Chlorophyll *a* Distribution in the Indian Sector of the Antarctic Ocean in 1978–1979

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1978–1979 年，南極海インド洋区におけるクロロフィル *a* 分布

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要旨: 1978–1979 年，第 20 次日本南極地域観測隊にて，南極海インド洋区におけるクロロフィル *a* 量の水平・垂直分布を調査した．12 月中旬に東経 110 度から 90 度へかけ南緯 34 度から 60 度への南下航路上，12 月下旬～1 月上旬に南緯 60 度以南域を東経 90 度から 39 度へかけての西方航路上，および 2 月下旬～3 月上旬に東経 40 度から 51 度へかけ南緯 65 度から 34 度への北上航路上において，2 時間間隔を含む表面観測を行った．北上航路上の南緯 52 度以南域では，6 観測点にて水深 500 m までの垂直分布を調べた．南下航路上では南極収束線域に高クロロフィル *a* 量 (1.0 mg/m³ 以上) がみられたが，北上航路上では亜熱帯収束線域に 0.5 mg/m³ 以上の値がみられた．両航路上における表面クロロフィル *a* 量の緯度変化の相異から，植物プランクトンの季節変動が示唆された．西方航路上におけるクロロフィル *a* 量の経度変化は，湧昇現象に関連すると思われた．0–250 m 水柱内クロロフィル *a* 現存量は，16.8～39.4 mg/m² であり，水深 50～100 m 付近に弱い亜表層クロロフィル極大がみられた．

Abstract: Horizontal and vertical distributions of chlorophyll *a* in the Indian sector of the Antarctic Ocean were investigated during the 20th Japanese Antarctic Research Expedition in 1978–1979. Surface observations including the two hours interval observation were carried out on the southward leg between 34°S, 110°E and 60°S, 90°E in middle December, on the westward leg between 90° and 39°E south of 60°S in late December to early January, and on the northward leg between 65°S, 40°E and 34°S, 51°E in late February to early March. Vertical observations down to a 500 m depth were done at six stations on the northward leg south of 52°S latitude. While high surface chlorophyll *a* concentrations (more than 1.0 mg/m³) were seen around the Antarctic Convergence on the southward leg, high concentrations more than 0.5 mg/m³ were distributed around the Subtropical Convergence on the northward leg. Difference in the latitudinal variations of surface chlorophyll *a* between the two legs suggested the seasonal periodicity of phytoplankton. Longitudinal variation on the westward leg seemed to be related with the upwellings of water. Integrated chlorophyll *a* stocks for a 0–250 m water column

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were in a range of 16.8–39.4 mg/m^2 and a weak subsurface chlorophyll *a* maximum was seen around 50–100 m depths.

1. Introduction

In the Indian sector of the Antarctic Ocean, a routine observation of surface chlorophyll *a* distribution has been continued by members of the Japanese Antarctic Research Expedition (JARE). The observation was ordinarily carried out two or three times a day along the cruise track of the icebreaker FUJI. Based on these observations, FUKUCHI (1980) estimated the chlorophyll *a* stocks for each of six different water masses between Subtropical water and Antarctic surface water and discussed the relation between the distribution of chlorophyll *a* and the seasonal periodicity of phytoplankton. His average figure of chlorophyll *a* stock is useful to evaluate the round stock. However, it is difficult to detect a fine variation of chlorophyll stock across different water masses due to a coarse interval of surface observations (50–170 mile intervals). PLANCKE (1977) employed a subsurface pumping method at a rate of one sample per hour during cruises and discussed the phytoplankton biomass and primary productivity in the subantarctic region extending from 40°S to 55°S and 20°E to 75°E. Recently, KURODA and FUKUCHI (1982) pointed out that the surface observation is a good expedient for evaluating the chlorophyll *a* stocks in the subsurface water column.

The present work was undertaken to clarify the fine variation of chlorophyll *a* across different water masses by surface observation at two-hours intervals. Also, the vertical observation was carried out in order to acquire the fundamental data for evaluating the chlorophyll *a* stocks in the Antarctic Ocean.

2. Methods and Materials

Surface water sampling was carried out two to three times a day at 0800, 1200 and 1800 by local time along the cruise track of the icebreaker FUJI between Tokyo and Syowa Station (69°00′S, 39°35′E), Antarctica. A total of 241 stations was occupied in the present work. Among them, intensive sampling at two-hours intervals was performed in the Indian sector of the Antarctic Ocean, *i.e.*, at 80 stations (Stns. 44–123) between 34°20′S, 111°45′E and 60°22′S, 88°59′E from 16 to 22 December in 1978 and at 39 stations (Stns. 160–198) between 53°53′S, 43°10′E and 36°27′S, 50°41′E from 1 to 5 March in 1979. Surface chlorophyll *a* concentration was determined by the colorimetric method (UNESCO, 1966), using a HITACHI model 101 spectrophotometer.

In addition, water samples from 12–14 layers down to the 500 m depth were collected by the Nansen bottles at six stations (Stns. 151, 153, 155, 157, 159 and 166).

Fluorometric determination of chlorophyll *a* was employed for the samples of vertical observations. The surface samples at 46 stations between Stns. 150 and 198 were also measured fluorometrically for intercalibrating the colorimetric and fluorometric determinations. A Shimadzu model RF-500 spectrofluorometer was used. Concentrations of chlorophyll *a* and phaeophytin were calculated from the following equations:

$$\text{Chl. } a \text{ (mg/m}^3\text{)} = (\text{Fo} - \text{Fa}) \times \frac{v}{1000V} \times \frac{1}{f_{\text{ph}}(R-1)}$$

$$\text{Phaeop. (mg/m}^3\text{)} = (R \cdot \text{Fa} - \text{Fo}) \times \frac{v}{1000V} \times \frac{1}{f_{\text{ph}}(R-1)}$$

where, Fo: fluorescence before acidification
Fa: fluorescence after acidification
v: volume of aceton extract in m*l*
V: volume of water sample in *l*
f_{ph} and R: constants

Two constants were determined based on the intercalibration between the present fluorometer and a Hitachi Spectrophotometer 139 incorporated with fluorometry attachments installed in the Oceanographic Laboratory of Tohoku University. Values of R and f_{ph} were 0.075 and 8.060 respectively.

A regression of chlorophyll observed by the fluorometric method on chlorophyll *a* determined by the colorimetric method for 46 sets of data in February and March 1979 was as follows;

$$\text{Chl. } a \text{ (mg/m}^3\text{, fluor.)} = 0.043 + 0.770 \times \text{Chl. } a \text{ (mg/m}^3\text{, color.)} \quad (N: 46,\ r = 0.982)$$

XBT observations were carried out concurrently with the surface observations by SUZUKI and KURANO (1982, in this volume).

