—研究ノート—
Scientific Note

The Surface Distributions of Nutrients and Chlorophyll *a* in the Area between 90°W and 20°E of the Antarctic Ocean and Adjacent Seas*

Fukashi FUKUI**, Nobuyuki KADOYA***, Shiro OKABE***
and Yuzo KOMAKI****

西経 90° から東経 20° に至る南極海および周辺海域における栄養塩とクロロフィル *a* の表面分布*

福井　深**・角谷伸之***・岡部史郎***・小牧勇蔵****

要旨: BIOMASS 研究観測 (SIBEX II) の一環として，開洋丸による調査を1984年11-12月および1985年1月に実施し，西経90度から東経20度に至る南極海および周辺海域の表面水の栄養塩およびクロロフィル *a* を測定した．栄養塩およびクロロフィル *a* 平均濃度は亜熱帯海域から南極海へ南下するに従い増加した．南極海の地域的な濃度変化はリン酸塩と硝酸塩が少なく，ケイ酸塩は大きい．ケイ酸塩(71±7 μM)の高い値がウェッデル海で得られ，また，Si : N : P の原子比は 44 : 16 : 1 となった．これらの高いケイ酸塩は深層水の湧昇に起因していると推定された．

Abstract: The surface distributions of chlorophyll *a* and nutrients were observed in the area between 90°W and 20°E of the Antarctic Ocean and adjacent seas in November and December 1984, and in January 1985, by R. V. KAIYO MARU as part of the national BIOMASS (SIBEX II) program. The mean concentrations of inorganic nutrients and chlorophyll *a* increase towared south from the Subtropical region to the Antarctic Ocean. Regional changes of phosphate and nitrate concentrations in the Antarctic water were small while those of silicate were large. High concentration of silicate (71±7 μM) was found in the Weddell Sea, and the average atomic ratio of Si : N : P was 44 : 16 : 1. These high silicates may have resulted by upwelling from the deep water.

1. Introduction

During the cruise SIBEX II (Second International BIOMASS Experiment, Phase Two) of the R.V. KAIYO MARU in November–December of 1984 and January of 1985, physical, chemical and biological studies were carried out in the eastern South Pacific Ocean, Eastern Drake Passage, Bellingshausen, Scotia, Weddell and Lazarev Seas. Measurements of nutrient matter and/or chlorophyll *a* in these areas were previously done by BURKHOLDER and SIEBURTH (1961), EL-SAYED *et al.* (1964), SAIJO and KAWASHIMA (1964), EL-SAYED and TAGUCHI (1981), and LIPSKI (1982). However, either of

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** 清水市生活環境部. Environmental Division of Shimizu City, 6–8, Asahicho, Shimizu 424.
*** 東海大学海洋学部. Faculty of Marine Science and Technology Tokai University, 20–1, Orido 3-chome, Shimizu 424.
**** 遠洋水産研究所. Far Seas Fisheries Research Laboratory, 7–1, Orido 5-chome, Shimizu 424.

them dealt with the meso-scale phenomena for each of the areas. Also, large-scale investigation from the Subtropical to Antarctic waters in the southeastern Pacific and Atlantic Oceans has not been yet reported. The present paper discusses the surface distributions of nutrients and chlorophyll *a* in connection with the meso- and macro-scale viewpoints.

2. Materials and Methods

The survey lines (A–D, D′–F) of the cruise are shown in Fig. 1 with the locations of sampling stations. Serial numbers are applied to stations for convenience in this paper independent of the definite numbers given to the stations in the KAIYO MARU's Cruise Report (SUISANCHÔ, 1986). The outlines of these lines are summarized in Table 1. The surface water was sampled by a plastic bucket, salinity was measured with a salinometer (Auto Lab 60 MK III). and dissolved oxygen was determined by the Winkler's method. Nitrate+nitrite was analyzed by the method of GRASSHOFF (1983) with modifications for auto analyzer measurement. Other inorganic nutrients were determined as follows: Phosphate by MURPHY and RILEY (1962), Silicate by TUNG-WHEI CHOW and ROBINSON (1953), Nitrite by BENDSCHNEIDER and ROBINSON (1952), and

