

EXPERIMENTAL DECOMPOSITION OF
PARTICULATE ORGANIC MATTER COLLECTED UNDER THE FAST
ICE IN LÜTZOW-HOLM BAY, ANTARCTICA WITH SPECIAL
REFERENCE TO THE FATE OF CARBON,
NITROGEN AND PHOSPHORUS

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Abstract: Available information on the decomposition of particulate organic materials under the fast ice is scarce. To estimate the *in situ* degradation, decomposition experiments of various kinds of particulate matter collected under the fast ice near Syowa Station (69°00'S, 39°35'E) were conducted at -1.5°C in the dark for 7 months from February to October 1984. The variations of Chl. *a*, carbon, nitrogen, phosphorus and oxygen consumption were particularly noted. Among the samples, particulate materials obtained by sediment traps set under the fast ice showed the most active decomposition compared with net plankton and surface sediment. In the decomposition of trapped sediment, two steps of first order reaction were observed. Corresponding rate constants for decomposition estimated from the variation of Chl. *a*, POC, PON were 0.021-0.081 day⁻¹ for k_1 (first step) and 0.016-0.0023 for k_2 (second step), respectively. These results indicate a fairly fast *in situ* decomposition of particulate organic matter under the fast ice.

1. Introduction

Under the fast ice in the Antarctic region, the primary production in seawater is restricted to the summer season, since underwater irradiance is insufficient in other seasons. Hence, organic matter produced by the photosynthesis of phytoplankton and ice algae in the relatively short period of time of the year is the sole food source for various kinds of animals such as secondary and tertiary producers (BUNT, 1968; ANDRIASHEV, 1968; HOSHIAI, 1977; FUKUCHI *et al.*, 1984). Therefore, the decomposition and the transformation processes of the organic matter should play very important roles in the organic food chain and in the nutrient cycle of the corresponding systems. Study on the decomposition of planktonic material under a controlled condition has quite a long history (VON BRAND *et al.*, 1937; SKOPINTSEV, 1949; GRILL and RICHARDS 1964; OTSUKI, 1968). Nevertheless, very little information is available on the decomposition processes of particulate organic matter under the fast ice, where temperature is extremely low compared

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with that of the temperate zone (HEMPEL, 1985; HOLM-HANSEN, 1985). From this viewpoint, we conducted a decomposition experiment on five kinds of particulate material collected under the fast ice and observed the time course change of particulate and dissolved components for the period from February to October 1984. From these results, the decomposition rate and the fate of organic matter at a very low temperature were deduced and discussed in detail.

2. Materials and Methods

Sampling of particulate material under the fast ice was made at a station (Stn. 3) in the Kita-no-ura Cove off East Ongul Island in Lützow-Holm Bay (Fig. 1) in February, 1984 during the 25th Japanese Antarctic Research Expedition. Sampling data on the five kinds of particulate organic materials are summarized in Table 1.

The particulate samples obtained were brought into the laboratory and each of

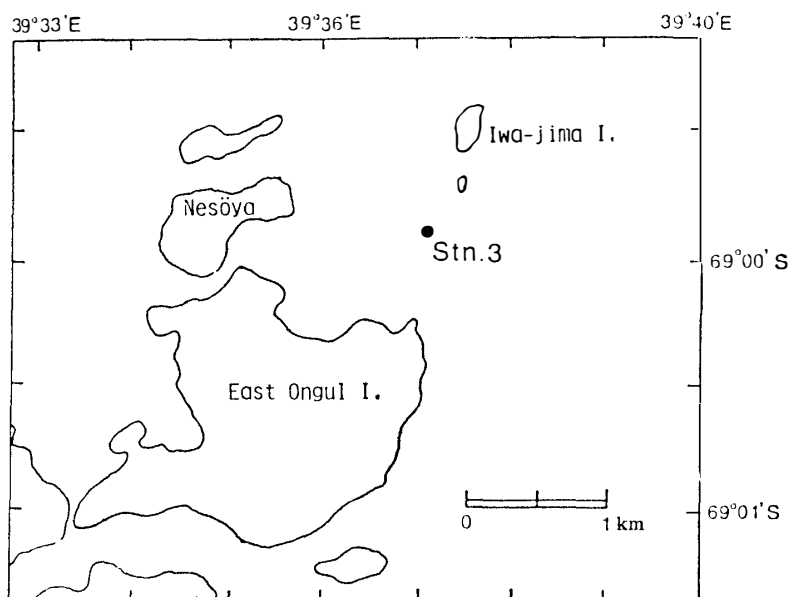


Fig. 1. Location of sampling stations.

