V32-cruise.

To save the space, we refrained from making separate description of each core, and, instead, figured it out as an columnar section (Fig. 3) which is divided into the following 11 lithologic units, as Fig. 4 illustrates examples. In the columns a sharp boundary between two lithologic units is shown by solid line, whereas a gradual one by broken line. In the following diagnoses, color is expressed according to the Rock Color Chart issued by the Geological Society of America.

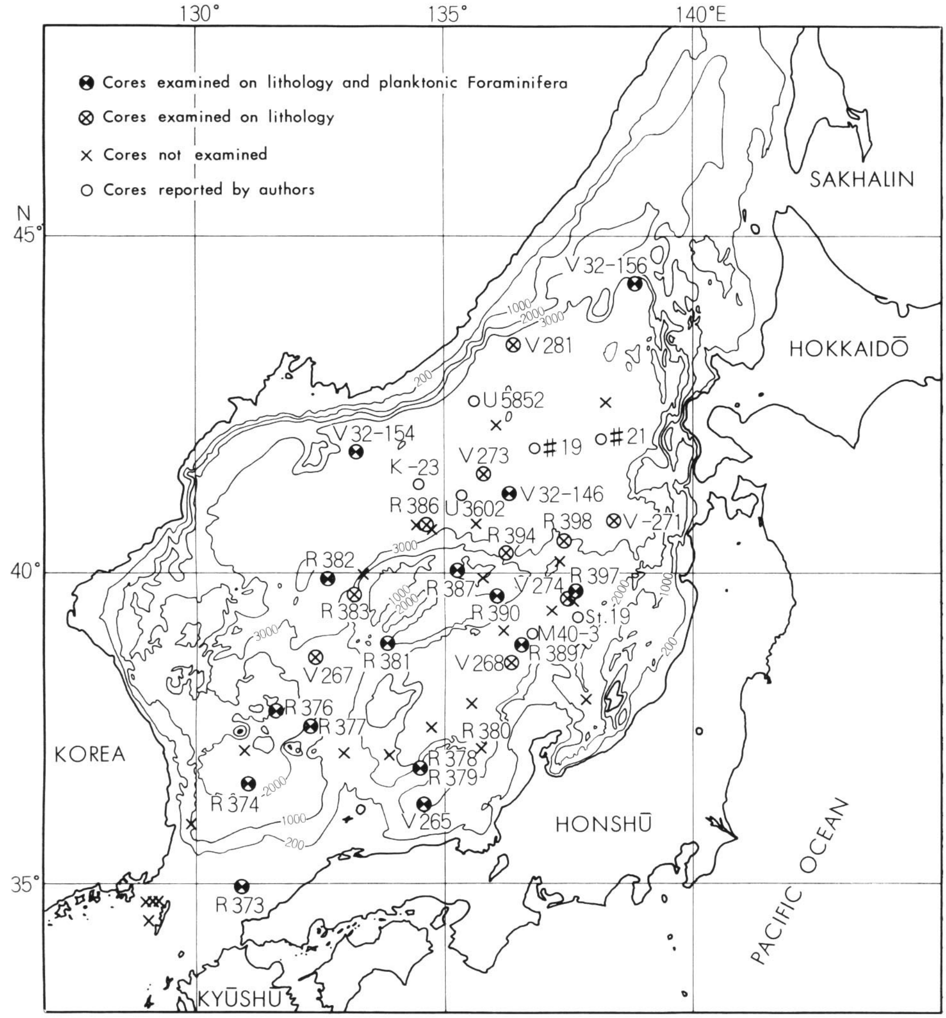

Fig. 2. Location map of the cores examined.

Abbreviations for the cores hitherto reported by authors are: U5852: USSR5852 (SHARUDO *et al.*, 1973), U3602: USSR3602 (KORENEVA, 1961), #19 and #21: #64–19 and –21 (MIYAKE *et al.*, 1968), St. 19: Seihu 67, St. 19 (NISHIDA, 1969), M40–3: (KOIZUMI, 1970), K–23: KH–69–2–23 (MIZUNO *et al.*, 1972).

"Clay"

Well developed in the cores taken from the Yamato Trough, Tsushima Trough and Japan Basin. In the Yamato Rise region, only the core RC12–394 contains this type of clay. The core came from the deepest location among five cores of the Yamato Rise region and, moreover, it is crowned by brown clay like those from the Japan Basin.

This "clay" unit can be subdivided into two; namely, homogeneous clay which is developed in the upper portion of several cores, and finely laminated clay which is found occasionally in the middle to lower portions of some cores.

(*"Homogeneous Clay"*)

Homogeneous, massive, and rich in diatoms; radiolarians, volcanic glass, minute quartz grains, and others are enclosed. In the cores RC12–374, V28–265 and RC12–379, all taken from depths shallower than about 2500 m, it shows gradual color change from olive gray (5Y3/2) at the top to dark olive gray (5Y3/1) or medium gray (N5) downwards, containing a considerable amount of Foraminifera throughout. On the other hand, the clay in cores from the greater depths than 2500 m, *i.e.* V28–267, V28–268, V28–274, RC12–398, RC12–382, RC12–386, V28–273, V28–271 and V28–281, contains very scarce or no Foraminifera, and is provided with the so-called oxydized zone of yellowish brown (10YR4/2) to brown color in the top portion. The base of the homogeneous clay often indicates a sharp change of facies.

(*"Laminated Clay"*)

Clay with very thin lamination is observed in some cores from trough and basin regions, *i.e.* RC12–377 in the Tsushima Trough, V28–268 and V28–274 in the Yamato Trough, RC12–382, RC12–386, and V28–281 in the Japan Basin. Particularly in the last core obtained just southeast off Olga of the Maritime Province of Siberia, this type of clay is very well developed as shown in Fig. 3. In all the cases, however, clay in the top portion is never laminated but is homogeneous. "Laminated clay" includes diatoms, quartz and igneous rock fragments both of medium-grained sand size, and is olive gray (5Y4/1) to olive black (5Y2/1) in color.

"Alternation"

Well developed in many cores from the Japan Basin, Tsushima Trough and Yamato Trough, except for their top portion where homogeneous clay is developed in general. From the mode of alternation, this unit may be divided into two major types, although their occurrence is not indicated stratigraphically and geographically. The first type is thinner and regular alternation of 1 to 2 cm thick silty sand layers and 4 to 6 cm thick clay layers. The second type is thicker and rather irregular alternation of 1 to 4 cm thick silty clay or clayey sand layer and 5 to 20 cm thick clay layers, usually grading from the psammitic layers upwards. As a variation of the second type, alternation of clay and diatomaceous clay or foraminiferal clay is present in some cores taken exclusively from the troughs, in other words, from the depth shallower than about 2500 m, probably above the CCD.

"Interbedded Clay"

Characterized by zonal, not rhythmical, color change of caly, namely, olive gray (5Y3/2), light gray (N7), dark gray (N3), greenish gray (5GY6/1), and so on. This type of clay is found in the cores RC12–389 (in the portion lower than 402 cm below the top), RC12–374 (lower than 563 cm), V28–267, V28–271, and RC12–382, although they are included into the unit "alternation" in Fig. 3. This color-changing zone usually shows a sharp boundary with the underlying bed, but a gradual one with the

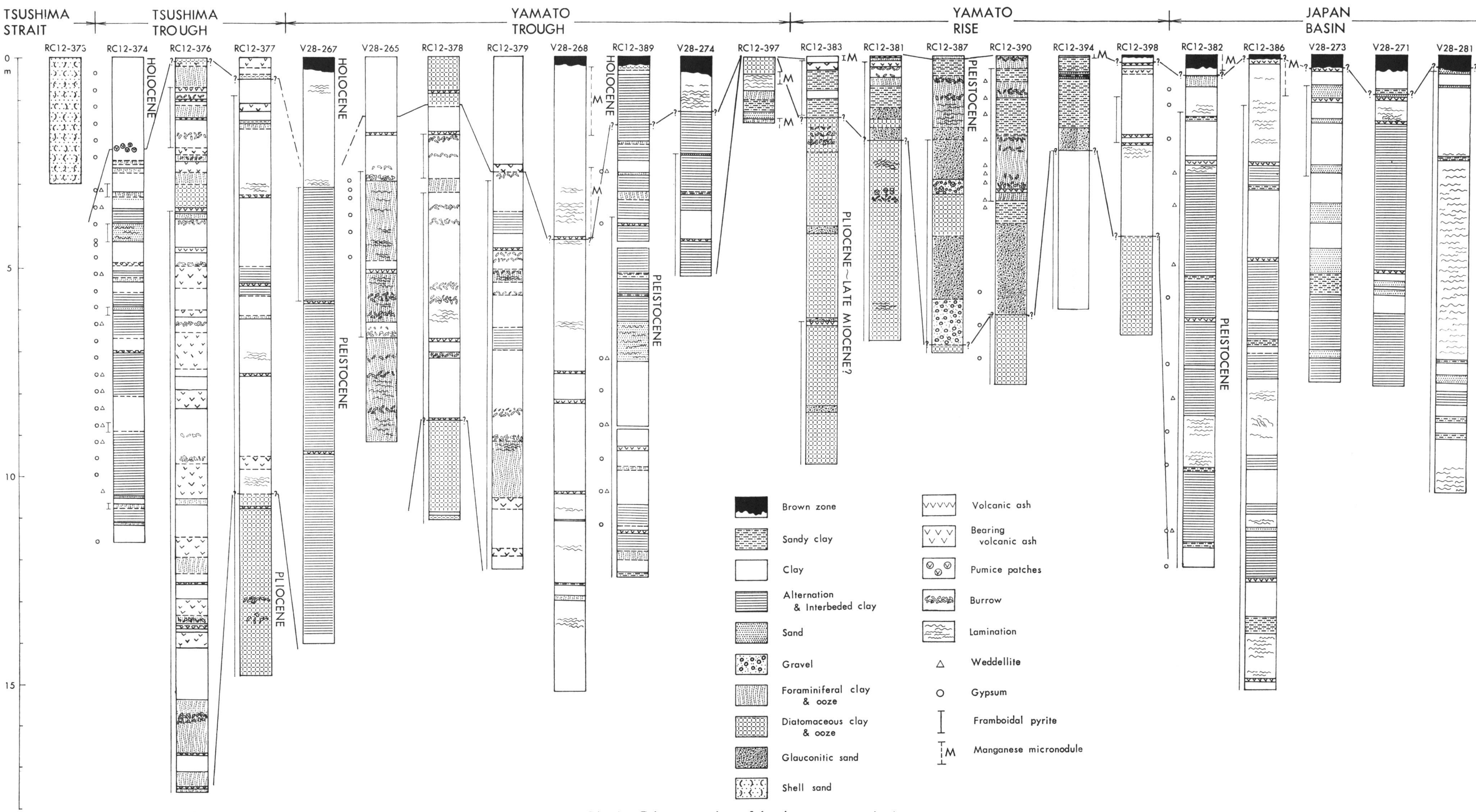

Fig. 3. Columnar sections of the piston cores examined

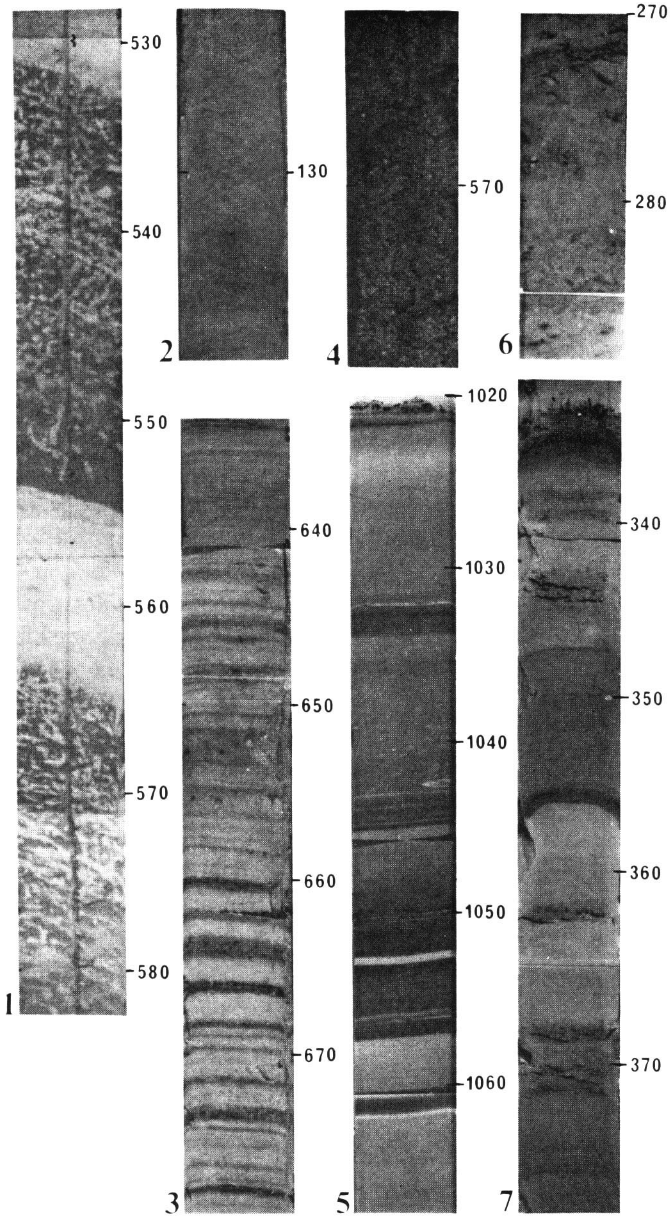

Fig. 4. Photographs showing diagnostic characteristics in seven lithologic units.
1. Burrowed lutite (Core RC12–378), 2. Homogeneous clay (RC12–374), 3. Laminated caly (V28–281), 4. Glauconitic sand (RC12–387), 5. Interbeded clay (V28–267), 6. Diatomaceous ooze (RC12–381), 7. Alternation of clayey sand and clay, between which the graded bedding is recognized (V28–271).

