SUSPENDED PARTICULATE MATTER IN THE WESTERN NORTH PACIFIC OCEAN

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Abstract

Suspended particulate material sampled from depths down to 4000 m in various areas of the western North Pacific and adjacent seas were studied. Data were collected from 95 stations including 48 large-volume water sampling stations during 13 cruises of the T.S. Oshoro-Maru, Hokkaido University, and of the R.V. Hakuho-Maru, Tokyo University, in 1965–1970. An additional series of 4 surface skimming trips were made in a small coastal embayment, Oshoro Bay, Hokkaido, in May-June, 1970.

Particulate matter in terms of dried weight, carbon and nitrogen showed a fairly consistent pattern in vertical distribution through the entire areas observed. Regression analyses confirmed that the average concentration in the surface layer (0–50 m) in an area was linearly correlated with the average concentrations in deeper layers of the same area. This finding suggests that there is a marked regionality in the particle content of the entire water column, and that the regional variation is ultimately controlled by the regional variation in primary production in the surface photic zone.

The surface skin samples obtained in Oshoro Bay contained particulate carbon of the orders of 367–5174 μgC/l, which were several times higher than in the bulk water. These high concentrations combined with exceedingly high carbon/chlorophyll *a* ratios obtained for surface bucket samples from the oceanic areas suggest that there should be occurring an intensive particle formation that is categorically different from the photosynthetic activity.

Contents

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Introduction

The term SESTON means filterable substance, and the lower limit in particle size depends upon the average pore size of the filter used. However, the amount of filter-passing small particles is usually neglibibly small compared to the amount filtered when a filter with an average pore size of one μ or so is used. The particulate matter, thus defined, comprises various components of living and dead materials; living components consist of phytoplankton organisms, zooplankton organisms, bacteria, fungi yeast etc. Dead components consist of detrital material from organisms and inorganic particles. Recent evidence[1)2)3)] shows that a significant fraction of non-living material is suspended in water in a form of aggregate, large and small, attached by bacteria and protozoa.

Parsons[4)] carried out the approximate calculation of relative abundance of these components as follows; soluble organic 100, particulate detritus 10 phytoplankton 2, zooplankton 0.2 and fish 0.002, using the data of standing crops of detritus, 105 mgC/m^3 and phytoplankton, 20 mgC/m^3 [5)], zooplankton, 2 mgC/m^3 [6)], and average amount of 1000 mgC/m^3 of soluble organic carbon[7)].

It is commonly known that the quantitatively important living organisms in the ocean are diatoms except in some areas where dinoflagellates are dominant. Living components of particulate materials, however, can not be determined directly but can indirectly be estimated using various conversion factors obtained experimentally from the correlation between the carbon content or dried weight of the organisms and their specific substances. Chlorophyll is one of the substances most commonly used to estimate the living biomass of phytoplankton. Recently the measurements of ATP and DNA began to be introduced in this problem as the promising materials indicative of the living mass[8)]. Although the conversion factor obtained for each of these specific substances is rather variable with respect to the physiology of the organisms, these approaches have provided a fairly consistent picture of the relative proportions of living and non-living material comprising a total seston in the euphotic layer. Krey[9)] calculated living biomass (dried weight) of phytoplankton by its conversion from chlorophyll measurements obtained in the North Sea and he reported that living fractions in terms of dried weight of seston were in most cases below 10%. Similar results were obtained in the North Sea and its surrounding areas by various authors.[10)11)12)13)14)15)] Hagmeier[16)] showed that the fractions were 20% in off shore areas and 10% in coastal areas of the Indian Ocean near Australia. On the other hand, carbon to chlorophyll *a* ratios in the range of 35–75 have been widely used for determining phytoplankton biomass.[17)18)19)20)21)22)] These ratios were obtained from actively growing cultured diatoms. These workers consistently showed that carbon to chlorophyll ratios observed for total particulate material in natural seawater have been found to be two to ten times higher than these values. Thus, the living

fraction in terms of organic carbon is also small compared with the dead fraction in natural seawater.

The fact that the major fraction of particulate material is not living even in the euphotic layer has been recently well confirmed by Zeitzschel[23] using an electronic counting method. That situation seemed to be somewhat puzzling if all of the non-living material were assumed to be simply detritus, that is, the decomposition products of living organisms. Riley[1] proposed a hypothesis that a certain fraction of the non-living material might be produced by some physical accretion of dissolved organic matter as demonstrated by Baylor *et al.*[24] and later by Sutcliffe *et al.*[25] The authors experimentally showed that film-like particles were produced by bubbling through a Millipore filtered seawater. Sutcliffe *et al.*[25] also discussed a possible occurrence of a similar phenomenon at the air/sea interface and a probable water movement that carried the particles thus produced down into the bulk water at the sites of sea slicks. The process of organic accretion has been frequently re-evaluated.[1][26][27][28][29] However, the experimental fact that the organic accretion actually occurs remains valid, and the yield of particles increases up to an equilibrium level determined by the concentration of dissolved organic matter.[30]

Particulate materials produced biologically or physically in the euphotic layer will be transported to deeper layers either by gravity,[31] or by migrating zooplankton,[32] and they might be consumed by heterotrophic organisms such as bacteria, ultraplankton and zooplankton, or chemically decomposed. Therefore, the concentration of particle was to be diminished progressively with depth. However, any patterns of the vertical distribution of particulate matter so far observed have shown no such a consistent tendency; the concentration decreases rapidly in a short depth interval just below the euphotic layer, but below about 200–400 m depth the variation is apparently of random nature and no consistent decrease with depth occurs. However, the obtained patterns in deep water varied among sea areas or possibly among workers, and can be grouped into three categories. Firstly, Menzel and coworkers concluded that the particulate organic carbon in the deep water in various areas of the Atlantic and in the Peru Current Area of the Pacific was homogeneously distributed in terms of time, space and depth.[33][34][35][36] Secondly, Riley *et al.*[37] and Gordon[38] observed the same area as Menzel's but pointed out the characteristic seasonal and regional variation of the average level of particle concentration in deep water in the North Atlantic Ocean. Thirdly, a remarkable layering in the vertical distribution was found by Dal Pont and Newell,[39] and Newell and Kerr[40] in the Indian Ocean, and by Hobson[41] and Holm-Hansen *et al.*[42] in the Eastern North Pacific Ocean.

The present investigation, described in Parts I and II, is concerned with the situation in the Western North Pacific. The areas observed were the Philippine

Sea, the East China Sea, the Japan Sea, the Okhotsk Sea, the Oyashio area off Hokkaido and the Bering Sea. These areas are widely scattered in the entire western North Pacific, and differ much in water mass characteristics, productivity and climatic conditions. Thus a close examination of particle distriution in these areas is particularly warranted in view of the controversial observations so far obtained in limited areas of the Atlantic and the Easter Pacific close to the land.

An additional work of sea surface skimming in a small embayment of Hokkaido was included in Part III. This part is a tentative venture to seek for a source of particulate organic matter at the air/sea interface where rich and diverse flora and fauna (neuston) were found to inhabit[43)44)] and adsorptive accumulation of organics actively occurs[48)].

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Materials and Methods

Materials used in this study were collected from several areas in the western North Pacific and adjacent seas in 1965–1970 (Fig. 1a). A total of 95 routine hydrographic stations including 48 stations at which large volume water samplings for particulate matter were also carried out were available. Sixty (Sts. 1–60) out of the 95 stations were obtained along a line at 142°E in successive four winters (January, 1966–1968 and December 1968– January 1969) during the CSK cruises of the Oshoro-Maru, Hokkaido University (Fig. 1b). In this series of stations

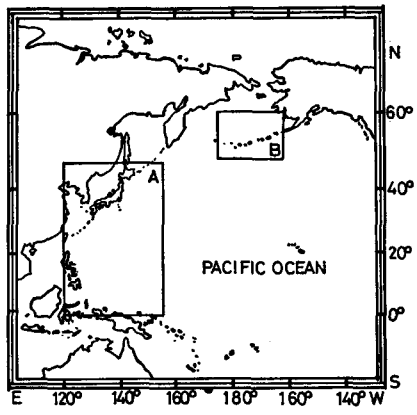

Fig. 1a. Areas of water sampling. For locations of stations, refer to Fig. 1b (Area A), Fig. 1c (Area B) and Table 1.

which distributed north of the equator up to 30°N with one exception located at 2°S, large volume water samplings were made at 18 stations in these four years (Table 1). A cruise of the Hakuho-Maru, Tokyo University in May-June, 1968 added 7 oceanic subtropical stations (Sts. 64–66 on the line of 125°E and Sts. 67–70 on the line of 132°E) and 3 stations (Sts. 61–63) located on the line of 125°E in the East China Sea (Fig. 1b, Table 1). A fixed area in the Oyashio Water off Erimo, Hokkaido (42°00′N, 146°00′E) was repeatedly visited once in each of three successive springs, 1965–1967, and again in fall 1969 by the Oshoro-Maru. A separate station number was assigned to each of the four occupations (Sts. 71, 72, 73, and 74) although the location of each station was practically the same (Fig. 1b, Table 1). Another systematic series of sampling stations was obtained in the Japan Sea in July-August, 1970 during a cruise of the Hakuho-Maru, and the distribution of the stations covered the main part of the Sea although only 6 stations were available (Sts. 76–81) (Fig. 1b. Table 1). Two more near-shore sampling stations close to Hokkaido were obtained in September, 1968, one in the Japan Sea (St. 75) and the other in the Okhotsk Sea (St. 82) during a cruise of the Oshoro-Maru (Fig. 1b, Table 1).

A separate group of 13 sampling stations was obtained in a single cruise of the Oshoro-Maru in the eastern part of the Bering Basin (Sts. 87–95) and in the Pacific close to the Aleutian Chain (St. 84) in June-August, 1967 (Fig. 1c, Table 1). The northern most station in the Bering was visited twice on June 15 and on August 17, and separate station numbers were assigned to each of these occupations (Sts. 92 and 94).

In each of these cruises, the routine hydrographic observations (temperature, salinity, dissolved oxygen and others) were carried out by cooperation of the scientists and crew aboard the vessel and the results were already published either

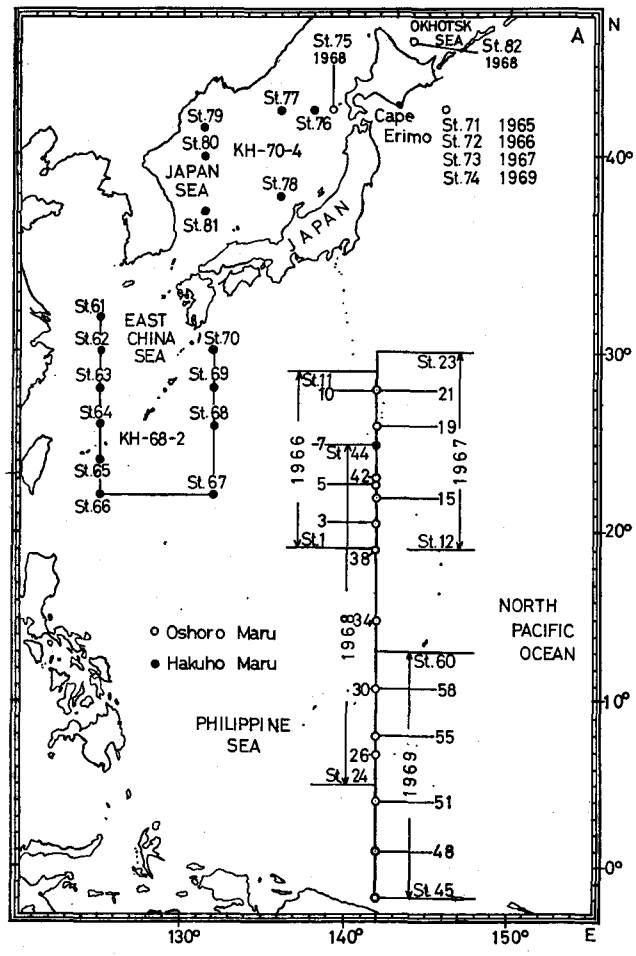

Fig. 1b. Locations of stations in Area A.

in a series of "Data Record of Oceanographic and Exploratory Fishing"[46)47)48)49)50)] or "Preliminary Report of The Hakuho-Maru Cruise KH-68-2"[51)]. So, no detailed description of the methods for these items are give here.

At each of the 48 large-volume water sampling stations, 2–5 Van Dorn Sampler casts were performed using a series of twin samplers. The samplers used were made of white polyethylene with rubber "plumber's friend" caps. The numbers of layers sampled and the maximum depth of sampling at each station are indicated in Table 1.

The water samples were divided into several subsamples, immediately filtered, and the filter pads were stored in a freezer for later analyses as follows.

Seston Dried Weight. A HA Millipore Filter (0.45 μ pore size and 47 mm diam.)

Table 1. List of oceanographic stations.

Area A

St. No in this paper	Time of occupation	St. No. original	Position	Routine hydrographic cast	Van Dorn sampling	Number of layer sampled	Max. sampling depth (m)
Oshoro Maru Cruise 16 (1966)							
1	Jan. 15	Os. 23	19°00′N-142°00′E	×	×	8	506
2	16	24	20°08′N-141°57′E	×			
3	17	25	20°47′N-141°45′E	×	×	10	3229
4	18	26	22°10′N-142°14′E	×			
5	19	27	22′51′N-142°04′E	×	×	9	2003
6	20	28	23°48′N-141°59′E	×			
7	21	29	25°01′N-141°47′E	×	×	9	1896
8	22	30	25°57′N-142°04′E	×			
9	22	31	27°00′N-141°50′E	×			
10	23	32	28°01′N-141°35′E	×	×	6	201
11	24	33	29°00′N-141°32′E	×			
Oshoro Maru Cruise 21 (1967)							
12	Jan. 25	21	19°07′N-141°51′E	×			
13	24	22	20°05′N-141°57′E	×			
14	26	23	21°00′N-142°00′E	×			
15	23	24	22°00′N-141°50′E	×	×	21	2445
16	22	25	23°14′N-142°00′E	×			
17	21	26	23°56′N-141°57′E	×			
18	20	27	25°08′N-141°56′E	×			
19	19	28	26°00′N-141°30′E	×	×	21	2598
20	28	29	27°01′N-141°30′E	×			
21	28	30	28°00′N-141°30′E	×	×	21	2900
22	29	31	29°01′N-142°04′E	×			
23	29	32	30°00′N-141°57′E	×			
Oshoro Maru Cruise 26 (1968)							
24	Jan. 14	8	05°23′N-142°17′E	×			
25	15	9	06°00′N-142°01′E	×			
26	15	10	07°00′N-141°59′E	×	×	26	1500
27	16	11	08°01′N-142°00′E	×			
28	17	12	09°18′N-141°35′E	×			
29	18	13	10°00′N-142°00′E	×			
30	18	14	11°00′N-142°00′E	×	×	16	678
31	19	15	12°00′N-142°00′E	×			
32	19	16	13°00′N-142°00′E	×			
33	20	17	14°00′N-142°01′E	×			
34	21	18	15°05′N-142°00′E	×	×	23	2580
35	22	19	16°00′N-141°59′E	×			
36	23	20	17°02′N-142°04′E	×			
37	24	21	18°02′N-141°58′E	×			
38	24	22	18°59′N-141°59′E	×	×	23	3000
39	25	23	20°02′N-142°00′E	×			
40	26	24	21°13′N-142°06′E	×			
41	27	25	22°00′N-142°00′E	×			
42	27	26	23°00′N-142°00′E	×	×	20	1490
43	28	27	24°00′N-142°00′E	×			
44	28	28	24°59′N-141°59′E	×			

Table 1. (Continued)

St. No. in this paper	Time of occupation	St. No original	Position	Routine hydrographic cast	Von Dorn sampling	Number of layer sampled	Max. sampling depth (m)
Oshoro Maru Cruise 30 (1969)							
45	Dec. 30	Os. 38	02°00′ S-142°00′E	×	×	21	2470
46	31	39	01°00′ S-142°00′E	×			
47	Jan. 1	40	00°01′ S-141°59′E	×			
48	2	41	01°00′N-142°00′E	×	×	14	533
49	2	42	01°41′N-142°18′E	×			
50	3	43	02°42′N-141°48′E	×			
51	4	44	04°00′N-141°48′E	×	×	20	1800
52	4	45	05°00′N-142°00′E	×			
53	5	46	06°03′N-141°52′E	×			
54	5	47	07°04′N-141°54′E	×			
55	6	48	08°01′N-141°58′E	×	×	18	1200
56	6	49	09°00′N-141°54′N	×			
57	7	50	10°10′N-141°55′E	×			
58	7	51	10°59′N-141°59′E	×	×	21	1980
59	8	52	12°00′N-142°03′E	×			
60	8	53	13°00′N-142°00′E	×			
Hakuho Maru Cruise KH-68-2 (1968)							
61	May 20	St. 1	31°48′N-125°01′E	×	×	4	40
62	23	2	29°60′N-124°60′E	×	×	5	50
63	24	3	28°00′N-125°01′E	×	×	5	100
64	25	4	26°01′N-125°01′E	×	×	12	1072
65	26	5	23°59′N-124°59′E	×	×	12	880
66	27	6	22°00′N-125°01′E	×	×	11	633
67	29	7	21°60′N-132°01′E	×	×	16	4040
68	31	9	26°00′N-131°60′E	×	×	9	416
69	June 1	10	28°00′N-132°00′E	×	×	14	2164
70	2	11	30°01′N-132°01′E	×	×	17	3315
Oshoro Maru Cruise 13 (1965)							
71	May 7	Os. 1	42°00′N-146°00′E	×	×	7	2000
Oshoro Maru Cruise 18 (1966)							
72	April 23	1	42°00′N-146°00′E	×	×	13	1821
Oshoro Maru Cruise 23 (1967)							
73	April 23	Os. 1	42°00′N-146°00′E	×	×	28	1490
Oshoro Maru Cruise 34 (1969)							
74	Sept. 9	1	42°00′N-146°00′E	×	×	19	2744
Oshoro Maru Cruise 29 (1968)							
75	Sept. 8	2	42°10′N-139°10′E	×	×	17	3000

Table. 1. (Continued)

St. No. in this paper	Time of occupation	St. No original	Position	Routine hydrographic cast	Van Dorn sampling	Number of layer sampled	Max. sampling depth (m)
Hakuho Maru Cruise KH-70-4 (1970)							
76	July 31	St. 1	42°29′N-138°29′E	×	×	23	3459
77	Aug. 2	2	42°28′N-135°57′E	×	×	23	3426
78	7	5	38°13′N-135°44′E	×	×	21	2434
79	17	7	41°10′N-131°28′E	×	×	23	3116
80	18	8	40°06′N-131°31′E	×	×	23	3071
81	22	9	37°18′N-131°30′E	×	×	20	1916
Oshoro Maru Cruise 29 (1968)							
82	Sept. 5	Os. 1	45°20′N-144°00′E	×	×	12	830
Area B							
Oshoro Maru Cruise 24 (1967)							
83	June 9	1	48°00′N-177°59′W	×			
84	10	2	49°00′N-178°00′W	×	×	19	1448
85	11	3	50°01′N-178°00′W	×			
86	11	4	51°00′N-178°00′W	×			
87	12	5	52°20′N-178°00′W	×	×	14	1149
88	12	6	53°49′N-177°47′W	×	×	16	1467
89	13	7	55°00′N-178°00′W	×			
90	14	8	56°00′N-178°00′W	×	×	19	1407
91	14	9	57°00′N-178°00′W	×			
92	15	10	58°03′N-178°04′W	×	×	18	947
93	July 1	46	54°34′N-165°58′W	×	×	10	396
94	Aug. 17	96	58°00′N-178°00′W	×	×	16	743
95	20	97	53°00′N-175°20′E	×	×	19	1374

was used for the determination of seston dried weight. The filter was, in advanece, boiled twice in redistilled water of 200 m*l* per sheet for 2 hours and washed with fresh distilled water of about 100 m*l* per sheet. The filter was put in a vacuum desiccator containing silica gel and dried in a 70°C oven for three to ten hours. After drying, it was exposed to the humidity controlled room air and acclimatized for 2 hours and then weighed as quickly as possible. This process of acclimatization was indispensable because an experiment showed that freshly dried filters rapidly get damp once exposed to laboratory air and increase in weight within half an hour up to about 1 mg per sheet with an average weight of about 100 mg: the increase in weight tended to slow down with time of acclimatization and after 2 hours of acclimatization, each filter attained a practically constant weight within a range of ±0.01 mg (S.D.)

Three to ten liters of seawater were filtered on board through the filter under approximately one-third the atomspheric pressure. As soon as the filtration was finished, the filter pad, including its margin, was washed three times with each 10–

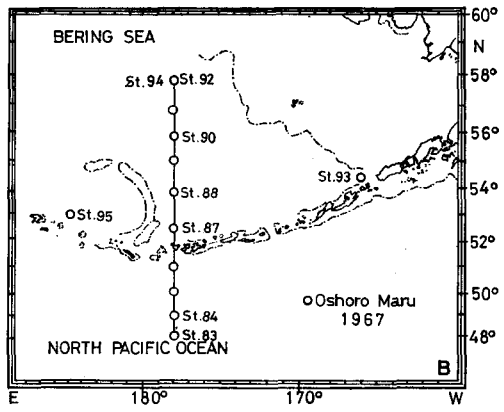

Fig. 1c. Locations of stations in Area B.

15 m*l* of isotonic ammonium formate solution (8%) to remove the salts trapped in the filter, and was stored in a freezer at -20°C.[52)53)54)] One blank filter for every 5–10 filters used was arbitrarily selected. No seawater sample was filtered through it and 30 m*l* of ammonium formate solution only was passed through. The filter pads were brought back to the shore laboratory, dried as before and weighed after acclimatization to the balance room air. Total seston dried weight was calculated from the difference between initial (Wi) and final (Wf) weights of the filter with the correction of the weight change of the blank filters before and after the sampling cruise.[55)]

$$\text{Dried weight of Seston (mg/}l\text{)} = 1/V\ (Wf - Wi + X) \qquad (1)$$

where V was the volume in liter of sample and X was the mean of the weight differences of the blanks in the batch. One batch usually consisted of 25–35 sheets of filters including the blanks.

The precision of determination of ($Wf - Wi$) can be attributed to the sensitivity of the analytical balance used, i.e., ±0.02 mg/sheet. In addition to this, the standard deviation of X was obtained for each batch; the range was 0.01–0.10 mg/sheet. This is a range which is significantly higher than obtained in the above acclimatization experiment and would probably indicate a general level of a contamination occurring during the processes of shipboard filtration, storage and transportation. The error in water volume measurements was at most 2% (100 m*l*/5 *l*) and was negligibly small compared with other sources of error. Therefore, the precision of the present measurements of seston dried weight was estimated to be ±0.20 mg/sheet or ±0.04 mg/*l*. The precision obtained is not adequately high for determining the amount of the order of 0.1–1.0 mg/*l*. The precision can be increased if an increased volume of sample water ws available, but this is a time consuming way for both sampling and filtration.

There is a possibility that a small amount of salts may persist in the filter pad even after the washing with an ammonium formate solution and be included in the dried weight of seston obtained. A test of this source of error using a fitered seawater, however, showed that the amount of salts remained after the washing and was of a negligible order of 0.01 mg/sheet. The test, however, does not exclude the possibility that an amount of salt may persist in the precipitate filtered off, but no information is available for estimating the amount of salts trapped in particles. It is considered that the amount of salts trapped is proportional to that of the precipitate and that the amount is extremely small and negligible as compared with that of salts remained in the filter. Therefore, no correction of the salt error was assumed to be necessary for determining the concentration of seston dried weight.

Chlorophyll a and Pheopigments. Phytoplankton pigments were determined either by the light absorption method using the Hitachi Perkin Elmer UV VIS spectrophotometer or by the fluorometric method using a fluorometry attachment with a Hitachi 139 or Hitachi Fluorometer (FPL-2).

Only one series of samples obtained at five stations, i.e., Sts. 1, 3, 5, 7, and 10 in 1966 were analyzed by the light absorption method and all the others by the fluorometric method. Among the latter, samples obtained from the Hakuho-Maru were analysed by the use of a Hitachi Fluorometer.

Light absorption method. This method was widely used for the determinations of chlorophyll *a* and caroteniods. Five liters of seawater subsample were filtered on board through a Millipore filter (HA, 47 mm). Immediately after filtration, the filters were stored in a deep freezer at -20°C. The concentration of chlorophyll *a* was determined in the shore laboratory using the method of Richards with Thompson[56] as modified by Parsons and Strickland[57] (cf. Nakajima and Nishizawa[58]). The precision of chlorophyll *a* determination with this method was ±0.005 mg as described by Strickland and Parsons.[55]

Fluorometric Method. Recently, Yentsch and Menzel[59] have introduced the fluorometric method in determining chlorophyll *a* and its decomposition product, pheophytin, separately. At present, this method has been commonly used for the measurement of plant pigments because of its simplicity and superior sensitivity.[60][61]

Two to five liters of seawater subsample were filtered through a Whatman GF/C glass fibre filter which was coated with magnesium carbonate powder by passing 2 m*l* of 1% aqueous suspension. After filtration, the filter was stored in a deep freezer at -20°C. The filter pad was homogenized in a tissue grinder or in an ordinary mortar with a pestle, and the macerated material was extracted with a 90% acetone solution of a measured volume (5-10 m*l*). The solution was centrifuged for 15 min at a 6000 rpm. The intensity of fluorescence (*Fo*) of the

supernatant clear solution was relatively measured to the fluorescence from a standard solution. The standard solution was either a 1 ppm fluorescein sodium solution (when using the Hitachi Fluorometer) or a 50 ppm fluorescein solium solution (when using the Hitachi 139). One or two drops of dilute hydrochloric acid (0.1 N, HCl) were added to the solution. Ten min. after the acidification, the intensity of fluorescence (*Fa*) was measured again. *Fo* and *Fa* are reasonably assumed to give the sums of fluorescence from the two components as follows.

$$Fo=Chl.\, f_{chl}+Ph\, f_{ph}, \tag{2}$$

and

$$Fa=Chl.\, f_{ph}+Ph\, f_{ph}, \tag{3}$$

where *Fo*: relative fluorescence intensity before acidification, *Fa*: relative fluorescence intensity after aidification, *Chl*: concentration of chlorophyll in mg/m^3 in the acetone extract, *Ph*: concentration of pheophytin in mg/m^3 in the acetone extract, f_{chl}: fluorescence intensity emitted from a unit concentration of chlorophyll (1 mg/m^3) in the acetone extract, and f_{ph}: fluorescence intensity emitted from a unit concentration of pheophytin (1 mg/m^3) in the acetone extract. From (2) and (3), with the consideration of acetone volume v in m*l* and sample volume V in liter, the concentrations of these two substances in the sample are obtained;

$$\text{chlorophyll } a \text{ (mg/m}^3) = \frac{F_0-F_a}{f_{ph}(R-1)} \cdot \frac{v}{V} \cdot 10^{-3}, \tag{4}$$

and

$$\text{pheopigments (mg/m}^3) = \frac{R(F_a-F_0)}{f_{ph}(R-1)} \cdot \frac{v}{V}\, 10^{-3}, \tag{5}$$

where $R=f_{chl}/f_{ph}$. When calculating these concentrations from (4) and (5), f_{chl} and *fph* were assumed to be constant and were determined in advance experimentally for each fluorometer using a fresh diatom culture. Both f_{chl} and f_{ph}, however, varied with the physiological condition of the culture used. The range of f_{chl} obtained using a healthy culture of Skeletonema costatum and a Hitachi 139 Fluorometer was 1.505 (R=4.83)–1.869 (R=5.38). A similar determination obtained using a healty culture of Phaeodactylum tricornutum yielded f_{chl}=1.895 with R=6.00 In these determinations, the culture used was assumed to contain no pheopigments and the chlorophyll *a* of the culture was determined by the cloroimetric method of Richards with Thompson.[56] Throughout the present study, f_{chl} was assumed to be 1.87 with R=5.5.[62]

Particulate Organic Carbon (*P.O.C.*) *and Nitrogen* (*P.O.N.*). Three to ten liters of each water sample were filtered immediately after sampling through a 47 mm whatman GF/C filter under approximately one-third of the atmospheric pressure. The pore size of this filter is not homogeneous, and is different from that of HA Millipore filter used for determining seston dried weight. Sheldon and Sutcliffe[63]

showed that the effective average pore size of Whatman GF/C filter would be 5–8 μ. The filters used were heated beforehand at 450°C for 30 min in an electric furnace. After filtration, the filter with particulate material was washed with a 3% sodium chloride solution, put in a small plastic container and stored in a deep freezer at –20°C. Before analyzing the samples thus obtained, the filter was once dried at about 50°C for 5 hours in an oven and the marginal area of the filter was cut off. The dried filter pad was then introduced into the combustion chamber of either a Yanagimoto MT–1 CHN Corder or a Hitachi 026 CHN Analyzer. Samples obtained in the Oshoro-Maru cruises 21, 23 and 24 and the Hakuho-Maru cruise KH–68–2 were analyzed using the Corder, and the remaining set of samples obtained in the Oshoro-Maru cruises 26, 30 and 34 and those of the Hakuho-Maru cruise KH–70–4 using the Analyzer (Table 1). Both of the Corder and the Analyzer involved a dry combustion of a sample and separate detection of CO_2 and N_2 gases evolved. The Corder is a modern version of the classical Pregl method, and the Analyzer is equipped with a gas chromatographic system at the final stage of detection. The temperature of the combussion furnace was about 750°C in either of the analyzers.

The factors converting obtained apparatus signals into amounts of carbon and nitrogen were obtained, on each measurement day, by analyzing a known amount of hippuric acid for the Corder and both caffeine and acetanilide for the Analyzer. The precision of these analyzers depends mostly upon the range of fluctuation of the conversion factors. For the analyzer, triplicate analyses of the standard reagents usually showed a considerable range of variation of the obtained factors, and the maximum range of the C-factor was ±3% and that of N-factor was ±1%. No attemp was made to estimate the range of fluctuation of the factors for the Corder and the ranges obtained for the Analyzer were assumed applicable to the Corder (cf. Fig. 2).

Obtained amounts of carbon and nitrogen were subjected to blank correction.

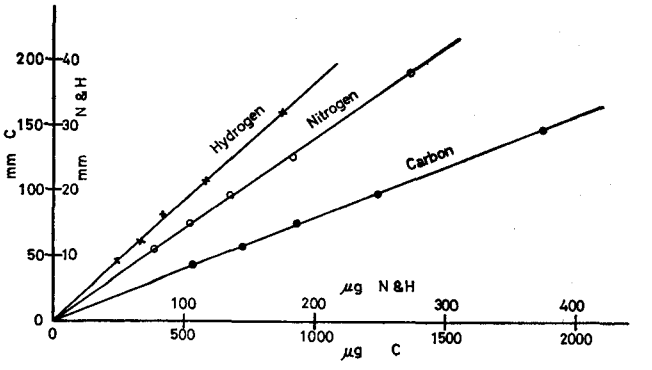

Fig. 2. Output of a Yanagimoto CHN Corder as a function of sample size.

The correction consisted of two sources of blanks, the filter blank and the adsorption blank.

I. *Filter blank.* Nine sheets of precombusted Whatman GF/C glass fibre filters which were arbitrarily selected from the packages that were once carried during a sampling cruise. They were analyzed with the filter blank. Appreciable amounts of carbon in the range of 6.5–11.1 μgC/sheet with a mean of 9.0±1.7 μgC/sheet (S.D.) were detected and no appreciable nitrogen was detected.

II. *Adsorption of D.O.M.* Menzel[28] has firstly demonstrated that D.O.C. was significantly adsorbed onto the filter during the filtration process of the seawater. The amount of the adsorbed carbon values from different extrapolating a series of carbon valued from different volumes of a water sample into a zero volume of water filtered was about 25 μgC/sheet of a 25 mm metal filter and 20–40 μgC/sheet of a glass fibre filter.

Ichikawa[64] published extensive data on particulate carbon and nitrogen samples from a long meridional section in the eastern Pacific Ocean. His data were obtained by subtracting the amounts of carbon and nitrogen collected from 1 l subsample from those from 6 l subsample for each water sample. The regression line of carbon onto the water volume filtered was never passed through the origin, and the intercept on the carbon axis was in a general range of 17–142 μgC with a grand mean of 65±25 μgC. The intercept on the nitrogen axis was −2.5–+37.6 μgN with a mean of 10.5±7.2 μgN. These values were apparently much higher than the filter blank mentioned above, and had fairly wide ranges of variation from sample to sample. The variation, however, seems to be of an essentially random nature, and no significant concentrations. If it is further assumed that the adsorption occurs randomly on the two filters used for each sample of water, a simple calculation leads to estimations of the adsorption error of ±18 μgC and of ±5.1 μgN per single determination, and these, of course, include the variation of the filter blank. In this work, blank corrections of 65 μgC and of 10.5 μgN were used for the data obtained using Hitachi 026 Analyzer and Yanagimoto MT-1 Corder. The final accuracies of determination were thus, ± (1.8–6.0) μgC/l and ±(0.5–1.7) μgN/l depending on the water volume filtered.

An additional series of sampling was made in a small coastal embayment, Oshoro Bay, Hokkaido in May-June, 1970 (see Fig. 30, p. 84). This embayment faces the Tsushima Warm Current. This series of observations was mainly concerned with microlayer skimming of the sea surface for detecting any surface concentration of organic matter. The apparatus used for skimming was a 16 mesh screen[65] made of stainless steel and framed with a rectangular brass rod (50 × 75 cm, see Fig. 31, p. 85). The samplings were made at 1600, 2200, 0400, and 1000 on every sampling day from a very small boat using a screen that was cleaned, in advance, with iso-propyl alcohol; it was dipped vertically just below

the surface, turned level with the surface and hauled up. The film of seawater adhering to the screen was drained into a polyethylene bottle. This operation was repeated 60–80 times to obtain 3–4 *l* of skin water. Samples from the subsurface layer, about 50 cm deep, were simultaneously taken for comparison using a small Van Dorn sampler.

The sample waters obtained were analysed for particulate materials using the methods described above. Subsamples were used for the following analyses. Colony numbers of heterotrophic bacteria were determined by the plate counting method. One m*l* of seawater was filtered immediately after sampling through a sterilized Millipore filter (HA) and the filter was cultured on a ZoBell's ager (2216E)[66] at 15–20°C. A subsample of about 500 m*l* which was filtered through a Millipore filter (HA) was poured into a plastic bottle, stored in a dry-ice box and later in a freezer at –20°C and following analyses were made using the preserved sample. Reactive phosphorus (PO_4–P) was measured by the method of Murphy and Riley[67] as described by Strickland and Parsons.[55] Nitrate (NO_3-N) and nitrite (NO_2-N) were determined with the method of Morris and Riley[68] and Bendscheider and Robinson,[69] respectively, as decribed by Strickland and Parsons.[55] Ammonia (NH_4-N) was analyzed by the method of Solòrzano.[70] Dissolved organic phosphorus (D.O.P.) and nitrogen (D.O.N.) were determined by the method of ultraviolet light oxidation.[55]

Results and Discussions

Part I. *Concentration of Total Sestonic Material and its Carbon Content in the Western North Pacific and Adjacent Seas.*

Data on total dried weight of sestonic material were available from only 34 stations among which particulate carbon data were also available from 25 stations. Maximum depths of sampling at these stations rarely exceeded 2000 m, and the number of layers sampled at each station was 4–23. The precision of the analytical method in dried weight determination was ±0.04 mg/*l* (S.D.), and was not adequately high. However, total dried weight of seston is considered to be an important measure that indicates the overall load of suspended particulate material inclusive of organic and inorganic fractions. In this Part, a description is made of total suspended material as expressed by dried weight in various areas in the western North Pacific Ocean. Particulate carbon data, where available, were used to calculate organic carbon/total dried weight ratio as a rough criterion of organic fraction, and the distribution of this ratio was also described.

Table 2 showed mean dried weights of seston (mg/*l*) at the 34 stations and mean carbon contents (%) at the 25 stations in a series of depth range, i.e., 0–50 m, 51–100 m, 101–200 m, 201–500 m, and every 500 m interval down below. Mean values of seston (mg/*l*) and carbon (μgC/*l*) were calculated by dividing the

Table 2. Average concentrations of seston dried weight (mg/*l*) and average organic carbon fractions (%) in a series of depth ranges i.e., 0–50 m., 51–100 m. 101–200 m., 201–500 m, and every 500 m interval down below at 34 stations in the western North Pacific Ocean and adjacent seas. At 9 out of the 34 stations, organic carbon data were lacking. Sample number (n) and total range (min-max) obtained in each depth range are also shown.