Table 1. Sampling data on particulate materials employed in the present study.

| Particulate sample | Sampling gear and method | Remarks |
|---------------------------|--|--|
| 1 Trapped sediment at 5m | Cylindrical sediment trap suspended at 5m depth beneath the ice | $\phi 150 \times 500$ mm, polyvinylchloride (PVC) |
| 2 Trapped sediment at 25m | Cylindrical sediment trap suspended at 25m depth beneath the ice | |
| 3 XX-13 net plankton | Standard vertical sampling with a Norpac net (XX-13 netting) | $\phi 45 \times 180$ cm; Mesh size of the net, 0.095 mm |
| 4 GG-54 net plankton | Standard vertical sampling with a Norpac net (GG-54 netting) | Mesh size of the net, 0.33 mm |
| 5 Surface bottom sediment | Ekman-Birge sediment sampler | Thin surface layer of the sample was exclusively scraped up by spatula |

them was resuspended in three liters of filtered seawater in five glass bottles, which were incubated at -1.5°C in the dark and served for serial analysis. Initial POC concentration for trapped sediment at 5 m, 25 m, XX-13 net plankton, GG-54 net plankton and surface sediment is 18.84, 8.88, 6.67, 3.31 and 35.26 mg/l, respectively. Temperature chosen was almost the same as that in *in situ* seawater under ice. Sampling was made 11 times from February to October in 1984 to clarify the time course change of decomposition. Determination of dry weight and chlorophyll pigments was made as indicators of the total mass of particulate material and the algal condition, respectively. Particulate organic carbon (POC), particulate organic nitrogen (PON) and particulate phosphorus (PP) were also determined as representative parameters of particulate organic substances. Dissolved inorganic phosphorus (DIP) and dissolved organic phosphorus (DOP) in resuspended seawater were determined throughout the experiment to estimate the solubilization and mineralization of phosphorus. Change in pH during the decomposition process was also measured by the use of pH electrode. Oxygen consumption by particulate samples at -1.5°C in the dark were determined by Winkler's method using 100-ml DO bottles during the first stage of decomposition. Chlorophyll and pheopigments were spectrophotometrically analyzed based on the method of LORENZEN (1967) using a Whatman GF/C glassfiber filter. Determination of POC and PON was made by the CHN analyzer (Yanagimoto MT-3) using the same glassfiber filter combusted in advance. Separation of PP from DIP and DOP was done with a pre-weighed Millipore filter (HA; pore diam. $0.45\ \mu\text{m}$), and after dry weight determination the samples were served for PP determination in which particulate material was digested in a Teflon container with perchloric acid and nitric acid at 150°C for 5 h, resulting phosphate being determined by the method of MURPHY and RILEY (1962) as modified by STRICKLAND and PARSONS (1972). Organic phosphorus in the filtrate was converted to orthophosphate by potassium persulfate digestion in an autoclave based on the procedure of MENZEL and CORWIN (1965), and then the total phosphorus in the filtrate (dissolved total phosphorus; DTP) was determined. DOP was calculated by subtracting the initial phosphate in the filtrate (DIP) from DTP.

3. Result and Discussion

3.1. Time course change of chlorophyll and pheopigments

On the assumption that particulate materials employed in the present study originated more or less from phytoplankton and/or ice algae, changes of Chl. *a* and pheopigments were analyzed. The concentration of Chl. *a* (Fig. 2) showed a sharp decrease in both trapped sediment samples and XX-13 net plankton.

As initial concentrations of the different particulate matter expressed as dry weight were almost the same, the differences of initial Chl. *a* concentration indicate the differences of the Chl. *a* content among the five samples. Therefore, initial Chl. *a* concentrations in Fig. 2 were in proportion to the ratio of initial Chl. *a* to dry weight of the particulate samples employed. Thus, the highest value of Chl. *a* content was found in the trapped sediment at 5 m depth while the lowest value was in the surface sediment.

Among these three samples which showed a sharp decrease, time of decomposition differed from each other. Taking up the half decomposition time (duration of time in

