Antarctic Research, Vol. 5, No. 2, 58～66, December 1994

The chemical characteristics of seawater in the Prydz Bay, Antarctica

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Received May 19, 1994

Abstract Based on some data obtained in the Sixth Chinese Antarctic Research Expedition during 1989/1990, the relationship between the distribution of nutrient and that of productivity in the Prydz Bay was discussed. The results show that outside the Emery Ice Shelf there exists an expanse of warm and salty waters, where within the euphotic layer the content of nutrient is relatively low, the saturation of dissolved oxygen is up to 120% and the content of chlorophyll a is more than 1.00 mg/m^3, all this indicating that the Prydz Bay may be considered as a high productivity area in Antarctica. The vertical distribution of chemical elements showed a strong spring layer like the thermocline, but at 350 m layer abnormal vertical nutrient distribution turned up, even though there was no distinct halocline. Finally the various factors causing this abnormaly were discussed.

Key words nutrient, dissolved oxygen, euphotic layer, Prydz Bay

1 Introduction

Many investigations conducted in the Prydz Bay, Antarctica have demonstrated there exists an expanse of warm, salty waters, located off the Emary Ice Shelf, with surface water temperature higher than that of outside the Bay. These features have been confirmed by the expedition of the 'OB' (Dong *et al.*, 1984). Wang *et al.* (1984) not only proved the existence of above mentioned thermohaline structure, but preliminarily revealed the open water area in the Prydz Bay was the site of high productivity, with low nutrient content and high dissolved oxygen.

This paper utilizes the data obtained in the Sixth Chinese Antarctic Research Expedition, in order to further illustrate the chemical characteristics of sea water in the Prydz Bay. The investigated location is shown in Fig 1.

2 Sample and method

Seawater samples were collected by using Niskin Sampler. Dissolved oxygen content was determined by using Winkler's method. The samples for nutrient analysis were first filtered through micropore filter membranes (0.45 μm), and then analysed by spectrophotometric method recommended by Strickland and Parsons (1968).

The standard solutions for analysis of the content of nutrient and dissolved oxygen were provided by Second Institute of Oceanography, SOA.

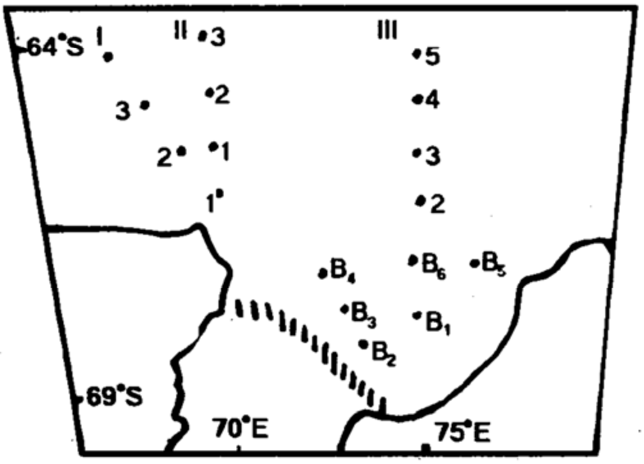

Fig 1. The station position of investigation.

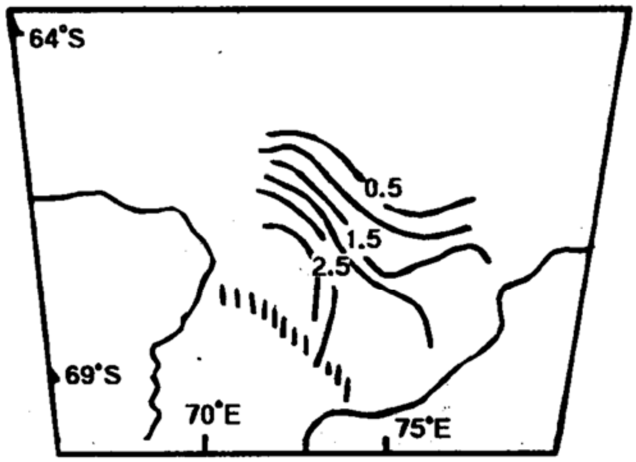

Fig 2. Horizontal distribution on temperture of seawater at surface layer.

