

# Interpretation of Diatom Thanatocoenoses from the North Pacific Applied to a Study of Core V20-130 (Studies of a Deep-sea Core V20-130. Part IV)

Taro Kanaya and Itaru Koizumi

## ABSTRACT

The geographical distribution of diatom species in modern sediments has been analysed on the basis of samples representing the uppermost layers of deep-sea cores collected at widely distributed stations in the Pacific ranging in latitude from 55°N to 55°S. More than 220 taxa have been identified from 118 samples subjected to the analysis. Analyses made on the distributions of each taxon and of recurrent groups formed by combination of diatom taxa resulted in a broad classification of modern diatom thanatocoenoses in the surface layer of the Pacific deep-sea sediments. Seven assemblages are recognized in this proposed classification of modern diatom thanatocoenoses in the North Pacific. They are: Subarctic assemblage, Northwest Marginal assemblage, Subarctic-Central Mixed assemblage, Northeast Transitional assemblage (North), Northeast Transitional assemblage (South), Central assemblage and Equatorial assemblage.

The geographical distribution, as well as the species compositions of these assemblages, reflects the present-day surface water circulation and distribution of upper watermasses in the North Pacific. The identification of assemblages in ancient thanatocoenoses, therefore, provides criteria useful in the interpretation of ancient oceanic conditions that controlled the diatom record in deeper layers of North Pacific cores.

Cold and warm water forms can also be discriminated through the analyses, and a variable  $Td$  can be defined that reflects the present-day latitudinal distribution of surface water isotherms in the North Pacific. The variable is defined as  $Td = (Xw/Xc + Xw) \times 100$ , where  $Xc$  and  $Xw$  are frequencies of cold and warm water forms, respectively, in a random count of 200 diatom specimens made for a sediment sample.  $Td$  values also provide criteria to be useful for the interpretation of the past records preserved in the North Pacific cores.

Diatoms in the core V20-130 (36°59' N, 152°36' E; depth, 6547m; length, 1039cm) were studied in an attempt to infer the fluctuation of surface water temperatures during the accumulation of the Pleistocene section represented in the core. The diatom temperature curve thought to reflect the fluctuations of surface water temperature is derived by plotting  $Td$  values obtained at 86 core levels examined of the core. The fluctuation of the curve through the core sequence is interpreted in the light of diatom assemblages whose types were determined at a number of maxima and minima of  $Td$  values shown by the curve. In the upper two thirds of the core, from the core level D-66 (655-656 cm) to the top, major changes in the  $Td$  values are marked by the changes in the type of assemblages, following a rule that can be related to the geographical distributions of these two parameters of diatom compositions in the modern sediments of the North Pacific; whereas, the same rule does not necessarily hold true in the lower one thirds of the core, from the bottom of the core up to the core level D-68 (675-676cm). It is concluded, therefore, that the diatom temperature curve derived illustrates the fluctuation of surface water temperatures in the upper two thirds more reliably than in the lower one third of the core V20-130. Three maxima of  $Td$ , ones at D-6 (60-61 cm), D-43 (425-426 cm) and D-62 (615-616 cm), are considered to reflect the temperature maxima of major warm stages during the Pleistocene; the major temperature minima of the cold stages are thought to be detected at D-3 (30-31 cm), D-8 (80-81 cm), D-31 (310-311 cm), D-47 (465-466 cm) and possibly at D-94 (935-936 cm).

Based on preserved forms, the diatom flora of the North Pacific appears to have acquired species compositions very similar to that of the present-day flora in middle latitudes before the time of deposition of the lowermost core levels of the core V20-130. The section represented in the core can be divided into two biostratigraphic zones: the upper zone represents the upper two thirds of the core,

and the lower zone represents the lower one third of the core. The lower zone corresponds approximately to the Teil zone (or local range zone) of *Coscinodiscus wailesii* of this part of the Pacific. The difference in species composition between the two zones is not great even though *Coscinodiscus wailesii* is lacking in the upper zone. It appears that the differences between the zones were caused by the changes that took place in certain other attributes of biocoenoses, other than species composition, which made different the structures of those biocoenoses on which the compositions of thanatocoenoses depended. Differences of this kind detected by comparing the types of diatom assemblages and *Td* values are interpreted as representing the important phases of the development of the North Pacific diatom flora during the Pleistocene in the middle latitudes of the western North Pacific.

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## INTRODUCTION AND PREVIOUS WORK

The first modern attempt to make use of diatom remains in the interpretation of deep-sea cores was by Lohman (1941) when he discussed the ecologic and geologic significance of diatoms from a series of Atlantic deep-sea cores between New Foundland and Ireland. Later, Kolbe (1954, 1955, 1957) discussed the characteristic species compositions of diatom assemblages in deep-sea sediments of the equatorial zone after studying the long cores taken by the Swedish Deep-sea Expedition of 1947-1948 from the Atlantic as well as from the Pacific and Indian Oceans. Since Kolbe's work a number of workers of the Soviet Union have been very active in the study of the diatoms in the deep-sea sediments of the Pacific and its neighbouring seas. Their papers include: Jousé (1957), on diatoms in the surface layer of the sediments of the Sea of Okhotsk; Semina and Jousé (1959), on the comparisons between diatom thanatocoenoses and biocoenoses in the western part of the Bering Sea; Seczka (1959), on the diatoms in a long core (19 m) from the Sea of Japan; Jousé (1961a, b), on the correlation of horizons marked by diatoms in longer cores from the northwestern part of the Pacific; Jousé (1962), a thorough summary of diatom studies carried out by Russian workers in the Soviet Far East Seas; Jousé (1963), on a further discussion of diatom stratigraphy of the deep-sea cores from the areas under different watermasses in northwestern Pacific; Belyaeva (1963), on the geographical differences of diatom assemblages in the surface layer of the Pacific sediments distributed between 56°N and 48°S latitudes; Jousé *et al.* (1962), on diatoms in the surface layer of the cores from the Indian as well as the Pacific sectors of the Antarctic; and Kozlova (1961, 1962, 1964), on biocoenoses of diatoms in the Indian and Pacific sectors of the Antarctic.

In his study of the North Atlantic cores located between 46° and 50°N Lat., Lohman (1941) pointed out that only one third of the species found in the cores had been reported by Lebour (1930) as living in the North Atlantic at the present time. Lohman therefore suggested that "Apparently many of the species found at present in the upper waters of this part of the North Atlantic are not deposited on the sea floor directly beneath but are carried away by currents and deposited elsewhere." (*op. cit.*, p. 58). Further, he came to the conclusion (*ibid.*, p. 62) that "Some of the diatoms necessarily started for the bottom many hundreds or possibly thousands of miles from their final resting place."

However, studies by Russian workers who have compared diatoms in bottom sediments with those in the plankton collected in particular areas have made it apparent that a good correlation exists in species composition between the diatom thanatocoenoses in the uppermost layer of the bottom sediments and the biocoenoses supported by the surface water of the same area. In this type of study, allowance is made for impoverishment of thanatocoenoses due to selective dissolving of the delicate frustules of diatoms belonging to certain genera, including two important genera of diatom plankton, *Chaetoceros* and *Rhizosolenia*. Except for few species, frustules of the vegetative cells of *Chaetoceros* and *Rhizosolenia* are rarely found in bottom sediments, despite the fact that these genera are represented in plankton by large numbers of species and individuals.

The geographical distribution of these two genera is well known. The geographical distribution in the Pacific of living representatives of those diatoms generally preserved in bottom sediments, on the other hand, has been less well known. Some of them are small in size, and are not always identified to species in routine planktological work. Further, their occurrences in plankton may be masked by the predominance of *Chaetoceros* and *Rhizosolenia*. By identifying all diatoms in plankton to species, Russian students have considerably removed this deficiency of knowledge, particularly in the Soviet Far East Seas. A few of their results are cited below to illustrate the extent to which thanatocoenoses can be compared with biocoenoses.

Of 61 diatom species found preserved in the surface layer of cores from the western

part of the Bering Sea, 52 were found in the surface plankton of the same area (Semina and Jousé, 1959, p. 55-56). A study made on cores from the Sea of Okhotsk revealed that the geographical distribution of several predominant species in the uppermost layers of the cores parallels their geographical distribution in the surface plankton (Jousé, 1957, figs. 7-13; 1962, figs. 6-11). When a census is made for species composition of each sample from the uppermost sediment layers in terms of marine oceanic, marine neritic and brackish and freshwater categories, the ratio of oceanic species to the other two categories in these layers increases systematically toward the center of the Okhotsk Sea Basin. Percentage maps of marine oceanic species in the sediments of the Okhotsk Sea Basin thus show patterns that generally correspond to the bathymetry of the basin (*ibid.*, 1957, fig. 6; 1962, fig. 5).

Semina (1958) presents a case where some species indigenous to either the cold, subarctic Oyashio Current or the warm Kuroshio Current and tropical waters are found living together in plankton at the zone of mixing off Japan made by the Oyashio and the Kuroshio. Therefore, long distance transportation of diatom frustules by currents away from their original habitats may not be the cause of mixed assemblages of cold and warm water species in the sediments of middle latitudes.

Through their findings, only a few of which were mentioned above, the Russian workers on diatoms have become convinced (*e.g.* Jousé, 1961a, 1961c, 1962) that: (1) the species composition of a diatom assemblage on the sea bottom depends to a large extent on the species composition of the plankton in the sea water above; (2) the species composition is a result of thermal and other physiogeographical conditions in the upper water masses; (3) the geographical zonality of diatom assemblages is well expressed in their present distribution in the Pacific; (4) climatic variations during the Quaternary caused the displacement of biogeographical zones in the ocean, synchronously with displacements of the upper water masses; and therefore (5) one may judge the thermal conditions at the time of sediment accumulation from the changes in the composition of diatom floras (1961c, p. 374). The discrepancy reported by Lohman (1941, p. 61) between the climatic curves based on diatoms and those based on Foraminifera for some North Atlantic cores was interpreted by Jousé (1962, p. 5) to have been caused not by the differences in settling velocities between diatom valves and Foraminifera tests as Lohman suggested, but by Lohman's assignment of diatom species to cold, temperate or warm water groups which was not necessarily correct for all species used for the construction of the curves.

The geographical distribution of diatoms in modern deep-sea sediments of the Pacific was studied (Kanaya, 1961; in preparation) in order to classify modern diatom thanatocoenoses in the deep-sea Pacific with a view towards establishing criteria useful in the interpretation of the ancient diatom assemblages in the deeper layers of Pacific cores. In these studies samples representing the uppermost layers of cores taken at widely distributed stations were studied over a wide range in latitude, from 55°N to 55°S. Bramlette (1961, p. 358, fig. 7) and Riedel (1963, p. 876-877, fig. 10), on the basis of data supplied by Kanaya, reasoned that lateral transport of diatom frustules by currents appears to be less important than was suggested by Lohman (1941). Riedel pointed out (*loc. cit.*) that the southern limit of a subarctic species, *Denticula seminae* in the surface sediments corresponds rather well to the southern limit of the subarctic water, and that the boundaries between the different thanatocoenoses in the northeastern Pacific remain distinct under the Aleutian and California current system. Kanaya's own studies (1961; in preparation) taken together with the Russian studies, have lead him to the conclusion that diatom valves reach the bottom after traveling much shorter horizontal distances than one would expect considering the assumed hydraulic diameters of single empty valves. Riedel suggested (*loc. cit.*) that diatoms may settle through the water column relatively rapidly as aggregates. Jousé holds the view (1957, p. 212) that the movement of water layers in different directions in

deeper layers cancel out the lateral transport of frustules after they pass through the column of surface currents.

The geographical distribution of individual species as well as of numbers of assemblages recognized in the surface layer of deep-sea sediments of the Pacific appear to reflect the present-day oceanographic conditions in the overlying waters (Kanaya, 1961). Therefore, an attempt to deduce past oceanographic conditions on the bases of changes in compositions of diatom assemblages in deeper layers of cores is not only justified, but promising.

Work along this line has already been carried out by Russian diatom workers on the deep-sea cores from the Soviet Far East Seas as well as of the western half of the North Pacific, and has resulted in their subdividing Quaternary sections represented in the cores into a number of horizons that, starting with Horizon I (Holocene), are said to represent alternately the interglacial and glacial "Epochs" in a descending order. Various combinations of species of diatoms, that are almost always present through the length of the cores studied, played a main role in identifying in sequence the fluctuation of the temperature of the surface water during the Quaternary in a relative manner, although the contents of amorphous silica as well as the granulometric character of the sediments has also been used as criteria wherever pertinent. Foraminifera were only infrequently found in those cores from deep-water localities of higher latitudes. So far five horizons (Horizon I-V) have been identified in the cores from the Okhotsk and western part of the Bering Seas (Jousé, 1962, p. 146-151, fig. 55; *ibid.*, p. 177-179, fig. 161) and four horizons (Horizon I-IV) in the cores from the Komandro-Kamtschatica area of the northwestern corner of the Pacific (*ibid.*, p. 202-207, fig. 70).

The oldest Quaternary horizons recognized by Russian workers in the cores from western Pacific was thought to be Horizon VII, represented by the lowermost part of a subarctic core of 12m in length (USSR 3163, Jousé 1961b, p. 192, fig. 2; Jousé 1961c. For location see also, Table 1 and Fig. 4 of the present paper). According to a recent paper by Romankevich *et al.* (1964) on absolute age determination of Quaternary sediments in the western part of the Pacific, the lowermost part of core USSR 3163 is now assigned to Horizon VIII. This age determination resulted in a redistribution of horizons in core USSR 3163 as well as the establishment of several subhorizons (compare Jousé, *op. cit.* fig. 2 with Romankevich *et al.*, *op. cit.*, fig. 2). Romankevich *et al.* base their correlation mainly on their determination of absolute ages by the Ionium method made for separate layers in 14 cores from the western part of the Pacific, and the Horizon VIII was tentatively correlated with the Günz or Nebraskan Stage; at least the upper six horizons of the eight were said by Romankevich *et al.* to be correlative to horizons in cores taken in the area under the present subtropical watermass; five horizons were said to be correlative to horizons in cores taken further south in the equatorial area. Oscillations of surface water temperature during the Quaternary were said to be detected on the basis of changes in diatom species compositions as well as in the compositions of sediments through the length of the cores (Romankevich *et al.*, *ibid.*, p. 66).

Undisturbed sediments in deep-sea cores yield records of marine Pleistocene history. One of direct interest to Pleistocene research is, as stated by Emiliani and Flint (1963, p. 906), the study of those parameters which were most affected by repeated glaciation of the continents. The micropaleontology of planktonic Foraminifera (*e.g.* the relative or absolute frequency of planktonic species of known geographic distribution; coiling directions of some planktonic species) has been chosen as one such parameter thought to reflect the temperature variation at the ocean surface (*e.g.* Ericson *et al.*, 1961). The comparisons between the climatic curves derived from the paleontological analysis of Foraminifera through the length of cores and the Oxygen-isotopic paleotemperature curves derived from

the oxygen-isotopic analysis of Foraminifera shells (*e.g.* Ericson *et al.*, 1961, p. 277, fig. 49) indicates that the climatic curves showing the change of temperatures in a relative manner are sensitive enough to permit the detection of glacial and interglacial stages even in equatorial cores (Emiliani and Flint, *op. cit.*, p. 907). These methods, using calcareous shells of Foraminifera as material, however, appear to be inapplicable in the northwestern Pacific when used to analyse the Quaternary records preserved in deep-sea cores, judging from the paucity of foraminiferal sediments in the Quaternary sections represented in the cores taken from the mid and high latitudes of the region (Jousé, 1962; Romankevich *et al.*, 1964, p. 65). Instead, sediments rich in siliceous micro-fossils predominate in the majority of these cores. Therefore, the parameter most likely to reflect temperature fluctuations must be sought among the records of organisms with siliceous tests.

The change in compositions of diatom thanatocoenoses can be chosen as such a parameter. Most diatom species are autotrophic, living only in the eutrophic zone of surface waters. Lateral transport of diatoms, before reaching the bottom, have been found to be limited to the extent that the composition of modern diatom thanatocoenoses preserved on the deep-sea bottom correlate with the conditions of overlying waters. Moreover, the geographical distribution of thanatocoenoses in the the North Pacific and the ecologies of the living representatives of those species preservable in bottom thanatocoenoses are much better known than were a decade ago. If paleotemperature curves somewhat similar in nature to those derived from foraminiferal sequences are obtained from diatom records, such curves will aid in the further elucidation of Pleistocene deep-sea stratigraphy of the North Pacific and related areas.

#### PURPOSE OF STUDY

The purpose of the present study is to interpret the diatom record in the core V20-130, mainly in terms of paleotemperature curve derived from diatom records of the core. This curve, which is thought to reflect, in a relative manner, the fluctuation of surface water temperatures in the North Pacific during the Pleistocene, is based on criteria developed during diatom studies made at the Scripps Institution of Oceanography of the uppermost layers of numerous cores taken in the Pacific (Kanaya, in preparation). Core V20-130, taken by the Lamont group, is the longest so far raised from the subtropical North Pacific, and will serve as an example of application of the criteria for the analysis of the deeper layers of cores from the North Pacific.

The paper is made up of three parts. Part I was prepared by the senior author to furnish background information necessary for the interpretation of the diatom temperature curve. It was taken from his study (*ibid.*) of diatom thanatocoenoses in the bottom surface sediments of the Pacific. Part II reports the results of the study made by both authors on the diatom sequence in the core V20-130. Part III is appended to give taxonomic references to all diatom species and varieties mentioned in the present paper.

#### ACKNOWLEDGEMENTS

The samples from the Lamont core, V20-130, were placed at the writers disposal through the courtesy of the Lamont Geological Observatory, New York and Dr. Hiroshi Ujiié of the National Science Museum, Tokyo.

The basis of the present paper was a study made by the senior author at the Scripps Institution of Oceanography, La Jolla, California. The study was carried out under the supervision of Prof. M. N. Bramlette with the generous support of the U.S. National Science Foundation, Grant no. NSF-G7388. Prof. Fred B. Phleger, Prof. Gustaf O. Arrhenius, Miss Frances L. Parker, Mr. William R. Riedel and Dr. John S.

Bradshaw of the Scripps Institution of Oceanography, as well as Dr. Reimer Simonsen of Institut für Meeresforschung, Bremerhaven, then at the Scripps Institution of Oceanography, helped through suggestions and criticisms. Advice was received from Prof. Edward W. Fager of the Scripps Institution of Oceanography concerning the application of recurrent group analysis to the diatom studies in the sediments.

The sediment samples collected by the Scripps Institution of Oceanography were made available to the senior author for his study. Sediments collected by the Institute of Oceanology of the Academy of Sciences of the USSR were made available for the study as a result of an exchange of samples (arranged by A.P. Jousé) between that Institute and the Scripps Institution of Oceanography. Dr. A.P. Jousé of the Institute of Oceanology, Moscow, also kindly discussed the taxonomies of some diatom species from the North Pacific cores with the senior author. Two Japanese samples incorporated in the present paper were collected by the cruises made by the Deep-sea Research Committee, Japan Society for the Promotion of Science, and by the Upper Mantle Project National Committee. One sample was supplied from the core collection of University of Washington.