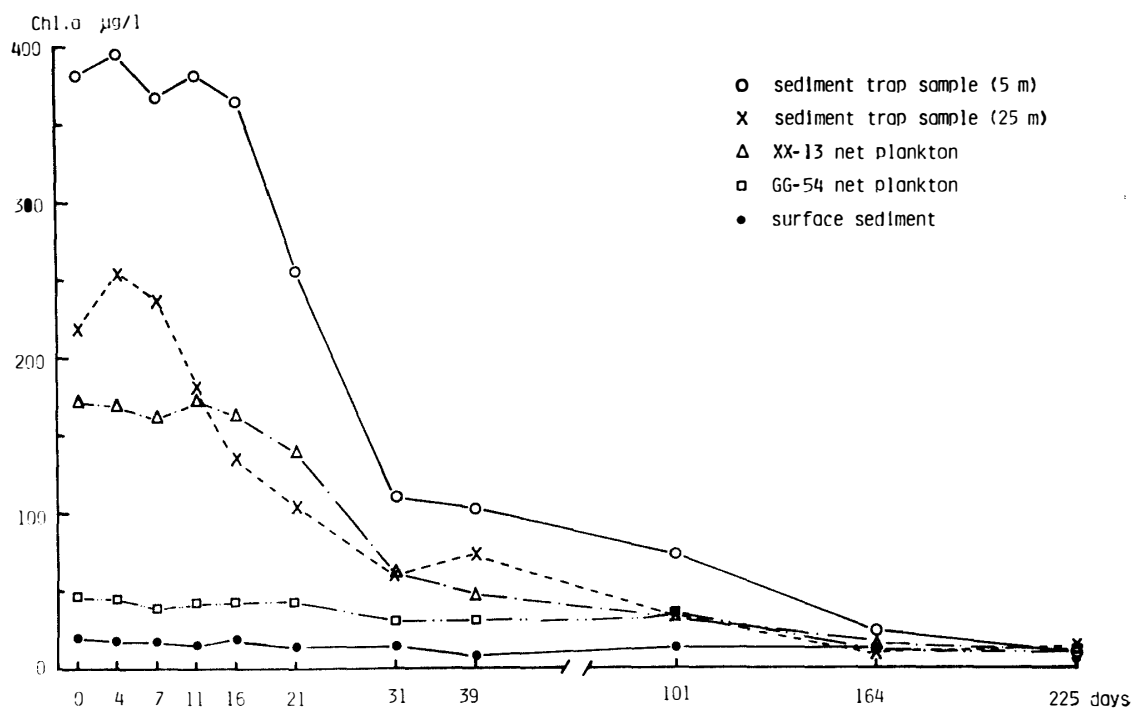


Fig. 2. Changes of chlorophyll *a* concentration during the decomposition experiment conducted at -1.5°C in the dark.

which initial concentration decreases to one half) as an indicator of decomposition rate, the time of trapped sediment at 25 m, at 5 m and XX-13 net plankton was 20, 25 and 29 days, respectively. Hence the 50% decomposition of Chl. *a* was the fastest in the trapped sediment, followed by XX-13 net plankton. On the other hand, decomposition of Chl. *a* in GG-54 net sample and surface sediment was not active throughout the duration of the experiment.

Pheopigments are intermediary substances produced during the degradation process of chlorophyll, and the pigments themselves are then subject to be broken down in the final stage of decomposition. The result of pheopigments determination is shown in Fig. 3. Characteristic peaks of pheopigments for the samples of trapped sediment at 25 m, at 5 m and XX-13 net plankton were observed on the 11th, 21st and 39th day, respectively. The order of these three peaks' time corresponded well to the decomposition rate of Chl. *a* as expressed previously by half decomposition time. During the course of decomposition no marked peak of pheopigments was observed in GG-54 net plankton and surface sediment.

3.2. Time course change of pH of the sample

As an overall indicator of decomposition activities of organic matter, pH of the sample water was measured during the experimental period. In general, when decomposition of organic matter is active, pH of the sample tends to decrease because of the production of both organic and inorganic acids.

In both the trapped samples and XX-13 net plankton, the distinct minima of pH values were observed on the 7th day. In the case of GG-54 net plankton minima of