3 Results

3. 1 Temperature and salinity

The horizontal distribution maps of surface temperature and salinity were presented in Fig. 2 and Fig. 3, respectively. The figures show that the isopleths of temperature and salinity both extend from the south to north by east, indicating that temperature and salinity decrease from inside to outside the Bay, with the maximum temperature of 3. 06℃, and the maximum salinity of 34. 34 in station B_3. Among six stations within the Bay, two stations (B_3, B_4) have the temperature higher than 3. 00℃. But in station B_6 the water temperature is the lowest, with the value of 1. 98℃. The salinity at station B_4 and B_5 was approximately 34. 00, and that at the rest stations was more than 34. 00. These distribution maps of temperature and salinity suggested that the surface water temperature within the Prydz Bay was greater in antarctic summer during 1989/1990 period than that offered by previous surveys, and hence it may have an influence on the characteristics of chemical parameters.

3. 2 The horizontal distribution of chemical elements

3. 2. 1 Nutrient

The horizontal distributions of PO_4-P, SiO_3-Si and NO_2-N+NO_3-N (abbrev. NO_3-N) in the Prydz Bay were showed in Fig. 4~6, respectively. All figures showed tongue-shaped isopleth extending from inside to outside the Bay. The nutreint content increases from inside to outside the Bay, especially with low contents of PO_4-P and NO_3-N at station B_2, B_3 and B_4 nearby the Emary Ice Shelf. The contents of PO_4-P were 0. 25, 0. 36 and 0. 22 $\mu mol/dm^3$, respectively, the contents of NO_3-N were 4. 58, 5. 60, 4. 02

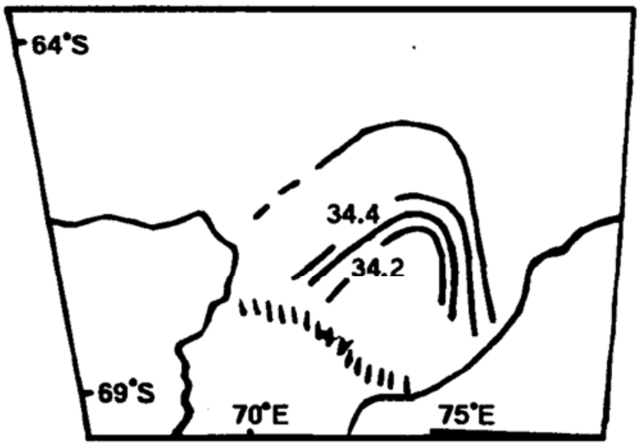

Fig. 3. Horizontal distribution on salinity of seawater at surface layer.

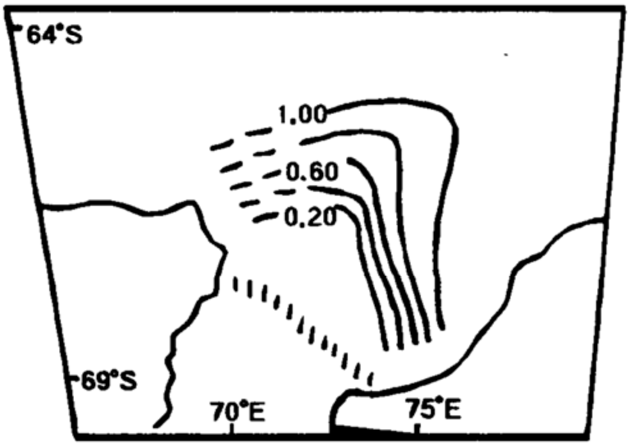

Fig. 4. Horizontal distribution of PO_4-P at surface layer.

