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Application of biologic silicon in modern sedimentary section to reconstruction of phytoplankton changes in the East China Sea and the Huanghai Sea during last 200 years

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Abstract
Biomarkers had been widely used to reconstruct phytoplankton productivity, and this method was applied in the East China Sea and the Huanghai Sea (Yellow Sea). In this study, Biologic Silicon (BSi) was used as productivity proxy to reconstruct productivity change of phytoplankton during last 200 years. The results show that the BSi contents of surficial sediments were in the range of 0.018%–2.516%, averaging 0.726%, and had a similar variation trend with phytoplankton biomass. The vertical distribution profiles revealed that BSi contents were relatively stable, in accordance with the variations of the contemporary phytoplankton standing crop index. According to the stability analysis of BSi in sediments, BSi was not degradaded for the past two hundred years and remained in sediments steadily. Thus, BSi in sediments had the potential to invert paleoproductivity. To conduct further survey, the linear regression equation between BSi contents and phytoplankton biomass index could be used to calculate the phytoplankton productivity by BSi, so that paleoproductivity may be reconstructed during last 200 years.

Key words: typical sea areas of the East China Sea and the Huanghai Sea, sediment, BSi, productivity reconstruction

1 Introduction

The ocean is an important carbon reservoir containing 55 times more carbon than the atmosphere, the "biological pump" is the most important process of the ocean carbon cycle, and as primary producers, the phytoplankton largely control the "biological pump" efficiency. Phytoplankton total productivity can both change the biological pump and its control on carbon cycles. Therefore, understanding the geological evolution of phytoplankton productivity could help us decipher carbon cycle variability and mechanisms. Although the productivity distributions in different seas and lakes have been studied widely (Yang et al., 2004; Xing et al., 2008; Ragueneau et al., 2000; Kohfeld et al., 2005), an agreement on standards measuring productivity has not been achieved by researchers in the East China Sea and the Huanghai Sea. This study focuses on productivity reconstruction using the sediments from the survey sea. The location is influenced by air-sea interaction, and high sedimentation rates offer high resolution records to register both marine and human activities changes. Therefore, it is significant in figuring out the productivity index in the Huanghai Sea and the East China Sea to understanding the productivity variation and the ocean carbon cycle.

According to the material, biomarkers of the Huanghai Sea and the East China Sea had been carried out by researchers many times (Jia, 2008), however, there were few reports of paleoproductivity reconstrction of these sea areas. Based on the previous scientific results, this study will utilize BSi as an index, and discuss its content in sediments using the data over modern times for reference, in order to investigate the reconstructing potential of BSi in measuring the phytoplankton productivity in the Huanghai Sea

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and the East China Sea. It is the first time for BSi to be used in reconstructing the total number of phytoplankton over the last 200 years in these sea areas, in order to prepare for further investigating fluctuation of paleoproductivity, nutritive salt variation and eutrophication occurrence and development as well. This paper also focused on providing basic data on understanding the efficiency of "biological pump" and the development of carbon cycle.

2 Methods and stations

Samples were collected by multi-corers from the East China Sea and the Huanghai Sea during cruises in April and October 2006 (Fig. 1). The samples were sub sampled at 1–2 cm and conserved at the temperatures of 0 to 5°C. The samples were grinded after drying them at constant temperature of 60°C and then measured the contents of BSi by the way of

