粒状有機物の海面濃縮について

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Concentration of Particulate Organic Material in the Sea Surface Layer* **

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Abstract

Vertical variations in particulate carbon concentration in upper 300 m depth were examined for the Bering Sea, the Oyashio Area off Hokkaido and the Subtropical and Tropical Areas of the North Pacific along the 142° E meridian line. The maximum concentration of the order of 50–200 μgC/lit was found at or close to the sea surface, and the concentration decreased rapidly with depth in a depth interval of 50–100 m, and tended to converge to a minimum concentration less than 50% the surface value. This pattern was in a sharp contrast to that of chlorophyll which almost always was characterized by a more or less distinct subsurface maximum occurring near the base of the euphotic layer. Assuming a typical pattern of particulate carbon profile close to the sea surface, the downward flux of particulate carbon in the near-surface layer was calculated leading to an estimation of the average local time rate of particulate matter formation at the sea surface of 260 mgC/m^2/day.

Introduction

Information on the regional distribution and seasonal variation of particulate organic carbon and nitrogen suspended in the water column of the main oceans is still meager. Particularly, data of a full seasonal cycle of the concentration of particulate material are lacking for ocanic areas except for a temperate North Atlantic region where the time interval of sampling was not adequately short though. Recently, Ichikawa (1971) and Nakajima (1971) analysed extensive sets of samples of particulate carbon and nitrogen obtained in the North Pacific and revealed, in particular, a strikingly regular regional variation in deepwater particulate material concentration. However, no adequate sets of data were available on the seasonal variation of particle concentration in these areas. Nevertheless, a fairly consistent pattern of vertical distribution of particulate organic matter has emerged from the data published so far for a number of stations scattered in the main oceans. Full discussion of this pattern is immature yet and should involve a variety of ecological problems that are largely beyond the scope of the present paper (*cf.* Riley, 1970; Nakajima, 1971). Here the discussion is limited to the situation that occurs in shallow surface layers of the oceans.

Material and Methods

Particulate organic carbon and nitrogen are commonly determined by passing 3-10 liters

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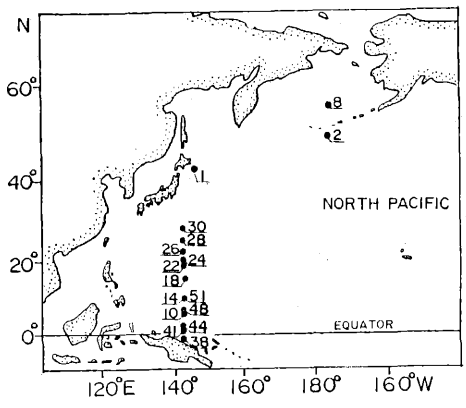

Fig. 1. Location of staions. The 16 stations were occupied in 1967-1969 during 5 Oshoro-Maru Cruises (no. 21, 23, 24, 26, 30). For exact location refer to Faculty of Fisheries, Hokkaido University (1968 a, b, and c, 1969, 1970).

of sample water through a filter with a pore size of 1μ or less and analysing the collected material for its carbon content. We used Whatman GF/C filters and the filter with its residue was washed with a 3% NaCl solution to remove inorganic carbon. The collected material was combusted at 750°C and the carbon-dioxide evolved was measured chromatographically using a CHN Analyser. Water sampling from depths was made by Van-Dorn bottle casts, and surface water samples were dipped with a polyethylene bucket. Chlorophyll and pheopigments were determind fluorometrically. The sampling areas covered in 1967-1969 distributed in the North-West Pacific including the Bering Sea, the Oyashio Area off eastern Hokkaido and Subtropical and Tropical areas along the 142°E meridian (Fig. 1).

Results

Some of typical profiles of particulate organic material obtained in shallow layers less than 300m are shown in the following figures (Figs. 2-5). In Fig. 2 are shown two examples obtained at two stations in the central area of the Bering Sea in June 1967. Surface

