ORGANIC COMPOUNDS OF THE SUSPENDED PARTICLES IN THE PACIFIC SECTOR OF THE SOUTHERN OCEAN

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Abstract: Particulate matter was collected from the ocean areas of the West Pacific and the Pacific Sector of the Antarctic Ocean (32°N–65°S, 125°–160°E) during the cruise of T.S. UMITAKA MARU of Tokyo University of Fisheries in 1980–1981. The samples were analyzed for organic carbon and nitrogen, carbohydrate, amino acids including free and combined forms, lipid and chlorophylls. Detailed analyses of fatty acids of the particulate samples were conducted to clarify their ecological significance in the Antarctic Ocean. Characteristic features of particulate organic matter in the Antarctic Ocean are as follows.

1) Particulate organic carbon (POC) and nitrogen (PON) collected from the surface waters of the western Pacific and Antarctic Oceans were determined as the ranges of 25.4–150 μgC/l and 3.50–25.2 μgC/l respectively. POC and PON are distributed with relatively low values in the western Pacific Ocean, while much higher level of the values was observed in the Antarctic Ocean. Regional variabilities of the values occurred to a great extent.

2) Particulate matter collected from the Antarctic Ocean was analyzed for carbohydrate, amino acid and lipid, which accounted for 18.6–40.3%, 11.1–16.5% and 22.7–37.8% of POC respectively. Lipid materials were much abundant in the particulate matter collected from the oceanic area south of the Antarctic Divergence.

3) Fatty acids with carbon atoms ranging from 14 to 24 were detected in the particulate matter from the Antarctic Ocean and were quantified by gas chromatography. The ratio of unsaturated fatty acids with carbon atoms of 16, 18 and 20 to total fatty acids tended to increase toward Antarctica. These unsaturated fatty acids accounted for more than 40% of total fatty acids of the particulate matter from the oceanic area south of the Antarctic Divergence.

4) Fecal pellet of *Euphausia superba* and its feed, *Dunaliella tertiolecta* were analyzed for fatty acids to elucidate their ecological significance in the Antarctic Ocean. The results obtained indicated that algal fatty acids and amino acids were digested exclusively by the zooplankton. Unsaturated fatty acids with carbon atoms of 16 and 18 accounted for more than 80% of total loss of the fatty acids during the digestion processes of algal organic matter by the zooplankton. These findings strongly suggested that unsaturated fatty acids must be one of the most ecologically significant organic materials in the Antarctic Ocean.

1. Introduction

The ocean around Antarctica is the world's most fertile area (NIENHUIS, 1981). EL-SAYED (1968) mentioned that waters south of the Antarctic Convergence supported

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a total production equivalent to about 20% of that produced by all of the world oceans. Compiling many data reported on the surface chlorophyll *a* concentration in the Antarctic Ocean, FUKUCHI (1980) reported that the surface chlorophyll stock in the Antarctic Ocean might not be so high as previously believed. However, available information on the distribution of particulate organic constituents except chlorophyll pigments in the Antarctic Ocean has been much limited.

In 1980–1981, we had an opportunity to visit the Pacific Sector of the Antarctic Ocean by the T.S. UMITAKA MARU of Tokyo University of Fisheries (Fig. 1). Particulate matter was collected from the oceanic areas between Australia and Antarctica and was analyzed for organic carbon (POC) and nitrogen (PON), and several biochemically interesting organic constituents. Detailed analyses of fatty acids of the particulate matter were also conducted to some extent. In this paper, we intend first to report the compiled data (TANOUE and HANDA, 1982; TANOUE *et al.*, 1982a, b) on the vertical and horizontal distribution profiles of particulate organic carbon and nitrogen in the Pacific Sector of the Antarctic Ocean. Secondly, regional change in the organic composition of particulate matter will be described in relation to water temperature distribution. Finally, ecological significance of fatty acid composition of the particulate matter from the south of the Antarctic Divergence will be discussed with the results obtained in feeding experiment of *Euphausia superba* living on the laboratory cultured alga.

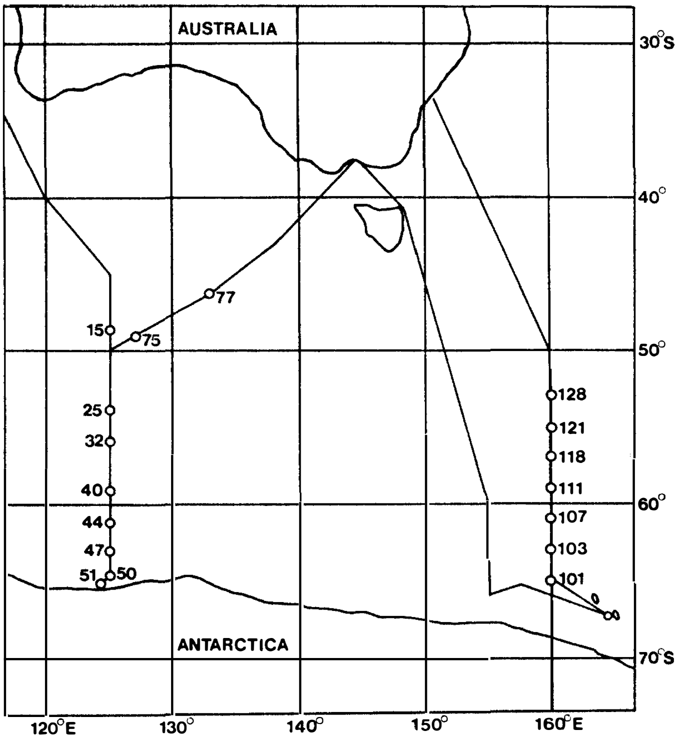

Fig. 1. The cruise track of T.S. UMITAKA MARU III. Each number represents the hydrographic station occupied.