Dr. Seymour O. Schlanger of the Department of Geology, University of California Riverside, Prof. Katora Hatai of Institute of Geology and Paleontology, Sendai, and Dr. Hiroshi Ujiie of the National Science Museum, Tokyo, kindly reviewed the manuscript. The present authors received the benefits of suggestions while discussing the subject with their colleagues at the Institute of Geology and Paleontology, Sendai. Mr. W. Riedel, of the Scripps Institution of Oceanography and Prof. Ivar Hessland of the Geological Institute, Stockholm University kindly read the manuscript critically.

#### **Part I: DISTRIBUTION OF DIATOM SPECIES IN THE SURFACE LAYER OF DEEP-SEA CORES FROM THE PACIFIC**

The areal distribution of diatom species was studied from widely distributed stations in the Pacific. The 118 cores studied represented a range in latitude from 55°N to 55°S. Of these 118 the locations of 83 North Pacific cores and 2 of South Pacific cores are shown in Fig. 4 and in Table 1. Most of the cores were taken from depths greater than 3000 m; the large majority were taken below 4500 m. The diatom bearing samples studied were, with few exceptions, taken from the uppermost section of the cores. The lithologies of the North Pacific samples varies between brown diatomaceous clay in higher latitudes to calcareous ooze in equatorial latitudes. The samples were taken from within the upper 5 cm of the gravity cores collected by the Scripps Institution of Oceanography. In the samples made available by the Institute of Oceanology, USSR, some slightly lower levels are represented (see Table 1). Care was taken to incorporate only undisturbed surface samples in the study. Of Scripps samples only those which were checked by W.R. Riedel as free of Tertiary forms of Radiolaria or calcareous nannoplankton were analysed for diatoms.

The procedure followed was to identify all diatoms found in the entire fields of one of two strewn slides made for each sample, and to make a count of two hundred specimens at random on another strewn slide made for the sample in order to estimate the relative frequencies of species in the sample. More than 220 species and varieties of approximately 45 genera were identified in this study.

The geographical distribution of diatom species in surface sediments was analysed in two ways: (1) by the examination of distributions of individual species and varieties over the area represented by the samples, and (2) by recurrent group analysis, a statistical method that allows one to select taxa that occur together sufficiently often to be considered as groups whose areal distribution can then be examined.

Table 1: Core locations and intervals studied

No.*	Core	Latitude	Longitude	Depth(m)	Intervals from which samples were taken (cm from the top of a core)
1	Muk 12 BG	54°46'N	168°19'W	1960	0-1
2	TP 40-1	53°57'N	171°11'E	1382	0-3
3	CK 8	53°01'N	176°15'W	3660	0-2
4	USSR 3357	52°23'N	170°48'E	6983	0-4
5	USSR 3403	52°13'N	160°55'E	4435	0-8
6	USSR 3274	51°04'N	162°17'E	5437	0-8
7	CK 11	49°39'N	177°39'W	4850	0-4
8	USSR 3257	48°46.7'N	155°00.0'E	6948	0-8
9	USSR 3114	48°39.8'N	160°51.2'E	5571	0-8
10	CK 6	46°57'N	164°49.5'W	5094	0-4
11	USSR 3109	45°53.3'N	154°47.9'E	5001	0-7.5
12	USSR 3108	44°51.6'N	155°42.5'E	4902	0-3
13	CK 13-3	44°45'N	173°02'W	4835	0-4
14	USSR 3163	43°49'N	156°38.3'E	5441	0-5
15	CK 4	42°29.9'N	162°08.2'W	5388	0-5
16	JYN II-10G	40°30'N	169°48'E	5550	0-2
17	JYN II-8G	40°29'N	172°33'E	4250	0-2
18	JEDS 6-207	40°24'N	148°30'E	5300	0-1
19	TP 71	40°05'N	146°45'E	5050	0-4
20	JYN II-14G	39°19'N	156°57'E	5635	0-2
21	Takuyo 6	39°06'N	143°24'E	2770	0-1
22	JYN II-17G	38°28'N	153°10'E	5690	0-2
23	USSR 3449	38°19'N	145°38'E	3449	5-10
24	JYN II-6	37°56'N	178°10'E	5250	0-2
25	USSR 3225	37°51.3'N	144°08.2'E	5090	0-10
26	JYN II-19	37°46'N	149°49'E	5910	0-2
27	V 20-130 PG	36°59'N	152°36'E	6547	0-1
28	CK 16	36°30'N	173°16.2'W	4195	0-4
29	USSR 4084	34°59.8'N	172°56.5'W	5971	0-3
30	TP 97	32°02'N	139°25'E	1336	0-4
31	USSR 3478	31°17.2'N	148°50.3'E	6177	0-5
32	USSR 3206	30°57'N	153°33'E	5836	0-6
33	USSR 3493	29°04.4'N	142°34.6'E	5194	0-5
34	USSR 3530	27°31.8'N	131°32.2'E	4963	7-12
35	CK 22	26°22'N	168°53'W	4450	0-10
36	MP 24	19°45'N	166°50'W	5200*	0-4
37	Cap 2 BG 1	0°43'N	169°20'E	4320	0-3
38	Muk B10G	53°15'N	157°02'W	4560	0-2
39	Muk B21G	52°32'N	141°44'W	3792	0-2
40	Muk H27G	52°31.8'N	142°06'W	3730	0-3
41	USSR 4151	49°38.4'N	139°42.1'W	3970	0-5
42	Univ. Wash. 144-10	49°04'N	133°00'W	3357	0-2
43	NthHol 8	48.37.5'N	157°29.1'W	5715	0-4
44	USSR 4158	46°57.9'N	144°00.7'W	4658	0-3
45	Cusp 11G	45°34'N	143°11'W	4700	0-2
46	Cas 2	45°02'N	127°13'W	2930	0-5
47	Cusp 9G	43°58'N	140°38'W	4450	0-2
48	Muk H5G	42°41'N	142°09.9'W	4290	0-2
49	Muk B31G	42°05'N	125°39'W	2917	0-3
50	NthHol 9	40°53'N	155°12.8'W	5343	0-5
51	NthHol 1	40°31.4'N	147°58.5'W	5370	0-4
52	USSR 4183	40°01.1'N	127°39.0'W	4460	0-5
53	CK 3	39°56.2'N	158°38'W	5005	0-5
54	Cusp 4G	39°30'N	125°52'W	3733	0-4
55	Men 18	39°30'N	133°05'W	4740	0-1
56	Men 27	39°05'N	139°26'W	5920	0-1



Table 1 Continued

57	NthHol 12	37°27.5'N	154°08'W	5582	0-4
58	CK 2	35°09'N	157°17.5'W	5627	0-3
59	Cusp 24G	34°29'N	126°02'W	4760	0-2
60	Cusp 2G	31°05'N	135°24'W	5160	0-4
61	Fan BG7	30°43'N	119°50'W	3900	0-4
62	CK 1	29°24'N	153°06'W	5664	0-4
63	Fan HMS 5	28°35'N	118°42'W	3470	0-3
64	MP 20-2	20°27'N	154°55'W	5100**	0-3
65	USSR 4293	19°56'N	134°05.4'W	5277	0-6
66	MSN 155G	15°09'N	137°06'W	4992	0-2
67	Chub 3	15°00'N	125°26.1'W	4380	0-3
68	Chub 4	14°01.5'N	125°29.5'W	4505	0-4
69	Chub 5	13°03.1'N	125°28.8'W	4448	0-5
70	Chub XIII G	12°13'N	111°03'W	3331	0-1
71	Chub VI G	11°56'N	91°43'W	3568	0-2
72	Chub XI G	11°38'N	103°48'W	3257	0-2
73	Chub VII	11°30'N	88°04'W	4869	0-3
74	MSN 150G	10°59'N	142°37'W	4978	0-2
75	Chub VIII G	9°48'N	93°12'W	3641	1-2
76	DWBG 6	9°36'N	130°41'W	5003	0-2
77	DWHT 8C	9°03'N	129°00'W	4650	0-2
78	MSN 147G	8°07'N	145°25'W	5100	0-2
79	DWBG 8	7°51'N	130°55'W	5069	0-2
80	Cap 48 BG 1	5°49'N	124°02.5'W	4125	0-3
81	MSN 142G	5°20'N	146°13'W	5089	0-2
82	MP 11-1	4°39'N	140°03'W	4400**	0-4
83	DWBG 149	4°08'N	115°46'W	4160	0-3
84	DWBG 12	3°12'N	131°31'W	4438	0-2
85	MSN 141G	3°17'N	146°51'W	4577	0-2
86	DWBG 13	1°01'N	132°14'W	4392	0-2
87	MSN 136G	1°54'S	148°45'W	4731	0-2
88	DWHH 89	4°02'S	113°18'W	4140	0-3

\* Serial numbers given correspond to those in Figs. 4, 6a and 6b.

\*\* Depths only approximate

In core designations, the following prefixes are abbreviations of the names of oceanic expeditions made by the Scripps Institution of Oceanography, La Jolla, California: Cap, Capricorn; Cas, Cascadia; Chub, Chubasco; Ck, Chinook; Cusp, not abbreviated; DW, Downwind; Fan, Fanfare; Jyn, Japanyon; MP, Midpac; MSN, Monsoon; NthHol, Northern Holiday. The cores collected by the Institute of Oceanology in Moscow are designated by the prefix USSR. The other abbreviations are: JEDS-6 for a cruise of Japanese Expedition Deep Sea made by the Deep-sea Research Committee in Tokyo; Takuyo-6 for a cruise made by Upper Mantle Project National Committee, Tokyo; V20 for a cruise made by the vessel Vema of the Lamont Geological Observatory, Palisades, New York; Univ. Wash. for a cruise made by University of Washington, Seattle.

### *Distributions of individual species*

Examination of distribution patterns of individual species and varieties reveals that there are marked patterns expressed by assemblages in the surface layer of deep-sea sediments in the Pacific, and that these patterns generally coincide with those formed by the upper watermasses (Fig. 1). Two lines of demarcation in diatom assemblages are particularly obvious: one at the boundary between the subarctic watermass and the central watermasses in the western North Pacific and another at the boundary between the subantarctic watermass and the central watermasses in the South Pacific. The relative frequency of occurrence of a number of species changes significantly at these two boundaries; two North Pacific examples are shown in Fig. 2 and Fig. 3. There are several species which are more or less restricted to cores from the equatorial zone. They distinguish the assemblage under the Pacific

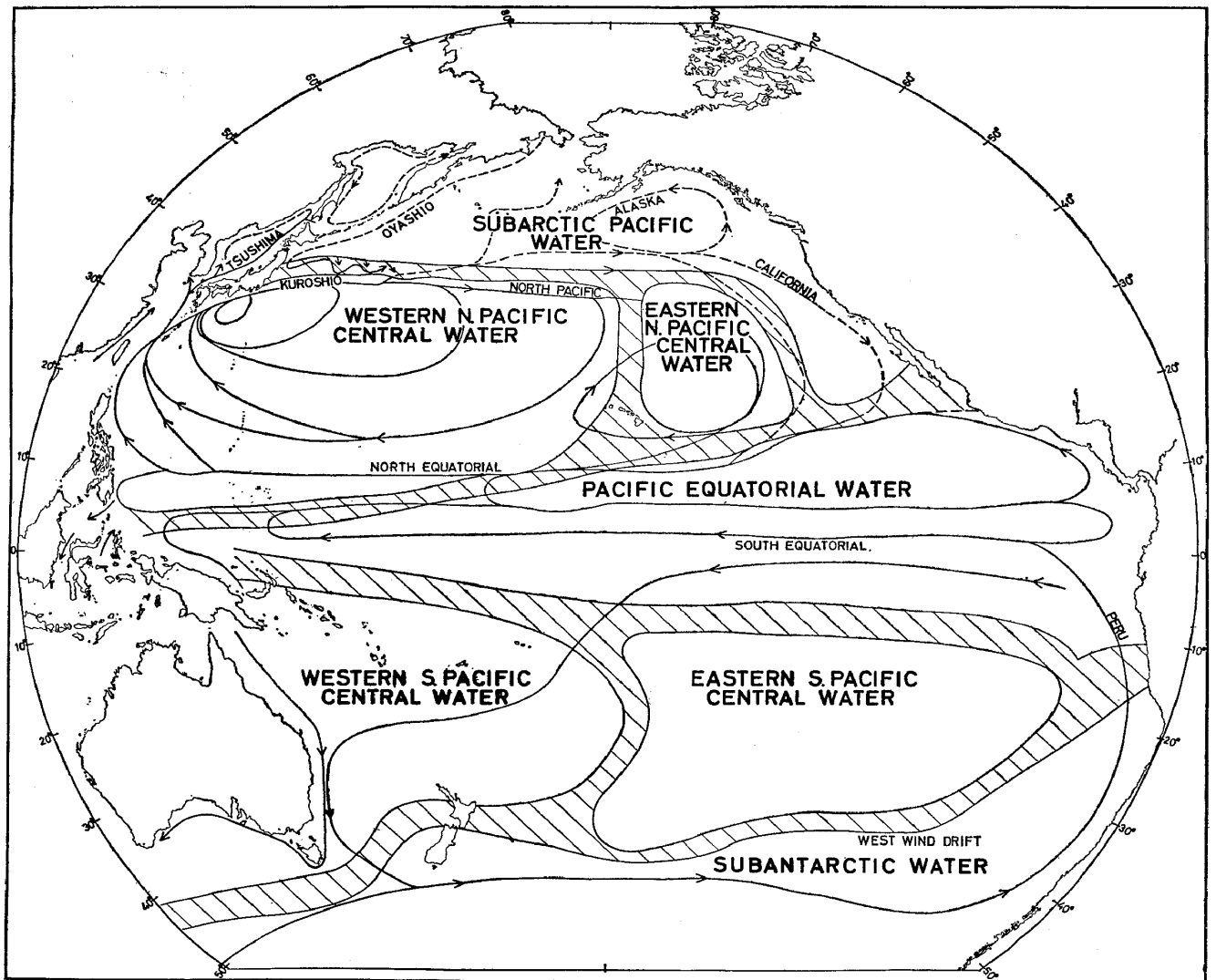


Fig. 1. Approximate boundaries of the upper watermasses of the Pacific Ocean together with courses of the major ocean currents. (Redrawn from Bradshaw, 1959, text-fig. 4)

Equatorial watermass from assemblages generally found in subtropical as well as tropical latitudes occupied by the Pacific Central watermasses of both hemispheres.

On the basis of their geographical distributions in the samples studied, species were chosen as representative of diatom assemblages of the different areas of the Pacific, because their distributions are more or less restricted to certain areas, and their occurrences in these areas are consistent, although they vary in their relative frequency of occurrence from one station to another. In the following list the species with an asterisk are common to abundant (10–40% or more) at the majority of the stations in their area of distribution, becoming rare in a transitional zone before they become totally absent. The representative taxa or forms (species and varieties) and their areas are as follows.

Subarctic area (of the the Subarctic watermass): \**Denticula seminae* Simonsen and Kanaya, \**Coscinodiscus marginatus* Ehr., \**Coscinodiscus excentricus* var. *jousei* (MS), *Rhizosolenia hebetata* f. *hiemalis* Gran, *Coscinodiscus oculus-iridis* var. *borealis* (Bail.) Cl., *Actinocyclus curvatulus* Jan., *Actinocyclus ochotensis* Jousé, and *Asteromphalus robustus* Cast.

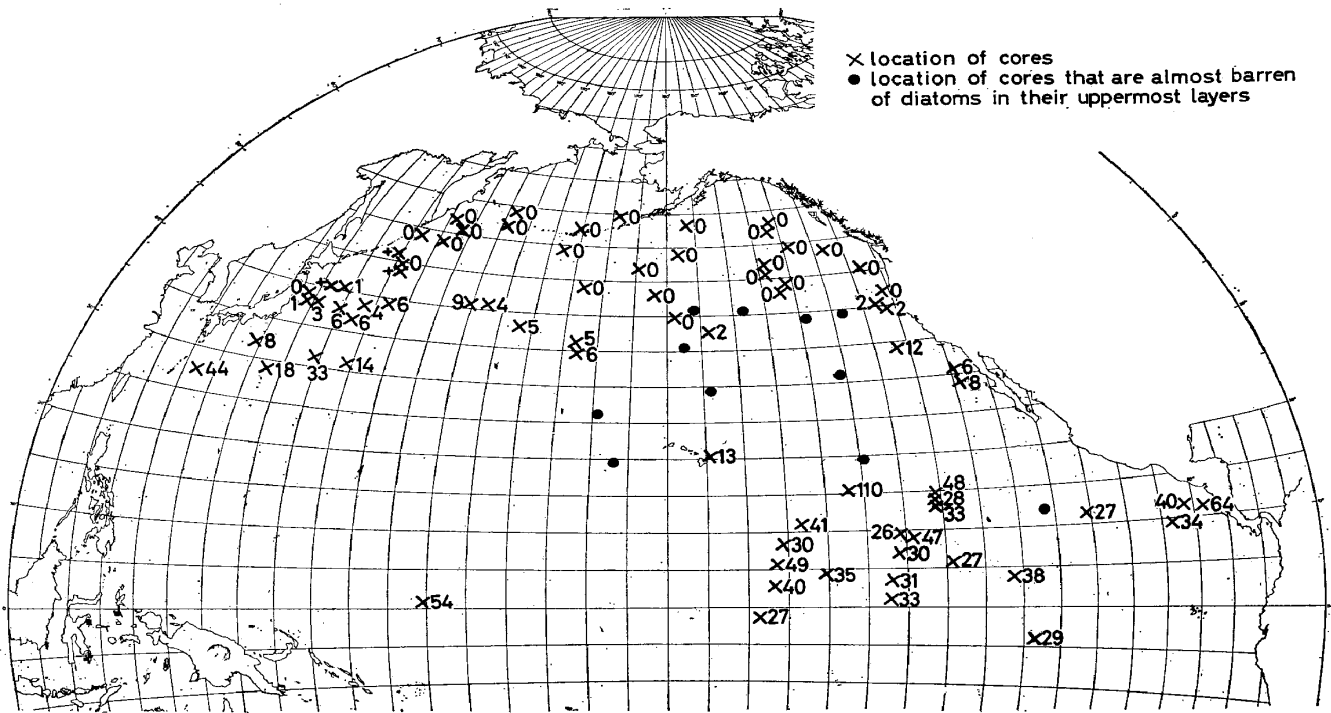


Fig. 2. Distribution of *Coscinodiscus nodulifer* A. Schmidt in sediment samples from the surface layer of deep-sea cores from the North Pacific. Numbers indicate the frequencies of the species in a count of 200 specimens made for each sample.