μmol/dm^3, respectively. The distribution of SiO_3-Si was slightly different from that of PO_4-P and NO_3-N ,this resulted from the high base value of SiO_3-Si, but their pattern of distribution was similar, with low content inside and high content outside the Bay.

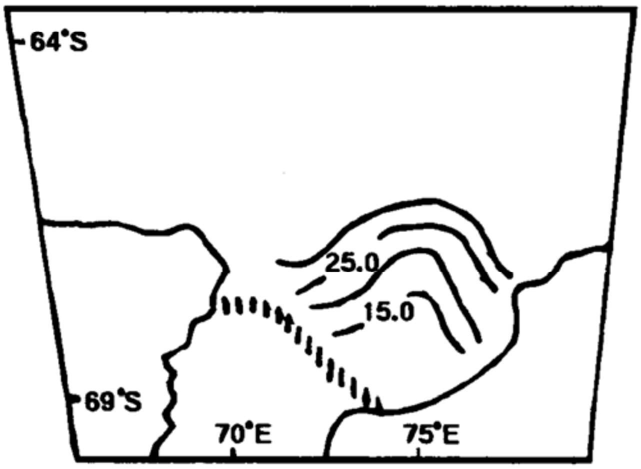

Fig. 5. Horizontal distribution of SiO_3-Si at surface layer.

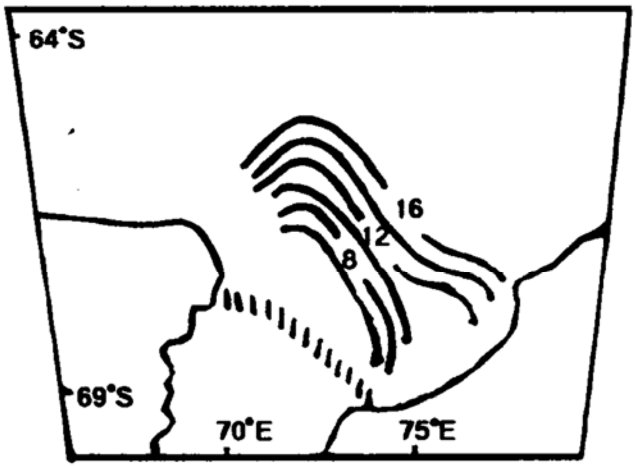

Fig. 6. Horizontal distribution of NO_3-N at surface layer.

3. 2. 2 Dissolved oxygen

The data on dissolved oxygen content and its saturation degree were listed in Table 1. The data showed that except at station B_6, the dissolved oxygen content was more than 8. 00 ml/L, and its saturation degree was above 100% within 50 m depth at the rest stations. The highest content of dissolved oxygen(abbrev. DO) occurred in station B_3 and B_4, with the value of 8. 90 ml/L and with the saturation degree of 129%, 114%, respectively. This presumely was due to the difference of water temperature. The Table 1 also revealed that DO content in water above 50 m had little influence by the change of water temperature, and furthermore, at the majority of stations the minimum content of DO appeared in 25 m or 50 m layer, instead on the surface layer. All these features, taken together with the presence of great dissolved oxygen saturation degree demonstrated an intensive photosynthesis occured in Antarctica in antarctic summer.

Table 1. Dissolved oxygen content, saturation and temperature data.

Layer	B_1			B_2			B_3			B_4			B_5			B_6		
(m)	DO	S	T	DO	S	T	DO	S	T	DO	S	T	DO	S	T	DO	S	T
0	8.11	112	2.81	8.69	118	2.76	8.20	113	3.06	8.30	114	3.00	8.17	110	2.12	7.97	107	1.98
25	8.54	112	1.25	8.70	118	2.47	8.90	122	2.57	8.16	109	1.99	8.21	107	2.12	7.99	107	1.93
50	8.49	109	-0.33	8.48	106	-0.5	-	-	-	8.90	114	0.46	8.20	106	1.76	7.98	107	1.64
100	7.41	-	-	7.52	90.8	-1.60	7.50	90.4	-1.67	7.30	88.7	-1.48	7.47	90.2	-1.47	7.90	99.7	-0.30
200	7.42	89.4	-1.93	7.32	88.2	-1.86	7.27	87.6	-1.76	7.32	88.1	-1.81	7.22	88.6	-1.31			

DO: Dissolved oxygen content ($\times 10^{-3}$); S: Saturation degree (%); T: Temperature (℃).