3. Results

Although the surface observation was extented from the western North Pacific to the Antarctic Ocean as summarized in Appendix 1, the present work was focused on the observations done in the Indian sector of the Antarctic Ocean. The chlorophyll *a* concentrations in the surface water south of 34°S are shown in Fig. 1.

Arbitrarily, the observations carried out between Stns. 44 and 121 were treated as the ones on the southward leg. In a same manner, Stns. 122–148 were on the westward leg and Stns. 151–199 were on the northward leg. Among them, the intensive observations of two-hours intervals were done between Stns. 44 and 123 and between Stns. 160 and 198 as mentioned previously. Stations occupied between Stns. 133 and

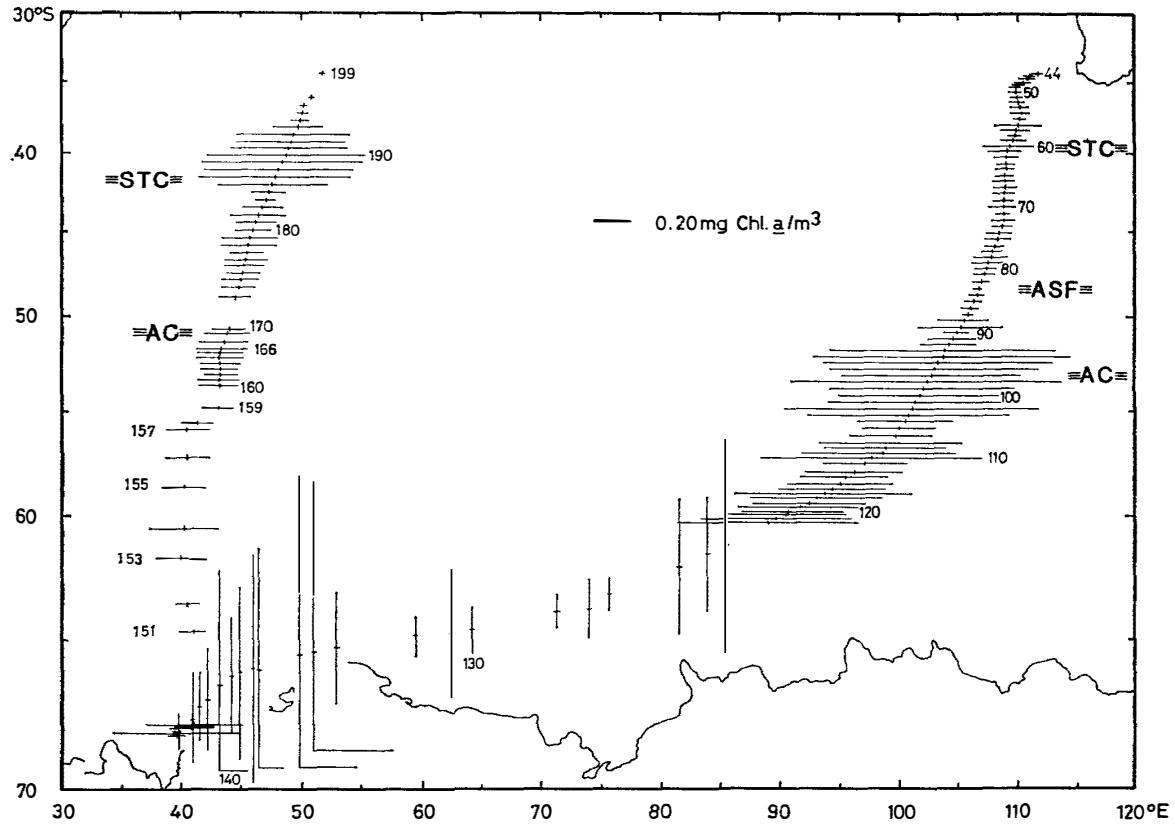

Fig. 1. Surface chlorophyll a concentration south of 34°S in the Indian sector of the Antarctic Ocean observed aboard the FUJI in 1978–1979. Numerals mean the serial number of the station. STC, ASF and AC indicate approximate locations of the Subtropical Convergence, Australasian Subantarctic Front and Antarctic Convergence, respectively.

143 were located in the pack ice region near the Antarctic Continent. Stns. 144–148 were in the lead water surrounded by the pack and fast ice.

Stations on the southward leg were observed between December 16 and 22, 1978, those on the westward leg were between December 22, 1978 and January 12, 1979, and those on the northward leg were between February 19 and March 5, 1979. There was a time lag of about two months between the southward and westward legs and the northward leg.

3.1. Latitudinal and longitudinal distributions of surface chlorophyll *a*

3.1.1. Surface distribution on the southward and westward legs in late December and early January

Vertical section of water temperature on the southward and westward legs is shown in Fig. 2 (lower), which was reproduced from the data given by SUZUKI and KURANO (1982). It is clear that the Subtropical (STC) and Antarctic Convergences (AC) were