2. Horizontal and Vertical Distributions of Particulate Organic Matter in the Pacific Sector of the Antarctic Ocean

POC, PON and chlorophylls: Horizontal distribution profiles of salinity, water temperature and particulate organic materials in the surface water from off Tokyo to the Antarctic Ocean are shown in Fig. 2.

POC in the oceanic areas from off Tokyo to 40°S was found to be less variable regionally ranging from 25.4 to 54.9 μgC/l with a mean value of 41.2±10.2 μgC/l (N=29). However, regional variabilities of POC ranging from 29.1 to 150 μgC/l with a mean value of 70.7±37.2 μgC/l (N=17) were found to a great extent in the oceanic area between 40° and 61°S in the Pacific Sector of the Antarctic Ocean.

The distribution profile of PON was almost identical with that of POC. High regional variability in POC concentration was also evident in the areas south of 40°S and its values ranged from 4.59 to 25.2 μgN/l with a mean value of 11.1±5.6 μgN/l (N=17). This caused almost similar values of the weight ratio of POC to PON (C/N) throughout the areas south of 40°S (Fig. 2C). High levels of chlorophyll *a* and chlorophyll *c* con-

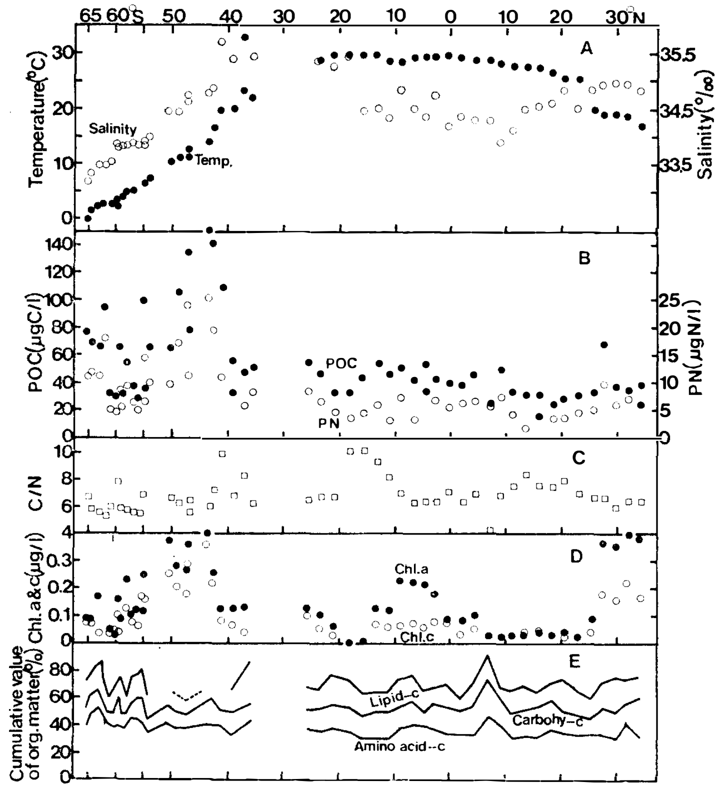

Fig. 2. Horizontal distributions of salinity, water temperature, particulate organic carbon (POC) and nitrogen (PON), C/N, chlorophylls a and c and cumulative percents of amino acid, carbohydrate and lipid carbons to particulate organic carbon.

centrations were found in the areas south of 40°S relative to the subtropical areas north of 40°S. The distribution profiles of the chlorophylls were almost similar to those of

POC and PON (Fig. 2D). In view of these findings, it can be seen that high level of the standing stock of phytoplankton occurs in the Antarctic Ocean. However, regional variability of the value is observed to a great extent.

Organic composition of particulate matter: Particulate proteins including free amino acid, carbohydrate and lipid were determined in the ranges of 11.4–60.8, 2.47–27.9 and 3.75–15.7 μgC/*l* respectively in the areas south of 40°S and 9.03–20.0, 4.47–10.9 and 3.33–11.5 μgC/*l* respectively in the areas north of 40°S. Regional variabilities of particulate organic constituents were found to be closely related to that of POC. This caused no regional variabilities of the ratios of various organic constituents of POC throughout the oceanic areas (Fig. 2E). The average ratios of protein carbon to POC were found to range from 34.8 to 44.9% in the whole areas examined. Carbohydrate carbon accounted for 11.2–18.5% of POC. A little higher level of the value was found in the equatorial area relative to those in the Antarctic area ranging from 11.2 to 13.8%. No significant change in the ratio of lipid carbon to POC ranging from 13.2 to 17.3% was found in the whole areas examined.

