

NOTE

## Oxygen-18 and Nutrients in the Surface Waters of the Bransfield Strait, Antarctica during Austral Summer 1990/91

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### 1990/91년 남극하계 브랜스필드 해협 표층해수의 $\delta^{18}\text{O}$ 와 영양염 분포

강동진<sup>1</sup> · 정창수<sup>1</sup> · 리쿠퍼<sup>2</sup> · 강천운<sup>1</sup> · 김예동<sup>1</sup> · 홍기훈<sup>1</sup>

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The oxygen isotope composition of surface waters in the Bransfield Strait was determined as one extra state variable in order to characterize water masses in the region, since salinity is significantly modified due to the freezing and ice-melting in the polar region. The salinity, temperature, and  $\delta^{18}\text{O}$  values vary from 34.0 to 34.5‰,  $-0.5$  to  $2.1^\circ\text{C}$  and  $-0.50$  to  $-0.26\text{‰}$ , respectively. The combined effects of evaporation, precipitation, freezing, ice-melting are reflected in the widely scattered data. Although it is small, the distribution of  $\delta^{18}\text{O}$  of the Bransfield Strait is strongly affected by the freezing-ice melting rather than the evaporation-precipitation. The ice melted fresh water which has higher temperature, depleted salinity and nutrients may be injected to the Bransfield Strait from the north. The concentrations of nutrients are decreasing gradually from the north to the south. The waters were characterized by two groups of higher (about 19.4) and lower N/P ratio (about 16.7). The lower N/P ratio is found in the northern part where ice-melted fresh water is injected, and the higher N/P ratio is found in the southern part of the Bransfield Strait.

Although more precise work is needed, the difference of N/P ratio can be an evidence of the ice melted water injection to the Bransfield Strait. Chlorophyll *a* concentrations, in general, increase from northwest (Weddell Sea) to the southeast (Smith and Hosseason Islands). Probably the injection of nutrient depleted fresh water from the ice melting reduce the chlorophyll *a* concentration.

남극 브랜스필드 해협의 표층 수괴 특성을 파악하기 위하여 수온, 염분 및 영양염류와 더불어 결빙이나 해빙의 영향을 받지 않는 산소 동위원소비를 측정하였다.

염분, 수온,  $\delta^{18}\text{O}$ 은 각각 34.0~34.5‰,  $-0.5\sim 2.1^\circ\text{C}$ ,  $-0.50\sim -0.26\text{‰}$ 의 분포 범위를 보이며, 이들의 지역적 분포는 대체로 해협의 북쪽에 저염, 고온의 해수가 남쪽에 고염, 저온의 해수가 존재한다.

T-S diagram은 일정한 경향성이 없이 분산된 결과를 보이는데, 이는 증발, 강우, 결빙 및 해빙의 복합적인 원인에 의한 것으로 보이며, 염분과  $\delta^{18}\text{O}$ 의 관계로 미루어 증발, 강우에 의한 영향보다는 결빙, 해빙에 의한 영향이 큰 것으로 나타났다.

영양염의 분포는 해협의 북쪽에서 낮고, 남쪽으로 가면서 높아지는 분포를 보인다. 해협의 북쪽에 고온, 저염 및 저영양염의 수괴가 분포하는 것으로 보아 브랜스필드 해협의 북쪽에서 얼음 녹은 물이 해협으로 유입되는 것으로 판단된다. 또한 N/P 비를 비교하여 보면 해협의 해수는 높은 N/P비 (19.4)와 낮은 N/P비 (16.7), 2개의 Group으로 나뉘어 지는데, 높은 N/P비는 해협의 북쪽에, 낮은 N/P비는 남쪽에 분포한다. 얼음이 녹으면서 표층해수에서의 질산염의 농도가 인산염의 농도보다 빨리 감소하며, peak ice 근처에서의 N/P비가 특히 높은 것으로 보고되어 이러한 N/P비의 분포도 해협의 북쪽에서 유입되는 얼음 녹은 물의 증거가 될 수 있을 것으로 생각된다.

엽록소 *a*의 분포는 대체로 Weddell Sea쪽에서 남동쪽으로 가면서 증가하며, 영양염 농도가 낮은 얼음 녹은 물의 유입이 엽록소 *a*의 농도를 감소시키는 것으로 사료된다.