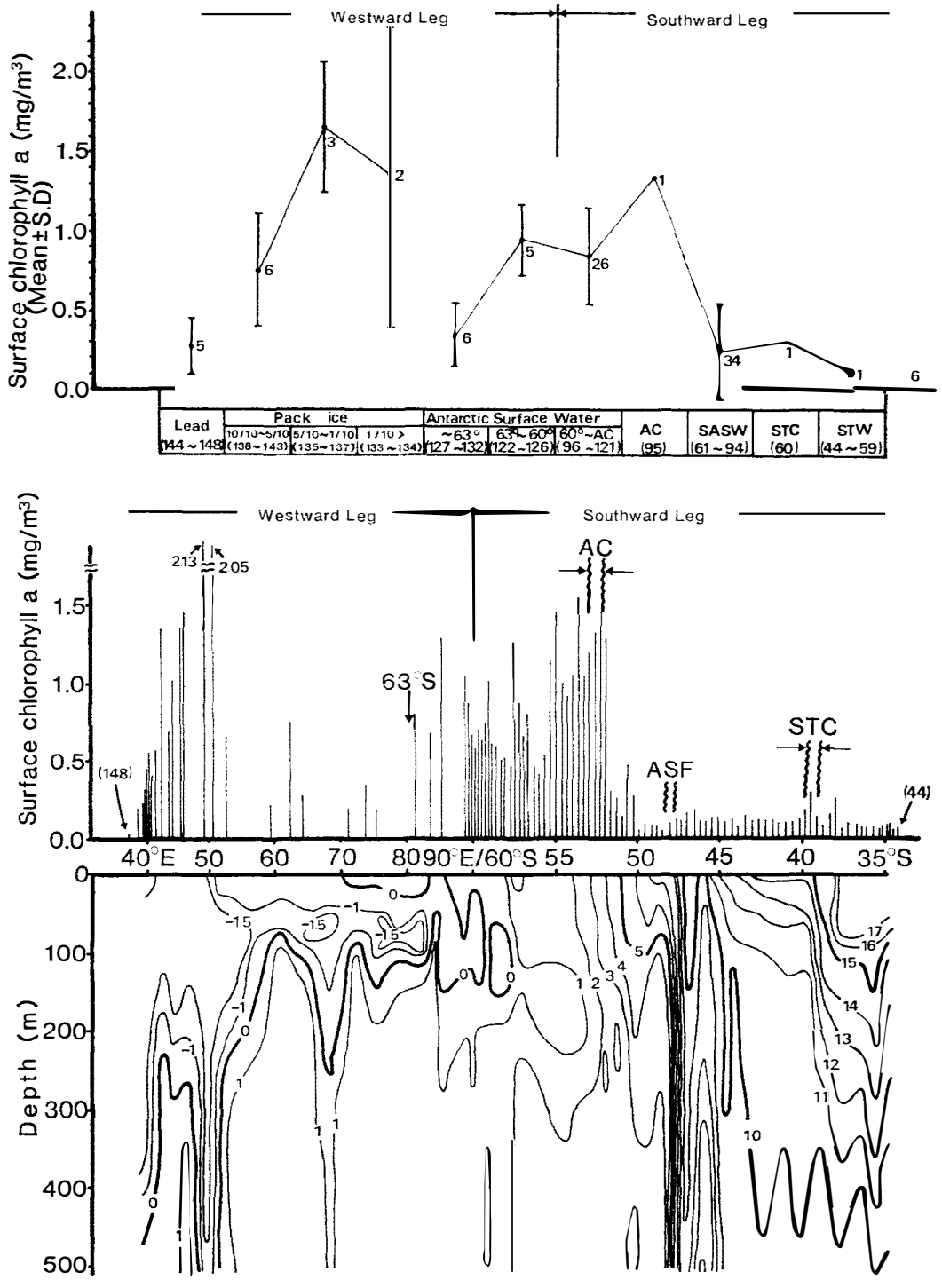

Fig. 2. Vertical section of water temperature (lower), surface chlorophyll a concentration (middle) and mean and standard deviations of surface chlorophyll a for each of different water masses (upper) on the southward and westward legs during a period from 16 December 1978 to 12 January 1979. Numerals and those in parentheses indicate the number of data pooled and the number of station, respectively. STC, ASF and AC as in Fig. 1.

located between Stn. 59 and 61 around 39°26′S and between Stns. 94 and 96 around 52°32′S, respectively. Furthermore, the Australasian Subantarctic Front (ASF; BURLING, 1961) was located between Stns. 81 and 82 around 47°50′S (see SUZUKI and KURANO, 1982). In the Antarctic water south of 60°S on the westward leg, the temperature minimum layer of less than −1.0°C was observed, while the upwellings were seen around 85°E, 72°E, 61°E and 45°E longitudes as indicated by the isotherm of 0°C.

Surface chlorophyll *a* concentrations are shown in Fig. 2 (middle). In the Subtropical and Subantarctic waters, the concentrations were low, usually less than 0.3 mg/m^3. It increased rapidly at Stn. 93 (1.29 mg/m^3) located just north of the AC. High concentrations were found in the Antarctic water on the southward leg, while those fluctuated between 0.42 (Stn. 105) and 1.55 mg/m^3 (Stn. 98). On the westward leg, the fluctuation in the open water became large between 0.20 (Stn. 127) and 1.28 mg/m^3 (Stn. 124). However, high concentrations seemed to occur in areas of the possible upwellings. In the pack ice area, the maximum concentration throughout the present observations was found at Stn. 135 (2.13 mg/m^3), though the concentrations fluctuated largely (0.41–2.13 mg/m^3). In the lead water, the concentrations were low in a range of 0.03–0.56 mg/m^3.

Mean value of chlorophyll *a* concentration and its standard deviation for each of 11 different water masses on the southward and westward legs were calculated and are illustrated in the upper part of Fig. 2. Mean value increased from the Subtropical water toward the AC zone (1.33 mg/m^3). Mean value seemed to decrease from north (0.83 mg/m^3) to south (0.34 mg/m^3) in the Antarctic water. In the pack ice area, high values of 0.75–1.65 mg/m^3 were observed, while low value of 0.28 mg/m^3 was seen in the lead water.

3.1.2. Surface distribution on the northward leg in late February and early March

In the lower part of Fig. 3, the vertical section of temperature along 40–50°E longitude on the northward leg is reproduced. AC and STC were located around 51°09′S between Stns. 94 and 96 and around 41°46′S between Stns. 59 and 61, respectively. ASF was not detected on this leg.

Surface chlorophyll *a* concentrations are shown in the middle part of Fig. 3. Concentrations were usually lower than 0.3 mg/m^3 in the Antarctic water as well as in the Subantarctic water south of STC. High concentrations more than 0.5 mg/m^3 were found only in the STC zone and in its northern water. Concentrations became very low in the rest of the Subtropical water. The mean and standard deviations of chlorophyll *a* concentration for each of seven different water masses are shown in the upper part of Fig. 3. Generally, the mean values in the Subantarctic and Antarctic waters were lower than 0.3 mg/m^3. On the other hand, those were higher than 0.4 mg/m^3 in STC and the Subtropical water. Latitudinal variation of chlorophyll *a* on this leg