Small numerals aside the columns indicate the depth below the top of core in cm.

overlying bed.

"Diatomaceous Clay"

Diatomaceous ooze and diatomaceous sandy clay are also included here.

This lithology can be seen in the middle to lower portions of the cores taken mainly from a submarine rise or its slopes toward basin or trough. It is particularly true for all the cores from the Yamato Rise and its slopes, except for the core RC12–394, in which only the top 2 m is composed of yellowish brown diatomaceous clay.

This type of clay found at relatively higher horizons is olive gray (5Y4/1) in color and contains abundant diatoms, radiolarians, and "OST" and also rather common Foraminifera. Minute grains of quartz and mica are rarely recovered. In many cases this unit changes gradually from the sediments underneath. Diatomaceous clay observed in the upper or top portion of the cores from the bottom of trough also belongs to this category; these cores are RC12–389, RC12–397 (both from the Yamato Trough) and RC12–376 (from the Tsushima Trough).

More firmed diatomaceous sandy clay is recognized characteristically in bottom few meters of the cores RC12–377 and RC12–378; both from the slope facing the trough. It is noticed that authigenic pyrite and volcanic glass are contained there. Radiolarians are rather few.

"Diatomaceous clay" in the cores (especially in their lower portion) from the Yamato Rise and its slopes is more compact than the above-mentioned firmed diatomaceous sandy clay, despite of the thinner thickness of it and of the overlying bed. This may imply that the present compactness is not due to the load of overlying sediments but to the older geologic age. Different from the other type, this diatomaceous clay to ooze is frequently colored in dark yellowish brown (10YR4/2) to brownish black (5YR2/1) besides olive gray (5Y4/1) for most general cases, and contains no calcium carbonate but abundant radiolarians, sponge spicules, and some glauconite grains.

"Foraminiferal Clay"

Foraminiferal marl, ooze, and sandy clay in the description of the Lamont core library are also included here.

Found in some cores from the lower latitude than about 40°N, with variable thickness (1 to 130 cm) and stratigraphic positions showing no tendency of development, except for the core V28–265 which was investigated before (UJIIÉ and ICHIKURA, 1973). About the lower two-third of the core consists of foraminiferal clay, although it was indicated as the finely laminated clay in the previous paper.

This unit is characterized by the abundance of planktonic Foraminifera, associated with common benthonic Foraminifera, radiolarians, diatoms and sponge spicules. In general, color of the upper portion of the cores is olive gray (5Y3/2), changing to greenish gray (5GY6/1) to dark gray (N3) downwards. In the core RC12–376 this color change occurs around 300 cm below the top, suggesting an environmental change to more oxidized condition upwards. It must be additionally noted that well rounded granules to pebbles of chert and basic igneous rock are contained in the top 5 cm of the core RC12–387 from the Yamato Rise; in its lower portion two gravel beds are inserted.

"Glauconitic Sand"

Developed only in the cores from the Yamato Rise region, sometimes as a very thick bed attaining maximum thickness of 218 cm. It is greenish black (5G2/1) to dark greenish gray (5GY4/1), and is composed of abundant (ca. 60 to 90%) glauconite grains and rare quartz and dark minerals. Siliceous microfossils such as radiolarians and diatoms are contained in considerable amounts. This is in sharp contact with underlying sediments.

It is noteworthy that large pebbles of olive gray lutite are rich in the basal portion of the glauconitic sand bed at 172 to 225 cm below the top of the core RC12–394. Throughout the interval from 432 to 580 cm below the top of the core RC12–387, three thin (1 to 3 cm on average) beds of diatomaceous clay are inserted.

Glauconite grains are scattered also in diatomaceous ooze from 170 to 198 cm below the top of the core RC12–381 and in foraminiferal ooze from 170 to 200 cm below the top of the core RC12–387; both from the Yamato Rise.

"Sandy Clay"

Developed either rather massively in the upper portion of the cores from the Yamato Rise region (*i.e.* RC12–383, RC12–381, RC12–387, RC12–390, and RC12–394), or as thin (some ten meters thick) beds in the cores from the Japan Basin (RC12–382, RC12–386, V28–273 and V28–271) and from the Yamato Trough (RC12–389, V28–274 and RC12–397).

In the cores from the Yamato Rise, the sandy clay shows a trend of color change from light olive gray (5Y6/1) for the top 10 cm, olive gray (5Y4/1) for the interval between about 10 cm and 40 cm below the top, and to greenish gray (5GY6/1) or dark greenish gray (5GY4/1) about 40 cm below. Sand grains are of quartz, volcanic glass, some dark minerals, glauconite, and mica. The clay is generally barren of biogenic remains except for some instances. The basal contact shows a gradual change in general.

Contrary to the above-mentioned case, the sandy clay in the basin and trough cores shows no stratigraphic trend of color change, though varying from olive gray (5Y4/1) to greenish gray (5GY6/1). Besides, instead of glauconite or volcanic glass, it contains framboidal pyrite. Excluding some amount of plant debris, organic remains are also scarce, rarely accompanied by diatom frustules and radiolarian tests. The basal boundary is sharp in most cases. These characters are similar to those found in thin sand beds to be mentioned below.

"Sand"

Recovered exclusively from the cores of the basin or trough bottom as thin (less than ca. 15 cm thick) beds except for the core V28–273. In the cores RC12–374 and RC12–389 it occurs as a thick bed. Microfossils are scarce except for the case of a thick bed in RC12–374. The basal contact is always sharp.

Six "sand" beds found in the core V28–273 consists of fine-grained sands of angular to subangular quartz, igneous (acidic to basic) rock fragments, mica, some dark minerals, and olivine. Although the uppermost bed is olive gray (5Y4/1) in color, the others below it are always dark gray (N3).

A thick bed of 95 cm in the core RC12–389 is made of laminated and very fine-grained sands of intermediate color between greenish gray (5GY4/1) and medium gray (N5). Minute plant fragments are especially dominant in its lower portion.

A 44 cm thick sand bed in the core RC12–374 is of dark greenish gray (5GY4/1) fine-grained sands with thin lamination. Microfossils, particularly Foraminifera and spicules of sponge, are rich and associated with rare ostracods.

Exceptionally medium- to coarse-grained sands make a 15 cm thick bed near the base of the core RC12–397. Besides its coarseness, the mineral composition of the bed consisting of metamorphic rock fragments, feldspar, magnetite, etc. may be ascribed to turbidite origin as suggested by its geographic location on the floor of the Toyama Submarine Canyon.

"Shell Sands"

Developed widely on the shelf around the Tsushima Strait (see UJIIÉ and MITSUOKA, 1969). Throughout the thickness the core RC12–373 consists of yellowish brown medium- to coarse-grained sands mostly of biogenic origin such as molluscan shell fragments, foraminiferal tests, and so on.

"Gravel"

Observed merely in the core RC12–387 as two layers (at 295 to 330 cm below the top and at 580 to 690 cm). It is olive black (5Y2/1) to greenish black (5G2/1) in color, and composed of rounded pebbles of basalt fragments with matrix containing glauconite, some dark minerals, and quartz. Pebbles of pumice are also found in the upper layer. Abundant sponge spicules and rare diatoms and radiolarians are contained. The contact with underlying diatomaceous ooze is sharp (in the lower one).

"Volcanic Ash"

Many cores are inserted with a single or a few 5 to 25 cm thick layers of volcanic ash. The color of the ash layers is homogeneously light olive gray (5Y6/1) because of the scarcity of heavy minerals. Besides predominant volcanic glasses of sand- to silt-size, quartz, pyrite, some dark minerals, radiolarian skeltons, and diatom frustules compose the layer.

Volcanic ash layers are characteristic in cores from basin and trough, particularly in the cores from the Tsushima Trough, of which the core RC12–376 is most abundant in ash layers; eight layers are inserted through the length of about 17 cm. As will be noted in the next chapter, the core RC12–376 seems to have reached the lowermost horizon of Pleistocene, without hiatus, unlike the other cores treated here. Therefore, the core will provide further tephrochronologic correlation of cores with fundamental criteria. Unfortunately, however, no attempt of tephrochronology has been made. For the present, it may be suggested only that an ash layer occurs near the Holocene-Pleistocene boundary, judging from the planktonic foraminiferal analysis, in four cores from the western Yamato Trough (including Oki Trough), *i.e.* in V28–265, RC12–378, RC12–379 and V28–268.

In addition to the volcanic ash layer, very fine-grained volcanic glass of a considerable amount is scattered in some lutite beds as shown in Fig. 3. Such tuffaceous lutite is also common in the cores from the Tsushima Trough, especially in the core RC12–376. Whitish pumiceous patches are observed in three cores.

"Burrows"

Certain kinds of mud dwelling worms left burrows about 0.4 cm across and 2 cm or longer, mainly in homogeneous lutite, *i.e.* clay, foraminiferal clay, and diatomaceous clay of the lithologic units described above. Laminated portions of these units and "alternation" unit contain no burrow.

It is particularly noteworthy that all the cores from the water depth shallower than ca. 1500 m include burrowed lutite at any level, whereas those from the deeper sea-bottom never contain it. This critical water depth coincides with a possible upper limit of the calcium carbonate compensation depth (CCD) of the present Sea of Japan as indicated in the next chapter, where the paleoecological meaning of the occurrence of burrows will be discussed together with other phenomena.

Another fact to be noticed here is that burrows are condensed just above the boundary between the homogeneous clay and the underlying laminated clay, and then become indistinct upward. This trend was well expressed in a columnar section of the core V28–265 figured before (UJIIÉ and ICHIKURA, 1973). This fact suggests that homogeneous clay might have been produced, at least partly, by active digging-up of laminated clay by mud dwelling worms.

Manganese micronodules

Contrary to the occurrence of burrows, manganese micronodules occur exclusively in the cores from the water depth below ca. 2100 m, in other words, below a possible lower limit of CCD of the present Sea of Japan. In all but one cores with manganese micronodules, they are found only in the top portion of cores, as is the usual case with the ocean bottom sediments of the world (ARRHENIUS, 1963). It is said that manganese nodules are formed on or near the ocean bottom surface exposed for a long time under an oxidized bottom water. As a conclusion, therefore, the occurrence mode of manganese micronodules in the Sea of Japan cores seems to indicate that the oxidized condition prevails in the Recent bottom water at depth deeper than ca. 2100 m (see Fig. 1 and Table 2). An exceptional occurrence can be seen in the interval from 260 to 460 cm below the top of the core V28–268.