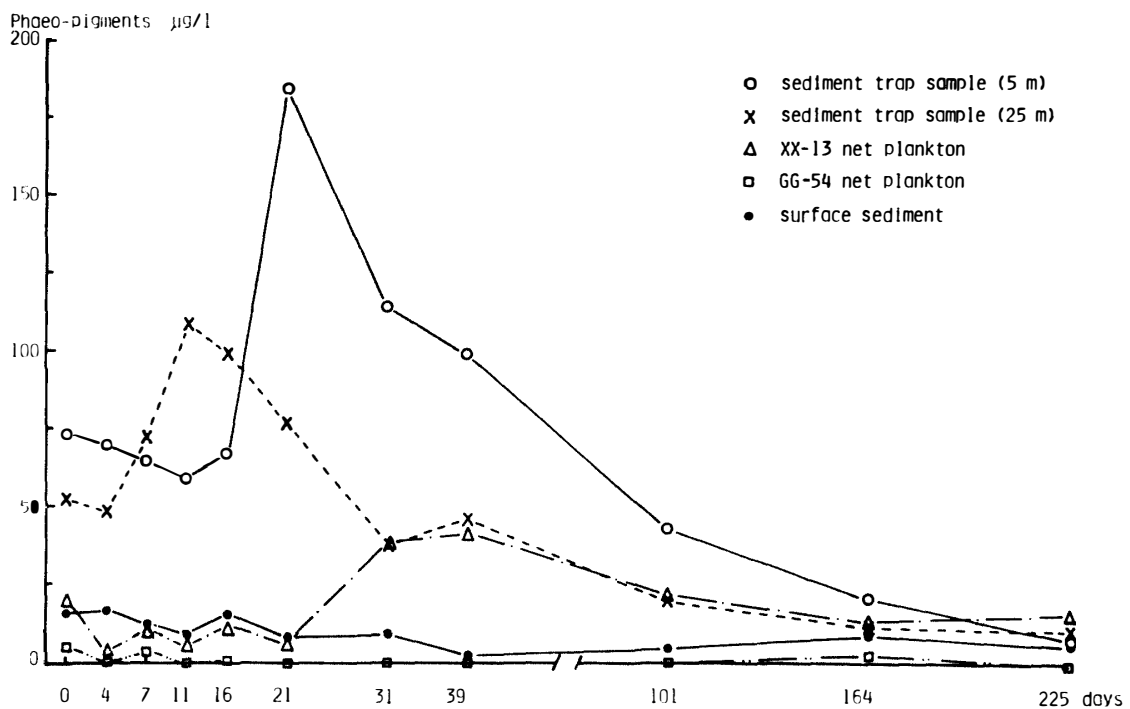


Fig. 3. Changes of pheopigments concentration during the decomposition experiment conducted at -1.5°C in the dark.

pH occurred later (31st–39th day). However, pH of the surface sediment did not show any marked decrease. These data support the idea that the decomposition of organic matter in trapped sediment and XX-13 net sample was very active, especially in the early stage of the experiment.

3.3. Time course change of POC during decomposition

POC is one of the most appropriate indicators of total particulate organic matter. Relative changes of POC during the experiment are shown in Fig. 4, in which the initial concentration of all samples was set at 100. Also in this case, decomposition of both trapped sediment and XX-13 net plankton was found to be very fast. The half decomposition time of POC was estimated to be around 30 days in the case of trapped samples and 40 or 45 days in the case of XX-13 net plankton. On the other hand, POC in the surface sediment showed only a little change indicating that carbon component in the sample was very refractory. The case of GG-54 net sample was quite unusual because POC increased distinctly in the intermediate stage of the experiment. As the primary production does not occur in principle in the dark condition set up, the result is rather difficult to explain. A possible interpretation might be the reconstruction of POC through chemical or microbiological activity by DOC in the initial sample (WILLIAMS, 1970, 1981; ELLIS-EVANS, 1985). However, the reason why POC of only this particular sample showed the marked increase remains unclear.