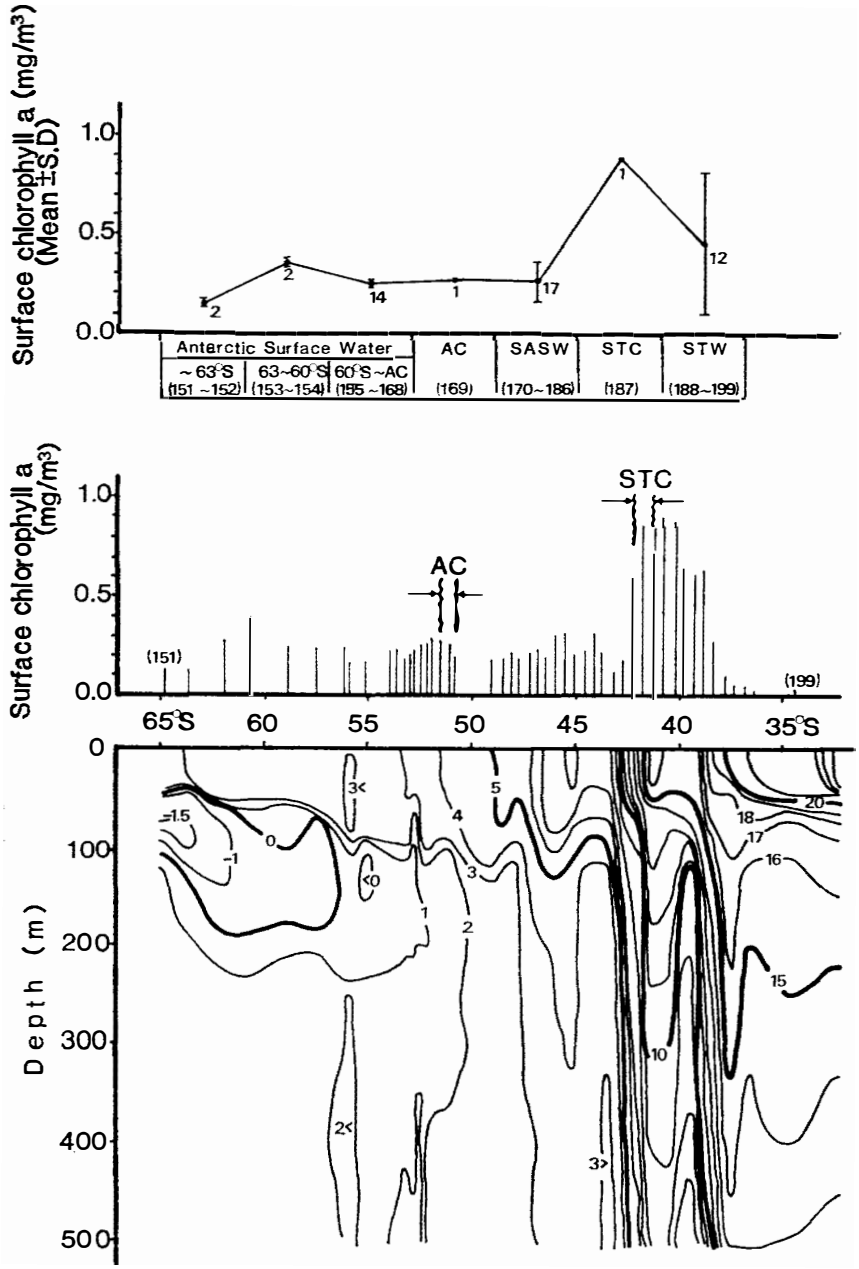

Fig. 3. Vertical section of water temperature (lower), surface chlorophyll a concentration (middle) and mean and standard deviations of surface chlorophyll a for each of different water masses (upper) on the northward leg from 19 February to 5 March 1979. Abbreviations and numerals as in Fig. 2.

showed a quite different pattern from that on the southward leg.

3.2. Vertical distribution of chlorophyll *a*

Concentrations of chlorophyll *a* and phaeophytin and pigment ratio (percentage

of chlorophyll *a* to the sum of chlorophyll *a* and phaeophytin) obtained at six stations of vertical observations are summarized in Appendix 2.

Vertical section of chlorophyll *a* down to a 400 m depth between 52° and 65°S latitudes along 40–43°E longitude is shown in Fig. 4. Throughout six stations, a weak subsurface chlorophyll *a* maximum was observed between 50–100 m depths, where the chlorophyll *a* concentration was in a range of 0.1–0.3 mg/m^3. The subsurface maximum layer seemed to overlie the temperature minimum layer (*cf.* Fig. 3). Chlorophyll *a* concentrations below the depths of 100–180 m were lower than 0.1 mg/m^3. The pigment ratio among six stations was extraordinary low, less than 10%, while a relatively high ratio was found in the surface water and in the subsurface chlorophyll *a* maximum layer. Integrated chlorophyll *a* stocks for a 0–250 m water column were calculated and were found to be in a range of 16.8–39.4 mg/m^2.

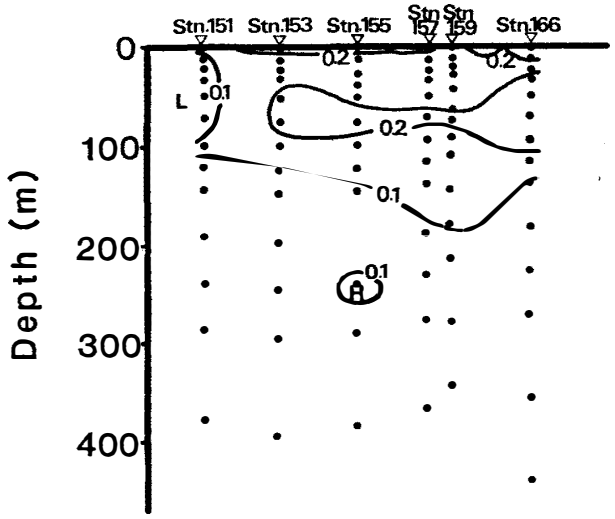

Fig. 4. Vertical section of chlorophyll a along 40–43°E longitudes on the northward leg from 24 February to 1 March 1979.

4. Discussion

Latitudinal variation of surface chlorophyll *a* on the southward leg is quite different from that on the northward leg. On the southward leg in late December, high chlorophyll *a* concentrations are found around the AC and low concentrations are distributed in the northern waters. Surface concentrations increase rapidly just north of the AC. No distinct changes are seen across the STC and the ASF. On the contrary, on the northward leg in late February and early March, about two months later than the southward leg, the latitudinal variation of surface chlorophyll *a* across the AC is very small, but the surface concentrations increase rapidly across the STC.

High concentrations are found in the STC and its northern water.

Although the areas observed differ between the southward and northward legs, these different latitudinal variations between the two legs might be related with the seasonal periodicity of phytoplankton in the Indian sector of the Antarctic Ocean. HART (1942) and HASLE (1969) mentioned that the peak of phytoplankton density appears more and more to the south as the austral summer season advances. FUKUCHI (1980) found that the maximum phytoplankton chlorophyll stock occurs in the AC zone in early summer (middle-late December) based on the JARE data. The latitudinal variation on the present southward leg agrees with his result.