Depth range (m)	St. 1 Seston dried weight (mg/*l*)		St. 3 Seston dried weight (mg/*l*)		St. 5 Seston dried weight (mg/*l*)		St. 7 Seston dried weight (mg/*l*)	
	n (min-max)	mean	n (min-max)	mean	n (min-max)	mean	n (min-max)	mean
0- 50	3(0.16-0.37)	0.24	3(0.14-0.20)	0.18	3(0.29-0.73)	0.43	3(0.16-0.23)	0.19
51- 100	2(0.17)	0.18	1(0.14)	0.15	1(0.18)	0.25	1(0.02)	0.09
101- 200	2(0.15-0.17)	0.16	2(0.15-0.19)	0.17	1(0.30)	0.27	2(0.09-0.16)	0.12
201- 500	1(0.19)	0.12	1(0.07)	0.11	1(0.27)	0.14		0.11
501-1000			1(0.07)	0.07	1(0.01)	0.01	1(0.06)	0.07
1001-1500				0.09	1(0.01)	0.04	1(0.07)	0.07
1501-2000				0.11		0.10		
2001-2500			1(0.13)	0.13				
2501-3000				0.12				

	St. 10	
0- 50	3(0.12-0.34)	0.19
51-100	1(0.07)	0.11
101-200	2(0.10-0.14)	0.11

Depth range (m)	St. 15 Seston dried weight (mg/*l*)		St. 15 Carbon fraction (%)		St. 19 Seston dried weight (mg/*l*)		St. 19 Carbon fraction (%)	
	n (min-max)	mean	n (min-max)	mean	n (min-max)	mean	n (min-max)	mean
0- 50	3(0.22-0.46)	0.25	3(9-15)	13	4(0.16-0.27)	0.20	4(18-37)	25
51- 100	2(0.07-0.32)	0.24	2(15-16)	14	2(0.17-0.29)	0.26	2(14-15)	15
101- 200	2(0.23-0.40)	0.28	2(11-15)	12	1(0.29)	0.29	1(23)	18
201- 500	3(0.18-0.26)	0.20	2(3- 5)	12	5(0.15-0.47)	0.20	5(4-48)	20
501-1000	3(0.10-0.30)	0.18	3(4-16)	10	5(0.06-0.19)	0.14	5(6-25)	22
1001-1500	2(0.10-0.14)	0.15	2(13-22)	15	2(0.18)	0.15	2(5-15)	15
1501-2000	2(0.13-0.25)	0.19	2(14-15)	15	1(0.19)	0.19	1(7)	7
2001-2500	1(0.14) (2001-2445m)	0.14	1(14)	14		0.16		

	St. 21				St. 61			
0- 50					4(0.45-1.56) (0-40m)	0.83	4(5-14)	10
51- 100	1(0.46)	0.39	1(5)	7				
101- 200	2(0.09-0.10)	0.12	2(32-74)	37				
201- 500	4(0.11-0.59)	0.31	4(3-13)	10				
501-1000	6(0.04-0.15)	0.12	5(9-34)	28				
1001-1500		0.11	2	31				
1501-2000	2(0.09-0.12)	0.11		5				
2001-2500		0.11		4				

	St. 62				St. 63			
0- 50	5(0.21-0.54)	0.40	4(13-31)	17	3(0.17-0.28)	0.25	3(12-29)	19
51- 100					2(0.34-0.44)	0.38	2(6- 7)	7

Table 2 (Continued)

Depth range (m)	St. 64				St. 65			
	Seston dried weight (mg/l)		Carbon fraction (%)		Seston dried weight (mg/l)		Carbon fraction (%)	
	n (min-max)	mean	n (min-max)	mean	n (min-max)	mean	n (min-max)	mean
0- 50	3(0.12-0.16)	0.14	3(15-23)	19	3(0.11-0.15)	0.13	3(18-24)	21
51- 100	2(0.15-0.19)	0.16	2(18-33)	24	2(0.10-0.17)	0.15	2(21-23)	20
101- 200	2(0.12-0.40)	0.23	2(15-25)	13	3(0.05-0.07)	0.07	3(13-40)	24
201- 500	2(0.07-0.11)	0.09	2(12-27)	18	1(0.05)	0.07	1(28)	25
501-1000	2(0.08-0.14)	0.11	2(5-12)	7	3(0.05-0.15) (500-880m)	0.08	3	28
	St. 66							
0- 50	3(0.11-0.20)	0.15	3(15-24)	21				
51- 100	2(0.11-0.16)	0.15	2(20)	21				
101- 200	3(0.08-0.18)	0.15	3(24-44)	25				
201- 500	2(0.09-0.10)	0.01	2(8-41)	24				
	St. 67				St. 68			
0- 50	3(0.12-0.20)	0.16	3(8-20)	13	3(0.12-0.19)	0.17	3(16-33)	24
51- 100	2(0.14-0.28)	0.19	2(10-11)	11	2(0.07-0.11)	0.11	2(19-30)	27
101- 200	3(0.07-0.23)	0.15	3(7-27)	9	3(0.07-0.10)	0.09	3(12-32)	18
201- 500	1(0.19)	0.16	1(7)	7				
501-1000	3(0.08-0.12)	0.10	3(1-29)	4				
1001-1500	1(0.06)	0.07	1(13)	8				
1501-2000		0.08		10				
2001-2500		0.11		6				
2501-3000	1(0.16)	0.14	1(4)	4				
3001-3500		0.15		5				
3501-4000	1(0.14)	0.15	1(9)	7				
	St. 69				St. 70			
0- 50	3(0.17-0.41)	0.25	3(7-21)	12	3(0.17-0.23)	0.20	3(21-27)	23
51- 100	2(0.12-0.35)	0.30	2(8-33)	10	2(0.13-0.17)	0.15	2(9-13)	16
101- 200	3(0.10-0.23)	0.14	3(9-14)	14	2(0.10-0.11)	0.12	2(6- 9)	7
201- 500	1(0.06)	0.08	1(12)	10	1(0.16)	0.14	1(13)	10
501-1000	2(0.06-0.12)	0.08	2(11-13)	16	3(0.06-0.16)	0.12	3(6-10)	8
1001-1500	1(0.10)	0.10	1(7)	10	1(0.06)	0.10	1(11)	8
1501-2000	1(0.10)	0.15	(6)	6	1(0.03)	0.06	1(13)	8
2001-2500					1(0.18)	0.15	1(3)	3
2501-3000					1(0.05)	0.08	1(17)	10
	St. 71				St. 72			
0- 50	4(0.73-1.36)	1.15			5(0.32-1.18)	0.68		
51- 100					2(0.43-0.61)	0.45		
101- 200					1(0.40)	0.50		
201- 500					3(0.17-0.40)	0.33		
501-1000					2(0.14-0.68)	0.43		
1001-1500						0.12		

Table 2. (Continued)

Depth range (m)	St. 74				St. 75			
	Seston dried weight (mg/*l*)		Carbon fraction (%)		Seston dried weight (mg/*l*)		Carbon fraction (%)	
	n (min-max)	mean	n (min-max)	mean	n (min-max)	mean	n (min-max)	mean
0- 50	6(1.02-3.95)	2.31	6(2-18)	6	6(0.15-0.43)	0.33		
51- 100	3(0.80-2.80)	1.90	3(1- 8)	2	1(0.17)	0.16		
101- 200	2(0.48-0.50)	0.57	2(9-15)	11		0.25		
201- 500	4(0.05-0.64)	0.47	4(6-54)	10	2(0.17-0.37)	0.26		
501-1000	4(0.10-0.64)	0.31	4(6-31)	13	3(0.15)	0.16		
1001-1500	2(0.20-0.35)	0.29	2(26-34)	26	1(0.13)	0.14		
1501-2000	1(0.17)	0.20	1(29)	24	1(0.26)	0.20		
2001-2500	1(0.38)	0.34	1(7)	10	1(0.10)	0.17		
2501-3000					1(0.37)	0.23		
	St. 76				St. 77			
0- 50	5(0.12-0.30)	0.20	5(14-28)	18	6(0.16-0.36)	0.25	6(10-27)	17
51- 100	2(0.17-0.25)	0.19	2(3-10)	9	1(0.11)	0.14	1(14)	18
101- 200	2(0.11-0.16)	0.16	2(8)	7	3(0.19-0.22)	0.20	1(9)	7
201- 500	1(0.21)	0.16	1(7)	8	3(0.03-0.17)	0.09	1(8)	12
501-1000	2(0.11-0.24)	0.16	2(3- 7)	5	3(0.05-0.13)	0.08	2(11-14)	14
1001-1500	1(0.05)	0.14	1(19)	6	1(0.09)	0.10	1(12)	13
1501-2000	1(0.14)	0.10	1(10)	12	2(0.10-0.24)	0.17		
2001-2500		0.13		7	1(0.24)	0.17		
2501-3000	1(0.08)	0.10	1(14)	9	1(0.13)	0.19		
3001-3500					1(0.13)	0.13		
	St. 78				St. 80			
0- 50	6(0.10-0.17)	0.14	6(25-39)	29	6(0.10-0.21)	0.15	6(16-43)	25
51- 100	2(0.10-0.20)	0.15	2(14-23)	19	2(0.12-0.13)	0.15	2(17-22)	18
101- 200	3(0.06-0.19)	0.13	3(9-42)	15	3(0.08-0.13)	0.11	3(11-14)	13
201- 500	4(0.04-0.10)	0.08	4(11-25)	18	4(0.05-0.17)	0.12	4(20-49)	22
501-1000	3(0.03-0.10)	0.06	3(14-41)	24	3(0.06-0.12)	0.10	3(11-31)	16
1001-1500	2(0.08-0.17)	0.10	2(6-21)	14	2(0.11)	0.10	2(22-26)	25
1501-2000	1(0.12)	0.15		9	1(0.16)	0.13	1(8)	18
2001-2500	1(0.08) (2001-2433m)	0.10	1(27)	19	1(0.14) (2001-2400m)	0.15	1(16)	14
	St. 82				St. 84			
0- 50	3(0.28-0.84)	0.42			5(0.19-0.35)	0.30	5(12-45)	17
51- 100	3(0.15-0.39)	0.21			2(0.23-0.26)	0.23	3(3- 5)	6
101- 200	3(0.19-0.44)	0.29			2(0.23-0.31)	0.18	2(4-10)	11
201- 500	2(0.16-0.48)	0.33			4(0.14-0.24)	0.19	4(12-41)	21
501-1000	1(0.31)	0.24			3(0.18-0.30)	0.27	3(11-28)	15
1001-1500	(501-830m)				1(0.80) (1001-1448m)	0.65	1(4)	2
	St. 87				St. 88			
0- 50	5(0.79-1.71)	1.07	5(19-33)	27	5(0.50-1.68)	1.17	5(9-36)	12
51- 100	2(0.26-0.50)	0.38	2(22-34)	25	2(0.20)	0.27	2(9-17)	15
101- 200	2(0.23-0.37)	0.33	2(26-56)	38	2(0.25-0.36)	0.31	2(9-15)	13
201- 500		0.35		17	2(0.15-0.30)	0.24	2(7-18)	9

Table 2. (Continued)

Depth range (m)	St. 87				St. 88			
	Seston dried weight (mg/l)		Carbon fraction (%)		Seston dried weight (mg/l)		Carbon fraction (%)	
	n (min-max)	mean	n (min-max)	mean	n (min-max)	mean	n (min-max)	mean
501-1000	2(0.15-0.33)	0.28	2(18-20)	20	2(0.33-0.49)	0.41	3(5- 6)	4
1001-1500					2(0.12-0.77) (1001-1467m)	0.37	2(2-15)	5
	St. 90				St. 92			
0- 50	5(0.54-1.17)	0.79	5(6-37)	13	5(0.26-0.61)	0.43	5(9-22)	15
51- 100	1(0.13)	0.30	1(20)	9	2(0.12-0.52)	0.30	2(3-20)	8
101- 200	3(0.20-0.34)	0.26	3(3-18)	4	3(0.18-0.27)	0.24	3(7-13)	11
201- 500	3(0.44-0.55)	0.49	3(4- 9)	8	4(0.17-0.31)	0.24	4(12-35)	17
501-1000	4(0.17-0.32)	0.22	4(5-23)	11	4(0.12-0.13)	0.13	3(5-30)	19
1001-1500	2(0.19-0.20) (1001-1407m)	0.20	2(6-11)	8	(501-947m)			
	St. 94				St. 95			
0- 50	5(0.32-0.96)	0.61	5(14-18)	16	5(0.23-0.73)	0.50	5(27-34)	25
51- 100	2(0.27-0.34)	0.30	2(9-22)	14	2(0.19)	0.20	2(15-19)	20
101- 200	3(0.21-0.29)	0.25	3(4-20)	18	3(0.10-0.25)	0.17	3(8-30)	11
201- 500	4(0.09-0.26)	0.14	4(5-13)	13	3(0.08-0.22)	0.15	3(20-38)	25
501-1000	2(0.16-0.18)	0.15	2(7-16)	11	1(0.20)	0.15	1(11)	19
1001-1500	(601-743)				2(0.16-0.22) (1001-1374m)	0.19	2(22-36)	26

integrated values (mg/m²) in each depth range by the depth range (m). Mean carbon fractions (%) was the ratio of the mean carbon concentration to the seston dried weight (the date of carbon are shown in Table 4, Part II). Values at depth boundaries were taken by linear interpolation when observed values in the depths were lacking.

The 34 stations that were avaliable were divided into 3 groups according to geographical locations of stations, i.e., (1) the Philippine Sea and the East China Sea including (a) the CSK area along a line at 142°E, (b) the Kuroshio area and (c) the shelf water of the East China Sea, (2) the Northern areas including the Oyashio Current area off Erimo, the Okhotsk Sea, a northern North Pacific water and the Bering Sea, and (3) the Japan Sea. Within each group, the areal means in the respective depth ranges were calculated for each of seston dried weight and carbon percent, and are shown in Table 3. In these tables "n" is the sample number obtained in each depth range, and minimum and maximum values in the observed dried weights and the calculated percentages in each depth range are shown in parentheses. Total amounts of seston dried weight integrated in each area within the depth ranges of 0–1500 m and 1501–the deepest sampling depth

are also shown together with the grand means of carbon percentage in each depth range in Table 3.

I. *The Philippine Sea and the East China Sea.*

(a) *CSK area along a line at* 142°E (Tables 2 and 3, Fig. 3). Data were available from 8 stations (Sts. 1, 3, 5, 7, 10, 15, 19 and 21) that were located in the oligotrophic subtropical area between 19°N and 28°N. Throughout these

Table 3. Areal mean concentrations of seston dried weight and carbon fractions in a series of depth ranges (cf. Table 2) in 9 areas in the western North Pacific Ocean and adjacent seas. Sample number (n) and total range (min-max) in each depth range are included. Average total seston weights per 1 m². and grand means of carbon percentage in two water columns of 0–1500 m. and 1501–the maximum depth for each area observed are also shown.

Table 3. (1) Phillippine Sea and East China Sea

(a) CSK area from 19°N to 28°N, 142°E line (b) Kuroshio area (KH–68–2)

Depth range (m)	Seston dried weight (mg/*l*)		Carbon fraction (%)		Seston dried weight (mg/*l*)		Carbon fraction (%)	
	n (min-max)	mean	n (min-max)	mean	n (min-max)	mean	n (min-max)	mean
0- 50	7(0.19-0.43)	0.24	2(13-15)	14	7(0.13-0.25)	0.17	7(12-23)	19
51- 100	8(0.09-0.39)	0.21	3(7-15)	12	7(0.11-0.30)	0.17	7(10-27)	18
101- 200	8(0.11-0.29)	0.19	3(12-37)	22	7(0.07-0.16)	0.14	7(7-25)	16
201- 500	7(0.11-0.31)	0.17	3(10-20)	14	6(0.07-0.16)	0.11	6(7-25)	15
501-1000	6(0.11-0.18)	0.13	3(10-28)	20	5(0.06-0.12)	0.09	5(4-28)	13
1001-1500	6(0.11-0.15)	0.10	3(15-31)	23	3(0.05-0.15)	0.09	3(8-10)	9
1501-2000	5(0.10-0.19)	0.19	3(5-15)	9	3(0.06-0.15)	0.10	3(6-10)	8
2001-2500	4(0.11-0.16)	0.16	3(4-14)	9	2(0.11-0.15)	0.13	2(3- 6)	5
2501-3000	1(0.12)				2(0.08-0.14)	0.11	2(4-10)	7
3001-3500					1(0.15)	0.15	1(5)	5
3501-4000					1(0.15)	0.15	1(7)	7
	Total (g/m²)				Total (g/m²)			
0-1500	205.5			19	154.0			13
1501-3000	200.0			9				
1501-4000					320.0			6

(c) Shelf water of the East China Sea (cf. Table 2 (2))

(2) Northern Areas

(d) Oyashio Current Region off Erimo (St. 72, April 1966)

Depth range (m)	Seston dried weight Total (g/m²)	Carbon fraction mean (%)
0-1500	426.0	

(e) Oyashio Current Region off Erimo (St. 74, Sept. 1969)

0-1500	708.5	21

(f) Northern North Pacific (St. 84)

0-1500	526.0	11

(g) the Bering Sea (St. 95)

0-1500	269.0	22

Table 3. (Continued)

(h) the Bering Sea from 52°N to 58°N, 178 W line. (3) the Japan Sea.

Depth range (m)	Seston dried weight (mg/l)		Carbon fraction (%)		Seston dried weight (mg/l)		Carbon fraction (%)	
	n (min-max)	mean	n (min-max)	mean	n (min-max)	mean	n (min-max)	mean
0- 50	5(0.43-1.17)	0.81	5(12-27)	17	5(0.14-0.33)	0.21	4(17-29)	22
51- 100	5(0.27-0.38)	0.31	5(8-25)	14	5(0.14-0.16)	0.16	4(9-19)	16
101- 200	5(0.24-0.33)	0.28	5(4-38)	17	5(0.11-0.25)	0.17	4(7-15)	11
201- 500	5(0.14-0.49)	0.29	5(8-17)	13	5(0.10-0.26)	0.15	4(8-22)	12
501-1000	5(0.13-0.41)	0.24	5(4-20)	13	5(0.06-0.16)	0.11	4(5-24)	15
1001-1500	2(0.20-0.37)	0.29	2(5- 8)	7	5(0.10-0.14)	0.12	4(6-25)	15
1501-2000					5(0.10-0.17)	0.15	3(9-18)	13
2001-2500					5(0.10-0.27)	0.16	3(7-19)	13
2501-3000					3(0.10-0.19)	0.17		
3001-3500					1(0.13)	0.13		
	Total (g/m²)				Total (g/m²)			
0-1500	436.0			11	195.5			14
1501-3500					305.0			12

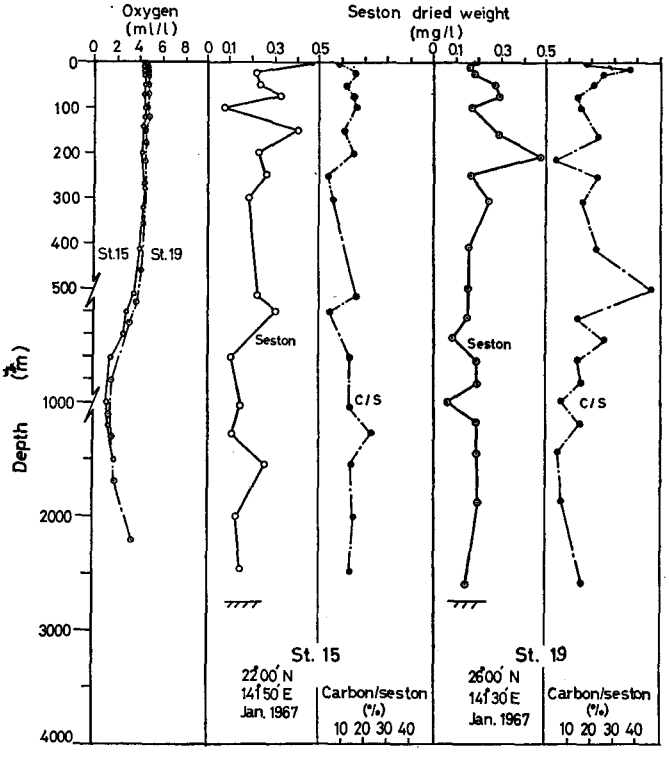

Fig. 3. Vertical profiles of dissolved oxygen, seston dried weight and organic carbon fraction of total dried weight at two stations located in the open waters of the Philippine Sea (Sta. 15 and 19), Jan. 1967, Oshoro-Maru Cruise 21.

stations the total range of dried weight of seston was 0.01–0.73 mg/*l*, and that of carbon fraction was 3–74%. The concentration tended to decrease with depth, but the rate of decrease was not much remarkable; the average concentration in 0–50 m layer was 0.24 mg/*l*, and that in 501–1000 m layer 0.13 mg/*l* (Table 3). The average total amount of particulate material suspended in the water column of 0–1500 m was 206 g/m^2. The carbon fraction did not show a consistent trend to decrease with depth; the average carbon fraction in the 0–50 m layer was 14% and that in the 501–1000 m layer was 20%.

The general ranges shown above covered more than one order of magnitude variation of the two parameters, but at each station, large variations occurred in two limited depth range; one in the surface layer less than 200 m depth and the other around the oxygen minimum layer located at about 1000 m depth. Two examples of vertical variations in dried weight and carbon fraction of seston are shown in Fig. 3.

In the surface layer, the sea surface concentrations were not always the highest; more common were subsurface maxima of particle concentration which were found located at various depths within the euphotic layer or even below that. It was very noticeable that the relatively highest average concentration in the surface layer (Table 2) was characterized by such a variation with depth that a sharp peak was alternated from layer to layer by a similarly sharp minimum which was frequently the lowest concentration through the entire water column observed. This is a situation which suggests that either the processes of formation or the processes of transport of these material would be localized in terms of time and space.

The irregular variation around the oxygen minimum layer was particularly marked at the two stations (Sts. 15 and 19). Oxygen depletion (nearly 1 m*l* O_2/*l*) was also more serious on 142°E line. There seems to be a tendency for carbon rich particles to accumulate in the oxygen depleted layer.

In the intermediate depth range between the subsurface layer and the oxygen minimum layer, vertical variation in particle concentration was minimal. However, the average level of concentration in this range (201–500 m) was different between this area and the Kuroshio area as mentioned below (area (b)); the former area had an average concentration of 0.17 mg/*l* and the latter 0.11 mg/*l* (Table 3).

Below the oxygen minimum layer, no consistent trend of variation with depth was observed and the general range obtained was 0.1–0.2 mg/*l*. However, three out of the eight stations available were less than 2500 m in the maximum depth of sampling, and the depth intervals of sampling were apparently too coarse to yield any consistent trend.

An inspection of Fig. 3 shows that the variation with depth of seston dried

weight is approximately inverse to that of carbon fraction. Distribution of carbon is fully described in the next Part of this paper, but here it is stated that the inverse relation mostly means that the seston carbon is comparatively constant all through the water column in relation to seston dried weight. For, instance, at St. 19, the seston carbon was in a range of 9–71 μgC/l (see p. 63. Fig. 17) whereas the seston dried weight was in a range of 0.06–0.47 mg/l. The inverse relation also means that the organic fraction is minor compared to the inorganic fraction. Average carbon fractions calculated for each depth range shown in Table 3 never exceeded 25%.

(b) *Kuroshio Area* (Tables 2 and 3, Fig. 4). Seven stations (Sts. 64–70) were available in the oceanic area on both sides of Ryukyu Islands where the Kuroshio and its compensation currents are dominating. General trends of vertical variations in seston and carbon fraction were similar to those in the previous area, but the seston level redued to a general range of 0.03–0.41 mg/l. The total amount of seston in the 0–1500 m water column was 154 g/m^2, being

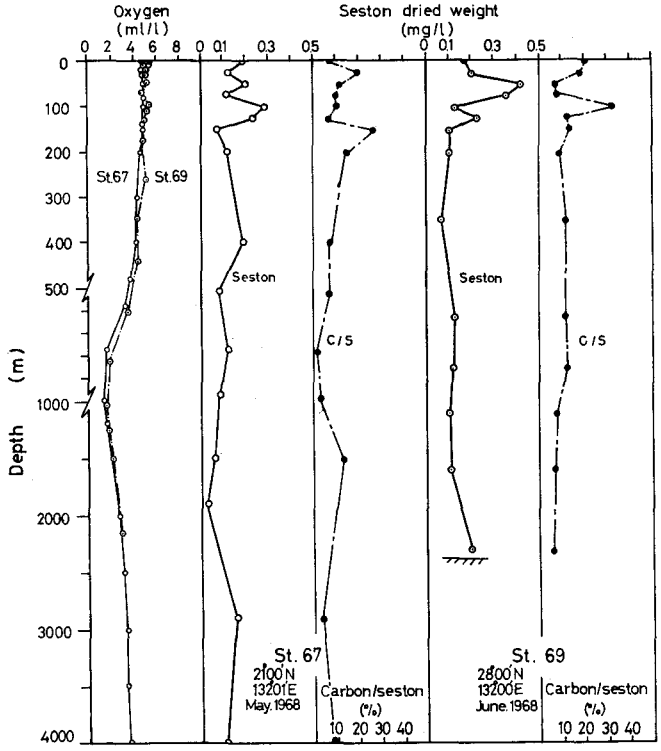

Fig. 4. Vertical profiles of dissolved oxygen, seston dried weight, and organic carbon fraction of total dried weight at two stations located in the Philippine Sea (Sta. 67 and 69), May to June 1968, Hakuho-Maru Cruise KH-68-2.

25% less than in the previous area. The average carbon fraction was also lower at 13%.

(c) *Shelf water of the East China Sea* (Table 2). Three stations (Sts. 61–63) in the East China Sea were located in the shallow region on the continental shelf less than 100 m in depth. The obtained range of seston dried weight was 0.17–1.56 mg/*l* and higher values tended to occur at the surface and close to the bottom. However, carbon fraction was in a range of 5–31% and lower fractions occurred in the bottom layer suggesting that stirred up bottom sediments were a significant component of suspended material.

II. *Northern areas* (Tables 2 and 3, Figs. 5a-5e). Four stations around Hokkaido were available; three (Sts. 71, 72 and 74) off Erimo, and the other (St. 82) off Kitami in the Okhotsk Sea. Six out of the remaining seven (Sts. 87, 88, 90, 92, 94, and 95) were distributed in the eastern part of the Bering Basin. St. 84 was located just south of the Aleutian Chain at 178°W line. Sts. 92 and 94 were located at the same position in the Bering Sea but occupied at different times.

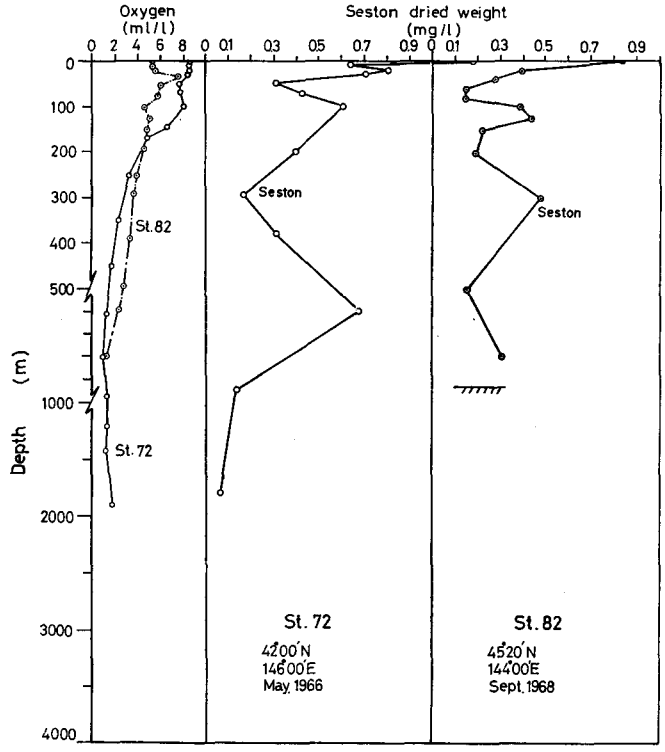

Fig. 5a. Vertical profiles of dissolved oxygen and seston dried weight at two stations located off Erimo (St. 72), May, 1966, Oshoro-Maru Cruise 18, and in the Okhotsk Sea (Sta. 82), Sept. 1968, Oshoro-Maru Cruise 29.

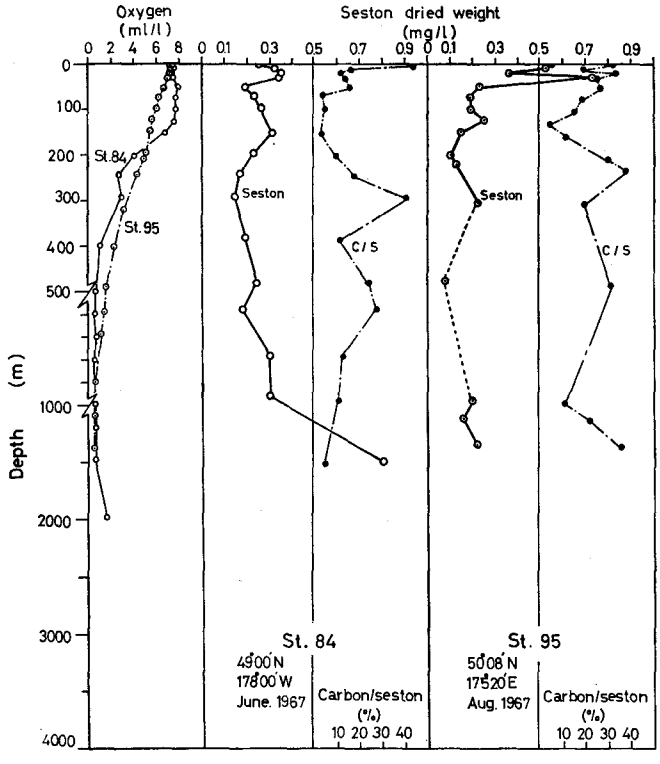

Fig. 5b. Vertical profiles of dissolved oxygen, seston dried weight and organic carbon fraction of total dried weight at two stations located in the northern North Pacific (Sta. 84) and the Bering Sea (Sta. 95), June to Aug. 1967, Oshoro-Maru Cruise 24.

These eleven stations, although scattered widely in location, were in the areas north of the polar front of the Pacific, and occupied in April-September. Thus, the results obtained at these stations are considered to represent the situation in the eutrophic northern areas.

At four stations around Hokkaido (Table 2), the general range of seston dried weight was 0.05–3.95 mg/*l*, much higher than the range obtained in the southern areas. The highest value was obtained just at the sea surface (St. 74, Table 2). The high content of particle was, however, confined to the shallow surface value and continued to decrease with depth to a marked minimum of 0.15–0.30 mg/*l* located at 50–70 m depth. This depth range coincided with or close to the bottom of the summer thermocline or the upper edge of the cold dichothermal layer. Just in the middle of the dichothermal layer below, however, a distinct maximum of 0.40–0.60 mg/*l* was found (ca. 100 m depth). Towards the bottom of the dichothermal layer the concentration decreased again. Similar cyclic variation was repeated once again in the deeper depth range below the

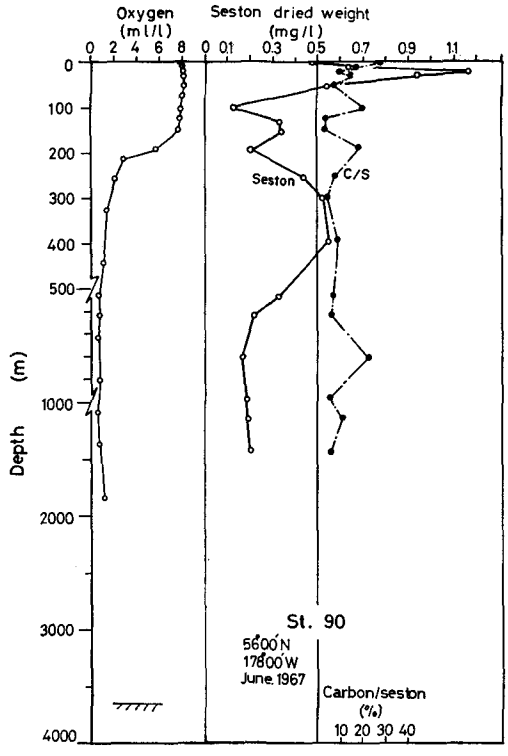

Fig. 5c. Vertical profiles of dissolved oxygen, seston dried weight and organic carbon fraction of total dried weight at St. 90 located in the Bering Sea, June to Aug. 1967, Oshoro-Maru Cruise 24.

dichothermal layer and the maximum concentration in this third cycle approximately coincided with the layer of maximum temperature, the depth of which, however, differed between two areas (400–500 m at St. 72 and 250–350 m at St. 62). The amplitude of each cycle did not show any tendency to damp with depth within the depth range observed, although the sea surface peak was usually anomalously high. This is a patttern of the vertical distribution of seston which is characteristically evident in the northern areas.

At the six stations in the Bering Sea, the similar pattern of the vertical distribution of seston dried weight was observed, but the peak values of each cycle with a peak of more than 0.5 mg/*l* at 400 m depth was very well developed. The sea surface peak disappeared at this station and a remarkably high value of 1.18 mg/*l* was found at 20 m depth. At the northern-most stations (Sts. 92 and 94) the third peak was not much evident but still recognizable. At the time of the first visit to this station (June 15) the first peak was at 20 m depth, but two months later it was just at the sea surface with a high value of 0.95 mg/*l*. The

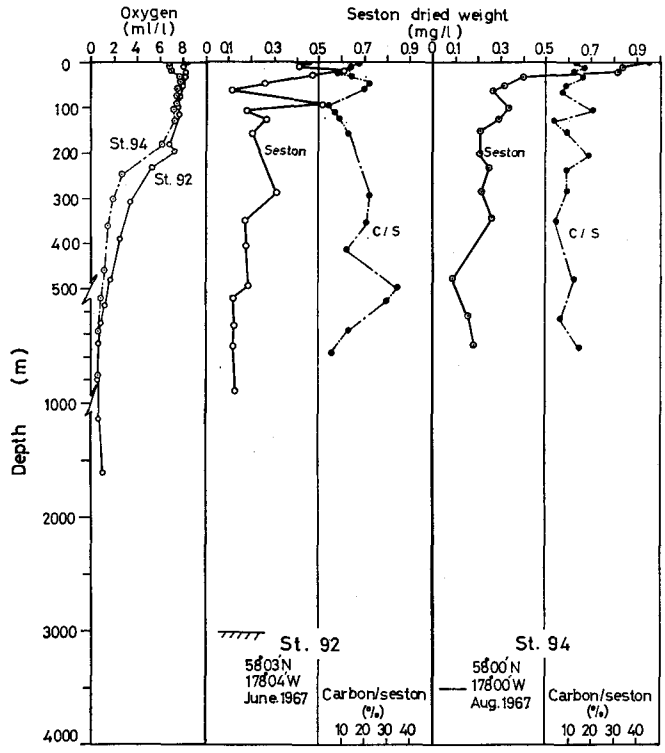

Fig. 5d. Vertical profiles of dissolved oxygen, seston dried weight and organic carbon fraction of total dried weight at two stations (Sta. 92 and 94) located in the Bering Sea, June to Aug. 1967, Oshoro-Maru Cruise 24.

data obtained at the time of the revisit showed, in comparison with the data in the first, that the extent of variation during the two months was considerable, particularly in shallow layers; the peak value in the middle of the dichothermal layer, for instance, reduced from 0.52 to 0.32 mg/*l*. However, this set of data also showed that the vertical arrangement of the variation cycles in seston has not much changed during the two months.

The Pacific station (St. 84) was probably located slightly south of the Alaskan Stream that flows east along and close to the Aleutian Chain, and the three cycles were still recognized though vaguely. Anomalously high value found at 1500 m depth of this station as well as St. 88 in the Bering would possibly be due to mixing with the turbid Alaskan Stream Water.

The general range of carbon fraction was 2–56%, and in these areas too, the vertical variation of the fraction was significantly inverse to that of seston dried weight at each station. The fraction never showed any trend to decrease consistently with depth; at some stations as in the previous regions, the fraction showed an average trend to increase considerably with depth (see Table 2).

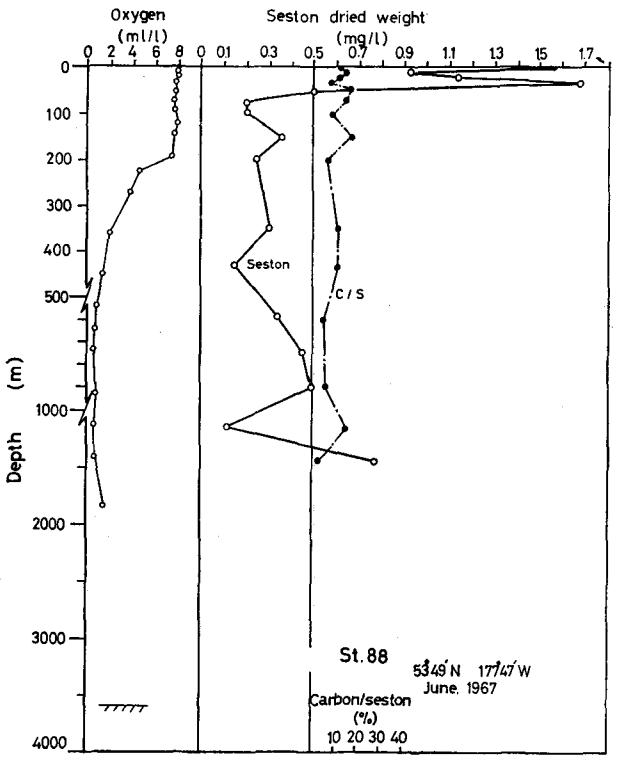

Fig. 5e. Vertical profiles of dissolved oxygen, seston dried weight and organic carbon fraction of total dried weight at Sta. 88 located in the Bering Sea. June, 1967. Oshoro-Maru Cruise 24.

Average total amount of seston in the 0–1500 m water column of the Bering Sea was 436 g/m², and at the spring station off Erimo (St. 72) it was 426 g/m²[22]. In fall, at the latter same location (St. 74), it was 709 g/m². These amounts were 2–3 times more abundant than in the southern area. However, average carbon fraction in the northern areas was close to 20%, and was not much different from that in the southern areas.

III. *The Japan Sea* (Tables 2 and 3. Figs. 6a-6c). Five summer stations (Sts. 75, 76, 77, 78 and 80) were obtained in this practically closed water body that opens to outer waters only through narrow four water ways less than 200 m in depth.