3.4. Variation of POC: PON ratio (C/N ratio)

The decomposition pattern of PON was almost the same as that of POC (Fig. 4),

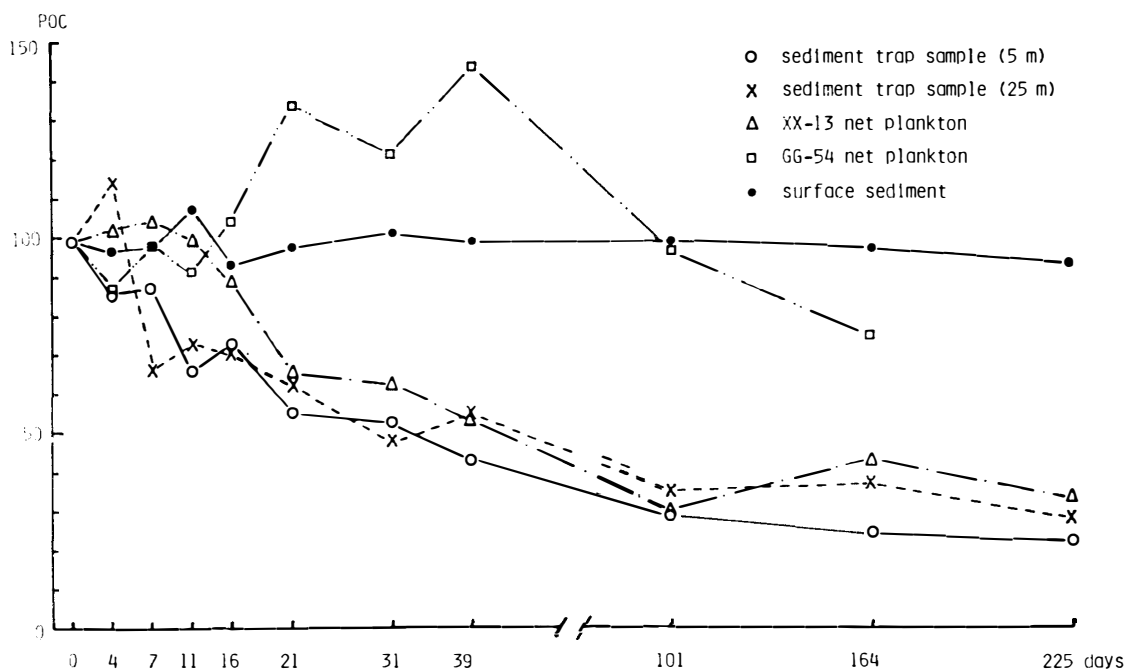


Fig. 4. Relative changes of particulate organic carbon (POC) during the decomposition experiment conducted at -1.5°C in the dark.

although there were some minor differences. The decomposition rate was faster in both trapped samples and XX-13 net plankton compared with other two samples. Half decomposition time was approximately 22–23 days, 32–33 days and 34–35 days for the trap sample at 25 m, 5 m and XX-13 net sample, respectively. The results showed that decomposition of PON was slightly faster than that of POC. In the final stage of decomposition, only around 20% of PON remained in the above three cases. Variation of PON in the GG-54 net sample and surface sediment was almost identical with that of POC. From these results, the change in the C/N ratio (Fig. 5) presented two remarkable characteristics. One was a very high and stable (*ca.* 14) C/N ratio of the surface sediment, and the other was a moderate increase of the C/N ratio in the other four cases during the course. This increase also suggests the faster decomposition of PON than POC.

3.5. Change of PP during decomposition

Relative changes in PP concentration (Fig. 6) are quite different from those in POC and PON. The most characteristic feature was a large increase in PP up to about 250% during the course of the experiment with XX-13 and GG-54 net plankton. On the other hand, PP in trapped samples showed a gradual decrease during the course and finally approximately 80% of PP was decomposed.

The reason why the intermediate increase of PP occurred only in the net samples was not clear. But the peak of PP on the 39th day in the case of GG-54 net sample corresponded well to the peak of POC and PON on the same day. Moreover, the PP peak on the 7th day in the case of XX-13 net plankton corresponded to the slight increase of POC and PON in the same stage of experiment. These results suggest that

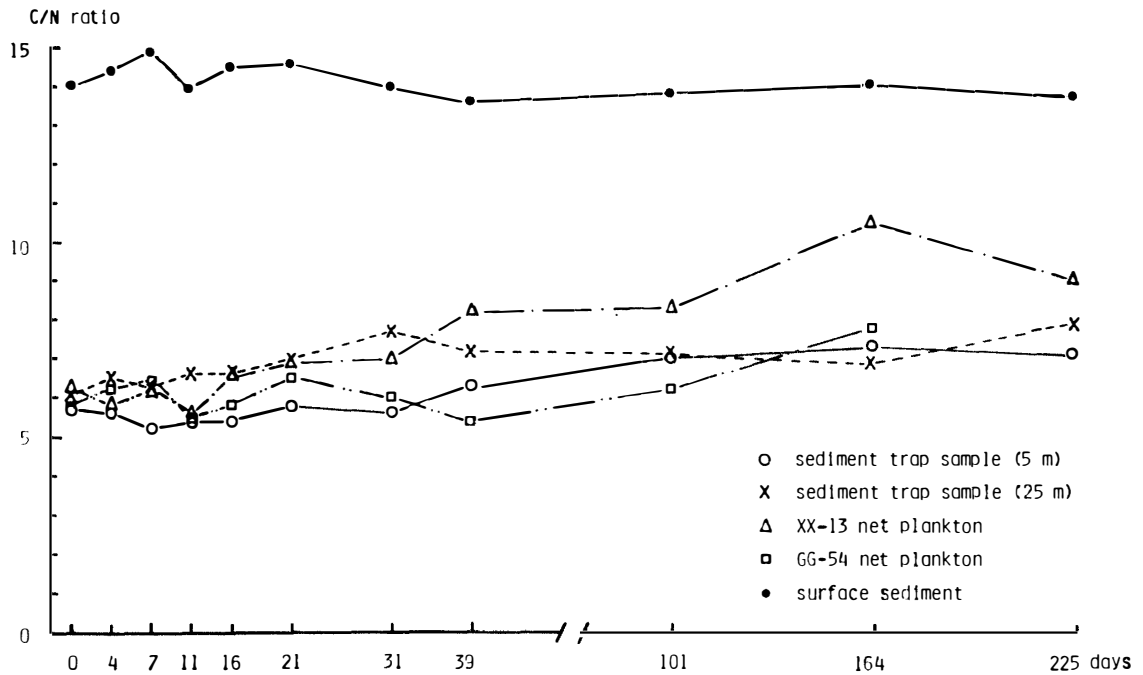


Fig. 5. Changes of POC/PON ratio during the decomposition experiment conducted at -1.5°C in the dark.