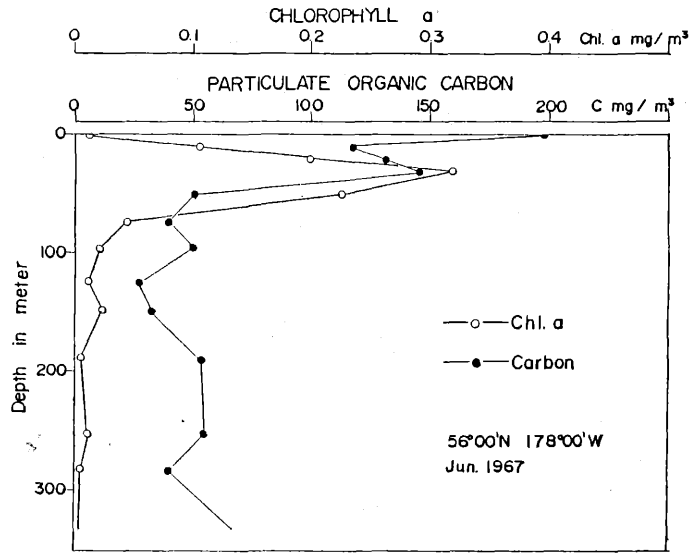

Fig. 2a. Vertical distribution of particulate organic carbon and chlorophyll *a* in 0-300 m depth range in the central Bering Sea. Os 8, Oshoro-Maru Cruise 21, June 14, 1967.

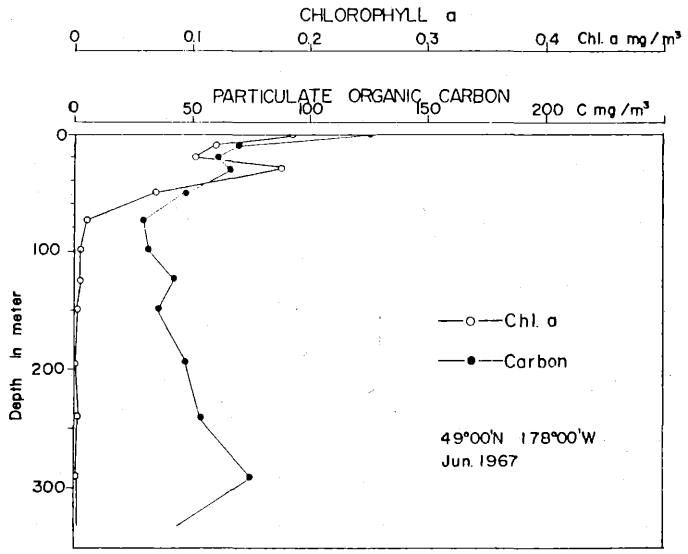

Fig. 2b. Vertical distribution of particulate organic carbon and chlorophyll *a* in 0-300 m depth range in the Pacific immediately south of the Aleutian Chain. Os 2, Oshoro-Maru Cruise 24, June 10, 1967.

values of carbon at these stations were in a range of 130-200 μgC/lit, while at a 10 m depth the values dropped to nearly one half the surface values. Values of chlorophyll and pheopigments, on the other hand, were relatively low at the surface ranging from 0.1 to 0.2 μg/lit, so that the carbon/chlorophyll ratio for total particles was a little more than 1,000.

Carbon further decreased fairly rapidly with depth below 10 m arriving at marked minima of less than 30 μgC/lit at about 100 m depth. Nitrogen followed nearly the same course as carbon but with some irregularities. This remarkable trend of rapid decrease of particulate carbon (and nitrogen) just beneath the surface was in a sharp contrast to the vertical variation of chlorophyll *a* and pheopigments. These pigments, usually and here too, increased with depth and attained a more or less marked maximum at the base of the euphotic layer. Carbon/chlorophyll ratio calculated for the chlorophyll maximum layer was 350 at one station and more than 500 at the other.

Fig. 3 shows a similar result observed in the Oyashio Current off eastern Hokkaido in April 1967. The situation was quite identical to that in the Bering. The surface value of carbon/chlorophyll ratio obtained here was again nearly 1,000. The trend of decrease in carbon and nitrogen here was somewhat irregular having a second peak at a 45 m depth, which, however, did not coincide with both chlorophyll and pheopigments peaks that were at 85 m and 65 m depths, respectively.

A more or less similar situation was found in the vast area of the western Pacific including the Subtropical region. The negative gradient of carbon near the surface became relatively obscure and irregular in the 10°-30°N zone with concurrent decrease in surface concentration of carbon that was fluctuating in a range from 45 to 75 μgC/lit. But the calculated carbon/chlorophyll ratio of the surface water was consistently high up to 1,000 or more (Fig. 4).