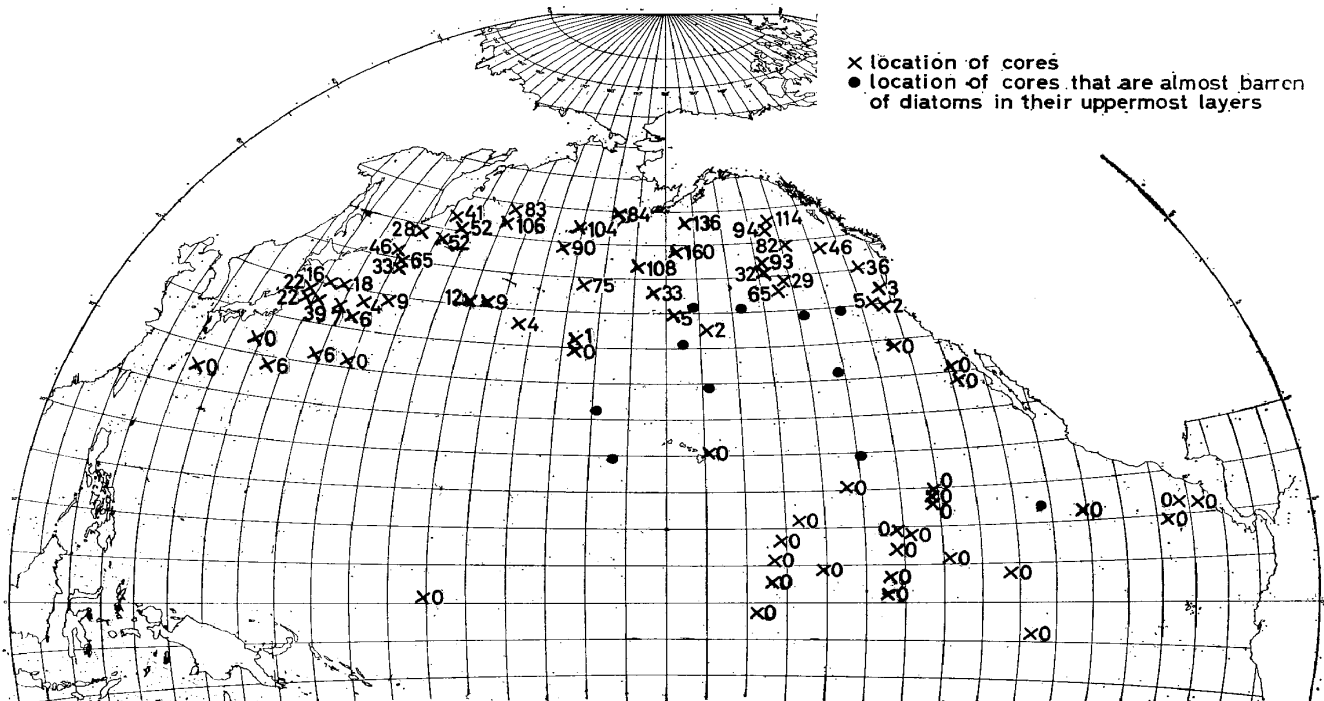


Fig. 3. Distribution of *Denticula seminae* Simonsen and Kanaya in sediment samples from the surface layer of deep-sea cores from the North Pacific. Numbers indicate the frequencies of the species in a count of 200 specimens made for each sample.

Subantarctic area (of the Subantarctic watermass): \**Fragilariopsis kerguelensis* (O'Meara) Hust., \**Coscinodiscus lentiginosus* Jan., *Eucampia balaustium* Cast., *Micropodiscus oliveranus* (O'Meara) Grun., *Hemidiscus karsteni* Jousé, and cfr. *Coscinosira antarctica* Kozlova.

Subtropical and tropical area in general (of the Pacific Central watermasses of both hemispheres and of the Pacific Equatorial watermass): \**Coscinodiscus nodulifer* Schmidt, \**Nitzschia marina* Grun., \**Pseudoeunotia doliolus* (Wall.) Schütt, *Hemidiscus cuneiformis* Wall., *Rhizosolenia bergonii* Perag., *Planktoniella sol* (Wall.) Schütt, *Actinocyclus subtilis* (Greg.) Ralfs, *Coscinodiscus africanus* Jan., *Coscinodiscus crenulatus* Grun., *Triceratium cinnamomeum* Grev., *Asteromphlus hiltonianus* (Grev.) Ralfs, and *Ethmodiscus rex* (Wall.) Hendy.

Equatorial area (of the Pacific Equatorial watermass): *Asteromphalus elegans* (Grev.) Ralfs and *Actinocyclus elongatus* Grun.

The taxa listed above are considered good criteria for interpreting diatom assemblages in deeper layers of cores because they represent thanatocoenoses of wide areal extension and therefore may be useful in interpreting the paleobiogeographical framework of the past. Other species and varieties identified but not listed above include cosmopolitan species, those species whose distribution is too local to be useful, and those species whose occurrences in an area are too sporadic to be reliable.

By the joint occurrences of the species listed above together with those showing more local distributions, geographical differences of diatom thanatocoenoses in the surface layer of the bottom sediments of the Pacific are readily recognized. The selection of the boundaries of the areas occupied by different diatom assemblages, however, are somewhat arbitrary inasmuch as the stations between which the transition in relative frequencies takes place are not necessarily the same for different species and varieties.

### Recurrent groups of diatoms

Examination of the diatom data of the bottom sediments indicates that certain species occur together rather often and others never occur together in the samples. Since the immediate factors which determine the abundance and distribution of living diatoms are not precisely known, an attempt was made to delineate groups of species by using joint occurrences of diatoms themselves as a basis for this grouping. The assumption made was that those species and/or varieties occurring together sufficiently often in bottom sediments to form a group should have had surface water habitats in common. Therefore, when species groups are identified, the areal distribution of these groups should show meaningful patterns in terms of known factors of the present oceanographic condition.

The decision on how to group species is ultimately a subjective one. However, the subjective elements can be reduced if the grouping is based on a defined index of affinity. The index of affinity proposed by Fager (1963, p. 421; Fager and McGowan, 1963) was adopted, and the recurrent groups were sought by the manual procedure described by Fager (1957). The method takes in account only the presence or absence of the species in samples; their relative frequencies are not considered.

According to the definition given by Fager, pairs of species are considered to show affinity, if they satisfy the following condition; if they do not satisfy the condition the pairs are considered not to show affinity. The condition is:

$$\frac{J}{\sqrt{N_A \cdot N_B}} - \frac{1}{2\sqrt{N_B}} \geq 0.5$$

where:  $N_A \leq N_B$  by definition;  $N_A$  is the total number of occurrences of species A;  $N_B$  is the

total number of occurrences of species B; J is the number of joint occurrences of species A and species B. The breakpoint was chosen at 0.5, because it was felt that species should be found together in somewhat more than half their recorded occurrences if they are to be grouped together (Fager and McGowan, 1963, p. 454). This requirement of affinity has been found to give biologically reasonable groups when applied to certain zooplankton from the North Pacific, to invertebrates in decaying oak wood *etc.* (Fager, 1963, *op. cit.*).

It was decided (Kanaya, in preparation) that a species should occur at more than a few stations before it could be considered important to be included in a group. Therefore an arbitrary minimum for  $N_A$  was set at 5. On this basis those taxa found at less than 5 stations were not further considered, leaving 75 taxa to be analysed. Records from samples poor in diatoms were also eliminated, because the presence or absence of a taxa was determined by the examination of only two slides, one for its entire area, another for a part of its area, for each sample; this left the records of 93 stations suitable for analysis. The procedure for the determination of recurrent groups based upon the defined index of affinity has been outlined by Fager (1957)\* and will not be repeated here. The examples given below serve to illustrate the nature of the index.

	$N_A$	$N_B$	J	Index of affinity	
example 1	9	9	6	= 0.5	affinity
example 2	9	12	6	< 0.5	no affinity
example 3	9	36	9	< 0.5	no affinity

These examples show that the index of affinity depends strongly on the ratio X, defined as  $N_B/N_A$ . When X is high, as in example 3, the pair shows no affinity even though all occurrences of species A occur in samples containing species B so that  $N_A=J$ . This ratio dependence prevents a cosmopolitan species from being classed as showing affinity for a local species, or for a species having sporadic occurrences.

Five recurrent groups have been determined incorporating 55 taxa of the 75 suitable for analysis. They are: group I (22 species and varieties); group II (13 species and varieties); group III (8 species); group IV (7 species); and group V (4 species). Their species

Table 2: Species compositions of recurrent groups

group I	
	<i>Thalassiosira decipiens</i> : (N; nB, sB, subT) [E; I]
	<i>Thalassionema nitzschioides</i> : (N; nB, sB)
	<i>Coscinodiscus excentricus</i>
	<i>Coscinodiscus tabularis</i> var. <i>egregius</i> : (O; sB)
W	<i>Coscinodiscus crenulatus</i> : (subT, T)
	<i>Thalassiosira ostrupi</i> : (subT)
W	<i>Coscinodiscus lineatus</i> : (O; T) [E; P, A, I]
W	<i>Pseudoeunotia doiolus</i> : (O; subT, T) [E; P, A]
W	<i>Coscinodiscus nodulifer</i> : (T) [E; P, A, I]
W	<i>Roperia tessellata</i> : (O; sB, T) [E; A]
W	<i>Coscinodiscus africanus</i> : [E; P, A, I]
	<i>Thalassionema nitzschioides</i> vars.: (sB)
W	<i>Coscinodiscus</i> cfr. <i>anguste-lineatus</i>
W	<i>Nitzschia marina</i> : (T) [E; P, A, I]
W	<i>Actinocyclus subtilis</i> : [E; A, I]

\* For this study requirement (1) in Fager (1957, p. 588) should read: the evidence for affinity for all pairs of species within the group.

Table 2 continued

- W *Hemidiscus cuneiformis*: (O; T) [E; P, A, I]  
 W *Ethmodiscus rex*: (O; T) [E; P, A, I]  
 W *Planktoniella sol*: (O; T)  
 W *Rhizosolenia bergonii*: (O; T) [E; I]  
 W *Coscinodiscus perforatus* var. *cellulosa*: (O; sB)  
 W *Roperia tessellata* var. *ovata*: (subT)  
 W *Roperia tessellata* var. *coscinodiscoidea*: (subT)  
 associated: *Cyclotella striata* (subL; nB)

## group II

- Coscinodiscus radiatus* var. MS: (O; sB, subT)  
 C *Actinocyclus curvatulus*: (O; nB)  
 C *Rhizosolenia hebetata*. f. *hiemalis*: (O; AB)  
 C *Coscinodiscus excentricus* var. *jousei* MS: (O; nB)  
 C *Actinocyclus divisus*: (O; sB)  
 C *Coscinodiscus marginatus*: (O; nB)  
 C *Denticula seminae*: (O; nB)  
 C *Asteromphalus robustus*: (O; nB)  
 C *Coscinodiscus oculus iridis* var. *borealis*: (O; nB)  
 C *Thalassiosira gravida*: (N; AB)  
 C *Coscinodiscus excentricus* var. *leasareolatus* MS  
 C *Biddulphia aurita*: (N; nB)  
 C *Actinocyclus ochotensis*: (O; nB)  
 associated: C *Coscinodiscus excentricus* var. *fasciculata*

## group III

- Fragilariopsis kerguelensis*: (O; SubAnt)  
*Fragilariopsis ritcherii*: (N; Ant)  
*Coscinodiscus lentiginosus*: (O; SubAnt)  
*Eucampia balaustium*: (N; Ant)  
*Asteromphalus hoockeri*: (O; SubAnt)  
*Hemidiscus karsteni*: (O; SubAnt)  
*Micropodiscus oliveranus*: (N; SubAnt, Ant)  
 cfr. *Coscinosira antarctica*: (N; Ant)  
 associated: *Thalassiosira gracilis*: (N; Ant)

## group IV

- C *Porosira glacialis*: (N; A, AB)  
 C *Thalassiosira kryophila*: (N; A)  
 C *Thalassiosira hyalina*: (N; A)  
 C *Thalassiosira nordenskioldi*: (N; AB)  
 C *Bacteriosira fragilis*: (N; A)  
 C *Fragilariopsis cylindrus* s. l.: (N; AB)  
 C *Chaetoceros furcellatus*: (N; A, AB)

## group V

- W *Triceratium cinnamomeum*: (T)  
 W *Asteromphalus hiltonianus*: (E; P)  
 W *Asteromphalus elegans*: [E; P]  
 W *Actinocyclus elongatus*\*: [E; P]  
 W *Asteromphalus marylandica*\*: (T)  
 associated: W *Asteromphalus imbricatus*: (T)

Abbreviations. N, neritic; O, oceanic; subL, sublittoral; A, Arctic; AB, arcto-boreal; AB, north boreal; sB, south boreal; subT, subtropical; T, tropical; [E; P], equatorial Pacific; [E; A], equatorial Atlantic; [E; I], equatorial Indian Ocean; subAnt, subantarctic; Ant, antarctic; C, cold water; W, warm water. \* Indicating alternatives: group V can have either of two species indicated, but can not have two species together.

composition and associates are given in Table 2. The recurrent groups thus formed represent the largest possible, separate units within which all pairs of species show affinity. Associated species shown on Table 2 are species which have affinity only with members of the recurrent group. Kanaya (1961), before studying additional Russian samples, established four recurrent groups. Incorporation of the records from the additional samples, mostly from the northwestern corner of the North Pacific, resulted in establishing 5 groups of the present paper. These groups are somewhat different from the four groups previously given.

For the majority of species listed in Table 2, ecological or biogeographical information has been given in a number of previous works. In this table, the habitats cited in parenthesis are those given by Russian studies (Semina, 1958; Jousé, 1962, 1963; Jousé *et al.*, 1962), in brackets refer to the distribution of the taxa in the equatorial cores studied by Kolbe (1954, 1955, 1957); P, A or I indicate that the species were on Koble's list (1957, p. 7) of the 10 most frequent species in the Pacific, Atlantic or Indian Ocean cores. Those species which were always among the 10 most frequent species in the equatorial cores from the three oceans were chosen by Kolbe to constitute the "dominant abyssal assemblage of the Equatorial Oceans" (*ibid.*, p. 8). All the species in the table are planktonic.

From Table 2 it appears reasonable to conclude that each recurrent group is formed by diatoms which share common habitats. Thus the following generalization can be made: group I is composed of planktonic diatoms known to be distributed in subtropical and tropical waters of the Pacific including the equatorial zone; group II are planktonic diatoms of the boreal zone of the North Pacific occupied by subarctic waters; group III is made up exclusively of subantarctic and antarctic planktonic species; group IV exclusively of arctic and arcto-boreal planktonic species; and group V of tropical or equatorial planktonic species. Another difference between group II and IV is that the latter consists of neritic species only, whereas the former is dominated by oceanic species.

Certain patterns appear when the stations at which the groups occur are plotted on a chart of the Pacific. All 22 taxa of group I are found at 13 stations distributed mainly in the equatorial zone of the east Pacific. Upon adding the 11 stations, 9 stations and 12 stations at which 21, 20 and 19 taxa, respectively, were found the pattern is extended successively to higher latitudes in both hemispheres. Samples from the rest of the stations contained 18 or less taxa of group I, the large majority contained 15 taxa or less. One station is represented by 18 and one station by 17 taxa.

A requirement has to be set for the selection of samples representing the group I assemblage. It was decided that at least 19 taxa of 22 must be present in a sample before placing it in the group I assemblage. This number was chosen because the stations with 19 or more taxa of group I result in an apparently meaningful pattern in the North Pacific while keeping to the requirement of the presence of a high percentage of taxa (Fager, 1957, p. 591). The minimum required number of taxa required for the identification of the other groups was set so that the approximate ratio of the minimum required number is to the total number as 19 is to 22, since 19 was chosen for group I which contains 22 taxa. Thus at least 11 of its 13 taxa must be found in order to identify group II as present as a group in a sample; at least 7 of its 8 taxa in case of group III; at least 6 of its 7 taxa in case of group IV, and all of its 4 taxa in case of group V.

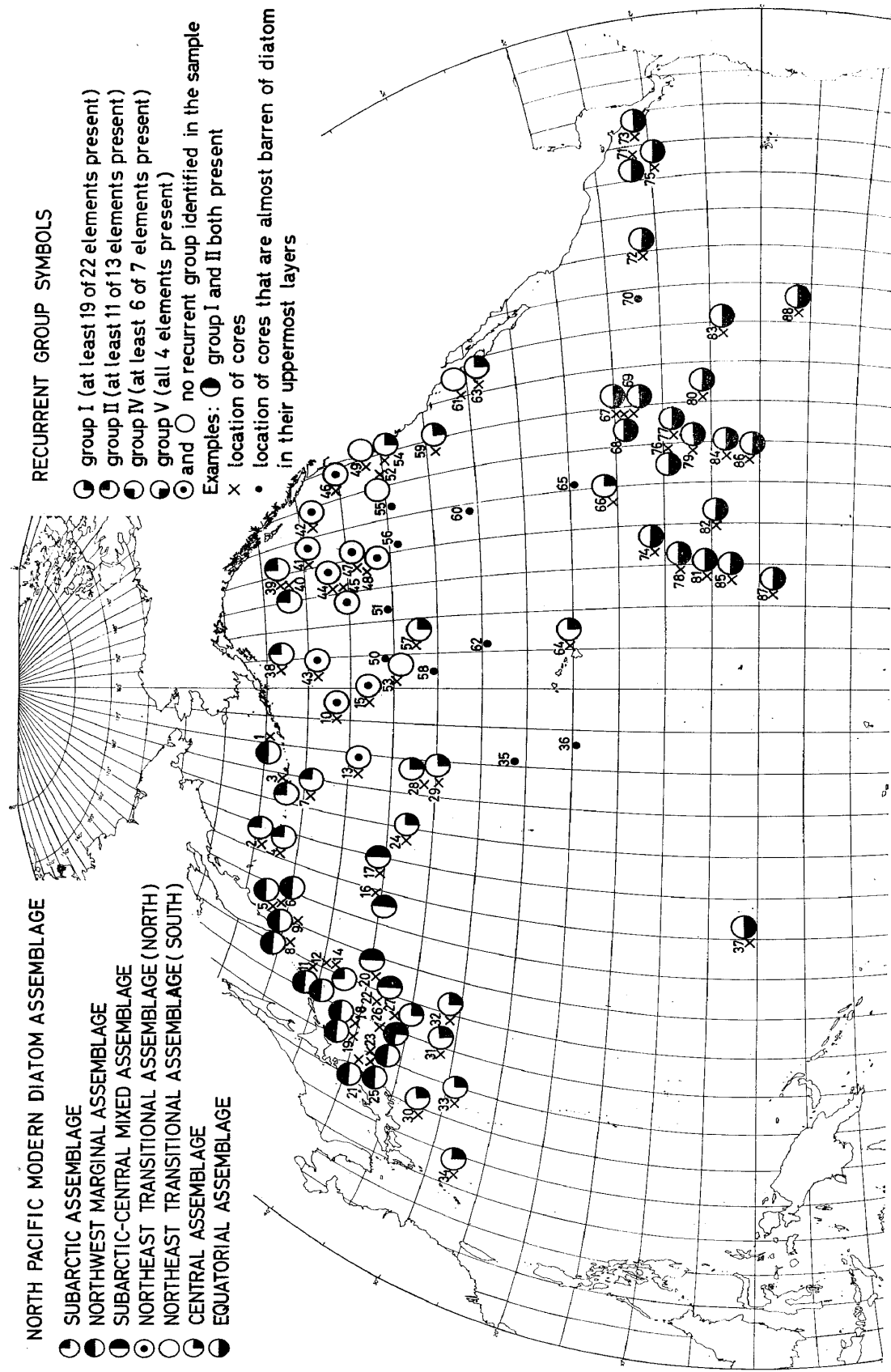


Fig. 4. Distributions of recurrent groups in the surface layer of deep-sea cores from the North Pacific, and of the North Pacific modern diatom assemblages (thanatocoenoses) defined. The characteristic species composition of each modern assemblage is definable in terms of recurrent groups of diatoms. Numbers given for core stations refer to the serial station numbers listed in Table I.