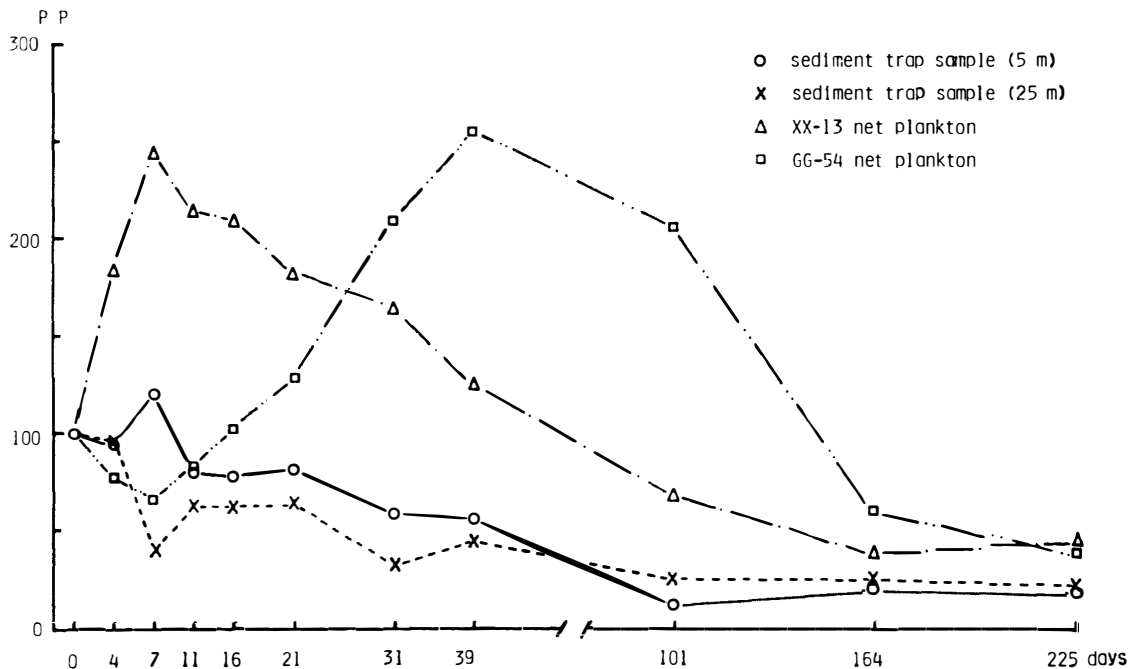


Fig. 6. Relative changes of particulate phosphorus (PP) during the decomposition experiment conducted at -1.5°C in the dark.

the uptake or absorption of dissolved phosphorus took place under a certain condition during the experiment.

Determination of PP in the surface sediment was also conducted but the result was excluded from the present discussion because of the lack of reliability of the data obtained.

3.6. Changes of phosphorus composition during the experiment

Phosphorus in seawater is often classified into three major forms; DIP, DOP and PP (WATT and HAYES, 1963). DIP is represented by orthophosphate, a typical plant nutrient, while PP in coastal water is usually composed of living phytoplankton and suspended detrital material. DOP is analytically identified as unreactive fraction of phosphorus in filtered seawater. Both decay of algal cells and excretion by zooplankton bring DOP into the environmental media. In addition, DOP is taken up by some sea microbes. From this point of view, observation was made on the phosphorus composition to estimate the transformation among phosphorus forms.

The changes of phosphorus composition in the trapped sediment at 25m are shown in Fig. 7. In this case DOP which had been observed during the first month completely mineralized to DIP after that period. In the final stage of decomposition approximately 90% of total phosphorus in the experimental system was DIP. The remaining 10% as a form of PP seemed to be very refractory. Changes in phosphorus composition in the case of trapped sediment at 5m and XX-13 net plankton were almost the same as that described above.