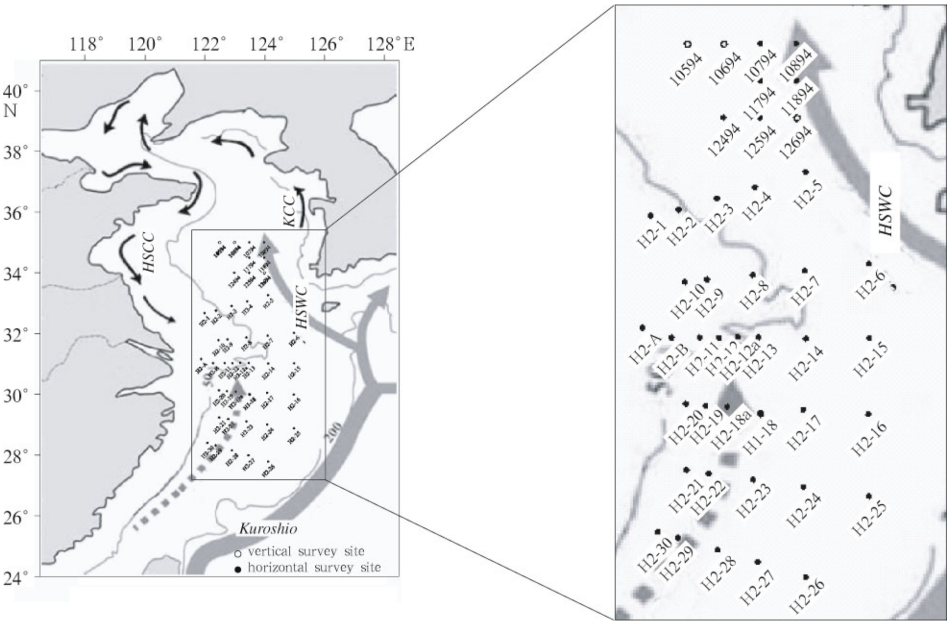

Fig.1. Investigation stations.

Zhao et al. (2005).

The ages of samples were determined with ^{210}Pb method and the starting time of 2006.

3 Results and discussion

3.1 *Results by sedimentation time*

The results of the ^{210}Pb dating of the four cores (Fig. 2) showed that the deposit velocities of Stas 10594, 10694 and 12694 in the southern Huanghai Sea were 0.350, 0.143, 0.153 cm/a, and the deposit histories of the three stations were about 150, 200, 230 a respectively. The deposit velocity of the Changjiang Estuary H1-18 was 0.225 cm/a, and the deposit history was about 130 a, These coincided with the result of Yang et al. (2010).

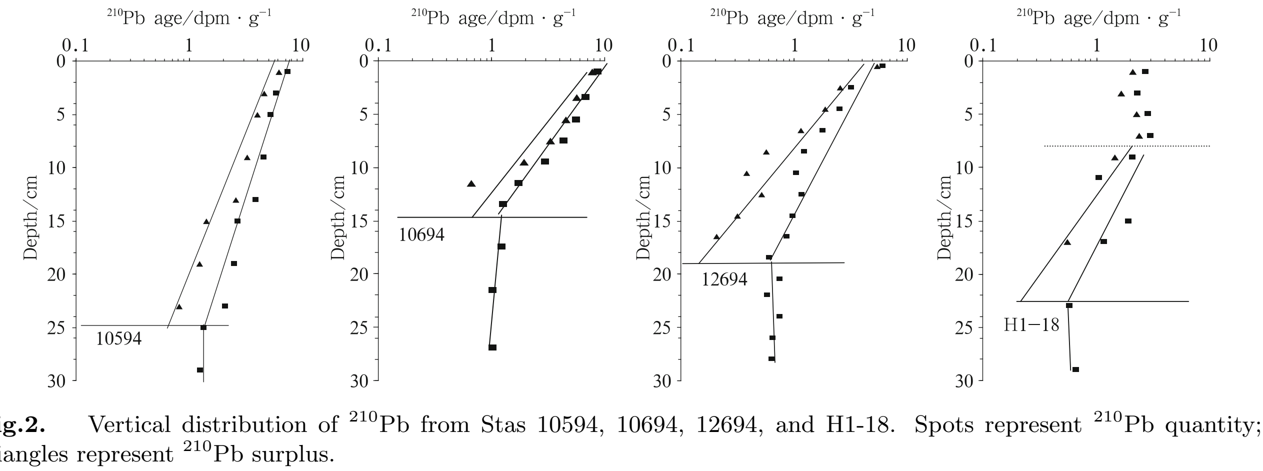

Fig.2. Vertical distribution of ^{210}Pb from Stas 10594, 10694, 12694, and H1-18. Spots represent ^{210}Pb quantity; triangles represent ^{210}Pb surplus.