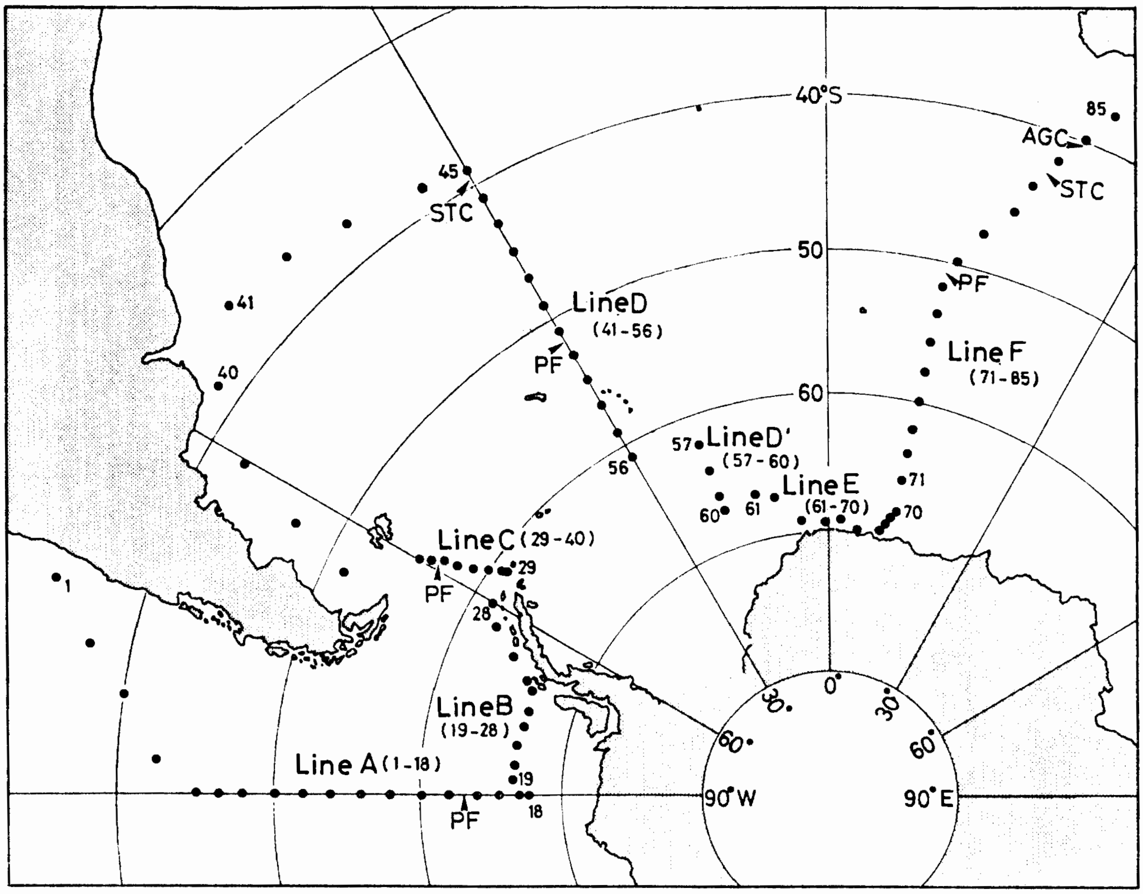

Fig. 1. Stations of surface observations during the cruise of the R. V. KAIYO MARU (SIBEX-II: 1984/85). Numerals indicate the serial station number. Triangles indicate approximate locations of Subtropical Convergence (STC), Agulhas Convergence (AGC) and Polar Front (PF).

Table 1. List of the stations for the surface observations during the cruise SIBEX II (1984/85) of the R.V. KAIYO MARU.

Line Name	A	B	C	D
Region	Southwestern Pacific	Bellingshausen Sea	Eastern Drake Passage	South Atlantic Soctia Sea
Survey area	along 90°W (35°–67°S) 34°S74W–44°S90°W	between 90°W and Eastern Drake Passage	Eastern Drake Passage 38°S 56°W	along 30°W (35°–61°S)
Date	23 Nov.–5 Dec.	6 Dec.–13 Dec.	13 Dec.–21 Dec.	30 Dec. '84–12 Jan. '85
Stn. No.	1–18	19–28	29–40	41–56

Line name	D′	E	F
Region	Weddell Sea	Lazarev Sea	Southeastern Atlantic
Survey area	along 20°W (62°–67°S)	between 20°W and 12.5°E	along 12.5°E (67°–38°S)
Date	13 Jan.–15 Jan.	16 Jan.–22 Jan.	22 Jan–28 Jan.
Stn. No.	57–60	61–70	71–85

Ammonia by KOROLEFF (1983). The colorimetric analyses were done on board using two spectrophotometers of Shimadzu Model UV-150-02 and Hirama Model 6B. Chlorophyll *a* was determined by the fluorometrical method with a Turner Model-III fluorometer after extraction with 90% acetone (STRICKLAND and PARSONS, 1972).