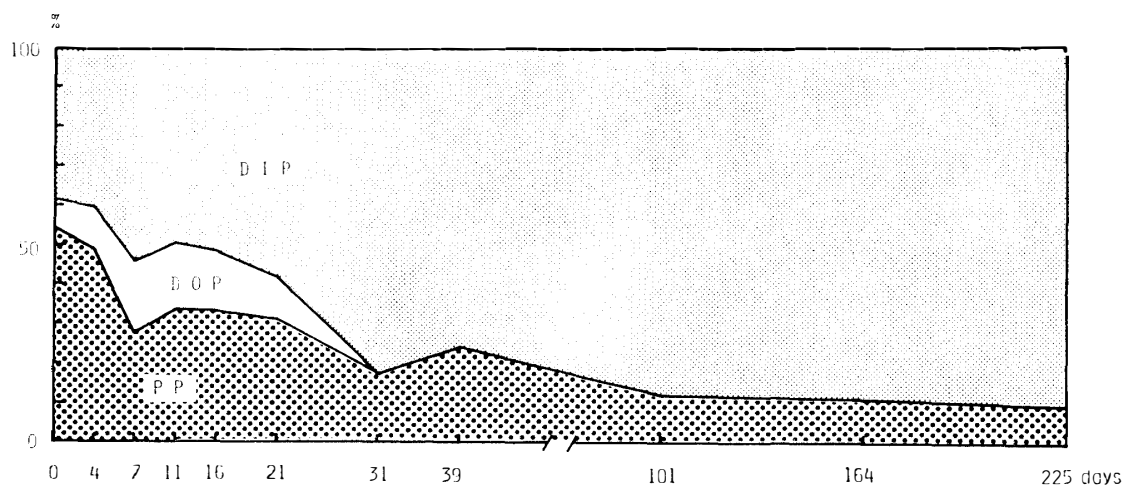


Fig. 7. Changes of phosphorus composition (DIP, DOP, PP%) during the decomposition of trapped sediment at 25 m depth.

3.7. Oxygen consumption during the decomposition

Oxygen consumption at -1.5°C was measured during the first 23 days using the same particulate samples. The results expressed as $\mu\text{l O}_2$ per mg dry weight of sample are shown in Fig. 8. Among the five samples examined, the trapped sediment at 5m showed the largest oxygen consumption per unit weight. This indicates that the microbial oxidation of organic matter was most active in this sample.

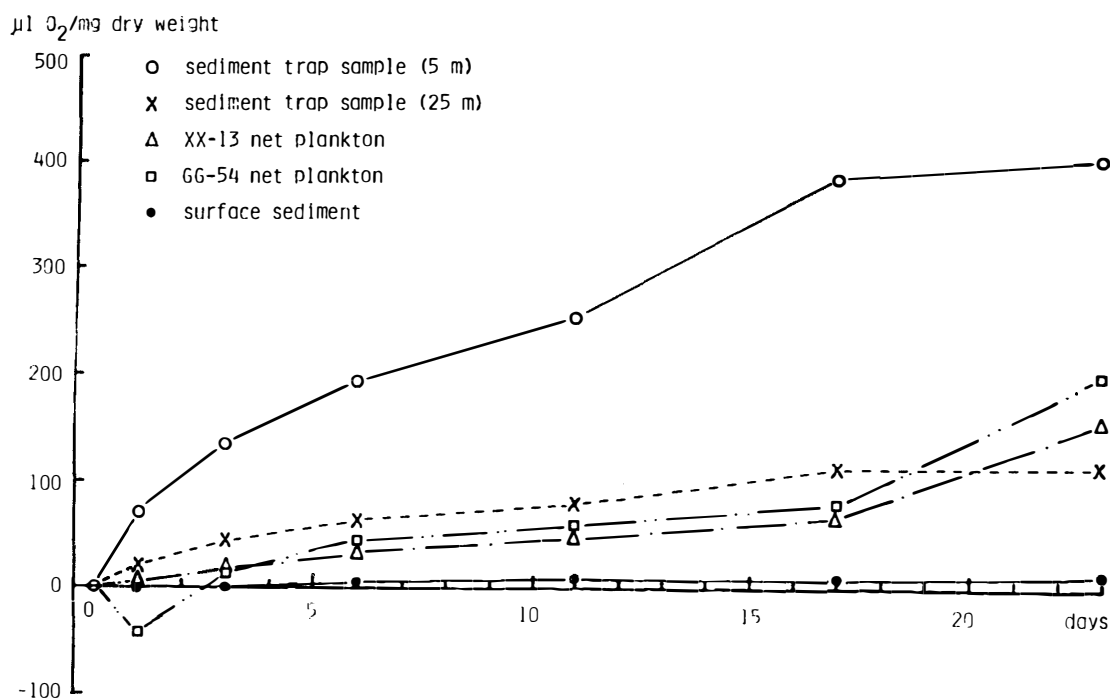


Fig. 8. Oxygen consumption by various particulate materials during the decomposition experiment conducted at -1.5°C in the dark.