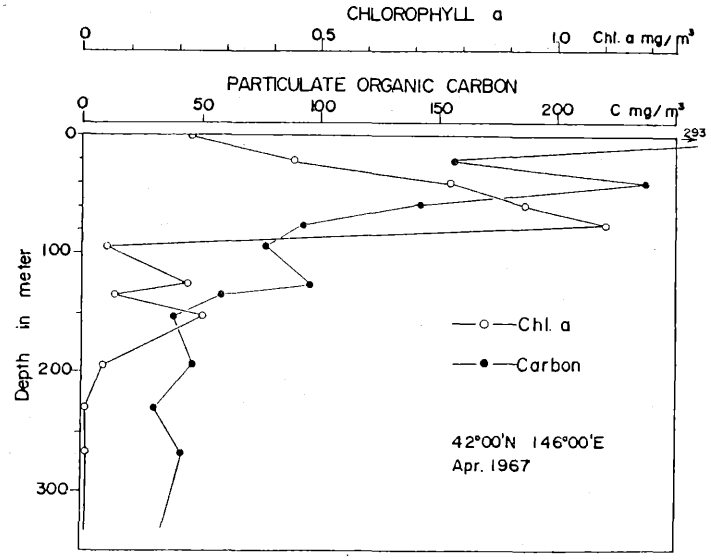

Fig. 3. Vertical distribution of particulate organic carbon and chlorophyll *a* in 0-300 m depth range in the Oyashio Current off Hokkaido. Os 1, Oshoro-Maru Cruise 23, April 23, 1967.

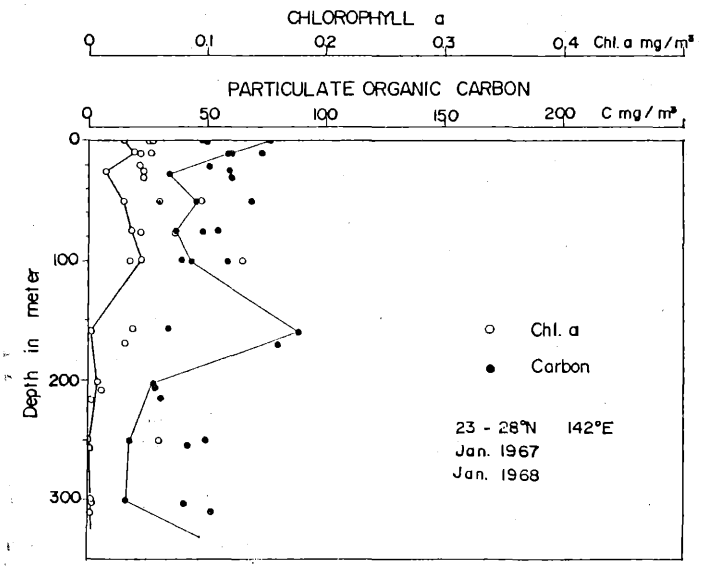

Fig. 4a. Vertical distribution of particulate organic carbon and chlorophyll *a* in 0-300 m depth range at three stations in the the Philippine Sea, 23-28° N, 142°E. Os 28 and 30 (serially connected profiles shown), Oshoro-Maru Cruise 21, January 19-28, 1967, and Os 26, Oshoro-Maru Cruise 26, January 27, 1968.

In the area south of 10°N, that is, in the Equatorial Counter Current region, the situation changed (Fig. 5) ; the surface carbon increased in concentration up to 120-165 μgC/lit