3. Horizontal and Vertical Distributions of the Particulate Organic Matter in the Antarctic Ocean

The hydrographic observations were conducted at 14 stations along transects of 125°E and 160°E in the Antarctic Ocean (Fig. 1). Particulate matter was collected from various depths at these stations and analyzed for POC and PON. The distribution profile of POC along the transect of 125°E is shown in Fig. 3. POC concentration was

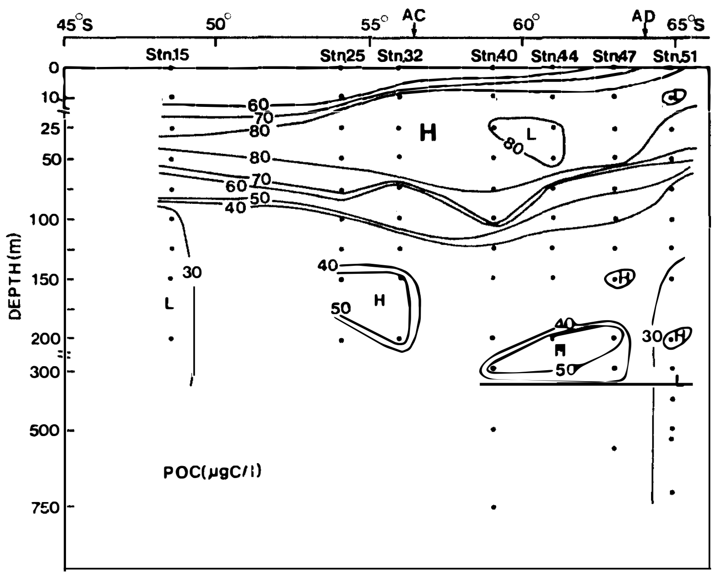

Fig. 3. Distribution profile of particulate organic carbon along the transect of 125° E.

found to be low in the surface water layer and maximum (more than 80 μgC/*l*) in the water layers between the depths of 10 and 75 m. The concentration of POC tended to decrease rapidly with depth in the water layers below 75 m depth throughout the stations.

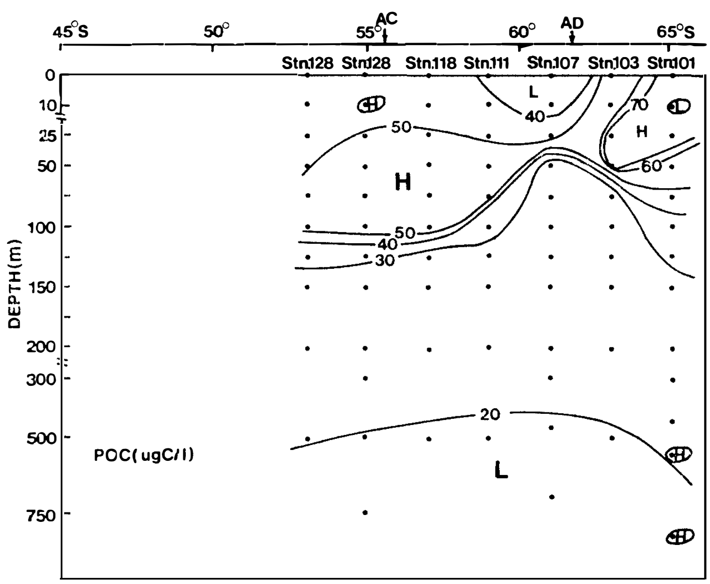

Fig. 4. Distribution profile of particulate organic carbon along the transect of 160° E.

Table 1. Summary of the average values (±1 SD) of particulate organic carbon and nitrogen, C/N and the ratios of amino acid, carbohydrate and lipid carbons to particulate organic carbon in the Antarctic Ocean.

Water layer (m)	Number of samples	POC μgC/l	PON μgN/l	C/N	AA-C / POC	Carb. -C / POC	Lipid-C / POC
Subtropical Convergence—Antarctic Convergence					%	%	%
0–100	28	58.1±17.1	7.71±2.36	7.63±0.95	34.1± 7.1	11.1±3.3	22.7±3.3
125–200	14	34.6±13.9	3.47±1.07	9.89±1.94	28.9±11.2	12.3±4.4	26.6±5.7
300–1500	6	28.5± 9.3	2.31±1.27	13.4 ±3.1	18.6± 5.9	16.5±6.3	28.4±3.6
Antarctic Convergence—Antarctic Divergence							
1–100	29	55.6±20.9	7.68±3.13	7.39±1.05	36.9± 8.5	11.8±2.1	21.6±4.9
125–200	13	33.5± 9.1	3.27±0.87	10.4 ±2.3	29.1± 9.4	12.3±3.7	26.7±6.1
300–1500	11	26.4±13.4	2.53±1.76	12.5 ±3.8	21.2±10.6	13.4±5.4	25.5±6.8
Southern area of Antarctic Divergence							
0–100	24	61.6±22.7	8.89±3.63	7.18±1.11	40.3± 9.2	12.7±3.6	30.8±6.5
125–200	12	35.3±15.4	3.32±1.48	10.8 ±1.4	24.7± 3.4	13.8±3.7	37.8±7.5
300–1500	18	33.1±22.3	2.22±1.53	18.2 ±9.7	18.7± 4.3	14.6±4.0	34.8±8.0

The distribution profile of POC along the transect of 160°E is shown in Fig. 4. POC was found to be low in the surface water layer. The maximum values of more than 50 μgC/l were found in the water layers between the depths of 25 m and 100 m. POC concentration tended to decrease rapidly with depth to the values of less than 30 μgC/l in the water layers below the depth of 100 m. The values were found to be less than 20 μgC/l in the water layers below the depth of 500 m.