The trapped sediment at 25 m showed the second largest consumption but not much differed from those of net plankton. Compared with these, oxygen consumption by the surface sediment was found to be extremely small.

From these results, decrease of particulate components such as Chl. *a*, POC, PON and PP, which was already referred to, was accompanied by oxygen consumption except for the surface sediment. Therefore, the decrease of particulate organic matter observed results in not only the solubilization of particulate component but also oxidative degradation at a very low temperature.

The difference in the rate of oxygen consumption and decomposition among samples might be ascribed to the organic composition of individual particulate samples. The organic composition depends on the relative abundance of living plankton, organic detritus and fecal pellets in the sample, which in turn is affected by the origin and history of the particulate material. Hence, for example, it is obvious not only that the plankton sample collected by XX-13 net is different from that obtained by GG-54 net but also the trapped sediment at the upper layer of the sea is likely to be more fresh than the surface sediment which has been exposed to longer degradation.

3.8. Estimation of the rate constant for decomposition

The rate constant for decomposition (k) under controlled laboratory conditions at -1.5°C was estimated from the semilog plot of the concentration of various particulate materials as a function of time. The calculation was based on the assumption that decomposition proceeded as a first order reaction. Therefore, linear regression and correlation coefficients between them were investigated first, and then k and half-life

Table 2. Estimation of the rate constant for decomposition and half-life of the various particulate organic materials.

| Sample | Parameter (A) | Period of* estimation (days) | Rate constant (day ⁻¹) -1.5°C | Half-life (day) -1.5°C | Correlation** coefficient |
|--------------------------|---------------|------------------------------|--|---------------------------|---------------------------|
| Trapped sediment at 5 m | Chl. <i>a</i> | 16-31 | k_1 0.081 | 8 | -0.9988 |
| | | 31-225 | k_2 0.014 | 50 | -0.9820 |
| | POC | 0-39 | k_1 0.021 | 33 | -0.9606 |
| | | 39-225 | k_2 0.0046 | 151 | -0.9558 |
| | PON | 0-39 | k_1 0.023 | 30 | -0.9586 |
| | | 39-225 | k_2 0.0046 | 151 | -0.9333 |
| Trapped sediment at 25 m | Chl. <i>a</i> | 4-31 | k_1 0.055 | 13 | -0.9983 |
| | | 39-164 | k_2 0.016 | 43 | -0.9915 |
| | POC | 4-31 | k_1 0.023 | 30 | -0.8428 |
| | | 39-225 | k_2 0.0023 | 301 | -0.9103 |
| | PON | 4-31 | k_1 0.030 | 23 | -0.9148 |
| | | 39-225 | k_2 0.0023 | 301 | -0.8993 |
| XX-13 net plankton | Chl. <i>a</i> | 11-39 | k_1 0.051 | 14 | -0.9775 |
| | | 39-225 | k_2 0.0069 | 100 | -0.9746 |

* Period of time during which first order kinetic was observed.

** Correlation coefficient between log (A) and time.

only for the period during which first order kinetic was observed were obtained (Table 2). Among these estimations, decomposition of Chl. *a*, POC and PON presented in Table 2 was found to show two steps of first order reaction indicated by rate constant k_1 and k_2 , respectively.

The first step of the assumed first order reaction occurred during the first 30 or 40 days and the second step on the following days. The value of k_1 is always higher than that of k_2 . The rate constant k_1 for POC decomposition was 0.021 day⁻¹ for trapped sediment at 5 m and 0.023 day⁻¹ for trapped sediment at 25 m, respectively. Half-life for each was calculated at 33 and at 30 days. The rate constant for PON was 0.023 day⁻¹ and 0.030 day⁻¹ for the respective trapped sediments. From these, the decomposition rate of PON is ascertained to be relatively higher than that of POC in the first stage of decomposition.

According to the literature, a low temperature generally induces a lower metabolic rate, hence a lower decomposition rate (SKOPINTSEV, 1949 cited in OGURA and ISHIWATARI 1966; SOROKIN, 1978). However, it is characteristic that these rate constants k_1 obtained at -1.5°C in the present study are comparable to those reported as determined under moderate temperature. For example, SOROKIN (1978) reviewed that corresponding k_1 varied between 0.01 and 0.15, and k_2 between 0.005 and 0.01. Therefore, the present results suggest that *in situ* decomposition of particulate organic material under the fast ice proceeds much faster than expected, presumably due to highly adapted microbial and enzymatic activity in the low temperature environment. The rate constant k_1 for Chl. *a* was always higher than that for POC and PON showing 0.051-0.081 day⁻¹. Calculated half-life of these Chl. *a* fell in 14-8 days, which exemplified the rapid degradation of particulate organic matter under the fast ice.

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