## INTRODUCTION

The global ocean chemistry is greatly influenced by the water masses originated from the Antarctic region. Reinforcing mechanism of new water production in the Weddell Sea and high nutrient concentration in this region as a whole require more scientific attention in order to understand the world ocean circulation and global climate changes. Ocean-ice-atmosphere interactions in the polar regions largely determine the physical properties of seawater.

The most widely used conservative tracers of water masses are temperature and salinity. In the polar coastal waters, however, salinity is significantly modified by local freezing and melting, and temperature is also modified by local heating and cooling. Therefore, temperature and salinity are not usually sufficient to characterize water masses, in the polar region. Oxygen isotope ratio of seawater does not change during freezing and ice melting, whereas salinity does. The effect of freezing and ice melting on salinity can be eliminated by employing the oxygen isotope ratio as a tracer. A brief introduction of oxygen isotope ratio of seawater is given here.

The ratios of the stable isotopes of H and O in water,  $^2\text{H}/^1\text{H}(\text{D}/\text{H})=1.5\times 10^{-4}$  and  $^{18}\text{O}/^{16}\text{O}=2.0\times 10^{-4}$ , are known to be quite constant in the bulk ocean (Craig, 1961b). In general, the concentrations of HDO and  $\text{H}_2^{18}\text{O}$  in surface waters of low and mid-latitudes are controlled by evaporation and precipitation; being enriched by evaporation and depleted by precipitation in the surface water. The net result of these processes is a linear relationship between isotope composition and salinity, the slope of which depends on the general evaporation and precipitation characteristics of the region (Ferronsky and Brezegov, 1989). At high latitudes, the effects of freezing and ice melting are added to the effects of evaporation and precipitation. Freezing increases the salinity of the liquid phase with less alteration of its isotope composition (Östlund and Hut, 1984). Thus variations in the isotope composition of polar waters may be used to identify the physical processes responsible

for the alteration of salinity (Weiss et al., 1979; Björk, 1990). In coastal waters, isotope composition can be used to identify the physical processes responsible for the alteration of water temperature, because of the relatively small volume and thermal mass of coastal waters, where temperature is no longer a conservative property (Torgensen, 1979). In the hydrological cycle of evaporation and condensation, these ratios of hydrogen and oxygen isotopes change in such a way that they are essentially covariant (Craig, 1961a). So, it is sufficient to determine only one isotope (oxygen-18 or deuterium) in order to understand the hydrological cycle. The ratio of the stable oxygen isotopes is a useful stable conservative tracers (radioactively stable and biochemically conservative, terminology according to Craig, 1969).

The ratio,  $^{18}\text{O}/^{16}\text{O}$  is usually not used directly for comparisons but, instead, the deviation of this ratio from the standard value. For water samples the standard material is V-SMOW, distributed by the International Atomic Energy Agency (IAEA) in Vienna, Austria.

The deviation of the  $^{18}\text{O}/^{16}\text{O}$  ratio in a sample with respect to the ratio in the standard, is defined as

$$\delta^{18}\text{O}_{\text{sample}} = \left[ \frac{(^{18}\text{O}/^{16}\text{O})_{\text{sample}}}{(^{18}\text{O}/^{16}\text{O})_{\text{V-SMOW}}} - 1 \right] \times 1000 (\text{‰})$$

For short, this value is denoted as  $\delta^{18}\text{O}$  hereafter.

When surface seawater evaporates, a considerable isotopic fractionation occurs so that vapor becomes isotopically lighter (i.e.  $\delta^{18}\text{O}$  goes negative). In its global transport toward the high latitude, the atmospheric water vapor undergoes extensive modifications by evaporation, precipitation, and air/sea molecular exchange so that  $\delta^{18}\text{O}$  values of vapor and precipitation in the Antarctic ranges between  $-10$  and  $-37\text{‰}$  varying with time of the year, distance from open ocean, etc. (Broecker, 1974; IAEA, 1990).