However, the peak of surface chlorophyll *a* does not appear in the southernmost water on the present northward leg (late February - early March). This fact would imply that the peak of surface chlorophyll *a* in the southernmost water occurs either before or after the time of the present observation. RAYMONT (1980) mentioned that there is frequently an autumn bloom of phytoplankton in moderately high and temperate latitudes. The observed peak around the STC might indicate the autumn bloom in the Subtropical water. This conclusion will be examined by comparing the data obtained by three Japanese research vessels in the Indian sector of the Antarctic Ocean

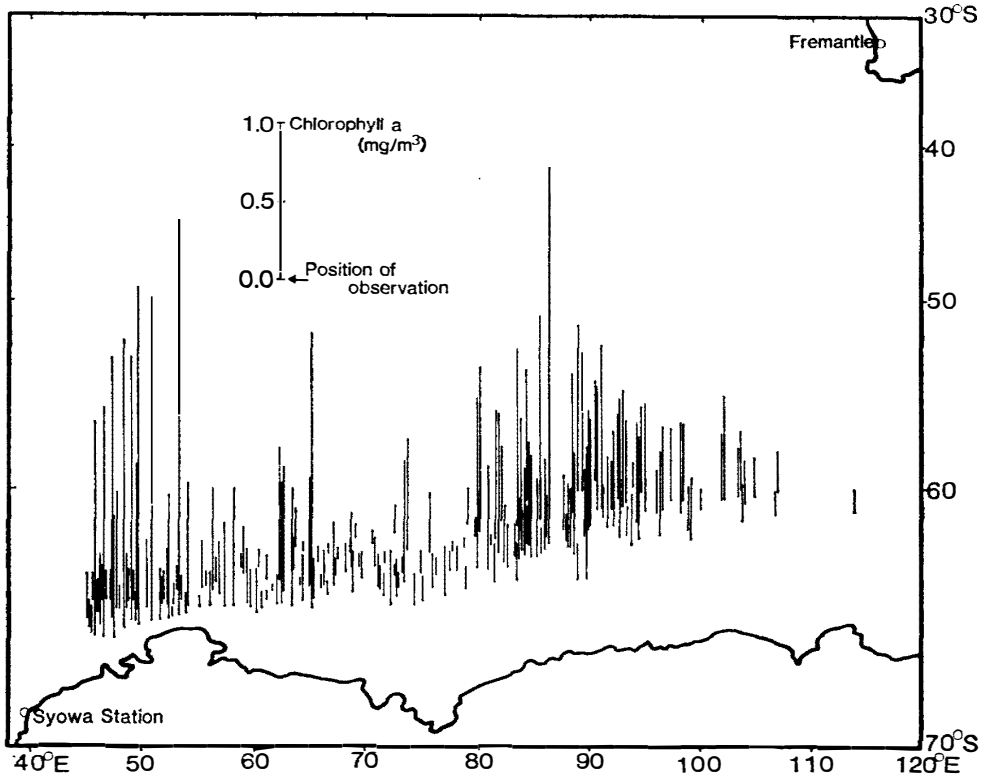

Fig. 5. Surface chlorophyll a concentration south of 60°S on the westward legs observed aboard the FUJI during 12 cruises in 1965/66 (JARE-7)—1979/80 (JARE-21).

which participated in the First International BIOMASS Experiment (1980/1981).

The intensive XBT observations in the present work have elucidated where the strong upwellings occur. Longitudinal variations of surface chlorophyll *a* on the westward leg seem to be related with the upwellings of water. Relatively high concentrations are found in areas where the isotherm of 0°C rises to a 100 m depth, *i.e.*, around 85°E, 72°E and 61°E (see Fig. 2). The surface chlorophyll *a* data accumulated by JARE are shown in Fig. 5. A total of 192 stations located south of 60°S on the westward legs were occupied during 12 FUJI cruises (JARE-7, -9, -10, -12, -14, -15, -16, -17, -18, -19, -20 and -21). Each cruise passes the same route during a definite time of year in late December. It is clearly seen from Fig. 5 that high chlorophyll *a* concentrations are concentrated in three areas around 85°E, 75°E and 65°E. These three areas coincide generally with the present three upwelling areas mentioned above. One of these areas is considered to be closely related with the Antarctic Divergence.

In addition to the three areas, high concentrations are also found in an area around

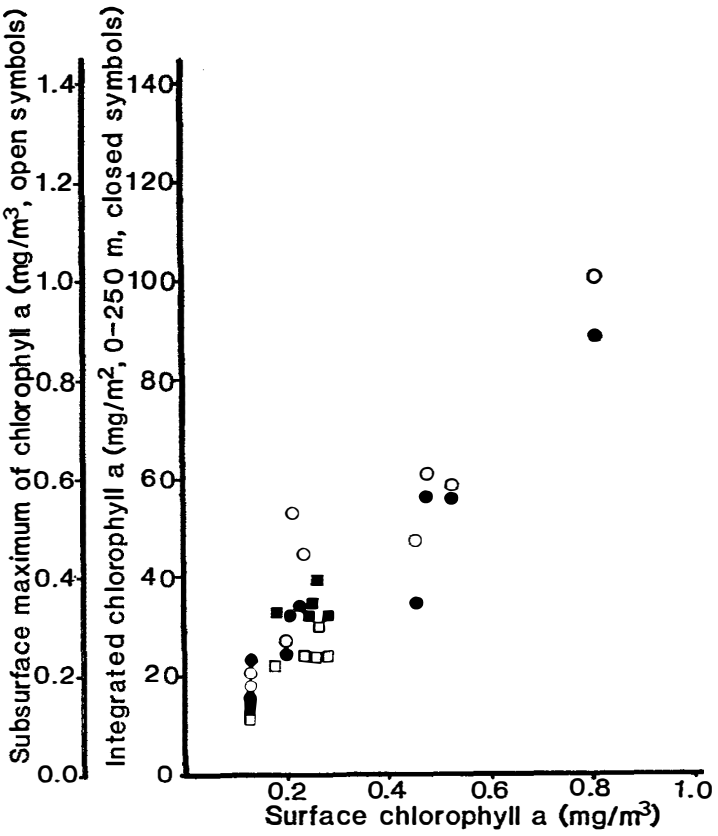

Fig. 6. Relationships of integrated chlorophyll a stocks in a 0–250 m water column or subsurface maximum of chlorophyll a against surface chlorophyll a concentrations. Square and circle symbols indicate the present results and those of KURODA and FUKUCHI (1982), respectively.