The total range of seston was 0.03–0.43 mg/*l* and that of carbon fraction 3–34% throughout these stations. The seston range was significantly lower than in the northern areas and quite similar to that obtained in the southern areas. It is also common in these two regions that major irregularities are concentrated in

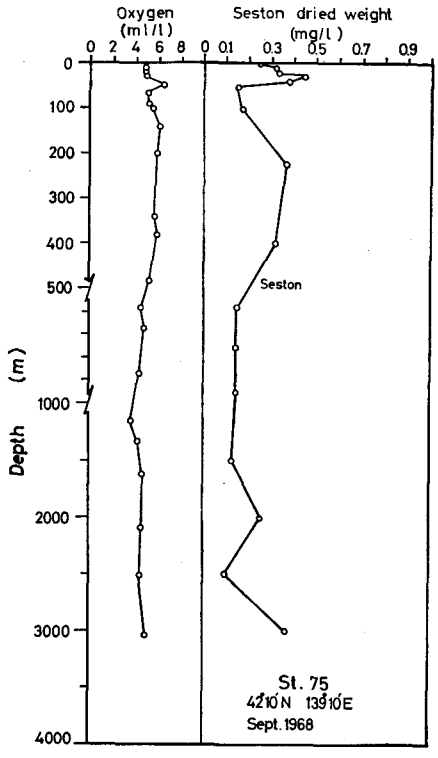

Fig. 6a. Vertical profiles of dissolved oxygen, and seston dried weight at Sta. 75 in the Japan Sea, Sept. 1968, Oshoro-Maru Cruise 29.

the surface layer less than 200 m depth and in the deeper depth range of 1000–2000 m although in the Japan Sea the entire water column is well aerated and the oxygen minimum layer is very indistinct. In the northern part of the Sea (Sts. 75–77 and 80) north of the polar front, a distinct peak of seston was observed at 30 m depth just in the middle of the remarkable knee of the thermocline prevailing in the area with a temperature gap of nearly 20°C within a few ten meters in depth range (see Figs. 24–26, Part II). Below the peak, a similarly distinct minimum of seston was located at the bottom of the thermocline or in a little deeper layer. At the station located south of the polar front (St. 78), the thermocline was less sharp due to a deeper reach of the warm surface water, and the alternation cycle of a peak and a minimum of seston was found repeated three times in the depth range of 0–400 m. The repetition was closely matched in vertical arrangement by the stepwise development of the thermocline; each maximum was formed at layer with a sharp temperature gradient and each minimum at a layer lower temperature gradient that was located just below the sharp one.

Below the thermocline, both seston and its carbon fraction did not show any consistent trend to decrease with depth as in the other areas described above and their variations were, more or less, inverse to each other.

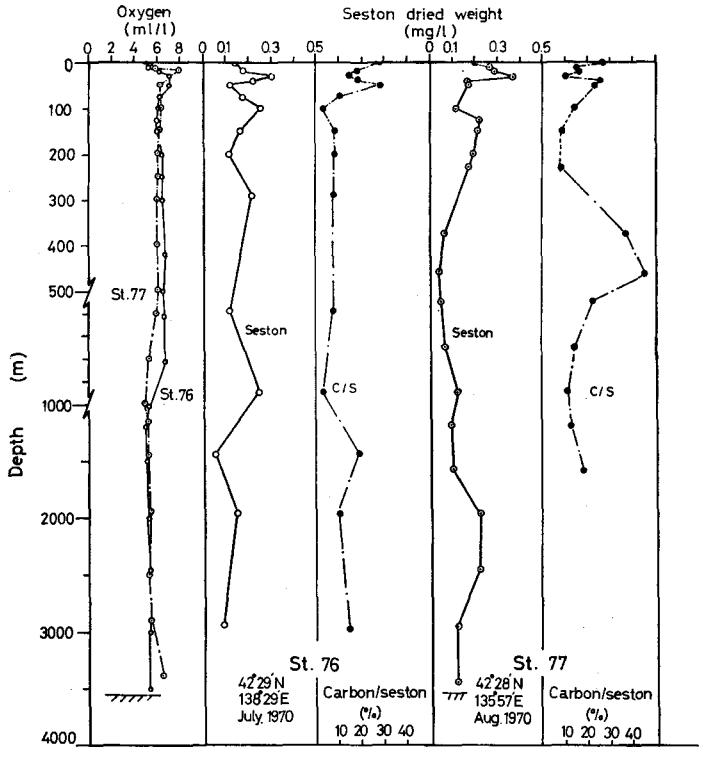

Fig. 6b. Vertical profiles of dissolved oxygen, seston dried weight and organic carbon fraction of total dried weight at two stations in the Japan Sea (Sta. 76 and 77), July to Aug. 1970, Hakuho-Maru Cruise KH-70-4.

Discussion

Total amount of suspended particulate material in the water column of 0–1500 m under a unit area of sea surface varied from area to area; the minimum of 154 g/m² was obtained from the Kuroshio area around Ryukyu Islands in May-June and the maximum of 709 g/m² from the Oyashio water off Erimo in September. In the latter area, an observation performed in April produced an estimate of 426 g/m², which is 40% less than the September value. In the Bering, the average level of seston contained in the 0–1500 m water column was 436 g/m² and the set of data obtained in June and in August at the northern-most location showed that the total amount of seston in the 0–500 m water column decreased from 132 to 112 g/m² during the two months. From these scanty data, it is inferred that the regional variation in total seston weight far exceeds the seasonal variation. The more than 4 folds variation of total seston (0–1500 m) from area to area, however, was well matched by nearly 5 folds variation in average seston concentration in the surface layer (0–50 m) in which most of the organic production

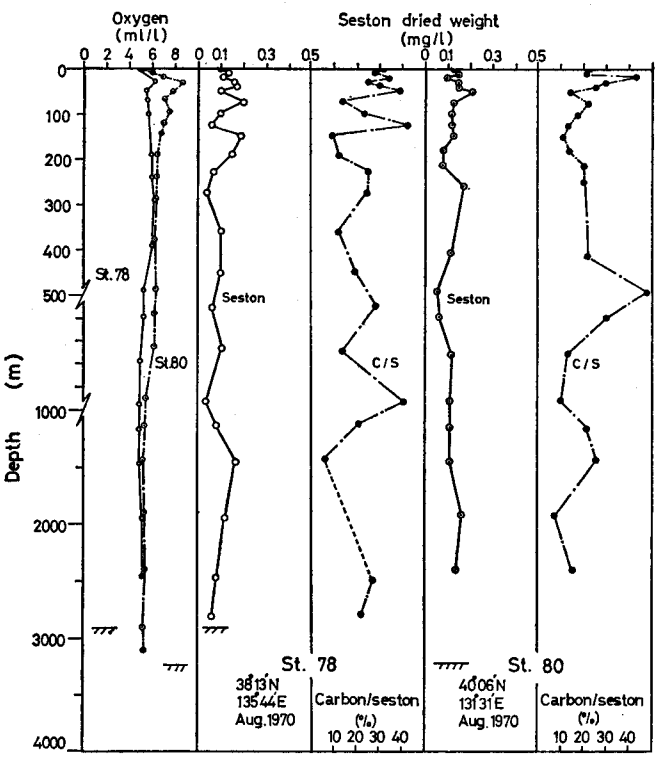

Fig. 6c. Vertical profiles of dissolved oxygen, seston dried weight and organic carbon fraction of total dried weight at two stations located in the Japan Sea, Aug. 1970, Hakuho-Maru Cruise KH-70-4.

occurs. The results of regression analyses of average seston concentrations of various depth ranges down to 1500 m upon the concentration in the surface layer (0–50 m) are shown in Fig. 7.

From this figure, it is clear that there exists a positive correlation between the average seston concentrations in the surface layer and in each depth range of 201–500 m (correlation coefficient: 0.717 ($P<0.05$), gradient: ca. 1/3), 501–1000 m, and 1001–1500 m. Two sets of data obtained from the northern North Pacific and the Oyashio area off Erimo (spring) were rather anomalous particularly in 1001–1500 m layer. However, these groups composed of a single station where only one layer was sampled below 1000 m. The positive correlation seems to mean that the variation in particle content in the euphotic layer induces a parallel variation in deeper layers and that the induction occurs in a fairly short time interval. If in fact the downward transport of surface-born particles was made only by passive sinking due to gravity of these particles with velocities of one to several meters per day, any change in concentration of deep water particles would have to have at least a few to several months of time lag behind the surface layer.

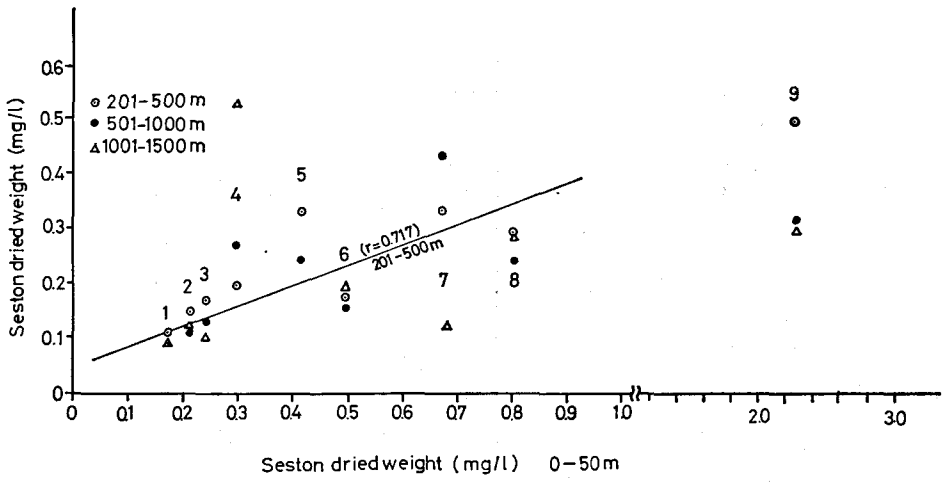

Fig. 7. Relationship between the average concentrations of seston dried weight in the surface layer (0–50 m.) and in deeper layers (201–500 m. 501–1000 m. and 1001–1500 m.) from 9 areas; 1: the Kuroshio area (Sta. 64–70, May to June, 1968), 2: the Japan Sea (Sta. 75, Sept. 1968, and Sta. 76–78 and 80, July to Aug. 1970), 3: the CSK area (Sts. 1, 3, 5, 7, and 10, Jan. 1966 and Sta. 15, 19 and 21, Jan. 1967), 4: the northern North Pacific (Sta. 84, June 1967), 5: the Okhotsk Sea (Sta. 82, Sept. 1968), 6: the Bering Sea (Sta. 95, Aug. 1967), 7: the Oyashio Current region (Sta. 72, April 1966), 8: the Bering Sea (Sta. 87, 88, 90, 92 and 94, June to Aug. 1967) and 9: the Oyashio Current region (Sta. 74, Sept. 1969).

Further, the same correlation directly contradicts the categorical claim of Menzel that the surface particles never sink down below a certain depth, say 100 m, and the particle distribution in deeper layers is essentially homogeneous. The present results seems to suggest that probably there is a system of vertical material transport which is rapid enough to induce in deep layers down to at least 1000 m a variation in particle concentration which is parallel to that in the surface layer.

Krey[71)72)] published an extensive set of data of seston dried weight obtained in the North Atlantic Ocean, and the obtained range of values was comparable with the present results. He reported that an area with higher seston values at the surface also had higher values at depths of 500 m and 1500 m. Recently, Jacobs and Ewing[73)] and Eittriem *et al.*[74)] found the existence of cloudly or nepheloid layers in the deep water of the North Atlantic Ocean using a Nephelometer. The former authors reported that concentrations of seston dried weight collected each from 200 *l* volume of sample water were ranged from 0.03 to 0.08 mg/*l* in deep water. These values were one order of magnitude less than those of the present observation. However, discrepancy might probably be due to the difference in sample treatment; they were mainly concerned with the clay component of seston and dried the samples at 100°C before weighing.

It has generally been expected that the organic fraction of seston is higher in the euphotic layer than below because most of the organic matter produced in the euphotic layer should be consumed during the downward transport. In the present observations, however, the carbon fraction did not decrease systematically with depth but fluctuated between 10 and 30%, and there was no consistent difference between the Kuroshio current system and the Oyashio current system. Although low values below 10% tended to occur in the deeper layers below 100 m at several stations, similarly low values were frequently found in shallower layers. More often was the mid-depth (1000–2000 m) occurrence of those carbon fractions that were higher than in the layers above and below. These values were roughly comparable to that in the oceanic average values as reported by Lisitzin[75] but slightly higher than that of Hobson[41], Riley[76], Postma[11] and Gordon[38] although the differences might be insignificant if the low precision level inherent in the gravimetric approach to determine the amount of total seston is taken into consideration.

Thus, from these results, there emerges a fairly consistent pattern in vertical distribution of particulate material in the ocean. The highest concentration is usually found at or near the sea surface. The concentration rapidly decreases within a short depth interval and arrives at a minimal level in a depth range close to the bottom of the convection layer. Within the thermocline another peak of the particle concentration usually occurs and is followed by a rapid decrease with depth; the decrease continues further down with a progressively decreasing rate, and a relatively low and stable concentration is attained in the depth range of 200–400 m. Below the depth, however, there appear one or two more peaks which are usually broad, extending over a few to several hundreds meters of depth range. The depth range in which this broad maximum occurs differs with regions and generally located in 300–1500 m. It is noticed that within this depth range, conspicuous layerings of watermass occur; the subsurface maximum temperature layer and the principal halocline in the northern areas, the salinity minimum layer in most of the temperate and subtropical areas, and the oxygen minimum layer in all of the areas are observed in the present study. However, the depth coincidence between the layering of water and that of particulate matter appeared to be, in most cases, obscure or sporadic in occurrence because of the coarse sampling interval.

The general pattern described above is an oversimplification, and the actual patterns observed were often more complicated. The pattern was more clearly recognized in northern eutrophic areas, and it was obscure in southern oligotrophic areas because the general concentration of seston reduced to such a low level that any variation could be masked by the analytical error.

The discussion, thus, lead to the aforementioned problem of positive correlation

Table 4. Average concentrations of particulate organic carbon (P.O.C.) and nitrogen (P.O.N.), and chlorophyll *a* in a series of depth ranges, i.e., 0–50 m. 51–100 m., 101–200 m., 201–500 m., and every 500 m. interval down below at 39 stations in the western North Pacific Ocean and adjacent seas. Sample number (n) and total range (min-max) in each depth range are also shown.

St. 15

Depth range (m)	P.O.C. (μg/l)		P.O.N. (μg/l)		Chlorophyll *a* (mg/m³)	
	n (min-max)	mean	n (min-max)	mean	n (min-max)	mean
0- 50	4(26.8-39.6)	31.8	4(4.2- 4.8)	4.3	4(0.01-0.03)	0.02
51- 100	2(11.0-47.1)	33.1	2(10.7-17.6)	12.6	2(0.04)	0.03
101- 200	2(34.8-45.6)	34.3	2(11.7-17.8)	14.2	1(0.01)	0.03
201- 500	3(6.5-38.8)	24.5	3(2.8- 7.5)	5.4		
501-1000	5(11.8-35.2)	18.8	5(1.0- 4.0)	2.5		
1001-1500	2(18.0-21.8)	23.0	2(2.2- 3.2)	3.4		
1501-2000	2(19.6-34.6)	28.2	2(5.8- 6.9)	6.3		
2001-2500	1(19.6) (2001-2445m)	19.6	1(0.4)	0.4		
0- 50	4(45.6-59.1)	50.0	4(2.6-7.9)	4.8	4(0.05-0.09)	0.06
51- 100	2(25.1-40.6)	40.2	2(5.9-8.0)	6.8	2(0.04)	0.05
101- 200	1(65.9)	53.0	1(8.9)	7.7	1(0.03)	0.03
201- 500	5(16.3-71.1)	39.9	5(2.2-6.7)	3.7		
501-1000	5(19.6-37.8)	30.4	5(2.0-1.4)	3.9		
1001-1500	2(9.0-26.6)	22.2	2(1.0-1.8)	2.1		
1501-2000	1(14.0)	12.6	1(1.0)	1.0		
2001-2500	1(21.0)	17.6	1(3.8)	2.4		
0- 50	4(20.5-62.1)	35.9	4(0.8-8.9)	2.9	4(0.02-0.04)	0.03
51- 100	1(22.3)	25.5	1(4.6)	4.6	1(0.04)	0.04
101- 200	2(29.6-74.1)	44.1	2(0.6-3.2)	1.7	2(0.00-0.05)	0.02
201- 500	4(2.0-64.1)	29.8	4(0.0-8.3)	3.9		
501-1000	6(14.0-74.6)	33.1	6(1.4-9.1)	3.0		
1001-1500	1(43.6)	33.9	1(7.1)	6.2		
1501-2000	2(0.3-10.0)	5.3	2(1.6-2.0)	1.9		
2001-2500		4.1		1.6		
2501-3000	1(14.0) (2501-2900m)	11.0	1(3.4)	2.5		

St. 26

0- 50	7(49.8-68.2)	60.3	7(6.9-10.2)	7.6	7(0.05-0.06)	0.05
51- 100	5(41.2-61.2)	58.8	5(3.9- 7.1)	5.5	5(0.06-0.16)	0.11
101- 200	3(21.4-24.6)	24.7	3(2.5- 3.7)	2.7	3(0.00-0.07)	0.03
201- 500	2(12.6-16.8)	21.4	2(1.9- 2.1)	2.3		
501-1000	5(24.3-33.1)	24.1	5(2.5- 2.8)	2.3		
1001-1500	3(28.9-32.3)	29.7	3(2.7- 2.9)	2.8		

St. 30

0- 50	5(40.1-62.7)	53.5	5(5.0- 6.8)	6.1	5(0.03-0.05)	0.04
51- 100	2(60.4-60.8)	61.0	2(6.4- 6.7)	6.4	2(0.06-0.11)	0.06
101- 200	1(57.2)	56.2	1(6.2)	6.2	1(0.08)	0.07
201- 500	5(19.8-37.9)	29.7	5(2.3- 4.5)	3.4		
501-1000	3(11.2-20.1) (501-678m)	16.5	3(2.0- 2.2)	2.6		

Table 4. (Continued)

St. 34

Depth range (m)	P.O.C. ($\mu g/l$)		P.O.N. ($\mu g/l$)		Chrlorophyll a (mg/m^3)	
	n (min-max)	mean	n (min-max)	mean	n (min-max)	mean
0- 50	5(32.1-68.4)	51.5	5(3.8- 6.7)	5.5	5(0.02-0.03)	0.02
51- 100	2(67.4-70.1)	60.2	2(7.2- 6.3)	6.0	2(0.05-0.09)	0.05
101- 200	2(46.2-47.2)	52.5	2(4.2- 5.1)	5.5	2(0.02-0.07)	0.07
201- 500	3(29.8-40.1)	37.5	3(3.1- 4.3)	3.9		
501-1000	6(12.7-60.1)	40.4	6(2.2- 5.7)	4.7		
1001-1500		31.3		3.5		
1501-2000	2(26.2-30.1)	27.5	2(2.9- 3.2)	3.0		
2001-2500	2(24.2-27.1)	24.6	2(2.9- 3.0)	3.0		
St. 38						
0- 50	5(49.2-72.4)	65.7	5(5.4- 8.4)	7.4	5(0.05-0.06)	0.06
51- 100	2(49.6-62.7)	52.8	2(5.2- 6.7)	5.7	2(0.05-0.10)	0.07
101- 200	1(61.4)	64.0	1(6.5)	6.5	1(0.04)	0.05
201- 500	5(29.8-68.6)	40.8	5(3.6- 6.0)	4.7		
501-1000	4(18.9-34.6)	26.9	4(2.9- 4.1)	3.5		
1001-1500	3(23.4-35.2)	31.2	3(2.7- 3.7)	3.4		
1501-2000	1(26.3)	31.6	1(2.9)	3.4		
St. 42						
0- 50	5(30.4-60.4)	51.1	5(4.6- 6.7)	5.5	5(0.04-0.06)	0.05
51- 100	2(48.1-59.6)	48.6	2(3.2- 5.3)	4.7	2(0.08-0.13)	0.09
101- 200	1(34.6)	39.2	1(4.7)	4.3	1(0.04)	0.07
201- 500	4(28.9-42.1)	33.0	4(4.5- 5.3)	4.5		
501-1000	5(18.7-34.6)	27.4	5(2.4- 3.3)	3.1		
1001-1500	3(31.4-36.2) (1001-1490m)	26.2	3(3.6- 3.8)	3.7		
St. 45						
0- 50	5(46.1-98.7)	66.3	5(6.2-12.4)	9.0	5(0.11-0.70)	0.41
51- 100	2(42.1-50.7)	54.3	2(7.6- 7.7)	7.9	2(0.02-0.18)	0.22
101- 200	3(39.6-50.3)	44.2	3(5.0- 7.8)	6.1	3(0.01-0.02)	0.01
201- 500	3(32.1-38.6)	33.4	3(4.8- 5.7)	5.1		
501-1000	4(16.8-31.4)	25.2	4(2.4- 4.7)	3.5		
1001-1500	1(22.7)	22.9	1(2.9)	3.2		
1501-2000	1(26.8)	24.9	1(3.0)	3.0		
2001-2500	2(19.8-21.2) (2001-2470m)	20.7	2(7.0- 7.3)	2.7		
St. 48						
0- 50	5(40.8-112.4)	62.4	5(6.2-16.2)	8.0	4(0.20-0.24)	0.21
51- 100	2(37.9- 53.5)	43.8	2(6.0- 8.3)	7.2	2(0.16-0.19)	0.19
101- 200	3(36.6-101.0)	43.9	3(3.9- 7.1)	6.2	3(0.01-0.12)	0.09
201- 500	3(49.9- 74.1)	65.8	3(5.3- 7.8)	6.4		
St. 51						
0- 50	5(55.5-120.1)	71.7	5(5.3-14.5)	8.4	5(0.07-0.20)	0.11
51- 100	2(30.2- 33.4)	38.5	2(4.1)	4.9	2(0.12-0.21)	0.19
101- 200	3(26.5- 48.6)	40.9	3(2.7- 4.8)	3.8	3(0.00-0.06)	0.04
201- 500	5(22.9- 47.3)	27.6	5(4.9- 8.7)	5.6		
501-1000	1(18.8)	18.0	1(4.2)	4.4		

Table 4. (Continued)

St. 55

Depth range (m)	P.O.C. ($\mu g/l$)		P.O.N. ($\mu g/l$)		Chlorophyll *a* (mg/m³)	
	n (min-max)	mean	n (min-max)	mean	n (min-max)	mean
0- 50	5(54.9-105.7)	87.1	5(6.4-14.9)	9.6	5(0.03-0.13)	0.02
51- 100	2(9.9- 39.0)	48.5	2(2.9- 6.4)	4.4	2(0.06-0.13)	0.11
101- 200	3(8.7- 24.8)	17.3	3(1.0- 3.5)	2.6	2(0.00-0.06)	0.02
201- 500	4(23.1- 47.0)	25.5	4(2.3- 9.2)	4.1		
501-1000	3(14.2- 89.6)	46.9	3(0.9- 6.2)	4.5		
1001-1500	1(21.0) (1001-1200m)	17.6	1(2.1)	1.0		
St. 58						
0- 50	5(56.4-166.8)	90.8	5(10.9-13.4)	12.5	5(0.01-0.03)	0.02
51- 100	2(59.1- 77.7)	75.6	2(8.2- 9.3)	9.4	2(0.02-0.13)	0.04
101- 200	2(38.6- 47.3)	46.7	2(5.5- 8.5)	6.9	3(0.00-0.09)	0.06
201- 500	3(10.6- 63.9)	25.0	3(3.6- 7.7)	4.6		
501-1000	2(23.4- 31.9)	28.9	2(1.6- 1.8)	1.7		
1001-1500	1(29.0)	28.9	1(1.2)	1.5		
1501-2000	2(21.7- 26.2) (1501-1980m)	24.7	2(1.5- 2.3)	1.9		
St. 61						
0- 50	4(46.0-114.9) (0-40m)	83.5	4(6.4-15.4)	11.5	3(0.16-0.65)	0.49
St. 62						
0- 50	5(57.5- 81.7)	69.7	5(8.0-12.7)	10.3	5(0.29-0.76)	0.54
St. 63						
0- 50	3(34.6- 55.4)	47.0	3(6.2-10.6)	8.6	3(1.16-1.68)	1.35
51- 100	2(24.4- 25.8)	27.7	2(2.6- 3.3)	3.9	2(0.20-0.32)	0.63
St. 64						
0- 50	3(18.2- 37.3)	27.2	3(2.7- 5.0)	4.2	3(0.55-1.12)	0.83
51- 100	2(33.6- 51.4)	38.7	2(4.4- 8.4)	6.0	2(0.81-1.40)	0.90
101- 200	2(17.8- 19.4)	30.6	2(2.7- 2.9)	2.8	3(0.13-1.64)	0.79
201- 500	2(12.8- 20.7)	16.1	2(1.6- 2.0)	1.8		
501-1000	2(6.3- 9.6)	8.2	2(0.4- 0.6)	0.5		
St. 65						
0- 50	3(22.9- 29.4)	27.1	3(3.5- 4.0)	3.9	3(0.14-0.22)	0.18
51- 100	2(23.2- 35.1)	30.8	2(3.6- 5.7)	4.8	2(0.36-0.42)	0.36
101- 200	3(6.5- 27.6)	17.0	3(0.7- 4.2)	2.6	3(0.01-0.19)	0.12
201- 500	1(22.3)	17.8	1(2.4)	2.0		
501-1000	3(18.0- 49.8) (501-880m)	28.1	3(2.0- 7.0)	3.6		

Table 4. (Continued)

St. 66

Depth range (m)	P.O.C. ($\mu g/l$)		P.O.N. ($\mu g/l$)		Chrlorophyll a (mg/m^3)	
	n (min-max)	mean	n (min-max)	mean	n (min-max)	mean
0- 50	3(27.8- 38.1)	31.0	3(4.3- 5.4)	4.6	3(0.13-0.18)	0.16
51- 100	2(22.0- 32.4)	31.3	2(3.2- 8.3)	6.3	2(0.20-0.56)	0.40
101- 200	3(35.4- 44.3)	37.9	3(5.7- 7.0)	6.0	2(0.03-0.21)	0.14
201- 500	2(7.1- 40.5)	24.0	2(0.6- 5.5)	3.2		
501-1000	1(7.1) (501-633m)	7.1	1(0.7)	0.7		

St. 67

0- 50	3(14.9- 23.6)	21.5	3(2.7- 3.2)	3.1	3(0.08-0.15)	0.10
51- 100	2(14.4- 31.0)	20.9	2(1.9- 4.6)	2.9	2(0.20-0.51)	0.27
101- 200	3(7.6- 15.0)	12.8	3(0.5- 2.0)	1.6	3(0.01-0.17)	0.14
201- 500	1(13.1)	10.6	1(1.5)	1.0		
501-1000	3(1.2- 5.7)	3.5	3(0.1- 0.3)	0.3		
1001-1500	1(7.9)	5.3	1(0.8)	0.5		
1501-2000		7.6		0.8		
2001-2500		6.9		0.8		
2501-3000	1(6.0)	6.2	1(0.7)	0.7		
3001-3500		7.8		1.0		
3501-4000	1(12.7)	11.1	1(1.8)	1.6		

St. 68

0- 50	3(23.8-45.9)	41.5	3(4.7- 8.3)	5.4	3(0.12-0.14)	0.13
51- 100	2(13.2-32.6)	29.6	2(2.2- 6.1)	4.6	2(0.11-0.19)	0.14
101- 200	3(12.3-20.3)	15.6	3(2.1- 3.3)	1.7	3(0.00-0.11)	0.08
201- 500	1(10.2) (201-416m)	12.6	1(2.3)	2.9		

St. 69

0- 50	3(26.6-35.2)	29.1	3(3.7- 5.9)	5.2	3(0.18-0.23)	0.47
51- 100	2(28.0-40.2)	31.1	2(4.7- 7.5)	5.2	2(0.24-0.52)	0.42
101- 200	3(8.9-28.7)	19.7	3(1.9- 6.0)	3.4	3(0.05-0.24)	0.05
201- 500	1(6.3)	7.8	1(0.8)	1.4		
501-1000	2(12.8-14.7)	12.8	2(1.8- 3.0)	2.2		
1001-1500	1(7.8)	10.4	1(1.5)	2.1		
1501-2000		8.6		1.8		

St. 70

0- 50	3(35.7-51.4)	45.8	3(7.5- 8.4)	7.8	3(0.35-0.71)	0.47
51- 100	2(16.1-17.0)	24.0	2(2.5- 3.5)	4.6	2(0.16-0.39)	0.42
101- 200	3(5.6-10.3)	8.1	3(0.9- 1.6)	1.4	3(0.27-0.65)	0.05
201- 500	1(20.1)	13.7	1(2.2)	1.7		
501-1000	3(6.2-11.7)	10.0	3(0.7- 1.3)	1.1		
1001-1500	1(6.8)	7.6	1(0.4)	0.5		
1501-2000	1(4.0)	4.5	1(0.2)	0.2		
2001-2500	1(4.5)	4.9	1(0.2)	0.3		
2501-3000	1(8.4)	7.6	1(1.1)	0.9		

Table 4. (Cntinued)

St. 73

Depth range (m)	P.O.C. ($\mu g/l$)		P.O.N. ($\mu g/l$)		Chlorophyll *a* mg/m^3)	
	n (min-max)	mean	n (min-max)	mean	n (min-max)	mean
0- 50	6(130.7-279.3)	203.5	6(21.8-42.0)	34.2	6(0.64-1.25)	1.19
51- 100	5(55.5-116.9)	93.2	5(9.0-20.9)	15.1	5(0.07-0.26)	0.30
101- 200	4(34.7- 58.1)	49.2	4(8.4-17.1)	13.0	4(0.05-0.14)	0.11
201- 500	4(21.8-150.3)	66.8	4(4.1-19.5)	9.7		
501-1000	7(17.6-155.3)	49.1	7(7.1-15.1)	10.9		
1001-1500	2(57.6- 86.7) (1001-1490m)	59.8	2(7.3-14.5)	12.6		
St. 74						
0- 50	6(60.2-221.4)	145.5	6(11.5-39.0)	22.4	6(0.17-0.35)	0.29
51- 100	3(34.6- 62.5)	47.4	3(9.2-10.0)	10.1	3(0.01-0.10)	0.10
101- 200	2(42.0- 72.3)	62.3	2(5.0- 7.1)	7.2	2(0.01)	0.01
201- 500	4(27.2- 85.4)	48.3	4(4.6-13.0)	8.9		
501-1000	4(22.2- 50.1)	38.8	4(5.2-12.4)	9.5		
1001-1500	2(52.1-119.4)	76.5	2(8.9-10.9)	9.9		
1501-2000	1(49.6)	48.4	1(6.9)	7.7		
2001-2500	1(25.5)	33.2	1(5.9)	6.2		
2501-3000	1(29.1) (2501-2744m)	50.4	1(6.9)	6.7		
St. 76						
0- 50	6(31.1- 43.3)	36.9	6(4.4- 5.9)	5.1	6(0.26-1.56)	0.64
51- 100	2(8.1- 16.8)	17.4	2(1.3- 3.1)	2.9	2(0.04-0.23)	0.54
101- 200	3(8.9- 13.0)	11.4	3(0.7- 1.4)	1.2	3(0.01-0.04)	0.02
201- 500	4(9.2- 16.1)	12.7	4(0.9- 2.8)	1.4		
501-1000	3(6.9- 8.0)	8.5	3(0.6- 1.3)	1.0		
1001-1500	2(8.0- 9.6)	8.6	2(0.4- 0.8)	0.6		
1501-2000	1(13.3)	11.7	1(0.7)	0.8		
2001-2500	1(5.1)	8.6	1(1.1)	0.9		
2501-3000	1(11.4)	8.8	1(1.0)	1.1		
3001-3500	1(12.2) (3001-3459m)	11.9	1(1.0)	1.0		
St. 77						
0- 50	6(35.8- 54.2)	41.5	6(3.4- 5.3)	4.5	5(0.54-1.24)	0.79
51- 100	2(15.5- 21.8)	24.5	2(1.4- 2.2)	2.5	2(0.13-0.32)	0.51
101- 200	1(18.2)	14.7	1(1.3)	1.5	3(0.01-0.02)	0.03
201- 500	2(11.0- 13.3)	11.1	2(0.9- 1.6)	1.0		
501-1000	2(8.6- 14.3)	10.8	2(0.8- 0.9)	0.9		
1001-1500	1(10.9)	13.3	1(0.7)	0.8		
St. 78						
0- 50	6(33.1- 51.2)	40.5	6(3.2- 6.6)	5.0	6(0.28-2.35)	0.68
51- 100	2(23.1- 27.2)	29.1	2(1.9- 3.0)	3.4	2(0.21-1.01)	1.15
101- 200	3(16.8- 24.9)	19.9	3(1.5- 2.7)	2.0	3(0.03-0.12)	0.09
201- 500	4(9.9- 19.2)	14.3	4(0.7- 2.4)	1.5		
501-1000	3(12.2- 17.0)	14.5	3(0.6- 0.8)	0.8		
1001-1500	2(10.3- 16.5)	13.7	2(0.6- 0.7)	0.7		
1501-2000		13.4		0.6		

Table 4. (Continued)

St. 78

Depth range (m)	P.O.C. ($\mu g/l$)		P.O.N. ($\mu g/l$)		Chlorophyll a (mg/m^3)	
	n (min-max)	mean	n (min-max)	mean	n (min-max)	mean
2001-2500	1(21.9)	19.4	1(1.2)	0.9		
2501-3000	1(13.0) (2501-2822m)	16.7	1(0.5)	0.8		
			St. 79			
0- 50	6(22.9- 51.1)	37.6	6(2.5- 7.7)	5.6	6(0.22-1.12)	0.58
51- 100	2(20.0- 26.5)	25.7	2(2.0- 4.3)	3.3	2(0.34-0.77)	0.76
101- 200	3(14.6- 21.2)	18.8	3(2.8- 2.9)	3.0	3(0.01-0.34)	0.14
201- 500	4(12.4- 25.0)	16.0	4(1.8- 4.2)	2.9		
501-1000	3(9.8- 16.7)	12.4	3(1.9- 3.1)	2.3		
1001-1500	2(11.9- 17.7)	15.2	2(2.6- 3.4)	3.0		
1501-2000	1(13.8)	13.1	1(2.5)	2.6		
2001-2500	1(13.4)	13.7	1(2.7)	2.2		
2501-3000	1(18.4)	16.7	1(3.2)	3.1		
			St. 80			
0- 50	6(28.4- 42.9)	37.4	6(3.9- 5.9)	5.5	6(0.22-1.10)	0.41
51 -100	2(20.2- 28.3)	27.6	2(2.2- 5.8)	4.9	2(0.42-0.48)	0.60
101- 200	3(10.9- 15.7)	14.5	3(1.8- 2.3)	2.1	3(0.01-0.06)	0.06
201- 500	4(16.3- 33.2)	26.0	4(1.7- 4.1)	3.1		
501-1000	3(12.3- 18.3)	16.4	3(2.1- 2.9)	2.5		
1001-1500	2(24.2- 28.6)	24.5	2(2.0- 2.2)	2.1		
1501-2000	1(19.3)	22.8	1(2.0)	2.1		
2001-2500	1(21.9)	20.7	1(2.6)	2.4		
			St. 81			
0- 50	6(46.3- 56.0)	44.9	6(5.3- 8.5)	6.6	6(0.29-1.02)	0.60
51- 100	2(16.3- 21.7)	27.8	2(3.1- 3.7)	4.8	2(0.22-0.39)	0.46
101- 200	3(12.5- 19.2)	15.6	3(1.9- 2.8)	2.4	3(0.01-0.04)	0.15
201- 500	4(14.6- 26.2)	21.6	4(1.7- 3.2)	2.5		
501-1000	3(14.3- 21.7)	18.8	3(2.1- 3.2)	2.7		
1001-1500	2(15.9- 18.0)	17.5	2(1.8- 2.2)	2.3		
1501-2000	1(14.4) (1501-1916m)	16.0	1(2.3)	2.1		
			St. 84			
0- 50	5(29.7-107.5)	50.3	5(4.5-12.4)	7.1	5(0.07-0.19)	0.13
51- 100	2(9.5- 11.0)	14.2	2(-0.3--0.2)	0.9	2(0.01)	0.03
101- 200	3(14.5- 26.5)	19.2	3(0.8- 1.0)	0.7	3(0.00-0.01)	0.00
201- 500	4(21.1- 59.8)	40.8	4(0.6- 4.8)	1.2		
501-1000	3(32.3- 52.5)	41.9	3(2.4- 3.9)	3.1		
1001-1500	2(-4.7- 30.0) (1001-1448m)	11.9	2(-1.5- 0.5)	-0.1		
			St. 87			
0- 50	5(91.4-436.7)	291.6	5(7.1-65.0)	47.1	5(0.25-1.49)	0.85
51- 100	2(57.5-167.5)	93.5	2(3.9- 6.4)	5.4	2(0.04-0.10)	0.12
101- 200	2(108.0-129.5)	127.1	2(2.8- 5.5)	4.7	2(0.04-0.11)	0.06

Table 4. (Continued)

St. 87

Depth range (m)	P.O.C. ($\mu g/l$)		P.O.N. ($\mu g/l$)		Chlorophyll a (mg/m^3)	
	n (min-max)	mean	n (min-max)	mean	n (min-max)	mean
201- 500	2(84.3- 93.5)	91.5	2(1.4- 3.5)	2.1		
501-1000	2(27.5- 66.3)	60.4	2(1.3- 1.4)	1.9		
1001-1500	1(71.5) (1001-1149m)	57.4	1(1.7)	1.6		
St. 88						
0- 50	5(83.0-181.7)	139.4	5(11.1- 28.2)	22.8	4(0.10-0.47)	0.31
51- 100	2(18.3- 30.5)	40.2	2(2.4- 2.8)	4.8	2(0.03-0.05)	0.05
101- 200	2(17.0- 63.0)	41.6	2(0.9- 2.2)	1.6	2(0.01-0.02)	0.02
201- 500	2(16.5- 32.8)	22.3	2(1.4- 2.5)	2.0		
501-1000	3(−0.1- 30.5)	16.1	3(−0.6- 0.3)	0.1		
1001-1500	2(13.8- 17.6) (1001-1467m)	17.0	2(−0.7- 2.1)	1.0		
St. 90						
0- 50	5(33.0-177.5)	104.3	5(8.9- 25.5)	17.0	5(0.01-0.32)	0.20
51- 100	2(22.0- 25.6)	25.9	2(1.5- 2.5)	3.8	2(0.02-0.04)	0.08
101- 200	3(9.4- 35.5)	11.1	3(0.3- 4.6)	1.8	3(0.01-0.02)	0.01
201- 500	3(21.8- 50.4)	37.0	3(1.4- 1.9)	1.9		
501-1000	4(9.3- 39.5)	23.2	4(0.4- 3.2)	2.0		
1001-1500	2(12.0- 20.5) (1001-1407m)	16.2	2(0.3- 1.0)	0.5		
St. 92						
0- 50	5(57.0- 83.3)	63.8	5(7.5- 15.1)	9.1	5(0.17-0.48)	0.29
51- 100	2(17.0- 24.3)	25.1	2(1.0- 3.9)	3.1	2(0.02-0.31)	0.17
101- 200	3(13.3- 26.4)	26.0	3(1.6- 2.8)	2.4	3(0.01-0.03)	0.02
201- 500	4(21.3- 71.0)	41.8	4(0.5- 2.6)	1.5		
501-1000	3(5.6- 35.5) (501-947m)	25.1	3(−0.2- 0.7)	0.7		
St. 93						
0- 50	4(59.8-450.3)	200.4	4(8.1- 57.9)	25.6	4(0.16-1.32)	0.87
51- 100	2(30.2- 32.9)	39.0	2(0.9- 2.5)	3.1	2(0.06-0.10)	0.10
101- 200	2(25.3- 43.4)	35.6	2(0.0- 7.2)	4.3	2(0.10)	0.10
201- 500	2(35.3- 48.0) (201-369m)	36.2	2(2.7- 7.4)	3.3		
St. 94						
0- 50	5(32.2-152.2)	95.1	5(5.9- 26.5)	17.1	5(0.02-0.38)	0.20
51- 100	2(24.9- 75.5)	42.4	2(0.5- 10.0)	4.7	2(0.01)	0.01
101- 200	3(11.9- 41.0)	45.2	3(0.5- 5.6)	6.1	3(0.01-0.15)	0.09
201- 500	4(11.9- 28.5)	18.0	4(1.2- 3.2)	2.1		
501-1000	2(11.9- 28.0) (501-743m)	16.3	2(1.2- 2.0)	1.8		

Table 4. (Continued)
St. 95

Depth range (m)	P.O.V. ($\mu g/l$)		P.O.N. ($\mu g/l$)		Chlorophyll a (mg/m^3)	
	n (min-max)	mean	n (min-max)	mean	n (min-max)	mean
0- 50	5(61.1-179.4)	125.9	5(8.3- 28.4)	19.5	5(0.27-0.83)	0.59
51- 100	2(28.9- 35.3)	39.2	2(3.1- 4.0)	4.7	2(0.03)	0.18
101- 200	3(6.3- 29.9)	18.3	3(0.9- 5.6)	3.6	3(0.01-0.02)	0.02
201- 500	3(25.1- 45.4)	36.9	3(3.1- 4.3)	3.6		
501-1000	2(27.3- 29.9)	28.3	2(−1.5−−1.0)	−0.7		
1001-1500	2(36.0- 78.5) (1001-1374m)	49.8	2(3.1- 9.7)	4.9		

seems to indicate that the amount of total particulate material suspended in a water column in a given area is ultimately controlled by the surface situation which is a linear function of the primary production in the area. This does not necessarily mean that the surface born particles are direct sources of deepwater particles. The carbon content of deepwater particles were not found to be consistently lower than that of the surface particles. Probably a certain fraction of particulate material in deeper layers might be the product of endogenous formation either by autochthonous heterotrophs or by spontaneous adsorption of dissolved organic matter. Both processes require a supply of dissolved organic matter, and migrating zooplankton might served as rapid messengers that carry these source materials down into the deep layer.

