

## Biogenic silica in surficial sediments of Prydz Bay, Antarctica

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**Abstract** The content and distribution of biogenic silica were investigated in sediment cores from Prydz Bay, Antarctica, during the CHINARE-18/21 cruise. The results show that the content of biogenic silica ( $\text{BSiO}_2$ ) is ranged from 4.89% to 85.41%, and the average content of biogenic silica is 30.90%, the highest value occurred at the IV-10 station. The profile of  $\text{BSiO}_2$  in sediment is contrast to that of silicate in the interstitial water. The content of biogenic silica and organic carbon in the surface sediments in the central area of Prydz Bay gyre were much higher than those in other area, and closely related to the Chla content and primary productivity of phytoplankton in the surface water column.

**Key words** biogenic silica, surface sediment, organic carbon, Prydz Bay.

### 1 Introduction

Biogenic silica ( $\text{BSiO}_2$ ) is one of the major biogenic components of oceanic sediments, and is produced in the euphotic zone of the ocean by siliceous plankton such as diatoms or radiolarians.  $\text{BSiO}_2$  in marine sediments can be used as paleoproductivity proxy [1,2]. It holds a strong potential because of: (1) the role played by diatoms in the biological pump of  $\text{CO}_2$  [3]; (2) the presence of silica-rich sediments around Antarctica and in the equatorial Pacific [4,5], where both play a key role as high nutrient low chlorophyll (HNLC) areas; and (3) the high preservation efficiency of biogenic silica ( $\text{BSiO}_2$  3%, as reported by Treguer et al., 1995) relative to organic carbon ( $\text{C}_{\text{org}}$ , 0.1%, as reported by Emerson and Hedges 1988) [6,7].

Diatoms are the dominant phytoplankton and the primary source of deep-sea sediments around Antarctica [4]. Southern Ocean sediments account for 25-50% of all biogenic silica burial worldwide [6,8]. When conditions become favorable for growth, diatoms are able to exploit nutrient-replete conditions, and can quickly consume dissolved Si, converting it to  $\text{BSiO}_2$  [9], which then supports the rapid export of Si from the surface layer to the deep ocean [10]. This process also exports diatom carbon from the surface layer to the deep ocean, making diatom blooms important in both the Si and C cycles of the Southern Ocean.

In contrast to other regions of the World Ocean [4,6,11-16], only a few studies have ad-

dressed the distribution  $\text{BSiO}_2$  in sediments in the Indian Ocean sector of the Southern Ocean [17-19]. In present study, what is reported is to knowledge the preliminary results of biogenic silica content of surface sediments taken from Prydz Bay, Antarctic, during the CHINARE-18/21 cruise.

## 2 Materials and methods

Seven multiple core sediment samples (IV-8, IV-10, III-13, II-9, IS-4, IS-11, D-1) were collected by no-perturbation- -sediment-collector with four tubes, during the cruise of CHINARE-18/21. Fig. 1 and tab. 1 shows the investigation area and stations. The tube diameter of collector is 10 cm, and the height 60 cm, total core length rang from 10 cm to 35 cm. The sediment in the upper 10 cm of each core was sliced into 1 cm intervals, and then the lower part (below 10 cm) sliced into 2 cm intervals. The pore water separation from the sediment slices was done by centrifugation (at 4000 g for 30 minutes). The water samples filtered through 0.45  $\mu\text{m}$  pore size cellulose acetate filters and  $\text{HgCl}_2$  added to, then stored until further analysis. The residuals of sediment were frozen in the centrifuge tube and stored until to be analyzed. Sediment processing was all carried out at in situ temperature ( $2^\circ\text{C}$ ) to avoid temperature artifacts.