Framboidal Pyrite

Since RUST (1935) named and pointed out its environmental significance, framboidal pyrite has been reported from various places of the world seas and some fresh waters by many authors, and has been regarded as an indicator of reduced condition of bottom water, although two different opinions are still arguing the mechanism of its formation, *i.e.* inorganic chemical precipitation versus direct inversion from reducing bacteria (HONJO *et al.*, 1965). As OKADA and SHIMA (1973) described its morphology in some detail, framboidal pyrite found in the Sea of Japan cores occurs as aggregate of tiny (3 to 25 micron across) octahedral crystals of pyrite, filling up the inside of

Table 2. Chart showing relationship between the water depths, from which the examined cores were taken, and their lithological characters, particularly of the top portions

COLOR OF CORE TOP	OLIVE			← →	YELLOWISH BROWN to BROWN		
WATER DEPTH	–1000m	1000m–	CCD	2000m–		3000m–	
TSUSHIMA TROUGH			:|RC12-376 [burrows]	|RC12-374 [weddellite] |RC12-377	8|V28-267		
YAMATO TROUGH		:|RC12-379 [burrows] :|V28-265 [burrows]	:|RC12-378 [burrows]		8|RC12-389 [weddellite] 8|V28-274 8|V28-268 [Mn] |RC12-397 [Mn]		
YAMATO RISE	:|RC12-387 [burrows]	:|RC12-390 [burrows; weddellite]	:|RC12-381 [burrows]	|RC12-383 [Mn] 8|RC12-394 [Mn]			
JAPAN BASIN					8|RC12-398	8|RC12-382 [Mn; weddellite] 8|V28-271 8|RC12-386 [Mn]	8|V28-273 8|V28-281

:| : with planktonic Foraminifera in the top portion 8| with brown clay in the top portion foraminiferal test, radiolarian capsule, diatom frustule, or tubular remain of uncertain organism (Plate 1 illustrates an example). At the same time, some other remains of the same organisms are filled up with aggregate of blackish and similar sized microspheres of clay. The same phenomenon has been observed in the other Recent sediments and sedimentary rocks at various places by one of the authors (H.U.). It may be inferred that framboidal pyrite is formed by inversion not from reducing bacteria directly but from clay microspheres containing much hydrogen sulphide through the activity of reducing bacteria. Hydrogen sulphide-rich clay may be deposited inside the organic remains in a colloidal form so that the observed microsphere may represent the colloid itself.

A most noticeable thing is that such a stratigraphic occurrence of framboidal pyrite is abundant in the lower portion but never found in the top portion of the Sea of Japan cores. In other words, framboidal pyrite occurs exclusively in and almost throughout the part older than Pleistocene so far as the cores from the Tsushima and Yamato Troughs are concerned. The geologic ages of these cores can be determined by planktonic foraminiferal evidences. If we could assume a drastic change from oxidized condition of bottom water in Holocene to reduced one of Pleistocene as suggested before (UJIIÉ and ICHIKURA, 1973) and will be discussed later, the upper limit of the continuous occurrence of framboidal pyrite would be used as a Holocene-Pleistocene boundary marker evern for the cores which were taken from below CCD and were not suitable for dating by planktonic Foraminifera.

Weddellite

The occurrence of tetragonal crystals of this peculiar mineral ($CaC_2O_42H_2O$) was reported first in the Sea of Japan by MATSUBARA and ICHIKURA (1975) from the core RC12–390; it was the sixth discovery from sediments of the world. After that we have found the crystals in the other three cores, *i.e.* RC12–374, RC12–389 and RC12–382. Their occurrences are restricted in the pre-Holocene portion which may have been deposited under reduced condition so far as these cores are concerned, although any other geographic trend of the occurrence has not been recognized.

Particularly in the interval from 320 to 520 cm below the top of the core RC12–374, weddellite is abundant occurring in various forms such as simple single crystal, penetration twin, single crystal pierced with a sponge spicule along the c-axis, minute crystals serially adhered along a vegetable fibre, and so on; some of them are illustrated in Plate 1. Since the core is rich in minute plant fragments, weddellite might have been originated from calcium oxalate precipitated inside the plants, although its origin is disputed whether it was secondarily formed during the storage of samples at laboratory or it was primarily present in the sediments (for further discussion see MATSUBARA and ICHIKURA, 1975).

Gypsum

Single crystals or feathered twins of gypsum were found in some horizons of the cores V28–265, RC12–389, and RC12–390 and throughout the core RC12–374 including even the Holocene portion. There seems to be somewhat close association with weddellite, but its environmental and stratigraphic significances are uncertain.

Planktonic Foraminifera, Biostratigraphy and Paleoenvironment

Planktonic Foraminiferal Materials

Fundamental samples for the study of planktonic Foraminifera are composed of ca. 3 cm long and ca. 2 cm across pieces of sediments which were picked out at about 20 or 40 cm intervals by Hiroshi UJIIÉ and Itaru KOIZUMI for the RC12 cores and by Norio FUJI for the V28 cores at the Lamont. Otherwise the shipboard samples of smaller pieces were utilized; particularly all the materials of the cores RC12–374, RC12–390, V32–146, V32–154, and V32–156 were the samples collected aboard by UJIIÉ or by Kenichi KURIHARA. Consequently, the total number of planktonic foraminiferal specimens thus obtained may not be always sufficient for quantitative analysis, but any information the specimens can offer is better than no information. A total of 200-odd planktonic foraminiferal specimens were picked out from the sediment-residue on the 200 mesh sieve and identified thoroughly. Benthonic forms encountered in the course of picking were also taken out for the estimation of "planktonic ratio" and for future study.

Table 3 is the occurrence charts of planktonic Foraminifera in 152 samples from 13 cores. Hundreds of samples other than the above were also examined but no planktonic Foraminifera was detected. The faunal compositions are summarized as Fig. 5, together with the previous result obtained from the core V28–265.

On the Occurrence of Planktonic Foraminifera and Holocene Environment

The occurrence of planktonic Foraminifera was recognized almost throughout the total length of seven cores, all from the water depth shallower than ca. 1500 m. The other cores contain no planktonic Foraminifera in their upper portion, though the middle and/or lower portions sometimes contain shells. Therefore, the calcium carbonate compensation depth (CCD) can be expected at a certain depth below about 1500 m.

Making a contrast with the foraminiferal occurrence, brown clay was observed at the top of all the cores taken from below about 2300 m of water depth, while the cores from above the depth have the olive-colored top, as shown in Table 2 and Fig. 1. Because three cores located above the boundary of the color change zone but still below 2000 m of water depth are barren in planktonic Foraminifera in their upper portion, the Recent CCD may be located above 2000 m. One of the three, RC12–383, yields manganese micronodules in the top portion like the cores topped with brown clay from the deeper sea bottom. Compiling these facts, therefore, it can be inferred that the Recent or Holocene CCD may be located between ca. 1500 m and ca. 2000 m. This means that typical pelagic sediments are distributed over the deep of the Sea of Japan which is much shallower than normal ocean floor exceeding some 4000 m, as revealed by NIINO *et al.* (1969), who reported the measurements of calcium carbonate content, organic carbon content, and color of 106 dredged samples of surface sedi-

Table 3. Occurrence chart of planktonic Foraminifera

	RC12-373						RC12-374													
	10	40	80	120	160	240	320	400	440	480	800	840	880	920	960	1000	1095	1120	1160	1200
1. *Globigerina bulloides* d'Orbigny		1	2			1							5			1	4	7		
2. *Globigerina umbilicata* Orr and Zaitzeff	2		1					27	13	1	27	3	79	48	14	49	1	29	45	
3. *Globigerina* cf. *falconensis* Blow			3	2		1														
4. *Globigerina foliata* Bolli										11			1			4	32	27		
5. *Globigerina foliata* Bolli, var.	1	4	5			5	1													
6. *Globigerina rubescens* Hofker				1					1								3			
7. *Globigerina* aff. *woodi* Jenkins																				
8. *Globigerina* aff. *angustiumbilicata* Bolli		1		16	2	5	4	20	74	19		8	5		39	26	37	54		
9. *Globigerina* aff. *angulisuturalis* Bolli																				
10. *Globigerina* spp.		1					3		2	1	3		1		1?			1		
11. "*Globigerina*" *quinqueloba* Natland	2		2	4		4	4	24	39	7		27	3	1	21	13	26	25		1
12. "*Globigerina*" *pachyderma* (Ehrenberg), sinistral					1?		4	19	54	42	137	193	119	210	115	167	104	53	175	13
13. "*Globigerina*" *pachyderma* (Ehrenberg), dextral						2		2			7	3	3	2	4	4	3		5	
14. *Globigerinita glutinata* (Egger) & its vars.			2	4		2			4	1					7		7	2		
15. *Globigerinita uvula* (Ehrenberg)			2				8	8	19	11	28	12	2	2	13	4	11	5		1
16. *Globigerinita* ? aff. *parkerae* (Bermudez)																				
17. *Globigerinoides elongatus* (d'Orbigny)						1														
18. *Globigerinoides ruber* (d'Orbigny) & its vars.		2	5	2	1												2			
19. *Globigerinoides* cf. *ruber* (d'Orbigny)										2										
20. *Globigerinoides tenellus* Parker						2														
21. *Globigerinoides* ? spp.																	1			
22. *Orbulina universa* d'Orbigny, s.l.																		1		
23. *Globoquadrina dutertrei* (d'Orbigny)				2	1?	6?												8		
24. *Globoquadrina* ? cf. *hexagona* (Natland)	1			2		4?				2					3		9	9		
25. *Globoquadrina* ? spp.															1	2	1			
26. *Globorotalia* (*Turborotalia*) cf. *inflata* (d'Orbigny)																	3	2		
27. *Globorotalia* (*Turborotalia*) cf. *anfracta* Parker			1	2			1		1						2		4	8		1
28. *Globorotalia* (*Turborotalia*) spp.									2		1?				1		1	1		
29. *Globorotalia* (*Globorotalia*) cf. *cultrata* (d'Orbigny)																				
30. *Globigerinella siphonifera* (d'Orbigny)						1														
31. *Globigerinella* sp.			2	1		3														
32. *Hastigerina* ? spp.									1						1		1?			
33. *Pulleniatina obliquiloculata* (Parker & Jones)				2												1?		1		
Total	6	9	25	38	5	37	25	100	210	97	203	246	218	263	223	271	250	233	225	16
Planktonic ratio	10	8	11	20	6	33	72	93	72	38	68	96	83	93	71	90	67	74	95	26

	RC12-377										
	75	135	484	504	525	544	593	613	645	663	684
1. *Globigerina bulloides* d'Orbigny											
2. *Globigerina umbilicata* Orr and Zaitzeff	143									1	46
3. *Globigerina* cf. *falconensis* Blow											
4. *Globigerina foliata* Bolli											
5. *Globigerina foliata* Bolli, var.											2
6. *Globigerina rubescens* Hofker											
7. *Globigerina* aff. *woodi* Jenkins											2
8. *Globigerina* aff. *angustiumbilicata* Bolli					1			1			4
9. *Globigerina* aff. *angulisuturalis* Bolli											
10. *Globigerina* spp.											1?
11. "*Globigerina*" *quinqueloba* Natland					1	2		3			16
12. "*Globigerina*" *pachyderma* (Ehrenberg), sinistral	91	82	10	237	268	245	36	237	4	7	184
13. "*Globigerina*" *pachyderma* (Ehrenberg), dextral	2	1		2	1	5		3			7
14.–33.											
Total	236	83	10	239	271	252	36	244	4	8	262
Planktonic ratio	95	98	19	100	96	99	68	92	25	100	96

	RC12-376																																	
	11	30	58	108	151	197	221	260	315	368	401	422	472	531	553	577	754	784	862	903	945	1051	1097	1123	1162	1191	1211	1227	1323	1507	1547	1600	1697	1743
1. *G. bulloides*			2?						21						1?										21	25				2?	15	58	1	12
2. *G. umbilicata*	4	145	103	32	44		31		23	159	195	194	1	5	14				4				3	23	161	6	90		62	157	4		43	12
3. *G.* cf. *falconensis*	2																																	
4. *G. foliata*	15								1																									
5. *G. foliata*, var.																										28					4	65		4
6. *G. rubescens*																										1?								
8. *G.* aff. *angustiumbilicata*		1	4	2					1						2						6			5						19			1	3
10. *G.* spp.			2						1		2										2													1
11. "*G.*" *quinqueloba*		11			7		1		3		16					1	27		2		5	2		18	4	1	1			70	3	8		14
12. "*G.*" *pachyderma* sinistral	4	64	88	46	184	282	168	30	62	2	9	14	3	1	43	1	183	117	207	22	200	230	2	170		140	167	213	217	425	66	30	3	55
13. "*G.*" *pachyderma* dextral		3		2	3	5	2	2	47						3	1	8	1	5		4	4				70	4	5	3	17	5	16		1
14. *G-nita glutinata* & vars.	2		1	1																														
15. *G-nita uvula*	1	8	11								1				2							1		6	11		1					8		4
21. *G-noides* ? spp.		1																																
23. *Gq. dutertrei*	2								18																1	2								
25. *Gq.* ? sp.			2																		1?													
29. *Gr.* (*Gr.*) cf. *cultrata*																																1		
Total	30	233	213	83	238	287	202	32	177	161	223	208	4	6	65	3	218	118	218	22	218	237	5	222	198	273	263	218	282	690	97	186	48	106
Planktonic ratio	35	100	100	87	99	100	100	97	68	95	99	100	29	15	77	8	99	13	91	100	95	95	83	85	29	60	99	100	61	98	32	25	7	21