Part II. *Concentrations of Particulate Organic Carbon, Nitrogen, and Phytoplankton Pigments in Relation to Hydrographic Structure of the Western North Pacific Ocean and Adjacent Seas.*

In the preceding part, the organic fraction of seston was discussed for the selected areas. In this Part, the distribution of particulate organic matter in terms of carbon and nitrogen will be described in detail in relation to the hydrographical structure of seas. Data on particulate materials (organic carbon and nitrogen, chlorophyll *a* and pheopigments) in seawater were available from 39 stations in the North Pacific Ocean and her marginal seas, i.e., the Philippine Sea, the East China Sea, the Japan Sea and the Bering Sea, and are summarized in Tables 4 and 5 in the same manner as in Part I.

I. *The Philippine Sea and the East China Sea.* A total of seventy routine hydrographic stations including 28 large volume water sampling stations were available along the three lines of 142°E from 2°S to 30°N (Oshoro-Maru, Winter 1966–1969), 125°E from 22°N to 32°N, and 132°E from 22°N to 30°N (KH–68–2, early Summer 1968) in these areas.

The section along a line of 142°E from 19° to 29°N in Jan. 1966 (Table 2, Figs

Table 5. Areal mean concentrations of P.O.C., P.O.N. and chlorophyll *a* in a series of depth ranges (cf. Table 4) in 13 areas, except for the shelf water of the East China Sea, in the western North Pacific Ocean and adjacent seas. Sample number (n) and total range (min-max) in each depth range are included. Average carbon and nitrogen per m^2. in two water columns of 0–1500 m. and 1501– the maximum depth observed and total chlorophyll *a* per m^3. in upper 200 m. depth for each area are also shown.

(1) Philippine Sea and East China Sea

(a) South Equatorial Current Region (SEC) (Sts. 45 and 48)

Depth range (m)	P.O.C. (μgC/l)		P.O.N. (μgN/l)		Chlorophyll *a* (mg/m^3)	
	n (min-max)	mean	n (min-max)	mean	n (min-max)	mean
0- 50	2(62.4-66.3)	64.4	2(8.0- 9.0)	8.5	2(0.21-0.41)	0.31
51- 100	2(43.8-54.3)	49.1	2(7.2- 7.9)	7.6	2(0.19-0.22)	0.21
101- 200	2(43.9-44.2)	44.1	2(6.1- 6.2)	6.2	2(0.01-0.09)	0.05
201- 500	2(33.4-65.8)	49.6	2(5.1- 6.4)	5.8		
501-1000	1(25.2)	25.2	1(3.5)	3.5		
1001-1500	1(22.9)	22.9	1(3.2)	3.2		
1501-2000	1(24.9)	24.9	1(3.0)	3.0		
2001-2500	1(20.7)	20.7	1(2.7)	2.7		
	Total (gC/m^2)		Total (gN/m^2)		Total (mg/m^2)	
0-1500	49.0		6.5		0-200m 31.0	
1500-2500	22.8		2.9			

(b) Equatorial Counter Current region (ECC) (Sts. 26, 51 and 55)

0- 50	3(60.3-87.1)	73.3	3(7.6- 9.6)	8.5	3(0.05-0.06)	0.06
51- 100	3(38.5-58.8)	48.5	3(4.4- 5.5)	4.9	3(0.11-0.49)	0.14
101- 200	3(17.3-40.9)	27.6	3(2.6- 3.8)	3.0	3(0.03-0.38)	0.03
201- 500	3(21.4-27.6)	24.8	3(2.3- 5.6)	4.0		
501-1000	3(18.0-46.9)	29.7	3(2.3- 4.5)	3.7		
1001-1500	2(17.6-29.7)	23.7	2(1.0- 2.8)	1.9		
	Total (g/Cm^2)		Total (gN/m^2)		Total (mg/m^2)	
0-1500	43.0		5.0		0-200m 13.0	

(c) North Equatorial Current region (NEC) (Sts. 15, 30, 34, 38 and 58)

0- 50	5(31.8-90.8)	58.7	5(4.3-12.5)	7.1	5(0.02-0.06)	0.03
51- 100	5(33.1-75.6)	46.1	5(5.7-12.6)	8.0	5(0.03-0.07)	0.05
101- 200	5(34.3-64.0)	50.7	5(5.5-14.2)	7.8	5(0.03-0.07)	0.06
201- 500	5(24.5-40.8)	31.5	5(3.4- 5.4)	4.4		
501-1000	5(16.5-40.4)	26.3	5(1.7- 4.7)	3.0		
1001-1500	4(23.0-28.9)	28.6	4(1.5- 3.5)	2.9		
	Total (gC/m^2)		Total (gN/m^2)		Total (mg/m^2)	
0-1500	47.2		5.8		0-200m 10.0	

(d) Kuroshio Counter region (KCC) (Sts. 19, 21 and 42)

0- 50	3(35.9-51.1)	45.7	3(2.9- 5.5)	4.4	3(0.03-0.06)	0.05
51- 100	3(25.5-48.6)	38.1	3(4.6- 6.8)	5.4	3(0.04-0.09)	0.06
101- 200	3(39.2-53.0)	45.4	3(1.7- 7.7)	4.6	3(0.02-0.07)	0.04
201- 500	3(29.8-39.9)	34.3	3(3.7- 4.5)	4.0		
501-1000	3(27.4-33.1)	30.3	3(3.0- 3.9)	3.3		
1001-1500	3(22.2-33.9)	27.5	3(2.1- 6.2)	4.0		
1501-2000	2(55.3-12.6)	9.0	2(1.0- 1.9)	1.5		

Table. 5 (Continued)

Depth range (m)	P.O.C. (μgC/l)		P.O.N. (μgN/l)		Chlorophyll a (mg/m^3)	
	n (min-max)	mean	n (min-max)	mean	n (min-max)	mean
2001-2500	2(4.1-17.6)	10.9	2(1.5- 2.4)	2.0		
2501-3000	1(14.0)	11.0	1(2.5)	2.5		
	Total (gC/m^2)		Total (gN/m^2)		Total (mg/m^2)	
0-1500	47.9		5.8		0-200m 9.5	
1501-3000	15.3		3.0			
(e) Kuroshio Counter Current region (KCC, KH-68-2) (Sts. 65, 66, 67, 68 and 69)						
0- 50	5(21.5-41.5)	30.0	5(3.1- 5.4)	4.4	5(0.10-0.47)	0.21
51- 100	5(20.9-31.3)	28.7	5(2.9- 6.3)	4.8	5(0.14-0.42)	0.32
101- 200	5(12.8-37.9)	19.8	5(1.6- 6.0)	3.1	5(0.05-0.14)	0.11
201- 500	5(7.8-24.0)	14.6	5(1.0- 3.2)	2.1		
501-1000	4(3.5-28.1)	12.9	4(0.3- 3.6)	1.7		
1001-1500	2(5.3-10.4)	7.9	2(0.5- 2.1)	1.3		
1501-2000	2(7.6- 8.6)	8.1	2(0.8- 1.8)	1.3		
2001-2500	1(6.9)	6.9	1(0.8)	0.8		
2501-3000	1(6.2)	6.2	1(0.7)	0.7		
3001-3500	1(7.8)	7.8	1(1.0)	1.0		
3501-4000	1(11.1)	11.1	1(1.6)	1.6		
	Total (gC/m^2)		Total (gN/m^2)		Total (mg/m^2)	
0-1500	19.7		2.9		0-200m 37.5	
1501-4000	20.1		2.7			
(f) Kuroshio Current region (KC) (Sts. 64 and 70)						
0- 50	2(27.2-45.8)	36.5	2(4.2- 7.8)	6.0	2(0.47-0.83)	0.65
51- 100	2(24.0-38.7)	31.5	2(4.6- 6.0)	5.3	2(0.42-0.90)	0.66
101- 200	2(8.1-30.6)	19.4	2(1.4- 2.8)	2.1	2(0.05-0.79)	0.42
201- 500	2(13.7-16.1)	14.9	2(1.7- 1.8)	1.8		
501-1000	2(8.2-10.0)	9.1	2(0.5- 1.1)	0.8		
1001-1500	1(7.6)	7.6	2(0.4- 0.5)	0.5		
1501-2000	1	4.5	1	0.2		
2001-2500	1	4.9	1	0.3		
2501-3000	1	7.6	1	0.9		
	Total (gC/m^2)		Total (gN/m^2)		Total (mg/m^2)	
0-1500	18.5		2.0		0-200m 107.5	
1501-3000	12.3		1.0			
(2) Northern Areas						
(g) Oyashio Current region (St. 73, April 1967)						
0-1500	94.2(gC/m^2)		18.4(gN/m^2)		0-200m 85.5(mg/m^2)	
(h) Oyashio Current region (St. 74, Sept. 1969)						
0-1500	88.0(gC/m^2)		14.7(gN/m^2)		0-200m 20.5(mg/m^2)	
1501-3000	66.0(〃)		10.3(gN/m^2)			
(i) Northern North Pacific (St. 84)						
0-1500	27.1(gC/m^2)		3.5(gN/m^2)		0-200m 8.0(mg/m^2)	

Table 5. (Contineed)

Depth range (m)	P.O.C. (μgC/l)		P.O.N. (μgN/l)		Chlorophyll a (mg/m^3)	
	n (min-max)	mean	n (min-max)	mean	n (min-max)	mean
(j) The Bering Sea (St. 87)						
0-1500	118.3		5.5		0-200m 54.5	
(k) The Bering Sea from 52°N to 58°N, 178°W line (Sts. 88, 90, 92 and 94)						
0- 50	4(63.8-139.4)	100.6	4(9.1-22.8)	16.5	4(0.20-0.31)	0.25
51- 100	4(25.1-42.4)	33.4	4(3.1- 4.8)	4.0	4(0.01-0.17)	0.08
101- 200	4(11.1-45.2)	40.0	4(1.6- 6.1)	3.0	4(0.01-0.09)	0.04
201- 500	4(18.0-41.8)	29.8	4(1.5- 2.1)	1.9		
501-1000	4(16.1-25.1)	20.2	4(0.1- 2.0)	1.2		
1001-1500	2(16.2-17.0)	16.6	2(0.5- 1.0)	0.8		
	Total (gC/m^2)		Total (gN/m^2)		Total (mg/m^2)	
0-1500	38.0		2.9		0-200m 20.5	
(l) The Bering Sea (St. 95)						
0-1500	60.2(gC/m^2)		5.1(gN/m^2)		0-200m 40.5(mg/m^2)	
(3) The Japan Sea						
(m) The Japan Sea (KH-70-4) (Sts. 76, 77, 78, 79, 80 and 81)						
0- 50	6(36.9-44.9)	39.8	6(4.5- 6.6)	5.4	6(0.41-0.79)	0.62
51- 100	6(17.4-29.6)	25.4	6(2 5- 4.9)	3.7	6(0.46-1.15)	0.68
101- 200	6(11.4-19.9)	15.8	6(1.2- 3.0)	2.0	6(0.02-0.15)	0.08
201- 500	6(11.1-26.0)	17.0	6(1.0- 3.1)	2.1		
501-1000	6(8.5-18.8)	13.6	6(0.8- 2.7)	1.7		
1001-1500	6(8.6-24.5)	15.5	6(0.6- 3.0)	1.6		
1501-2000	5(11.7-22.8)	15.4	5(0.6- 2.6)	1.6		
2001-2500	4(8.6-20.7)	15.6	4(0.9- 2.4)	1.6		
2501-3000	3(8.8-16.7)	14.1	3(0.8- 3.1)	1.7		
3001-3500	1(11.9)	11.9	1(1.9)	1.0		
	Total (gC/m^2)		Total (gN/m^2)		Total (mg/m^2)	
0-1500	24.5		2.9		0-200m 73.0	
1501-3500	28.5		3.0			

8a-8d). The temperature and salinity sections (Figs 8a and 8b) show that the subtropical convergence line was clearly recognized at about 25°N in this year. The entire section was divided by the convergence line into the two regions i.e. Kuroshio Counter Current (KCC) and North Equatorial Current (NEC). In the south of the convergence line the thermocline was well developed in the layer of 100–200 m where the corresponding intermediate water of high salinity more than 34.90‰ was encountered. The subarctic intermediate water characterized by the low salinity (34.2‰) existed in the layers of 600–800 m.

Chlorophyll a (Fig. 8c) ranged from 0.01 mg/m^3 to 0.25 mg/m^3 in the upper 200 m layer and the maximum concentration appeared near the 100 m depth layer, or in the upper layer of the thermocline through this section, in contrast with the

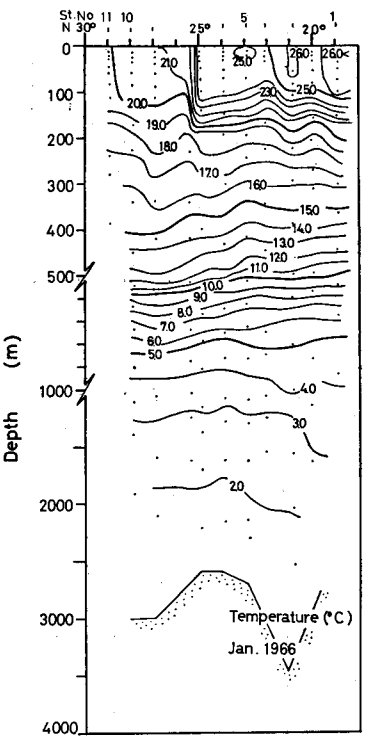

Fig. 8a. Section of temperature along a 142°E. line from 19° to 29°N., Jan. 1966 Oshoro-Maru Cruise 16.

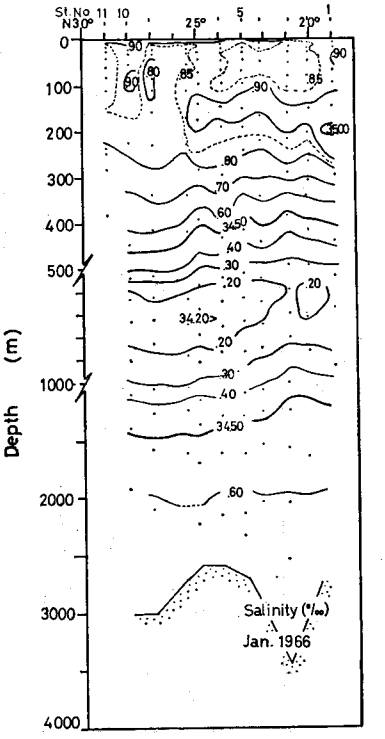

Fig. 8b. Section of salinity along a 142°E. line from 19° to 29°N., Jan. 1966, Oshoro-Maru Cruise 16.

low concentration at sea surface. The concentration of chlorophyll *a* was generally higher in the KCC region than in the NEC region. Below the 200 m layer, appreciable concentrations of chlorophyll, less than 0.02 mg/m^3, were observed down to a depth of 3000 m. On the other hand, the maximum layer of seston dried weight was in the surface layer of 0–30 m (Fig. 8d). In the layer around 100 m depth where the chlorophyll maximum appeared was the minimum of seston dried weight. This is a clear-cut example of inverse correlation between chlorophyll *a* and total seston. Further, the secondary maximum of seston dried weight was observed just below the minimum layer mainly in the KCC area. Seston dried weight showed an extremely homogeneous distribution within the 300–1500 m, although seston decreased markedly in the core of the subarctic intermediate water. This year no data on particulate orgacnic carbon and nitrogen were available.

The section along a line of 142°E from 16°N to 26°N in Jan. 1967 (Figs. 9a-e). The same area, as in the previous year, were re-visited but only three stations were obtained. The general hydrographic situation was practically the same as in 1966

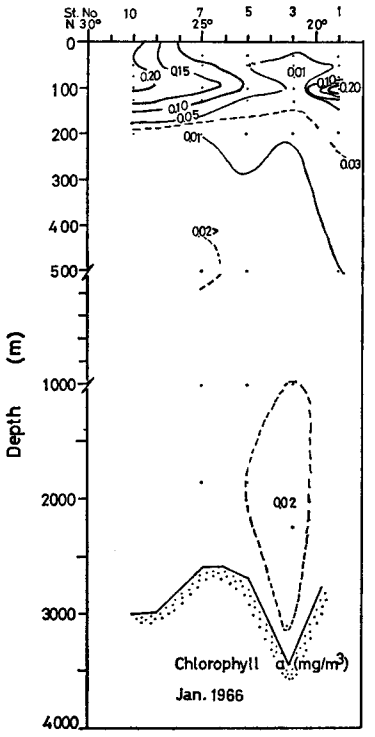

Fig. 8c. Section of chlorophyll *a* along a 142°E. line from 19° to 29°N., Jan. 1966 Oshoro-Maru Cruise 16.

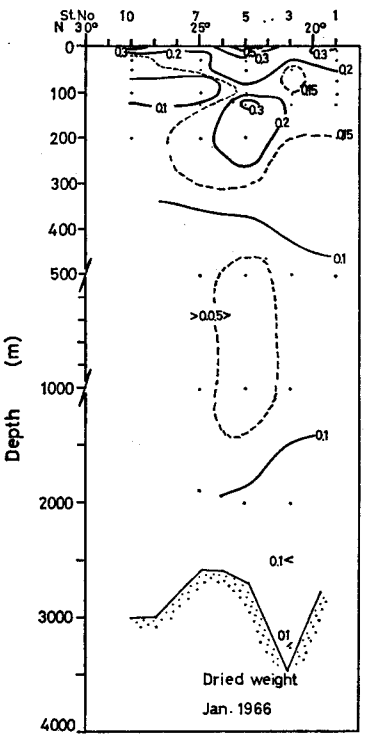

Fig. 8d. Section of seston dried weight along a 142°E. line from 19° to 29°N., Jan. 1966, Oshoro-Maru Cruise 16.

except that the subtropical convergence line was observed at 23.30°N this year. Chlorophyll *a* in the euphotic layer was low, ranging from 0.03 to 0.09 mg/m³ and relatively high values were observed in the layer of 50–100 m. A trace amount of chlorophyll *a* was observed even from the deepest sample obtained but it is conspicuous that at about 1500 m a considerable amount of chlorophyll *a* (0.02–0.03 mg/m³) was detected in three samples. On the other hand, the concentration of particulate organic carbon was ranged between 10 and 74 μgC/l except for a few abnormally low values. The carbon concentration did not decrease with increasing depth and was slightly higher in the KCC than in the NEC through the entire water column observed. Its surface minimum occurred at a 100 m depth where the maximum or relatively high amount of chlorophyll *a* appeared. The second and third minimum layers were recognized in the 200–300 m and 600–800 m layers, respectively. The latter corresponded in the depth range with the subarctic intermediate water.

The variation of nitrogen approximately coincided with that of carbon, but nitrogen concentration was higher in the NEC area than in the KCC area.

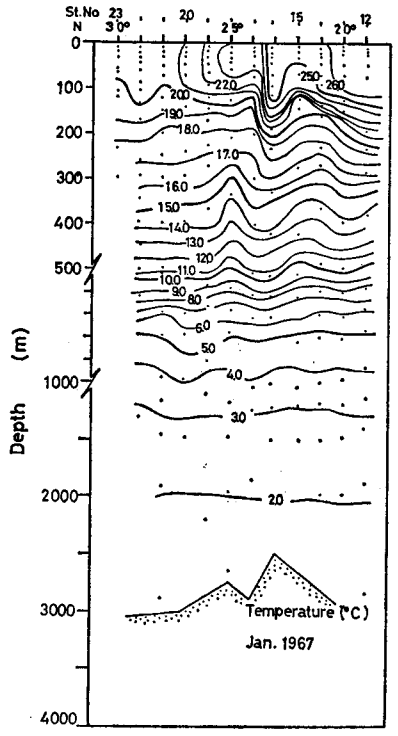

Fig. 9a. Section of temperature along a 142°E. line from 19° to 30°N., Jan. 1967, Oshoro-Maru Cruise 21.

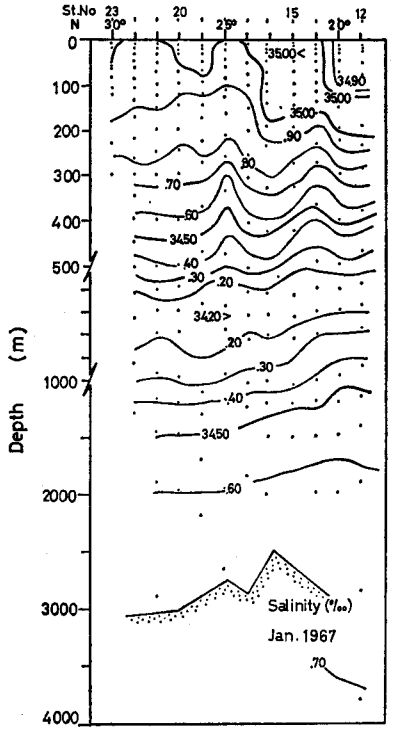

Fig. 9b. Section of salinity along a 142°E. line from 19° to 30°N., Jan. 1967, Oshoro-Maru Cruise 21.

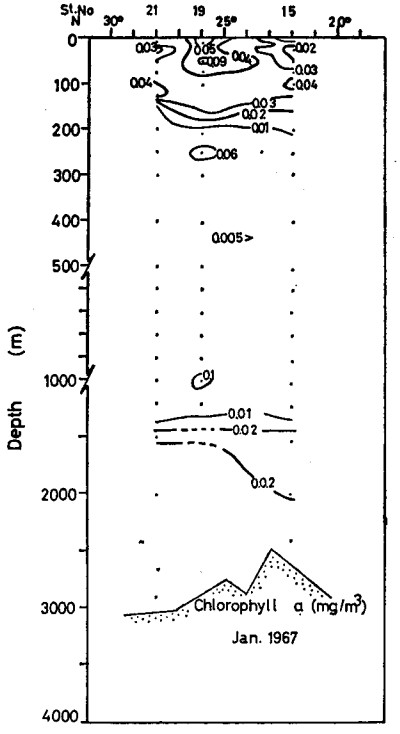

Fig. 9c. Section of chlorophyll *a* along a 142°E. line from 19° to 30°N., Jan. 1967, Oshoro-Maru Cruise 21.

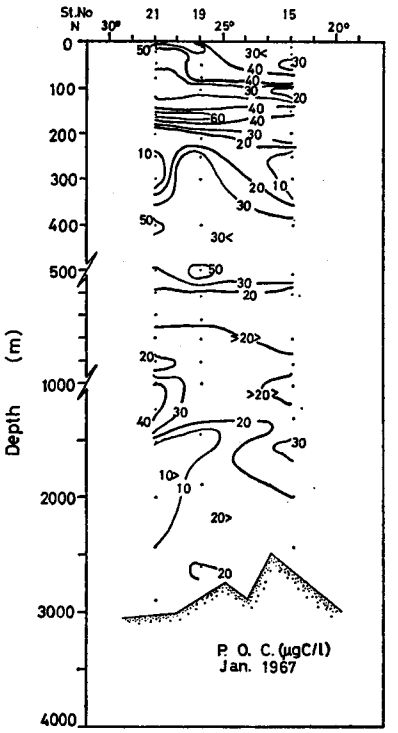

Fig. 9d. Section of particulate organic carbon along a 142°E. line 19° to 30°N. Jan. 1967, Oshoro-Maru Cruise 21.

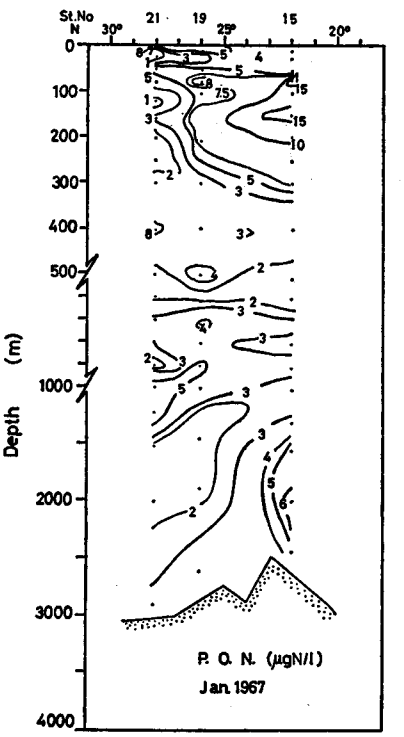

Fig. 9e. Section of particulate organic nitrogen along a 142°E. line 19° to 30°N., Jan. 1967, Oshoro-Maru Cruise 21.

The section along a line of 142°E from 5° to 25°N, Jan. 1968 (Figs. 10a-10e). The temperature and salinity sections showed that the subtropical convergence line existed near the 22°, and the boundary between the North Equatorial Current and the equatorial Counter Current (ECC) appeared between 9° and 10°N. Isothermal lines became gradually dense from north to south, and the thermocline was progressively well developed toward the south in the 100–200 m layer. A marked minimum of surface salinity existed from 16° to 8°N in the upper 100 m layer overlying the high salinity intermediate water. Another core of minimum salinity of the subarctic intermediate water was encountered within 600–800 m in the KCC region, and extending toward the divergence zone near 10°N.

Concentration of chlorophyll *a* was in the range of 0.04–0.15 mg/m^3 in the euphotic layer and the core (0.08–0.15 mg/m^3) existed in the narrow layer at about 100 m depth. The amount of chlorophyll *a* was slightly lower in the NEC areas. The vertical profiles of particulate organic carbon and nitrogen were quite similar to each other, both showing a well stratified distribution throughout the section. The first maximum of more than 50 μgC/*l* appeared at the surface. The

secondary maximum which was almost comparable to the surface maximum occurred in a close association with the chlorophyll maximum. This situation was quite different from that obtained in the previous two sections, although the surface maxima of carbon and nitrogen were not attended by any chlorophyll maximum. Below the 300 m depth, particulate carbon ranged between 10 and 40 μgC/l except for a high value of above 60 μgC/l and nitrogen between 1 and 4 μgN/l except a correspondingly high value of above 5 μgN/l obtained in the layer of 500–700 m at 15°N. Carbon and nitrogen were more than 30 μgC/l and 3 μgN/l in the layer of the subarctic intermediate water, while in the 800–1000 m depth layer, just below the Subarctic Intermediate water, a marked minimum of carbon less than 30 μgC/l was located and extended towards the convergence zone near 10°N.

The section along a line of 142°E from 2°S to 13°N Dec. 1968–Jan. 1969 (Figs. 11a-11e). A boundary of temperature and salinity in the surface layer located at about 5°N seemed to separate the Equatorial Counter Current and the South Equatorial Current (SEC). In the upper 60 m layer between 10° and 5°N, a watermass of extremely low salinity less than 34.20‰ existed. The high salinity

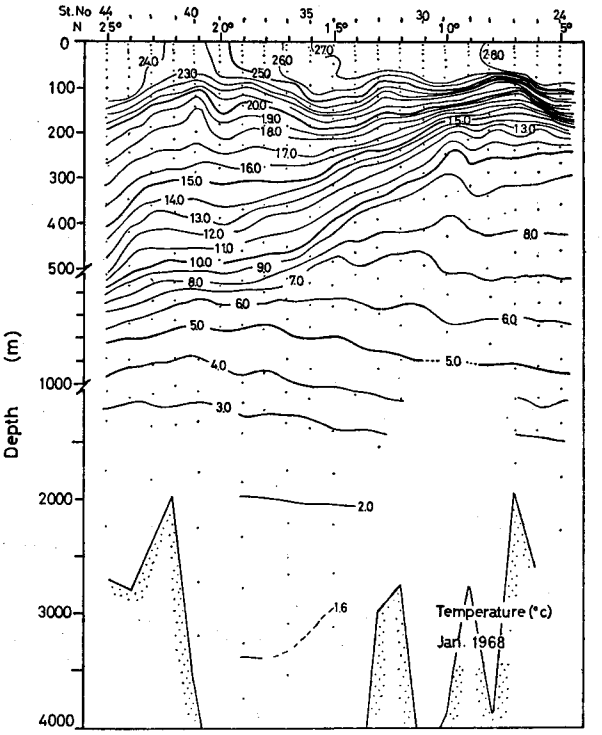

Fig. 10a. Section of temperature along a 142°E. line from 5° to 25°N., Jan. 1968, Oshoro-Maru Cruise 26.

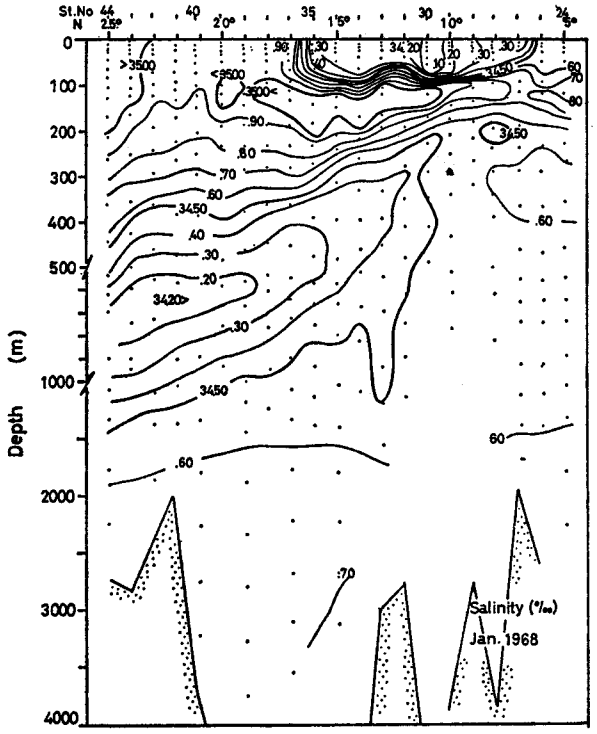

Fig. 10b. Section of salinity along a 142°E. line from 5° to 25°N., Jan. 1968, Oshoro-Maru Cruise 26.

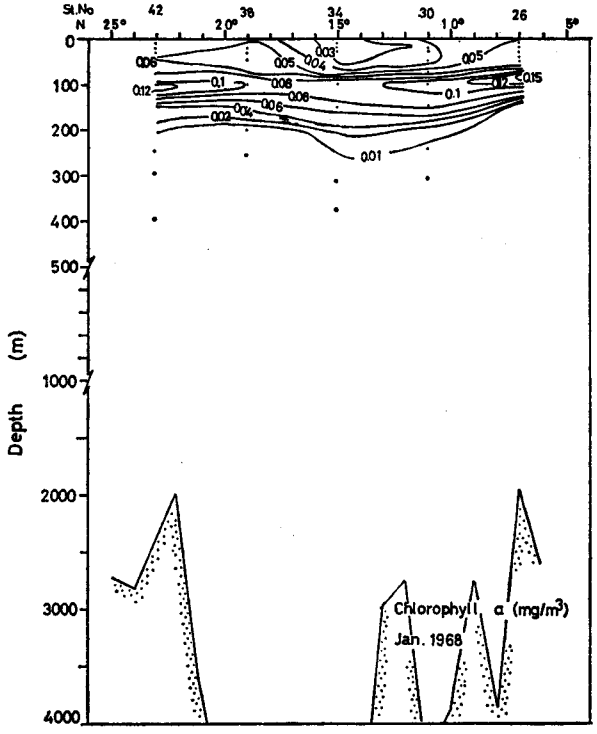

Fig. 10c. Section of chlorophyll *a* along a 142°E. line from 7° to 23°N., Jan. 1968, Oshoro-Maru Cruise 26.

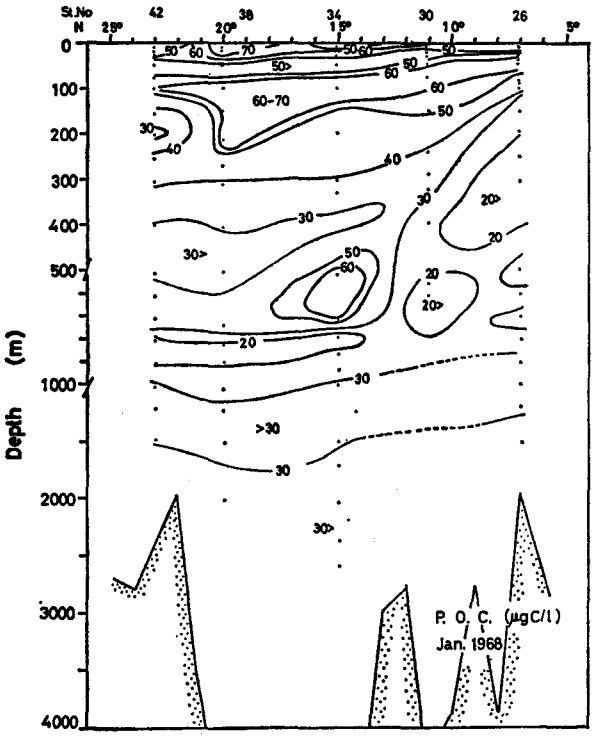

Fig. 10d. Section of particulate organic carbon along a 142°E. line from 7° to 23°N., Jan. 1968, Oshoro-Maru Cruise 26.