3. Results and Discussion

3.1. Surface distribution of physical parameters

Changes of nutrients and chlorophyll *a* as well as oceanographic parameters on seven lines are shown in Fig. 2 and the average figures of these in three water masses, *i.e.* Subtropical (north of Subtropical Convergence: STC), Subantractic (between STC and polar front: PF) and Antarctic (south of PF) waters, are summarized in Table 2. Positions of STC and PF were roughly recognized based on the analyses of thermo-salinograph records, XBT and nutrients. On the southward lines, PF on lines A (along 90°W) and D (along 30°W) was located around 62°S (Stns. 14–15) and 51°S (Stns. 51–52), respectively, and STC on line D was located around 39°S (Stns. 45–46). On the northward line, PF of lines C (eastern Drake Passage) and F (along 12.5°E) was located between 56°50′–56°40′S (Stns. 34–35) and around 52°S (Stns. 78–79), respectively, and STC on line F was located around 44°S (Stns. 82–83). Locations of these fronts (Figs. 1 and 2) are somewhat similar to those reported by DEACON (1982). Moreover, in the south of Africa, the Agulhas Convergence (AGC) was recognized around only a few latitudinal degrees north of the STC as stated by FUKASE (1962) and TANIGUCHI *et al.* (1986). This convergence may be located around 40°S (Stns. 83–84), as indicated by temperature increase of *ca.* 6°C.

The largest changes of physical parameters in the eastern Drake Passage (line C) were observed around PF, and skipping values of temperature and salinity were 3.7°C (6.5–2.8°C) and 0.33 (34.141–33.811), respectively. EL-SAYED *et al.* (1964) reported the marked decrease from 5.0 to 2.2°C around 58°S. Temperature difference in the

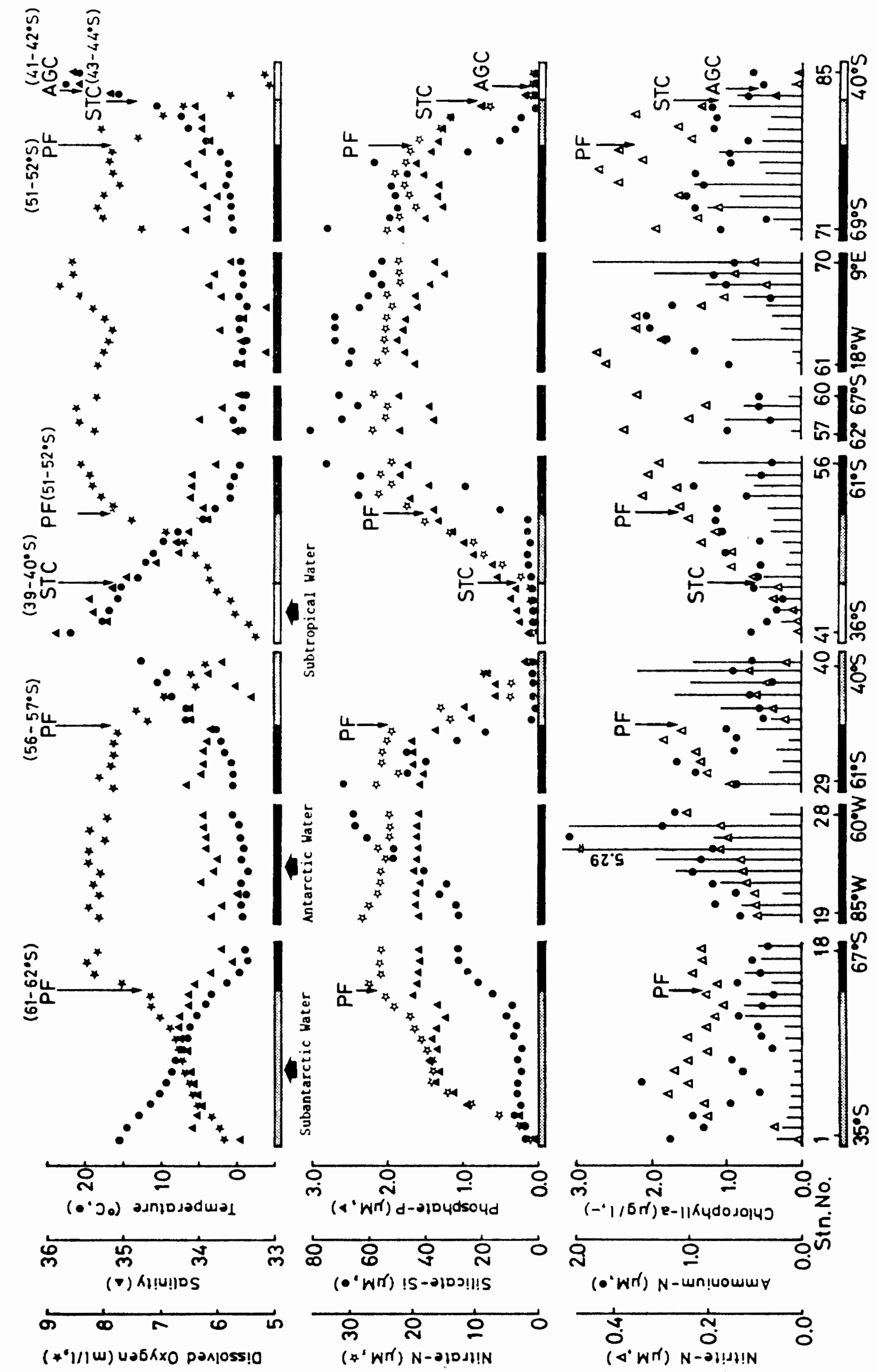

Fig. 2. Distribution of surface temperature, salinity, dissolved oxygen, inorganic nutrients and chlorophyll *a* along seven lines in the Antarctic Ocean and adjacent seas.