The characteristics of water masses in Weddell Sea are well known (Weiss et al., 1979; Morgan, 1982; Schlosser et al., 1990), however, those of the Bransfield Strait, coastal zone of Antarctica are

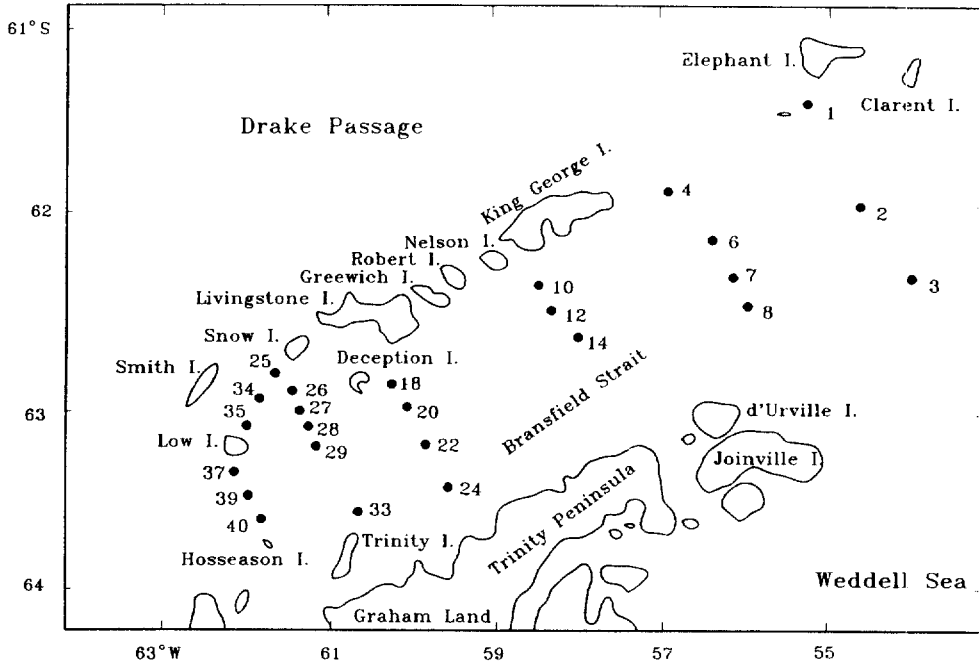


Fig. 1. Oceanographic sampling stations in the Bransfield Strait, Antarctica.

poorly known (Heywood, 1985). Primary productivity in the Bransfield Strait appears to be controlled by the water column stability (Hong et al., 1991). Therefore, the understanding of the controlling mechanisms of the water column stability is required to predict global climate change. Stability of the water column in the Antarctic region depends on the fresh water supply, i.e., the addition of meteoric water as land runoff including ice-melt, direct precipitation and melting of sea ice. In this study, we try to determine the characteristics of the surface water in the Bransfield Strait using not only temperature and salinity but oxygen isotope as conservative tracers and other non-conservative tracers.

## MATERIALS AND METHODS

Hydrographic survey and water samples were taken in the Bransfield Strait and Maxwell Bay during 19 December 1990 to 7 January 1991 (Fig. 1). Water samples were collected using 12 bottle rosette mounted Niskin samplers at the surface. 10, 30, 50, 75, 100, 200, 300, 500, 1000, 1200, and

1500 meters depths. Sea surface temperature and salinity were measured using the reversing thermometer and Guildline Portosal 8410 salinometer due to the failure of CTD. Nutrients were analyzed using a UV-VIS spectrophotometer (Parsons et al., 1984), on board without filtration of seawater samples. *In vivo* fluorescence was also determined with Turner Design field fluorometer (Model 10-005R), and later calibrated to the chlorophyll *a* (acetone extracts, Parsons et al., 1984) in the laboratory (Ansan, Korea) using a limited number of frozen samples.

Oxygen isotope ratio of sea water was determined using Isotope Ratio Mass Spectrometer (VG SIRA II) with an automatic H<sub>2</sub>O/CO<sub>2</sub> equilibrator (ISOPREP 18). The isotope ratio of oxygen in water is equilibrated with the isotope ratio of oxygen in CO<sub>2</sub> gas for 6 hours at 25°C with mild shaking. Reference CO<sub>2</sub> gases obtained from U.S. Oak Ridge National Laboratory and Korea Basic Science Center (KBSC) were used to calibrate our KORDI CO<sub>2</sub> gas. Table 1 shows the isotope ratios of KORDI reference gas with respect to PDB (carbonate from Pee Dee Belemnite formation). The values

Table 1. The isotope ratios of KORDI reference CO<sub>2</sub> gas (mean s.d.; n=4)

KORDI reference CO <sub>2</sub> gas	relative to PDB
Isotope ratio of 45/44	-27.163‰ ± 0.046
Isotope ratio of 46/44	-16.941‰ ± 0.059