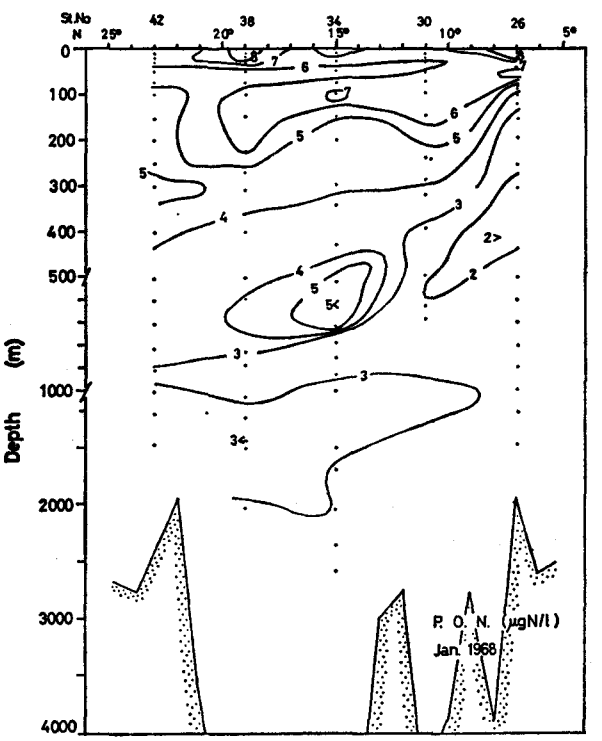

Fig. 10e. Section of particulate organic nitrogen along a 142°E. line from 7° to 23°N., Jan. 1968, Oshoro-Maru Cruise 26.

intermediate water (more than 35%) of the South Equatorial Current was encountered in the 100–300 m layer and the subarctic intermediate water spread up to 10°N.

The depth of the maximum layer of chlorophyll *a* became gradually shallower from 100 m at 11°N towards the equator, and the concentration also increased towards the equator. At the equator, the maximum concentration of chlorophyll above 0.2 mg/m³ was close to the sea surface. On the other hand, the maximum of carbon in the range of 75–100 μgC/*l* occurred in the upper 50 m layer. Below 100 m depth, the distribution of carbon was nearly parallel with that of salinity; carbon was homogeneous and as low as 20 μgC/*l* in the ECC area except an extremely high value of 90 μgC/*l* at 600 m, while in the SEC area, carbon ranged from 20 to 100 μgC/*l* and showed a marked layering. There was no much difference in distribution pattern between carbon and nitrogen.

The section along a line of 132°E from 22° to 30°N, May-June. 1968 (Figs. 12a –12e). The northern most stations of this section (St. 70) was located in the Kuroshio Current and other stations in the Kuroshio Counter Current; surface salinity at St. 70 was slightly low due to the low salinity water of the East China Sea as compared with the Kuroshio Counter Current. Throughout the section,

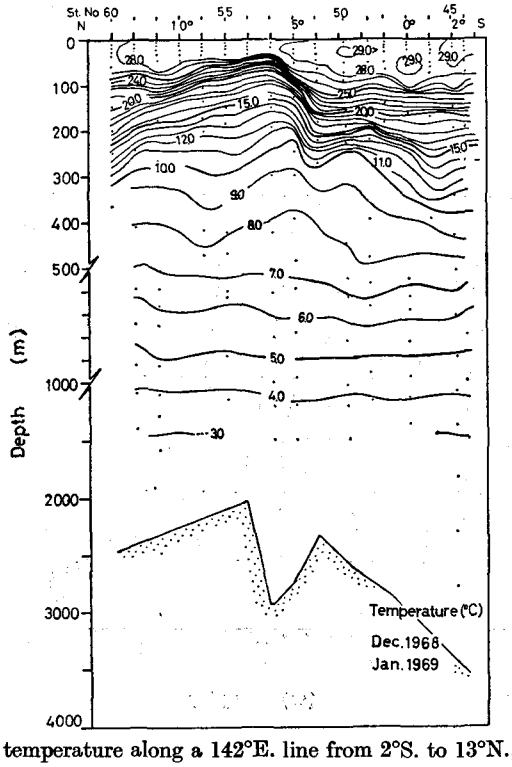

Fig. 11a. Section of temperature along a 142°E. line from 2°S. to 13°N., Dec. 1968 to Jan. 1969, Oshoro-Maru Cruise 30.

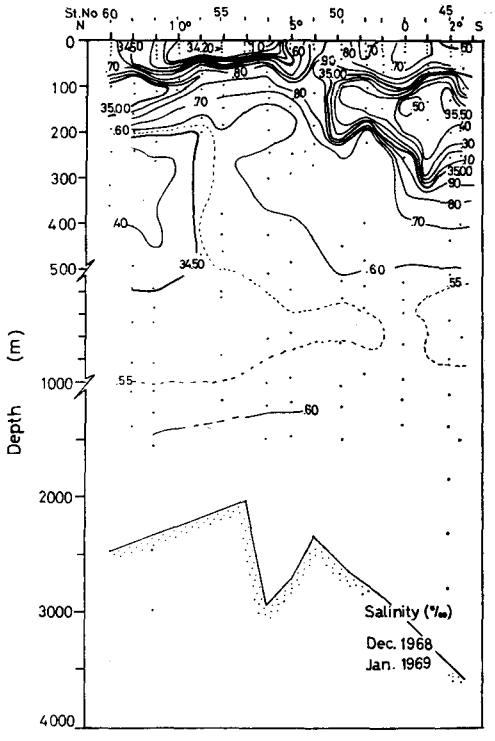

Fig. 11b. Section of salinity along a 142°E, line from 2°S. to 13°N., Dec. 1968 to Jan. 1969, Oshoro-Maru Cruise 30.

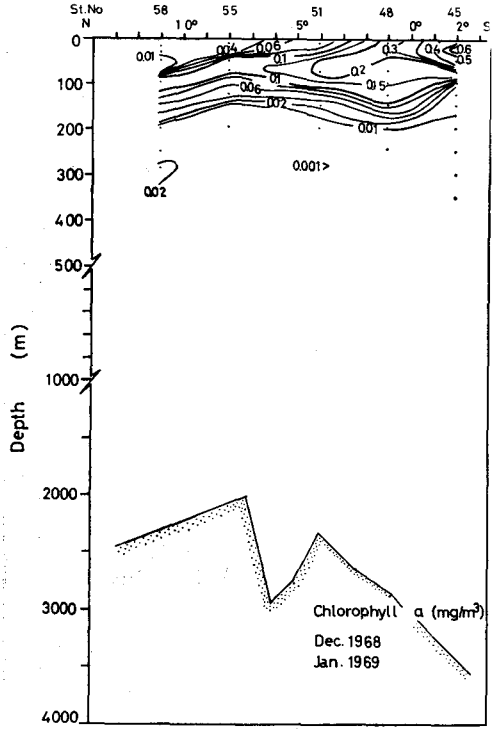

Fig. 11c. Section of chlorophyll *a* along a 142°E. line from 2°S. to 11°N., Dec. 1968 to Jan. 1969, Oshoro-Maru Cruise 30.

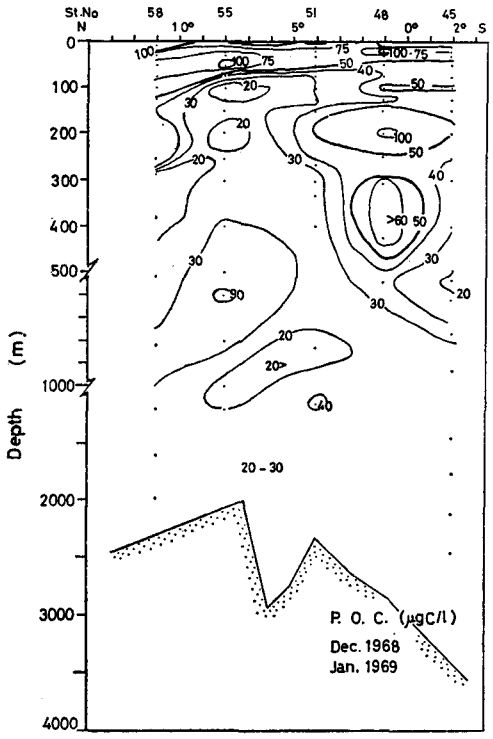

Fig. 11d. Section of particulate organic carbon along a 142°E. line from 2°S. to 11°N., Dec. 1968 to Jan. 1969, Oshoro-Maru Cruise 30.

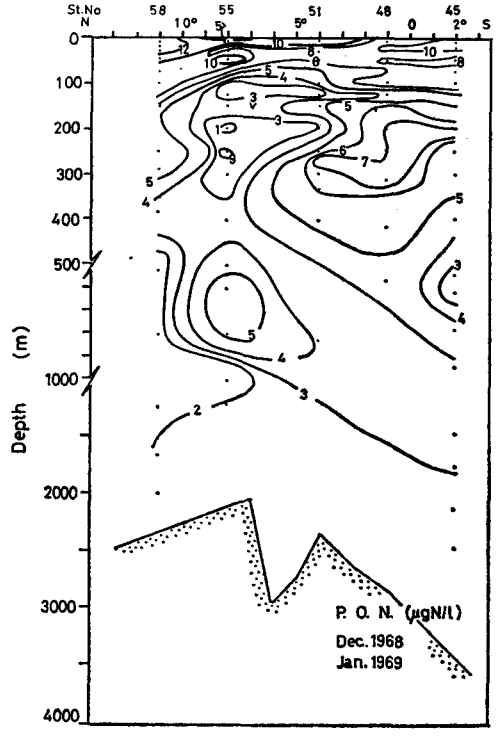

Fig. 11e. Section of particulate organic nitrogen along a 142°E. line from 2°S. to 11°N., Dec. 1968 to Jan. 1969, Oshoro-Maru Cruise 30.

the thermocline was not so marked while the intermediate high salinity water existed within a depth range of 50–150 m with the core at 100 m. The subarctic intermediate water (34.2 ‰) was encountered in the layer of 600–800 m depth.

Chlorophyll *a* ranged from 0.03 to 0.71 mg/m^3 in the upper 150 m layer and its maximum layer existed in 50–100 m. The concentration was higher in the Kuroshio Current than in the KCC area. Carbon and nitrogen were similar in distribution. The concentrations of both elements in the upper 200 m layer were in the range of 13–58 μgC/l and 1.4–9.2 μgN/l, respectively, while they did not show any large variation below 400 m layer and remained within narrow ranges of 10–20 μgC/l and of 1–4 μgN/l, respectively.

The section along a line of 125°E from 22° to 32°N, May 1968 (Figs. 13a-13e) This section includes the East China Sea and the southern area of the Ryukyu Island. Sts. 61–63 were located in the continental shelf area with a maximum depth of 50–100 m. St. 64 was in the Kuroshio Current and the remaining two stations in the Kuroshio Counter Current.

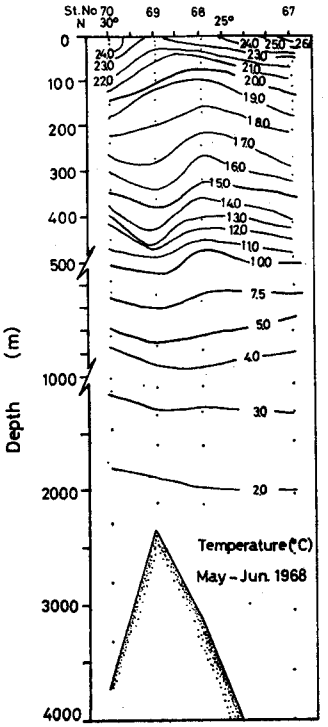

Fig. 12a. Section of temperature along a 132°E. line from 22° to 30°N., May to June 1968, Hakuho-Maru Cruise KH-68-2.

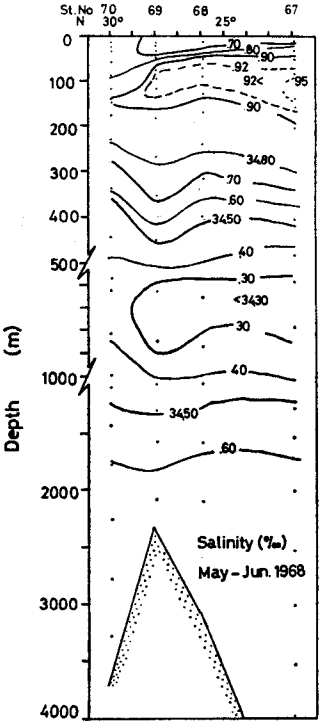

Fig. 12b. Section of salinity along a 132°E. line from 22° to 30°N., May to June, 1968, Hakuho-Maru Cruise KH-68-2.

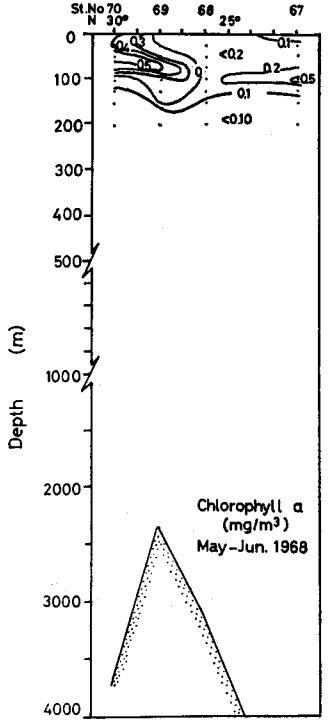

Fig. 12c. Section of chlorophyll *a* along a 132°E. line from 22° to 30°N., May to June, 1968, Hakuho-Maru Cruise KH–68–2.

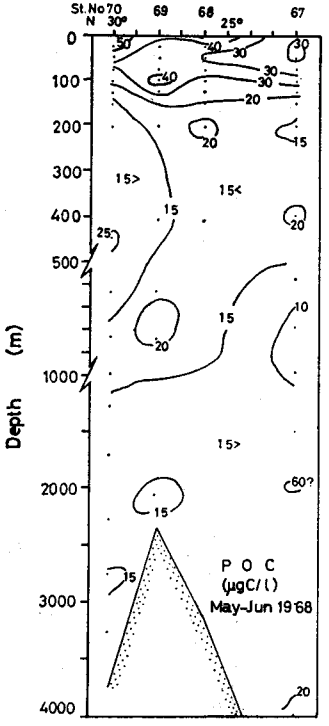

Fig. 12d. Section of particulate organic carbon along a 132°E. line from 22° to 30°N., May to June, 1968, Hakuho-Maru Cruise KH–68–2.

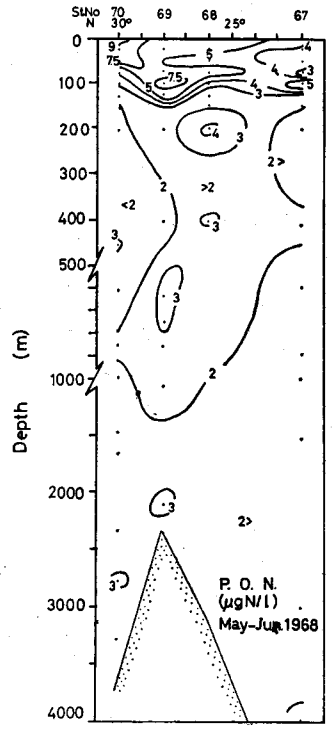

Fig. 12e. Section of particulate organic nitrogen along a 132°E. line from 22° to 30°N., May to June, 1968, Hakuho-Maru Cruise KH–68–2.

In the KCC area, chlorophyll *a* ranged from 0.01 to 0.56 mg/m³ with the maximum layer at 75 m. In the East China Sea, chlorophyll concentration was in the range of 0.13–1.68 mg/m³ with the highest concentration in the region of the Kuroshio Current. Chlorophyll decreased towards the north and at the northern most station it was as low as 0.16 mg/m³ at the surface.

In the shelf water, the variation of both carbon and nitrogen was not parallel with that of chlorophyll. Their concentrations in the subsurface layer decreased rapidly from north (115 μgC/l) to south (about 50 μgC/l), while chlorophyll increased from about 0.5 mg/m³ to 1.50 mg/m³. In the KC and KCC areas carbon and nitrogen decreased to about one-third of the values in the shelf water and showed no marked variation in the upper 100 m layer. But, in the intermediate water below 100 m, the layering was more pronounced in the KCC area than in the KC area.

The distribution patterns described above are fairly complicated and delicately different from area to area. So the descriptions that have been made are supplemented by examining more fully vertical profiles of these variables at selected

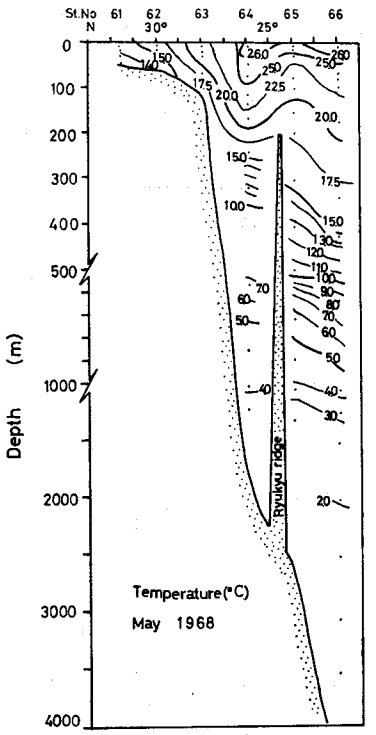

Fig. 13a. Section of temperature along a 125°E. line from 22° to 32°N., May, 1968, Hakuho-Maru Cruise KH-68-2.

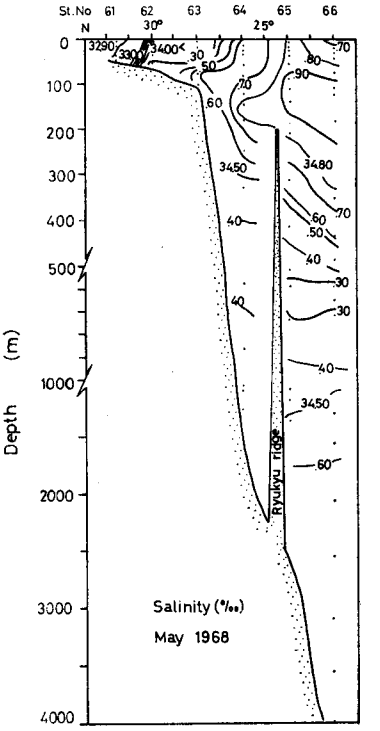

Fig. 13b. Section of salinity along a 125°E. line from 22° to 32°N., May, 1968, Hakuho-Maru Cruise KH-68-2.

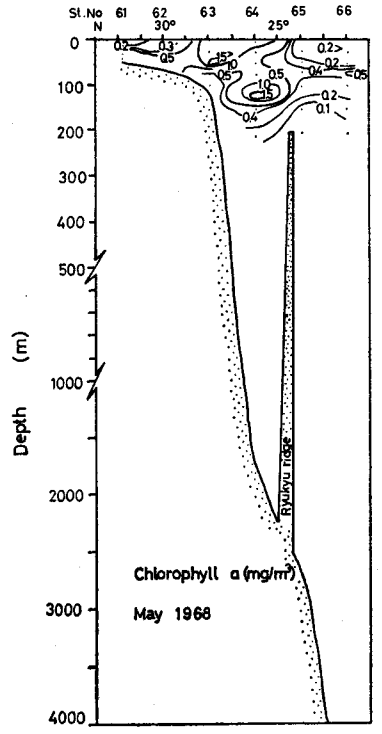

Fig. 13c. Section of chlorophyll *a* along a 125°E. line from 22° to 32°N., May, 1968, Hakuho-Maru Cruise KH–68–2.

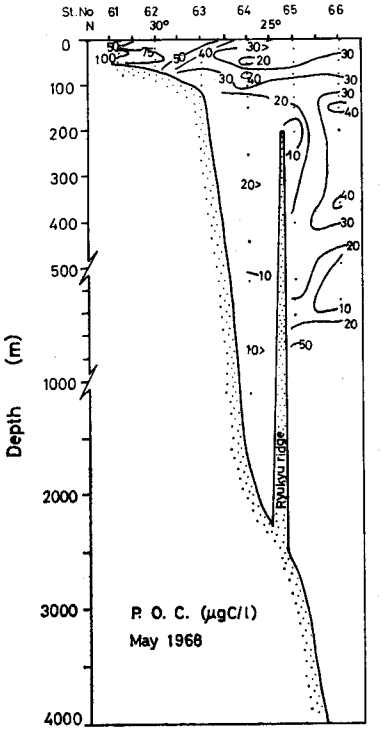

Fig. 13d. Section of particulate organic carbon along a 125°E. line from 22° to 32°N., May 1968, Hakuho-Maru Cruise KH–68–2.

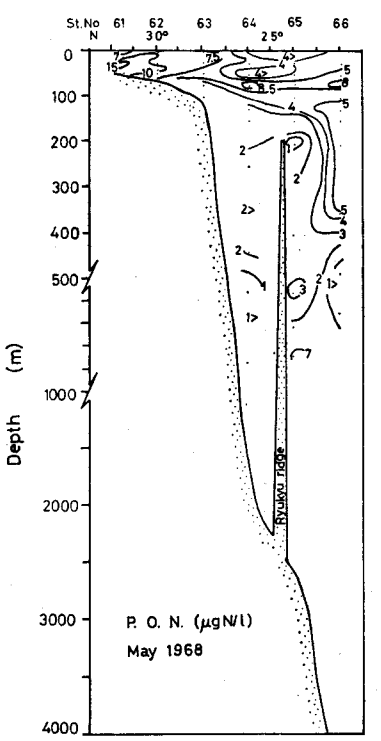

Fig. 13e. Section of particulate organic nitrogen along a 125°E. line from 22° to 32°N., May 1968, Hakuho-Maru Cruise KH–68–2.

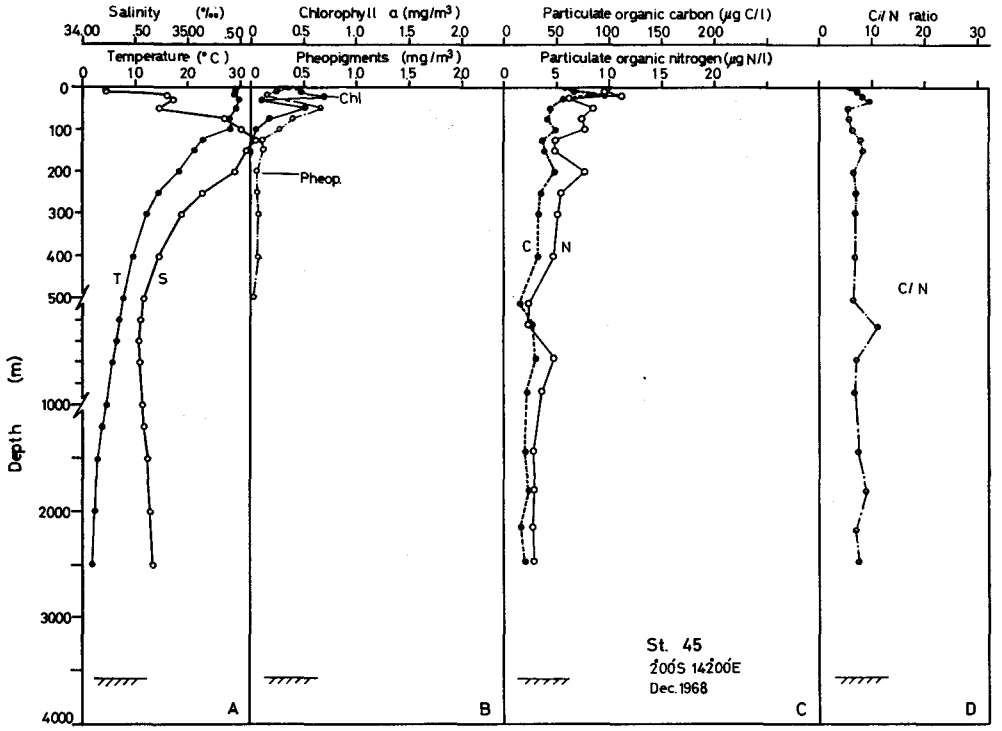

Fig. 14. Profiles of temperature and salinity (A), chlorophyll *a* and pheopigments (B), P.O.C. and P.O.N. (C), and C/N ratio (D) at Sta. 45 in the south Equatorial Current, Dec. 1968, Oshoro-Maru Cruise 30.

stations.

(a) *SEC area* (St. 45, Fig. 14). The vertical distributions of temperature, salinity, phytoplankton pigments, particulate carbon and nitrogen, and C/N ratio obtained at St. 45 were shown in Fig. 14. Temperature was generally high (29°C) and homogeneous in the upper 100 m. The thermocline existed in the layer between 100 m and 150 m, and below the thermocline temperature decreased exponentially with depth (2°C at 2000 m). Salinity was low (34.2‰) at the surface and increased rapidly with depth and reached the maximum of 35.6‰ at 125 m depth (high salinity intermediate water). Below the layer, it slowly decreased with depth and attained a minor minimum (34.6‰) in the mid-depth layer of about 600 m (subantarctic intermediate water).

Chlorophyll *a* distributed only in the upper 100 m layer, having two peaks at 20 m (0.70 mg/m³) and 50 m depth (0.50 mg/m³). Pheopigments decreased from the surface to a 20 m depth in contrast to the chlorophyll increase, but at 50 m depth they attained a peak, parallel to chlorophyll, of 0.63 mg/m³.

Particulate organic carbon increased with depth from surface (60 μgC/l) to 20 m (98 μgC/l) in parallel with chlorophyll *a*, but no measureable peak was associated

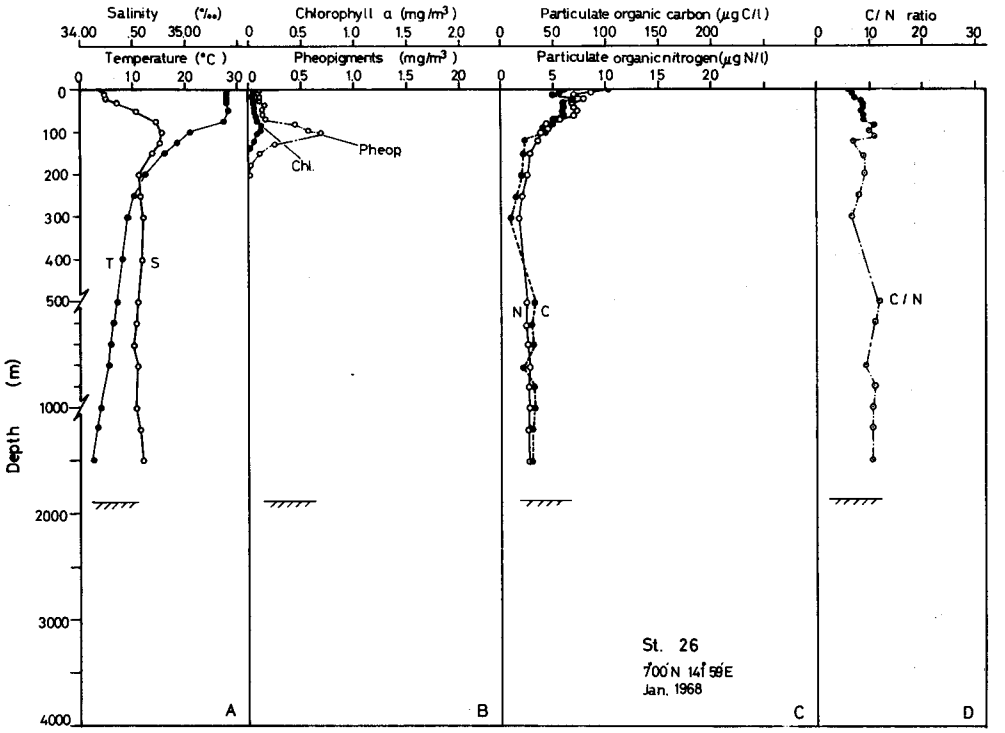

Fig. 15. Profiles of temperature and salinity (A), chlorophyll *a* and pheopigments (B), P.O.C. and P.O.N. (C) and C/N ratio (D) at Sta. 26 in the Equatorical Counter Current, Jan. 1968, Oshoro-Maru Cruise 26.

with the secondary peak of chlorophyll *a* observed at 50 m. Below the 20 m depth, carbon tended to decrease gradually with increasing depth down to the maximum depth observed although there were some irregularities observed near 150 m, 200 m, and 600 m depth. Nitrogen varied nearly parallel with carbon and the two irregularities observed at 150 m and about 600 m layers were more marked than that of carbon. The former was located in the high salinity intermediate water and the latter in the top layer of the salinity minimum layer.

The C/N ratio showed a rapid increase from the surface (6) to 30 m (9.5), but rapidly decreased (5) in the 50 m layer where phytoplankton pigments were abundant. It increased again to about 10 at 150 m depth. The ratio at 200 m depth and below was in a narrow range of 6.4–7.6 except for a single high value (11) at 600 m depth.

(b) *ECC area* (St. 26, Fig. 15). General patterns of vertical distributions of temperature and salinity were quite similar to those of the previous station except that the salinity of the intermediate water which appeared at 100 m depth layer was lower (34.8‰) and no marked intermediate minimum of salinity occurred in deeper layer.

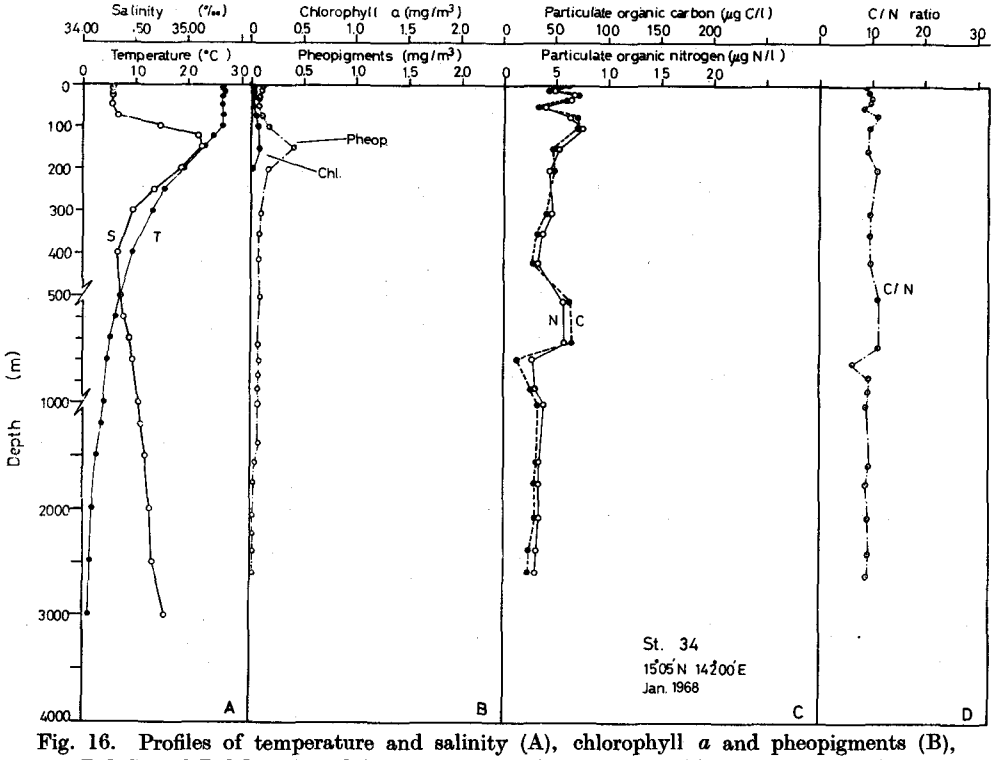

Fig. 16. Profiles of temperature and salinity (A), chlorophyll *a* and pheopigments (B), P.O.C. and P.O.N. (C) and C/N ratio (D) at Sta. 34 in the North Equatorial Current, Jan. 1968, Oshoro-Maru Cruise 26.

Chlorophyll *a* and pheopigments were low, less than 0.01 mg/m³ and 0.03 mg/m³ respectively, in the upper 75 m layer as compared with the high values in the SEC area. Both increased in the thermocline but the maximum of chlorophyll (0.16 mg/m³) occurred in the 80 m depth while that of pheopigments (0.70 mg/m³) occured in the layer of 100 m depth.

Particulate organic carbon and nitrogen tended to decrease with depth from the shallow layer down to 300 m, but increased slightly at 500 m and kept nearly constant level (30 μgC/*l* and 2.8 μgN/*l*) in the deeper water. The existence of secondary maximum of P.O.C. or P.O.N. was not observed. The C/N ratio ranged between 6 and 8.5 throughout the surface–300 m layer except for a value of about 11 obtained at the chlorophyll maximum layer, but below this layer, it increased to around 10. In the deep water the ratio was somewhat higher than that in the SEC area.

(c) *NEC area* (St. 34 Fig. 16). The hydrographical structure observed in this area was only slightly different from that in the ECC area; the intermediate salinity maximum increased to 35.1‰ and a minimum (34.3‰) layer at 400 m depth was much more developed.

The chlorophyll maximum layer occurred in the 100 m depth layer, and pheopigments had its peak in a slightly deeper layer. The concentration of pigments were comparable to but slightly lower than in the ECC area. Particulate carbon and nitrogen varied with depth in close parallelism with each other. From surface to deeper layer, they tended to decrease slowly with depth with two irregularities; one was found in the euphotic layer (0–150 m) in which two peaks of both carbon and nitrogen occurred in the layer of 20 m (68 μgC/l and 6.6 μgN/l) and 100 m depth (70 μgC/l and 7.2 μgN/l) and one peak of carbon at 20 m was not accompanied with the chlorophyll *a* peak, while the other at 100 m areas coincided with the chlorophyll *a* maximum. The other occurred in 500–1000 m depth range, and involved a pair of a broad and conspicuous maximum in the 500–700 m layer and a similarly marked minimum at a 750 m depth. The latter maximum was coincided in depth with an increase of salinity below the subarctic intermediate water.

Through the entire water column observed, the C/N ratio did not vary much with depth, but remained in a narrow range between 8 and 10 except for a few values among which two were higher than 10 and obtained at the peaks of carbon in the euphotic layer, and one was less than 6 and obtained at the minimum of carbon at 800 m depth.

(d) *KCC area* (Figs. 17 and 18). Two examples were selected: one a winter station (d-I, St. 19) and the other a summer station (d-II, St. 67).

d-I (Fig. 17). The profiles of temperature and salinity in shallow layers were much simpler than but below 300 m depth practically similar to those in the previous station. The shallow layer was covered by the high salinity water (35.0 ‰), and the core of the intermediate high salinity water observed in the southern tropical areas disappeared. The subarctic intermediate water which was characterized by low salinity was more clearly observed with the core (34.1‰) at 700 m. The thermocline was less developed and occurred between 100 m and 150 m depth.

The concentration of chlorophyll was extremely low and less than 0.1 mg/m^3 while pheopigments occurred in a wide range from 0.3 to 0.03 mg/m^3 in the whole water column observed. Two peaks of chlorophyll *a* (about 0.1 mg/m^3) associated with the relatively high amount of pheopigments were found in the layers of 50 m in the euphotic layer and 250 m in the intermediate water. It was assumed that the latter peak of chlorophyll might be the result of a quick transportation of surface particles as discussed in Part I. Further, pheopigments kept a high level of around 0.15 mg/m^3 even in the deep water. Particulate organic carbon and nitrogen also showed no consistent decrease with increasing depth but showed a characteristic layering phenomenon with a large fluctuation in wide ranges between 9 and 71 μgC/l and between 1.0 and 8.9 μgN/l, respectively. Below 1000

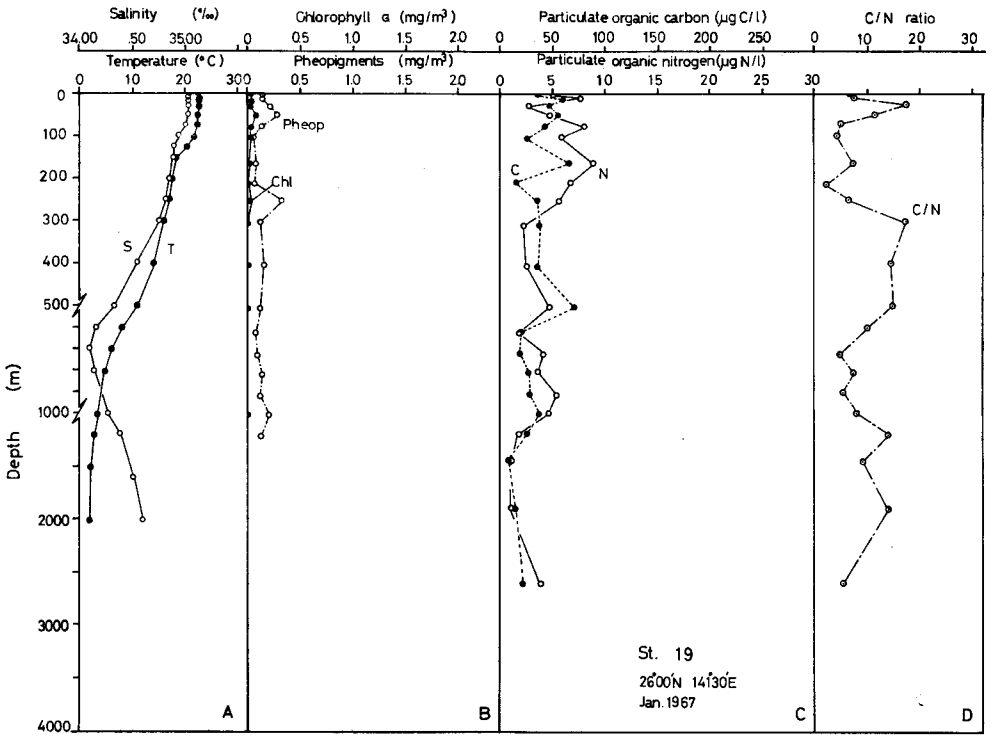

Fig. 17. Profiles of temperature and salinity (A), chlorophyll *a* and pheopigments (B), P.O.C. and P.O.N. (C), and C/N ratio (D) at St. 19 in the Kuroshio Counter Current, Jan. 1967, Oshoro-Maru Cruise 21.

m depth, carbon and nitrogen tended to decrease down to the levels of 10 μgC/*l* and 1 μgN/*l*. C/N ratios were in a range of 2.5–17.5 and very variable with depth. It is noticeable that the C/N ratios obtained from the layers around the thermocline and the intermediate subarctic water were characteristically low with a general range of 2–8.

d-II (Fig. 18). The patterns of temperature and salinity profiles observed were quite similar to that in the winter station except that the surface layer (0–10 m) was covered by the water of high temperature (28°C) and low salinity (34.7‰).