Table 2. Means and standard deviations of surface nutrients and chlorophyll a for

Line Name	A	B	C
Parameters	Southweastern Pacific (Along 90°W) Mean±S.D. (n)	Bellingshausen Sea (90°W-E.D.P.) Mean±S.D. (n)	Eastern Drake Pasage Mean±S.D. (n)
Water Temp. (°C)			
Salinity			
Dissolved Oxygen (m*l*/*l*)			
Phosphate (μM)			
Silicate (μM)			
Nitrate (μM)			
Nitrite (μM)			
Ammonia (μM)			
Chlorophyll *a* (μg/*l*)			
Water Temp. (°C)	8.8 ±3.7 (14)		9.3 ±2.3 (6)
Salinity	34.07±0.22 (13)		33.77±0.33 (6)
Dissolved Oxygen (m*l*/*l*)	6.59±0.44 (14)		0.88±0.45 (6)
Phosphate (μM)	1.08±0.52 (14)		0.64±0.28 (6)
Silicate (μM)	8±3 (14)		2±1 (6)
Nitrate (μM)	15.1 ±7.1 (14)		8.4 ±6.1 (6)
Nitrite (μM)	0.19±0.08 (14)		0.07±0.04 (6)
Ammonia (μM)	$0.6_2 \pm 0.3_6$ (14)		$0.3_9 \pm 0.1_2$ (6)
Chlorophyll *a* (μg/*l*)	0.29±0.25 (14)		1.37±0.60 (6)
Water Temp. (°C)	−0.4 ±1.2 (4)	−0.6 ±0.6 (10)	1.4 ±0.9 (6)
Salinity	33.77±0.21 (4)	33.81±0.14 (10)	33.94±0.11 (6)
Dissolved Oxygen (m*l*/*l*)	8.14±0.28 (4)	8.20±0.12 (10)	7.95±0.13 (6)
Phosphate (μM)	1.58±0.02 (4)	1.59±0.02 (10)	1.58±0.12 (6)
Silicate (μM)	26±3 (4)	46±15 (10)	42±17 (6)
Nitrate (μM)	26.0 ±0.5 (4)	25.5 ±1.5 (10)	24.8 ±1.2 (6)
Nitrite (μM)	0.21±0.03 (4)	0.14±0.04 (10)	0.23±0.05 (6)
Ammonia (μM)	$0.4_1 \pm 0.1_2$ (4)	$1.1_4 \pm 0.4_6$ (10)	$0.7_6 \pm 0.2_2$ (6)
Chlorophyll *a* (μg/*l*)	0.56±0.15 (4)	1.61±1.15 (10)	0.43±0.29 (6)

eastern Drake Passage in the present results (southward decrease from 6.5 to 2.8°C) was larger than that reported by of EL-SAYED *et al.* (1964). The width of PF in the eastern Drake Passage was only about 11 km (estimated from continuous measurement data) latitudinally and it seems to be narrower than that oo the other lines. Surface temperature and salinity generally decreased southward to the PF (Figs. 2 and 3), but salinity on line A (long 90°W) gradually increased at PF. In the Antarctic water the ranges of temperature and salinity were −1.4–2.8°C and 33.103–34.178, respectively (Fig. 3). From the average figures of three water masses (Table 2), it is clear that *water masses along seven lines in the Antarctic Ocean and adjacent seas (1984–85).*