Table 2 The comparison of δ<sup>18</sup>O values of international standards between IAEA certified ones and measured ones in this study

IAEA certified	KORDI	difference
GISP -24.85	-24.874	0.1%
SLAP -55.50	-55.731	0.4%

of isotope ratio for PDB were converted to the V-SMOW (Vienna Standard Mean Ocean Water) scale using a following formula (IAEA, 1981).

$$\delta^{18}\text{O}_{\text{V-SMOW}} = 1.03086 \times \delta^{18}\text{O}_{\text{PDB}} + 30.86$$

Each sample and reference gas were analyzed six times. The integration time and the inter cycle delay time between reference and sample runs were set as 20 seconds and 30 seconds, respectively. Their internal precision was 0.011‰ to 0.027‰. To check the accuracy, precision, and reproducibility of the analysis, international standards of GISP (Greenland Ice Sheet Precipitation), SLAP (Standard Light Arctic Precipitation) were run.

Table 2 shows the certified values and our measured isotope ratios. These values are within the error of the certified values; there are only 0.1% and 0.4% differences for GISP and SLAP, respectively. Two to four working standard sea water samples collected at 1250 m deep in the East Sea (ESDW) were run in every batch as a working substandard. The oxygen isotope ratio of ESDW is  $0.072 \pm 0.013\text{‰}$  relative to V-SMOW.

## RESULTS AND DISCUSSION

Temperature, salinity, oxygen isotope compositions, and nutrients of the surface water of the Bransfield Strait are given in Table 3. The spatial distributions of salinity, temperature, and δ<sup>18</sup>O are shown in Fig. 2. Property plots are given in Figs. 3. Chlorophyll *a* concentration is given in Fig. 4.

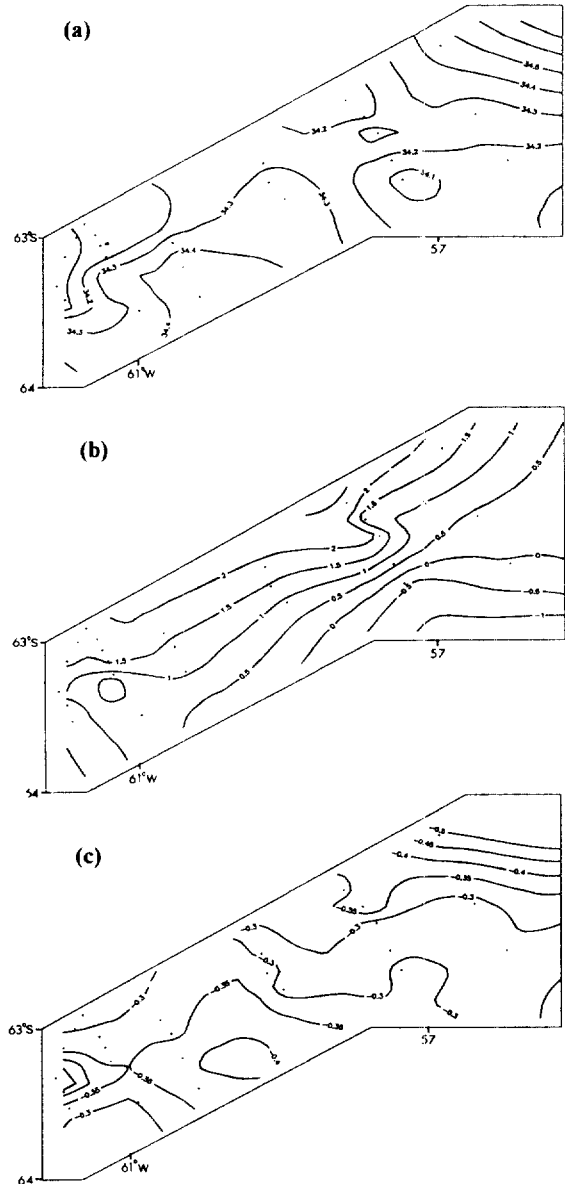


Fig. 2. Spatial distribution of (a) salinity, (b) temperature, and (c) δ<sup>18</sup>O in surface waters of the Bransfield Strait, Antarctica.

Overall, the distribution of water temperature and salinity are similar to those reported previously by Hong et al. (1991).