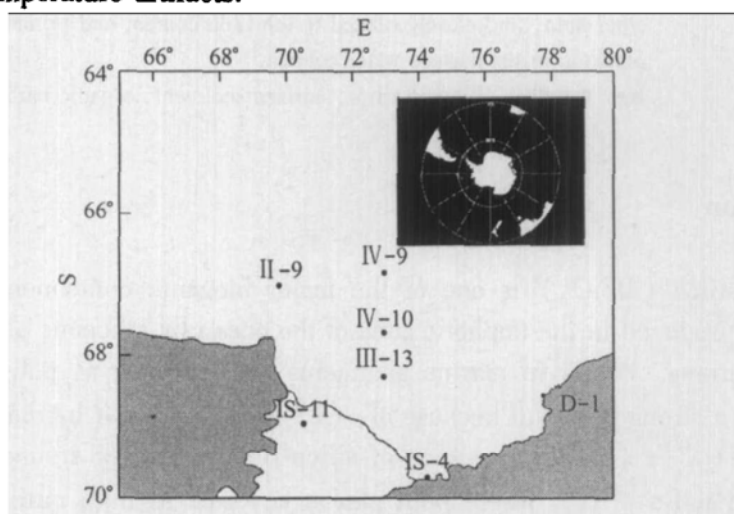


Fig. 1 Sampling stations in the Prydz Bay.

Table 1. Sampling station

| Station | Location                 | Depth (m) | Time      |
|---------|--------------------------|-----------|-----------|
| IV-8    | 72°59'06" E; 66°51'12" S | 510       | 2002-2-23 |
| IV-10   | 72°56'30" E; 67°30'00" S | 596       | 2002-2-23 |
| II-9    | 70°38'10" E; 66°53'00" S | 416       | 2005-1-30 |
| III-13  | 73°07'28" E; 67°59'51" S | 658       | 2005-1-31 |
| IS-4    | 74°04'45" E; 68°54'00" S | 678       | 2005-2-2  |
| IS-11   | 71°02'36" E; 68°32'36" S | 624       | 2005-2-1  |
| D-1     | 77°53'00" E; 68°33'00" S | 30        | 2002-2-25 |

The biogenic silica concentrations of the dry sediment were determined by wet alkaline

extraction [20]. In order to remove organics and carbonates, 5 ml 10%  $H_2O_2$  and 5ml 1N HCl were added. Sediment samples were placed in a centrifuge tube and digested in 2M  $Na_2CO_3$  at 85°C for 5h. Nutrients concentrations in pore water were analyzed in the laboratory using an autoanalyzer (Brown Lubbi). The chlorophyll a concentration was analyzed and determined with the fluorescence method in the "Standards of Marine Survey" (The STSA, 1991). Organic carbon (OC) in the sediments was determined by heatronic and infrared C/S analyzer.

### 3 Result

#### 3.1 Content of $BSiO_2$ in sediments

Biogenic silica contents of surface sediments from Prydz Bay are shown in Fig. 2-a. Very high  $BSiO_2$  contents of 85.41 wt. %, 68.20 wt. % were observed in IV-10 and III-13, respectively. The lower contents of  $BSiO_2$  were occurred in IS-4 21.02% and IS-11 27.95%, the two stations were near the Amery Ice-Shelf. In IV-8, which locate in the edge of the continental slope, the contents of  $BSiO_2$  were much lower than that in IV-10, however, there is only a half latitude interval between the two stations. Fig. 2-b is the distribution of OC, which show the similar trend like that of  $BSiO_2$ , the highest contents occurred in IV-10 with 1.05 wt. % and III-13 with 0.99 wt. %, and the lowest content was only 0.19 wt. % in IV-8. Fig. 3-a/b show the down core distribution of  $BSiO_2$ , in IS-4 and IS-11 the contents of  $BSiO_2$  of up10cm decreased sharply with depth, and under 10cm the contents changed weakly. Although there was not the sharp gradient of  $BSiO_2$  in both IV-10 and III-13 sediment profiles as in IS-4 and IS-11, the contents of  $BSiO_2$  in IV-10 and III-13 decreased with the irregular vary, especially in III-13.