The average concentrations of POC and PON were found to be almost the same order of magnitude in each of the water layers throughout the water masses as shown in Table 1. These values of POC and PON were determined as ranging from 55.6 to 61.6 μgC/l and from 7.68 to 8.89 μgN/l respectively in the surface and subsurface water layers of these water masses, but these values tended to increase with depth.

POC and PON values obtained in this work were a little higher than those found in the low latitude areas of the Indian Ocean (NEWEL and KERR, 1968; CHESTER and STONER, 1974), of the Pacific Ocean (HOLM-HANSEN, 1969; GORDON, 1971) and of the Atlantic Ocean (CHESTER and STONER, 1974; GORDON, 1977). However, much higher values of POC and PON concentrations ranging from 91 to 269 μgC/l and from 13 to 30 μgN/l respectively in the water layers from the surface to 100 m depth were determined in the northern North Pacific and the Bering Sea. In view of these findings, it can be seen that average values of the standing stocks of POC and PON in the Antarctic Ocean are found to be little less than those obtained with high latitude areas of the northern hemisphere. However, it should be noted that regional variability of POC as well as that of chlorophyll *a* has been found in the surface waters of the Antarctic Ocean as mentioned before. This must be one of the most distinctive characteristics in the distribution profiles of particulate organic matter for the Antarctic Ocean.

The ratios of amino acid, carbohydrate and lipid carbons to POC were calculated (Table 1). The ratio of total amino acid carbon to POC (AA-C/POC) was found to be 40% in the water layers above the thermocline and this value tended to decrease with depth. The values were found to be about 20% in the water layers below the depth of 200 m. Vertical distribution profiles of AA-C/POC were almost identical between the stations examined.

AA-C/POC was found to range from 34.1 to 40.3% in the surface and subsurface water layers of the Antarctic Ocean (Table 1). The values tended to decrease with depth to the range of 18.6–21.1% in the deep water layers. These ratios are almost identical with those obtained in the northern North Pacific and the Bering Sea (TANOUE and HANDA, 1979), in the Oyashio and Aleutian Arc areas (HANDA and YANAGI, 1969) and in the Sargasso Sea off Guadalpe Island, Mexico (DEGENS, 1970).

The ratio of carbohydrate to POC (Carb. -C/POC) was found not to show any significant vertical and horizontal trends. The values were determined to range from 10 to 20% throughout the water layers of the Subtropical Convergence–Antarctic Convergence, Antarctic Convergence–Antractic Divergence and south of Antarctic Divergence areas.

The ratio of lipid carbon to POC (Lipid-C/POC) was calculated for the particulate matter collected from the Antarctic Ocean. The values obtained varied regionally and vertically. The values of the ratio were found to be 20–30% in the water layers from the surface through 1500 m depth in the oceanic areas from the Subtropical Convergence to the Antarctic Divergence, while much high values of the ratio ranging from 30 to 40% were found in the surface and intermediate water layers of the south of the Antarctic Divergence (Figs. 5 and 6) where the dichothermal water layers were developed in both of the areas along the transect of 125° and 160°E. The data shown in Figs. 5 and 6 indicate distinctively that more development of the dichothermal waters gives higher values of Lipid-C/POC.

Lipid-C/POC has been reported in the particulate samples collected from various oceanic areas. HANDA *et al.* (1972) reported that Lipid-C/POC was found ranging from 7.5 to 15% in the particulate samples from the tropical and subtropical areas of the North and South Pacific Oceans. Lipid-C/POC ranging from 5.5 to 15% was also

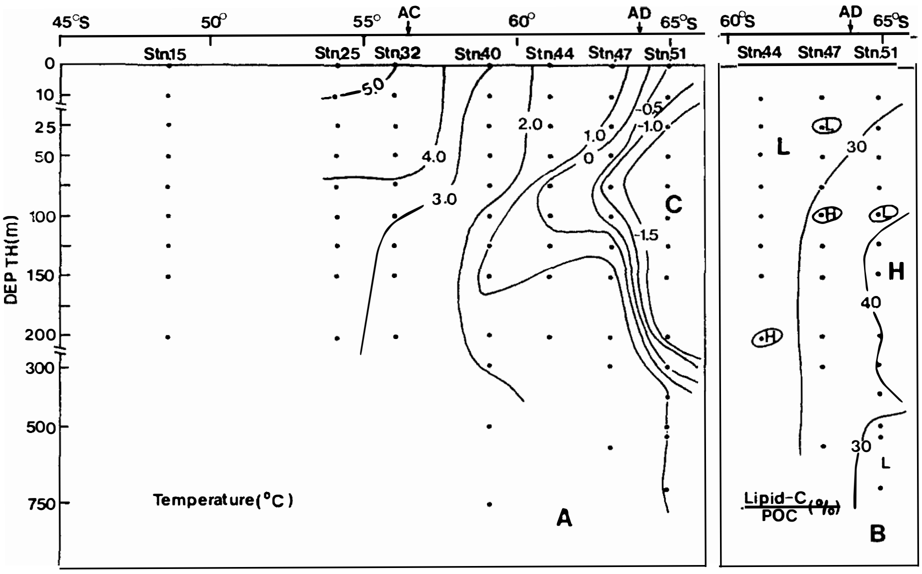

Fig. 5. Distribution profiles of water temperature (A) and ratio of lipid carbon to particulate organic carbon (B) along the transect of 125°E.