3.2 *Horizontal distribution of BSi*

The results show that the horizontal distribution of BSi in the study area were in the range of 0.018%–2.516%, averaging 0.726% (Fig.3). Additionally, the Changjiang estuarine region was around the center of the investigated area. The lowest BSi value was found in Site H2-18 around there, which was as same as the result of research from Wang et al. (2008). The south of the study area with the affluent of nutritive salt between south Zhejiang offshore current and north Taiwan warm current where BSi contents were the highest (Baumgarter et al., 1992; Ning et al., 2000).

Above all, we concluded that the contents of BSi showed the reduced tendency from north to south and from coast to the distant sea. The phytoplankton biomass, diatom and chlorophyll a (Chl a) showed the similar tendency.

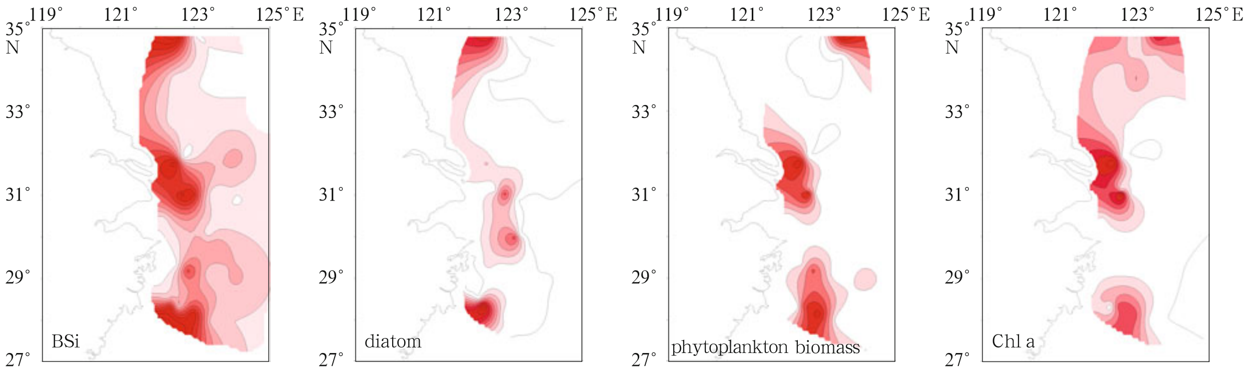

Fig.3. Horizontal distribution of BSi contents (%), phytoplankton biomass ($\times 10^4$ ind./m^3), diatom ($\times 10^4$ ind./m^3) and Chl a (mg/m^3) in sedimentations.

3.3 *Vertical distribution of BSi*

Effected by the stable currents, vertical distributions of BSi from three cores in the southern Huanghai Sea were relatively stable (Fig. 4). Due to the influence of offshore current in the southern Huanghai Sea, BSi contents in Core 10594 were as a whole higher than that in both Cores 10694 and 12694, showing a downward tendency in contents of BSi with time approaching. As to Core H1–18 near the Zhoushan Islands, the contents of BSi were relatively lower than other cores which may be caused by the terrigenous dilute effect (Yang et al., 2010), as well as, at 10 cm below the surface of the core, there was a relatively large fluctuation of the BSi contents as high as 0.782% ,which far exceeded the average level, the specific reason requires further research (Zhao et al., 2005; Ning et al., 2000; Chen et al., 2005; Ye et al., 2004; Wang et al., 2002; Shen et al., 1991; Shen et al., 1993; Lu et al., 1996).