	RC12-378																				
	0	44	83	107	141	190	249	289	321	360	400	444	478	501	540	560	590	690	741	793	841
1. *G. bulloides*		1																			
2. *G. umbilicata*		1	9		146	30	12	53	22	11	50		25			1		33	2	41	1
3. *G.* cf. *falconensis*																					
4. *G. foliata*																					
5. *G. foliata*, var.													1								
6. *G. rubesceans*																					
8. *G.* aff. *angustiumbilicata*		21	4		2	1	1		1	7	8	29	9	7	35	24		18			
9. *G.* aff. *angulisuturalis*		2																			
10. *G.* spp.	1	3	2	1		2		1	3	4				1	2	1	1	1			
11. "*G.*" *quinqueloba*	2	31	37		9	1			1	8	3	41	32	39	64	34		11	1		2
12. "*G.*" *pachyderma* sinistral	7	25	11	2	31	170	200	162	160	174	146	131	141	152	91	141		126	4	7	
13. "*G.*" *pachyderma* dextral	24	125	131		3	7		4	4	2	1	6	4	5	1	1	1		1?	1	
14. *G-nita glutinata* & vars.	1	2							1				1		1						
15. *G-nita uvula*		2	1	1	21	1				5	1	7	15	9	14	20	1	10		1	
17. *G-noides elongatus*	1																				
18. *G-noides ruber* & vars.		1																			
20. *G-noides tenellus*	2																				
21. *G-noides* ? spp.														1							
23. *Gq. dutertrei*	3		8													1					
24. *Gq.* ? cf. *hexagona*		3	11										2?								
28. *Gr.* (*T.*) spp.																		2			
Total	41	217	214	4	212	212	213	220	192	211	209	214	230	214	209	222	3	201	8	50	3
Planktonic ratio	41	43	85	100	91	85	80	99	74	94	77	96	98	96	99	96	100	100	30	65	100

	RC12-389									RC12-397						RC12-381		
	80	206	240	300	320	640	960	1199	1206	3	23	43	63	93	123	10	23	61
1. *G. bulloides*														2	1			
2. *G. umbilicata*		195		126	84		9	151	197			15	16		5	30	36	7
3. *G.* cf. *falconensis*																		
4. *G. foliata*			1?			5						2	5	2	13			
5. *G. foliata*, var.																		
6. *G. rubesceans*														3?				
8. *G.* aff. *angustiumbilicata*	5		9			117				2		24	63	99	2		4	
9. *G.* aff. *angulisuturalis*																		
10. *G.* spp.			1	1		3							2		1		1	
11. "*G.*" *quinqueloba*	1		2		1	46				1		19	29	54	3		5	
12. "*G.*" *pachyderma* sinistral		39	1	128	140	21	229	77	40	1	2	74	54	63	4	177	154	20
13. "*G.*" *pachyderma* dextral				3	6		3		3			2	7	1		3	1	
14. *G-nita glutinata* & vars.	1											3						
15. *G-nita uvula*	2		1			37						6	15	15	3		2	
17. *G-noides elongatus*																		
18. *G-noides ruber* & vars.																		
20. *G-noides tenellus*																		
21. *G-noides* ? spp.												3						
23. *Gq. dutertrei*												4						
24. *Gq.* ? cf. *hexagona*			1			3						3	1					
28. *Gr.* (*T.*) spp.												1						
Total	9	234	13	258	231	232	241	228	240	4	2	156	192	239	32	210	203	27
Planktonic ratio	64	100	65	100	99	77	99	99	100	36	100	84	78	73	46	99	95	16

	RC12-387									RC12-390										
	0	10	60	80	100	118	140	163	180	60	100	120	140	200	220	240	260	280	300	340
1. *G. bulloides*						1														
2. *G. umbilicata*	49	14	56	86	75	82	86	60	4	1?				70	56	49	40	11	3	
4. *G. foliata*								1												
6. *G. rubescens*																				
8. *G.* aff. *angustiumbilicata*							4	5	3			5	1				1			
10. *G.* spp.						1		1	1					2	1			1		
11. "*G.*" *quinqueloba*			10			9	26	41	20			7	2	1?	7	1		4	4	
12. "*G.*" *pachyderma* sinistral	128	77	156	120	120	113	94	93	169	208	27			143	163	151	169	198	210	190
13. "*G.*" *pachyderma* dextral	20	3	1	11	16	11	16	16	14	3				2	1?	3	3	3	2	3
14. *G-nita glutinata* & vars.				1?									1							
15. *G-nita uvula*									5	2		25	2			1				
21. *G-noides* ? spp.												1								
24. *Gq.* ? cf. *hexagona*																				
25. *Gq.* ? sp.								2												
28. *Gr.* (*T.*) spp.																				
33. *P. obliquiloculata*									1?											
Total	197	94	223	218	211	222	226	219	217	214	27	38	6	218	228	205	213	217	219	193
Planktonic ratio	87	62	99	94	85	90	100	100	97	94	13	100	100	82	87	97	79	82	89	.99

	V32-146						V32-156								V32-154								
	160	350	450	530	663	757	152	215	288	330	387	678	943	1180	164	395	571	675	742	835	903	1000	1049
1. *G. bulloides*				1	3															1	1		1
2. *G. umbilicata*	2		4		3	3	35	169	123		7	5	34	128	3	3	12	36	4	2	55	104	88
4. *G. foliata*			1	7		6	1																
6. *G. rubescens*																							
8. *G.* aff. *angustiumbilicata*			2	55	26	88			4						2	1	2				6	6	2
10. *G.* spp.				1?	1?			1	1												1	3	
11. "*G.*" *quinqueloba*				10	10	10	1	1	1						1				2		2	2	1
12. "*G.*" *pachyderma* sinistral	1	157	22		16	1	49	84	100	10	6		87	3	87	82	94	174	49	1	158	193	117
13. "*G.*" *pachyderma* dextral		13	1		1		3	3	4?	1			1			3	3	9	4		9	10	11
14. *G-nita glutinata* & vars.					3	6																	
15. *G-nita uvula*				51	11	45																	
21. *G-noides* ? spp.																							
24. *Gq.* ? cf. *hexagona*				4		6?																	
25. *Gq.* ? sp.																							
28. *Gr.* (*T.*) spp.						1																	
33. *P. obliquiloculata*																							
Total	3	170	30	149	74	166	89	258	233	11	13	5	122	131	93	89	111	219	59	4	232	318	220
Planktonic ratio	75	100	100	68	75	78	47	100	100	100	100	100	88	99	83	51	89	90	86	8	98	99	99

ments from the Sea as evidences.

Recently BERGER and WINTERER (1973) showed such a definite trend of CCD as shallowing quickly toward the poles and the continents from the global viewpoint. So far as the Sea of Japan is concerned, however, we would like to regard that the extraordinarily shallow CCD is ascribed to peculiar characters of the bottom water, namely, oversaturated in soluble oxygen, chilled enough, and of so rather low in salinity for a bottom water. NISHIMURA (1974) cited the hydrographic measurements in summer such as 0.22°C of water temperature and 34.13‰ of salinity at the depth of 3000 m in the middle of the Japan Basin. Besides similar measurements, NIINO *et al.* (1969) cited about 5 *ml* of soluble oxygen content per 1 *l* of water around 4000 m water depth in the same season; this value approximates to the content in the near-surface water.

As introduced already in the foregoing chapter, the peculiarity of the bottom water may be due to the process that the surface water rich in oxygen off Maritime Province of Siberia was chilled by the Siberian Cold Air Mass in winter, sunk to deep, and then was entrapped within the Sea for years.

Holocene-Pleistocene Boundary

In the previous paper dealing with the core V28–265 (UJIIÉ and ICHIKURA, 1973) we decided the Holocene-Pleistocene boundary primarily based upon the remarkable change of coiling ratio of *"Globigerina" pachyderma* from sinistral predominant population to dextral one. This criterion has been used in rather high latitude regions since BANDY (1960) recognized it in the cores from off California and ERICSON (1969) applied it on the Atlantic Ocean cores. Using the core V28–265, we also pointed out extinction of *Globigerina umbilicata*, which is common in the Pleistocene to Pliocene portion, and suggested a drastic change from reduced environment to oxidized one around the boundary. This environmental change was substantiated by an apparently increased occurrence of benthonic Foraminifera (or a remarkable decrease of "planktonic ratio") in the Holocene portion and by the occurrence of framboidal pyrite limited within the Pleistocene portion.

Assumption of the warmer condition of the Holocene was supported by the floral analyses of planktonic diatoms (KOIZUMI, 1973) and of pollens (FUJI in UJIIÉ, 1975) contained in the same core. And the Holocene portion is relatively poor in benthonic diatoms and also in *Merosira sulcata*, which is a diatom species typical in littoral zone. These observations might suggest that the Sea of Japan has deepened quickly from Pleistocene to Holocene. It may have resulted in a more opened sea as might be reflected on the radiolarian occurrence which is restricted in the Holocene portion so far as the upper half of the core V28–265 is concerned (SUGANO in UJIIÉ, 1975). The uranium content of the core shows very high concentration attaining to ca. 10 ppm per 1 gr. of sediments in a portion beneath the Holocene-Pleistocene boundary (SUGIMURA in UJIIÉ, *op. cit.*). Previously SUGIMURA (in MIYAKE *et al.*, 1968) recognized similarly high concentration in their "Pleistocene" of two short cores (Nos. 64–19

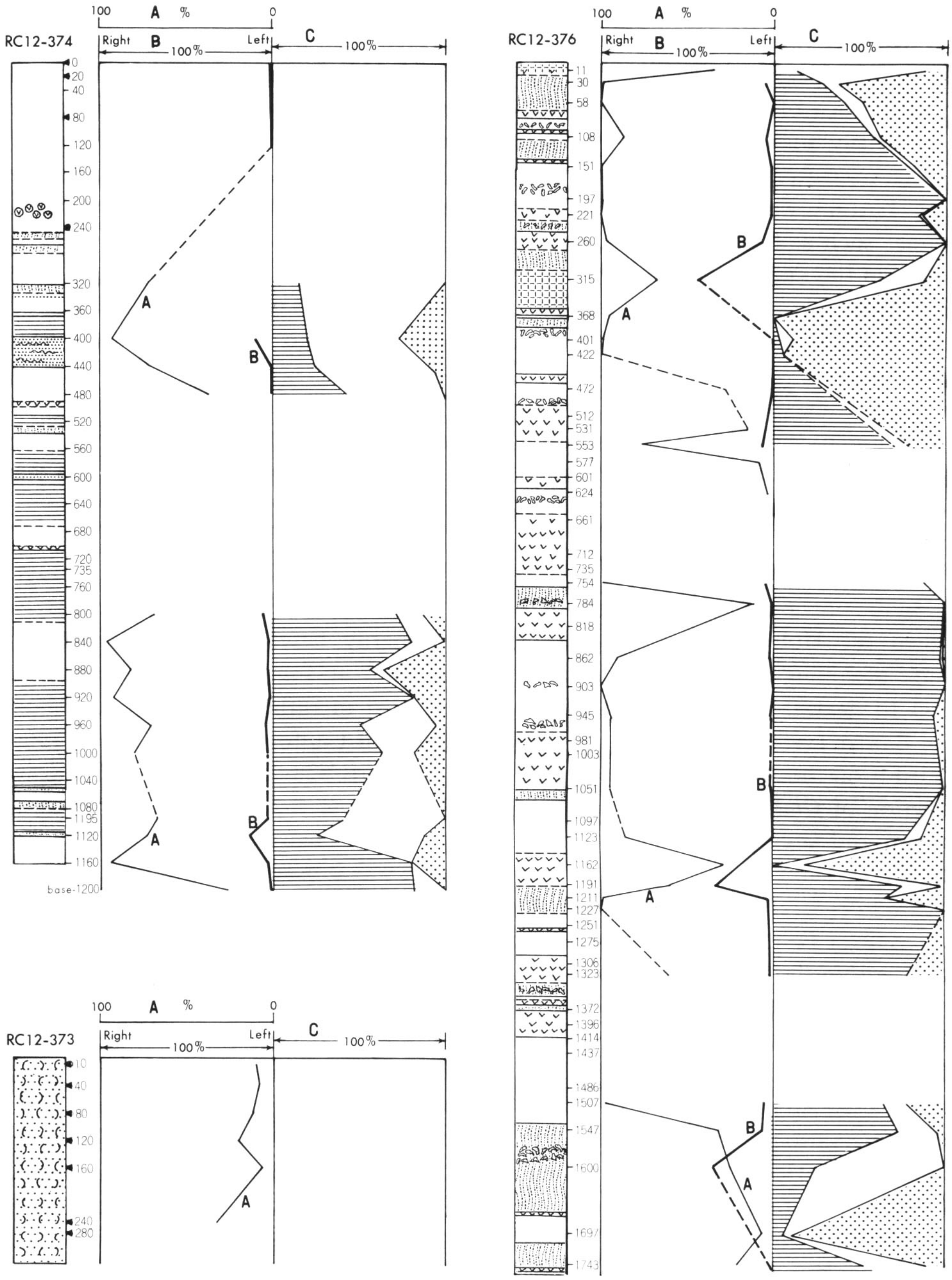
RC12-374
RC12-373
RC12-376
A %
100
0
Right
B
Left
100%
C
100%
base-1200