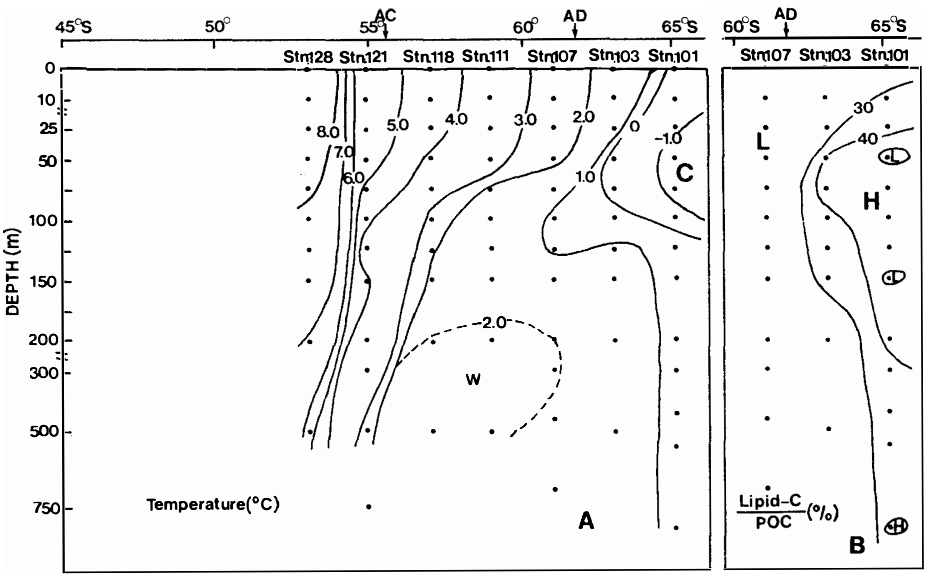

Fig. 6. Distribution profiles of water temperature (A) and ratio of lipid carbon to particulate organic carbon (B) along the transect of 160°E.

found in the particulate samples from the Oyashio area (HANDA and YANAGI, 1969) and the northern North Pacific including the Bering Sea (TANOUE and HANDA, 1979). From these findings, it can be seen that high level of Lipid-C/POC is one of the most distinctive characteristics in the organic composition of the particulate matter in the south of the Antarctic Divergence.

Recently SMITH and MORRIS (1980) found that 80% of carbon fixed by phytoplankton were incorporated into lipid materials under the conditions of low light intensity and low water temperature (below 0°C) in the Antarctic Ocean, whereas only 20% of total fixed carbon during photosynthetic reaction of phytoplankton are found in cellular lipid under high water temperature (above 0°C) and high light intensity. These findings seem to give an important clue to clarify the high level of Lipid-C/POC especially found in the south of Antarctic Divergence.

4. Fatty Acid Composition of the Particulate Matter from the Antarctic Ocean

Particulate organic matter plays an important role in the marine food chain as a potential food for the secondary producers (STRICKLAND, 1965; RILEY and CHESTERS, 1971). It has been reported that fatty acids of phytoplankton were digested by zooplankton (TANOUE *et al.*, 1982a,b), thus, chemical studies of the particulate matter can be assumed to give invaluable information on the nutritional potential of the organic component for marine organisms.

Table 2. Fatty acid compositions of the particulate matter collected from the water layers of the surface through 600 m depth at a station (BIOMASS cruise) near the pack ice area of the Antarctic Ocean.

Fatty acid[a)]	Depth		
	Surface (5 m)	50 m wt %	600 m
14 : 0	20.6	14.0	5.86
Anteiso[b)]-15 : 0	tr.[c)]	tr.	0.53
Iso-15 : 0	0.96	1.62	1.38
15 : 0	0.76	1.82	3.67
16 : unsat.[d)]	14.8	9.55	3.53
16 : 0	20.7	27.8	39.8
Anteiso-17 : 0	tr.	tr.	tr.
Iso-17 : 0	0.96	1.85	2.91
17 : 0	0.40	1.11	2.40
18 : unsat.	21.4	12.3	5.68
18 : 0	6.41	16.1	24.4
19 : 0	tr.	tr.	tr.
20 : unsat.	9.99	6.46	1.19
20 : 0	1.14	1.43	2.13
22 : unsat.	tr.	2.47	tr.
22 : 0	1.30	2.11	3.96
23 : 0	tr.	tr.	tr.
24 : unsat.	tr.	0.51	tr.
24 : 0	tr.	0.86	1.97
Total fatty acid (μg/l)	4.93	6.44	2.33
FA-C/POC (%)[e)]	5.15	3.97	4.63
FA-C/lipid-C (%)[f)]	20.3	11.4	17.1
Branched-FA/FA (%)[g)]	1.92	3.47	4.82
Temperature (°C)	−0.72	−1.76	1.34

a) All the fatty acids are given by carbon chain length: number of double bond; b) Branched fatty acid; c) Trace (less than 0.5% of total fatty acid); d) Unsaturated fatty acids; e) Weight percent of fatty acid carbon to particulate organic carbon; f) Weight percent of fatty acid carbon to lipid carbon; g) Weight percent of branched (anteiso+iso) to total fatty acids.