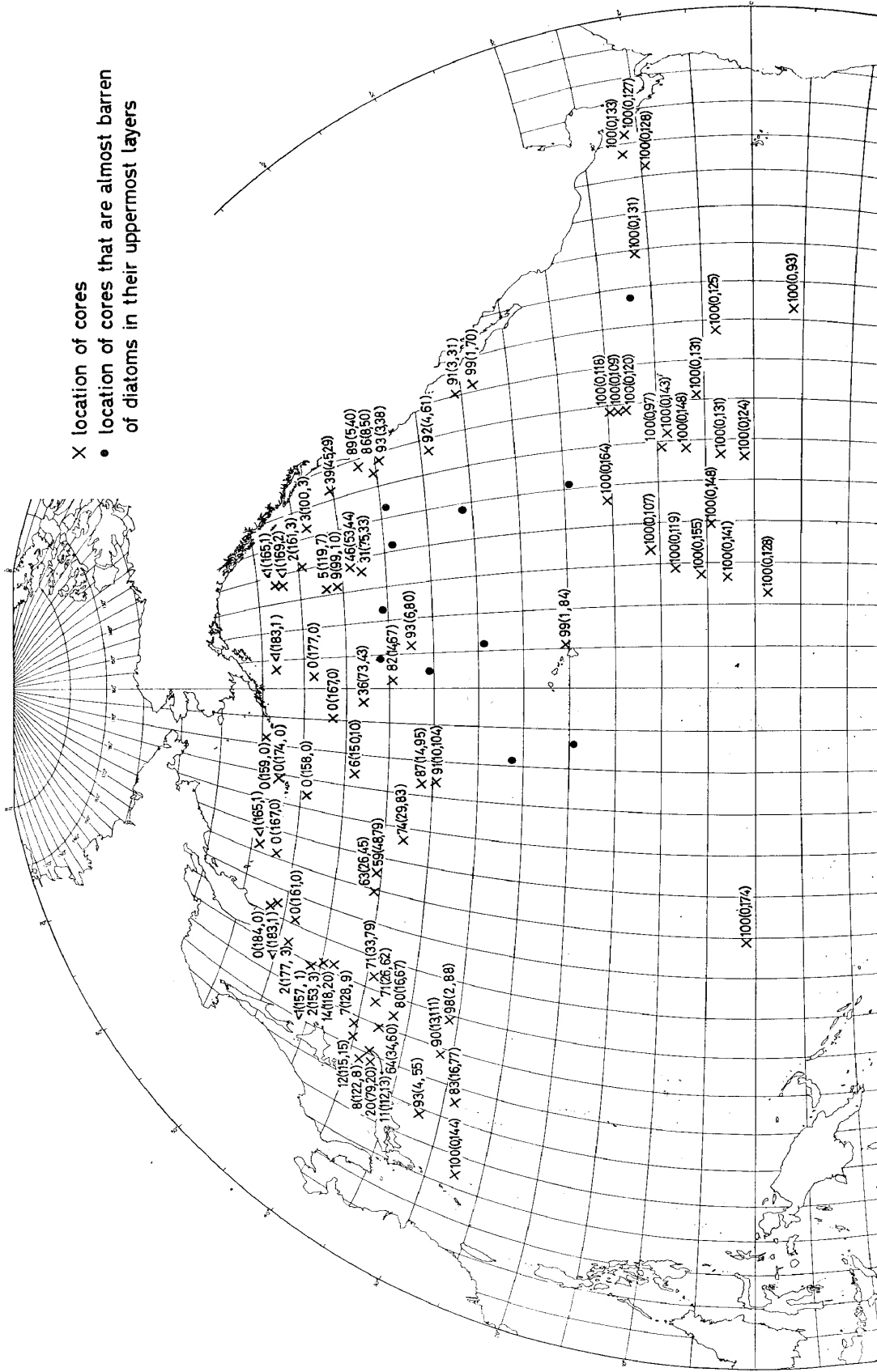


Fig. 5. Distribution of the values of  $T_d$  obtained for diatom thanatocoenoses in the surface layer of deep-sea cores from the North Pacific.  $T_d = (X_w/X_c + X_w) \times 100$ , where  $X_c$  is the frequency of cold water species and  $X_w$  is the frequency of warm water species in a count of 200 specimens made for a sample. The two numbers given in parenthesis indicate the values of  $X_c$  and  $X_w$ .

On Fig. 4 the geographical distributions of the recurrent groups in the surface layer of the bottom sediments of the North Pacific are shown by indicating the core at which each group has been identified. The original core numbers, locations, depths and the levels of samples representing the surface layer at each station are given in Table 1. The cores shown in Fig. 4 include those 83 cores which were available from the North Pacific at the time the recurrent group analysis was made. Only two of 35 cores then available from the South Pacific are shown in the figure; three cores, 18, 21, and 27 which became available later were added to the record. The characteristics of these three samples were determined in terms of recurrent groups, the criteria for which were derived based upon previously studied cores.

A comparison between the distribution patterns of recurrent groups\* (Fig. 4) and the distribution of the major upper water masses of the North Pacific (Fig. 1) make it evident that the patterns and the known habitats of the constituents of the groups are well explained in terms of the distribution of major upper water masses and currents in the North Pacific. Group II, made up mostly of known subarctic species was identified only in the area where Subarctic Pacific water is known to occupy the upper water column; the group loses its identity in the eastern part of the North Pacific where the subarctic water begins to lose its subarctic character as it travels east and south from its source. The distribution of group IV coincides well with the path of the cold Oyashio Current which flows toward the southwest along the northwestern coast of the North Pacific until it turns east off northern Honshu to form a mixed zone with the warm Kuroshio Current. Surface water of lower temperature and salinity from the Bering Sea and the Sea of Okhotsk contribute to the Oyashio; all the elements of group IV are of the known neritic diatom flora of the Okhotsk and Bering Seas as well as in the northwestern corner of the North Pacific (Jousé, 1962). At all stations at which group IV was identified, the group II was also identified. Group I has been identified at the stations from subtropical and tropical latitudes of both hemispheres. The upper waters of these latitudes are the Pacific Central waters of both hemispheres, the Pacific Equatorial water, and the California Current in its southern area where it becomes warmer. Group V was found to be more restricted in area: its pattern coincides only with that of Pacific Equatorial water. The mixing of the Pacific subarctic and Pacific Central waters takes place in the northwest Pacific where the Oyashio and the Kuroshio meet to flow east more or less along the parallel of 40°N. All stations at which both group II and group I were identified fall within the geographical range of the mixed zone.

A rather remarkable feature revealed is that no exceptional core\*\* has been found within these patterns, and they appear to have a definite meaning in terms of the present oceanography of the Pacific. The discrete group patterns shown by the recurrent groups generally coincide with single species patterns mentioned earlier. The recurrent group patterns, however, define areas more reliably than single species patterns or combinations of a few species. The recurrent groups and their patterns, moreover, open the way for explicit descriptions of the floral character and distribution of modern diatom thanatocoenoses in the bottom of the deep-sea Pacific. Within the framework of recurrent group patterns the relative and absolute frequencies of individual species may be better interpreted.

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\* Group III made up of subantarctic and antarctic species has been identified only at the stations south of 45°S Lat.

\*\* The record from Fan BG 7 (only 13 elements of group I present) which is an exception to this generalization is interpreted as the result of a disturbed core. It appears that only a part of the original modern thanatocoenoses was found. At least four Tertiary diatom species, all believed to be of Miocene in age, were frequent. The sample was brownish gray mud.

*Modern diatom assemblages in the surface layers of the North Pacific  
deep-sea cores, and cold and warm water species*

The analysis of the geographical distribution of diatoms in deep-sea cores from the two different approaches outlined above has resulted in a broad classification of the modern diatom thanatocoenoses in the North Pacific deep-sea sediments (Table 3). The areal distribution of these assemblages in the North Pacific can be read from Fig. 4.

Table 3: Classification of modern diatom thanatocoenoses  
in the North Pacific

<i>Diatom assemblages</i>	<i>Characteristics</i>	
	<i>Recurrent groups identified</i>	<i>additional criteria</i>
Subarctic assemblage	group II only	
Northwest Marginal assemblage	groups II & IV	
Subarctic-Central Mixed assemblage	groups II & I	
Northeast Transitional assemblage (North)	area between that of groups II and I, but identified with neither of them	<i>Denticula seminae</i> > 10% (20/200) or $Xc^* > Xw^{**}$
Northeast Transitional assemblage (South)	<i>ibid.</i>	<i>Denticula seminae</i> ≤ 10% (20/200) or $Xc < Xw$
Central assemblage	group I only	
Equatorial assemblage	groups I & V	

\*  $Xc$ : frequency of the cold water forms in a count of 200 specimens

\*\*  $Xw$ : frequency of the warm water forms in a count of 200 specimens

Samples from the surfacial layers of cores from more stations are needed to map the North Pacific in terms of these assemblages. It is unlikely, however, that additional samples will materially alter the geographical relationships of assemblages presented in Fig. 4. Not much improvement of coverage is expected for the subtropical latitudes in the west and east North Pacific under the Pacific Central watermasses (Fig. 1), because diatoms are known to be very rare or totally absent in the surface layer of sediments of that general area (Belyaeva, 1963, fig. 4), except for those samples from below the marginal parts of the oceanic gyral there.

The list of taxa forming five recurrent groups (Table 2) includes most of the species whose occurrences were discussed by previous authors (*e.g.* Jousé, 1962, 1963; Jousé *et al.*, 1962; Kolbe, 1954, 1957; Belyaeva, 1963) in one way or another in connection with their role in Quaternary thanatocoenoses in the Pacific. There are many other species that are not included in the recurrent groups. They were not put into the groups, because they occurred at less than five stations, or because they showed no affinity with others to form a recurrent group; the list of these species did not appear to include species which are of particular importance in characterizing a contemporary flora of the bottom sediments. A reservation should be made, however, for the subantarctic and antarctic species, inasmuch as the samples representing subarctic latitudes available for the recurrent group analysis appear to be too few to have made the group III large enough to contain all important species in characterizing the modern thanatocoenoses there.

It is very likely, therefore, that the modern diatom assemblages (thanatocoenoses) distributed in the undisturbed surface layer of the deep-sea of the North Pacific are characterized adequately by the criteria given in Table 3. Using these criteria a change of assemblages in deeper layers of a core may now be interpreted in terms of the shift of patterns of upper water circulation. If identifications of the above described recurrent groups are made in deeper layers of cores and these identifications show that the species composition of ancient diatom floras do not differ greatly from the modern flora, then the statistics obtained on the distribution of species in modern sediments can be reasonably applied to the analysis of ancient assemblages.

The fluctuation of surface temperature of oceanic water during the Pleistocene has been successfully detected in deep-sea cores from Atlantic by micropaleontological means using Foraminifera (*e.g.* Ericson *et al.*, 1961). Attempts have already been made by Russian workers to identify cold and warm stages by diatoms in deep-sea cores from the North Pacific (Jousé, 1961 a, b, 1962, 1963). It is our opinion that if paleotemperature curves, somewhat similar in nature to those derived from Foraminifera (*e.g.*, in Ericson *et al.*, *op. cit.*), can be derived from diatom records they will serve for further elucidation of the Quaternary stratigraphy of the North Pacific. Examination of records of relative frequencies of individual diatom species suggest that the ratio of relative frequencies between the subarctic species and the subtropical and tropical species may be of aid in constructing relative temperature curves.

The previous information indicates (see Table 2) that all taxa of recurrent group IV can be called cold water species in the sense that they are indigenous to the subarctic area, that is, they have their "home area" (Johnson and Brinton, 1963, p. 382) definitely in surface subarctic waters. Similarly, taxa in group II are judged to be cold water forms, species and varieties, except one taxon, *C. radiatus* var. The cold water forms thus chosen are indicated by C in Table 2. Those species and varieties judged to be indigenous to the areas of the Central and Equatorial watermasses are grouped together as warm water forms, and are chosen from group I and group V. They are indicated by W in Table 2. All species of group V are included in this category without question, but some taxa of group I are excluded, because their distribution did not appear to be much affected by water type or by latitude, judging from the previous records (see Table 2) as well as from data on the surface layer of the bottom sediments. On the other hand, a few taxa which were lacking in previous records are included on the grounds that they occurred frequently enough in subtropical and tropical samples to include them in group I, and they did not extend to distribute in the uppermost part of the subarctic cores studied.

Only a two fold classification defining cold and warm water groups is presented, since the writers failed to distinguish diatom taxa which appear to be indigenous to the mixed zone of the Subarctic and Central watermasses in the northwestern Pacific. Semina (1958) illustrated the characteristics of phytoplankton of the mixed zone in the northwest Pacific in terms of the mixture of boreal and tropical species. Modern diatom thanatocoenoses in bottom sediments from the "Transitional fauna area", defined through zooplankton studies (Bradshaw, 1959, fig. 35; Johnson and Brinton, 1963, fig. 4), are characterized in the present study by a mixture of elements from group I and group II.

From the records of specimen counts made at random for each sample, frequencies, in a count of 200 specimens, of cold and warm water diatoms were obtained. From these frequencies a variable  $Td$  defined as  $Td = (Xw/Xc + Xw) \times 100$  where  $Xw$  is the frequency of warm water forms and  $Xc$  is the frequency of cold water forms, respectively, was obtained. Values of  $Td$  obtained for diatom thanatocoenoses in the surface layer of the North Pacific cores are plotted in Fig. 5. The two numbers given in the parenthesis at each station are the value of  $Xc$  and  $Xw$ .  $Td$  ranges in value from 0 to 100. Going from the area

of subarctic waters to that of tropical waters  $Td$ , with only a few exceptions, becomes systematically large toward the lower latitudes. A comparison of Fig. 5 with the charts showing the distribution of the surface water temperature of the North Pacific (*e.g.*, Sverdrup *et al.*, 1942, chart II, III; Bradshaw, 1959, text-fig. 2) suggest that the statistics here presented reflect to a remarkable degree the latitudinal distribution of surface water isotherms of the North Pacific, although their changes are abrupt rather than gradual at the known oceanographic boundaries. The value of  $Td$  in deeper layers of cores appears to the present writers to be a useful tool with which to analyse the surface water temperature fluctuations during the Pleistocene in the North Pacific.

## Part II: DIATOMS FROM CORE V20-130

### *Method of study*

Seven samples from the trigger gravity core, 31cm in length, and 101 samples from the main piston core, 1039cm in length, were placed at the writers disposal for study. The levels at which the samples were taken are shown by Ujiié (1965). All of the samples made available from the trigger core and from the upper three-fifths of the piston core were examined; intervals between the levels studied were 5cm in the trigger core, and, with a few exceptions, 10cm in the upper part of the piston core. Time did not permit examination of all the available samples from the lower two-fifths of the piston core and therefore a 20cm interval was set for the study of the lower part. Eighty-six samples altogether were studied. Each sample studied represents a layer 1 cm thick, except for a composite sample, D-0, which represents the uppermost 5 cm of the material from the piston core. The levels studied are indicated in chart 1 (by graduations on the right side of the 2nd column from the left).

Slides were prepared for each sample in the following way. One gram (dry weight) of sediment was placed in boiling  $H_2O_2$  which was then allowed to cool. After this treatment a suspension was made by adding distilled water. The suspension was then centrifuged for 2 minutes at 1500 r.p.m. in order to separate the clay fractions as much as possible from the coarser fractions that contained the diatom valves; centrifuge tubes 10 cm long were used; the centrifuging was repeated once, after decanting off the finer clay fractions. Normally the coarse residue was divided into quarters and one quarter was diluted with 200 cc of distilled water and thoroughly shaken in a graduated cylinder to make a suspension; one-half cc of this suspension was taken by pipette and placed on a square cover glass (18 mm  $\times$  18 mm). The coverglass was dried and mounted on a slide using Hyrax. This procedure makes possible the estimation of the number of diatom valves in an unit weight of sediment. In some samples where diatoms were very abundant 300 cc or 400 cc of distilled water were used to make the suspension from which the 0.5 cc portion was pipetted.

A random count of 200 diatom valves was made on each slide in order to estimate the relative frequencies of species and varieties in a sample. By using a mechanical stage, the counting was done along lines of traverse until 200 specimens were counted. For the counting a combination of 100X objectives and 10X wide field eyepieces were used; this combination gave a field of 180 $\mu$  diameter for the microscope used. Only specimens representing more than one half of a diatom valve were counted, with the exception of *Rhizosolenia* for which valves were counted if the apical process was found preserved. This method excludes valves of extremely large *Coscinodiscus* and of *Ethmodiscus* which are usually found only as fragments. Also excluded from the counting were species belonging to the genus *Xanthiopyxis*, a form genus for resting-spores of species belonging to a number of genera whose vegetative cells are rarely preserved in bottom sediments; setae of vegetative cells of *Chaetoceros* were not included in the counting either. The frequencies of

those species excluded from the counting, particularly the fragments of *Ethmodicus rex*, of large *Coscinodiscus* (of *C. wailesii* in this study), and *Xanthiopyxis* were recorded separately, during the counting. All diatoms were identified to species and varieties, except a few whose exact identification was not possible. The estimate of numbers of diatom valves in 1 gram of sediment sample (hereafter called the diatom number) was made from the number of traverses needed to count 200 specimens.

In this study, 200 specimens were counted in from three to ten traverses, chosen at random, each traverse covering an area  $180\mu$  in width and  $18000\mu$  in length. The area covered, therefore, represents only a fraction of the total slide area. Examination of the entire slide area, however, was made only at selected core levels in connection with the present paper, partly because the time available was limited, and partly because it did not appear to be necessary to examine a slide over its entire area at all sample levels for the immediate purpose of the present paper. The number of taxa that appeared in each sample during the routine counting of 200 valves generally range between 35 and 55.

$Td = (Xw/Xc + Xw) \times 100$  was calculated on the basis of relative frequencies of warm and cold water forms, as defined in the Part I of the present paper, found in each sample. The diatom temperature curve derived by plotting the value of  $Td$  at the sampled levels is given in Chart 1. Also given in Chart 1 are: (1) the estimated number of diatom valves in 1 gram of sediment (diatom number); (2) sum of frequencies of cold and warm water forms in a count of 200 specimens; (3) graphs showing the comparisons of the fluctuation of relative frequencies of numbers of more important species through the levels of the core. Those taxa which showed a relative frequency of  $9/200$  or greater at least once in the samples were selected from the counting records; their records of frequencies are given in Table 4. In the sample size chosen ( $N=200$ ) for the counting, 9 is the smallest number that is distinguished with significance from zero frequency (*e.g.* Kanaya, 1957). All information presented in Chart 1 and Table 4 is based on the random count of 200 specimens.