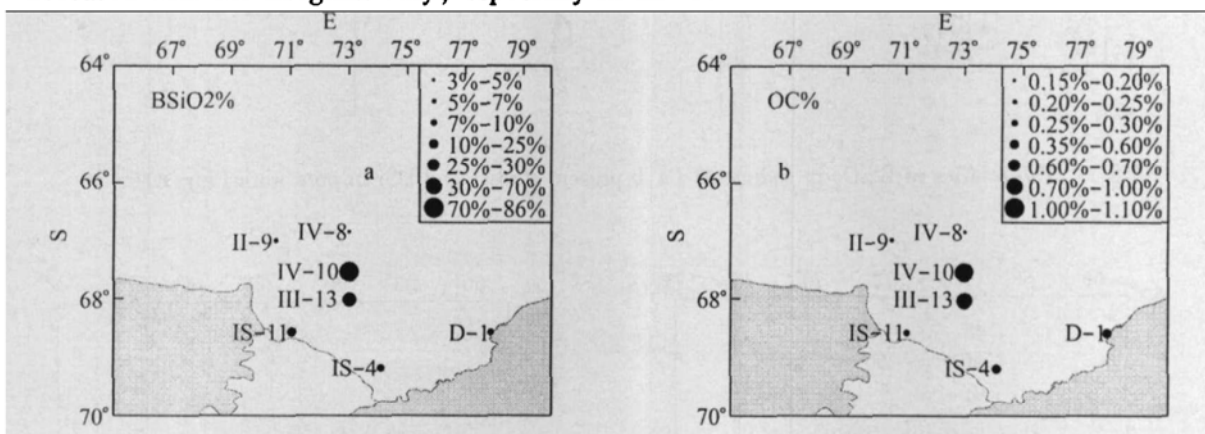


Fig. 2 Distribution of  $BSiO_2$  (a) and OC (b) in surface sediments in Prydz Bay.

The mole ratios of  $Si_{bio}/C_{org}$  ranged between 1.55 to 18.44 and the average value was 9.07. Since the  $Si_{bio}/C_{org}$  value of IV-10, III-13 was 14.47 and 12.26, respectively, which were significantly greater than the Si/C molar ratio value of 0.13, reported for diatoms growing under nutrient-replete conditions [21], and the reported  $Si_{bio}/C_{org}$  molar export ratio value of 2.6 at 1000m in the north open sea of Prydz Bay [22], sediments are enriched in biogenic silica relative to organic carbon during settling and burial. The increase

with depth in the  $Si_{bio}/C_{org}$  ratios requires an elevated sub-euphotic rate of  $C_{org}$  remineralization versus biogenic silica preservation<sup>[10,23-26]</sup>.

### 3.2 Distribution of $BSiO_2$ in sediments

Fig. 3-c shows the profiles of dissolved silicate (DSi) in the pore water of sediments in IV-8, IV-10 and D-1, which were contrary to the distribution of  $BSiO_2$  in sediment cores<sup>[27]</sup>. With depth increased the concentration of DSi in pore water exponentially approached to a stable asymptotic concentration of  $500-650 \mu mol/dm^3$ . The early diagenetic processes of  $BSiO_2$  in sediment were complicate and the dissolution process of  $BSiO_2$  was controlled not only by solid dissolution but also by the adsorption of clay and precipitation by authigenic mineral. In present study, dissolution was the main part during the burial process of  $BSiO_2$  and led to the enrichment of DSi in the pore water gradually. Although the pore water concentrations of DSi at IV-8 and IV-10 are similar, but the contents of  $BSiO_2$  different greatly in the sediment core at the two station, which indicate that there was significant difference in the  $BSiO_2$  dissolution mechanisms and the early diagenetic processes between the two stations.