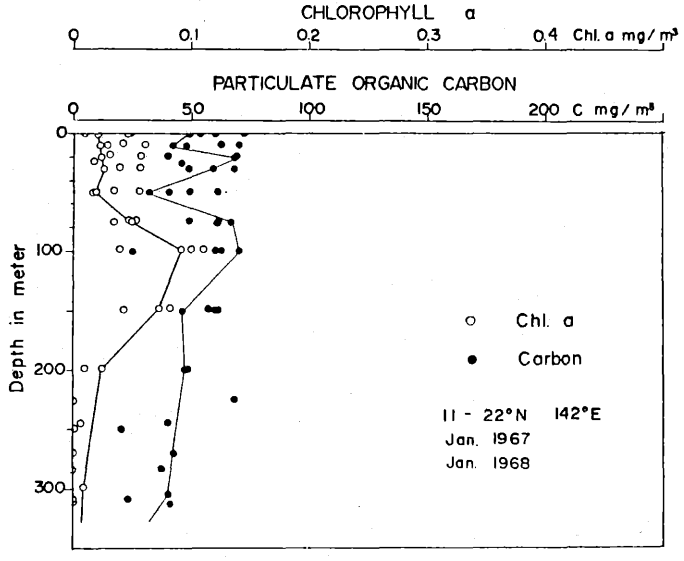

Fig. 4b. Vertical distribution of particulate organic carbon and chlorophyll *a* in 0-300 m depth range at four stations in the Philippine Sea, 11-24°N, 140°E. Os 21, Oshoro-Maru Cruise 21, January 29, 1967, and Os 14, 18 (serially connected profiles shown) and 22, Oshoro-Maru Cruise 26, January 18-24, 1968.

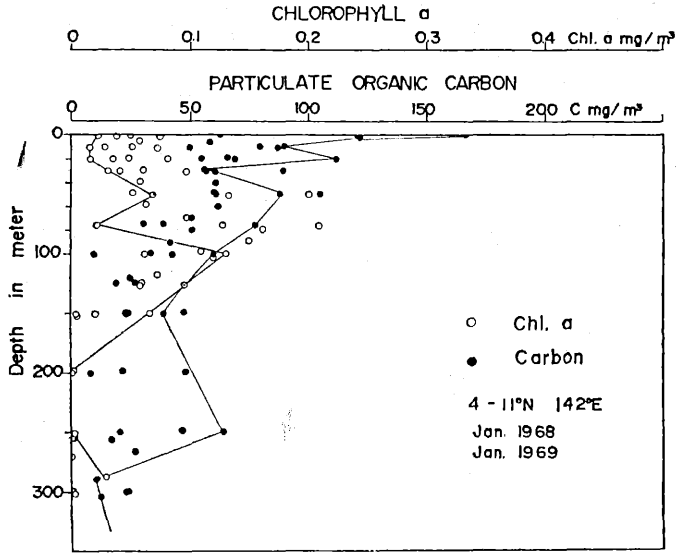

Fig. 5. Vertical distribution of particulate organic carbon and chlorophyll *a* in 0-300 m depth range at four stations in the Philippine Sea, 4-11°N, 142°E. Os 10, Oshoro-Maru Cruise 26, January 15, 1968, and Os 44, 48 and 51 (serially connected profiles shown), Oshoro-Maru Cruise 30, January 4-7, 1969.

and this high value quickly decreased with depth in a few tens meters vertical distance converging more or less irregularly to a level of 50 μgC/lit or less. Carbon/chlorophyll ratio at the surface in this region ranged from 1,500 to as high as 8,000. The ratio seems to be decreasing with latitude within the area, but a small number of stations (3 stations) permits no generalization. Anyway, throughout all the regions mentioned above, the chlorophyll profile was nearly consistent in that the surface value was relatively low and it increased with depth up to a subsurface maximum that was 2-5 times higher than the surface value. The subsurface maximum was scarcely coincident in depth with subsurface maximum of carbon, and if so, the correspondence was very poor.

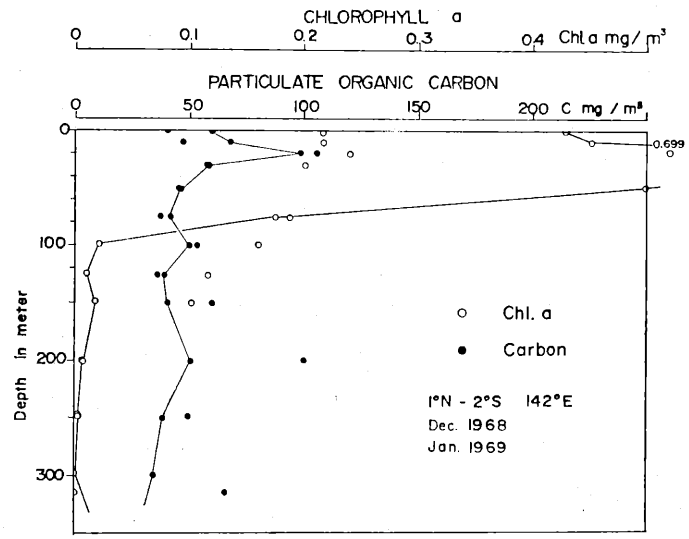

Fig. 6. Vertical distribution of particulate organic carbon and chlorophyll *a* in 0-300 m depth range at two stations in the equatorial region, 1°N-2°S, 142°E. Os 38 (serially connected profiles shown) and 41, Oshoro-Maru Cruise 30, December 30, 1968-January 2, 1969.