In this section, we intended to reported the vertical and horizontal variabilities of fatty acid composition of the particulate samples collected from the various oceanic areas from 7°N to 64°S in the Pacific Sector of the Southern Ocean (Table 2).

Lipid material was extracted from particulate matter collected from the Southern Ocean with chloroform-methanol (2:1 v/v). The extract was saponified with 0.5 N KOH and esterified with BF_3 in methanol. Fatty acid methyl esters were analyzed by gas chromatography using the instrument equipped with a hydrogen flame-ionization

Table 3. Fatty acid compositions of the particulate matter collected from the surface water at various latitudes. Water samples were collected under the bottom of the ship by pumping during cruise of the ship. The locations of the samples are shown in the foot note.

Fatty acid[i] \ Approximate location	64°S[a] 108°E	62°S[b] 160°E	60°S[c] 155°E	52°S[d] 160°E	36°S[e] 152°E	14°S[f] 155°E	01°S[g] 152°E	07°N[h] 108°E
				wt %				
14 : 0	20.6	26.6	24.7	17.5	24.2	22.7	12.6	16.8
Anteiso[j]-15 : 0	tr.[k]	tr.	tr.	tr.	tr.	1.79	0.79	tr.
Iso-15 : 0	0.95	1.73	1.11	1.75	2.62	3.78	1.55	1.61
15 : 0	0.76	1.68	1.01	1.67	1.88	3.30	1.64	1.59
16 : unsat.[l]	14.8	22.0	16.3	11.5	10.7	14.3	6.53	7.41
16 : 0	20.7	20.9	21.3	25.8	29.4	33.3	30.8	42.4
Anteiso-17 : 0	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.
Iso-17 : 0	0.96	tr.	0.70	tr.	1.89	tr.	tr.	tr.
17 : 0	tr.	0.83	0.53	0.70	1.13	1.24	1.24	1.77
18 : unsat.	21.4	13.8	16.8	13.3	13.1	8.20	12.9	11.4
18 : 0	6.41	4.65	8.06	19.7	9.15	8.82	28.0	13.5
19 : 0	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.
20 : unsat.	9.99	4.97	6.32	0.95	1.70	0.50	0.65	tr.
20 : 0	1.14	0.80	0.86	1.71	0.86	0.65	2.07	1.14
22 : unsat.	1.30	0.88	tr.	tr.	1.71	tr.	tr.	tr.
22 : 0	tr.	0.90	1.45	3.88	1.56	1.36	1.28	1.77
23 : 0	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.
24 : unsat.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.
24 : 0	tr.	tr.	0.93	tr.	tr.	tr.	tr.	0.60
Total fatty acid ($\mu g/l$)	4.93	3.38	2.76	2.27	1.89	4.13	4.43	2.20
FA-C/POC (%)[m]	5.15	3.98	3.53	3.45	2.88	5.53	8.22	5.35
FA-C/lipid-C (%)[n]	20.3	27.6	26.7	20.3	16.6	33.5	49.8	32.4
$\frac{16:\text{unsat.}}{16:0}$	0.71	1.05	0.77	0.43	0.35	0.43	0.21	0.17
$\frac{18:\text{unsat.}}{18:0}$	3.34	2.97	2.08	0.68	1.43	0.93	0.46	0.84
$\frac{20:\text{unsat.}}{20:0}$	8.76	6.21	7.35	0.56	1.98	0.77	0.31	—

a) 64°35.0′S : 124°57.1′E, b) (62°59.8′S : 159°58.1′E)-(61°00.7′S : 160°01.0′E), c) (59°37.7′S : 154°58.9′E)-(61°38.6′S : 154°58.1′E), d) (53°04.4′S : 160°06.9′E)-(52°21.0′S : 160°03.4′E), e) (36°53.3′S : 152°58.8′E)-(35°11.0′S : 151°58.7′E), f) (15°37.4′S : 154°48.7′E)-(13°20.4′S : 154°40.0′E), g) (02°42.4′S : 152°22.6′E)-(00°33.0′S : 152°09.0′E), h) (08°16.2′N : 109°13.2′E)-(06°11.3′N : 107°33.3′E); i) All the fatty acids are given by carbon chain length : number of double bond; j) Branched fatty acid; k) Trace (less than 0.5%); l) Unsaturated fatty acids; m) Weight percent of fatty acid carbon to particulate organic carbon; n) Weight percent of fatty acid carbon to lipid carbon.

detector under the following conditions: glass column (2 m length × 3 mm diameter) packed with 1% OV–1; carrier gas, N_2; oven temperature 120–310°C programed at 5°C/min and combined gas chromatography and mass spectrometry.