50°E, where pack ice is usually distributed. High concentrations in this area might be associated with the distribution of the so-called ice algae. Therefore, the chlorophyll *a* concentrations in this area can not be compared directly with the other data obtained in the open waters.

Integrated chlorophyll *a* stocks for a 0–250 m water column obtained from the present six stations (16.8–39.4 mg/m^2) are within the range reported by KURODA and FUKUCHI (1982) from the Indian Antarctic water in late February–early March (17–89 mg/m^2). HOLM-HANSEN *et al.* (1977) reported that the integrated stocks for a 0–200 m water column were 10.6–30.8 (mean: 21.8) mg/m^2 in November–January, 0.7–16.9 (mean: 6.7) mg/m^2 in January–February, and 13.3–15.2 (mean: 14.2) mg/m^2 in March–May in the Antarctic Ocean south of the AC. The integrated chlorophyll *a* stocks in a 0–250 m water column and the subsurface maximum of chlorophyll *a* concentrations obtained in the present work are plotted against the surface chlorophyll concentrations together with the data reported by KURODA and FUKUCHI (1982) (Fig. 6). Their data were obtained from the Subtropical, Subantarctic and Antarctic waters. Positive correlations among these values support the opinion stated by KURODA and FUKUCHI (1982), "surface concentrations may be a good expedient for evaluating the chlorophyll *a* stocks in the subsurface layer."

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Appendix 1. Data on surface chlorophyll a concentrations and water temperature observed aboard the FUJI toward Syowa Station, Antarctica, in 1978–1979.

STATION NO.	DATE	TIME	LATITUDE	LONGITUDE	CHLOROPHYLL-A	WATER TEMP.
1	1978 NOV. 26	0800	32 15 N	138 12 E	0.24	23.2
2		1200	31 39	137 50	0.43	21.8
3		1800	30 41	137 14	0.75	21.5
4	27	0800	28 29	136 9	0.17	24.6
5		1200	27 47	135 50	0.08	25.3
6		1800	26 38	135 16	0.10	25.1
7	28	0800	23 59	133 58	0.04	25.2
8		1200	23 12	133 33	0.14	24.5
9		1800	22 6	132 54	0.04	26.3
10	29	0800	19 26	131 54	0.07	27.6
11		1200	18 40	131 31	0.07	27.5
12		1800	17 34	130 54	0.05	26.8
13	30	0800	14 54	129 48	0.08	27.7
14		1200	14 8	129 29	0.05	27.9
15		1700	13 12	129 3	0.05	28.2
16	DEC. 1	0800	10 9	127 53	0.03	28.4
17		1200	9 20	127 20	0.03	28.3
18		1800	8 8	126 57	0.03	28.1
19	2	0800	5 11	125 33	0.33	27.9
20		1200	4 34	124 50	0.02	28.4
21		1700	3 53	123 54	0.11	28.5
22	3	0800	2 9	121 31	0.31	28.7
23		1200	1 45	120 54	0.32	28.7
24		1800	1 4	119 58	0.22	28.8
25	4	0800	1 41 S	118 53	0.15	29.1
26		1200	2 34	118 38	0.29	29.4
27		1800	3 48	118 7	0.17	29.6
28	5	0800	6 39	116 35	0.46	29.6
29		1200	7 29	116 15	0.49	28.8
30		1800	8 45	115 45	0.52	28.0
31	6	0800	11 60	114 50	0.06	28.8
32		1200	12 58	114 47	0.10	29.1
33		1800	14 22	114 27	0.06	29.1
34	7	0800	17 44	113 51	0.06	26.9
35		1200	18 38	113 40	0.06	25.8
36		1800	20 1	113 26	0.04	25.5
37	8	0800	23 13	112 54	0.09	23.8
38		1200	24 1	112 46	0.17	23.8
39		1800	25 12	112 30	0.33	22.6
40	9	0800	27 56	112 59	0.12	22.2

Appendix 1 (continued).

STATION NO.	DATE	TIME	LATITUDE	LONGITUDE	CHLOROPHYLL-A	WATER TEMP.
41	DEC. 9	1200	28 41 S	113 12 E	0.09	22.3
42		1800	29 46	113 51	0.08	21.3
FREMANTLE						
43	15	1800	32 45	114 26	0.10	20.8
44	16	0800	34 20	111 45	0.07	18.2
45		1000	34 31	111 18	0.07	17.6
46		1200	34 43	110 52	0.10	17.4
47		1400	34 55	110 29	0.10	17.4
48		1600	35 7	110 6	0.09	17.6
49		1800	35 20	109 52	0.07	17.7
50		2000	35 43	109 51	0.08	17.8
51		2200	36 4	110 0	0.08	17.8
52	17	0000	36 27	110 9	0.08	17.6
53		0200	36 49	110 16	0.10	17.3
54		0400	37 11	110 22	0.11	16.9
55		0600	37 35	110 18	0.07	17.4
56		0800	37 58	110 7	0.27	15.6
57		1000	38 21	109 57	0.17	15.4
58		1200	38 43	109 49	0.09	15.6
59		1400	39 5	109 35	0.15	15.5
60		1600	39 27	109 21	0.30	14.7
61		1800	39 47	109 11	0.19	14.2
62		2000	40 10	109 2	0.14	14.9
63		2200	40 35	109 2	0.11	14.8
64	18	0000	40 59	109 2	0.11	15.2
65		0200	41 24	109 0	0.11	14.8
66		0400	41 48	108 60	0.13	14.5
67		0600	42 11	108 57	0.13	14.6
68		0800	42 35	108 55	0.13	13.8
69		1000	43 1	108 54	0.13	14.0
70		1200	43 27	108 54	0.16	13.8
71		1400	43 52	108 53	0.09	13.4
72		1600	44 17	108 51	0.14	12.7
73		1800	44 39	108 42	0.12	12.3
74		2000	45 2	108 31	0.15	12.3
75		2200	45 26	108 21	0.15	11.1
76	19	0000	45 51	108 9	0.11	9.9
77		0200	46 11	107 56	0.12	9.7
78		0400	46 32	107 44	0.19	11.0
79		0600	46 53	107 33	0.18	11.3
80		0800	47 15	107 22	0.13	9.3

Appendix 1 (continued).