In the Equatorial region where two series of observation obtained in Jan. 1969 were available, the situation was much different (Fig. 6). Among others the general level of chlorophyll concentration at the surface was high above 0.2-0.4 μgC/lit that was slightly higher than even the surface values obtained in the areas north of the polar front. A subsurface maximum existed also in this region but was shallow at a 20 m depth and only 10 % higher than the surface value, while the surface carbon was very low and nearly 50 μgC/lit. Carbon increased with depth down to the 20 m depth nearly parallel to the increase of chlorophyll. Below 20 m, however, the parallelism between carbon and chlorophyll broke off ; carbon rapidly decreased with depth to a low level of about 50 μgC/lit, while chlorophyll remained at a relatively high level down to the 75-150 m depth. Thus the carbon/chlorophyll ratio at the surface was in arange of 170-200 which was distinctly lower than the same ratio obtained in the subtropical, temperate and boreal regions mentioned above. Below the subsurface maximum of chlorophyll in the Equatorial region, the same ratio often reduced down

to nearly 100 or less suggesting that the main component of particles in that layer was living phytoplankton.

Discussion

These observations seem to suggest various problems concerning a possible role, or roles. of the sea surface in producing particulate organic material. One obvious thing is that the sea surface is a locus where an intensive production of particulate matter occurs; although the field data shown above do not indicate any precise mechanism of production, it would certainly be different from primary photosynthetic production that is, of course, related to chlorophyll activity.

Recent developments of neuston studies already revealed some of biological sides of the problem (Tsiban, 1970 ; Zaitsev, 1970). Naval Research Lab people (*e. g.* Jarvis, 1965) have presented convincing laboratory evidence that the air-water interface prepares an excellent locus where an intensive adsorption of dissolved organic material occurs. These works are an important contribution to the chemico-physical sides of the problem.

Ecologically, however, no adequate estimate of natural time rate of production of particulate carbon at the sea surface as well as in the bulk water below is known. We tried a crude calculation to get a rough estimate of this local time rate at the natural sea surface as follows. If we assume that particulate carbon just beneath the sea surface has a concentration C and sinks with a sinking velocity v, the downward flux of particulate carbon per unit time would be expressed by

$$Cv - A\frac{dC}{dz} .$$

The first term simply means sinking transport and the second term the transport by diffusion of ambient water. A is the Austausch, and depth z is taken positive downward. Under the assumption of steady state, the downward transport just beneath the sea surface will be a good estimate of the sea surface production. No organic material is assumed to come from above the sea surface. C and dC/dz can be measured directly, but v and A just beneath the sea surface have to be appropriately assumed. As a first approximation v is taken 1 m/day (Nakajima and Nishizawa, 1972) and C as an average 100 μgC/lit. A near the surface is dependent on various factors such as sea condition, density stratification of water and so on. As a tentative venture, 10 cm^2/sec is taken. The results of calculation are : 260 mgC/m^2/day for the sinking transport and 43mgC/m^2/day for the diffusive transport. The calculation of the gradient dC/dz was simply done by assuming the concentration of particulate carbon to decrease with depth to half the surface value in 100 m depth. However, our surface values mentioned above are obtained from bucket samples and possibly contaminated by the skin material in an essentially negligible degree. Further, there is evidence that the particle distribution within a short water column of 1 m or so just beneath the sea surface is vertically much homogeneous. If so, the diffusive transport can simply be neglected. The assumption made for sinking velocity (1 m/day) would probably be maximal as the average for sea surface particles (*cf.* Riley, 1970). However, there is a reason to believe that the skin materials are locally sucked down into the bulk water by a convergent down-draft of the surface water with a velocity of a few to several cm/sec (Riley, 1970;

Sutcliffe *et al.*, 1963).

Anyway, this crude and apparently oversimplified consideration leads to, at most, a few tenths of one gram carbon per m^2 per day as a first order approximation of the local time rate of surface production of particulate material. If these assumptions are essentially correct, the rate obtained for this extremely thin surface skin layer would be, at least, not negligible compared to the average rate of photosynthetic organic production in the entire euphotic water column as observed by the conventional ^{14}C method.

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