4 Biogenic silica implications for phytoplankton productivity reconstructions

The distributions of BSi contents, diatoms, Chl a contents and the phytoplankton biomass in the study area were similar, which had close relationship with the primary productivity of sediments. On the premise that the BSi was stable in sediment for a long time, quantitative analysis could be made in the BSi and the phytoplankton biomass index to assess the paleoproductivity and to record the occurrence and development of the eutrophication.

4.1 *Correlation analysis between BSi of surface sediments and the phytoplankton standing crop*

It can be seen from Table 1 that BSi concentration was related to the contents of diatoms, phytoplankton biomass and Chl a. As a whole, the BSi mainly came from diatoms, so the level of linear fitting to BSi and diatoms was the highest (R^2=0.712 8, P=0.04). Therefore the distribution of BSi in sediments from the Huanghai Sea was significantly related to the diatom biomass and reflected its changes. In comparison, the relevance between BSi and phytoplankton biomass was not significant, which was reported by Liu et al. (2001) of the corresponding area. The reason may lie in that ocean phytoplankton distributed by regions and the proportion of diatoms among the whole phytoplankton biomass varies in regions (Wang et al., 2002; Shen et al., 1991; Shen et al., 1993; Lu et al., 1996; Liu et al., 2001; Jiao et al., 1998).