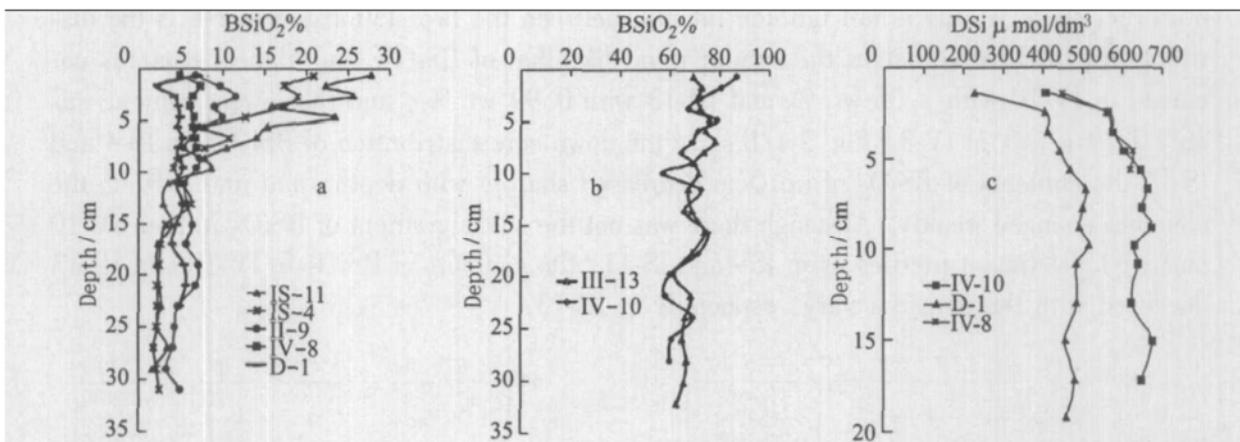


Fig. 3 The profiles of  $BSiO_2$  in sediments (a, b present study) and DSi in pore water (Fig. c)<sup>[27]</sup>.

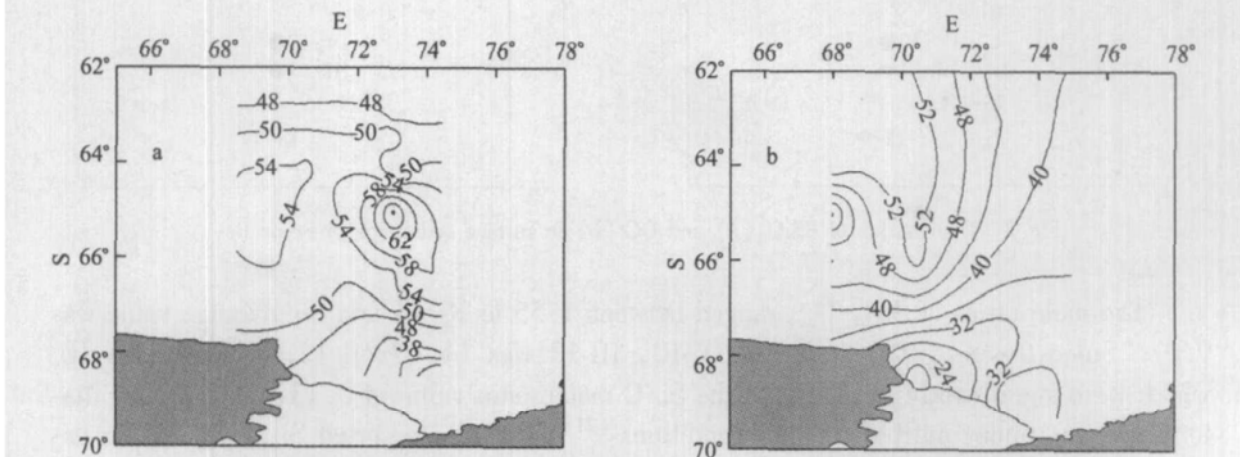


Fig. 4 Concentrations of silicate in surface water of Prydz Bay, a:2002, b:2005.

#### 4 Discussion

BSiO<sub>2</sub> in sediment is coming from the surface layer of the ocean, when biogenic silica is synthesized as siliceous phytoplankton (such as diatoms, radiolarians, silicoflagellates, and sponge spicules.) [12], mostly diatoms, build up their frustules by pumping silicic acid (dissolved silica) from the surface layer. Where high opal deposits are found in sediments high primary production is expected in the surface layer. In modern ocean environment and sediment, the key elements that control the distribution of BSiO<sub>2</sub> in the sediment include distribution of nutrients such as silicate in the surface water, content of chl<sub>a</sub>, primary production, and other environment factors, such as light and vertical stability of water masses and so on.