Fig. 5 a

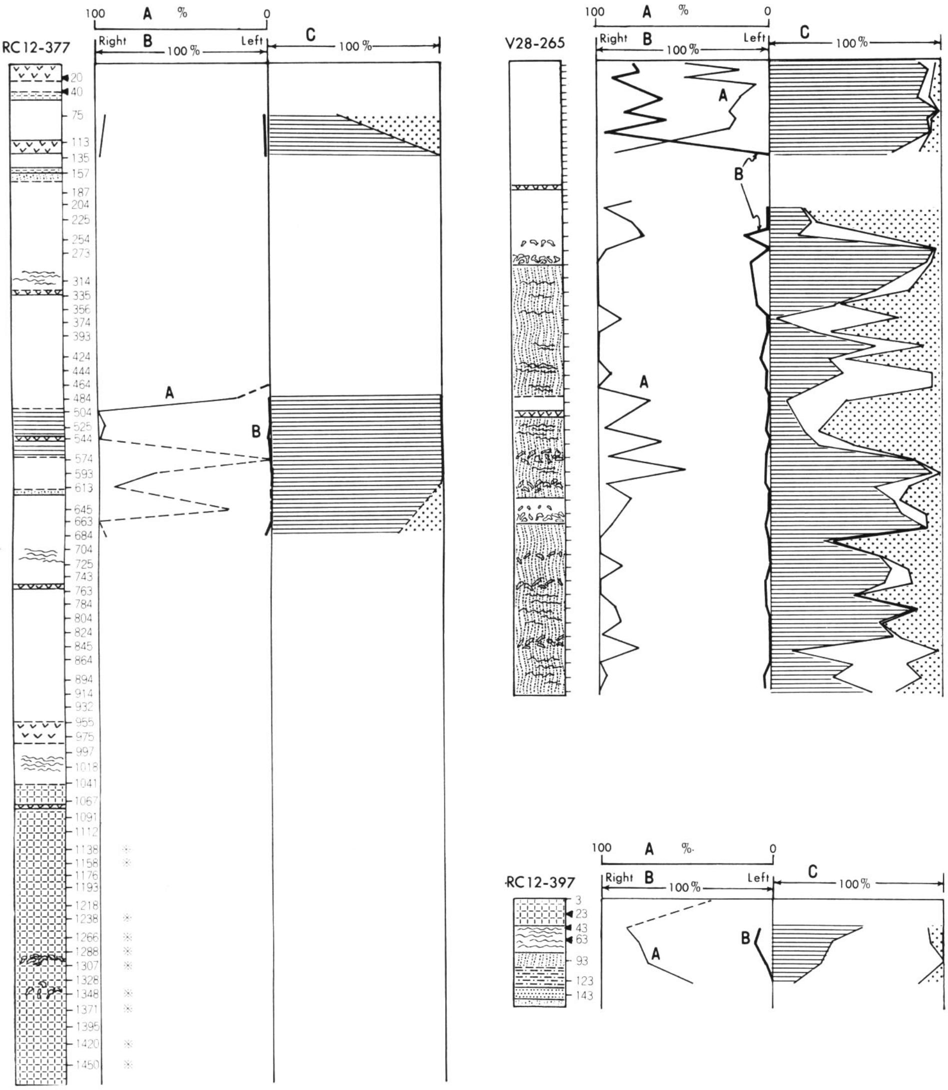

Fig. 5 b

Fig. 5 a–e. Stratigraphical change of planktonic foraminiferal assemblages in 14 cores.
A: "Planktonic ratio" (ratio of planktonic specimens to the total including benthonic ones), B: Coiling ratio of "*Globigerina*" *pachyderma*, C: Faunal composition, where only two leading species, "*G.*" *pachyderma* and *G. umbilicata*, are discriminated (for the other minor elements, see Table 3). Small numerals aside the columnar sections indicate the sampling levels below the top of cores in cm. Triangle marks mean shipboard samples.

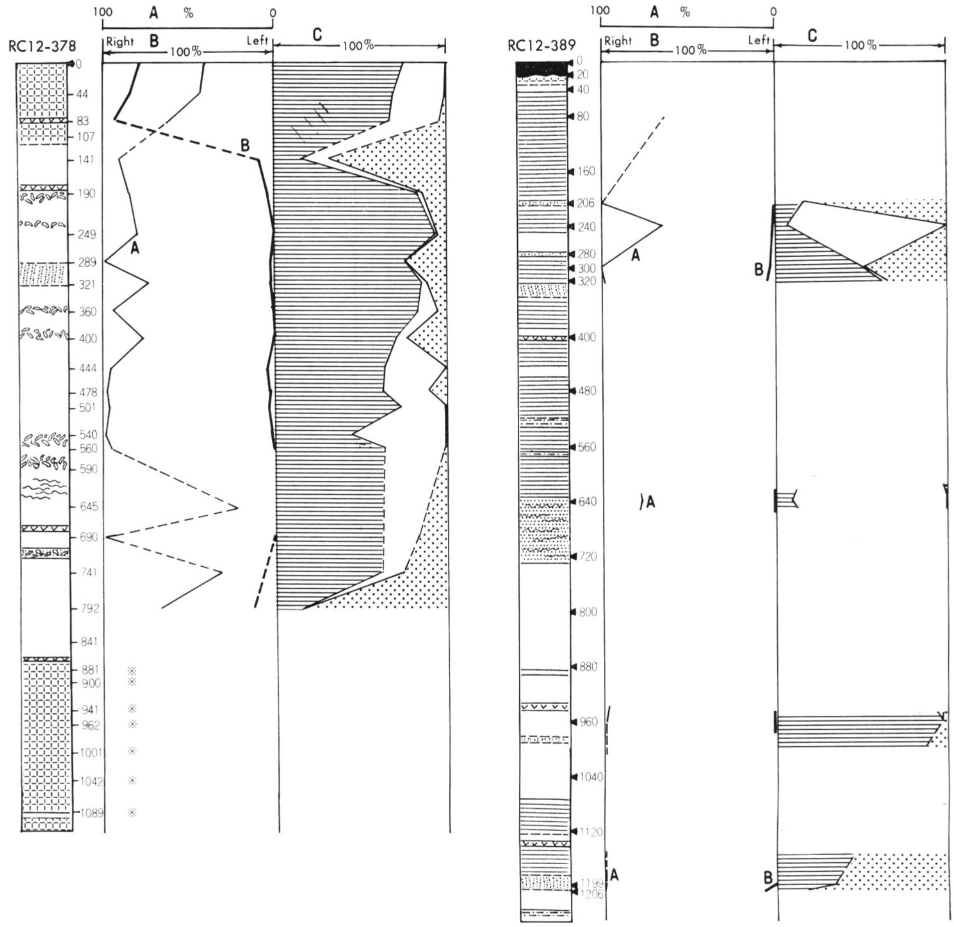
RC12-378
100 A % 0
Right B 100% Left
C 100%
0
44
83
107
141
190
249
289
321
360
400
444
478
501
540
560
590
645
690
741
792
841
881
900
941
962
1001
1042
1089
RC12-389
100 A % 0
Right B 100% Left
C 100%
0
20
40
80
160
206
240
280
300
320
400
480
560
640
720
800
880
960
1040
1120
1199
1206

Fig. 5 c

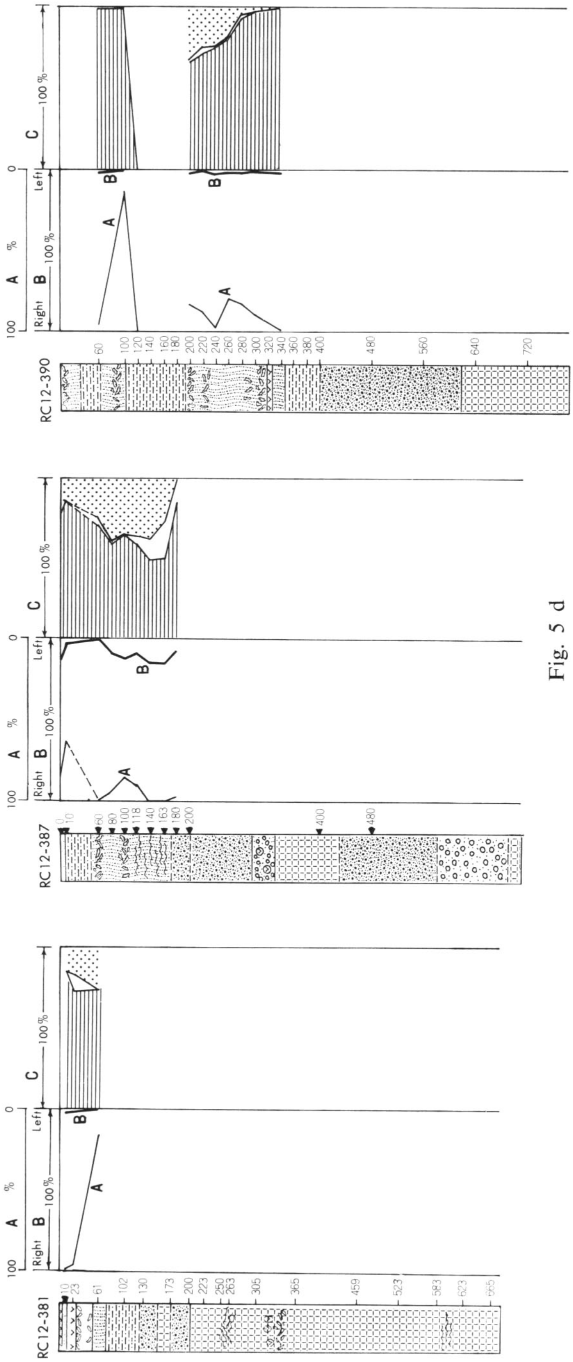
RC12-390
RC12-387
RC12-381
A
B
C
%
100 %
Left
Right
0
100
60 100 120 140 160 180 200 220 240 260 280 300 320 340 360 380 400 480 560 640 720
0 10 60 80 100 118 140 163 180 200 400 480
10 23 61 102 130 173 200 223 250 263 305 365 459 523 583 623