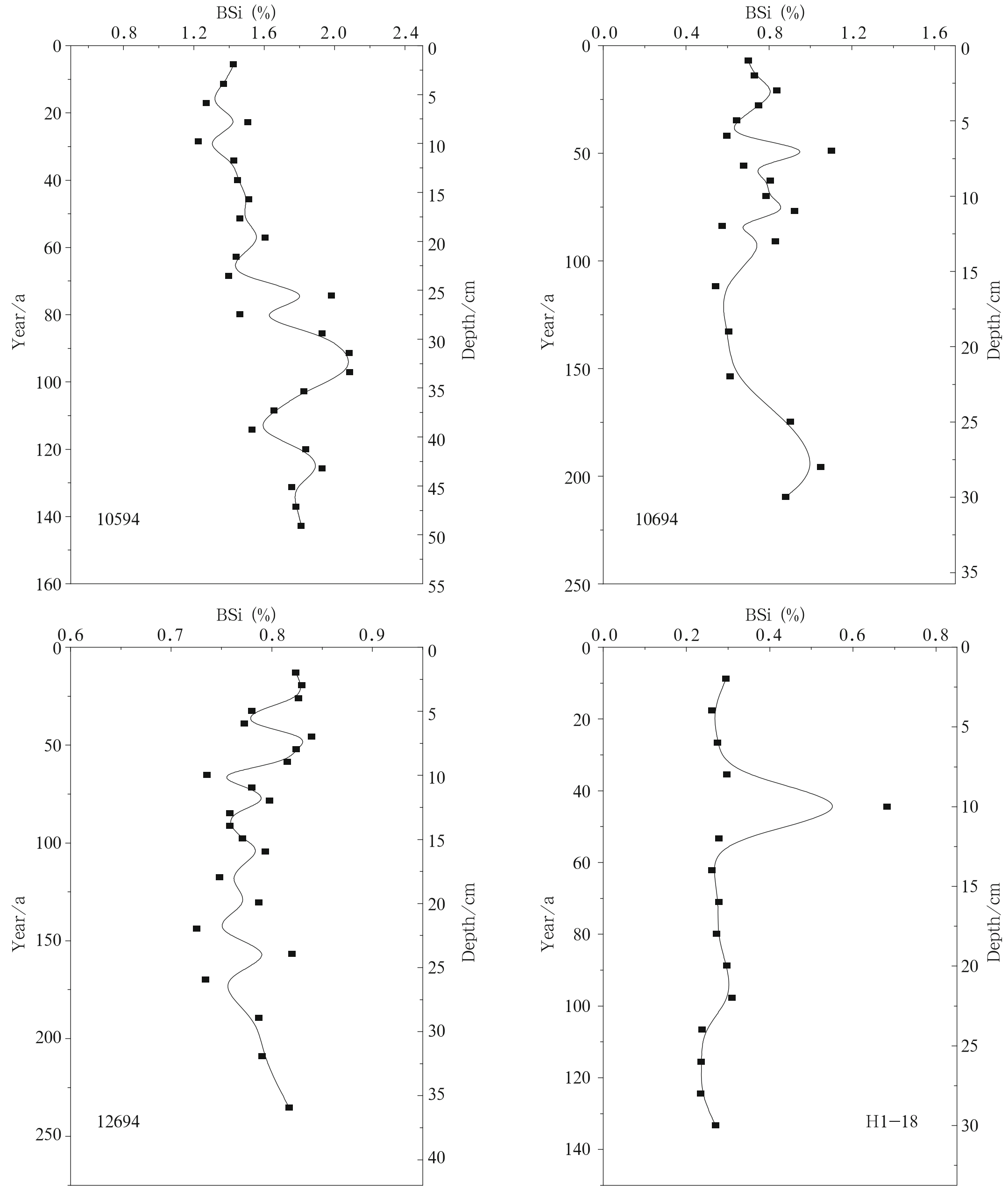

Fig.4. Vertical distribution of BSi.

Table 1. Relevance between BSi contents and phytoplankton standing crop index (P <0.05)

Phytoplankton biomass index	BSi	
	Regression equation	R^2
Diatom biomass/$\times 10^4$ ind.$\cdot$m^{-3}	$y = 13.9x - 38.531$	0.712 8
Phytoplankton biomass/$\times 10^4$ ind.$\cdot$m^{-3}	$y = 18.071x - 9.309\ 5$	0.308 3
Chl a contents/mg$\cdot$m^{-3}	$y = 0.501\ 8x + 0.181$	0.484 5

4.2 *Relevance between the BSi contents and phytoplankton biomass index in column sediments*

Because of the lack of data, we can only get the reports about the phytoplankton biomass index from 1961 to 2006. It was really hard to analyze the phytoplankton productivity over the last 200 years systematically. We were trying to use the trend lines and average level over four seasons to estimate the annual phytoplankton biomass index and chose the relatively reasonable data for analysis (Ning et al., 2000; Zheng et al., 2003; Zhou et al., 2004; Chen et al., 2006; Ning et al., 1985; Chai, 1986; Guo and Pan, 1992a,b; Gu and Yuan, 1995; Zhao et al., 2001; Wang et al., 2005).

It can be seen from Table 2 that there was a significant linear correlation between BSi and diatom at Core 10594 and 10694. The correlation could be attributed to three reasons: (1) at the south of the Huanghai Sea, half of the phytoplankton were made up by diatoms; (2) the BSi originates mainly from diatom; (3) vertical BSi variation may reflect the historical account. However, there was no significant correlation between BSi and diatom at Core 12694 (R^2=0.305 9, P=0.02), The reasons may be as follows: the thermocline of this area prevented the nutrient salts inputting from the bottom layer to the surface layer, which made the lower contents of nutrient salts and lower primary productivity (diatom contents less than 0.3×10^4 ind./m^3) at the euphotic layer, however, the contents of BSi were higher (the mean value of BSi was 0.788%) in the survey sea, which means the distribution trend of diatom contents did not accord with the mean value of BSi. Compared with the diatoms, the phytoplankton biomass and Chl a were influenced by more factors, such as the nutritive salt contents, the depth of water, ocean current and the temperatures (Long, 2002). So the correlation between the BSi contents and the phytoplankton biomass as well as between the BSi contents and Chl a were not significant. According to the results, the sedimentary environment of the southern Huanghai Sea was stable and the primary productivity were higher at Cores 10594 and 10694, the BSi could be used as the index to reconstruct the fluctuation of diatom (Chen et al., 2005; Wang, 2002; Shen, 1991; Shen, 1993; Lu et al., 1996; Liu et al., 2001; Long, 2002; Wang, 2001; Wang, 2002). On the other hand, because of the lower primary productivity, the sedimentary BSi may not be used as an index to reconstruct paleoproductivity fluctuation in Core 12694.