In all stations the dissolved oxygen content in water column below 50 m was less than 8.00 ml/L, ranging from 7.52~7.22 ml/L and saturation degree about 89%, The dissolved oxygen content was still somewhat high in water below the thermocline, which was one of characteristics of coastal area in Anarctica.

3.3 The section and vertical distribution of nutrient

The section distribution of PO_4-P, NO_3-N and SiO_3-Si was showed in Fig. 7. The figure displayed that there was strong nutricline between 25 m and 100 m, expressed by dense isopleth and great gradient. Both in section A and in section C, the isopleths of PO_4-P and SiO_3-Si paralleled with seabed, indicating that there happened intensive photosynthesis. The profile of NO_3-N in section B, however, showed slightly abnormal, seemingly implying the existence of upwelling of rich-nutrient water. This case needed to be further investigated.

But there surprisingly appeared a low-nutrient zone in 350 m layer in the Fig. 7, with especially low content in station B_3 and B_4. The feature may result from the penetration of low-nutrient, melt-ice water into the 350 m water layer. By contrasting the distributions in 3 sections, it can be concluded that in section A, the content of PO_4-P is much lower than that in others; in the section B the content of NO_3-N is low, with its influence reaching as far as to station B_6; in the section C, although there was a isopleth of 70 μmol/dm^3, the content of SiO_3-Si at 350 m layer was also as high as 69.59 μmol/dm^3. This feature could not exclude the possibility of subsiding of low-nutrient water.

To further clearly demonstrate the presence of low-nutrient water at 350 m layer, the chemical element profiles at station B_3 and B_4 were presented (Fig. 8a, 8b). In both profiles, the curves of nutrient were unusually bending at 350 m layer, illustrating the

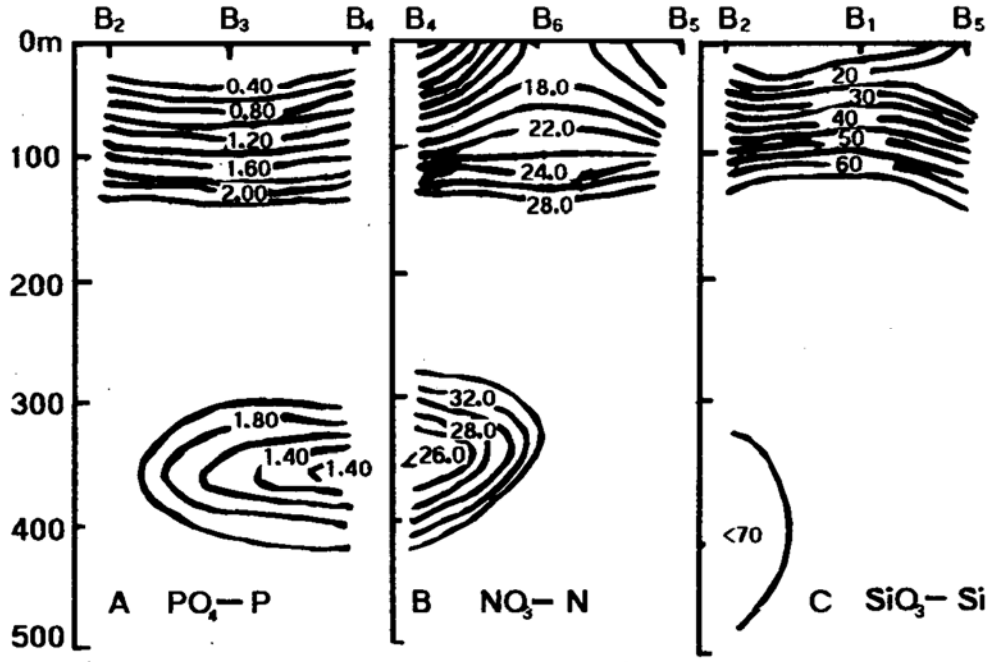

Fig. 7. Distribution of nutrients on cross-section.