D	D′	E	F	
South Atlantic Scotia Sea (Along 30°W) Mean±S.D. (n)	Weddell Sea (Along 20°W) Mean±S.D. (n)	Lazarev Sea (20°W–12.5°E) Mean±S.D. (n)	Southeastern Atlantic (Along 12.5°E) Mean±S.D. (n)	Overall Means Mean±S.D. (n)
Subtropical Water				
17.4±2.6 (5)			19.6 ±3.5 (3)	18.2 ±3.0 (8)
35.40±0.29 (5)			35.47±0.19 (3)	35.42±0.25 (8)
5.69±0.27 (5)			5.32±0.37 (3)	5.56±0.34 (8)
0.26±0.09 (5)			0.10±0.07 (3)	0.20±0.11 (8)
2±1 (5)			3±1 (3)	3±1 (8)
0.6 ±0.6 (5)			0.0 (3)	0.4 ±0.6 (8)
0.02±0.03 (5)			0.02±0.03 (3)	0.02±0.03 (8)
$0.3_1 \pm 0.1_8$ (5)			$0.4_2 \pm 0.0_7$ (3)	$0.3_5 \pm 0.1_2$ (8)
0.31±0.19 (5)			0.34±0.42 (3)	0.32±0.26 (8)
Subantarctic Water				
9.7 ±3.2 (6)			7.1 ±2.6 (4)	9.0 ±3.4 (30)
34.35±0.37 (6)			34.00±0.21 (4)	34.05±0.32 (29)
6.67±0.53 (6)			7.27±0.70 (4)	6.74±0.53 (30)
0.91±0.30 (6)			1.12±0.27 (4)	0.96±0.44 (30)
4±1 (6)			8±5 (4)	6±4 (30)
10.5 ±5.6 (6)			14.6 ±4.5 (4)	12.7 ±6.7 (30)
0.17±0.05 (6)			0.27±0.06 (4)	0.17±0.08 (30)
$0.5_5 \pm 0.1_9$ (6)			$0.7_0 \pm 0.1_5$ (4)	$0.5_7 \pm 0.2_8$ (30)
0.30±0.16 (6)			0.57±0.28 (4)	0.55±0.54 (30)
Antarctic Water				
0.7 ±1.2 (5)	−0.6 ±0.5 (4)	−0.6 ±0.5 (10)	1.0 ±0.6 (8)	0.1 ±1.1 (47)
33.99±0.14 (5)	33.64±0.24 (4)	33.52±0.27 (10)	33.97±0.16 (8)	33.79±0.25 (47)
8.21±0.21 (5)	8.31±0.19 (4)	8.28±0.34 (10)	7.87±0.22 (8)	8.13±0.27 (47)
1.63±0.18 (5)	1.61±0.23 (4)	1.61±0.20 (10)	1.48±0.17 (8)	1.58±0.15 (47)
49±28 (5)	71±7 (4)	64±7 (10)	51±14 (8)	51±18 (47)
23.7 ±1.5 (5)	25.5 ±1.5 (4)	23.9 ±1.3 (10)	21.8 ±1.6 (8)	24.3 ±1.9 (47)
0.30±0.04 (5)	0.29±0.09 (4)	0.25±0.13 (10)	0.31±0.09 (8)	0.24±0.10 (47)
$0.5_5 \pm 0.3_0$ (5)	$0.4_3 \pm 0.1_6$ (4)	$0.8_9 \pm 0.3_7$ (10)	$0.7_7 \pm 0.2_3$ (8)	$0.7_9 \pm 0.3_9$ (47)
0.76±0.35 (5)	0.49±0.41 (4)	0.89±0.88 (10)	0.76±0.45 (8)	0.89±0.92 (47)

temperature and salinity in the Antarctic water were lower than those in other northern water masses.

3.2. Surface distributions of dissolved oxygen, nutrients and chlorophyll *a*

3.2.1. Dissolved oxygen

The dissolved oxygen content on lines A, C, D and F gradually increased toward south in the area of the PF (Fig. 2). In the Bellingshausen Sea (line B), the dissolved oxygen content exceeded 8.0 m*l*/*l* and fluctuated slightly. The oxygen contents (8.3–

8.0 ml/l) at two stations near the South Shetland Islands (line B, Stns. 27 and 28) showed a fairly good agreement with that reported by WOJÉWODZKI *et al.* (1985), in spite of the seasonal difference between ours and theirs. The maximum concentartion (8.85 ml/l) throughout the present survey was found at Stn. 68 (line F) off the Princess Astrid Coast. This value was a little higher than such a highest value (8.79 ml/l) in EL-SAYED and MANDELLI (1965) from the surface water of the Scotia Sea. On line C, between Elephant Island and the Falkland Islands, the oxygen content tended to decrease gradually northwestward from 8.19 to 7.28 ml/l, and a marked stepwise decrease was observed between two stations (Stns. 34 and 35) on both sides of PF. EL-SAYED *et al.* (1964) and EL-SAYED and MANDELLI (1965) reported a decreasing tendency of dissolved oxygen contents agreeing with ours in the same and adjacent areas.