The historical events may be reflected well by the Vertical BSi variation, so there is a significant linear correlation between the BSi and the diatom at Core H1-18 (R^2=0.61); According to the investigation, almost 85% of the phytoplankton were made up by the diatom (Wang, 2000), so there was a significant linear correlation between BSi and phytoplankton at Site H1-18 (R^2=0.550 3).

Table 2. Relevance between the BSi contents and phytoplankton biomass index during the past 200 years (P <0.05)

Core	Phytoplankton biomass index	BSi	
		Regression equation	R^2
10594	Diatom biomass/$\times10^4$ ind.$\cdot$m^{-3}	$y = 131.63x - 2\ 684.3$	0.58
	Phytoplankton biomass/$\times10^4$ ind.$\cdot$m^{-3}	$y = 369.09x - 7\ 681.1$	0.38
	Chl a contents/mg$\cdot$m^{-3}	$y = 0.106\ 3x - 1.653\ 4$	0.46
10694	Diatom biomass/$\times10^4$ ind.$\cdot$m^{-3}	$y = 459x - 306.54$	0.764 5
	Phytoplankton biomass/$\times10^4$ ind.$\cdot$m^{-3}	$y = 714.54x - 461.4$	0.944 8
	Chl a contents/mg$\cdot$m^{-3}	$y = 0.101\ 2x + 0.023\ 6$	0.502 6
12694	Diatom biomass/$\times10^4$ ind.$\cdot$m^{-3}	$y = 154.26x - 392.96$	0.30
	Phytoplankton biomass/$\times10^4$ ind.$\cdot$m^{-3}	$y = 28.066x - 52.353$	7.06×10^{-2}
	Chl a contents/mg$\cdot$m^{-3}	$y = 0.065\ 2x + 0.506\ 9$	3.90×10^{-2}
H1-18	Diatom biomass/$\times10^4$ ind.$\cdot$m^{-3}	$y = 240.89x - 581.4$	0.61
	Phytoplankton biomass/$\times10^4$ ind.$\cdot$m^{-3}	$y = 77.07x - 180.27$	0.55
	Chl a contents/mg$\cdot$m^{-3}	$y = 0.287\ 5x + 0.697\ 5$	0.31

4.3 *Stability of BSi in sediments*

As the index of paleoproductivity, the stability of sedimentary BSi was an important factor which was mainly considered in this study. The method of Jia et al. (2008) was carried out to check up the stability of BSi.

From Fig.5, we could see that the contents of $\sum$ BSi fluctuated in the surface layer, which indicated that the state of the sedimentary BSi was unstable due to short depositing. Along with the years elapsed, BSi contents had arrived at the stable level progressively, and the $\sum$ BSi and sediment times showed significantly positive correlation. Therefore, it was concluded that BSi in sediments may be used as an index to reconstruct the fluctuations of paleoproductivity.