existence of low-nutrient water at that depth. Furthermore, profile at station B_3 showed that at 25 m layer there existed a weak spring layer, suggesting that the magnitude of photosynthesis at that layer was the greatest. A strong nutricline lies between 25 m layer and 100 m layer.

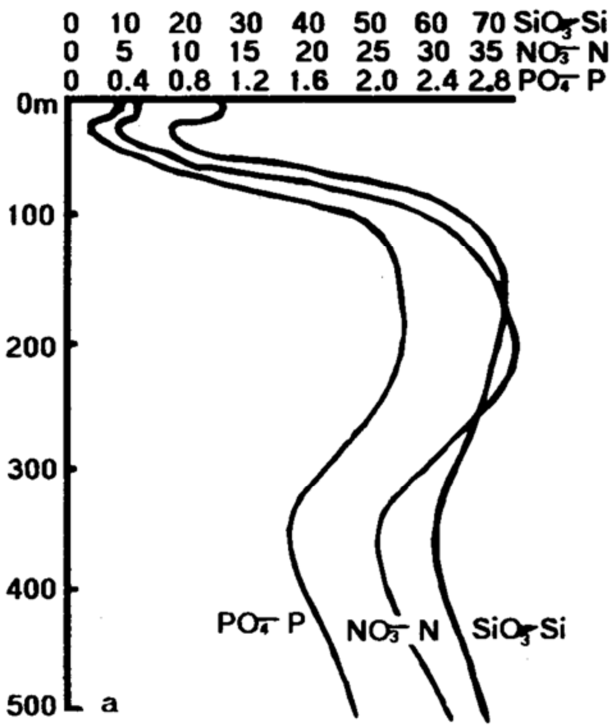

Fig. 8a. Vertical distribution of nutrients at B_3 station.

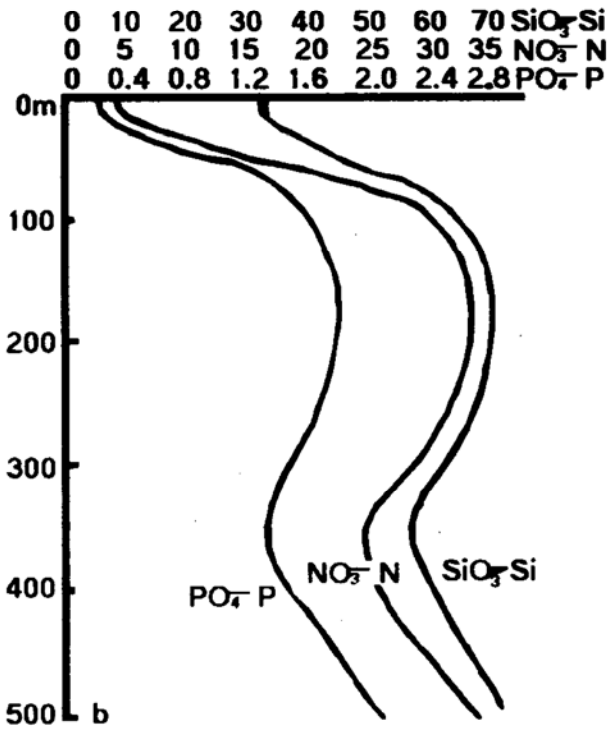

Fig. 8b. Vertical distribution of nutrients at B_4 station.