### Hydrographic features

Waters in the Bransfield Strait are believed to

Table 3. Measured salinity, nutrients and  $\delta^{18}\text{O}$  in the surface waters of the Bransfield Strait (Antarctica) during austral summer (1990-1991). See Fig. 1 for the location of the station.

Station	Temp. °C	Sal. ‰	NO <sub>2</sub> μM	NO <sub>3</sub> μM	Si μM	PO <sub>4</sub> μM	Chl-a μg/l	$\delta^{18}\text{O}$ ‰
1	1.75	34.456	0.38	23.86	60.85	2.30	0.26	-0.50
2	0.40	34.238	0.40	35.48	75.21	2.65	0.24	-0.28
3	0.01	34.170	0.33	32.66	66.47	—	0.11	-0.30
4	2.40	34.144	—	35.90	—	2.67	0.27	-0.34
5	1.05	34.169	0.44	22.50	66.62	1.97	0.11	-0.41
6	2.38	34.399	0.38	31.83	72.45	2.68	0.20	-0.26
7	0.63	34.140	0.30	38.60	65.45	2.54	0.50	-0.26
8	-0.50	34.048	0.23	37.76	63.70	2.76	—	-0.35
10	1.85	34.291	0.24	11.88	47.06	1.68	1.06	-0.29
12	1.45	34.318	0.24	29.44	68.08	2.65	0.27	-0.36
14	0.88	34.407	0.34	46.14	55.94	2.92	0.68	-0.27
18	1.70	34.168	0.39	30.77	67.21	2.58	0.62	-0.33
20	1.30	34.368	0.44	33.16	75.17	2.63	0.79	-0.33
22	1.35	34.450	0.31	35.74	74.56	2.90	0.50	-0.42
24	0.47	34.457	0.30	—	71.17	—	0.54	-0.38
25	1.60	34.169	0.32	—	56.71	—	1.85	-0.23
26	1.81	34.118	0.42	—	58.65	—	2.18	-0.28
27	1.96	34.065	0.47	28.24	67.21	2.35	2.24	-0.35
28	1.70	34.170	0.42	25.23	51.91	2.31	0.87	-0.30
29	0.30	34.418	0.42	20.73	69.05	2.21	0.93	-0.35
33	0.80	34.301	0.24	24.00	66.46	2.21	0.42	-0.29
34	1.53	34.135	0.33	36.54	65.75	2.64	1.90	-0.34
35	1.54	34.029	0.38	37.92	62.54	2.63	1.58	-0.35
37	0.95	34.084	0.36	44.21	64.34	2.88	0.32	-0.50
39	1.45	34.063	0.42	30.09	69.65	2.33	5.59	-0.37
40	1.40	34.280	0.39	40.30	82.70	2.46	0.97	-0.31
MX1	1.99	34.200	0.38	31.63	64.87	2.42	0.72	-0.38
MX2	2.10	34.212	0.42	41.47	70.12	2.76	0.86	-0.33
G01	0.75	34.261	0.34	35.97	49.41	2.97	1.43	-0.35
G02	1.00	34.195	0.25	23.77	60.00	3.03	0.55	-0.44
G03	1.20	34.249	0.30	29.09	64.70	2.43	0.93	-0.46
G04	1.92	34.169	0.35	34.84	67.05	2.21	1.73	-0.32
G13	2.30	34.112	0.34	36.22	67.20	2.28	1.20	-0.33
G15	1.92	34.305	0.34	44.87	74.78	2.84	1.13	-0.37

be the product of interactions between two distinctive surface waters and local influences. Weddell Sea water enters around the Joinville and d'Urville Islands to spread northward across the Strait and southwards along the coast of the Peninsula (Fig. 1). Waters from the southeast Pacific Basin enter between the Low, Smith and Snow Islands and pass north and south of the Deception Island. The cold bottom water of the Bransfield Trough is formed in situ during the formation of ice from waters lying over shallow coastal shelf area in winter (Heywood, 1985). The waters of lower salinity are

present in the western part and southeast of the Bransfield Strait near the mouth of Weddell Sea (Fig. 2a). The warm waters are predominant toward the north of the Bransfield Strait (Fig. 2b).