### Lithology

A separate study is being made of the lithology of the core and no attempt is made here to give a general description. Only a few points, particularly pertinent to the present study will be mentioned. According to field observations of the core by R. Grinnel (Ujiié, 1965), the sediment of the upper 18cm of the piston core is in a rather distinct "light reddish-brown" color. This brown color disappears approximately 30cm from the top of the core. The two uppermost samples made available to the writers, D-0 (0-5cm) and D-1 (10-11cm), are dark yellow brown silty clay (ref. Rock-color Chart Comm., 1963); D-2 (20-21cm) is light olive gray silty clay with medium olive brown mottling; D-3 (30-31cm) is light olive gray silty clay and all lower samples are light olive gray to olive gray silty clay, as was mentioned by R. Grinnel. In the trigger gravity core samples, an obvious color change is observed between DT-3 (15.5-16.5cm; dark yellow brown) and DT-4 (20.5-21.5cm; olive gray), both are silty clay. From diatom data, notably the relative frequencies of *Pseudoecumotia dobiolus* (see Chart 1), a rather distinct difference is found to exist between the uppermost three samples, DT-2 (10.5-11.5cm) and above, and the lower four DT-3 (15.5-16.5cm) and below, in the trigger core. In the piston core, a similar boundary between diatom assemblages was found between D-2 (20-21cm) and D-3 (30-31cm). The uppermost sample from the trigger core, DT-0 (0-1cm), and the uppermost sample from the piston core D-0 (represented by a composite sample of the uppermost 5cm) are both diatom oozes, they are both dark yellow brown in color and both have higher values of  $Td$  (see Chart 1). It is concluded therefore that the uppermost part of the piston core corresponds to the uppermost part of the trigger core, and that approximately the top 20 cm of the piston core corresponds approximately to the top 12 cm of the trigger core. It is judged

that the sediment column of the deep-sea bottom surface is represented more correctly in the piston core, and the column in the trigger core has been shortened (Eircson *et al.*, 1956).

As is shown in Chart 1, the estimated diatom number drops rather sharply within the uppermost 10cm of the piston core, and this number remains less than  $20 \times 10^6$  through the core except at a few places between the 220cm and 330cm levels. Radiolaria skeletons are common throughout the core, but diatoms seems to contribute much more than Radiolaria to the biogenous amorphous silica content of the present samples. We designate as diatom or siliceous ooze only those few samples having a diatom number greater than  $20 \times 10^6$ . The remaining samples are considered diatomaceous or siliceous silty clay or clayey silt. It may be of interest to point out that Ck 8 (0–2cm)\*, brown so-called diatom ooze from the Bering Sea, contains  $27 \times 10^6$  diatom valves per gram but less Radiolaria than are usually found present in this core. The biogenous opal content of the same sample measured by Goldberg (1958) was a little over 20 percent. Jousé found, in the surface layer of a core from the mixed zone of the northwest Pacific a diatom number of  $10.2 \times 10^6$ , and an amorphous silica content of 6.3 percent (Jousé, 1963, p. 1023).

Three layers of volcanic ash were reported. R. Grinnel gave them the following field description: "Prominent, thick, and firm beds of pinkish-brown and grayish-white volcanic ash cut the layer horizontally at 274–288 cm, 430–435 cm and 480–488 cm. (Ujiie, 1965, p. 177). Their levels, according to the measurements made by Ujiie (*ibid.*, fig. 1), are indicated in Chart 1.

#### *General features of the flora in the core*

Before interpreting the temperature curve, the applicability of the criteria derived on the basis of the modern flora to the flora of the geologic past may be analysed through discussing the general features of the flora in the core. Seventeen taxa of recurrent group I, 9 taxa of recurrent group II and 3 taxa of recurrent group IV appeared during the counting in D-101 (1005–1006cm), the lowermost sample of the core (see Chart 1). These species and varieties include all of those cold and warm water forms that contribute greatly in modern thanatocoenoses to the frequencies of the groups of the two fold classification. When the level of D-92 (915–916cm) is reached, all species of group II and all species of group IV are recorded in the core, as well as all species of group I, except *Actinocyclus subtilis*. It is at much higher levels that all four species of group V come into the record, but these contribute far less to the total makeup of the warm water species than species of group I do, even in the modern equatorial thanatocoenoses.

Of three recurrent groups the taxa reached the number required for the identification of the individual groups in modern sediments even in a count of 200 specimens. Thus from the record of countings group I, group II and group IV were respectively found in seven, six and one samples from core V20-130. Judging from the fact that the number of taxa that appeared in the small area examined on each slide come close in still many other samples to the number required for the identification of the groups, it was felt that both group I and group II will very likely to be found together in a good number of samples from the core when more fields are examined on each slide.

The appearance of most of the cold and warm water forms in the lowermost part of the core, the identification of well defined recurrent groups in some samples, and the probability of identifying groups in a good number of samples from the core seem to justify the conclusion that the flora in the strata represented by the piston core sequence is similar in floral characteristics, expressed in species composition, to the flora of modern thanatocoenoses, provided that the presence of species other than those observed in modern

\* For location, see Table 1 and Chart 4.

flora in the North Pacific is not significant in the core sequence.

In a sequence from a subarctic core, USSR 4112 (47°32'N, 160°03'E; length, 297 cm; depth, 5158 m), Jousé found (1963) that two species, *Rhizosolenia curvirostris* Jousé and *Actinocyclus oculatus* Jousé, were present in the lower part of the core and characterized an older flora. This older flora, with these two species that appeared to be extinct, is different from the younger flora, which practically lacks these two, but is accompanied by new ecological races and varieties, according to Jousé (*ibid.*). This floral contrast made possible a biostratigraphic subdivision of the sequence in that core. From the lithological change in the core sequence that coincided with the floral change, Jousé suggested that two cycles of sedimentation, one from the bottom of the core to 154 cm level, and one from that level to the top of the core, could be distinguished and that these represent collectively the middle and upper parts of the Quaternary sediments. Jousé placed the boundary in that core between her Horizon IV (glacial) and Horizon III (interglacial) at the 154 cm level. The three glacial stages identified in the Russian core were then named: the Aleutian glacial epoch (Horizon VI), the Kurile glacial epoch (Horizon IV), and Kamtchatka glacial epoch (Horizon II) with interglacial Horizons between them.

The species other than those observed in the modern flora in the North Pacific do appear in the V20-130 sequence, but the present writers consider their occurrences less significant than that observed at the USSR 4112 sequence. For example, *Actinocyclus oculatus* Jousé occurred also in the present core, V20-130, in seven samples at levels between D-59 (585-586 cm) and D-17 (170-171 cm). However, the occurrences of the species in this interval, which appeared to indicate the range of this species in the V20-130, was sporadic in only 7 samples of 39 representing the interval, and its relative frequencies even when occurred were too small (6/200 or 3%, or less) to consider the species significant in discussing the change of flora in the V20-130 sequence. The change caused by the presence of *Coscinodiscus wailesii* Gran and Angust only in the lower part of the core is more noticeable.

*Coscinodiscus wailesii* Gran and Angust is a large diatom ranging in size from 160  $\mu$  to 350  $\mu$  in diameter, and was described from living plankton in the Puget Sound waters near Seattle (Gran and Angust, 1931). The species was always found in fragments in slides made for the present study. Because of this, the species was not included in the counts; frequencies of its fragments were counted separately while carrying out the regular counts to obtain their frequencies relative to the total of other diatom valves in the same slide. Rough estimates of their volume relative to that of the other 200 specimens counted were made. Their estimated volumes are shown in Chart 1 by the solid black area in the column for the diatom numbers. As shown in the column, the diatom number does not vary very much in the lower part of the core. Based on the estimated volume of *C. wailesii* valves it appears that this species, which is consistently present in the lower part of the core and which contributes twice as much volume to the sediments than all the other diatoms counted combined at some lower core levels, disappears before reaching the core level D-64 (635-636 cm). Using smaller magnifications, numbers of slides from the upper horizons were scanned to verify this observation. Fragments of *C. wailesii* are practically lacking in the samples from core levels higher than D-64 (635-636 cm). The change is exaggerated because of the comparatively large size of the fragments, 40-100  $\mu$  on a side. A single valve and high girdle of this species, could supply 50 or more fragments of considerable size. The change in its abundance that took place between D-68 and D-66, however, seems certain.

Cupp remarked (1943, p. 59) on the occurrences of *C. wailesii* in plankton of the West Coast of North America as "Described from Puget Sound, Washington. Not uncommon off Southern California." Kanaya has failed to notice the species during his study of bottom sediments of that part of the North Pacific. So far as the present writers are aware, *C.*



*walesii* has not been reported from the plankton records of the western North Pacific. The species was, however, found by Jousé (1961 b) in deeper layers of long cores from the north-western Pacific. At USSR 3163 (approx. 12 m in length; for core station see Table 1 of the present paper) from the subarctic area, the species was found to be restricted to an interval, 765–975 cm, in the lower part of the core (*ibid.*, p. 191). In a more southerly station, USSR 3156 (39°57.3'N, 164°52.4'E; depth, 5414 m; length approx. 4.5 m) it was reported to be restricted only to an interval, (350–370cm), of the lower part of the core (*loc. cit.*). Both intervals were interpreted as representing an interglacial horizon (Horizon V) on the basis of diatom analysis, and their correlation was facilitated by the limited vertical range of *C. walesii* in both cores. Jousé believed (*loc. cit.*) that *C. walesii* is a thermophilic species. Romankevich *et al.* (1964) later placed the interval 765–975cm in USSR 3163 as corresponding to the subhorizons of Horizon VI (glacial). The presence of *C. walesii* does not appear to deny the application of the *Td* values to the lower part of the Core V20–130. It is very likely that the species is one of those indefinite ones that is not interpretable as either cold or warm water species as these terms used in the present study. The previous records of its occurrences in plankton (Gran and Angust, 1931; Cupp, 1943) seems to suggest this. The fact remains, however, that *C. walesii* is present in the diatom assemblages in the lower parts of cores V20–130, USSR 3163 and USSR 3156 and is not found in the assemblages of the upper part. It appears that this species which is now living in the eastern part of the North Pacific is found only in the lower parts of the cores from the western part of the North Pacific.

More frequent species in the core V20–130 are listed in Table 4. Their relative frequencies at all core levels studied are given in the same table. The list includes all species that showed relative frequencies of 9/200 or greater at least once in the samples from the core. They were all found in the uppermost layers of the cores from the North Pacific mentioned in the earlier part of this paper. As can be seen from Table 4, they all occurred through the entire length of the core. The observed frequencies in a count of 200 specimens listed in Table 4 generally fall within the range that were observed for the same species in those North Pacific bottom surface samples (Kanaya, in preparation). Exceptions are that of *Coscinodiscus radiatus* var., *Cyclotella striata*, *Melosira sulcata* and *Actinocyclus ehrenbergii* var. These taxa occurred more frequently at some levels of the present core than they did in the uppermost layers of the North Pacific cores.

Some of the species in Table 4 showed wider ranges of morphological variation than they do in the modern thanatocoenoses in the North Pacific. Identification of some of the species were sometimes difficult because of unusual variants and because of intermediate forms. So far as the present writers are aware intervals in the core in which the ambiguous forms are frequent alternate with those in which most species are represented by typical forms. Therefore, one finds the typical representatives of these species even in the lowermost part of the core. More critical taxonomic study is needed to determine the nature of this kind of change. Those species in Table 4 that showed a wider range of morphological variation than they do in modern thanatocoenoses include: *Coscinodiscus radiatus* var. (with *C. radiatus* s.s. probably only in the lower part of the core), *Coscinodiscus marginatus*, *Coscinodiscus nodulifer*, *Thalassiosira decipiens*. That *Coscinodiscus radiatus* var., *Cyclotella striata*, *Melosira sulcata* and *Actinocyclus ehrenbergii* vars. in Table 4 occurred more frequently in the deeper layers of the core V20–130 than they usually do in the modern deep-sea thanatocoenoses in the North Pacific was pointed out. However, the study of the North Pacific modern thanatocoenoses showed that these four taxa, as well as some other taxa in Table 4, are not interpretable as either cold or warm water species (or forms) as these terms are used in the present study. All the rest of the taxa in Table 4 are either cold or warm water species of the present study. We believe,

therefore, that the present floral analysis in terms of cold and warm water species selected from the modern thanatocoenoses has not left unnoticed the important cold or warm water species that contributed greatly in number to the contents of diatom assemblages of the lower layers in the core V20-130.

Ten Tertiary marine species were altogether recorded from 9 samples from the present core V20-130. The species recorded are: *Actinocyclus ingens* Ratt., *Actinocyclus tsugaruensis* Kanaya, *Cosmiodiscus intersectus* (Brun) Jousé, *Coscinodiscus elegans* Grev., *Coscinodiscus yabei* Kanaya, *Denticula kamtchatica* Zabelina, *Denticula hustedti* Simonsen and Kanaya, *Denticula nicobarica* Grund. and *Rouxia* cfr. *peragalli* Brun et Herib. They occurred in various species combinations at the following core levels: in the trigger core, DT-4 (20.5-21.5 cm), the DT-5 (25.5-26.5 cm); in the piston core D-30 (300-301cm), D-66 (655-656cm), D-72 (715-716 cm), D-92 (915-916 cm), D-95 (945-946 cm), D-98 (975-976 cm) and D-101 (1005-1006cm). The largest number of species occurring together was 4 species in the D-101 and the DT-6. In four samples only one species of those listed above was found. Whenever found, each species was always represented by a single specimen in a count of 200 specimens.

All the species mentioned above have been known to have their geologic ranges more or less restricted to the middle to late Miocene in Japan and California (Kanaya, 1959; Simonsen and Kanaya, 1961), except *Cosmiodiscus intersectus* and *Denticula kamtchatica*. The known geologic range of *C. intersectus* extends into the lower Pliocene strata in Sakhalin and Kamtchatka (Jousé, 1962); *D. kamtchatica* whose range has been believed to be restricted to the Pliocene (Jousé, *ibid.*; Simonsen and Kanaya, *op. cit.*) was found also in the upper Miocene rocks in few Tertiary sections in northeast Japan (Koizumi, 1966).

More or less solitary occurrences of Tertiary diatoms in deeper layers of deep-sea cores have been frequently reported in Russian studies (Jousé, 1962, 1963, elsewhere). These sparse occurrences in the Pleistocene core sequences of Tertiary species have been attributed in many cases in Russian studies to the increased influx of terrigenous material by the erosion of shores during the stages of lowering sea levels, because Tertiary species occurred in deep-sea core in the horizons judged to be of the glacial stages (Jousé, *ibids.*). From the randomness in core levels of their occurrences, and from small frequencies of their occurrences when found, it is safe to judge that the Tertiary diatoms in the present core were reworked from older sediments exposed somewhere, and did not belong to the flora that prevailed in the North Pacific during the accumulation of the sequence represented in core V20-130. Freshwater diatoms and marine benthonic diatoms are only infrequently seen in the present samples, and their occurrences do not appear to be related with that of the Tertiary species. No particular changes in relative frequencies of marine benthonic species coincide in core-level with the occurrences of Tertiary species. The occurrences of Tertiary species in the present core, therefore, were not likely to be particularly related to the conditions related to the glaciation.

Our knowledge of Pliocene marine diatoms in middle latitudes is still fragmentary, particularly as relates to the late Pliocene. Nevertheless, the studies being carried out by the present authors on Neogene diatoms in northern Honshu are adding evidence (*e.g.* Koizumi, 1966) to confirm that a large majority of species chosen by Jousé (1962, p. 239, pl. 76) as indicative of the Pliocene flora of the Soviet Far East are also widespread in the Pliocene rocks in northern Japan, and that these rocks also contain a large number of species chosen as important constituents of the modern flora in the present study.

The writers failed to find any of those Pliocene species in core V20-130, except for solitary occurrences of *Denticula kamtchatica* and *Cosmiodiscus intersectus* at a few core-levels and these are considered as secondary in origin. On the other hand, the species composition of the flora has not changed much through the entire length of the core, except that

noticed for the disappearance of *Coscinodiscus wailesii*. The writers feel in concluding that Core V20-130 is still within the Pleistocene sequence and did not penetrate the Pliocene sediments.

The field descriptions, as well as the lithologies of the samples available at hand, of core show that sediment sequence in the core lacks abrupt changes in lithology and texture, except for three layers of volcanic ash. (see Chart 1). Diatom thanatocoenoses are free from unusual participation of fresh-water or shallow water marine species as well as Tertiary species. We therefore assume that core V20-130 is undisturbed in its diatom components.

#### Diatom temperature curve

The temperature curve derived by plotting the values of  $Td$  obtained for each sample from the core V20-130 is shown in Chart 1. The values of  $Td$  ranged from 26 at D-46 (455-456cm) to 80 at the uppermost level, DT-0 (0-1 cm), in the trigger core. The relationships between the values of  $Td$  in the modern sediments represented by the surface layer of the North Pacific cores and in the surface temperatures of overlying waters are shown in Fig. 6.