Fig. 5 d

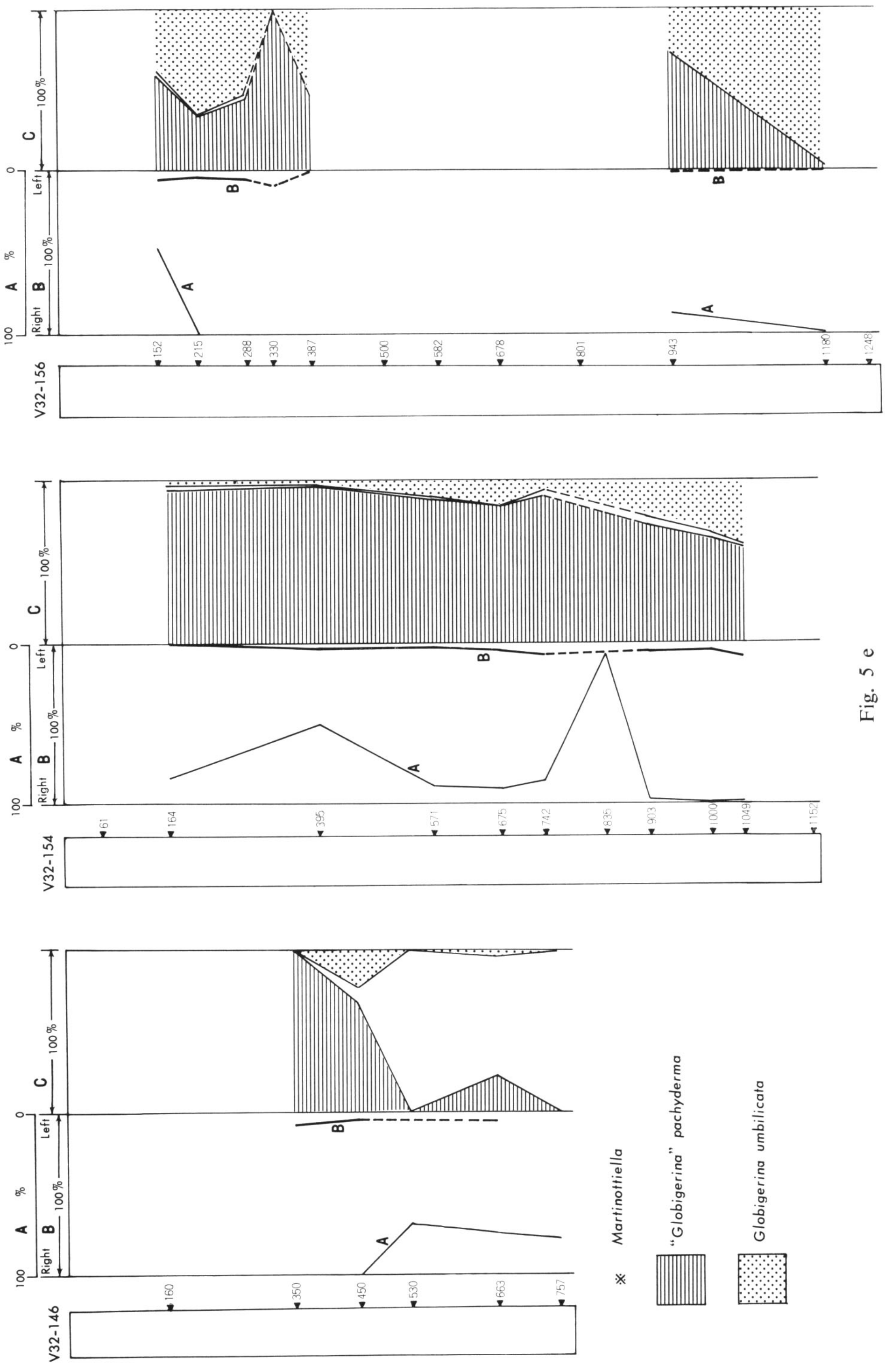
V32-156
152
215
288
330
387
500
582
678
801
943
1180
1248
V32-154
61
164
395
571
675
742
835
903
1000
1049
1152
V32-146
160
350
450
530
663
757
A %
B 100%
C 100%
Left
Right
0
100
※ Martinottiella
"Globigerina" pachyderma
Globigerina umbilicata

Fig. 5 e

and 64–21) from the Japan Basin and considered the high content as ascribable to the reduced bottom water during the Pleistocene period. This assumption might be accepted theoretically but not practically, because the uranium content measured for the majority of Pleistocene portion of the core V28–265 is not so high but of the same order as seen in the Holocene portion.

Comprehensive study of the core summarized above has revealed that the Holocene-Pleistocene boundary in the Sea of Japan cores can be defined by various criteria from the points of paleoenvironmental view. Therefore, we adopted one or combination of the following three criteria for the correlation of the boundaries in twenty-six cores; they are the coiling change of *"Globigerina" pachyderma*, the extinction level of *Globigerina umbilicata*, which seems to be a characteristic taxon in the North Pacific region as pointed by us (UJIIÉ and ICHIKURA, 1973) and supported by INGLE (1975) based on the Deep Sea Drilling Project cores, and the upper limit of framboidal pyrite occurrence. Although the last criterion may be more doubtful or approximative than the other two, the obtained results appear to be quite reasonable, particularly for the cores from the water depth below the Recent CCD, where any planktonic foraminiferal evidence could not be acquired for the Holocene portion. To ascertain the definite boundary, planktonic ratio was also referred to.

Reviewing the Holocene-Pleistocene boundary in the twenty-six cores (see Fig. 3), it can be said that its depth below the core top varies with place though there is a trend in different regions as follows: Core from the Tsushima Strait region represents only a part of Holocene yielding warm water fauna of planktonic Foraminifera somewhat similar to those reported from 56 surface samples of the Strait before (UJIIÉ, 1974). In the Tsushima and Yamato Trough regions, the depth ranges from slightly more than 1 m to about 4.5 m except for the cases measuring less than 1 m in four cores, three of which were from the near-top portion of a local topographic high or from the slope of the submarine rise. Such location as this means that perhaps the deposition was very slow and was even accompained by submarine erosion. Submarine erosion could be expected for the core RC12–397, since it was taken from the floor of the Toyama Submarine Canyon. As described in the foregoing chapter, lithology of this core implies the erosion, and the diatomaceous clay exposed in the top portion might be of Tertiary deposition, even though manganese micronodules are included in the bed below it.

A more prominent characteristic was noticed in five cores all from the Yamato Rise region; that is, the Holocene deposit is almost absent. In these cores the Pleistocene sediments are also very thin, being a few meters thick as will be stated again.

The Holocene deposits in the Japan Basin seem to be ca. 20 cm to 100 cm thick, excluding a case of the core V32–146, judging from the upper limit of framboidal pyrite occurrence or of planktonic Foraminifera. The thickness is distinctly, but not remarkable, thinner than that in the deep of the Tsushima and Yamato Troughs. This fact probably reflects the greater area of deposition and the smaller amount of detrital supply in the Japan Basin.

Referring to the above-mentioned data, we would like to give short remarks on the Holocene base in the Sea of Japan sediments hitherto judged by authors (for the locations see Fig. 2). In the Yamato Trough region, NISHIDA (1969) gave the depth of 60 cm below the top of the core Seihu 67-St. 19 as the Holocene base according to the nannoplankton contained, and KOIZUMI (1970) showed that of 63 cm in the core M40–3 based on diatom analysis. Both depths are too shallow. On the other hand, MAIYA *et al.* (1976) estimated the level between 271 and 280 cm below the top of the core RC12–379 as the base using the coiling ratio of *"Globigerina" pachyderma* and C^{14} radiometric dating. SAITO (personal communication), one of the authors, has a question why the depth is approximately twice of as much that proposed by UJIIÉ and ICHIKURA (1973) for the core V28–265 despite of their close locations to each other. However, the same volcanic ash layer is inserted near the base of Holocene in the both cores. This difference in thickness may be due to different physiographies of the sites.

Concerning the Japan Basin cores, reasonable depths of the Holocene base were given for two cores; namely, at 140 cm by diatom, 110 cm by pollen analysis, 170 cm by Foraminifera for the core USSR–3602 (*fide* KORENEVA, 1961) and at 60 cm by diatom for KH–69–2–23 (MIZUNO *et al.*, 1975). On the other hand, the depths estimated by other researchers were too shallow, such as 15 cm below the top of the cores 64–19 and 64–21 on the basis of Io/Th ratio and uranium content (MIYAKE *et al.*, 1968) and 18 cm in the core USSR–5852 by Foraminifera (SHARUDO *et al.*, 1973); the latter case involves some doubts about the identification of Foraminifera as suggested before (UJIIÉ, 1975).

Pleistocene Paleoenvironment

As seen in the foregoing lines, a remarkably reduced condition of bottom water can be inferred mainly by the common occurrence of framboidal pyrite and the decreased occurrence of benthonic Foraminifera in the greater part of the Pleistocene portion of the cores treated here. Such a condition could have been produced if the sea-level lowered during the ice age (*eg.* BLOOM *et al.*, 1969), then the shallow straits between the Sea of Japan and the Pacific Ocean emerged above water so that the Sea was finally enclosed by a continuous island arc. Stangnancy of water within the Sea thus resulted may have been accelerated by the inactive vertical circulation of water, because the climatic gradient between the northern and southern margins of the Sea may have been very slight and so the "refrigeration effect by the Siberian Air Mass" could not be expected. As the cause of this reduced condition, KOBAYASHI and NOMURA (1972) proposed a conjection that the Sea of Japan was icebound all over. This simple assumption can never be acceptable in view of the common occurrence of many sorts of planktonic microfossils in the Pleistocene. NISHIMURA (1973, 1975) also denied this conjecture from his long experience of investigation of the Recent marine animals, especially fishes, of the Sea, although he erroneously supposed that such a reduced condition disappeared in the latest ice age. Many direct evidences from the sea bottom sedi ments sufficiently indicate anaerobic bottom water for the latest Pleistocene.

About the older Pleistocene paleoenvironment, however, we have not yet enough evidences because of the lack of exact dating. INGLE (1975) reported a probable interglacial age around 500 m below the sea bottom, namely near the bottom of a drilling core at Site 299, Deep Sea Drilling Project Leg 31, in the northern Yamato Trough. Unfortunately no continuous occurrence of planktonic Foraminifera was recognized in the core even though its lithofacies indicates an anaerobic condition prevalent almost throughout. Compared with this greater thickness, the Pleistocene in the cores reported by previous authors seems to be too thin, even if the estimates of the Holocene thickness in some cores may be acceptable.

The core RC12–376 from a topographic high in the Tsushima Trough region appears to have no or very thin (less than 11 cm) Holocene portion but thick Pleistocene one. In this Pleistocene sequence, it can be recognized that the right-coiling specimens of *"Globigerina" pachyderma* increase somewhat at three horizons, *i.e.* around 315 cm, 1191 cm, and 1600 cm below the top, implying a mild or comparatively warm climate. Approximately at the same levels, benthonic Foraminifera increases in occurrence as shown by decreased planktonic ratio (Fig. 5), and also *"G." pachyderma* gives way to *Globigerina umbilicata*, which is another leading member of the Pleistocene planktonic foraminiferal fauna of the Sea of Japan. The present fluctuation is not so remarkable that it might be correlated with interstadial-stadial change within the last glacial age, "Wurm" glacial stage. However, these three levels seem to correspond with three interglacial stages, if two assumptions hold good. The first assumption is that the top ca. 10 cm of this core represents the whole Holocene, the sedimentation rate is rather constant, and then the bottom of the core reaches to the early Pleistocene. The second one is that, during the Pleistocene stage, all the straits were not so deep nor wide as to allow any free-flowing of oceanic water, particularly of the ancient Kuroshio Warm Current, into the Sea of Japan. This status may be supported by geological information about the areas surrounding the two deepest and broadest straits, the Tsushima Strait (UJIIÉ and MITSUOKA, 1969) and the Tsugaru Strait (UOZUMI, 1967). Thus, migration of warm water tolerant species of planktonic Foraminifera into the Sea must have been prevented during the interglacial stages, too, so that the weak fluctuation of the faunal change was resulted in unlike the usual case. Similar increases of *G. umbilicata* and right coiling *"G." pachyderma* were observed around 792 cm below the top of the core RC12–378 taken from the Oki Ridge of the Yamato Trough region. In this case, however, the diatomaceous clay of probable pre-Pleistocene is developed below the level, and the older part of Pleistocene is absent.

With the present knowledge, though still limited, of planktonic Foraminifera and lithology, an enclosed marginal sea may be supposed for the Sea of Japan during almost the whole period of Pleistocene. The enclosed condition resulted in impoverlishment of benthonic Foraminifera, but its influence may not have been so critical for the water depths shallower than the possible upper limit of the present-day CCD, that is, above ca. 1500 m, since burrowed lutite was found exclusively in the cores from the depths above that level (Table 3). In other words, this fact suggests that the present day bottom relief of the Sea of Japan has been maintained since the Pleistocene. It must be noted also that the thickness of Pleistocene in the cores from the Yamato Rise region is very thin ranging from the one fourth to one tenth of the minimal value estimated for the core RC12–376, the one having the thinnest Pleistocene portion among the cores from the troughs and basin in the Sea. This means that the Rise has remained high since the Pleistocene.