A temperature-salinity diagram is shown in Fig. 3a. The ranges of temperature and salinity are  $-0.5$  to  $2.1^\circ\text{C}$  and  $34.0$  to  $34.5\text{‰}$ , respectively. Salinity values are similar to those of the Weddell Sea Summer Surface Water (WSSW), whereas temperature values are somewhat higher. Some points of the stations near Weddell Sea (Station 2,3,7,8) lie within the reported values of WSSW ( $T: -2 \sim 1$

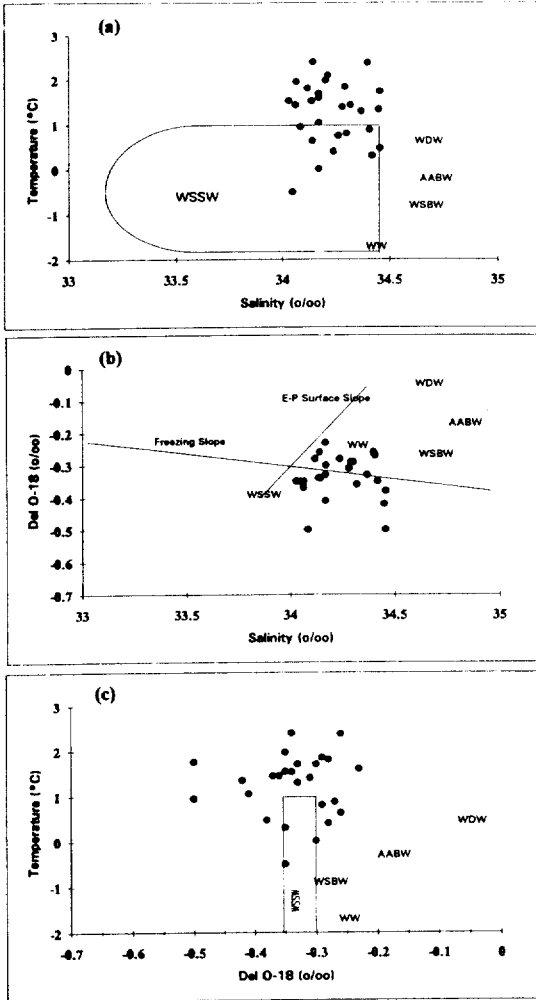


Fig. 3. (a) Temperature-salinity diagram in surface waters, (b) Salinity vs.  $\delta^{18}\text{O}$  in surface waters (Freezing slope: after Craig and Hom, 1968; Evaporation-Precipitation surface slope: after Craig and Gordon, 1965), (c) Temperature vs.  $\delta^{18}\text{O}$  in surface waters. Note, WDW: Warm Deep Water, AABW: Antarctic Bottom Water, WSBW: Weddell Sea Bottom Water, WSSW: Weddell Sea Summer Surface Water, WW: Weddell Sea Winter Water.

$^{\circ}\text{C}$ , S: 33.0~34.4‰; Weiss et al., 1979). The complicated effects of evaporation, precipitation, freezing, ice melting may make the data scatter (Fig. 3a; Weiss et al., 1979).