The values of  $Td$  calculated for each sediment sample from the western half of the North Pacific (st. no. 1-37\* in Fig. 4 and Table 1) are plotted in Fig. 6a and Fig. 6b against the approximate surface water temperature at the core stations read from Chart II (February average) and Chart III (August average) of Sverdrup *et al.* (1942). Both figures suggest that a positive relationship exists between the values of observed  $Td$  in the uppermost part of the cores and the surface temperatures of the oceanic waters at the core locations, if plottings for five stations in Fig. 6b, JEDS 6-207, TP 71, Takuyo-6, USSR 3449 and USSR 3225 (st. no. 18, 19, 21, 23 and 25, respectively, in Fig. 4, Fig. 6a, and Fig. 6b) are not considered. Ranging in latitude from approximately  $38^{\circ}$  to  $40^{\circ}$ N., these five stations are in the area of mixing between the Oyashio and the Kuroshio off northern Japan where the complicated temperature distribution may not warrant a temperature read-

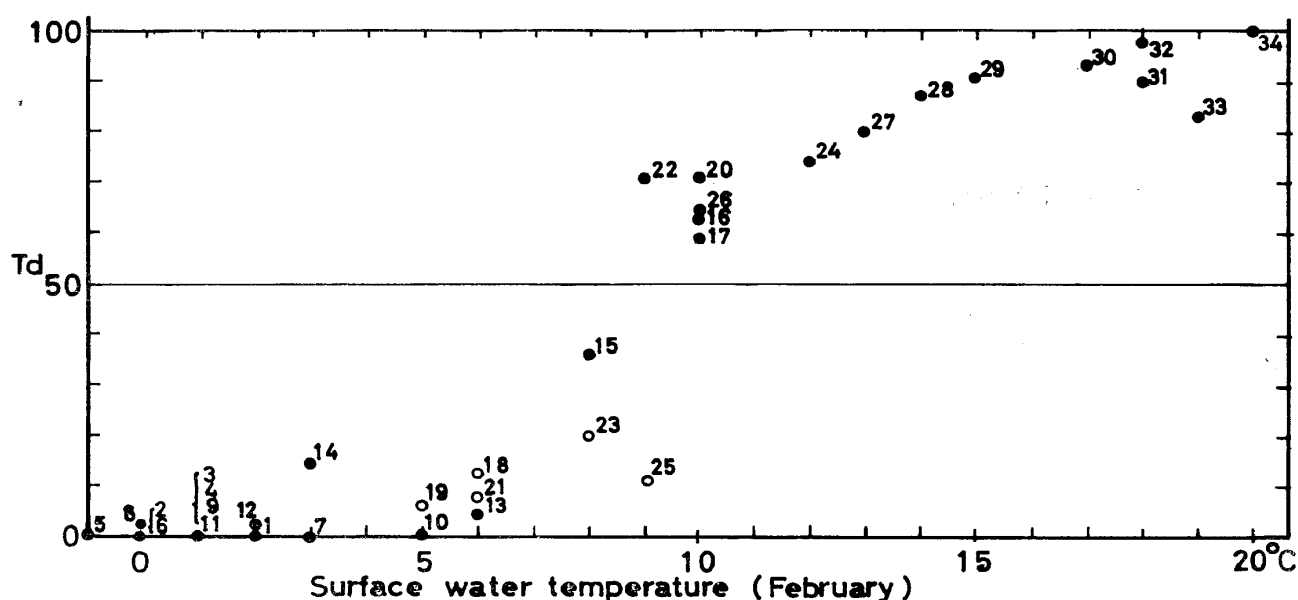


Fig. 6 a

\* Except st. nos. 35, 36 and 37 for Fig. 6a, and st. no. 35 and 36 for Fig. 6b (compare Fig. 4 and Fig. 5 for localities)

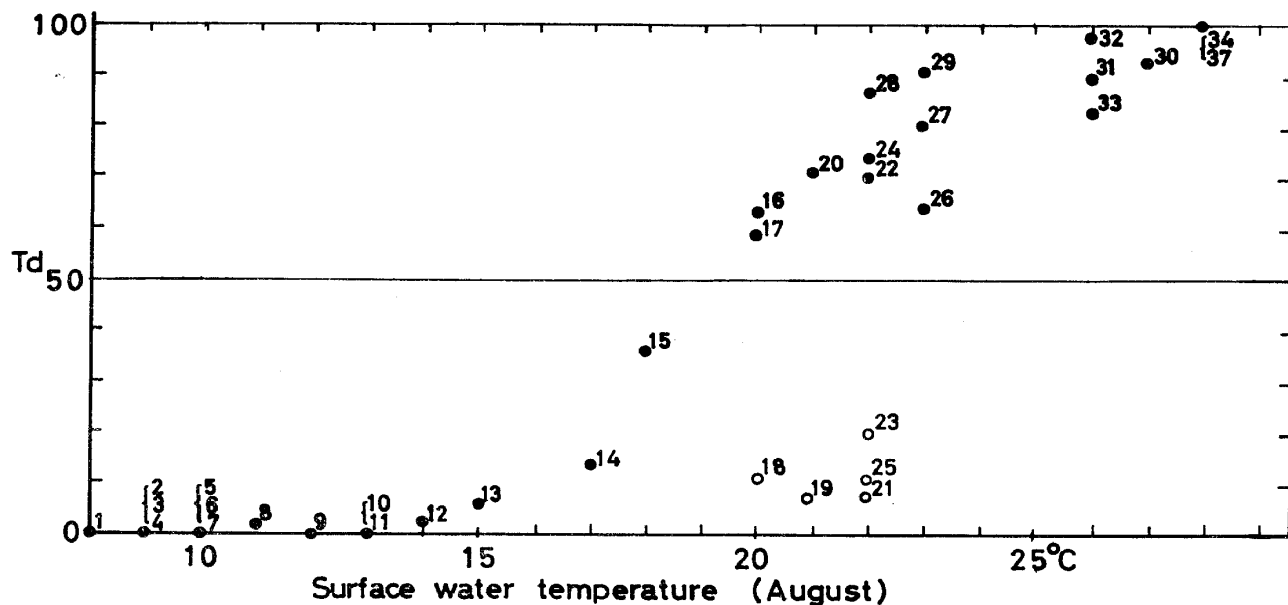


Fig. 6 b

Fig. 6. Graphs showing the relationship between the values of  $Td$  in the surface layer of the deep-sea cores from the western half of the North Pacific and surface water temperature of the oceanic water at the core location. Approximate surface water temperatures at the core stations were read from Chart II (February) and III (August) in Sverdrup *et al.* (1942). The numbers given for plottings refer to the serial station number of cores listed in Table 1. The plottings in open circles in Fig. 6b are considered anomalous from the general trend; the plottings for the same five stations are also indicated by open circles in fig. 6a.

ing from a small scale chart even it is a mere approximation. Frequent occurrences of group IV species (mostly arcto-boreal and north boreal neritic, see Table 2), which are practically lacking in the samples from stations of similar latitudes further east, make diatom assemblages of the five stations distinct from others that are within this latitudinal zone (see Fig. 4). These five western stations, therefore, may be tentatively excluded from consideration for the immediate purpose of the discussion.

The  $Td$  value is 80 (st. no. 27 in Figs. 6a and 6b) for the uppermost level of the core, DT-0 (0-1 cm); the average surface temperature is 23°C in August and 13°C in February, according to Sverdrup *et al.*, (*ibid.*). At two stations, Jyn II-10 (st. no. 16 in Figs. 4, 6a, 6b) and Jyn II-8 (st. no. 17, *ibid.*),  $Td$  values were around 60; at both stations the average for August and February temperatures are 20°C and 10°C, respectively. From this and from Figs. 6a and 6b, it seems reasonable to conclude that  $Td=50$  indicates the average temperatures lower than 20°C during summer and lower than 10°C during winter. More data is needed to make estimations of temperatures corresponding to the value of  $P=25$ , one close to the smallest value obtained in the present core, because of the lack of good control in this range of the value of  $Td$ . However, Fig. 6a and Fig. 6b at least suggest that the value of  $Td=25$  corresponds to average surface water temperatures as being probably 17°-18°C in summer, and not less than 6°C in winter. From these rough approximations, we tentatively conclude that the change of the values of  $Td$  from 80 to 25 roughly corresponds to the change in average surface water temperatures from 23°C to 17°-18°C during summer and from 13°C to not less than 6°C during winter. The value of  $Td=50$  that is intermediate between those two indicates approximately the midpoint of the temperature range corresponding to that of  $Td$  and therefore may be used as the value to which colder or warmer core intervals are referred.

The estimated value of  $Td=80$  in the uppermost part of the core, DT-0, represented

by the top 1 cm of the trigger core is taken as reflecting the present day surface water temperatures at the locality. There are good reasons (*e.g.* Emiliani and Flint, 1963) for believing that the major temperature maxima during the Pleistocene interglacial stages was equal to or even exceeded the present day temperature. The uppermost temperature minimum detected both in the trigger core and in the piston core is assumed here to represent the last temperature minimum in the last major cold stage; the value of  $Td=39$  at D-3 (30-31 cm) represents this level in core V20-130. If the foregoing discussion is valid, the curve appears to show a number of major warm and cold stages with the temperature extremes in comparative magnitudes.

Interpretations of the curve must be made with caution because the values of  $Td$  are reliable only with a certain range.\* Therefore, minor oscillations of the curve are not necessarily meaningful. Notwithstanding these uncertainties, the presence of at least four major temperature maxima in this core sequence seems apparent. They occur at: the top of the core, DT-0 (0-1 cm) or D-0 (0-5 cm), at D-6 (60-61 cm), at D-43 (425-426 cm) and at D-62 (615-616 cm). At these four core levels the values of  $Td$  are close to or greater than 70, and are within the confidence interval of observed  $Td=80$ \*\* . The type of diatom assemblage at these core levels are first examined.

In the uppermost part of the core, D-0 (0-5 cm) and DT-0 (0-1 cm), only recurrent group I was identified. This placed the sample in the Central assemblage (see Chart 1, Fig. 4, st. no. 27, and Table 3). The counting records at the other three core levels, D-6, D-43 and D-62, for which more or less similarly large values of  $Td$  were observed, suggested that D-62 may have only group I present, whereas D-6 and D-43 may have both group I and group II present. One strewn slide was further examined for each of these three samples through its entire area for the recurrent groups. It was confirmed that, as suspected, in D-6 and D-43 both group I and group II are present, but in D-62 only group I is present, according to the criteria set for the identification of the groups in the modern sediments. It follows that, if the classification of modern diatom thanatocoenoses in the North Pacific (Table 2, 3 and Fig. 4) is applied to the deeper layers of the core, D-62 (615-616cm) belongs to the same diatom assemblage as the uppermost part of the core, the Central assemblage, whereas D-6 (60-61 cm) and D-43 (425-426 cm) belongs to another assemblage immediately north, the Subarctic-Central Mixed assemblage. It seems reasonable to infer, therefore, that during the deposition of level D-62 (615-616cm) the surface water temperature and the distribution of the upper watermasses were very similar to present day conditions. The core levels D-6 (60-61 cm) and D-43 (425-426cm) may reflect slightly lower temperatures than obtained at the present time, because the surface water conditions at the time of their deposition were such that the Subarctic-Central Mixed assemblage extended south and occupied the present locality of V20-130 (st. no. 27 in Fig. 4). The same symbols used in Fig. 4 indicate on Chart 1 the recurrent groups

\* The proportion of warm water species was estimated by  $Xw/Xc + Xw$  where  $Xc$  and  $Xw$  are the frequencies of the cold water and warm water forms respectively in a random count of 200 specimens. The value  $Xc + Xw$ , that is the sample size  $N$  used in estimating  $Td$ , is not the same at different core levels because the value of  $Xc + Xw$  varies depending upon the frequencies in the original counting ( $N=200$ ) of those indifferent species that were not assigned either to cold or to warm water groups. Since the observed proportion  $Xw/Xc + Xw = Td/100$  should be viewed as an estimate within a confidence interval, it becomes less reliable when the value of  $Xc + Xw$  is smaller, that is, when indefinite species are more frequent in the sample. The values of  $Xc + Xw$  are shown in Chart 1 at all core levels examined. They range approximately from 50 to 100. The confidence limits for the proportion  $p$  corresponding to a observed proportion for the sample size  $N=50$  and  $N=100$  are found in statistical tables (*e.g.* Dixon and Massy, 1957, tables A 9a-9d).

\*\* The lower confidence limit corresponding to the observed  $Td/100=0.8$  is approximately 0.67 for  $N=74$  and confidence coefficient 95% (see Dixon and Massy, *ibid.*, table A-9c)

identified at these four core levels as well as at other core levels for which the additional examination of a strewn slide was conducted for the recurrent groups.

D-3 (30-31cm), which has the value of  $Td=39$  is taken as representing the latest major temperature minimum during the last major cold stage. For the identification of the recurrent group one strewn slide was examined through its entire area; only group II was identified. Therefore this core level is characterized by the Subarctic assemblage. Group I elements did not reach the required number for identification, 19, because 5 taxa out of the total of 22 were lacking. The taxa lacking were: *Coscinodiscus africanus*, *Hemidiscus cuneiformis*, *Planktoniella sol*, *Roperia tessellata* var. *ovata* and *Coscinodiscus perforatus* var. *cellulosa* (see Table 2). When this is interpreted in terms of the distribution of modern diatom assemblages in the North Pacific sediments (Fig. 4), a subarctic oceanic condition analogous to the one now prevailing to the north of the mixed zone of the Oyashio and Kuroshio must be assumed. This confirms that the surface water temperature at the time of deposition of the D-3 level (30-31 cm) was significantly lower than that of the uppermost part of the core, as the comparison of  $Td$  values at two core levels easily suggests. A continuous decrease in surface temperature from D-6 (60-61 cm) to D-3 (30-31 cm) thus seems also certain.

Distinguishing major temperature minima in lower core levels is more difficult, but the four major temperature maxima already established serve as guides.

*Interval between D-6 (61-61 cm) and D-43 (425-426 cm):* - Two samples, D-8 (80-81 cm) and D-31 (310-311 cm) were checked first for recurrent groups. The two were chosen because (1) the values of  $Td$  are sufficiently close (39 at D-8, and 33 at D-31) to that at D-3 ( $Td=39$ ), and (2) the numbers of group I elements (mostly of warm water species) found while counting 200 specimens each in these two samples were considerably smaller (15 in D-8 and 14 in D-31) compared to the other core levels showing a similar value of  $Td$ . In both D-8 and D-31, only group II was identified by the examination of an entire area of strewn slide, thus establishing that they belong to the Subarctic assemblage as does D-3 (30-31 cm). The routine counting record showed that D-22 (220-221 cm) with the value of  $Td=42$ , contained the required numbers of elements of group I and 10 of the elements of group II, only one less than the required number for identification of group II. The chance of identifying group II in this sample by examining a larger area on a slide seemed very high. D-21 (210-211 cm) has a smaller estimated value of  $Td$ , ( $Td=40$ ), than D-22. Therefore, the sample was further examined for recurrent groups to see if the sample lacked group I. However, both group I and group II were found. Therefore, the sample yields the Subarctic-Central Mixed assemblage. The Subarctic-Central Mixed assemblage was south of the core locality during the deposition of D-31 and D-8 but moved to the locality from the south at the time of deposition of the core level D-21 and very probably D-22. The surface temperature may have been slightly higher during D-21 and D-22 time than during D-8 and D-31 time.

It seems apparent that temperature changes of the first order took place between D-43 and D-31 time and between D-8 and D-6 time, accompanying the shift of diatom assemblages from one place to another. The shape of the curve between two more distinct temperature minima, D-31 and D-8, appears to reflect temperature changes of lesser magnitude:  $Td$  values oscillate over narrower ranges, and the counting record strongly suggests that the Subarctic-Central Mixed assemblage remained over this locality throughout this time interval.

*Interval between D-43 (425-426 cm) and D-62 (615-616 cm):* - The value of  $Td$  at D-46 (455-456 cm) is 26, the smallest value observed in the core, and suggests a major temperature minimum. The number of elements of group I and group II appeared in the counting were 13 and 10, respectively. Further examination of a strewn slide confirmed that

only group II is present in the sample, representing the Subarctic assemblage. The decrease of  $Td$  value from a distinct maximum at D-62 toward D-46, and its increase thereafter toward D-43, another distinct maximum, appear to represent a first order fluctuation of the surface temperature. The fluctuations of  $Td$  between D-62 and D-46 appear to be of less significance. D-59 (585-586 cm) and D-54 (535-536 cm), in which group II was identified during the routine counting, were further checked and found to be lacking group I, thus assigned to the Subarctic assemblage.

*Intervals between D-62 (615-616 cm) and D-101 (1005-1006 cm):* - D-94 (935-936 cm) appears to represent a major temperature minimum with a distinctly small value of  $Td=34$ , intermediate between the value at D-3 (30-31 cm) and the volumes at D-46 (455-456 cm). The diatom assemblage at the D-94 core level was found to be the Subarctic assemblage. From D-100 (955-956 cm), at which the Pacific Subarctic-Central Mixed assemblage was found, the values of  $Td$  decrease toward D-94. From D-94 (935-936 cm) to D-62 (615-616 cm), the general trend of the temperature curve so far derived is one of successive increase of  $Td$  values with oscillations in lesser magnitudes.

As mentioned previously, a 20 cm interval was set for the study of the part of the core lower than D-60 (595-596 cm). Further study at closer intervals is needed before interpreting the curve between D-94 (935-936 cm) and D-62 (615-616 cm). However, a survey of the types of assemblages found at these peaks between D-94 and D-62 so far checked indicates that the rule which generally holds true in the upper part of the core for the relationship between the value of  $Td$  and the type of diatom assemblage does not necessarily hold true in the part of the core below D-66 (655-656 cm).

The value of  $Td$  is 37 at D-86 (855-856 cm). In the intervals above D-62 (615-616 cm), the samples that have such small values of  $Td$  carry the Subarctic assemblage. Examination of slide from D-86 over its entire area for recurrent groups revealed, however, that whereas group II elements did not reach the required number, the group I elements did and, therefore, the sample carries the Central assemblage. In the upper part of the core, only three samples, at DT-0 (0-1 cm), D-0 (0-5 cm) and D-62 (615-616 cm), all showing distinctly greater values of  $Td$ , have been identified as bearing this warm water assemblage.

Furthermore, there are indications that the occurrences of recurrent group elements are less consistent in the core interval between D-101 (1005-1006 cm) and D-62 (615-616 cm), except the part from D-66 (655-656 cm) through D-62, than in the upper intervals of the core. Through the core levels from D-66 to the top, samples having intermediate values between distinctly smaller and greater values of  $Td$  usually show good indications, in their counting records, that they belong to the Subarctic-Central Mixed assemblage because they carry enough elements of both group I and group II to be identified as such if examinations are made over large areas of strewn slides. This was verified at a number of core levels as mentioned earlier. In the lower part of the core, below D-66, however, such indications are rarely apparent from the counting records. Instead the counting records suggest that neither group I nor group II may be identifiable even if large areas of slides are examined at peaks of oscillations of lesser magnitude between D-94 (935-936 cm) and D-62 (615-616 cm), such as D-80 (795-796 cm), D-76 (755-756 cm), D-70 (695-696 cm) and D-68 (675-676 cm). This was confirmed by examination of the entire area of a strewn slide for each sample. On the other hand, the counting records have led to the identification of the mixed assemblage at the core level, D-74 (735-736 cm).

The fact that the Subarctic-Central Mixed assemblage is present at a few core levels below D-66 argues against the conclusion that the species composition of the diatom flora in the North Pacific during the accumulation of the lower part of the core was much different from that of the present day. The presence of samples lacking in both group I

and group II may indicate that some of the species found consistently in the modern thanatocoenoses of the North Pacific may not have yet acquired that consistency in the North Pacific, particularly of its western half, during the accumulation of the lower part of the core. Sample D-86 (855-856 cm) is anomalous in that it has a low observed value of  $Td$  but carries a warm Central assemblage in terms of the classification of modern thanatocoenoses. This anomaly seems to suggest that the interspecies relationships of species could have been different in the diatom biocoenoses then extant in the Pacific, although the North Pacific diatom flora might already have acquired a species composition similar to the present-day flora of the region in so far as the species here chosen for characterizing modern thanatocoenoses.

### Discussion

In the foregoing pages, the changes that took place in two independent parameters drawn from diatom thanatocoenoses, the value of  $Td$  and the type of diatom assemblage, were compared (see diatom temperature curve in Chart 1). It was established that the fluctuation of values of observed  $Td$  and shifts in diatom assemblages, in the upper two thirds of the core from D-66 (655-656cm) to the top, follow a pattern that can be related to the geographical distributions of these two parameters in the modern sediments of the northwestern Pacific. There are indications that in this core interval diatom assemblages bearing the same characteristics in species composition as their modern representatives had their values of  $Td$  in the similar range as are observed for their modern representatives.\* The agreement between  $Td$  values and type of assemblage means that a high degree of correlation in certain attributes determining the structure of biocoenoses must exist between those biocoenoses that occupied the North Pacific during the accumulation of the upper two thirds of the core and those that exist in the area at the present-day. These two sets, ancient and modern biocoenoses, must be similar not only in species composition but also in the areal distributions in the North Pacific as well as in relative population densities of their constituents. We conclude therefore, that there are grounds to justify the direct application of  $Td$  values in inferring the fluctuation of surface water temperatures during the accumulation of the upper two thirds of the core, starting at D-66 and thereabove, and that the diatom temperature curve derived for this part of the core illustrates reliably the fluctuation of surface water temperature above this core locality.