3.2.2. Phosphate

The phosphate content on line A (long 90°W) was as low as 0.21 μM around 40°S and it abruptly increased up to 0.93 μM near 42.5°S. In the Bellingshausen Sea (line B), phosphate contents more than 1.5 μM were observed uniformly. On the eastbound cruise track along the pack ice zone on lines B (Bellingshausen Sea) and E (Lazarev Sea), the phosphate concentrations higher than 1.60 μM were found on line E and these values on line E were higher than those observed on line B. TOKARCZYK *et al.* (1985a) reported that the surface phosphate concentration is uniform around 0.5 mg-at/m^3 in the north of the South Shetland Islands. This value is lower than ours obtained on line B. Latitudinal changes of phosphate in the eastern Drake Passage (line C) decreased from 1.38 down to 0.87 μM at the PF. However, no marked change of phosphate concentration at the PF was reported by EL-SAYED *et al.* (1964). In the Scotia and Weddell Seas (lines D and D′), the concentrations were more than 1.30 μM and fluctuated remarkably. In the same region, EL-SAYED *et al.* (1964) observed the high concentration of phosphate (1.71–2.69 μM). In the Antarctic waters along 12.5°E (line F), the concentration ranged between 1.25 and 1.80 μM, and it decreased to 0.18 μM toward the STC. Further, the phosphate content abruptly decreased to 0.04 μM at the Agulhas Convergence located north of STC.

3.2.3. Silicate

Silicate concentrations on line A were within the range of 5–10 μM from 35°S to the PF, and the value continued to increase from the PF into the Bellingshausen Sea. High value of 68 μM was observed at a station close to the Antarctic Peninsula. SZPIGANOWICZ *et al.* (1985) observed the silicate concentration between 30 and 50 mg-at/m^3 in the western area of the Antarctic Peninsula. EL-SAYED *et al.* (1964) reported that the concentration was 47.8 μg-at/l in the southern part of the Drake Passage near the South Shetland Islands. The highest concentration of 85.5 μg-at/l was observed in the southern part of the eastern Drake Passage near Elephant Island (EL-SAYED and MANDELLI, 1965). These results mean the relatively high silicate concentration has been observed on many occasions around the Antarctic Peninsula. The silicate content in the eastern Drake Passage (line C) decreased toward north from 19 in the south to 3 μM at the PF. Crossing the PF, the latitudinal changes of silicate contents were previously reported by EL-SAYED *et al.* (1964) in the central Drake Passage, 5.3–15.2 μg-at/l, and by EL-SAYED and MANDELLI (1965) in the eastern passage, 11.0–34.50 μg-at/l. On the contrary, no remarkable change of silicate was observed in the Drake Passage according to SIEVERS and NOWLIN, Jr. (1984). On line D (30°W), the silicate content tended to fluctuate in the following manner: it increased from 13 μM at the PF to the largest value, 64 μM at Stn. 53, then decreased down to 26 μM (Stn. 54) and increased once again toward the southernmost station (Stn. 65, 61°S). The silicate concentration in the Weddell Sea (line D′) was relatively higher (64–80 μM) in comparison with the previous reports (EL-SAYED and MANDELLI, 1965; EL-SAYED and TAGUCHI, 1981; MICHEL, 1984). Such high silicate contents as found at the stations on line D′ may indicate the influence of deep water which is intruding to the area from the South Orkney Islands area. The influence is also suggested in that the temperature minimum, lower than −1.0°C, was observed by XBT at the surface at each station on line D′. On the line F (12.5°E), the change of silicate content at the PF (11 μM; 25–14 μM) was smaller than that found in the region *ca.* 2° apart from the PF (23 μM; 25–58 μM). The concentration less than 5 μM was observed at STC and AGC.

3.2.4. Nitrate

Nitrate along lines A and D gradually increased to the south and its distribution pattern was the same the that of dissolved oxygen. The nitrate content was higher than 23 μM in the Bellingshausen Sea (line B). TOKARCZYK *et al.* (1985b) reporthted that the nitrate concentration ranged between 5 and 20 mg-at/m^3 in the north of King George Island. According to our data, nitrate concentrations on line B were relatively higher than those reported by TOKARCZYK *et al.* (1985a) and phosphate distribution pattern also showed the asme tendency. The concentration is nearly constant (23–26 μM) in the Antarctic water in the eastern Drake Passage (line C) and it decreased abruptly down to 14.8 μM at the PF and the north of it. The nitrate content along 30°W (line D) was 3.0 μM around the STC and it gradually increased up to 25.0 μM in the Antarctic region south of 55°S. The distribution of nitrate concentration more than 25.0 μM was the same as reported by MICHEL (1984). Longitudinal and latitudinal variations of nitrate concentration on lines D, D′, E and F showed the same pattern as phosphate.

3.2.5. Ammonia

The ammonia content of lines A, B and C ranged from 0.2_5 to 1.4_1 μM, from 0.5_8 to 2.1_0 μM and from 0.2_6 to 1.1_1 μM, respectively. High concentrations more than 1.0 μM were found in the Bellingshausen Sea waters close to the continent. The ammonia content fluctuated largely (0.1_5–0.9_5 μM) on lines D and D′. High concentrations ranging between 0.6 and 1.3_7 μM were found in the Lazarev Sea water (line E) which were similar to those in the Bellingshausen Sea (line B, 85°–60°W). BIGGS *et al.* (1985) reported the ammonia concentrations ranging between 0.5_0 and 1.3_5 μM, and they also pointed out that the highest ones were found in such areas as along the Ross Iceshelf and in open water 50 km from the pack ice. From those results, ammonia of high concentration is likely to be found near the land and the pack ice.