By using the method for calculation of strength of nutricline provided by Wang *et al.* (1984), we calculated the strength of phosphicline, nitricline and silicline at station B_3, with the value of 0. 025, 0. 4, and 0. 68 $\mu mol/m^3$, respectively. A comparison of the results with those reported by Wang *et al.* (1984), it can be concluded that the strength of SiO_3-Si was nearly equal, that of PO_4-P less and that of NO_3-N greater. In a word, generally there was double-spring layer in the nutrient vertical distribution in antarctic sea area in antarctic summer, and the strength of spring layer was nearly the same order of magnitude. But sometimes the strength shows great differences owing to the different depth used in calculation.

3. 4 The ratio of N to P and T-O_2 curve

3. 4. 1 The ratio of N/P

The ratio of N/P is 16 in ocean water, so is both in organism and in seawater (Riley, 1975). This biochemical feature was also clearly seen in the Prydz Bay, with ratio of N to P varying from 14 to 17 . But in term of statistical consideration, this value was slightly lower as compared with those in ocean water (Riley, 1975). Furthermore, the ratio in the studied area was different from those in bay of the north hemiphere where the strength of run off is rather strong (Wang *et al.*, 1990). This may be effect of the low contents of N and P in the ice-melted water, Antarctica which has little influence on the change of ratio.

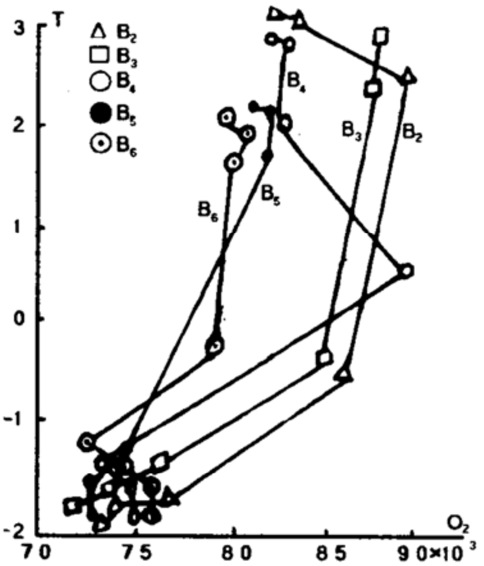

Fig. 9. T-O_2 curves at the B_2-B_6 station.

3. 4. 2 Characteristics of T-O_2 curve

Fig. 9 showed the T-O_2 curve at stations within the Prydz Bay . It revealed the following characteristics of different water mass. Firstly , the waters from surface to the depth of 50 m is marked by high temperature and high dissolved oxygen content, with high primary productivity. Next is followed by the thermocline and spring layer of dissolved oxygen. Finally it is the deeper waters with the temperature of −1.00°C, the dissolved oxygen content of approximately 7.40×10^{3}. Nevertheless, the figure also presented the somewhat difference between at station B_2, B_3, B_4 and at station B_5, B_6, water temperature and dissolved oxygen content in the euphotic layer were higher at former stations than those at later stations. This case may be attributed to the different position of stations, and therefore the points of which in the euphotic layer were scattered. The points in deeper layer at all stations, however, were concentrated within a area of 1 cm^2, indicating the similar physical-chemical features of the deeper waters of the Prydz Bay.

4 Discussion

(1) Under the action of current, the pack ice in the Prydz Bay flow northwestward from outside of Emery Ice Shelf (Dong *et al.*, 1984). When antarctic summer came and after all the pack ice floated out, there appeared a large area open water in the Prydz Bay. Under the radiation of the sun, the surface water temperature rose so quickly that the water temperature within the bay was higher than that outside the bay, and that strong thermocline was formed. So it was expected that quite high primary productivity occurred in this open water area. But there appeared a weak halocline, the reason why the surface water salinity was more than 34.00 in the Prydz Bay, and why it was greater inside the bay than outside the bay, may be due to two possibilities. One possibility is the existence of a weak eddy current within the bay which led to upwelling of salty deep water, but its rising speed was so low that the nutrient content is still lower in the euphotic zone under the effect of photosynthesis, and thus there existed a strong nutricline. The other possibility is the action of current. When the current flowing into the bay from the direction of Davis Station was blocked both by the Emery Ice Shelf and the west bank of the bay, the deep and salty water may rise up to surface, strengthening and mixed with the eddy current, which make the salinity high in the surface waters. But this process also went on much slowly, and it could not yet solve the question of lower nutrient content. In a word, the special phenomenon appeared in the bay requires to be further studied.