It was pointed out (p. 116) that heavy participation of the group IV species that are neritic produces a group of modern thanatocoenoses whose  $Td$  values do not fall in a general trend that otherwise appears to exist between the  $Td$  values and the surface water temperatures in the western half of the North Pacific (Fig. 6 and Fig. 6b). Thanatocoenoses of such composition were not found in core V20-130.

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\* In the western half of the North Pacific (St. 1-37 of Fig. 4; also compare Fig. 4 with Fig. 5),  $Td$  values observed for the Central assemblage in the modern sediments range from 74 to 100. This same assemblage, where it was identified in the upper two thirds of the present core, had  $Td$  values greater than 74: 80 at DT-0, 74 at D-0, and 75 at D-62. The  $Td$  values of the Subarctic and Subarctic-Central Mixed assemblages in the modern sediments range, respectively, from 0 to 14 and from 59 to 71. The values of  $Td$  observed for the Subarctic assemblages found in the upper two thirds of the core in all cases are greater than 14 therefore are greater than the  $Td$  of the same assemblage in modern sediments. Some  $Td$  values observed for the Subarctic-Central Mixed assemblage identified in the upper two thirds of the core are less than 59 (see Chart 1). These noncoincidences of  $Td$  values of modern sediments and ancient sediments from the upper two thirds of the core are interpreted as the result of the scarcity of samples from latitudes near the boundary of these two assemblages in modern sediments. (see Figs. 4 and 5). Perhaps the study of more samples from this critical area would extend the  $Td$  value range of modern sediments.



More information is needed in order to correlate the given values of  $Td$  with reliable surface water temperature readings. The data so far available allows the estimate, however crude that may be, to be made that the total range of surface water temperature fluctuation during the accumulation of the upper two thirds of the core was approximately 6°C, ranging from that estimated for a temperature minimum at D-46 (17°~18°C for summer; not less than 6°C for winter) to that estimated at a temperature maxima at the top of the core as well as at D-62 (23°C for summer; 13°C for winter).

The diatom temperature curve for the lower one third of the core, below D-66 (655-656cm) must be cautiously interpreted. As mentioned previously there are core levels (e.g. D-101, D-100, D-94, D-74) at which the relationship between  $Td$  value and type of assemblage agrees with what is expected from their relationship in the modern sediments in the western half of the North Pacific. However, the two parameters do not agree at D-86 (855-856 cm). Further, it was found that some of the taxa constituting recurrent groups I and group II in the modern thanatocoenoses appear to have been less consistent in their occurrences through this lower one third of the core than through the upper two thirds of the core as well as in modern thanatocoenoses in the western half of the North Pacific. The disagreement between the value of  $Td$  and type of assemblage, and the inconsistency of occurrence of some of group I and group II elements are interpreted as indicating that the diatom biocoenoses in the western half of the North Pacific had not acquired a close similarity to the modern biocoenoses until the time of deposition of core level D-66. We believe, therefore, that the  $Td$  values observed in samples from the lower one third of the core can not be applied with the same reliability as those values from the upper two thirds of the core in interpreting the surface water temperature of the past. The diatom temperature curve in the lower part of the core below D-66 may reflect the fluctuations of surface water temperature, but with less degree of assurance.

That the structure of diatom biocoenoses changed and became similar to that of the present-day as core level D-66 (655-656cm) was approached during deposition seems to be borne out by other lines of evidence. As mentioned earlier (p. ) *Coscinodiscus wailesii*, consistent through the lower part of the core, is practically lacking in core level D-64 (635-636 cm) and above (Chart 1). Further, some of those species chosen as more frequent (table 4) tend to make up a larger share of the thanatocoenoses in the lower part than in the upper part of the core. This is best shown by *Denticula seminae* and by *Coscinodiscus marginatus*; the change in relative frequency appears to take place at between D-68 and D-66 for these cold water species (Chart 1). This same trend is also observed for a few warm water species, *Coscinodiscus nodulifer*, *Pseudoeunotia doliolus* and *Nitzschia marina* except that these species appear to regain the important role they had in the lower part of the core again in the uppermost part of the core. The level at which the change in relative frequency takes place is not at between D-68 and D-66, but at slightly higher core levels, probably between D-62 and D-60 (Chart 1), for example, in the cases of two former species. The concurrence of these changes in a core interval between D-68 and D-60 within which the change in structure of biocoenoses is thought to be detected to have taken place seems to justify a subdivision of the core sequence into two units of biostratigraphic importance. We consider that two biostratigraphic units distinguished in the core represent different phases of the floral development of the Pleistocene diatom flora of the western North Pacific. Thus the lower zone represents an older phase, the upper zone the younger phase. The species composition of diatoms in sediments is not much different in two zones, but two units differ in consistencies in occurrences of some group I and group II elements indicated by the presence of samples lacking in both group I and group II, and in interspecies relationships indicated by the difference in relationship between the value of  $Td$  and the type of diatom assemblage. The boundary between the two zones is placed between D-66 and D-68. The Teil zone of

*Coscinodiscus wailesii* may be taken as a guide to approximate the range of the lower zone in the present core, although it extends up to D-66.

Fluctuation of some other attributes may now be compared with that of the diatom temperature curve. The comparisons of curves given in Chart 1 suggest that a similarity exists between the fluctuation of relative frequencies of warm water forms as a whole (4th column from the left in Chart) and the diatom temperature curve. It appears that fluctuations in the relative frequencies of warm water forms are more responsible than fluctuations in the cold water forms for the configuration of the diatom temperature curve, since the relative frequencies of the cold water species as a whole are more constant, except in the lower part of the core. At the core levels where larger values of  $Td$  indicate temperature maxima peaks of greater frequencies of warm water species are often observed (5th column from left). However, different species contribute to different peaks. Peaks characterized by *Nitzschia marina* at D-43 (425-426 cm) and by *Pseudoeunotia doliohus* at D-62 (615-616 cm) may be useful for correlating the major temperature maxima in the present core with that in the other cores, if a study similar to the present one is made on more cores in the same neighbourhood. On the other hand, the occurrences of cold water species in the present core (4th and 6th column from the left in Chart 1) suggest that temperature minima may not be necessarily represented in a diatom sequence in subtropical latitudes by appreciable increases in certain cold water species.

Russian studies of the Soviet Far Eastern Seas have led to the generalization (Jousé, 1962) that the concentration of diatom valves and thus of amorphous biogenous silica in sediments is lower in glacial stages than in interglacial ones in the higher latitudes of the Pacific. This was explained by Jousé (*ibid.* p. 257) as due to a lessening in the supply of diatom valves to bottom sediments during glacial ages since the growth season of the diatom flora was shorter due to the ice cover that existed on the sea for longer periods during the year. And further, that the concentration of diatoms in bottom sediments was diluted to a greater degree by the greater influx of terrigenous material during glacial ages when the sea levels were lower (*ibid.*) On the other hand, Jousé (1963) found that sediments of glacial stages are richer in diatoms than sediments of interglacial stages in equatorial cores. She took this as confirming the view presented by Arrhenius (1952) that organic productivity was higher during glacial stages than in interglacial stages in the Equatorial Pacific.

A comparison between the fluctuation of diatom number through core levels (first column from the left in Chart 1) and the diatom temperature curve suggests that the correlation is not obvious between them in the present core. The solid area in the lower part of the graph given for the diatom number in the core represents the estimated volume of *C. wailesii*. This was done in order to make the graph better reflect the concentration of amorphous silica.

Correlating major temperature minima and maxima inferred by the present study in the Pleistocene sequence in core V20-130 with that of continental Pleistocene stages should be considered as premature. A similar study on more cores from the subtropical latitudes should be carried out before any positive statements can be made on the general trend of the fluctuation of surface water temperatures in the western half of the North Pacific during the Pleistocene. Through comparing fluctuations observed in other cores, such parts of the temperature curve as observed in core V20-130 in the core interval between D-43 and D-8 may be better interpreted. Even when the general trend of fluctuation is established there will remain the need for good time controls, or indicators, over correlation, in order to set us free from the circular reasoning inherent in correlating established peaks of temperature fluctuation in deep-sea cores with continental Pleistocene records.

Data have been accumulated on the succession of Pleistocene events which have left records on the Japanese islands (*e.g.* Kobayashi, 1965; Nakagawa, 1965). A correlation,

aided by good time controls, between those continental events and the temperature fluctuations in the Pleistocene deep-sea core sequence in middle latitudes of the North Pacific will contribute greatly to our understanding of the Pleistocene in the northwestern border of the Pacific.

Some of the findings in the present study which are pertinent to future studies of deep-sea Pleistocene stratigraphy of the North Pacific are discussed below.

As is obvious from Figs. 5, 6a and 6b,  $Td$  values become zero at the stations from the northern subarctic latitudes and reach 100 at the stations from the southern subtropical latitudes. Surface water temperatures corresponding to the  $Td$  range of 0–100 range from approximately 15°C to 26°C in summer in the western half of the Pacific. Therefore, the index  $Td$  as defined as  $Td = (Xw/Xc + Xw) \times 100$  may not reflect the Pleistocene temperature fluctuations satisfactorily when applied to the analysis of cores from tropical latitudes or subarctic cores at the localities north of approximately 50°N latitude. Modification\* of the index  $Td$  is necessary to make it applicable to such cores.

We assumed that the minimum of  $Td$  at D-3 (30–31 cm) in core V20-130 reflects the last major temperature minimum of the last major cold stage. The core must be studied at closer intervals to confirm this. It is unlikely, however, that another temperature minimum of a magnitude similar to that at D-3 (30–31 cm) was left unnoticed in the present study within the upper 30 cm of the piston core in view of the parallelism apparent in  $Td$  curves obtained for the piston core and for the trigger core. A recent study by Romankevich *et al.* (1964) reports the thickness of their Horizon I (postglacial: Holocene) to be 26 cm representing deposition during the last 9000 years at the station USSR 3451 (appr. 37°30'N; 145°E, depth 5678 m), the nearest core available for comparison. If thickness means anything in time-correlation of deep-sea at different localities, the thickness of the postglacial sediments are more or less similar at two cores, the core V20-130 and USSR 3451. Jousé recognized the postglacial climatic optimum, represented by a rise in surface water temperature shown by diatom compositions, in numbers of subarctic cores (Jousé, 1961b, pl. 2). Romankevich *et al.* appears to consider what considered to be the interval of post-glacial climatic optimum by Jousé, at least in the case of USSR 3163, as representing the interstadial (with the absolute age ranges between 26 to 48 × 10<sup>3</sup> year B.P.) in the last glacial stage (compare Jousé, *ibid.* and Romankevich *et al.*, *ibid.*, pl. 2 and table 2).

We consider that the maxima of  $Td$  found at D-6 (60–61 cm), D-43 (425–426 cm) and at D-62 (615–616 cm) indicates that the surface water temperature during the accumulation of these core-levels was not greatly different from that of the present-day, which is represented by the  $Td$  value at DT-0 (0–1 cm),  $Td=80$ . Further, it is inferred that the temperature could have been slightly lower at the times of D-6 and D-43 than that at the two other major maxima, DT-0 and D-62, as the differences in the type of diatom assemblages suggests. The evaluation of the maximum at D-6 (60–61 cm) in connection with the last major cold stage depends upon the evaluation of another but lesser  $Td$  maximum just below with the peak at D-11 (110–111 cm).  $Td$  values at D-11,  $Td=63$ , is not significantly different from the one at D-6,  $Td=70$  (Dixon and Massey, 1957, Table A-9c). The counting record strongly suggest that the Subarctic-Central Mixed assemblage characterizes D-11 as well as D-10 (100–101 cm) just as it does at D-6. If a  $Td$  of 50 is viewed as a reference to which the colder and warmer core intervals may be compared in

\* Russian students (*e.g.* Jousé, 1962) have classified cold water species into finer categories such as arctic, arctoboreal, and north-boreal, and warm water species into subtropical and equatorial. If a one-directional trend is found among relative frequencies of these species in finer categories in modern sediments of particular regions, a set or sets of their frequencies can replace  $Xc$  and  $Xw$  used in the present study. So-called "south boreal" species in Russian studies (*ibid.*) may be worth considering also in this connection.

this core sequence, the moderate maximum with the peak at D-11 represents a warmer interval. The relationship, both in their  $Td$  values and their vertical spacing in the cores, of these three peaks, D-0, D-6 and D-11, found in the upper part of the core V20-130 must be further checked for consistency in the other cores, before the fitting of the peaks found in the core V20-130 with that of major warm units based on Oxygen-isotopic temperatures in other deep-sea cores (*in* Emiliani & Flint, 1963 figs. 4, 5 and 6) is attempted on the basis of the homotaxial relationship of cold and warm core stages. It seems safe to consider that the minima of  $Td$  at D-8 (80-81cm), D-31 (310-311 cm) and D-46 (455-456 cm) and possibly that at D-94 (935-936cm) represent major temperature minima of a magnitude not much different from that found at D-3 (30-31 cm).

The Pleistocene aspect of diatom thanatocoenoses throughout the core V20-130 was mentioned. The differences observed in diatom composition between the lower one third, from D-101 up to D-68, and the upper two thirds, from D-66 to the top, of the core, was interpreted as representing two phases in the development of the Pleistocene flora of this part of the North Pacific. The placing of this boundary between the older and younger phase of the flora in core V20-130 in the deep-sea Pleistocene sequence is open to question because of the lack of information in floral analysis which make the comparison possible. The only possible tie that may relate this boundary to those floral boundaries reported in Russian studies of the North Pacific cores is the occurrences of *Coscinodiscus wailesii*. If the Teil zone of *Coscinodiscus wailesii*, which represents approximately the older phase of the diatom flora in the core V20-130, in the northwestern Pacific is emphasized, the lower one third of the core V20-130 may be correlated with Horizon V (interglacial) of Jousé. Jousé (1961 b) used the Teil zone of *C. wailesii* to identify Horizon V at two cores: at USSR 3163 (43°49' N; 156°38.3' E; depth 5441 m; length, appr. 12 m) in an interval 763-975 cm, and at USSR 3156 (39°57.3'N, 164°52.4'E; depth 5414m; length appr. 4.5 m) in an interval 350-370cm. As mentioned earlier (p. 113), Romankevich *et al.* (1964) placed that core interval in USSR 3163 in subhorizons of a glacial stage (Horizon VI) which they tentatively correlate with the Kansan or Mindel Glacial Stage (*ibid.*, p. 63 and pl. 2). The difference in thickness of the Teil zone varies in the three cores, ranging from only 20 cm in USSR 3156 to at least 360 cm in V20-130 at which thickness the core did not even reaches the lower boundary of the Teil zone.

Mineralogical, geochemical and other paleontological studies of core V20-130 may also reveal variations in other components through the length of the core. Only through a cross-checking of the evidence obtained by different lines of studies will the Pleistocene succession of events, geological, oceanographical as well as biological, that left records in the core V20-130 be reconstructed.

### Part III: FLORAL REFERENCE

The species are arranged alphabetically in the list. For the taxonomic position of genera, the readers are referred to Hustedt (1927-) whose system of classification of diatom has been fully adopted in the present study.

In the following floral reference, the species and varieties are referred to Hustedt (*ibid.*) in cases where they were treated in his series, indicating that we have followed the concepts of the taxa summarized explicitly by Hustedt in his revised descriptions; the citation of original description and a comprehensive list of synonyms will be found in Hustedt. For those taxa which were not treated by Hustedt (*ibid.*), references are made, as much as possible, to the original descriptions. Additional references are cited, selected from descriptions and illustrations that are particularly helpful for the identification of the taxon preserved in the bottom sediments. Short remarks are given whenever felt necessary, pending description in future publication (Kanaya, in preparation).