Silicate, or silicic acid (H<sub>4</sub>SiO<sub>4</sub>), is a very important nutrient in the ocean. Unlike the other major nutrients, such as phosphate, nitrate, or ammonium, which are needed by almost all marine plankton, silicate is an essential chemical requirement only for certain biota, such as diatoms, radiolaria, silicoflagellates, and siliceous sponges. The dissolved silicate in the ocean is converted by these various plants and animals into particulate silica, which serves primarily as structural material (i. e. the biota's hard parts). In the Prydz Bay, the average concentration of silicate was 40 μmol/dm<sup>3</sup>, which was much higher than the concentration 1-10 μmol/dm<sup>3</sup> of other area. Thus the silicate was not the limited factor for the growing of phytoplankton in Prydz Bay. Fig. 4-a/b show the concentration of silicate in the surface water during CHINARE-18(2002) and CHINARE-21(2005), in the Austral summer, high concentrations occurred in the continental slope and deeper open sea area, and low concentrations occurred in the inner part of Prydz Bay which near the Amery Ice Shelf. On the contrary, the concentrations of chl<sub>a</sub> and primary productivity were much higher in the Prydz Bay and the adjacent continental shelf, and lower in the continental slope and deeper open sea area, based on the data collected from several cruises [28,29]. The highest value of chl<sub>a</sub> concentration 3.86 mg/m<sup>3</sup>, and primary productivity 573.8 mg · m<sup>2</sup> · d<sup>-1</sup>, occurred in IV-10, during chinare-18(2001) (Fig. 5, Tab. 2<sup>[30]</sup>), the chl<sub>a</sub> concentrations ranged from 1.36 ~ 3.86 mg · m<sup>-3</sup>. Moreover, study of cell abundance, species composition of phytoplankton in Prydz Bay and its adjacent sea area during the Austral summer show that diatoms were predominant, the high abundance of phytoplankton occurred in the area south of 67°S in Prydz Bay<sup>[31,32]</sup>. In Fig. 6, positive correlation between chl<sub>a</sub> in surface water and BSiO<sub>2</sub>, OC in surface sediments were showed, which suggest that there was close correlation between the biogeochemical processes, such as primary productivity, in the up water column and BSiO<sub>2</sub> recorder in surface sediments.

Table 2. The value of primary productivity of Prydz Bay<sup>[30]</sup>

| Area  | continental shelf | slope       | deep sea     | average       |
|---|-------------------|-------------|--------------|---------------|
| primary productivity<br>/mg · m <sup>-2</sup> · d <sup>-1</sup> |                   |             |              |               |
| Net -   | 247.0 ± 178.7     | 8.3 ± 0.3   | 28.3 ± 25.2  | 84.3 ± 133.0  |
| Nano -  | 78.8 ± 36.9       | 18.9 ± 24.8 | 39.1 ± 42.0  | 46.3 ± 41.4   |
| Pico -  | 30.0 ± 4.5        | 54.7 ± 45.3 | 33.0 ± 21.3  | 36.1 ± 22.8   |
| total   | 355.8 ± 192.1     | 82.0 ± 20.8 | 100.5 ± 83.4 | 166.7 ± 160.3 |

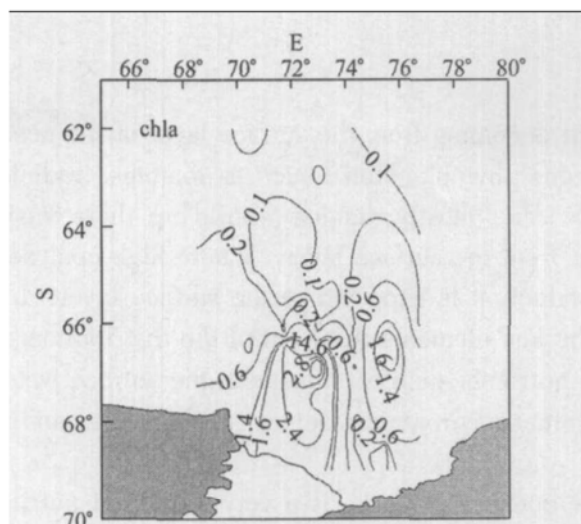


Fig. 5 Concentrations of chl a in surface water of Prydz Bay, 2002.