4.1. Horizontal variability of fatty acid composition of particulate matter

Particulate matter collected from the surface water in various oceanic areas from 7°N to 64°S was examined for fatty acid composition as shown in Table 3. The concentration of fatty acids in the particulate samples collected from these oceanic areas was determined to be ranging from 1.89 to 4.93 μg/*l* which accounted for 2.88–8.22% of POC.

Fatty acids with carbon atoms ranging 14 to 24 were found to occur in these particulate samples. It is of interest that unsaturated fatty acids with carbon atoms of 16, 18, 20 and 22 accounted for 20.1% of total fatty acids in the tropical and subtropical areas, while the abundance of the unsaturated fatty acids tended to increase with steep gradient toward Antarctica in the Subantarctic through Antarctic Oceans and the unsaturated fatty acid accounted for 47.5% of total fatty acid in the particulate matter from the oceanic area south of the Antarctic Divergence. The trend of the horizontal distribution of unsaturated fatty acids is more distinctively demonstrated by the ratios of 16: unsat., 18: unsat. and 20: unsat. acids to 16: 0, 18: 0 and 20: 0 acids respectively (Table 3).

It has been reported by many workers that unsaturated fatty acids with carbon atoms of 16, 18 and 20 are determined as major components of the fatty acids in various marine phytoplankton including Chrysophyceae, Haptophyceae, Chrysophyceae and Bacillariophyceae (ACKMAN *et al.*, 1964; KATES and VOLCANI, 1966; DEMORT *et al.*, 1972). In view of these findings on fatty acid composition, it can be seen that fatty acid composition of the particulate matter collected from the Subantarctic and Antarctic areas is much affected by that of phytoplankton than those from the Tropical and Subtropical areas.

4.2. Vertical profile of fatty acid composition of particulate matter

The fatty acid compositions of the particulate matter at three depths of water layers were examined at a station (64°35.0′S, 124°57.1′E) located near the pack-ice area. Fatty acids with carbon atoms ranging from 14 to 24 were detected throughout the samples and distribution profiles of these fatty acids (fatty acid composition) changed markedly with depth (Table 2).

Fatty acids of 14: 0, 16: 0 and 18: unsat. were predominant in the particulate matter collected from the surface and subsurface (50 m depth) layers, where these fatty acids accounted for 62.7 and 54.1% of total fatty acids respectively. It is obvious, however that unsaturated fatty acids tended to decrease from 46.2% (surface layer) to 10.4% (600 m depth), while saturated fatty acids of 16: 0 and 18: 0 become consequently dominant in the particulate matter from deep water. It has been reported that unsaturated fatty acid is very susceptible to the biological action (RHEAD *et al.*, 1971). Therefore, such decrease in the percentage of unsaturated fatty acids with depth is concluded to be exclusively due to the biological degradation of unsaturated fatty acids during the sinking of the particulate matter from the surface to deep waters.

5. Digestion of Algal Organic Matter by *Euphausia superba*

The chemistry of zooplankton fecal pellet has been given more attention because of its significance in the energy transfer processes of the food web in the surface through deep waters (JOHANNES and SATOMI, 1966; PAFFENHÖFER and KNOWLES, 1979) in the benthic community (NEWELL, 1965). Thus, we did our experiment to try to elucidate the ecological and/or biochemical significance of algal fatty acids for *Euphausia superba* although it was unlikely that the green alga serve the zooplankton generally as food in the Antarctic Ocean.

Euphausia superba collected in the Antarctic Ocean at 65°40′S, 150°35′E was maintained in an aquarium at 0.7°C in a laboratory on land and fed on *Dunaliella tertiolecta* cells. The fecal pellets produced by the zooplankton were collected from the aquarium once a day by pipete, sorted out from *Dunaliell* cells and collected onto a glass fiber filter.

Organic carbon and nitrogen of *Dunaliella tertiolecta* cells and fecal pellets produced by *Euphausia superba* are shown in Fig. 7. The concentration of fatty acid in the

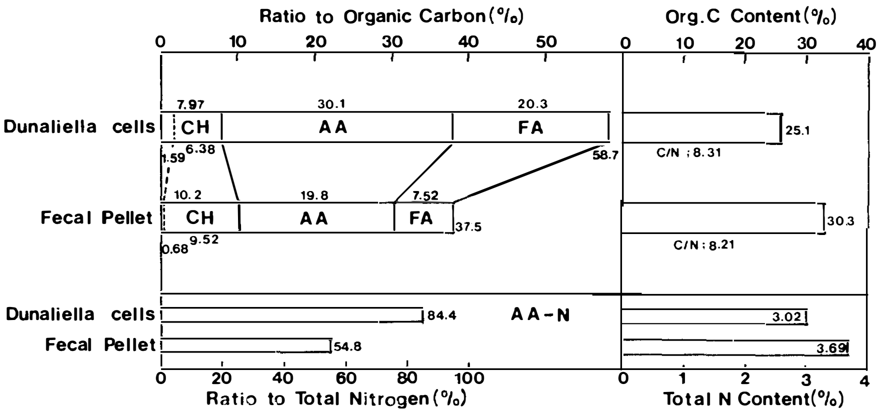

Fig. 7. Organic carbon and nitrogen contents and ratios of carbohydrate (CH), amino acid (AA) and fatty acid (FA) carbon to total organic carbon and of the amino acid nitrogen (AA-N) to total nitrogen of the Dunaliella *cells and the fecal pellet.*

fecal pellet as well as amino acid including free and combined forms markedly decreased in comparison with that of the algal cells although a little increased values of organic carbon and nitrogen were observed in the fecal pellet relative to the algal cells.