- Actinocyclus curvatulus* Jan., in A. Schmidt, 1878: Hustedt, 1928, Kieselalg., Teil I., p. 538, fig. 307; Hustedt, 1958, p. 129, figs. 82, 83.
- Actinocyclus divisus* (Grun.) Hustedt, 1958: 1958b, p. 129 pl. 8, fig. 81. Syn., *Coscinodiscus divisus* Grun., 1884: Hustedt, 1928, Kieselalg., Teil I, p. 410, fig. 218.
- Actinocyclus ehrenbergi* Ralfs vars. Represented mostly by *Actinocyclus ehrenbergi* var. *crassa* (W. Smith) Hustedt: 1929, Kieselalg., Teil I, p. 529, fig. 301.
- Actinocyclus elongatus* Grun. in Van Heurck, 1880: pl. 125, fig. 15; Kolbe, 1955, p. 164, pl. 2, fig. 20. Syn., *Actinocyclus ellipticus* var. *elongatus* (Grun.) Kolbe, 1954: p. 20, pl. 3, fig. 28, 31.
- Actinocyclus ingens* Ratt., 1890: p. 149, pl. 11, fig. 7; Kanaya, 1959, p. 97, pl. 7, figs. 6–9 and pl. 8, figs. 1–4.
- Actinocyclus ochotensis* Jousé, 1961: 1961d, pl. 3, fig. 4. (illustration only)
- Actinocyclus oculatus* Jousé, 1961: 1961d, pl. 3, fig. 3. (illustration only)
- Actinocyclus subtilis* (Greg.) Ralfs, 1861: Hustedt, 1929, Kieselalg., Teil I, p. 534, fig. 304.
- Actinocyclus tsugaruensis* Kanaya, 1959: p. 99, pl. 8, figs. 5–8.
- Actinocyclus undulatus* (Bail.) Ralf, 1861: Hustedt, 1929, Kieselalg., Teil I, p. 475, fig. 264.
- Asterolampra marylandica* Ehr., 1845: Hustedt, 1929, Kieselalg., Teil I, p. 485, fig. 271; Kolbe, 1954, p. 23.
- Asteromphalus elegans* Grev., 1859: Schmidt, 1876, Atlas, pl. 38, figs. 1, 2; Rattray, 1889, p. 660; Koble, 1954, p. 23. See *Asteromalmpra elegans* Grev., 1860: p. 119, pl. 4, fig. 16.
- Asteromphalus hiltonianus* (Grev.) Ralfs, 1861: Rattray, 1889, p. 661; Kolbe, 1954, p. 23. Syn., *Asterolampra hiltonianus* Grev., 1860, p. 117, pl. 4, fig. 15.
- Asteromphalus hoockeri* Ehr., 1854: pl. 35A, fig. XXI, 2; Hustedt, 1958b, p. 127, figs. 88–90; Jousé et al., 1962, p. 81, Tab. II, figs. 10, 11.
- Asteromphalus imbricatus* Wall., 1860: p. 46, fig. 2; Koble, 1957, p. 25, pl. 1, fig. 1. Syn. *Asterolampra imbriciata* (Wall.) Grev.: 1860, p. 119, pl. 4, fig. 17.
- Asteromphalus robustus* Castr., 1875: Hustedt, 1929, Kieselalg., Teil I, p. 497, fig. 278; Jousé, 1962, pl. 3, fig. 5.
- Bacteriosira fragilis* Gran, 1900: Hustedt, 1929, Kieselalg., Teil I, p. 544, fig. 310; Jousé, 1962, pl. 2, fig. 15. Syn., *Coscinodiscus bathyomphalus* Cl., 1883: Hustedt, 1928, Kieselalg., Teil I, p. 431, fig. 234., (resting spore).
- Biddulphia auritia* (Lyngb.) Bréb. and Godey, 1838: Hustedt, 1930, Kieselalg., Teil I, p. 846, fig. 501; Cupp, 1943, p. 161, fig. 112A.
- Chaetoceros furcellatus* Bail, 1865: Hustedt, 1930, Kieselalg., Teil I, p. 749, fig. 433; Jousé, 1962, pl. 2, fig. 10.
- Coscinodiscus africanus* Jan. 1878: Hustedt, 1928, Kieselalg., Teil I, p. 428, fig. 231; Lohman, 1941, p. 69, pl. 13, figs. 4, 7, 10.
- Coscinodiscus* cfr. *anguste-lineatus* A. Schmidt, 1868: Atlas, pl. 59, fig. 34; Koble, 1954, p. 27; Kolbe, 1955, p. 168; Kolbe, 1957, p. 29.
- Coscinodiscus centrales* (Ehr.) var. *pacifica* Gran and Angust, 1931: p. 446, fig. 23.
- Coscinodiscus crenulatus* Grun., 1884: Hustedt, 1928, Kieselalg., Teil I, p. 411, fig. 219; Hasle, 1960, pl. 2, figs. 14–18.
- Coscinodiscus elegans* Grev., 1866: p. 3, fig. 6; Schmidt, 1886, Atlas, pl. 58, fig. 7; Schmidt, 1891, pl. 163, fig. 10; Kanaya, 1959, p. 75, pl. 3, figs. 6, 7.
- Coscinodiscus excentricus* Ehr., 1839: Hustedt, 1928, Kieselalg., Teil I, p. 388, fig. 201. Syn., *Thalassiosira excentrica* Cl. (in part); Jousé, 1957, p. 205–206, pl. 4, figs. 2–4.
- Coscinodiscus excentricus* Ehr. var. *jousei* Kanaya (MS). Distinguished from the species mainly by a well developed valve mantle which is seen as a darker ring surrounding the outer border of valve, particularly under lower magnifications (e.g., 40×10); areolae remain in same size, 8–10 in 10 $\mu$ , throughout most part of a valve. *Thalassiosira excentrica* Cl. in Russian papers (e.g., Jousé, 1957, 1962) includes this form (Jousé by personal communication).
- Coscinodiscus excentricus* Ehr. var. *leasareolatus* Kanaya (MS). Distinguished from the species mainly in having the meshwork of areolae conspicuously loose in the central border of a valve. *Thalassiosira excentrica* Cl. in Russian papers (e.g. Jousé, 1957; *ibid.*, 1962) includes this form (Jousé, by personal communication). See *Thalassiosira excentrica* Cl. in Jousé, 1961d, pl. 3, fig. 8.
- Coscinodiscus excentricus* Ehr. var. *fasciculata* Hustedt, 1928: Kieselalg., Teil I, p. 390, fig. 202.

- Coscinodiscus lentiginosus* Jan., in Schmidt 1878: Atlas, pl. 58, fig. 11; Hustedt, 1958b, p. 116, figs. 22–25; Jousé *et al.*, 1962, Table 1, figs. 13–18.
- Coscinodiscus lineatus* Ehr., 1938: Hustedt, 1928, Kieselalg., Teil I, p. 292, fig. 204.
- Coscinodiscus marginatus* Ehr., 1843: Hustedt, 1928, Kieselalg., Teil I, p. 416, fig. 223; Cupp, 1943, p. 55, fig. 19; Jousé, 1962, pl. 3, figs. 2, 3.
- Coscinodiscus nodulifer* A. Schmidt, 1878: Hustedt, 1928, Kieselalg., Teil I, p. 426, fig. 229; Koble, 1954, p. 33, pl. III, figs. 35–37.
- Coscinodiscus oculus-iridis* Ehr. var. *borealis* (Bail.) Cleve, 1883: Hustedt, 1928, Kieselalg., Teil I, p. 456, fig. 253.
- Coscinodiscus perforatus* Ehr. var. *cellulosa* Grun., 1884: Hustedt, 1928, Kieselalgen, Teil I, p. 447, fig. 246.
- Coscinodiscus radiatus* Ehr., 1839: Hustedt, 1928, Kieselalg., Teil I, p. 420, fig. 225; Cupp, 1943, p. 56, fig. 20.
- Coscinodiscus radiatus* Ehr. var. The name has been applied to specimens with a few interstitial meshes on a valve which otherwise is identifiable with *Coscinodiscus radiatus* Ehr.
- Coscinodiscus stellaris* Roper, 1858: Hustedt, 1928, Kieselalg., Teil I, p. 396, fig. 207; Jousé, 1962, pl. 63, fig. 12.
- Coscinodiscus tabularis* Grun var. *egregius* (Ratt.) Hustedt: 1928, Kieselalg., Teil I, p. 428, fig. 230b.
- Coscinodiscus wailesii* Gran and August, 1931: p. 448, fig. 26; Cupp, 1943, p. 58, fig. 23.
- Coscinodiscus yabei* Kanaya, 1959: p. 86, pl. 5, figs. 6–9.
- Coscinosira antarctica* Kozlova, 1962: p. 9, pl. 8, fig. 1; Jousé *et al.*, 1962, p. 66, Tab. IV, figs. 12, 13.
- Cosmiodiscus intersectus* (Brun) Jousé, 1961: 1961e, p. 68; Jousé, 1962, pl. 78, fig. 6.
- Cyclotella striata* (Kütz.) Grun., 1880: Hustedt, 1928, Kieselalg., Teil I, p. 344, fig. 176.
- Denticula hustedtii* Simonsen and Kanaya, 1961: p. 501, pl. 1, figs. 19–23.
- Denticula kamtschatica* Zabelina, 1934: p. 16, figs. 7–9; Jousé, 1959, pl. 4, fig. 19; Simonsen and Kanaya, 1961, p. 503, pl. 1, figs. 14–18.
- Denticula nicobarica* Grun., 1868: van Heurck, 1880, pl. 49, fig. 3; Simonsen and Kanaya, 1961, p. 503, pl. 1, figs. 11–13.
- Denticula seminae* Simonsen and Kanaya, 1961: p. 503, pl. 1, figs. 26–30. Syn., *Denticula marina* Semina, 1956: p. 82.
- Ethmodiscus rex* (Ratt.) Hendy, 1953: in Wiseman and Hendy, 1953, p. 51, pls. 1, 2; Koble, 1957, p. 34, pl. IV, figs. 46, 47.
- Eucampia balaustium* Castr., 1886: p. 97, pl. 18, fig. 5; Hustedt, 1958b, p. 136, figs. 40–43.
- Fragilariopsis cylindrus* (Grun). Helmek and Krieger, 1954: Teil II, p. 17, figs. 187–189; Hustedt, 1958a, p. 203; Hustedt, 1958b, p. 162, figs. 145, 146. Syn., *Fragilaria cylindrus* Grunow, 1884: Hustedt, 1931, Kieselalg., Teil II, p. 152, fig. 665.
- Fragilariopsis kerguelensis* (O'Meara) Hustedt, 1952: p. 294; Hustedt, 1958b, p. 162, figs. 121–127, fig. 158. Syn., *Fragilariopsis antarctica* (Cast.) Hustedt, 1913: in Schmidt's Atlas., pl. 299, figs. 9–14; Jousé *et al.*, 1962, p. 85, Tab. III, figs. 4–7.
- Fragilariopsis ritscherii* Hustedt, 1958: 1958b, p. 164, figs. 133–136, 153.
- Hemidiscus cuneiformis* Wall., 1860: Hustedt, 1930, Kieselalg., Teil I, p. 904, fig. 542.
- Hemidiscus karsteni* Jousé, 1962: in Jousé *et al.*, 1962, p. 78, Tab. II, figs. 7–9. The form identified by Kanaya as *Hemidiscus rotundus* Jan. ex. Hustedt in Bramlette, 1961, should now be called by this name.
- Melosira sulcata* (Ehr.) Kützing, 1844: Hustedt, 1928, Kieselalg., Teil I, p. 276, fig. 119.
- Micropodiscus oliveranus* (O'Meara) Gurn. in Van Heurck, 1880: pl. 118, fig. 5; Hustedt, 1958b, p. 120. *Schimperiella antarctica* Karsten as revised by Jousé *et al.* (1962, p. 80, Tab. V. 4–6) takes this species as one of its synonyms.
- Nitzschia marina* Grun. in Van Heurck, 1880: pl. 57, figs. 26, 27; Kolbe, 1954, p. 40, pl. 3, figs. 38–40.
- Nitzschia sicula* (Castracane) Hustedt, 1958: 1958b, p. 180. Syn., *Pseudonitzschia sicula* (Cast.): Peragallo, 1897–1908, pl. 72, fig. 27.
- Planktoniella sol* (Wall.) Schütt, 1893: Hustedt, 1928, Kieselalg., Teil I, p. 465, fig. 295; Hasle, 1960, p. 11, pl. III, figs. 19, 20.
- Porosira glacialis* (Grun.) Jørg., 1905: Hustedt, 1928, Kieselalg., Teil I, p. 315, fig. 153; Jousé, 1957, pl. 3, figs. 4a, 4b; Jousé, 1962, pl. 2, fig. 1, pl. 79, fig. 11.
- Pseudoeunotia doliolus* (Wall.) Grun., 1880: Hustedt, 1932, Kieselalg., Teil II, p. 258, fig. 737; Kolbe,

- 1954, p. 43, pl. III, fig. 41.
- Rhizosolenia bergonii* Perag., 1892: Hustedt, 1929, Kieselalg., Teil I, p. 575, fig. 327.
- Rhizosolenia curvirostris* Jousé, 1961: 1961d, pl. 3, fig. 7. (illustration only)
- Rhizosolenia hebetata* (Bail.) Gran. f. *hiemalis* Gran, 1904: Hustedt, 1929, Kieselalg., Teil I, p. 590, fig. 337; Jousé, 1957, pl. 4, fig. 3.
- Roperia tessellata* (Roper) Grun., 1881: Hustedt, 1928, Kieselalg., Teil I, p. 523, fig. 297.
- Roperia tessellata* (Roper) Grun. var. *coscinodiscoidea* (Mann) Kolbe, 1955: p. 176, pl. 1, fig. 1.
- Roperia tessellata* (Roper) Grun. var. *ovata* Mann, 1925: p. 143, pl. 31, fig. 3.
- Rouxia peragalli* Brun et Heribaud, 1893: Hanna, 1930, p. 180, pl. 14, fig. 1, 5; Kanaya, 1959, p. 111, pl. 9, figs. 16–18.
- Thalassionema nitzschioides* Grun., 1881: Hustedt, 1932, Kieselalg., Teil II, p. 244, fig. 723; Cupp, 1943, p. 182, fig. 133.
- Thalassionema nitzschioides* Grun. vars. Following three varieties are represented. *Thalassionema nitzschioides* var. *inflata* Heiden and Kolbe, 1928; p. 564, pl. 35, fig. 116. *Thalassionema nitzschioides* var. *parva* Heiden and Kolbe, 1928: *ibid.*, fig. 118. *Thalassionema nitzschioides* var. *incurvata* Heiden and Kolbe, 1928: *ibid.*, fig. 117.
- Thalassiosira decipiens* (Grun.) Jørg., 1905: Hustedt, 1928, Kieselalg., Teil I, p. 322, fig. 158; Cupp, 1943, p. 48, fig. 10.
- Thalassiosira gracilis* (Karst.) Hustedt, 1958: 1958b, p. 109, figs. 4–7; Jousé *et al.*, 1962, p. 68, Tab. IV, figs. 4–10.
- Thalassiosira gravida* Cleve, 1896: Hustedt, 1928, Kieselalg., Teil I, p. 325, fig. 161; Jousé, 1957, pl. 3, fig. 8; Jousé, 1962, pl. 2, figs. 7, 8.
- Thalassiosira hyalina* (Grun.) Grun., 1897: Hustedt, 1928, Kieselalg., Teil I, p. 323, fig. 159; Jousé 1962, pl. 2, fig. 4.
- Thalassiosira kryophila* (Grun.) Jørg., 1905: Hustedt, 1928, Kieselalg., Teil I, p. 324, fig. 160.
- Thalassiosira nordenskiöldi* Cleve, 1875: Hustedt, 1928, Kieselalg., Teil I, p. 321, fig. 157; Jousé, 1962, pl. 2, fig. 6.
- Thalassiosira oestrupi* (Ostf.) Proskina-Lavrenko, 1956; Hasle, 1960, p. 8, pl. 1, figs. 5–7, 11. Syn., *Coscinosira oestrupi* Ostf., 1900: Hustedt, 1928, Kieselalg., Teil I, p. 318, fig. 155.
- Thalassiothrix* spp. at least following two species are represented. *Thalassiothrix longissima* Cleve and Grunow, 1880: Hustedt, 1932, Kieselalg., Teil II, p. 247, fig. 726. *Thalassiothrix frauenfeldii* Grun., 1880: Hustedt, 1932, Kieselalg., Teil II, p. 247, fig. 727.
- Triceratium cinnamomeum* Grev., 1863: p. 232, pl. 9, fig. 12; Schmidt, 1880, Atlas, pl. 151, figs. 23, 24, 26, 27; Kolbe, 1954, p. 47, figs. 18, 20.

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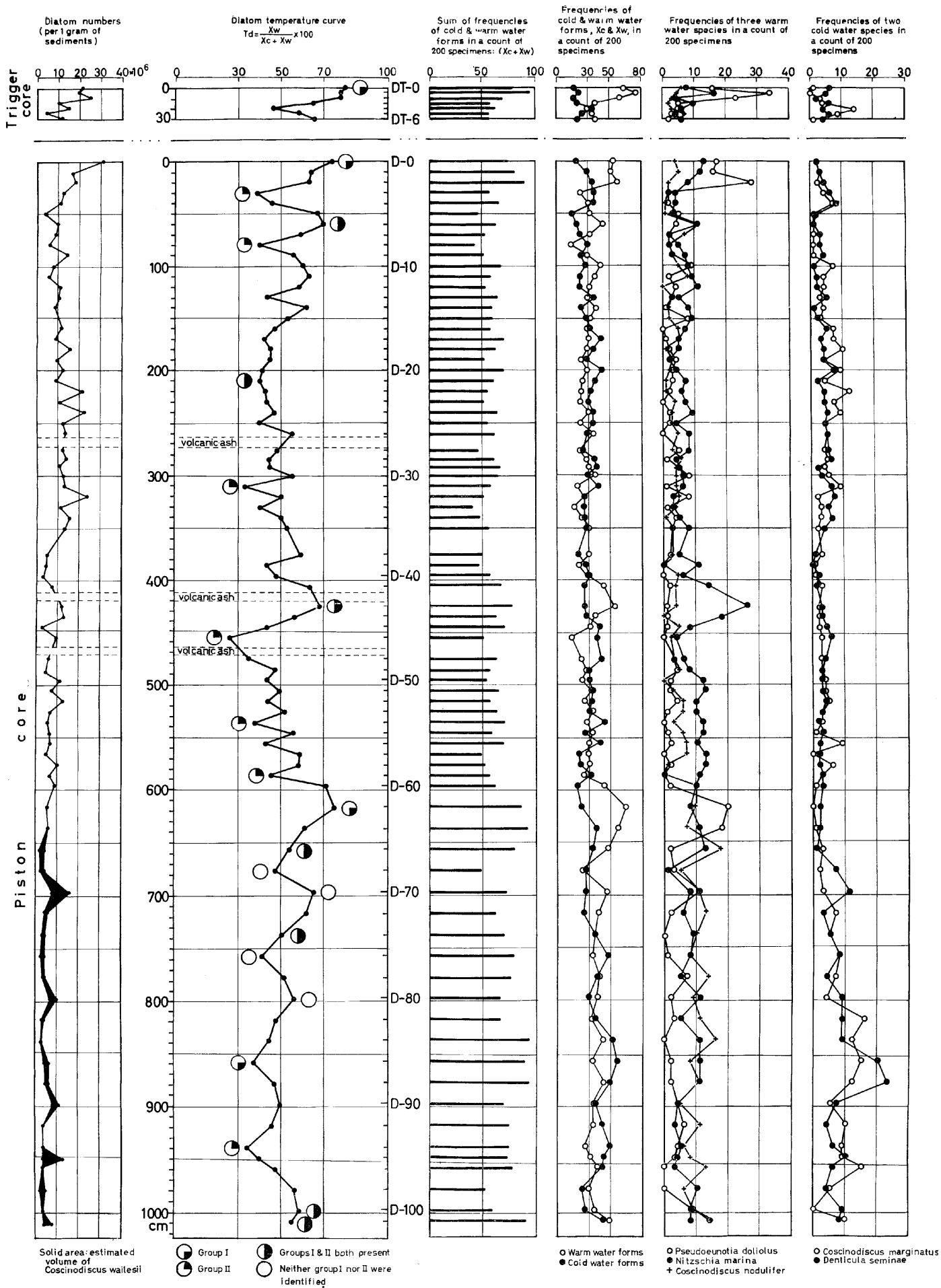


Chart 1. Core V20-130 (36°59'N, 152°36'E; depth, 6547 m; length, 1039 cm): diatom temperature curve and the graphs showing the fluctuations of some other attributes through the core sequence.

SAMPLES	SPECIES
...	<i>Actinocyclus curvatus</i>
...	A. <i>divisus</i>
...	A. <i>ehrenbergi</i> vars.
...	<i>Actinopterychus undulatus</i>
...	<i>Coscinodiscus centrales</i> var. <i>pacifica</i>
...	C. <i>excentricus</i>
...	C. <i>excentricus</i> var. <i>jousei</i>
...	C. <i>lineatus</i>
...	C. <i>marginatus</i>
...	C. <i>nodulifer</i>
...	C. <i>oculus iridis</i> var. <i>borealis</i>
...	C. <i>radiatus</i> var.
...	C. <i>stellaris</i>
...	C. <i>tabularis</i> var. <i>egregius</i>
...	<i>Cyclotella striata</i>
...	<i>Denticula seminae</i>
...	<i>Hemidiscus cuneiformis</i>
...	<i>Melosira sulcata</i>
...	<i>Nitzschia marina</i>
...	N. <i>sicula</i>
...	<i>Planktoniella sol</i>
...	<i>Pseudoeunotia doliolus</i>
...	<i>Roperia tessellata</i>
...	<i>Thalassionema nitzschioides</i>
...	T. <i>nitzschioides</i> vars.
...	<i>Thalassiosira decipiens</i>
...	T. <i>gravida</i>
...	T. <i>oestrupi</i>
...	<i>Thalassiothrix</i> spp.

Table 4. More frequent diatoms in Core V20-130 and their frequencies in a count of 200 specimens made at core levels studied.