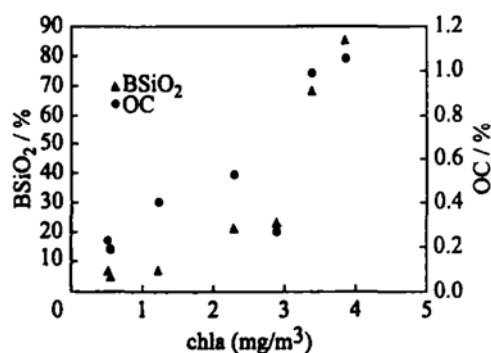


Fig. 6 The correlation between BSiO<sub>2</sub>, OC and Chl a in surface sediments.

Since stability of water masses is another key element for the primary productivity besides nutrients, the content and distribution of BSiO<sub>2</sub> in sediments were also controlled by the physical processes in the upper water column. The area south of 66.86°S is continental shelf, and the area north of 66.86°S is continental slope and open sea area. The slope area is near the Antarctica Divergence and infected by shearing of west wind drift and east wind drift, stronger surface mixing results in bad vertical stability [33,34], consequently result in mixed layer depths exceeding the euphotic layer depths. Therefore, phytoplankton forced by flow went through the euphotic layer quickly, and can not use sufficient light for photosynthesis, which leads to low chl a and primary productivity. IV-8 with low contents of BSiO<sub>2</sub> in the sediments was just in the edge of slope. However, IV-10 and III-13 were located in the mouth of Prydz Bay. The bay is dominated by the Amery Depression, a broad, deep basin. The depression is bordered by Four Ladies Bank to the northeast and Fram Bank to the northwest. Both of which are relatively shallow and form a partial barrier to water exchange with the deep ocean [35]. Thus in IV-10 stability of the water is strong and beneficial for the growth and propagation of the photosynthesis phytoplankton [28,30]. Another reason that assumed for the much higher concentration of IV-10 than that of IV-8 is the depositional environment, which in IV-10 is relatively stable than that in IV-8. In IV-8 the deep water column is influenced by the Antarctic Circumpolar Current (ACC), and most of the particle matters

have been removed by strong bottom currents. And a cyclonic gyre, which is centered in the mid- to western part of the bay, extending offshore to about 65°S [33,36], may also act as a transport mechanism, advecting the oceanic diatom assemblage onto the continental shelf where it eventually merges with the shelf and/or coastal assemblage.

## 5 Conclusion

From the resulted data, it is possible to draw the following conclusions.

1. Surface sediments from the Prydz Bay are characterized by very high BSiO<sub>2</sub> contents, and a regional pattern of contents show that maximum concentrations of both BSiO<sub>2</sub> and organic carbon were found in IV-10 which located in the continental shelf of Prydz Bay, and the lowest contents occurred in IV-8 which located in the edge of the continental slope. The biogenic silica/organic carbon ratios in sediments of Prydz Bay indicate that in study area preservation efficiency of organic carbon are higher than that of BSiO<sub>2</sub>. The study of the relations of BSiO<sub>2</sub> with environmental parameters show that spatial variation of BSiO<sub>2</sub> in sediments appears well correlated with the biogeochemical processes and stability of water masses in the upper surface water.

2. The down core concentration of BSiO<sub>2</sub> displayed a decrease from surface layer to the deep depth, especially in IS-4 and IS-11 concentration of BSiO<sub>2</sub> strongly decreased in the upper 10cm, however, the profile of DSi in pore water increased with depth, indicating that dissolution is the main process during the burial of BSiO<sub>2</sub> in sediments. There are significant difference in the BSiO<sub>2</sub> dissolution mechanisms and the early diagenetic processes among the stations.

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