STATION NO.	DATE	TIME	LATITUDE	LONGITUDE	CHLOROPHYLL-A	WATER TEMP.
81	DEC. 19	1000	47 38 S	107 13 E	0.13	9.2
82		1200	48 1	106 59	0.11	7.4
83		1400	48 25	106 51	0.06	7.3
84		1600	48 47	106 40	0.09	7.6
85		1800	49 9	106 26	0.10	7.2
86		2000	49 31	106 9	0.10	6.2
87		2200	49 51	105 51	0.07	6.3
88	20	0000	50 12	105 32	0.29	5.9
89		0200	50 33	105 13	0.48	5.6
90		0400	50 54	104 54	0.15	4.9
91		0600	51 14	104 35	0.28	4.9
92		0800	51 34	104 16	0.32	5.1
93		1000	51 54	103 58	1.29	4.8
94		1200	52 13	103 44	1.46	3.9
95		1400	52 32	103 26	1.33	3.7
96		1600	52 52	103 9	1.20	2.7
97		1800	53 12	102 49	1.05	2.9
98		2000	53 33	102 28	1.55	3.5
99		2200	53 53	102 7	1.06	1.8
100	21	0000	54 13	101 51	0.93	1.7
101		0200	54 33	101 27	1.00	1.9
102		0400	54 54	101 8	1.46	2.5
103		0600	55 15	100 50	1.15	1.9
104		0800	55 35	100 29	0.55	1.5
105		1000	55 55	100 10	0.42	1.2
106		1200	56 14	99 49	0.47	0.8
107		1400	56 35	99 30	0.81	1.9
108		1600	56 51	98 56	0.67	1.8
109		1800	57 6	98 21	0.88	2.2
110		2000	57 22	97 44	1.27	2.5
111		2200	57 38	97 8	0.48	1.5
112	22	0000	58 2	96 14	0.52	0.7
113		0200	58 18	95 40	0.50	1.0
114		0400	58 34	95 4	0.61	0.5
115		0600	58 48	94 26	0.62	0.7
116		0800	58 59	93 42	1.02	0.8
117		1000	59 12	93 5	0.76	0.5
118		1200	59 25	92 26	0.65	0.1
119		1400	59 37	91 46	0.71	0.8
120		1600	59 49	91 7	0.59	0.6

Appendix 1 (continued).

STATION NO.	DATE	TIME	LATITUDE	LONGITUDE	CHLOROPHYLL-A	WATER TEMP.
121	DEC. 22	1800	60 0 S	90 25 E	0.68	0.7
122		2000	60 11	89 42	0.87	0.8
123		2200	60 22	88 59	1.05	0.8
124	23	0800	61 20	85 23	1.28	-0.4
125		1200	61 42	83 55	0.69	-0.1
126		1800	62 13	81 38	0.81	0.3
127	24	0800	63 20	75 38	0.20	0.0
128		1200	63 35	73 55	0.36	0.1
129		1800	64 2	71 17	0.21	0.1
130	25	0800	64 43	64 18	0.29	-0.2
131		1200	64 49	62 25	0.76	-0.2
132		1800	64 58	59 28	0.23	0.1
133	26	0800	65 21	52 43	0.67	-0.7
134		1200	65 30	50 48	2.03	-0.8
135		2325	65 39	49 29	2.13	-1.7
136	27	0800	66 11	46 16	1.46	-1.5
137		1200	66 7	45 45	1.36	-1.5
138		1600	66 13	44 33	1.03	-1.6
139		1800	66 21	44 1	0.70	-1.6
140	28	0000	66 42	42 57	1.35	-1.7
141		0800	67 10	41 57	0.58	-1.6
142		1200	67 24	41 17	0.41	-1.7
143	29	1200	67 53	40 46	0.45	-1.5
144		1400	67 59	40 52	0.56	-0.6
145		1600	68 5	40 44	0.33	-0.9
146	1979 JAN. 3	1500	68 4	40 46	0.24	-1.5
147		1800	68 13	39 31	0.21	-1.7
148	12	1030	68 16	39 13	0.03	-1.3
ICE EDGE OFF SYOWA STATION						
149	27	2200	68 20	39 21	0.10	-0.8
150	FEB. 19	1800	68 17	39 33	0.72	-1.6
151	24	1200	64 43	40 52	0.14	1.5
152	25	0000	63 37	40 21	0.13	2.2
153		1200	61 52	39 58	0.28	2.4
154	26	0000	60 36	40 9	0.40	2.5
155		1200	58 46	40 17	0.25	2.5
156	27	0000	57 25	40 21	0.25	2.4
157		0800	56 7	40 23	0.25	2.8
158	28	0000	55 47	41 22	0.17	2.6
159		1200	55 4	43 2	0.17	2.8
160	MAR. 1	0000	53 53	43 10	0.23	3.0

Appendix 1 (continued).

STATION NO.	DATE	TIME	LATITUDE	LONGITUDE	CHLOROPHYLL-A	WATER TEMP.
161	MAR. 1	0200	53 35 S	43 12 E	0.24	3.2
162		0400	53 18	43 13	0.19	3.0
163		0600	52 59	43 13	0.21	3.1
164		0800	52 42	43 14	0.23	3.2
165		1000	52 26	43 16	0.26	3.8
166		1200	52 9	43 16	0.27	3.9
167		1600	51 56	43 22	0.29	3.9
168		1800	51 29	43 33	0.28	4.0
169		2000	51 3	43 46	0.26	4.2
170		2200	50 49	43 53	0.20	4.6
171	2	1700	49 2	44 36	0.18	5.0
172		2000	48 30	44 47	0.19	5.1
173		2200	48 7	44 55	0.21	5.5
174	3	0000	47 43	45 3	0.19	5.3
175		0200	47 17	45 12	0.22	5.7
176		0400	46 52	45 21	0.24	6.4
177		0600	46 28	45 28	0.20	7.3
178		0800	46 1	45 34	0.31	7.5
179		1000	45 33	45 40	0.32	7.3
180		1200	45 5	45 57	0.21	8.4
181		1400	44 37	46 12	0.23	7.4
182		1600	44 10	46 26	0.32	7.9
183		1800	43 42	46 41	0.22	7.7
184		2000	43 13	46 59	0.12	7.8
185		2200	42 44	47 16	0.18	10.5
186	4	0000	42 15	47 33	0.61	12.2
187		0200	41 46	47 50	0.86	14.2
188		0400	41 17	48 8	0.85	16.6
189		0600	40 47	48 25	0.91	16.4
190		0800	40 18	48 39	0.89	15.6
191		1000	39 49	48 54	0.66	16.2
192		1200	39 21	49 8	0.62	15.2
193		1400	38 52	49 24	0.64	15.6
194		1600	38 23	49 39	0.28	18.8
195		1800	37 54	49 55	0.10	20.1
196		2000	37 25	50 11	0.06	20.1
197		2200	36 56	50 26	0.05	20.3
198	5	0000	36 27	50 41	0.03	21.3
199		0800	34 34	51 38	0.04	21.3
200		1200	33 35	51 47	0.04	21.4

Appendix 1 (continued).