Chlorophyll *a* and pheopigments increased from the surface with depth and attained maxima (0.5 mg/m^3 and 0.9 mg/m^3, respectively) at 100 m, and below this layer they suddenly decreased. These profiles found here were quite similar to those obtained in the ECC and NEC areas described above (Figs. 15 and 16), but the depth difference between the peaks of chlorophyll and pheopigments was not observed here. Carbon and nitrogen profiles were as in other cases described above, different from that of pigments. Only a minor peak of organic matter (46 μgC/l) was observed at the layer of chlorophyll maximum, and the entire

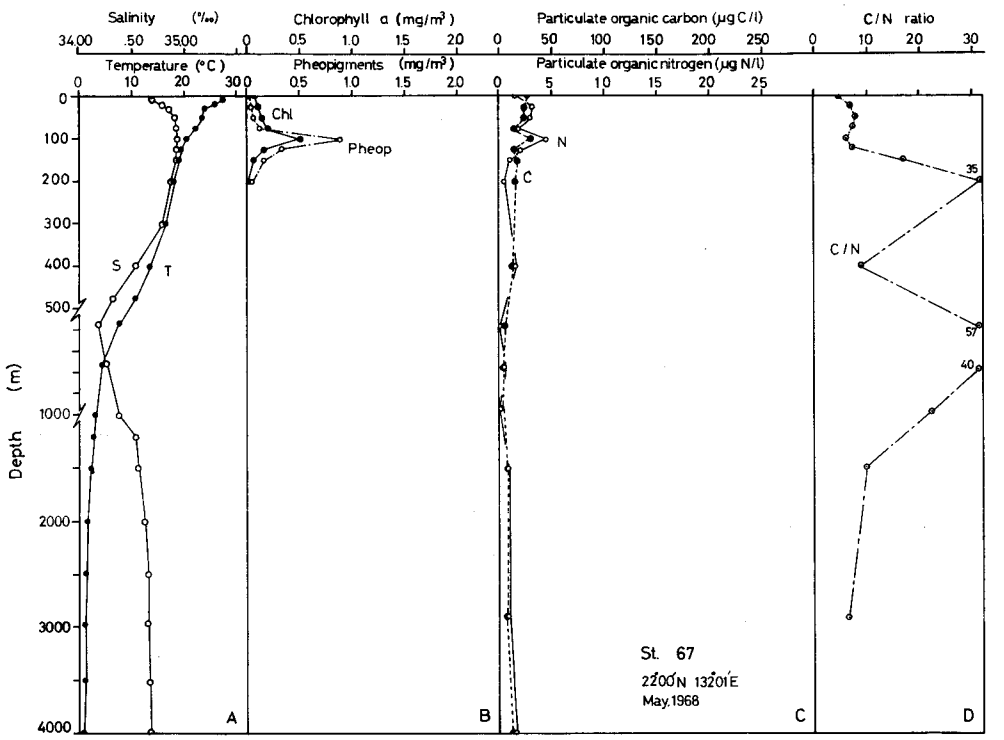

Fig. 18. Profiles of temperature and salinity (A), chlorophyll *a* and pheopigments (B), P.O.C. and P.O.N. (C), and C/N ratio (D) at St. 67 in the Kuroshio Counter Current, May 1968, Hakuho-Maru Cruise KH-68-2.

convection layer in which the concentration of chlorophyll was minimal, was populated by particulate organic matter with the average concentration of 30 μgC/*l*. However, the level of particulate matter were low in the entire water column and the marked layering as observed in the winter season was not found. The C/N ratio was ranged from 5.5 to 8 in the euphotic layer, but in mid-depth layers the ratio was anomalously high (17–57). These values would probably be erroneous because of the low level of nitrogen that scarcely exceeded the range of analytical "error" (cf. p. 14).

(e) *KC area* (St. 64, Fig. 19). This station was obtained between the Ryukyu Island and the continental shelf in the East China Sea, and was probably located in the Kuroshio Current. Temperature gradually decreased with depth from the surface down to the maximum depth observed (1500 m), while salinity had a maximum at 150 m depth (34.8‰) and a minimum at 500 m depth (34.4‰). Phytoplankton pigments showed a characteristic pattern in distribution; chlorophyll *a* had two maxima at the surface (1.1 mg/m^3) and as 125 m depth (1.6 mg/m^3), while pheopigments concentration was as low as 0.03 mg/m^3 in the surface, and increased rapidly with depth attaining a remarkable peak of 2.4 mg/m^3 also

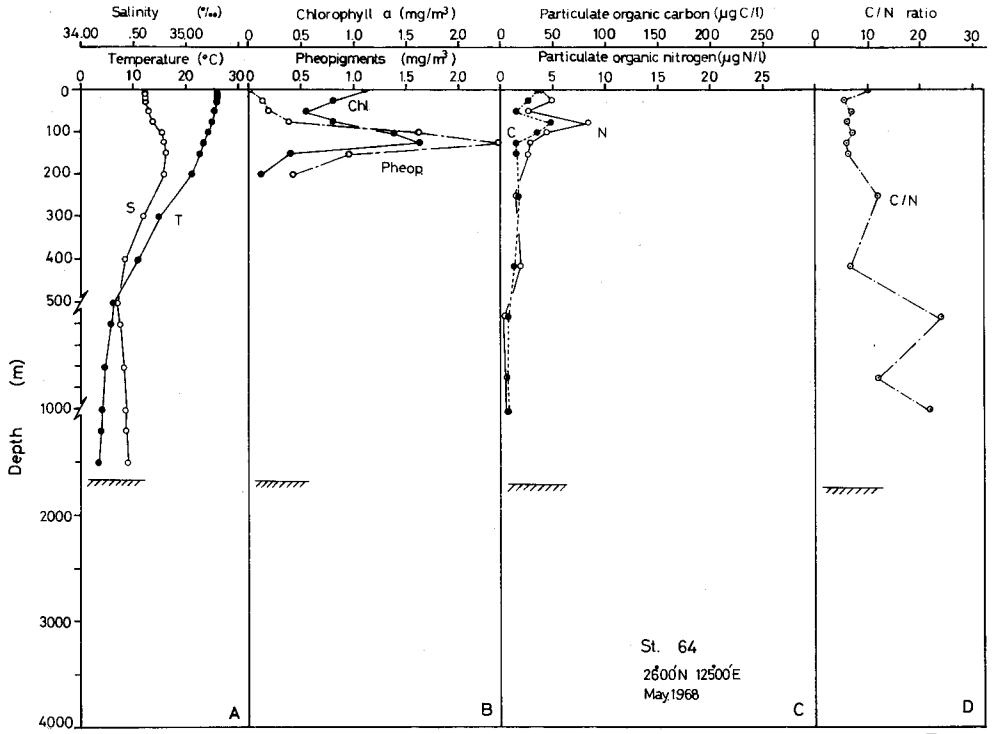

Fig. 19. Profiles of temperature and salinity (A), chlorophyll *a* and pheopigments (B), P.O.C. and P.O.N. (C), and C/N ratio (D) at Sta. 64 in the Kuroshio Current, May 1968, Hakuho-Maru Cruise KH-68-2.

at a 125 m depth. Vertical variation in particulate matter was apparently parallel to that of chlorophyll, but the subsurface maxima of carbon and nitrogen were at 75 m depth. At the depth of subsurface chlorophyll maximum (125 m), the carbon value reduced to a minimal level of 15 μgC/*l*. Below the 125 m depth, both carbon and nitrogen remained minimal down to 1000 m depth. The C/N ratio increased with depth from the surface value of about 5 to the deepwater value that exceeded 20. However, the latter values would be erroneously too high due to the reason mentioned in (d).

II. *Northern Areas.* Samplings were carried out at all 15 stations; two (Sts. 73 and 74) were the same in location (off Erimo, Hokkaido) and visited twice, and the others (Sts. 83–95) were in the northern part of North Pacific and the Bering Sea. It is well known that the water mass in these areas is quite different from that of the Kuroshio Current area described above.

(a) *Oyashio Current Region off Erimo.* This station was occupied in April 1967 and again in September 1969.

(a)-I. *The spring station* (St. 73, Fig. 20). The temperature profile showed the characteristic pattern of the cold water mass; the surface temperature was

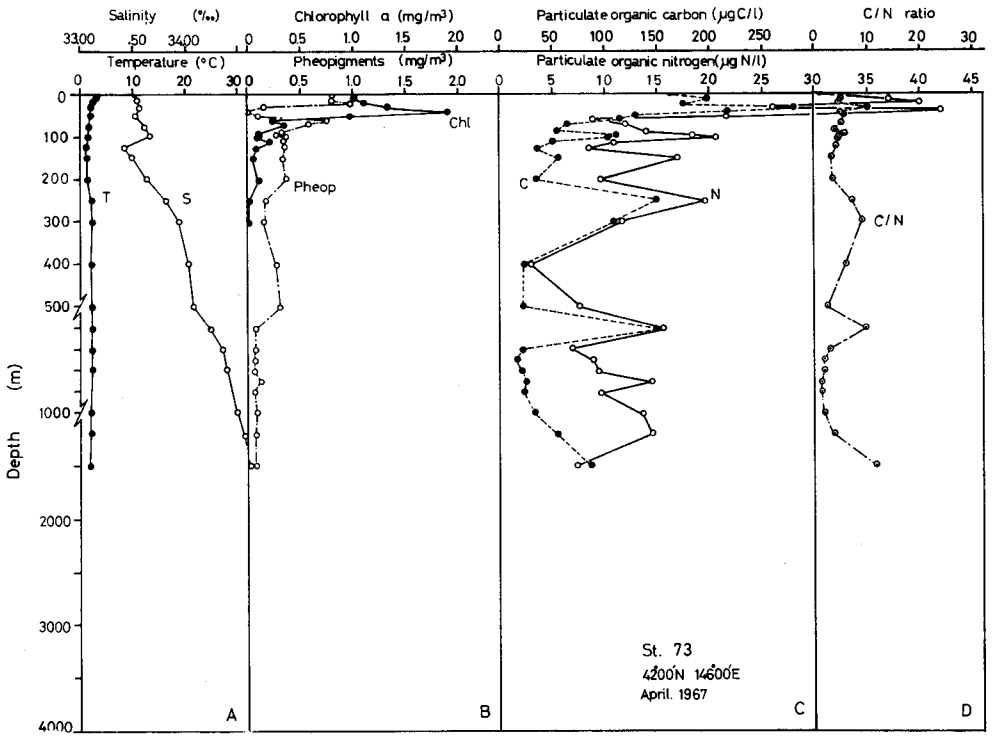

Fig. 20. Profiles of temperature and salinity (A), chlorophyll *a* and pheopigments (B), P.O.C. and P.O.N. (C), and C/N ratio (D) at Sta. 73 in the Oyashio Current off Erimo, April 1967, Oshoro-Maru Cruise 23.

as low as 3.5°C, and the minimum of temperature (1.5°C) was observed in the 125 m layer (dichothermal layer). The thermocline was not yet well developed in this season. A broad maximum of temperature close to 3°C existed in the layer between 250 and 800 m depth. Salinity, however, was relatively high at about 33.5‰ at the surface, and decreased down to 33.4‰ in the core of the dichothermal layer (the principal halocline). The relatively high surface salinity seemed to be due to the influence of the Kuroshio Extension. It is well known that an isolated warm water mass of Kuroshio origin often appears and persists for several months in the vicinity of this station.

The concentration of chlorophyll *a* in the upper 50 m layer was more than 1.0 mg/m³, indicating that the vernal blooming was occurring in this area. Chlorophyll *a* rapidly increased with depth and attained a remarkable peak (1.0 mg/m³) at 40 m but suddenly decreased down below 0.3 mg/m³ in a few ten-meter depth interval. Pheopigments were considerable in concentration (0.8–1.0 mg/m³) at the surface, but could not be detected from the chlorophyll maximum layer. It suddenly increased up to 0.8 mg/m³ at a 60 m depth layer where chlorophyll

was less than 0.25 mg/m^3. Thus, a characteristic inverse correlation was found between chlorophyll and pheopigments in the euphotic layer. Further, the concentration of pheopigments remained fairly high (0.2–0.4 mg/m^3) in the layers down below the 500 m depth, while chlorophyll *a* existed in the lowest concentration that could scarcely be detected. Profiles of particulate organic carbon and nitrogen were remarkably complicated. The total ranges obtained in the 1500 m water column were 17–267 μgC/*l* and 4–42 μgN/*l*, respectively. The primary carbon maximum occurred at 30 m depth and that of nitrogen at 20 m depth, both being shallower than the chlorophyll maximum (40m). The high concentration of particulate matter above 160 μgC/*l* and 30 μgN/*l* with C/N ratios close to 5 was confined to the shallow euphotic layer and it suddenly decrease a down to a minimal level at the base of the euphotic layer; the decrease in carbon was more marked than nitrogen resulting in low C/N ratios concentrated in the entire dichothermal layer.

Below the dichothermal layer, two remarkably high concentrations of organic material were found superimposed on the general low level of 20–25 μgC/*l* in carbon; one in the principal halocline and the other in the layer of intermediate temperature maximum (600 m). Nitrogen concentrations varied nearly parallel with carbon, but tended to remain relatively high in deeper layers below 500 m depth, leading to the occurrence of very low C/N ratios around 2 in 700–1000 m depth range.

a-II. *The fall station* (St. 74, Fig. 21). Surface temperature was high (18.3°C) and a well developed thermocline was established in the layer of 20–75 m. Surface salinity was 33.0‰ and was characteristically low. The core of the dichothermal layer was located at 75 m depth, and the general relation of T-S curve below the dichothermal layer was practically similar to that obtained in the early spring (St. 73).

Chlorophyll *a* observed in the upper 75 m layer ranged from 0.17 to 3.5 mg/m^3, one order less than that of the vernal blooming in 1967. In the same layer pheopigments ranged between 0.40 and 0.96 mg/m^3. Such an inverse correlation between them as found in spring 1967 was not observed in this fall. Below the dichothermal layer, pheopigments showed a nearly uniform distribution with the average concentration of 0.1 mg/m^3. This was also lower than that in spring 1967.

Marked primary maxima of carbon and nitrogen (220 μgC/*l* and 39 μgN/*l*, respectively) occurred in the top layer of the thermocline, both decreased rapidly with depth. This large variation of organic matter did not well corresponded with the variation in chlorophyll *a* which was far less variable in the euphotic layer. It is noticeable that a carbon minimum was associated with the dichothermal layer. Below the dichothermal layer, both carbon and nitrogen showed very

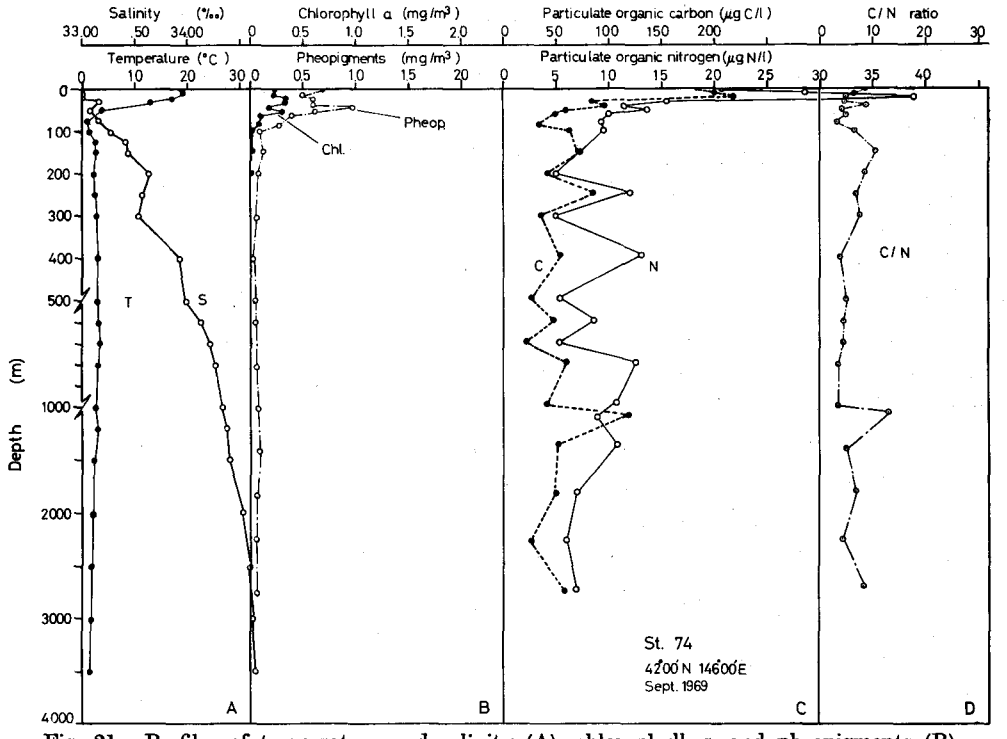

Fig. 21. Profiles of temperature and salinity (A), chlorophyll *a* and pheopigments (B), P.O.C. and P.O.N. (C), and C/N ratio (D) at Sta. 74 in the Oyashio Current off Erimo, Sept. 1969, Oshoro-Maru Cruise 34.

irregular variations with depth approximately parallel with each other, but the magnitude of the fluctuation was larger in carbon than in nitrogen. The average concentration of carbon below the dichothermal layer was about 50 μgC/*l*, more than twice that in spring, and the average concentration of nitrogen was 8 μgN/*l*, nearly 2/3 that in spring. The resultant C/N ratios were in a range of 4–8, still low but significantly higher than in spring.

(b) *Northern North Pacific and Bering Sea.*

b-I *The section along a line of 178°W from 48°N to 60°N June 1967* (Figs. 22a-22e). On the south side of the Aleutian Ridge, a warm, low saline water existed in the shallow layer but an appreciable intermediate cold water (2.7°C) was in about 150 m layer. The core of the Alaskan Stream is usually very narrow. Below the well mixed surface layer, a marked dense halocline was found in the layer of 150–200 m. A relatively high salinity intermediate water underlying the halocline was observed at 50°N, showing a narrow intrusion of the Kamtchatka Gyre Water along the shear zone between the Alaskan Stream and the Subarctic Water. Thus,

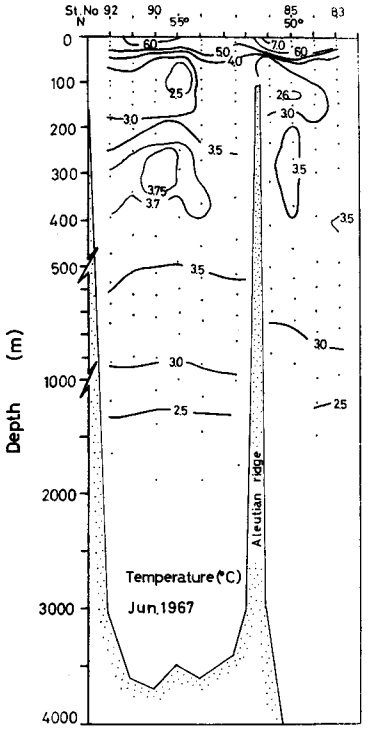

Fig. 22a. Section of temperature along a 178°W. line from 48° to 58°N., June 1967, Oshoro-Maru Cruise 24.

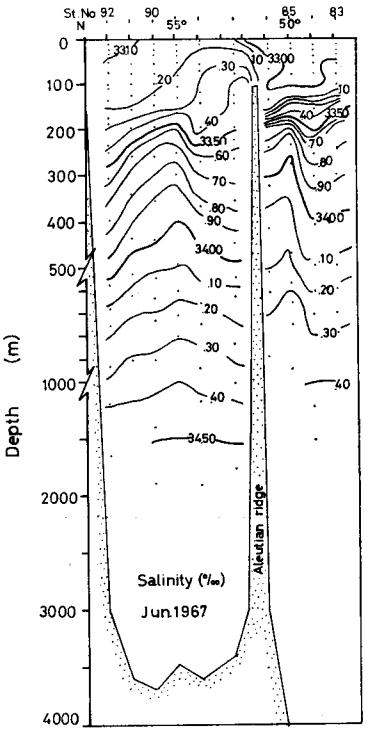

Fig. 22b. Section of salinity along a 178°W. line from 48° to 58°N., June 1967, Oshoro-Maru Cruise 24.

the water at St. 84 at 49°N where a series of large volume water sampling was done belonged to the Subarctic Water region.

On the north side of the ridge, the surface water had a lower temperature and higher salinity than on the south, and the intermediate cold water was indistinct. This was due to the vertical mixing of the Alaskan Stream occurring when it passed through the Aleutian Chain. The intermediate cold water became clearly defined towards the north in the layer of 50–150 m overlying the principal lalocline at about 200 m depth layer.

The concentration of chlorophyll in the euphotic layer widely ranged from 0.10 to 1.50 mg/m^3 throughout the section. At a single station in the subarctic water (St. 84) chlorophyll *a* at most 0.20 mg/m^3, while at station 87 just north of the ridge it was 1.5 mg/m^3 in 20–30 m layer. Further north from St. 88, chlorophyll *a* concentration decreased to less than 0.50 mg/m^3 with the maximum in the subsurface layer of 20–50 m depth. In the dichothermal layer, chlorophyll *a* was very low, being far less than 0.10 mg/m^3. Particulate organic carbon ranged from about 50 to 400 μgC/*l* in the euphotic layer and was highest in the sea surface.

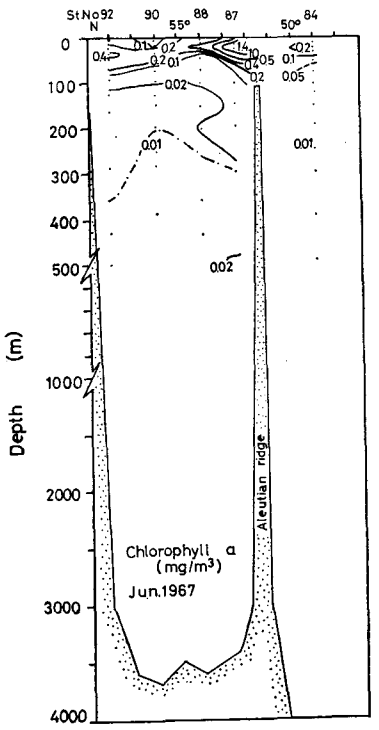

Fig. 22c. Section of chlorophyll *a* along a 178°W. line from 49° to 58°N., June 1967, Oshoro-Maru Cruise 24.

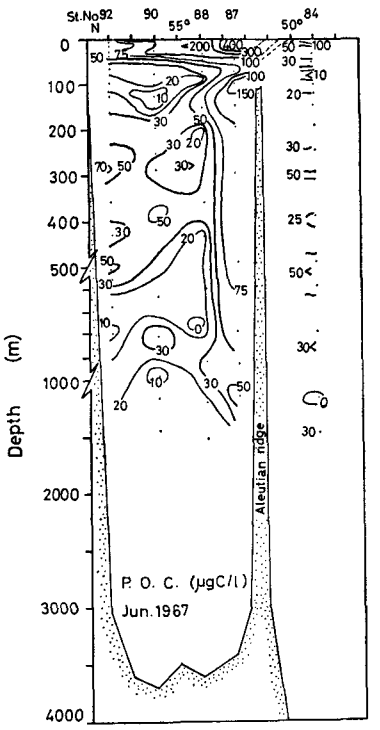

Fig. 22d. Section of particulate organic carbon along a 178°W. line from 49° to 58°N., June 1967, Oshoro-Maru Cruise 24.

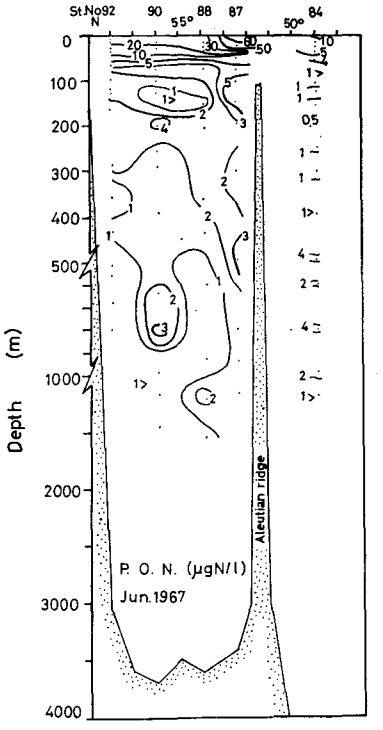

Fig. 22e. Section of particulate organic nitrogen' along a 178°W. line from 49° to 58°N., June 1967, Oshoro-Maru Cruise 24.

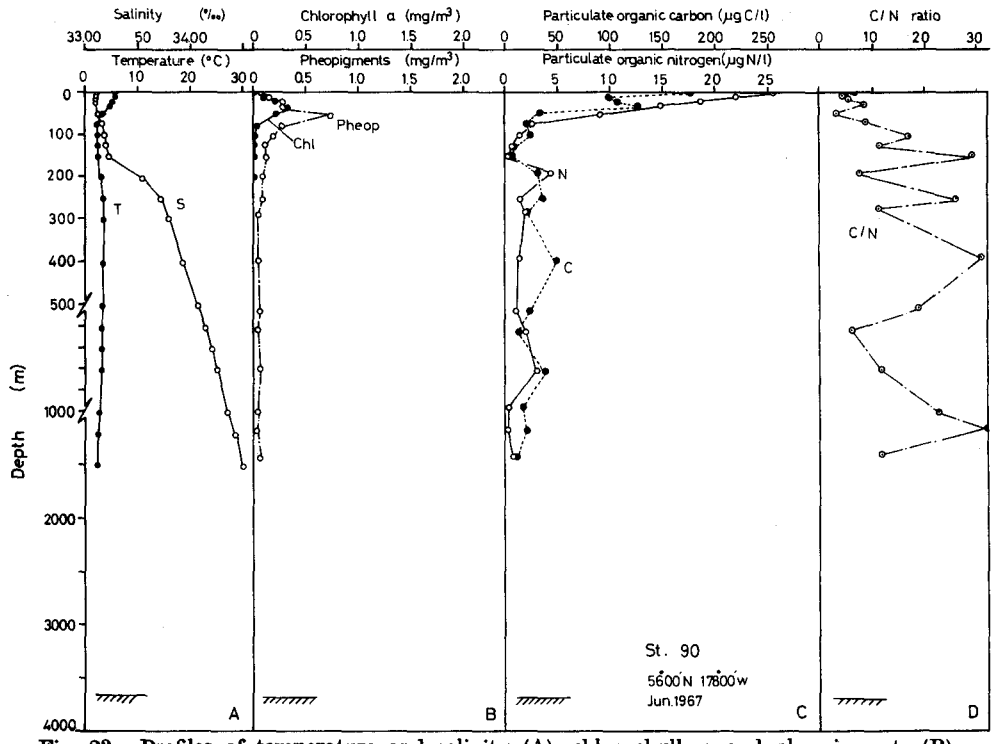

Fig. 23. Profiles of temperature and salinity (A), chlorophyll *a* and pheopigments (B), P.O.C. and P.O.N. (C), and C/N ratio (D) at Sta. 90 in the Bering Sea, June 1967, Oshoro-Maru Cruise 24.

Carbon concentration rapidly decreased with depth through the thermocline down to about 10–60 μgC/*l* but below 100 m it again increased to 30–170 μgC/*l*. This secondary maximum roughly coincided in depth with the principal halocline. Thus, a marked minimum layer of carbon existed in the depth range of the dichothermal layer in the Bering Sea and of the upper part of the dichothermal layer in the subarctic water. In the deeper layer, particulate carbon did not decrease consistently with depth but the marked layering persisted down to the maximum depth observed (1500 m). The details of vertical profiles at a representative station are described below.

b-II *The water in the central basin of the Bering Sea in June 1967* (St. 90, Fig. 23). Both chlorophyll *a* and pheopigments had marked maxima in the thermocline but the peak of chlorophyll *a* was at 30 m depth and that of pheopigments at 50 m depth. The linear increases of these pigments observed in the upper 50 m layer, however, were not at all reflected in the distribution of particulate carbon and nitrogen. Carbon and nitrogen had remarkable primary peaks at the sea surface (180 μgC/*l* and 25 μgN/*l*) and decreased rapidly with depth attaining the characteristic minima at the bottom of the dichothermal layer (8 μgC/*l* and 0.4 μgN/*l*) with

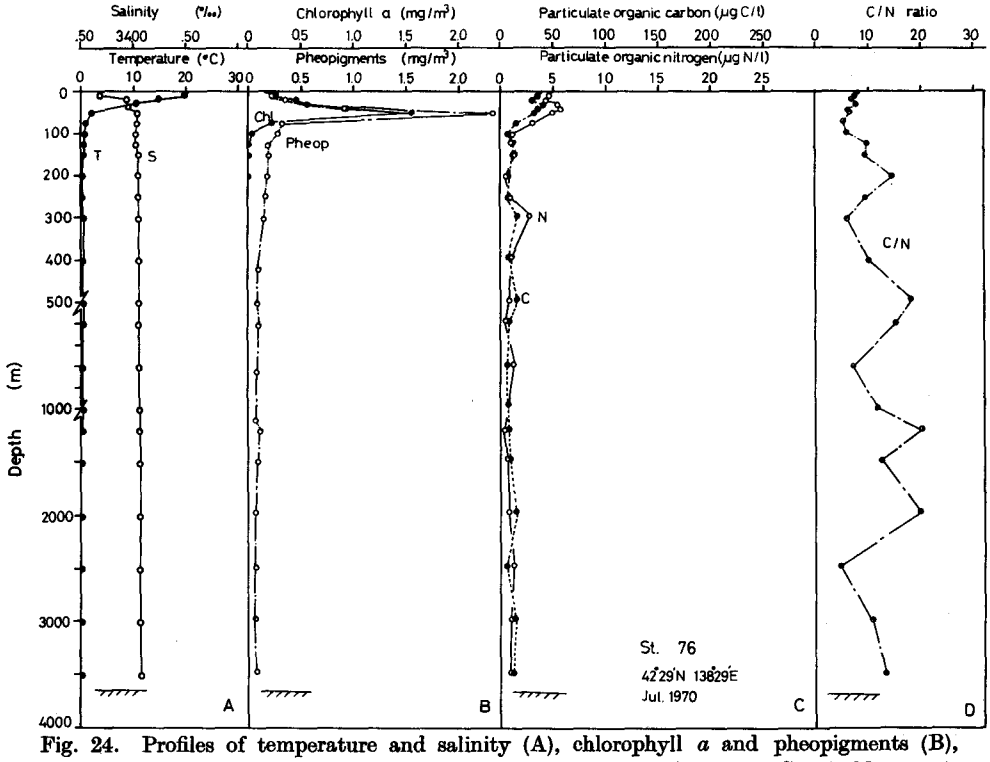

Fig. 24. Profiles of temperature and salinity (A), chlorophyll *a* and pheopigments (B), P.O.C. and P.O.N. (C) and C/N ratio (D) at Sta. 76 in the Japan Sea (cold sector), Aug. 1970, Hakuho-Maru Cruise KH-70-4.

some minor irregularities in carbon in the thermocline. This is another clear-cut example of inverse correlation between particulate matter and pigments in the shallow layer. The occurrence of the secondary maximum of carbon and nitrogen in the principal halocline, and of the third maximum of carbon in the layer of intermediate maximum temperature (300–400 m) were also notable features common to other stations in this area as well as in the Oyashio water off Erimo. The C/N ratios obtained in the water column below the thermocline in this station, however, were very high compared to those obtained in the Oyashio water.

III. *Japan Sea.* The Japan Sea is divided into a warm sector on the Japanese side and a cold sector on the Korean and Siberian side. It is well known that the water of the Japan Sea can be classified into the Surface Water, Middle Water, and Deep Water; in detail, water of low salinity (1–4°C, 33.90‰) penetrates under the warm, high salinity Middle Water which originates from the water in the intermediate layers of Kuroshio origin. The thickness of the penetrating water and the Middle Water was different between a warm sector and a cold sector in the Japan Sea.[77]

The distributions of the six stations and the hydrographical data obtained

show that Sts. 76 and 77 were in the Maritime Province Cold Current area in the cold sector, Sts. 78 and 81 in the vicinity of the Tsushima Warm Current in the warm sector and Sts. 79 and 80 near the polar sector from the area between Liman Current and South Japan Sea Gyre.[78] The situation in each of these sectors is described below using the data obtained at selected stations.

(a) *Cold Sector* (St. 76, Fig. 24). The hydrographic structure in this area is quite simple. Warm surface water with low salinity (20°C, 33.7‰) overlays a very homogeneous water column with a temperature close to 0°C and salinity of 34.05‰. The sharp boundary layer between these waters or the thermocline was located in 10–50 m depth range. Chlorophyll *a* and pheopigments at the surface water were very low in concentration (0.19 mg/m^3 and 0.15 mg/m^3, respectively), and rapidly increased with depth attaining conspicuous maxima of as high as 1.60 mg/m^3 in chlorophyll *a* and 2.77 mg/m^3 in pheopigments at the bottom of the thermocline (50 m). Below the 50 m depth, both decreased quickly with depth; chlorophyll disappeared below 100 m depth and only pheopigments kept a constant level of nearly 0.1 mg/m^3 in the deep water. Particulate carbon and nitrogen slightly decreased from the surface with depth, and had minor peaks in the layers shallower than the chlorophyll maximum layer; the peak of carbon was at 30 m and that of nitrogen was at 40 m depth. Below the layers of the peak concentrations, both decreased with depth down to 100 m, and in the entire water column below that depth the concentrations of both carbon and nitrogen were essentially homogeneous (10 μgC/l and 1 μgN/l); the minor variations observed were of the order of the analytical error. The C/N ratio decreased with depth from 8 at the sea surface to 5 at 75 m depth. Below the 100 m layer, however, the ratio fluctuated in a wide range of 5–20, in a sharp contrast to the striking homogeneity in particle concentration as well as in hydrographical condition.

(b) *Warm Sector* (St. 78, Fig. 25). The hydrographic structure in the upper 500 m layer was quite different from that of St. 76; a warm and high salinity intermediate water was marked in this station with the core at 50 m depth (12°C, 34.6‰), and the effect of this water spread down to 400–500 m depth. However, the general pattern of phytoplankton pigments as well as P.O.C. and P.O.N. distributions were similar to that of the cold sector mentioned above.

(c) *The polar front area* (St. 80, Fig. 26). T-S relation was similar to that of the cold sector. In detail, the horizontal penetration of a low salinity water was observed in the layer of 100–200 m depth underlying the intermediate water that was much diluted in salinity and reduced in temperature due to mixing. The characteristic profiles of chlorophyll *a* and pheopigments were also obtained in this area. The profiles of carbon and nitrogen were not much different from those of the previous two areas, but the average concentration of nitrogen notably increased by about 1 μgN/l in the deeper layer. So, the C/N ratio was low (around

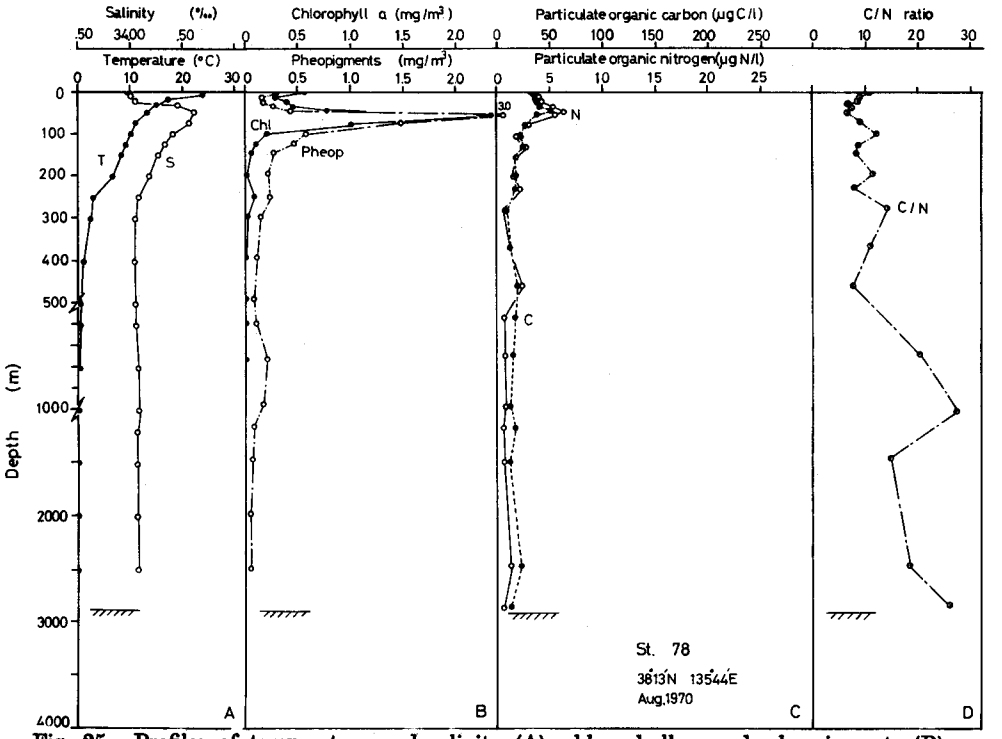

Fig. 25. Profiles of temperature and salinity (A), chlorophyll *a* and pheopigments (B), P.O.C. and P.O.N. (C), and C/N ratio Sat St. 78 in the Japan Sea (warm sector), Aug. 1970, Hakuho-Maru Cruise KH-70-4.