Pre-Pleistocene Sequence.

In many cores from the Yamato Rise region, rather thin Pleistocene sediments are underlain by a glauconitic sand bed which suggests very slow sedimentation rate as stated already. Below the bed, diatomaceous ooze to clay is well developed in general. Although no planktonic Foraminifera was recovered from the diatomaceous lutite, the rich diatom flora contained is assigned to the *Denticula seminae* forma *fossilis*/*Denticula kamtschatica* Zone to *Denticula hustedtii* Zone, *i.e.* early Middle Pliocene to Late Miocene, according to KOIZUMI (personal communication).* Diatomaceous rocks of similar age and lithology are distributed all over the Sea of Japan as revealed by the "Deep Sea Drilling Project" and by a number of seismic profiler surveys (*e.g.*, LUDWIG *et al.*, 1975; HILDE and WAGEMAN, 1973) which showed the diatomaceous lutite as an acoustic transparent layer beneath the opaque one probably of turbidite origin. If the 'turbidite" is of Pleistocene age, its extensive development might have been caused by the eustatic upheaval of surrounding lands and, even of the Yamato Rise. Contrary to rather discontinuous occurrence of the "Pleistocene sequence", the diatomaceous lutite seems to continue well from the Rise region to the basin or trough regions, both in stratigraphy as mentioned above and in structure as shown in many seismic profiler records.

In connection with this trend, a hiatus might be expected between the Pleistocene and the pre-Pleistocene for the Yamato Rise region as suggested by common insertions of thick glauconitic sand beds. In the core RC12–387, moreover, two gravel beds were observed beneath two glauconitic sand beds, respectively. The inferred hiatus might reflect an upheaval of the Yamato Rise.

Most recently L. H. BURCKLE and F. AKIBA (personal communication) found abundant fresh water diatoms in the part between 225 and 601 cm below the top of the core RC12–394 from the Yamato Rise. In the columnar section shown in Fig. 3, this interval is composed of homogeneous clay underlain by glauconitic sand bed a about 50 cm thick, and contains *Denticula kamtschatica*, a planktonic diatom species indicating Middle to Lower Pliocene. Also considering a character of the associated pollens,

* This age determination might be substantiated by the occurrence of *Martinottiella communis* and *Miliammina echigoensis* through the diatomaceous lutite of the cores RC12–377 and RC12–378 (see Fig. 3). These "arenaceous" Foraminifera are characteristic in the Shiiya Formation and its equivalents of latest Miocene (or Pliocene?), on the Sea of Japan coast (*e.g.*, MATSUNAGA, 1963).

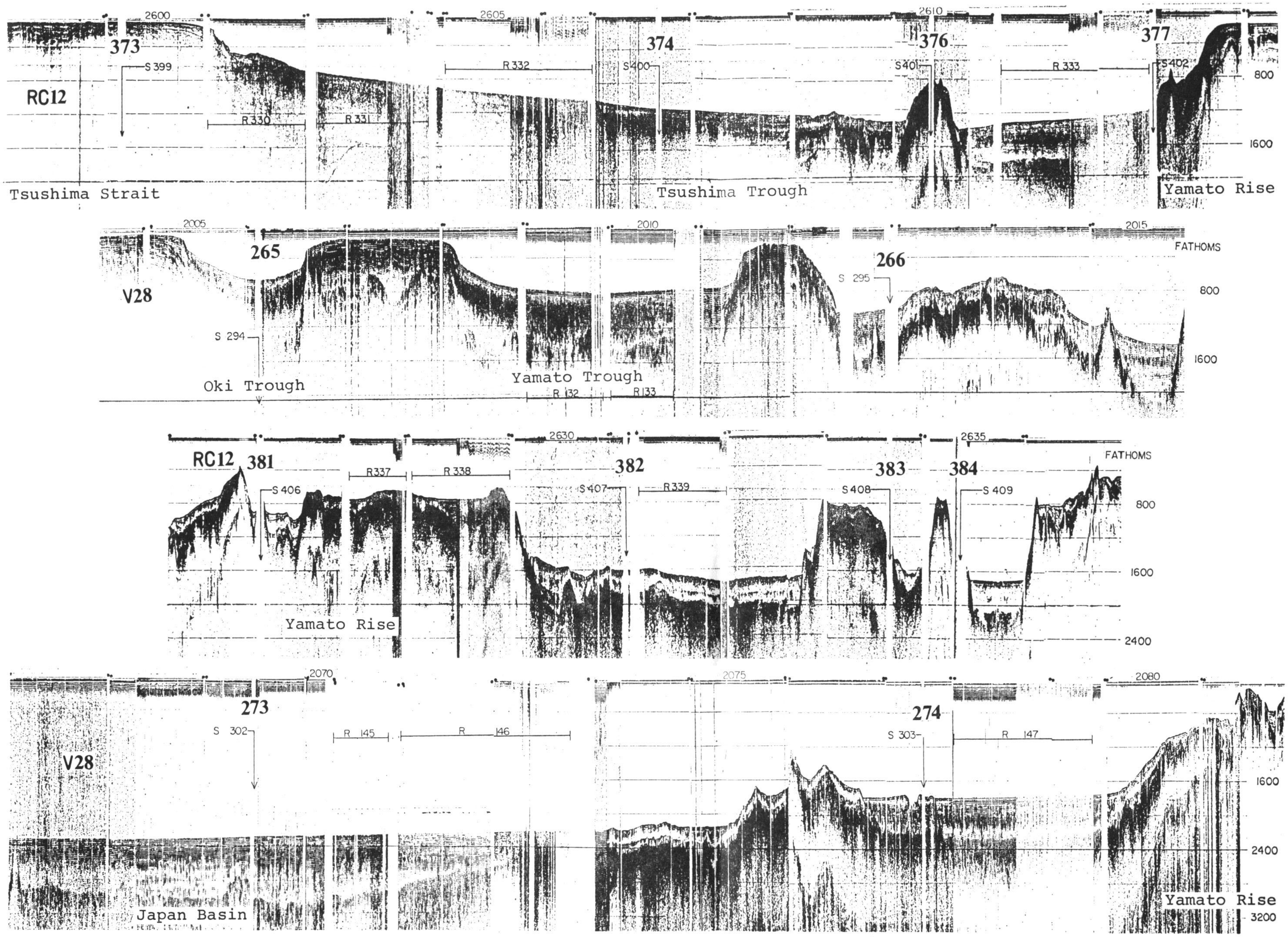

Fig. 6. Seismic profiler records showing the relationship between the coring sites and the geologic structure as examples (for the details of the structure according to seismologic approaches, see LUDWIG *et al.*, 1975).

they presumed that there was a fresh water lake of considerable scale. If his presumption is valid, we must think a remarkable upheaval before the sediments were laid down, probably before the Pliocene. NISHIMURA (1964 *et seq.*), on the basis of his study of fresh water fishes from the surrounding lands, proposed the presence of a greater fresh water lake within the Sea, during middle Pliocene period, without reliable evidence for the age determination. So far as the records retained in the core samples of sediments are concerned, however, no trace of such a large scaled lake could be inferred, at least in that period.

Acknowledgements

This work was carried out as part of the projects under the Japan–U.S. Cooperative Science Program, entitled "Study of sedimentary deposits of the Sea of Japan and surrounding terrains" (4R006) from 1969 to 1971 and "Late Cenozoic stratigraphy and paleoenvironment of northern Japan and its adjacent seas" (4R028) from 1975 to 1976. We are greatly indebted to the Japan Society for the Promotion of Science for the grant-in-aid. Our sincere thanks are also expressed to all the participants from the United States, particularly from the Lamont-Doherty Geological Observatory of Columbia University, for their kind cooperation. The late Maurice EWING, former director, Tsunemasa SAITO, James D. HAYS, and many other persons of the Lamont offered us these precious piston core samples and valuable information. We are indebted also to the Japanese participants for their intimate collaboration, such as Sadanori MURAUCHI of Chiba University, Itaru KOIZUMI of Osaka University, Yukio SUGIMURA of the Meterological Research Institute, Norio FUJI of Kanazawa University, Kenji KURIHARA of St. Paul University, Kaoru OINUMA of Toyo University, Makoto SHIMA of the Institute of Physical and Chemical Research.

The groundwork of this paper was made up by M. ICHIKURA, when he was a research student of the National Science Museum in fiscal year 1972, under the guidance of and cooperation with H. UJIIÉ.

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Explanation of Plates

(a: spiral view; b: apertural and edge view; c: umbilical view; otherwise noted. All figures are scanning electron micrographs)

Plate 1

Fig. 1. A penetration twin of weddellite, from RC12–374: 520 cm*, ×100.
Fig. 2. Weddellite crystals adhered upon an organic fibre, from RC12–374: 520 cm, ×20.
Fig. 3. Weddellite pierced with a spong spicule along the c-axis, from RC12–374: 520 cm, ×66.
Fig. 4. A penetration twin of gypsum, from RC12–374: 160 cm, ×20.
Fig. 5. Tabular gypsum, from V28–265: 38 cm, ×20.
Fig. 6. Framboidal pyrite aggregate filling up a tubular remain of unknown organism, from RC12–374: 741 cm, ×66.
Fig. 7. *Martinottiella communis* (D'ORBIGNY), Micropaleontology Collection, National Science Museum, Tokyo 1419, from diatomaceous clay, RC12–378: 1001 cm, ×37.
Fig. 8. *Miliammina echigoensis* ASANO and INOMATA, Micropal. Coll. N.S.M. 1420, from the same materials as the above, ×80.
Fig. 9. *"Globigerina" pachyderma* (EHRENBERG), dextral form, Micropal. Coll. N.S.M. 1435, from RC12–378: 44 cm, ×100.
Figs. 10, 11. *"Globigerina" pachyderma* (EHRENBERG), sinistral forms, Micropal. Coll. N.S.M. 1433 and 1434, from RC12–378: 44 cm, ×100.

Plate 2

Figs. 1–3. *Globigerina umbilicata* ORR and ZAITZEFF, two adults and one young specimen; young form possesses already heavily ornamented wall and a rather restricted aperture, Micropal. Coll. N.S.M. 1424, from V32–156: 288 cm, 1423, and 1426, both from RC12–376: 30 cm, two adults ×66, a young form ×133.
Fig. 4. *Globigerina foliata* BOLLI, with rather restricted aperture in comparison with typical form, Micropal. Coll. N.S.M. 1427, from RC12–376: 11 cm, ×100.
Fig. 5. *Globigerina bulloides* D'ORBIGNY, Micropal. Coll. N.S.M. 1421, from RC12–376: 1600 cm, ×66.

* Core number and sampling level below the top of core.

Plate 3

Fig. 1. *Globigerina rubescens* HOFKER, showing sporadical occurrence, Micropal. Coll. N.S.M. 1429, from RC12–374: 1095, ×100.

Fig. 2. *Globigerina* aff. *angustiumbilicata* BOLLI, four and half chambered form (five chambered form is not illustrated here), Micropal. Coll. N.S.M. 1430, from RC12–378: 540, ×100.

Figs. 3, 4. *"Globigerina" quinqueloba* NATLAND, Micropal. Coll. N.S.M. 1431 and 1432; 4: a type having umbilical aperture with a distinct lip similar to that of *G. falconensis*, from RC12–378: 540 cm, ×100.

Fig. 5. *Globigerinita glutinata* (EGGER), umbilical view, where bulla was broken away showing an appearance resemblable to *Globigerina juvenilis* BOLLI, from RC12–374: 960 cm, ×100.

Fig. 6. *Globigerinita uvula* (EHRENBERG), Micropal. Coll. N.S.M. 1436, (c: edge and not apertural view), from RC12–378: 141 cm, ×100.

Fig. 7. *Pulleniatina obliquiloculata* (PARKER and JONES), Micropal. Coll. N.S.M. 1443, from RC12–374: 1120 cm, ×100.