3.2.6. Chlorophyll *a*

Chlorophyll *a* contents along 90°W (line A) were within the range of 0.09–0.78 μg/*l* (Fig. 2). In the Bellingshausen Sea (line B), chlorophyll *a* fluctuated remarkably, and the highest value of 5.29 μg/*l* was observed near the pack ice zone at Stn. 25. LIPSKI (1982) found a high chlorophyll *a* concentration (4.19 μg/*l*) in the inshore water off the Antarctic Peninsula. High chlorophyll *a* concentrations were also reported in the pack ice waters and/or the coastal waters by MANDELLI and BURKHOLDER (1966), FUKUCHI *et al.* (1984) and SMITH and NELSON (1985). Between 51° and 38°S, on the extension of line C, the concentrations were higher than 1.0 $\mu g/l$ on the Argentine continental shelf water near the Falkland Islands. In the Argentine continental shelf waters, EL-SAYED (1967) reported a mean surface chlorophyll *a* value of 0.78 ± 1.19 mg/m^3 during his nine cruises (1962–1965) and the highest average chlorophyll *a* of 2.29 ± 3.27 mg/m^3 was recorded during his Cruise 4 (August 23–October 5, 1963). Chlorophyll *a* was within the range of 0.05 to 0.91 $\mu g/l$ in the Lazarev Sea (line E). According to the results obtained by SAIJO and KAWASHIMA (1964) in this region (59°–60°S, 15.5°W–10°E), the chlorophyll *a* concentrations ranged from 0.09 to 0.50 mg/m^3. The concentrations higher than 0.9 $\mu g/l$ were found north of the PF and around the STC on 12.5°E (line F). However, the concentration became lower in the rest of the Subtropical water north of the STC.

As seen from the mean chlorophyll *a* concentrations in Table 2, the contents of the Antarctic water were usualy more than 0.5 $\mu g/l$ except those in the eastern Drake Passage, and the highest mean value of 1.61 $\mu g/l$ was observed in the Bellingshausen Sea (line B). EL-SAYED (1967) reported that the mean chlorophyll *a* concentration was 0.36 $\mu g/l$ in the Drake Passage, and 1.33 $\mu g/l$ in the Bellingshausen Sea. His values agree with our results. According to FUKUCHI (1980), the mean surface chlorophyll *a* concentration from oceanic waters in the three sectors, *i.e.* Pacific, Atlantic and Indian sectors of the Antarctic Ocean, ranged from 0.12 to 0.42 $\mu g/l$ which were calculated on the data during routine observations of the Japanese Antarctic Research Expedition (JARE) from 1965 to 1976. Mean chlorophyll *a* concentrations calculated in the present study (0.89 $\mu g/l$) seem to be conciderably higher than those in the previous results.

3. 3. Characteristic of the Antarctic surface water

Of all stations in the Antarctic surface waters, the water temperature and salinity ranged -1.4–2.8°C and 33.103–34.136, respectively (Fig. 3). Based on the physical parameters, a regional distribution of water masses in the Antarctic suface waters was hardly detected.

The atomic ratios of N (NO_3) to P (PO_4) and Si (SiO_3) to P (PO_4) were calculated in the Antarctic waters of the seven survey lines (Table 3). MAEDA *et al.* (1985) and FUKUI *et al.* (1986) reported that the high biological activity induced the changes of nitrate to phosphate ratios. In the present results, the average nitrate to phosphate (N/P) ratios in these lines were relatively constant (14.6–16.4), and the ratios were comparably the same as thos in the non-blooming zone observed by FUKUI *et al.* (1986). Although the ratios of nitrate to phosphate on the seven survey lines were relatively constant, the ratio of silicate to phosphate was largely different from line to line. The highest ratio of silicate to phosphate (44.5) was observed along line D′ in the Weddell Sea. This may be attributed to a regional upwelling of deep water having high silicate concentration.

The statistical correlations among temperature, salinity, nutrients and chlorophyll *a* in the Antarctic surface waters are presented in Table 4. This correlation matrix emphasizes the highly significant positive correlation between phosphate and nitrate. Temperature shows a negative correlation with dissolved oxygen and nitrate, while a positive correlation to salinity. Ammonia exhibits week correlations with each of all seven components. TANIGUCHI *et al.* (1986) and FUKUCHI *et al.* (1986) reported close relationship of chlorophyll *a* to temperature based on data collected with a prototype of continuous measuring-recording system (on board the icebreaker SHIRASE), though they referred to no definite conclusions. According to the present results from the matrix of temperature and chlorophyll *a*, a weak negative correlation was found. On the other hand, ALLANSON *et al.* (1981) reported the strong correlation between potential primary production and chlorophyll *a* in the surface water. Thus, the statistical comparison among the components of physical, biological and chemical (nutrients) may be a usefull way to elucidate interrelationships among these elements.