8) compared with the high C/N ratios obtained in the previous areas.

Thus, the vertical distribution of particulate matter were more or less similar in all these areas. However, the minimum layer and the secondary maximum layer of particulate matter as observed clearly in the northern areas were indistinct but was barely recognized. For example, these phenomena were relatively marked at St. 80 (Fig. 26); the minimum layer appeared in association with the penetrating low saline water centering at about 150 m depth and the secondary maximum with the top layer of the Deep Water (about 250 m). At St. 78 (Fig. 25), the minimum layer occurred in the layer of 300–400 m depth, which was deeper than that at St. 80 and the secondary maximum was also observed underlying a weak salinity minimum layer or the top layer of the Deep Water at 450 m depth. The deepening of the minimum and maximum layers is considered to be associated with the deeper reach of the surface water at this station. A similar phenomenon was barely observed also at St. 76 (Fig. 24) where the minimum layer was in 100–200 m layer and the secondary maximum at 300 m layer.

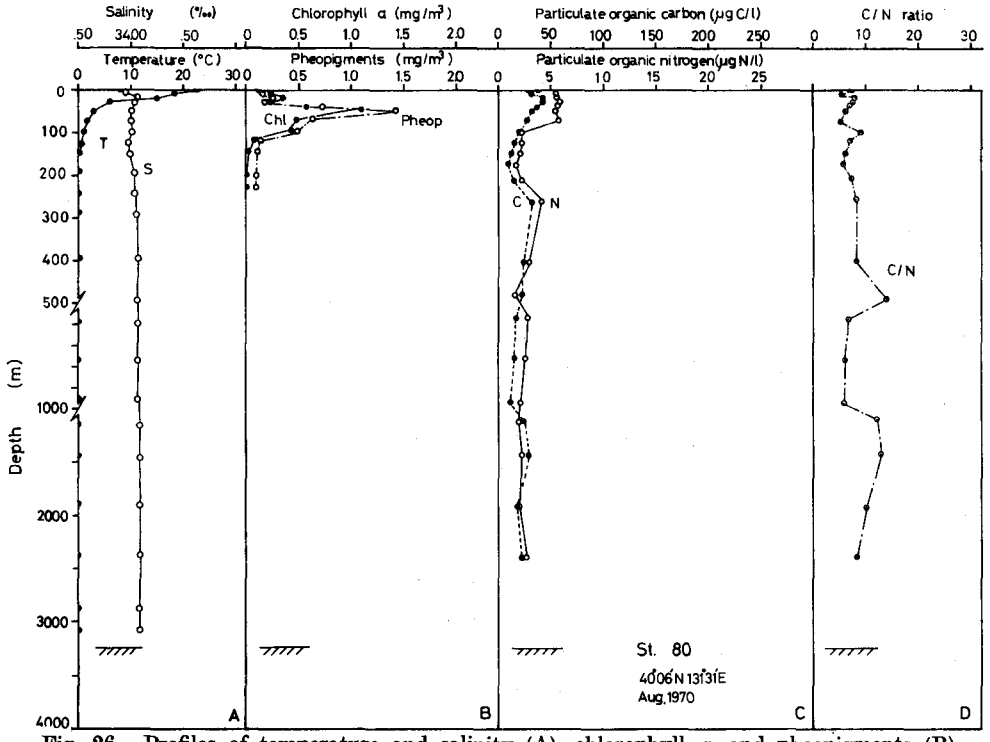

Fig. 26. Profiles of temperature and salinity (A), chlorophyll *a* and pheopigments (B), P.O.C. and P.O.N. (C), and C/N ratio Aat. ta. 80 in the Japan Sea (polar front area), Aug. 1970, Hakuho-Maru Cruise KH-70-4.

Discussion

Throughout the thirteen regions of the western North Pacific Ocean and adjacent seas observed, the average total amount of particulate carbon suspended in the water column 0–1500 m under one square meter of sea surface ranged from 18.2 gC to 118.3 gC (Table 5). The lowest value was obtained in the Kuroshio Current near Ryukyu Islands, and the highest one was obtained from the Bering Sea immediate north of the Aleutian Chain (St. 87). On the other hand, the mean concentration of particulate carbon in the surface layer (0–50 m) was in the range from 30 to 203 μgC/l (excluding a value of 291 μgC/l obtained at St. 87 where a strong influence of land drainage was seen). Thus, only 15% or less of the total carbon in the 0–1500 m water column is in the euphotic layer.

The surface concentration of particulate organic matter was, on the areal average, the highest concentration within the entire water column in all of the thirteen regions. This was particularly evident in the northern area, and the surface values above 100 μgC/l were quite common. The high carbon concentration, however, was most commonly confined to a shallow layer of a few ten-meter depth,

and the concentration decreased very rapidly down to a minimal level occurring in a depth range of 100–200 m, although at some stations the trend of decrease was obscure particularly in the oligotrophic southern areas. This rapid decrease in carbon as well as in nitrogen in the surface layer was in a sharp contrast to the similarly rapid increases with depth in chlorophyll *a* and pheopigments. This latter situation has been well recognized as a universal phenomenon and is explained either by the physiological adaptation of phytoplankton population to solar radiation[79] or by the combined effects of decreasing solar radiation and its increasing nutrient supply.[80] This inverse correlation between carbon and chlorophyll in the surface layer was repeatedly confirmed in most of the areas observed in the present study. The resultant carbon/chlorophyll ratios were usually very high at the sea surface, being in a general range from 200 to as high as 15000 and the lower values of less than 1000 occurred only in the tropical area where an intensive surface photosynthesis is usually taking place supported by an active upwelling. The ratio decreased with depth, and at the chlorophyll maximum layer it usually attained a minimum that was in a general range of 50–500. On the other hand, recent evidence[21][22][23] shows that the carbon/chlorophyll ratio of natural phytoplankton population is in a relatively narrow range of 30–90, and even nutrient deficient populations have not the carbon/chlorophyll ratios significantly higher than 100. The carbon/chlorophyll ratios obtained in the eupnotic layer, thus show that the major component of seston in the shallow euphotic layer is not, at least, living phytoplankton. It is highly possible that the source of these chlorophyll-devoid organic matter is in the sea surface because the amount of these material is almost always highest at the sea surface and the decrease with depth is nearly exponential. The process of formation of these particles is not well known, but Nishizawa and Nakajima[81] using the data obtained along a 142° line, calculated the local time rate of particle formation at the sea surface based on an assumption that the exponential decrease of carbon with depth near the sea surface is steady, and obtained a result of 0.043–0.26 $gC/m^2/day$. This is a range close to the total photosynthetic production in the entire euphotic layer of the area concerned. The surface waters used in this and previous Parts were dipped with buckets and no particular attention was paid to the particle concentration in the extreme surface skin. In the last Part of this paper, an observation of the surface skin and related discussion will be presented.

The relation between particulate organic carbon and chlorophyll *a* for all observations obtained in the euphotic layer in respective areas is shown in Figs. 27a-27c. In all of the areas observed, the mutual correlation was very poor and apparently no consistent patterns emerge. In the four areas along the 142°E line (A, B, C, and D), most of the points were clustered in the domain of high carbon chlorophyll ratio of more than 200. Particularly in the NEC and KCC

areas, all the points were distributed in the domained of more than 400 in the ratio. These are the areas that are most oligotrophic and low in primary productivity. In the SEC area, the distribution of points were similar in pattern to those of the northern area, indicating the common feature of eutrophy. The KC area (E) and the Japan Sea (F) were characterised by the relatively low C/Chl. rations; in these areas a well developed chlorophyll maximum layer exists in which the predominant component is living phytoplankton. Data in the Oyashio area (G) and the Bering Sea (H) showed a fairly good linear relationship between carbon and chlorophyll extending over wide ranges of both variables. This is probably

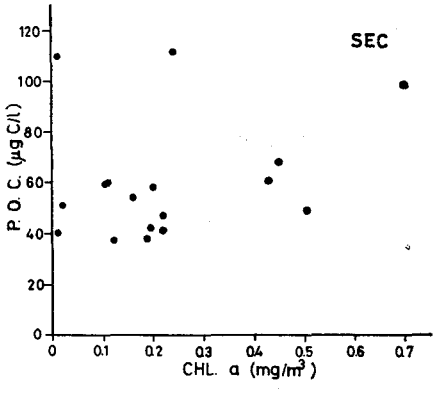

Fig. 27. a (A)

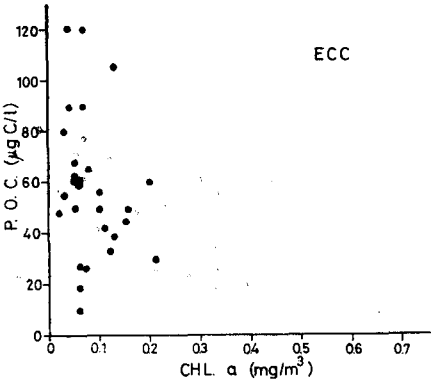

Fig. 27. a (B)

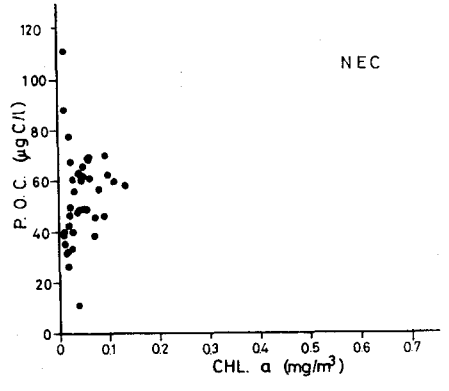

Fig. 27. a (C)

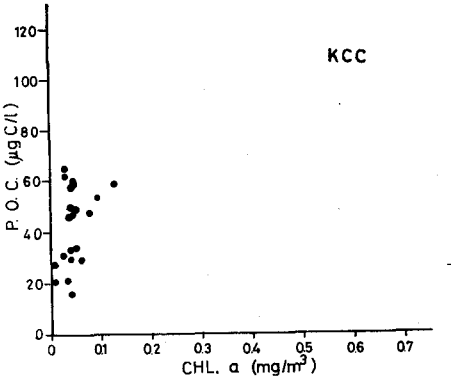

Fig. 27. a (D)

Fig. 27a. Relationship between P.O.C. and chlorophyll *a* in the euphotic layer in 4 areas: (A) the South Equatorial Current region (Sta. 45 and 48, Dec. 1968 to Jan. 1969), (B) the Equatorial Counter Current region (Sta. 26, Jan. 1968 and Sts. 51 and 55, Jan. 1969), (C) the North Equatorial Current region (Sta. 15, Jan. 1967, Sta. 30, 34, and 38, Jan. 1968, and Sta. 58, Jan. 1969), and (D) the Kuroshio Counter Current region (Sta. 19 and 21, Jan. 1967, and Sta. 42, Jan. 1968), in the Philippine Sea.

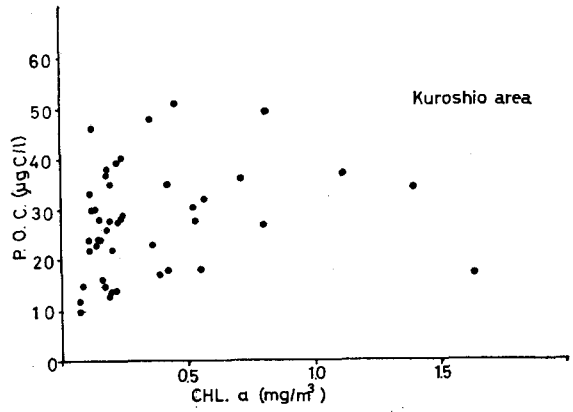

Fig. 27. b (E)

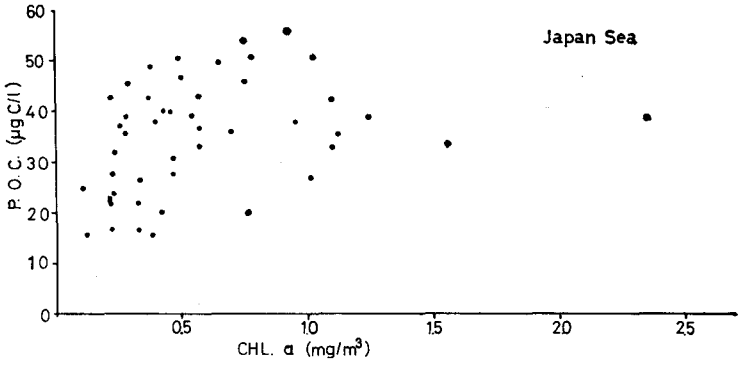

Fig. 27. b (F)

Fig. 27b. Relationship between P.O.C. and chlorophyll *a* in the euphotic layer in two areas: (E) the Kuroshio area (Sta. 64–70, May to June 1968) in the Philippine Sea and the East China Sea, and (F) the Japan Sea (Sta. 76–81, July to Aug. 1970).

a situation common to truely eutrophic areas.

Below the main thermocline or the euphotic layer, more or less distinct minimum of organic matter concentration occurred, and this minimum layer seemed to separate the particle rich surface layer from the entire water column down below. The depth range in which this minimum occurred nearly coincided with the water straum of minimum stability. Below the minimum, the secondary maximum occurred and the depth range of this maximum coincided with the layer of relatively high stability such as the principal halocline in the northern area, and the top layer of the deep water of the Japan sea. The third maximum was also commonly observed in or close to the intermediate subarctic water or the top of the bottom water (the intermediate layer of maximum temperature in the north). This cyclic variation in particle concentration was particularly conspicuous in the

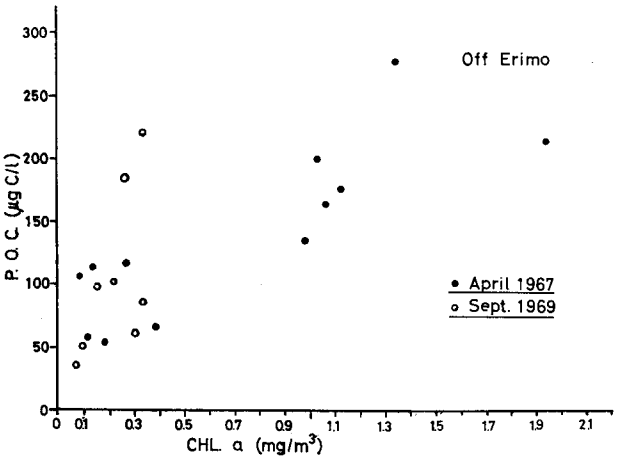

Fig. 27. c (G)

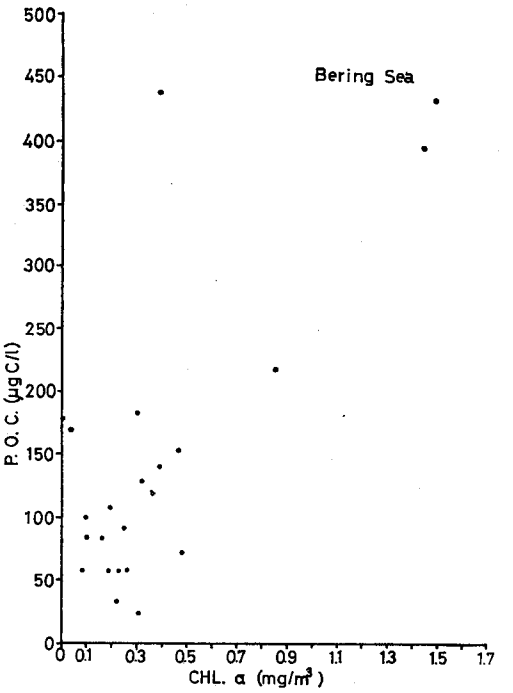

Fig. 27. c (H)

Fig. 27c. Relationship between P.O.C. and chlorophyll *a* in the euphotic layer in two areas: (G) the Oyashio Current region off Erimo (solid circles; sta. 73, April 1967, and open circles; Sta. 74, Sept. 1969), and (H) the Bering Sea (Sta. 87, 88, 90 and 92, June 1967).

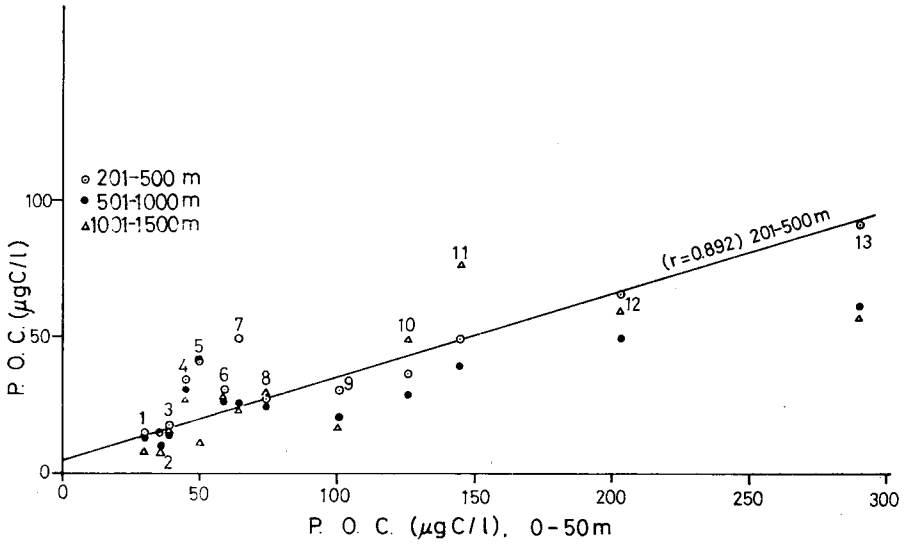

Fig. 28. Relationship between the average concentrations of particulate organic carbon in the surface layer (0–50 m.) and in deeper layers (201–500 m., 501–1000 m. and 1001–1500 m.) from 13 areas; 1: the Kuroshio Counter current region (Sta. 65–69, May to June 1968), 2: the Kuroshio Current region (Sta. 64 and 70, May to June 1968), 3: the Japan Sea (Sta. 76–81, July to Aug. 1970), 4: the Kuroshio Counter Current region (Sta. 19 and 21, Jan. 1967 and Sta. 42 Jan. 1968), 5: the Northern North Pacific (Sta. 84, June 1967), 6: the North Equatorial Current region (Sta. 15, Jan. 1967, Sta. 30, 34 and 38, Jan. 1968, and Sta. 58, Jan. 1969), 7: the South Equatorial Current region (Sta. 45 and 48, Dec. 1968 to Jan. 1969), 8: the Equatorial Counter Current region (Sta. 26, Jan. 1968 and Sta. 51 and 55, Jan. 1969), 9: the Bering Sea (Sta. 95, Aug. 1967), 10: the Bering Sea (Sta. 88, 90, 92 and 94, June to Aug. 1967), 11: the Oyashio Current region (Sta. 74, Sept. 1969), 12: the Oyashio Current region (Sta. 73, April 1967), and 13: the Bering Sea (Sta. 87, June 1967).

northern eutrophic areas, and the vertical profile of carbon and nitrogen was notably non-random. In the oligotrophic southern areas and the Japan sea, the variation was minimal but, in detail, the cyclic trend of variation was still recognizable.

These results are similar to the observations obtained in the Tasman Sea by Dal Pont and Newell[39] and in the Indian Ocean by Newell and Kerr.[40] Holm-Hansen *et al.*[42] also found a similar layering in the Baja California open water. The same result, however, are in a sharp contrast to the observations made by Menzel and coworkers.[35)36)33)19)34)82)] These authors observed various areas of both the Atlantic and the eastern Pacific close to the continent and claimed that all of the particulate carbon produced in the euphotic layer solubilized in the surface layer and never sink down below, say 100 m depth except in a few localized convergent areas and that the particulate organic matter existing below that depth is resistant to oxidation, non-utilizable for phagotrophic organisms and

carried only by the large scale circulation of the oceans, attaining an essentially uniform distribution with respect to time, space and depth.

Using the areal average data presented in Table 5, the present author constructed a correlation diagram in which the average surface (0–50 m) carbon concentration of a region was taken on the abscissa and the average carbon concentrations in deeper layers (201–500 m, 501–1000 m, and 1001–1500 m) of the same region on the ordinate (Fig. 28). A similar correlation diagram for nitrogen was also made (Fig. 29). In these diagrams, all of the thirteen sets of data were plotted, but five sets among the thirteen were composed each of single station data as specified in the figures, and these data are not considered to be adequately stable average values for respective areas. Tese data were also obtained in different seasons. Neverthless, these figures show that the regression of the material concentration in the surface layer is significantly good. Calculated correlation coefficient of P.O.C. for 201–500 m layer was 0.892 and significant at 99% confidence. The two sets of data obtained at the same location off Erimo but at different seasons (11, fall; 12, spring) were closely situated just on the average regression line (201–500 m). However, the data from deeper layers showed somewhat scattered.

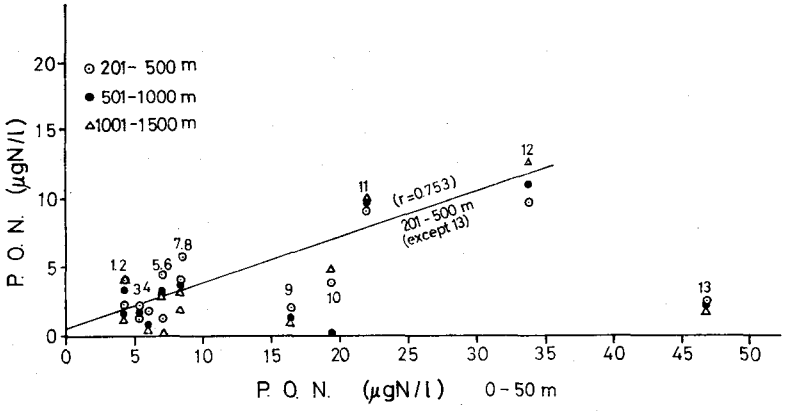

Fig. 29. Relationship between the average concentration of particulate organic nitrogen in the surface layer (0–50 m.) and in deeper layers (201–500 m. 501–1000 m., and 1001–1500 m.) from 13 areas; 1: the Kuroshio Counter Current region (Sta. 65–69, May to June 1968), 2: the Kuroshio Counter Current region (Sta. 19 and 21, Jan. 1967 and Sta. 42, Jan. 1968), 3: the Japan Sea (Sta. 76–81, July to Aug. 1970), 4: the Kuroshio Current region (Sta. 64 and 70, May to June 1968), 5: the Northern North Pacific (Sta. 84, June 1967), 6: the North Equatorial Current region (Sta. 15, Jan. 1967, Sta. 30, 34, and 38, Jan. 1968, and Sta. 58, Jan. 1969), 7: the South Equatorial Current region (Sta. 45 and 48, Dec. 1968 to Jan. 1969), 8: the Equatorial Counter Current (Sta. 26, Jan. 1968 and Sta. 51 and 55, Jan. 1969), 9: the Bering Sea (Sta. 88, 90, 92 and 94, June to Aug. 1967), 10: the Bering Sea (Sta. 95, Aug. 1967), 11: the Oyashio Current region (Sta. 74, Sept. 1969), 12: the Oyashio Current region (Sta. 73, April 1967) and 13: the Bering Sea (Sta. 87, June 1967).

From the regression analyses just shown, as well as from the considerations so far made on the profiles of particulate material in the thirteen areas, the present author considers that the origin of the particulate material in deeper layers down to at least 1500 m is in the surface layer immediately overlying rather than a far distant convergent area, and that the process of transport from above is fairly rapid compared to the sinking velocity ordinarily assigned to these particles, i.e., 1–5 m/day. This discussion, thus leads to the same line of argument as has earlier been made in Part I. A direct and rapid sinking of surface particles in the form of fecal pellets is possible when one takes into consideration the characteristically high concentration of pheopigments extended down to about a 1000 m depth or more. However, the pheopigments profile was usually very uniform in deeper layers, but the carbon or nitrogen profile was much more irregular, suggesting that the pellet component would probably be minor. Wheeler[83] found that calanoid copepod carcasses are rather exceeding in standing crop than living calanoid copepod in the water layers 2000–4000 m in depth in the Atlantic Ocean, but the carbon values derived from these carcasses were, at most, 1.8 μgC/m^3 and negligibly small. Dal Pont and Newell[39] considered that the observed layering of particulate organic material in the deep water of the Tasman Sea was due to the horizontal advection of different water mass. However, the present results show that the average concentration of deepwater particulate material in a given area is closely correlated with the concentration of surface particles in the area. Ichikawa's[64] extensive data of particulate carbon and nitrogen obtained in a long meridional section of the eastern Pacific Ocean clearly demonstrated that the entire section along a line at 155°W from 50°N to 15°S was divided into at least 6 large water columns according to their average contents of carbon and nitrogen, and in all of the six water columns there was a strict correlation between the particle contents in the 0–150 m layer and in the 150–4000 m layer.

Most possibly, the material transport is carried out by zooplankton migration or the ladder of migration[32], and a local formation of detritus (fecal pellet) would occur in depths. This process, if exists, would produce detritus with a higher nutritional value than that which had fallen from surface waters. However, more possibly would migrating zooplankton carry down organic matter and excrete it in a dissolved form. The excreted material will be quickly utilized by autochthonous protozoa as has recently been identified by Fournier[84] or by bacteria as have been quantitatively determined by ATP or DNA measurement.[8)85)86] Pomeroy and Johannes[87] also demonstrated the existence of an appreciable concentration of heterotrophic consumers in deep layers of the ocean by the total respiration. The last named authors also presented a fine description of the symbiotic microcosm organic aggregates that were sampled from 800–100 m depth of the Atlantic and were observed by fluorescent microscopy. Thus, there is one more possibility that

Table 6. The mean C/N ratio obtained by several authors in the various oceanic regions in the two columns of 0–100 m. and 100–1000 m. layers.

Area	C: N Ratio		Reference
	0–100 m	100–1000 m	
Southwest Pacific	3.2	3.7	Dal Pont and Newell[39]
Off southern California	5.5	10.9	Holm-Hansen *et al.*[42]
South Atlantic	5.7-7.2	5.4-12.0 16.0(2500m)	Holm-Hanesn *et al.*[86]
Northwest Atlantic	4.5-5.5	2.0-3.0	Menzel and Ryther[19]
Southeast Indian	9.8	12.3	Newell and Kerr[40]
Northeast Pacific	6.0	3.1	Parsons and Strickland[88]
Northeast Pacific	8	13	Williams[89]
Southwest Pacific	7 (0-200m)	8 (200m)	

excreted dissolved organic matter is quickly adsorbed onto the surfaces of existing particles and accelerates the growth of these attached heterotrophic microorganisms. If all of these processes worked out in natural oceans, the fruits of the surface production would result in a renewal of particulate organic matter in deeper layers in a short time.

The C/N ratios obtained in the present study were highly variable with a total range of 0.2–305. However, most values ranged from 2 to 50 and some of extremely low and high values are primarily suspect because of the low precision of nitrogen determination. The variable observations of this ratio, as can be seen in Table 6, has been a controversy among workers these last several years and no final solution has been obtained. For instance, in oligotrophic areas such as the Japan Sea and the KCC area, only the C/N ratio varied in a wide range of 0.2–58, and particulate organic carbon and nitrogen as well as pigments, temperature and salinity remained in very narrow respective ranges. The C/N ratios obtained in the Oyashio area off Erimo were characteristically low in comparison with the values obtained in the Bering Sea in which other conditions were practically similar to those in the former area. The variability would possibly involve a considerable degree of analytical error, but the relative variability from layer to layer at a fixed station seems to be still surprising, and this situation might again suggest that there is involved some kind of biological activity that is especially sporadic and microzonally localized in an environment exceedingly poor in energy source.

Part III. *Micro-Layer Concentration of Organic Materials at the Surface Skin in a Small Embayment.*

A number of oceanographers have paid attention to the phenomenon that an accumulation of particulate matter occurs at sea surface skin.[90][91][92][93][94] These

workers were mainly concerned with possible slick-forming mechanisms in open sea areas and were consistent in recognizing that the slick-bands are loci in which accumulations of particulate material occur because of the localized convergent motion of surface water. However, recent evidences[25)89)95)] show that the accumulation of materials at the sea surface is not confined to the slick bands; sample waters skimmed from the sea surface apparently free from slicks contain particulate and dissolved organic material that is significantly higher in concentration than in the bulk water.

The present investigations were designed to detect similar phenomena in a small coastal embayment and in particular to find possible variations of the organic concentration at the sea surface with respect to time in a two months period. Four sampling trips were made in May and June 1970 with a fortnightly interval. In each trip, 4–5 water samplings were made during 24 hr at the central area of the Bay (Fig. 30). The methods of sampling and subsequent analyses were indicated earlier (cf. p. 14) and a photograph of the used screen sampler is shown in Fig. 31. All the results obtained in these four trips are tabulated in Tables 7a, 7b, 7c and 7d, and the variations of selected items and their ratios are shown in Figs. 32 and 33.

I) *Concentration Factor.* Particulate carbon in the surface skin was in a general range of 367–5174 μgC/l and that in 0.5 m layer was 125–347 μgC/l. Thus, it is clear that particulate organic carbon was more concentrated in the surface skin

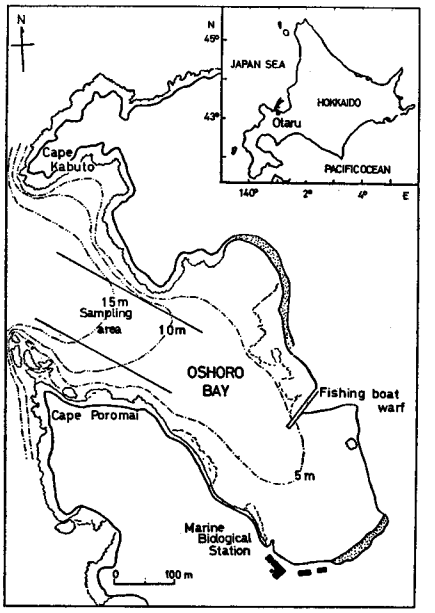

Fig. 30. Stations for surface skin sampling in Oshoro Bay, Hokkaido, Japan. May to June, 1970.

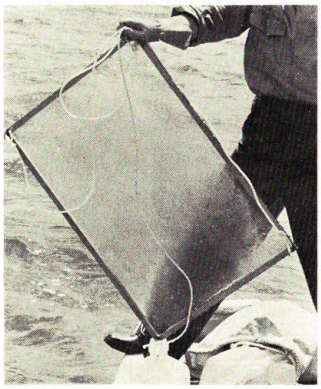

Fig. 31. Stainless steel screen (16-mesh, 50×75 cm.) used for surface skin sampling in Oshoro Bay.

that in the subsurface layer in all the observations during these two months. The concentration factor for carbon in the skin relative to the subsurface layer ranged from 1.6 to 17.6 with a mean of 5.4. The concentration of particulate nitrogen was also consistently higher in the skin, but the concentration factor was in a range of 1.1–5.1 with a mean of 2.7, being much lower than for carbon. The same factor for seston dried weight ranged from 0.8–5.9 with a mean of 2.3. Consequently, inorganic fractions in seston which were estimated by subtracting the organic matter (P.O.C. × 2) from dried weight, remained relatively constant; the factor for the inorganic matter thus calculated ranged from 0.25 to 3.7 with a mean of 1.5.

It has generally been assumed that the abundance of chlorophyll *a* is minor in the extremely thin layer of the sea surface due to the effect of the photo-inhibition for photosynthesis. In the present observations, the concentration of chlorophyll *a* in the skin was not lower than in the subsurface layer in 12 out of the 17 pairs of samples and that of pheopigments was not lower in 14 out of the 17 pairs of samples. The mean factor was 1.5 for chlorophyll *a* and 2.3 for pheopigments. This evidence might suggest either that some activities of phytoplankton exist in the skin, or that the water is well mixed with the subsurface water. The former situation seemed to be a possibility because the inverse correlation between the amount of chlorophyll *a* and the nutrients was monthly observed at the skin as described later. Concentration factors for heterotrophic bacteria ranged between 0.8 and 15 (mean 4.0).

Inorganic nutrients were not always concentrated in the surface skin layer: the concentration factor of nitrite was 0.75–11.2 (mean 3.5) except for a high value of 63.6 and that of ammonia was 0.08–18.3 (mean 4.8), and these factors were generally higher but more variable than the same factors of NO_3-N, and

dissolved organic substances. Concentration factors less than 1 were obtained in two observations in PO_4-P, six in NO_2-N, two in NO_3-N, and three in NH_4-N. For example, the extremely low value of 0.08 in ammonia was obtained in a single sample at 21*00* on June 20, 1970.

Table 7a. Concentrations of particulate matter (dried weight, organic carbon (P.O.C.), organic nitrogen (P.O.N.), chlorophyll *a*, pheopigments and colony numbers of heterotrophic bacteria) and dissolved matter (reactive phosphorus (PO_4-P), Nitrate (NO_3-N), nitrite (NO_2-N), ammonia (NH_4-N), organic phosphorus (D.O.P.), and organic nitrogen (D.O.N.)), in the surface skin and the subsurface water (ca. 50 cm. deep) in Oshoro Bay on May 9–10, 1970. Values in parentheses are concentration factors in the skin relative to the subsurface layer.

Date Time		May. 9 16.*00*	May. 9 22.*00*	May. 10 04.*00*	May. 10 10.*00*	May. 10 15.*00*
Dried Weight (mg/*l*)	0(m)	6.49	15.50	7.06	8.24	24.10
		(1.5)	(3.2)	(3.2)	(1.1)	(5.9)
	0.5	4.27	4.89	2.19	7.79	4.10
P.O.C. (μg/*l*)	0	1304.3	5173.9	2338.3		1702.8
		(10.5)	(17.6)	(6.7)		(6.0)
	0.5	124.4	293.2	347.5	214.3	281.8
P.O.N. (μg/*l*)	0	141.1	331.7	227.8		217.8
		(2.7)	(5.1)	(4.1)		(3.3)
	0.5	52.8	65.0	56.1	62.5	66.1
Chl. *a* (mg/m³)	0	0.186	2.052	0.731	0.698	1.749
		(0.59)	(6.37)	(1.65)	(1.14)	(1.90)
	0.5	0.313	0.322	0.442	0.610	0.919
Pheop. (mg/m³)	0	0.268	6.714	1.956	0.937	3.522
		(0.76)	(8.79)	(3.81)	(1.14)	(5.25)
	0.5	0.352	0.763	0.513	0.822	0.671
Bacteria (cell/m*l*)	0	207	LA	LA	683	LA
	0.5	213	LA	223	487	LA
PO_4-P (μg-at/*l*)	0	0.651	1.465	0.385	0.350	0.525
		(1.32)	(5.81)	(1.83)	(1.43)	(5.35)
	0.5	0.490	0.252	0.210	0.245	0.098
NO_3-N (μg-at/*l*)	0	2.484	3.241	2.094	1.230	2.745
		(1.00)	(1.24)	(4.05)	(0.36)	(2.11)
	0.5	2.488	2.619	0.517	3.435	1.300
NO_2-N (μg-at/*l*)	0	1.407	0.609	0.431	0.281	0.153
		(11.17)	(9.09)	(5.26)	(5.62)	(2.15)
	0.5	0.126	0.067	0.082	0.050	0.071
NH_4-N (μg-at/*l*)	0	3.392	12.294	1.504	1.459	1.907
		(4.24)	(18.29)	(18.12)	(5.07)	(2.84)
	0.5	0.800	0.672	0.083	0.288	0.672
D.O.P. (μg-at/*l*)	0	0.028	0.105	0.266	0.154	
			(1.50)	(9.50)		
	0.5		0.070	0.028		0.091
D.O.N. (μg-at/*l*)	0	6.386	1.819	7.861	9.429	11.043
		(0.92)	(0.50)	(1.39)	(4.02)	(1.03)
	0.5	6.918	3.611	5.643	2.344	10.731

Table 7b. The same items as in Table 7a, on May 23–24, 1970.