STATION NO.	DATE	TIME	LATITUDE	LONGITUDE	CHLOROPHYLL-A	WATER TEMP.
201	MAR. 5	1800	32 17 S	52 27 E	0.05	24.7
202	6	0800	29 16	53 48	0.05	25.2
203		1200	28 28	54 6	0.03	25.0
204		1800	27 15	54 39	0.06	26.6
205	7	0800	24 26	55 53	0.04	26.4
206		1200	23 41	56 6	0.03	26.8
207		1800	22 37	56 28	0.06	27.2
208	17	0800	17 45	60 58	0.05	27.9
209		1800	16 41	62 28	0.02	28.3
210	18	0800	15 6	64 43	0.04	28.0
211		1800	14 0	66 9	0.01	29.0
212	19	0800	12 40	68 12	0.03	28.9
213		1800	11 38	69 39	0.02	28.8
214	20	0800	10 5	71 43	0.03	28.5
215		1800	9 1	73 16	0.02	28.7
216	21	0800	7 21	75 34	0.06	28.6
217		1800	6 15	77 9	0.05	29.1
218	22	0800	4 36	79 29	0.05	29.2
219		1800	3 23	81 7	0.04	30.5
220	23	0800	1 50	83 30	0.03	29.5
221		1800	0 46	84 57	0.01	30.3
222	24	0800	0 53 N	87 13	0.06	30.4
223		1800	2 6	88 45	0.03	30.6
224	25	0800	3 39	90 51	0.04	30.2
225		1800	4 39	92 21	0.09	29.8
226	26	0800	5 57	94 40	0.15	30.0
227		1800	6 8	96 20	0.08	29.9
228	27	0800	5 2	98 49	0.18	29.8
229		1500	4 24	99 48	0.24	30.5
230	30	0800	3 17	100 32	0.40	30.0
231		1800	2 24	101 41	0.61	29.9
SINGAPORE						
232	APR. 9	0800	2 45	107 58	0.05	29.8
233		1800	4 27	109 2	0.01	30.1
234	10	0800	6 57	110 23	0.01	29.0
235		1800	8 43	111 21	0.05	29.4
236	11	0800	11 10	112 59	0.07	29.3
237		1800	11 17	113 8	0.05	29.3
238	12	0800	14 54	115 59	0.07	28.2
239		1800	16 7	117 29	0.06	29.0
240	13	0800	18 3	119 44	0.08	27.9
241	13	1800	19 29	121 32	0.11	27.0

Appendix 2. Data on chlorophyll a, phaeophytin and pigment ratio observed at six stations of vertical observations in the Indian sector of the Antarctic Ocean in 1979.

Station No.	Date	Position	Depth (m)	Chl. *a* (mg/m³)	Phaeo. (mg/m³)	Pigment ratio (%)
151	1979	64°43′S	0	0.15	1.59	8.6
	Feb. 24	40°52′E	10	0.08	2.00	3.8
			19	0.09	2.14	4.0
			29	0.06	2.39	2.4
			48	0.07	1.73	3.9
			72	0.07	2.83	2.4
			96	0.11	2.77	3.8
			120	0.09	2.43	3.6
			143	0.05	2.17	3.9
			190	0.06	3.22	1.8
			237	0.03	2.90	1.0
			284	0.03	3.01	1.0
			377	0.09	2.70	3.2
153	Feb. 25	61°52′S	0	0.25	2.90	7.9
		39°58′E	10	0.16	2.87	5.3
			20	0.19	4.70	3.9
			29	0.18	2.37	7.1
			49	0.24	2.71	8.1
			73	0.26	3.55	6.8
			97	0.17	3.21	5.0
			122	0.09	3.85	2.3
			147	0.06	2.52	2.3
			196	0.04	2.87	1.4
			245	0.07	5.89	1.2
			294	0.04	4.44	0.9
			392	0.04	2.67	1.5
			490	0.11	6.85	1.6
155	Feb. 26	58°46′S	0	0.22	1.55	12.4
		40°17′E	10	0.17	3.98	4.1
			19	0.19	5.64	3.3
			29	0.19	4.63	3.9
			48	0.16	3.03	5.0
			72	0.24	3.76	6.0
			96	0.15	5.09	2.9
			120	0.13	3.31	3.8
			144	0.06	3.62	1.6
			240	0.13	7.35	1.7
			288	0.07	4.63	1.5
			384	0.03	2.27	1.3

Appendix 2 (continued).

Station No.	Date	Position	Depth (m)	Chl. *a* (mg/m³)	Phaeo. (mg/m³)	Pigment ratio (%)
157	1979	56°07′S	0	0.23	1.93	10.6
	Feb. 27	40°23′E	9	0.16	3.40	4.5
			19	0.18	4.10	4.2
			28	0.20	5.64	3.4
			46	0.16	2.43	6.2
			69	0.24	4.40	5.2
			92	0.16	4.41	3.5
			115	0.09	4.14	2.1
			137	0.13	3.37	3.7
			183	0.08	3.13	2.5
			228	0.06	4.42	1.3
			273	0.08	2.53	3.1
			363	0.04	2.55	1.5
			453	0.08	3.36	2.3
159	Feb. 28	55°13′S	0	0.17	1.77	8.8
		43°07′E	8	0.14	3.31	4.1
			16	0.12	3.56	3.3
			23	0.12	3.36	3.4
			39	0.17	5.33	3.1
			58	0.18	4.65	3.7
			71	0.22	5.36	3.9
			88	0.19	2.12	8.2
			106	0.19	4.10	4.4
			141	0.12	5.42	2.2
			176	0.12	6.22	1.9
			211	0.05	4.80	1.0
			279	0.07	5.82	1.2
			341	0.07	4.63	1.5
166	Mar. 1	52°01′S	0	0.27	2.17	11.1
		43°17′E	9	0.23	3.56	6.1
			18	0.17	3.57	4.5
			27	0.28	6.94	3.9
			45	0.30	6.41	4.5
			68	0.24	3.94	5.7
			91	0.25	2.81	8.2
			113	0.17	4.86	3.4
			135	0.10	2.90	3.3
			179	0.07	3.61	1.9
			224	0.07	4.50	1.5
			268	0.05	2.19	2.2
			356	0.04	2.93	1.3
			439	0.06	3.53	1.7