(2) As is mentioned above, the Prydz Bay was a zone of high primary productivity. In antarctic summer the nutrient content was very low within the euphotic layer, which may be attributed to the effect of photosynthesis. To further demonstrate this phenomenon, an analysis was made of the chemical characteristics of sea water within the depth of 100 m and their correlation with the environmental factors. The results are showed in the following:

$$SiO_3\text{-}Si = -0.075\times T + 3.72 \qquad (n=30, r=-0.91)$$
$$PO_4\text{-}P = -0.149\times O_2 + 8.66 \qquad (n=28, r=-0.76)$$

$NO_3\text{-}N = 0.043 \times S + 32.55$ $(n=30, r=0.082)$

$PO_4\text{-}P = 15.00 \times NO_3\text{-}N + 0.78$ $(n=30, r=0.99)$

$PO_4\text{-}P = 24.52 \times SiO_3\text{-}Si + 6.77$ $(n=30, r=0.82)$

The above statistical results showed a close correlation between the nutrient content in the seawater and the water temperature , with the correlation coefficient as high as −0.91, being characteristics of antarctic summer surface water. The close correlation between the nutrient content and the dissolved oxygen in upper euphotic layer was another feature in antarctic sea. Nevertheless, this only existed in the stations where the sea water was stable greatly, because oxygen level within euphotic layer was in the state of supersaturation , in which oxygen was easy to set forth into the atmosphere, and furthermore its content was also the function as the water temperature and salinity. The correlation coefficient , however, was still as high as −0.76, in spite of many factors affecting them, which suggests the strength of photosynthesis in this sea area. PO_4-P was well related with NO_3-N, having the correlation coefficient of 0.99, implying the simultaneous assimilation of N, P during process of photosynthesis. The result discussed above was confirmed by the ratio of N to P, whose value of 15 is also consistent with previous report (Jehan and Treguer, 1985).

Nutrient content was not statistically related with the salinity in sea water, which wasn't consistent with the effects of melted-ice, fresh water on the nutrient content, so other special mechanisms must be responsible for this phenomenon, such as the upwelling of deeper water. This also was further supported by the conclusion that there existed a high salinity water in the studied area.

(3) To further illustrate the Prydz Bay to be an area of high productivity , the data on concentration of chlorophyll a in this area were quoted and listed in the Table 2. Table 2 not only reveals that the productivity at stations within the Prydz Bay is higher than those outside the Bay, but also suggests that the highest photosynthesis occurs between 25 m layer and 50 m layer. It was generally true that productivity within the Prydz Bay was higher than that outside the bay. This was consistent with the conclusion found in Brandfield Strait and its adjacent area (Wang *et al.*, 1984, 1989). Summerizing the discussion above, it is evident that there is a zone of low nutrient content in near-shore sea water of the Prydz Bay during the antarctic summer.

Table 2. Chlorophyll a data (mg · C/m^2 · d).

Depth (m)	B_1	B_2	B_3	B_4	B_5	B_6.	I 4	I 5
0	0.328	1.341	1.417	0.754	0.748	0.657	0.157	0.008
25	0.566	1.265	1.394	1.084	0.852	0.548	0.425	0.094
50	0.796	1.950	1.318	0.402	0.755	0.618	0.512	0.108
100	0.179	1.836	1.097	1.143	0.159	0.222	0.162	0.167
150	1.074	0.522	0.397	0.709	0.220	0.114	0.046	0.065
200	0.307	0.366	0.227	0.373	0.115	0.079	0.019	0.043

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