#### $\delta^{18}\text{O}$ in the Bransfield Strait

The values of  $\delta^{18}\text{O}$  varies from  $-0.50$  to  $-0.26$

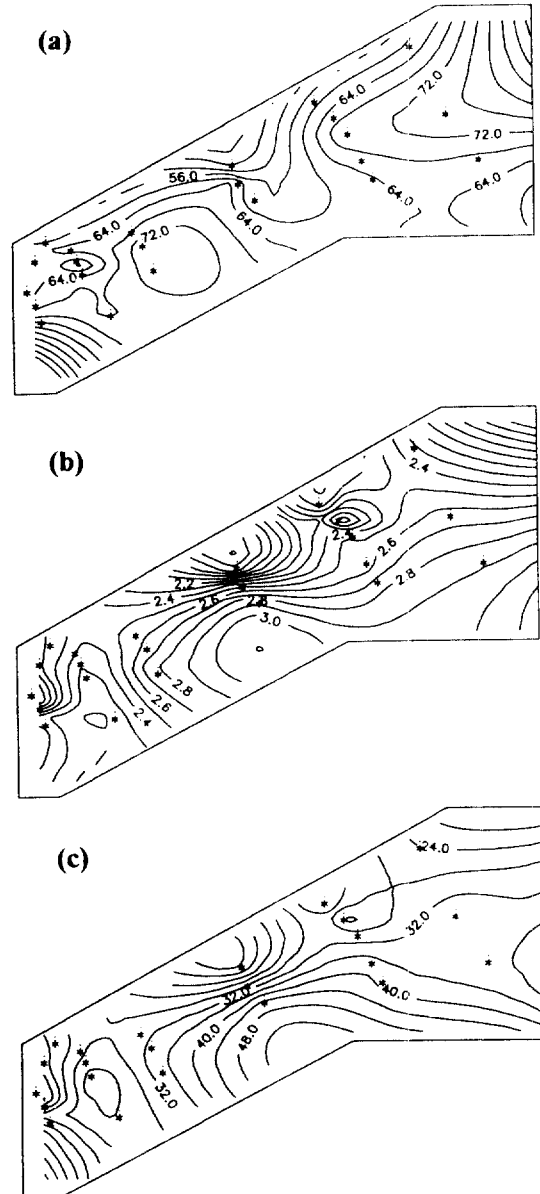


Fig. 4. Spatial distribution of (a) nitrate, (b) phosphate, and (c) silica in surface waters of the Bransfield Strait, Antarctica.

‰ in the surface waters of the Bransfield Strait. The values are within the reported range of variation (Table 4). Considering the spatial distribution of  $\delta^{18}\text{O}$ , near the islands located western and northern part of the Bransfield Strait, the  $\delta^{18}\text{O}$  values are depleted (less than  $-0.4$ ‰). Also, there exists an enriched  $\delta^{18}\text{O}$  tongue from Weddell Sea (Fig.

Table 4.  $\delta^{18}\text{O}$  in the Antarctic ocean (‰)

		source
Antarctic Bottom Water (AABW)	-0.20	1
Weddell Sea (Central) surface water(WSSW)	-0.3~-0.35	1
winter water(WW)	-0.3~-0.35	1
warm deep water(WDW)	-0.1~-0.15	2
bottom water(WSBW)	-0.29	1
Ross Ice Shelf	-42	3
Central Antarctic (surface)	-55	4
Precipitation (current) 62.25°S 64.27°W	-6~-15	5
75.50°S 26.65°W	-12~-36	5

Source: 1. Weiss et al. (1979), 2. Schlosser et al. (1990), 3. Grootes and Stuiver (1983), 4. Morgan (1982), 5. IAEA (1990)

2c), and this lies within the WSSW values (Weiss et al., 1979). Therefore, it can be said that WSSW is injected into the Bransfield Strait.

The values of  $\delta^{18}\text{O}$ , salinity, and temperature are scattered considerably (Figs. 3b and 3c). This characteristics of Weddell Sea surface water was reported earlier (Weiss et al., 1979). There may be complicated processes in the surface waters of the Bransfield Strait and Weddell Sea. In the case of Weddell Sea, combined actions of freezing-melting and evaporation-precipitation are the main cause of the scattered data because the freezing and evaporation-precipitation slope lines pass through the points of WSSW (Weiss et al., 1979). The freezing slope line is drawn arbitrarily to pass through our data envelopes, but the evaporation-precipitation slope line is not (Fig. 3b). The points around the freezing slope line correspond to the data from the stations at the northern part of the Bransfield Strait. This can be the evidence that freezing and ice melting are processing in northern part of the Bransfield Strait.

Though it is small, the freezing-ice melting may affect the distribution of  $\delta^{18}\text{O}$  of the Bransfield Strait, while the evidence of evaporation-precipitation is hardly found in the Bransfield Strait.

#### Nutrients

The nutrient concentrations are somewhat higher than expected. Nitrate, nitrite, silica, and phosphate concentrations of the surface water in the Bransfield Strait vary from 20  $\mu\text{M}$  to 46  $\mu\text{M}$ , 0.2