In conclusion, dissolved oxygen, phosphate and nitrate concentrations within the Antarctic water changed regionally with a relatively small range on any of seven line (A–F). On the contrary, silicate, nitrite, ammonia and chlorophyll *a* fluctuated remarkably from place to place. The rather uniform distributions of dissolved oxygen,

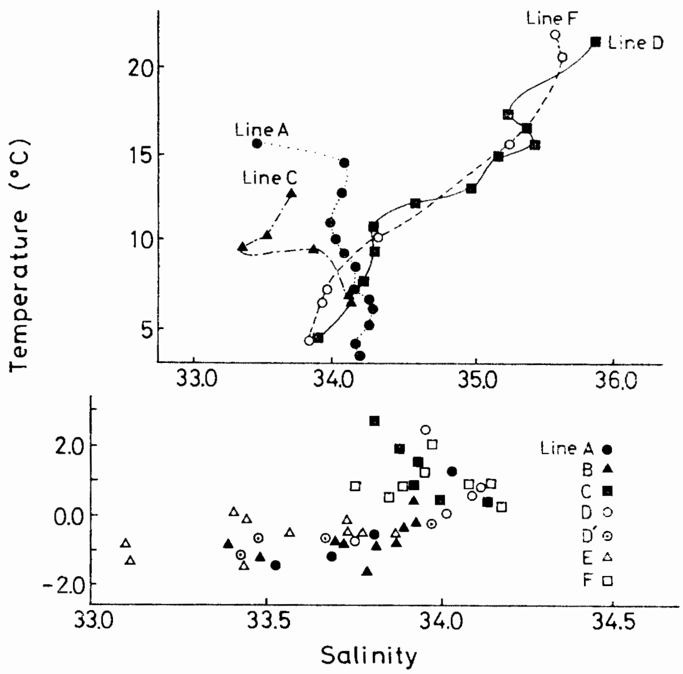

Fig. 3. Temperature-salinity diagrams in the surface waters along seven lines in the Antarctic Ocean and adjacent seas.

Table 3. The ratios of silicate to phosphate and nitrate to phosphate in different regions of the Antarctic water.

Line Name	Region	SiO_3/PO_4	NO_3/PO_4	Si : N : P
A	Southwestern Pacific	16.3± 2.0 (4)	16.4±0.2 (4)	16 : 16 : 1
B	Bellingshausen Sea	28.8± 9.5 (10)	16.0±0.9 (10)	29 : 16 : 1
C	Eastern Drake Pasage	26.3±10.8 (6)	15.7±1.1 (6)	26 : 16 : 1
D	South Atlantic Scotia Sea	28.7±14.8 (5)	14.6±0.9 (5)	29 : 15 : 1
D′	Wedell Sea	44.5± 4.4 (4)	16.0±1.4 (4)	44 : 16 : 1
E	Lazarev Sea	39.9± 2.7 (10)	15.0±1.4 (10)	40 : 15 : 1
F	Southeastern Atlantic	34.0± 7.4 (8)	14.9±0.9 (8)	34 : 15 : 1

Table 4. Correlation matrix for nine parameters measured in the surface waters of the Antarctic waters.

Temp.	Sal.	DO	PO_4	SiO_3	NO_3	NO_2	NH_4	Chl. *a*
Temp.	0. 577**	−0. 545**	−0. 329*	−0. 349*	−0. 420**	0. 333*	−0. 086	−0. 197
	Sal.	−0. 248	−0. 247	−0. 233	−0. 187	−0. 095	−0. 093	0. 118
		DO	−0. 244	0. 122	−0. 012	−0. 494**	−0. 225	0. 417**
			PO_4	0. 402**	0. 630**	0. 340*	0. 063	−0. 280
				SiO_3	−0. 009	0. 297*	0. 022	0. 052
					NO_3	−0. 123	0. 002	−0. 158
						NO_2	−0. 114	−0. 376**
							NH_4	0. 061
								Chl. *a*

n=47
* significant at P<0.05
** significant at P<0.01

phosphate and nitrate in the Antarctic water may have been influenced by upwelling. Moreover, the high concentration of silicate in the Weddell Sea may be reflecting a strong influence of deep water. While, nitrite concentration, together with ammonia and chlorophyll *a* may fluctuate with a wide range under the active biological processes during the austral summer.

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