Fatty acid composition of *Dunaliella* cells and the fecal pellet sample were determined and shown in Table 4. Fatty acids with carbon atoms ranging from 14 to 24 were detected in both of the samples. 16: unsat., 16: 0 and 18: unsat. acids were found as main components of the fatty acids in *Dunaliella* cells as observed in various species of phytoplankton as well as in the fecal pellet from *Euphausia superba*. These facts indicate that practically no molecular discrimination in fatty acid compositions takes place during the processes of the fecal pellet formation from *Dunaliella* cells in *Euphausia superba*, but a large difference in fatty acid concentration between *Dunaliella* cells and fecal pellet is observed (Table 4). Such a fatty acid material consisted of 16:

Table 4. Fatty acid composition of the Dunaliella *cells and the fecal pellet.*

Fatty acid	*Dunaliella* cells mg/g dry matter (A)	%	Fecal pellet mg/g dry matter (B)	%	A–B	(A–B)/C
14 : 0	0.45	0.65	0.95	3.21	−0.50	
Anteiso-15 : 0	ND	—	—	tr.	—	
Iso-15 : 0	ND	—	0.20	0.64	−0.20	
15 : 0	ND	—	0.25	0.85	−0.25	
16 : unsat.	7.29	10.6	1.23	4.17	6.06	15.4
16 : 0	13.6	19.7	6.26	21.2	7.34	18.7
17 : 0	ND	—	—	tr.	—	—
18 : unsat.	45.1	65.6	18.8	63.2	26.3	67.1
18 : 0	2.39	3.47	1.40	4.73	0.99	2.52
20 : 0	ND	—	—	tr.	—	
22 : 0	tr.	—	—	tr.	—	
24 : 0	tr.	—	—	tr.	—	
26 : 0	ND	—	0.56	1.90	−0.56	
Total	68.8	100	29.6	100	39.2(C)	
Fatty acid carbon/ organic carbon (%)		20.3		7.52		

unsat., 16:0, 18: unsat. and 18:0 which accounted for 15.4, 18.7, 67.1 and 2.52% of total loss of fatty acid materials during the digestion processes of *Dunaliella* cells by *Euphausia superba*. In view of these findings, it can be seen that fatty acids of *Dunaliella* cells must be most important as a diet of *Euphausia superba* as well as amino acids with free and combined forms. The data obtained in this work also indicate that unsaturated fatty acids play an important role in energy metabolism of the zooplankton because 16: unsat. and 18: unsat. acids account for more than 80% of total loss of fatty acids during the digestion processes of *Dunaliella* cells by this zooplankton.

In summary, particulate matter was collected from the oceanic areas between Australia and Antarctica in 1980–1981 and analyzed for organic carbon and nitrogen, carbohydrate, amino acids including free and combined forms and lipid materials. Detailed analyses of fatty acids in the particulate matter were conducted to clarify their ecological significance in the Antarctic Ocean.

Characteristic features of particulate organic matter in the Antarctic Ocean are as follows.

1) Particulate matter was collected from the surface waters in 32°N (off Tokyo) –65°S, 140°–160°E and analyzed for POC and PON, which were determined without any significant regional variabilities in the oceanic areas from off Tokyo to 41°S. However, much higher level of the values of POC and PON was determined in the Antarctic Ocean from 41° to 65°S and regional variabilities of the values occurred to a great extent.

2) Particulate matter collected from the Pacific Sector of the Antarctic Ocean was analyzed for carbohydrate, amino acid and lipid materials. Horizontal and vertical variabilities of the composition of these organic materials were much less in extent throughout the oceanic areas except lipid materials in the areas south of the Antarctic Divergence, where unexpectedly high values of the abundance of lipid exceeding 40% of POC were obtained.

3) Fatty acids with carbon atoms ranging from 14 to 24 were detected in the particulate matter from the surface through the deep waters and quantified by gas chromatography. A remarkable change in the fatty acid composition was observed in the areas between the oceanic areas south and north of the Antarctic Convergence. The ratio of unsaturated fatty acids with carbon atoms of 16, 18 and 20 to total fatty acids tended to increase toward the area south of the Antarctic Divergence, where unsaturated fatty acids accounted for more than 40% of total fatty acids of the particulate matter.

4) Fecal pellet of *Euphausia superba* and its feed *Dunaliella tertiolecta* were analyzed for fatty acids to elucidate the ecological and/or biochemical significance of algal fatty acids for *Euphausia superba*. It was found that the zooplankton digested fatty acids of the alga as well as amino acids during the fecal pellet formation, and unsaturated fatty acids with carbon atoms of 16 and 18 accounted for more than 80% of total loss of fatty acids.

5) Unsaturated fatty acids are demonstrated to be easily digested by the zooplankton living there. These findings strongly suggested that unsaturated fatty acids must be one of the most ecologically significant organic materials in the Antarctic Ocean.

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