Date Time		May. 23 15.*00*	May. 23 21.*00*	May. 24 04.*00*	May. 24 10.*00*
Dried Weight (mg/*l*)	0(m)	5.50 (4.1)	3.62 (2.3)		4.15 (2.6)
	0.5	1.33	1.55	1.32	1.62
P.O.C. (μg/*l*)	0	891.1 (5.4)	698.0 (3.5)	886.8 (6.4)	596.8 (4.5)
	0.5	164.1	202.0	138.4	132.1
P.O.N. (μg/*l*)	0	103.6 (2.9)	113.6 (2.8)	128.9 (4.9)	86.1 (2.7)
	0.5	36.3	41.3	26.6	32.3
Chl. *a* (mg/m^3)	0	0.956 (0.94)	0.796 (0.99)	0.941 (1.87)	0.628 (1.28)
	0.5	1.020	0.800	0.503	0.491
Pheop. (mg/m^3)	0	0.671 (1.22)	1.991 (1.99)	0.874 (1.92)	1.546 (5.58)
	0.5	0.549	1.001	0.455	0.277
Bacteria (cell/m*l*)	0	125 (0.6)	642 (2.8)	394 (5.2)	435 (7.6)
	0.5	211	227	76	57
PO_4-P (μg-at/*l*)	0	0.124 (4.28)	0.175 (1.84)	0.131 (3.50)	0.139 (2.10)
	0.5	0.029	0.095	0.037	0.066
NO_3-N (μg-at/*l*)	0	0.255 (0.66)	0.713 (1.86)	0.857 (0.70)	1.617 (1.42)
	0.5	0.387	0.383	1.229	1.136
NO_2-N (μg-at/*l*)	0	1.205 (63.6)	0.092 (4.0)	0.071 (5.46)	0.061 (2.44)
	0.5	0.019	0.023	0.013	0.025
NH_4-N (μg-at/*l*)	0	11.368 (13.3)	1.936 (1.53)	1.067 (1.80)	1.146 (0.92)
	0.5	0.853	1.264	0.593	1.249
D.O.P. (μg-at/*l*)	0	0.204 (1.27)	0.277 (1.23)	0.219 (1.50)	0.387 (2.65)
	0.5	0.161	0.226	0.146	0.146
D.O.N. (μg-at/*l*)	0	10.252 (1.23)	8.594 (1.10)	6.583 (0.99)	7.994 (1.45)
	0.5	8.303	7.836	6.677	5.511

As for the dissolved organic phosphorus and nitrogen, a description similar to the major nutrients can be made and the factors fluctuated within about 50% except for a few high values.

II) *Variabilities with respect to time.* It was very difficult to interpret the daily variation of these substances in both layers because the Oshoro Bay was not perfectly isolated from the outer sea; daily variation at a fixed location might include possible effect to take a broad view of variability with respect to time.

In the first sampling period (May 9–10, 1970) (Table 7a), the observed diurnal

Table 7c. The same items as in Table 7a, on June 6–7, 1970.

Date Time		June. 6 15.00	June. 6 21.00	June. 7 04.00	June. 7 10.00
Dried Weight (mg/l)	0(m)	2.40 (1.5)	3.53 (2.2)	3.36 (2.2)	3.43 (2.6)
	0.5	1.64	1.59	1.51	1.34
P.O.C. (μg/l)	0	846.7 (4.4)	945.0 (4.9)	1051.7 (4.6)	811.0 (4.0)
	0.5	191.5	194.3	230.5	202.5
P.O.N. (μg/l)	0	72.0 (1.7)	120.8 (3.0)	94.0 (2.1)	83.7 (2.2)
	0.5	41.8	39.8	45.0	38.5
Chla. *a* (mg/m³)	0	1.842 (0.78)	1.721 (1.08)	1.978 (1.18)	1.971 (1.45)
	0.5	2.373	1.592	1.673	1.361
Pheop. (mg/m₃)	0	2.169 (1.14)	2.027 (1.75)	0.937 (1.24)	1.171 (1.12)
	0.5	1.898	1.159	0.758	1.044
Bacteria (cell/ml)	0	911 (1.07)	1185 (3.05)	864 (2.24)	550 (3.57)
	0.5	852	389	385	154
PO_4-P (μg-at/l)	0	0.125 (1.21)	0.088 (2.38)	0.118 (7.87)	0.125 (2.12)
	0.5	0.103	0.037	0.015	0.059
NO_3-N (μg-at/l)	0	2.479 (8.15)	1.872 (2.57)	2.748 (2.85)	2.635 (1.06)
	0.5	0.304	0.727	0.963	2.490
NO_2-N (μg-at/l)	0	0.098 (2.57)	0.048 (1.33)	0.040 (1.11)	0.074 (0.85)
	0.5	0.038	0.036	0.036	0.087
NH_4-N (μg-at/l)	0	1.640 (5.75)	0.732 (1.38)	0.832 (2.58)	1.101 (1.06)
	0.5	0.285	0.531	0.323	1.040
D.O.P. (μg-at/l)	0	0.287 (0.81)	0.147 (0.45)	0.145 (0.56)	0.228 (1.10)
	0.5	0.353	0.323	0.257	0.308
D.O.P. (μg-at/l)	0	10.418 (1.31)	9.471 (1.15)	8.098 (0.75)	5.869 (0.67)
	0.5	7.927	8.267	10.807	8.713

variation was larger in the surface skin than in the subsurface layer. During the 24 hrs, the seston dried weight in the skin showed very much scattered values ranging between 6.49 and 24.0 mg/*l* as compared with the range in the subsurface layer, i.e., 2.10–7.79 mg/*l*. POC and PON in the skin were also scattered in wide ranges from 1304 μgC/*l* to 5174 μgC/*l* and from 141 to 332 μgN/*l*, respectively, whereas in the subsurface layer it was from 124 to 348 μgC/*l* and from 53 to 66 μgN/*l*, respectively. Inorganic contents as calculated above, ranged between 3.88 and 11.15 mg/*l* in the skin and between 1.49 and 4.30 mg/*l* in the subsurface

Table 7d. The same items as in Table 7a, on June 20–21, 1970.

Date Time		June. 20 15.*00*	June. 20 21.*00*	June. 21 04.*00*	June. 21 10.*00*
Dried Weight (mg/*l*)	0	2.15 (1.42)	2.14 (0.96)	2.15 (1.10)	0.90 (0.81)
	0.5	1.51	2.21	1.91	1.10
P.O.C. (μg/*l*)	0	454.5 (2.2)	441.9 (1.8)	491.4 (2.7)	367.6 (1.6)
	0.5	207.6	243.6	182.2	231.3
P.O.N. (μg/*l*)	0	72.3 (1.9)	60.9 (1.4)	56.2 (1.6)	46.4 (1.1)
	0.5	38.6	42.6	35.8	43.5
Chl. *a* (mg/m_3)	0	1.618 (1.00)	1.502 (1.02)	1.950 (0.75)	2.166 (0.66)
	0.5	1.614	1.478	2.592	3.292
Pheop. (mg/m_3)	0	1.288 (1.30)	0.882 (1.03)	1.031 (0.92)	1.097 (0.54)
	0.5	0.994	0.853	1.118	2.020
Bacteria (cell/*ml*)	0	7990 (5.0)	5156 (15.0)	1402 (1.4)	5040 (0.9)
	0.5	1639	384	1023	5895
PO_4-P (μg-at/*l*)	0	0.082 (1.82)	0.060 (2.73)	0.052 (0.78)	0.052 (0.87)
	0.5	0.045	0.022	0.067	0.060
NO_3-N (μg-at/*l*)	0	0.366 (1.10)	0.386 (1.02)	0.234 (0.52)	0.142 (0.19)
	0.5	0.334	0.378	0.454	0.734
NO_2-N (μg-at/*l*)	0	0.069 (2.50)	0.048 (1.50)	0.032 (1.19)	0.027 (0.75)
	0.5	0.027	0.032	0.027	0.036
NH_4-N (μg-at/*l*)	0	0.891 (0.80)	0.429 (0.08)	1.188 (1.57)	0.495 (1.25)
	0.5	1.109	5.115	0.759	0.396
D.O.P. (μg-at/*l*)	0	0.305 (0.80)	0.365 (5.45)	0.439 (2.57)	0.387 (1.53)
	0.5	0.379	0.067	0.171	0.253
D.O.N. (μg-at/*l*)	0	8.647 (1.14)	7.467 (2.90)	6.828 (1.15)	8.145 (1.02)
	0.5	7.597	2.565	5.937	8.004

layer. This is in a sharp contrast to the carbon contents mentioned above in which the skin concentration was nearly one order of magnitude higher than in the subsurface. In particular, at 16*00*, May 9, no accumulation of inorganic material at the skin was observed but the carbon in the skin was as much as 10 times higher than in the bulk. Thus, the carbon content as an indicator of organic fraction in seston was significantly higher in the skin (20–30% except for 7% at 15*00*) than in the subsurface layer (2.7–6.9% except a single value of 15.8% at 04*00*).

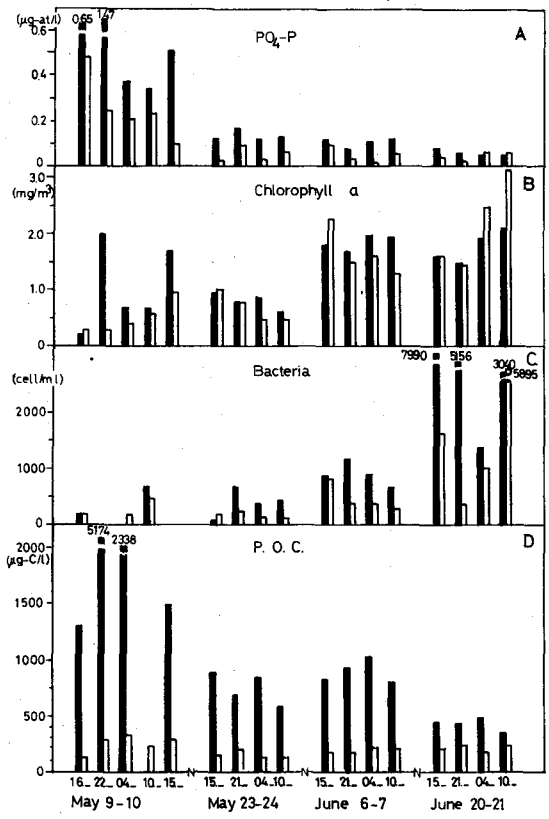

Fig. 32. Monthly variations in concentrations of PO_4-P (A), chlorophyll *a* (B), bacterial cell number (C), and P.O.C. (D), in the skin (solid column) and in the subsurface layer (ca. 50 cm. deep, open column) in Oshoro Bay, May to June, 1970.

The C/N ratio in the skin was in a range from 7.8 to 15.6 and in the bulk from 2.3 to 6.2, suggesting qualitative differences in particles between both layers. The C/N ratio obtained in the subsurface layer was within the accepted range of the same ratio for living phytoplankton, i.e., 3–6.[17)18)96)]

Chlorophyll *a* and pheopigments at the skin varied parallelly with each other ranging from 0.19 to 2.05 mg/m^3 and from 0.26 to 6.71 mg/m^3 in the skin, respectively, while in the subsurface layer these were in narrow ranges between 0.31 and 0.92 mg/m^3 and between 0.35 and 0.82 mg/m^3, respectively. Consequently, carbon to chlorophyll *a* ratio was extremely high, ranging from 973 to 7062 in the skin and from 351 to 910 in the subsurface layer. Since the C/Chl. ratio of living natural phytoplankton is at most 100,[21)22)] these values were 3 to 70 times as much as that of phytoplankton. These facts indicate the existence of a large amount of non-living particulate materials in the skin as well as in the subsurface layer.

As for the variation of dissolved matter, the magnitude of fluctuation of each

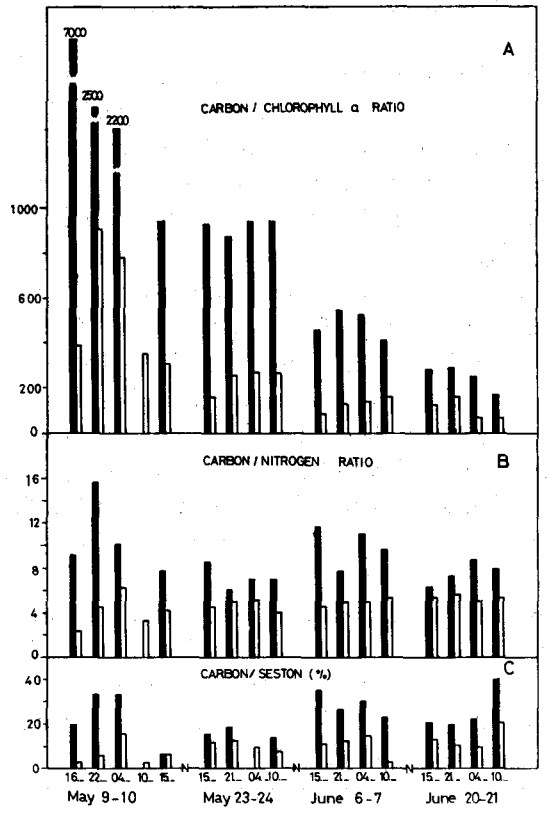

Fig. 33. Monthly variations of carbon to chlorophyll *a* ratio (A), carbon to nitrogen ratio (B), and percent carbon fraction of seston in the skin (solid column) and in the subsurface layer (ca. 50 cm. deep, open column) in Oshoro Bay, May to June, 1970.

variable was also larger in the skin water than in the subsurface layer. A marked localization of the dissolved matter as well as particulate matter was observed at 22*00* in the skin water; a relatively high concentration of the inorganic nutrients and an extremely low concentration of DON were observed together with a large quantity of the particulate materials as described above. The situation might suggest that the sea surface was entirely covered at the time of observation with the slick. In this sampling period, the bay was temporarily covered by coloured low saline water(freshet) transported from outside of the Bay. The extreme variability of particle contents described above would reflect the effect of this and advection can not be considered to be variabilities in a single water pacel. In later sampling times, no such advection of water was recognized.

After the second sampling time, the range in daily variation of each substance in the skin as well as in the subsurface layer became gradually narrow, as compared with that in the first sampling time, although a few abnormally high or low

concentrations were often observed in bacteria, ammonia and nitrite (Tables 7b, 7c, 7d).

Throughout the entire sampling period, the mean level of particulate carbon and nitrogen in the skin water tended to decrease gradually as compared with their relatively constant concentrations in the subsurface layer; the average amount of particulate carbon and nitrogen in the skin decreased from 2,630 μgC/l in the first sampling to 439 μgC/l in the last sampling and from 230 μgN/l to 59 μgN/l, respectively (Fig. 32).

On the other hand, daily averages of chlorophyll a and heterotrophic bacteria in the skin increased from 1.08 mg/m^3 to 1.81 mg/m^3 and from 445 cell/ml to 4897 cell/ml, respectively (Fig. 32). The increase of chlorophyll a was simultaneously associated with the gradual decrease in reactive phosphorous, indicating a seasonal progression of phytoplankton blooming (Fig. 32). Consequently, C/Chl ratios decreased from around 3000 obtained in the first sampling to around 250 in the last sampling in the skin and from 900 to 100 in the subsurface layer (Fig. 33). However, carbon/seston and carbon/nitrogen ratios show no such consistent variation with season in both layers.

Thus, typical inverse correlations between particulate carbon and chlorophyll and between carbon and bacteria were observed from May to June. The situation was more pronounced in the skin water than in the subsurface layer. This correlation is considered to indicate that the major fraction of particulate carbon was non-living and that the development of phytoplankton blooming was closely accompanied by the progress of bacterial mineralization of the organic matter.

Variations of dissolved organic phosphorus and nitrogen in the skin were between 7.3–8.4 μg-at/l and between 0.14 and 0.37 μg-at/l, respectively (cf. Tables 7a, 7b, 7c and 7d), and showed no remarkable monthly trend.

Discussion

In the present observation, a 16-mesh stainless steel screen[65)97)] was used for the collection of the sea surface skin water. By this apparatus the skin of 150 μ in thickness was skimmed.[65)] Williams[89)] carried out a collection of skin water using the same screen in open waters off California and Peru, and reported that the concentration factors were in the range of 3.1–48.8 for particulate materials and 1.7–4.9 for dissolved organic materials in the skin relative to the subsurface layer. Goering and Menzel[98)] pointed out that the concentrations of the nutrients (phosphate, nitrite and ammonia) at the surface skin were significantly higher than that of the subsurface layer. In the present observation, however, it was confirmed that only organic carbon and nitrogen were consistently concentrated in the skin layer relative to the subsurface layer although the concentration factors were much smaller than the results of Williams. His factors, however, were ratios of

the concentrations in the surface skin to those in 24–74 m depth layers and are not directly comparable with the present results.

Surface chemical investigation have well demonstrated that the sea surface is usually covered with a mono or multi-molecular layer of adsorbable organic substances regardless of the sea condition.[45)65)99)100)101)102)103)104)105)106)107)] There is a good possibility that the material which is adsorbed onto the sea/air interface and forms the multilayer, may collapse into film detritus due to wave action. Although recent evidence seems to negate this possibility[106)], Harvey[107)] reported that unidentified particulate substances and dinoflagellates were also much more abundant in the skin 60 μ in thickness than in the bucket samples of the subsurface waters. Sieburth[97)] and Tsiban[44)], also using similar sampling gears, observed the accumulation of bacteria on the sea surface microlayer. At the Oshoro Bay, however, a direct microscopic examination of living organisms showed that the diatom was extremely abundant in both layers in the total plankton in this season and no significant differences between the two layers were observed.[108)] However, bacterial concentrations were significantly higher at the skin through the entire period as mentioned above and in the early half period of the observation, chlorophyll *a* was also higher at the skin (Fig. 32).

The evidence that organisms (phytoplankton and bacteria) and inorganic nutrients were in most cases concentrated in the skin might suggest that both production and mineralization occur intensively in this localized microlayer. In addition, a production of organic matter by some physico-chemical mechanisms might occur in the skin layer because the present data show that C/Chl a ratios and C/N ratios that are much higher than those of phytoplankton were obtained in the skin layer. It seems necessary to add here that the concentration factors calculated above were based on an arbitrary assumption that the thickness of the skin layer is the same as the thickness of the sampled layer i.e. 150 μ. If the skin layer was assumed to have a thickness of molecular dimension, say 20–50 Å, resultant concentration factors would be four to five orders of magnitude higher.

Ramsey[93)94)] related observed accumulations of particles in convergence lines to the convergent water movement caused by internal waves, and described that the suspended matter in the subsurface layer was transported upwards with bubbles. On the other hand, Sutcliffe *et al*[25)] demonstrated that organic films are produced from dissolved organic matter by bubbling at the sea surface and are carried down into the bulk water by the downward water movement associated with the Langmuir circulation. Various hypotheses have been proposed as to a possible mechanism of particle formation; physico-chemical adsorption of dissolved organic material onto bubbles[24)], adsorption of the dissolved organic matter onto inorganic materials[95)109)110)111)], bacterial growth[26)29)] and the interaction of bubble and bacteria[27)]. Whatever mechanisms it may involve, the fact that chlorophyll

a and heterotrophic bacteria progressively increased from May to June in the Oshoro Bay while the particulate carbon showed a consistent decrease during the same time interval (see Figs. 32 and 33) might probably suggest that the formation of particles was not only due to the production of organisms but also due to some other mechanisms categorically different from both photo-synthesis and bacterial synthesis. Considering that in most cases only organic matter was preferentially concentrated in the surface skin, some sort of adsorptive process is considered to be most acceptable.

General Discussion

The present investigations revealed, among others, that (1) the concentration of deepwater particulate matter in terms of either organic carbon and nitrogen or dried weight total seston markedly varies regionally within the entire western North Pacific and adjacent seas. The total range of variation was 0.01–0.77 mg/*l* in dried weight and 0–155 μgC/*l* in carbon (0–19.5 μgN/*l* in nitrogen), (2) the regional variation in deep water is closely parallel to that in the surface layer (0–50 m), in which the range of variation was 0.10–3.95 mg/*l* in dried weight and 15–450 μgC/*l* in carbon (0.8–65.0 μgN/*l*), and (3) the vertical decrease in concentration of particulate matter was stepwise; a phenomenal decrease occurred in the surface layer itself, attaining a more or less marked minimum located at the base of the euphotic layer, and a similar set of variation is usually repeated cyclically in deeper layers with progressively less phenomenal rates of decrease with depth.

These findings directly contradict the results of most of the previous workers mentioned above, and seem to need a new explanation other than those presented so far. The parallelism of the concentrations between the surface layer and deeper layers suggests that the major source of the deep water particulate material is in the surface layer. However, considering that the present results were obtained from different areas in different seasons and that the primary production in the surface layer in most of the areas is variable with respect to season, the material transfer from the surface to deeper layers has to be very rapid. Existing information on the sinking speed of the suspended particles show that the speed varies with the size and shape of the particles and is in a general range of 0.1–5 m/day.[41)112)] A recent review of Smayda[113)] showed that most living phytoplankton cells have low sinking rates, less than 1 m/day, and that fecal pellets have a general range of sinking rate of 36–376 m/day. Although the sinking rate varies with the shape, size and texture of the pellets, and these being dependent on food source, these rates are from 1 to 3 orders of magnitude greater than that for most phytoplankton cells. Furthermore, there is evidence that *Calanus* feeding on rich *Cheatoceros* cultures produces fecal pellets every 5 to 7 min.[114)] Thus, the rapid transit through the zooplankton gut combined with the high sinking rates suggests

that fecal pellets would be potentially important in rapid transport of particulate material to depth. Johannes and Satomi[115] estimated that the rate of incorporation of organic matter into fecal pellets in the sea exceeds the rate of incorporation of organic matter into herbivore tissue. The present observations reveal that the concentration of pheopigments in deeper layers below the photic zone is in a general range of 0.01–0.4 mg/m^3 and much higher than that of chlorophyll which was often detectable but usually negligibly low in concentration. This would probably reflect the downward transport of pellet material to depth.

However, as discussed in Part II, the vertical profile of pheopigments was very uniform in deeper layers and in a sharp contrast to the irregular profiles of particulate carbon and nitrogen. This means that the pellet component would probably be minor although no information is available how much fraction of the deep water pheopigments is associated with the pellet materials.

Another possibility is the vertical migration of zooplankton. Nakajima[116] described the vertical distribution of particulate carbon in the Bering Sea and discussed the layering in particle concentration in relation to the vertical distribution of zooplankton. The pattern in zooplankton profile obtained by divided vertical net hauls[117] was nearly parallel to the profile of particulate carbon; in the 200–500 m depth layer where a marked secondary maximum of particulate material occurred, there was found a similarly marked maximum of zooplankton standing crop. Minoda[118] analysed the vertical distribution of copepods in the subarctic water and the Bering Sea, and reported that a distinct increase in standind crop of copepod species was observed in a 200–500 m depth layer which which corresponded to the transition zone between the subarctic surface water and the deep water. McAllister[6] showed that at station **P** in the Gulf of Alaska, a consistent minimum in zooplankton standing crop occurred in the 100–200 m depth layer in which the pronounced minimum of particle contents also occurred. This parallelism in vertical profile between zooplankton crop and particulate material seems to indicate either that zooplankton tends to stay in a layer rich in particulate food or that the particulate materials are rich in a layer zooplankton tend to stay in. Probably, these are different chapters of the same story, and mean that migrating zooplankton carries down considerable amounts of surface material down to depth and release a fraction of the same into the ambient water in which they stay. The process of release would be that of excretion of fecal pellets or organic and inorganic matter in dissolved forms. The released organic material will be further utilized or decomposed. However, the released dissolved matter will not be utilized directly by the heterotrophic consumers mentioned earlier in Part II (see p. 83) because of too low concentration. Most possibly the released material will be adsorbed onto the surfaces of existing particles resulting in a substantial concentration suitable for utilization by bacteria and protista as detected by

Fournier[84], Holm-Hansen *et al*[8], Hamilton[85] Holm-Hansen[86] and Pomeroy and Johannes.[87] The plausible fluorescent microscopy of the symbiotic microcom organic aggregates made by the last named authors is considered to have revealed actual loci of this concentration and utilization. If these assumptions are correct, it is quite natural that the layering in particulate material is nearly parallel to

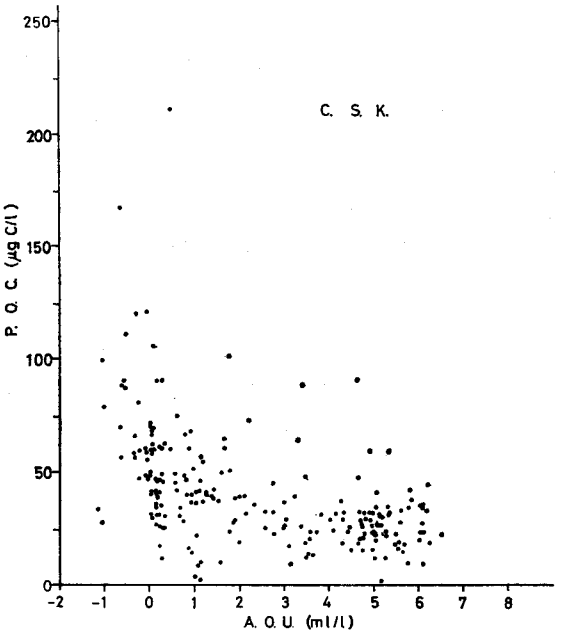

Fig. 34a. Relationship between P.O.C. and A.O.U. observed in the CSK area in the Philippine Sea from 2°S. to 30°N., 142°E. line.

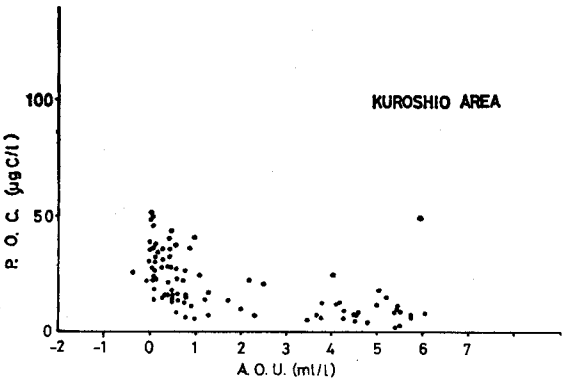

Fig. 34b. Relationship between P.O.C. and A.O.U. observed in Kuroshio area in the Philippine Sea and the East China Sea (KH-68-2).

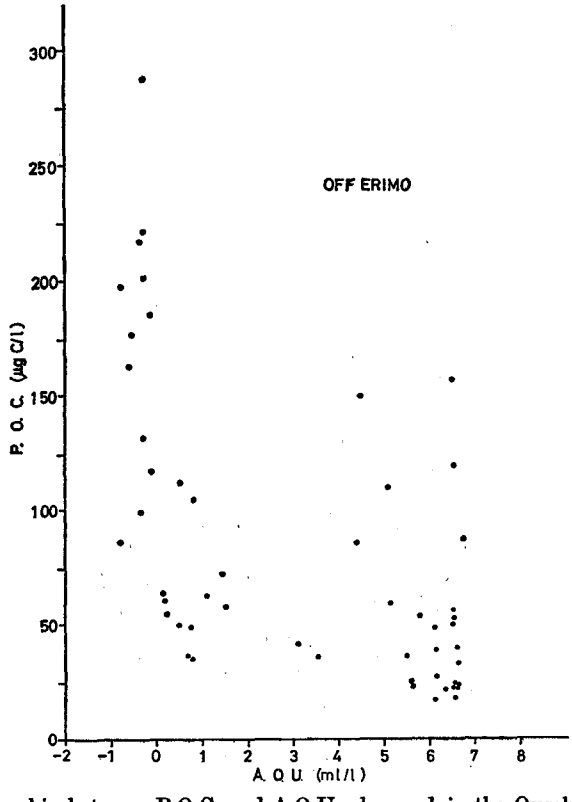

Fig. 34c. Relationship between P.O.C. and A.O.U. observed in the Oyashio Current region off Erimo.

the vertical profile of zooplankton standing crops, and the scheme of organic renewal by adsorption in deep water originally presented by Riley *et al.*[37] is reasonably accepted.

A series of diagrams showing the relation between P.O.C. and A.O.U. (apparent oxygen utilization) is shown in Figs. 34a-34e for 6 major areas where sufficient numbers of observations were available. Although there is a general tendency of increasing A.O.U. with decreasing P.O.C. in each area, the points are highly scattered and anomalously high values of P.O.C. are found in the domain of high A.O.U. particularly in eutrophic areas such as the Bering Sea and the sea area off Erimo. This is considered to be explained by the relative freshness of some of deep water particles that were quickly transported from the surface layer, or renewed in situ either by adsorption[37] or by heterotrophic activities.[119] Organic fraction within total seston as well as the C/N ratio of particulate matter never showed a consistent trend to decrease with depth in the present observations, and Gordon[38] experimentally showed that 20% of organic carbon taken from deep

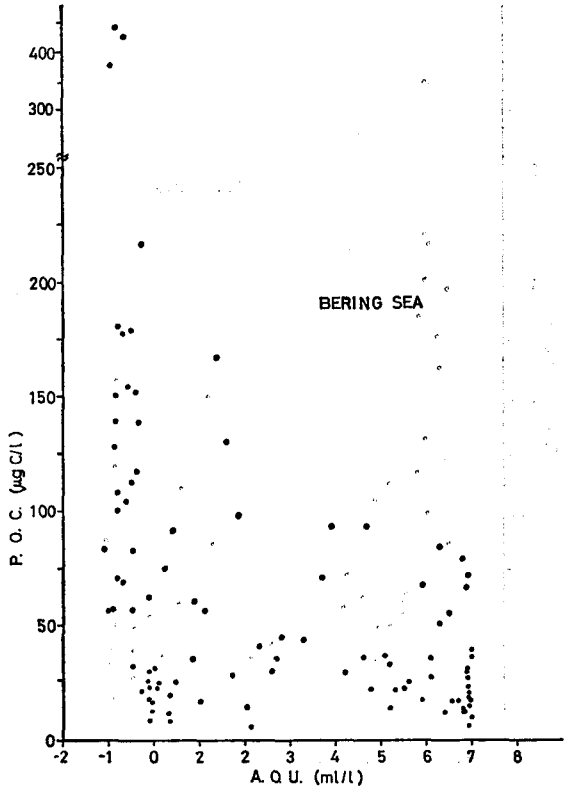

Fig. 34d. Relationship between P.O.C. and A.O.U. observed in the Bering Sea.

layers of the Atlantic could be oxidized by a mixture of emzymes. Detailed processes of adsorption and utilization of dissolved organic matter occurring on the surface of existing particles are not much clear. A recent interesting experiment by Khailov and Finenko[120], however, revealed that proteinaceous material or polysaccharides dissolved in sea water are quickly adsorbed onto the surface of existing particles (detritus or glass beads) and decomposed immediately by microoraganisms resulting in a quick increase in microbiomass. Sheldon *et al.*[29] showed that a filtered seawater sample was apparently particle free only for a few hours after filtration; a spontaneous particle formation occurred immediately and a more or less steady concentration was attained in a few days. If all of these processes work out efficiently in the natural environment, the material transport from the surface layer down to depth will be very quick and the fruits of the surface production will be renewed in deeper layers in a few to several days. Osterberg *et al.*[121] could detect short half lived fission products from sea cucumbers collected off the Oregon coast from 2800 m depth, and obtained a Gamma-ray spectrum that was practically similar to that obtained for sea-cucumbers taken in

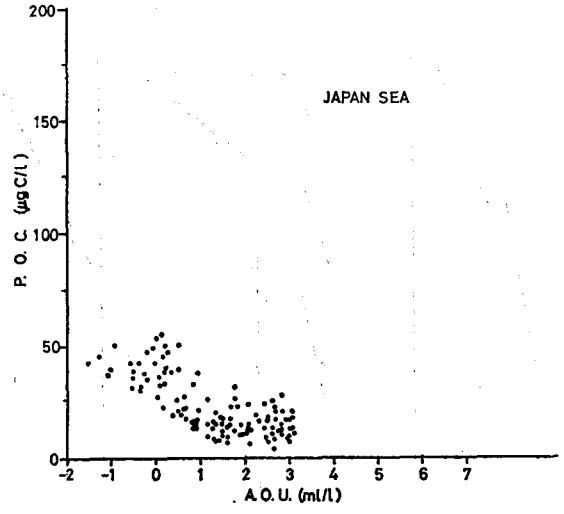

Fig. 34e. Relationship between P.O.C. and A.O.U. observed in the Japan Sea (KH-70-4).

200 m of water close to the shore. Transit time calculated from the small difference between the two spectra was 7–12 day. The vast volume of water beneath the euphotic layer is not the dead world as suggested by Menzel but a live biosphere that is constantly exchanging utilizable material with the surface layer and supporting various activities of organisms living in the aphotic environment.

The stepwise variation of particle concentration mentioned in (3), poses another problem of layering in deep waters. Although this pattern of variation was not much clear in oligotrophic areas, in northern eutrophic seas the stepwise decrease in particle concentration was apparently recognized (Fig. 35). The trend of decrease in each step was nearly exponential and expressed by

$$C_i = C_{io} e^{-k_i (z_i - z_{io})} \qquad (6)$$

in which C_{io} is the maximum concentration occurring at a depth Z_{io} in the ith step, and C_i is the concentration at a depth Z_i. The rate of decrease k_i was in a general range of 0.002–0.04 and higher values occurred in the surface layer. If we assume that the decrease rate k_i indicates the intensity of utilization of these particles that occurs during the downward transport with a constant velocity V_i, the stepwise decrease expressed by (6) leads to the conclusion that in each step the rate of utilization is relatively constant, and the decrease in k_i with depth means a similar stepwise decrease in utilization. These assumption might probably be related with the ladder of zooplankton migration proposed by Vinogradov.[32] The rapid transport itself mentioned above might probably be stepwise, and any accumulation or renewal might occur at a few localized zones principally deter-

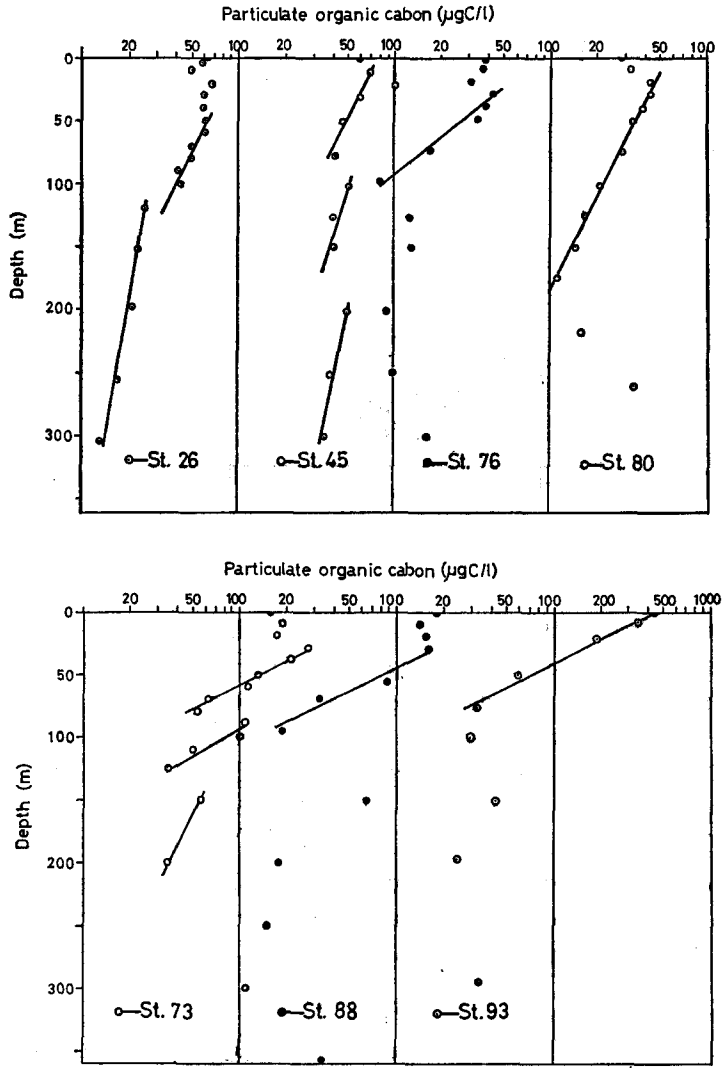

Fig. 35. Logarithmic decrease of particulate organic carbon with depth in the upper 300 m. layer in some typical stations; Sta. 26 and 45 in the southern area (CSK), Sta. 73, 88, and 93 in the northern area (off Erimo and the Bering sea, and Sta. 76 and 80 in the Japan sea).

mined by hydrographical conditions such as stability, or oxygen concentration. However, no adequate data on zooplankton migration were available, and any further speculation will be meaningless.

Whatever mechanisms may be involved in material transfer down to depth, there is no doubt that ultimate source of particulate organic material is in the surface photic zone less than 100 m in depth, and photosynthetic production is

generally accepted as a primary process to produce organic material. However, a significant fraction of the organic production is released as dissolved organic matter into seawater[122]. The present observations repeatedly showed that (1) a major fraction of suspended material in the surface layer is not phytoplankton but pigments devoid organic material that is possibly non-living, and (2) the vertical profile of particulate organic matter does not reflect that of chlorophyll nor of pheopigments. In fact, at most of the eutrophic stations, there occurred a consistently high concentration of particulate material at the sea surface, but the surface concentration of pigments was relatively low resulting in extremely high surface ratios of carbon to chlorophyll *a* with a general range from 1000 to as high as 15000. Even in the chlorophyll maximum layer, the same ratio never reduced down below 150 except for the intensive upwelling area along the equator. The surface skimming described in Part III further revealed that the concentration of particulate organic matter in the surface skin layer was several folds higher than in the subsurface layer (ca. 50 cm deep). The observations were made in a small coastal embayment and probably do not reflect oceanic situation, but recent evidence[123)89] showed that in open oceanic area, the concentration factors of particulate organic carbon and nitrogen at the surface skin were much higher than in coastal areas.

One obvious conclusion that can be deduced from these observations is that the extreme skin layer is a locus where an intensive formation of particulate organic matter occurs. The strict mechanism of formation is not precisely known and is under controversy among workers. The local time rate of particle formation at the skin is also not known; a tentative calculation of Nishizawa and Nakajima[81] would probably be an overestimate because some of detrital particles tend to float up from beneath the surface and accumulate there.

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