Plate 4

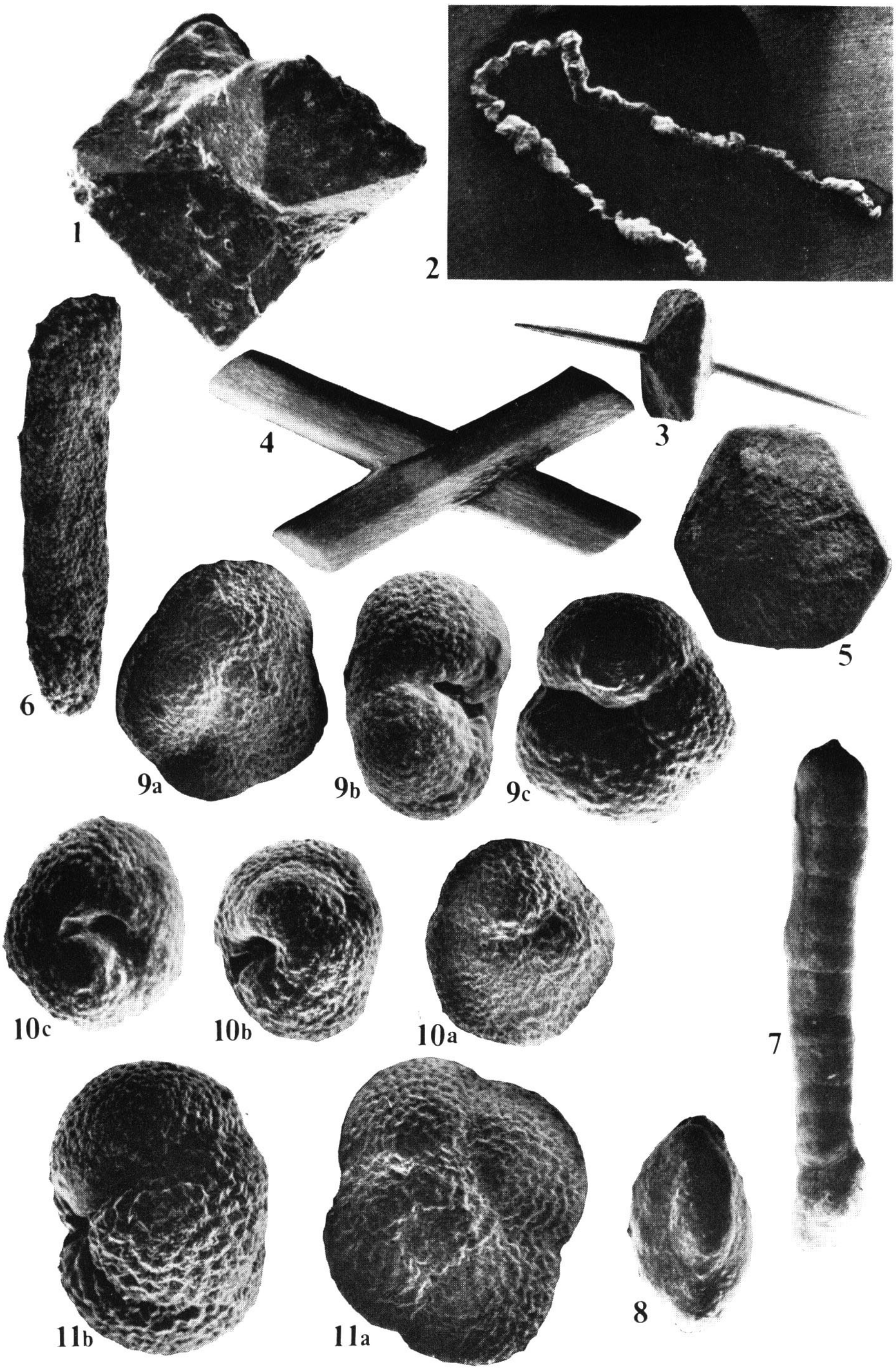
Fig. 1. *Globorotalia (Turborotalia) inflata* (D'ORBIGNY), young form (no adult form was recovered from the cores treated here), Micropal. Coll. N.S.M. 1441, from RC12–374: 1120 cm, ×100.

Fig. 2. *Globorotalia (Globorotalia) cultrata* (D'ORBIGNY), juvenile form (no adult form was found in the cores treated here), Micropal. Coll. N.S.M. 1442, from RC12–374: 960 cm, ×100.

Fig. 3. *Globigerina ruber* (D'ORBIGNY), Micropal. Coll N.S.M. 1437, from RC12–374: 1095 cm, ×100.

Fig. 4. *Orbulina universa* D'ORBIGNY, var., spiral view, showing the protruded earlier whorl of relatively large size compared with rather small test-size, Micropal. Coll. N.S.M. 1438, from RC12–374: 1120 cm, ×100.

Figs. 5, 6. *"Globoquadrina" dutertrei* (D'ORBIGNY), 5: umbilical view of five chambered form with distinct lip, Micropal. Coll. N.S.M. 1439, ×85, 6: four chambered form, Micropal. Coll. N.S.M. 1440, ×100, both from RC12–376: 315 cm.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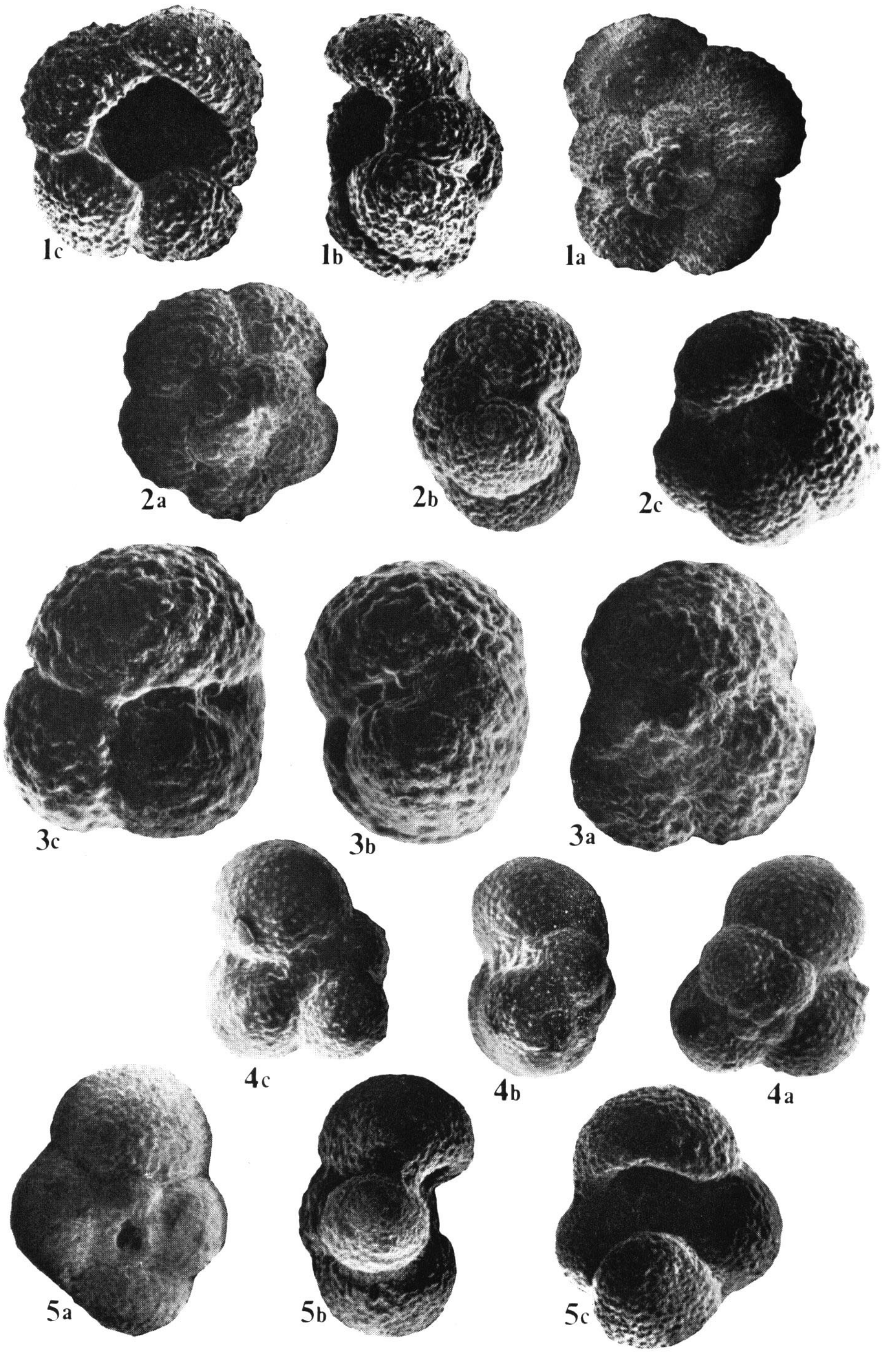
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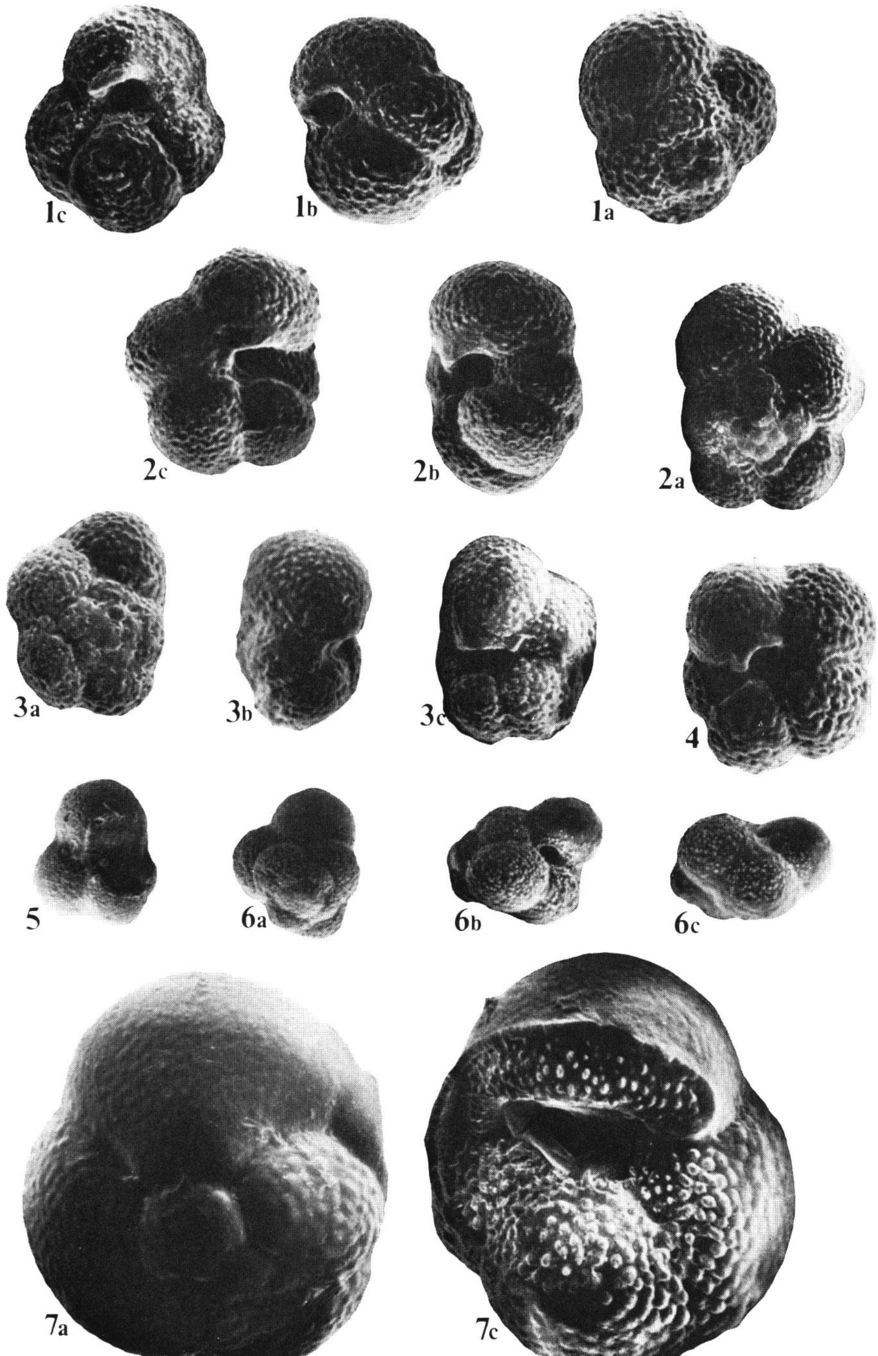
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