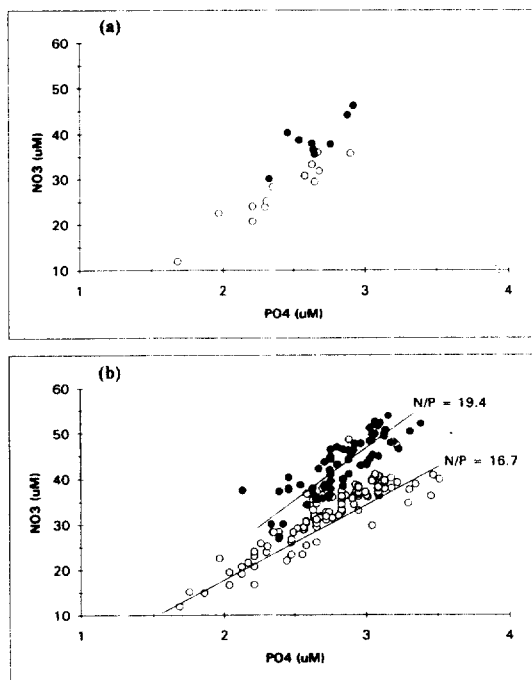


Fig. 5. (a) Nitrate vs. phosphate in surface waters, (b) Nitrate vs. phosphate in depths. The regression line for the closed circles has a slope equivalent to  $\text{N/P}=19.4$  (Station 2, 7, 8, 14, 24, 25, 33, 34, 35, 37, 39, 40), and 16.7 for open circles (Station 1, 6, 10, 12, 18, 20, 22, 26, 27, 28, 29).

$\mu\text{M}$  to 0.5  $\mu\text{M}$ , 47  $\mu\text{M}$  to 83  $\mu\text{M}$ , 1.6  $\mu\text{M}$  to 2.9  $\mu\text{M}$ , respectively.

All the nutrient concentration decrease gradually to north in the middle of the Bransfield Strait as the  $\delta^{18}\text{O}$  distribution. In the northern part of the Bransfield Strait that has lower nutrients concentrations, salinity is lower, temperature and  $\delta^{18}\text{O}$

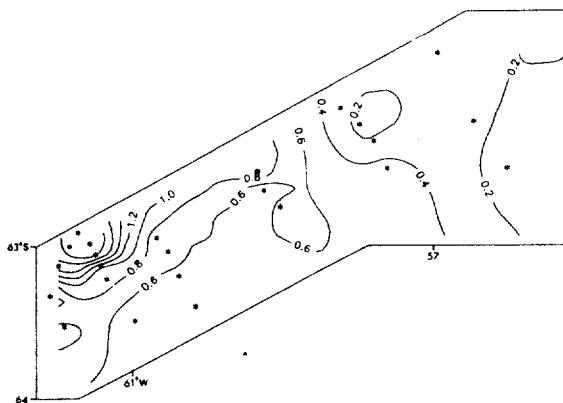


Fig. 6. Spatial distribution of chlorophyll *a* in the surface water of the Bransfield Strait, Antarctica.

are higher than in the southern part. Therefore, ice melted fresh water may be injected to the Bransfield Strait from the north.

Nitrate is plotted against phosphate in the surface waters and in the all depths in Figs. 5a and 5b, respectively. The points of Fig. 5b can be divided into two groups. One has higher N/P ratio (19.4: closed circle in Fig. 5b) and another has lower (16.7: open circle in Fig. 5b). The lower N/P ratio is found in the northern part where ice melted fresh water is injected, and the higher N/P ratio is found in the southern part of the Bransfield Strait. The nitrate concentration in the surface water decreases much faster than phosphate with ice melting (Iwanami et al., 1986), and near the pack ice, N/P ratio is extremely high (Satoh et al., 1982). Although more precise work is needed, the differences of N/P ratio may imply the injection of the ice melted water to the Bransfield Strait.

Whether it is inherent character to the Bransfield Strait water or merely sampling and analytical error remains to be seen. Non-conservative tracers of nutrients in the ocean have also used extensively to provide insight into processes and rates of water mass formation. Therefore, more attention should be given in the determination of nutrients in further work.

#### Plant pigments

Chlorophyll *a* concentration, in general, increases from 0.2  $\mu\text{g/l}$  in the northwest (Weddell Sea) to 6.0  $\mu\text{g/l}$  in the southeast (Smith and Brabant Islands; Fig. 6). Probably the injection of nutrient depleted fresh water from ice melting may reduce the chlorophyll *a* concentration since chlorophyll *a* maxima generally occur in the subsurface in the Bransfield Strait (Hong et al., 1991).

#### ACKNOWLEDGMENTS

The authors thank Dr. T. Lee of KORDI for comments and suggestions, Mr. K. S. Lee of KBSC for calibrating our reference gases, and the participating members of the 4th KARP. This work was supported in part by the Ministry of Science and Technology through KORDI (BSPG 00140-400-7) awarded to GHH, and KORDI (BSPI 00141) to YDK.

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Accepted September 23, 1992