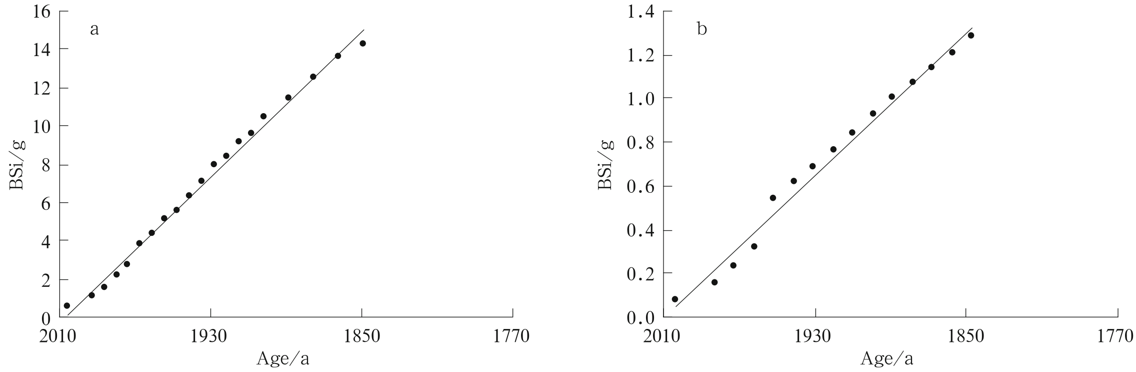

Fig.5. Linear regression analysis of ∑ BSi and age. a. The southern Huanghai Sea and b. the Changjiang River Estuary.

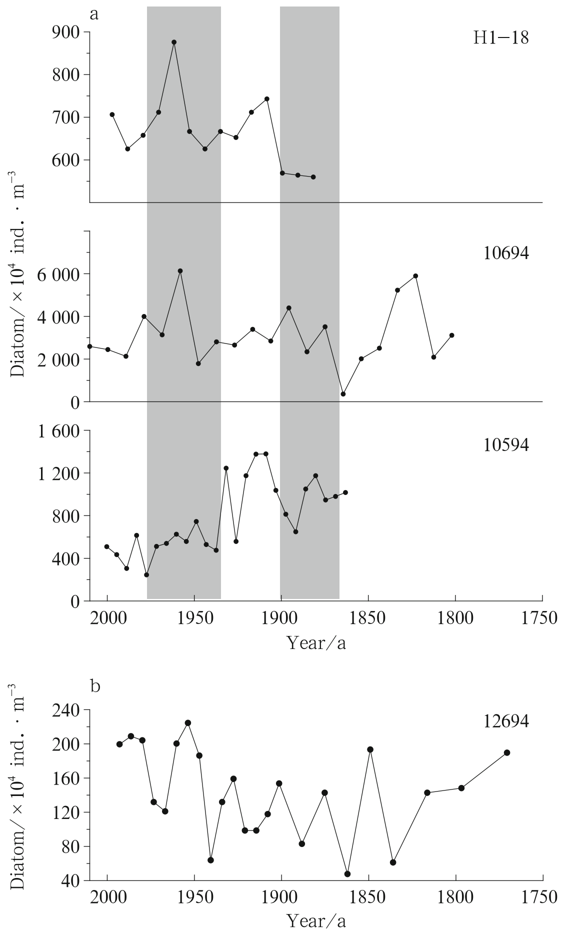

Fig.6. Phytoplankton biomass richness variation with times calculated by Bsi.

5 Reconstruction

From all the above discussion, we can draw a fundamental conclusion that BSi could be used as an index to reconstruct the diatom in Cores 10594, 10694 and H1-18 according to the equation of linear regression between the diatom and BSi contents.

According to Fig.6a, the averaging of diatom from Cores 10594 and 10694 was higher than Core H1-18, which was reported many times (Wang, 2002; Shen, 1991; Shen, 1993; Lu et al., 1996; Liu et al., 2001; He, 1998; Jia et al., 1998), it may be caused by the influence of the coastal current along the southwestern Huanghai Sea and the human being action. As well as, there was a lower level in about the 1890s, because of the lack of data, we can hardly found in any files, but the Sino-Japanese War around the study area and the war of 1900 launched by the allied forces of eight powers against China around those years, reducing the important nutrient for diatom just like BSi, N and P might rapidly cause the lower diatom contents. With the recovering of the area, the contents of diatom increased slowly and stably during the interval 1900s to 1940s, till 1960s, it was found that the diatom contents had a higher level which was proved in many files (Ning et al., 2000; Zheng et al., 2003; Zhou et al., 2004; Chen et al., 2006; Ning et al., 1985; Chai, 1986; Guo and Pan, 1992a, b; Gu et al., 1995; Zhao et al., 2001; Wang et al., 2005), which means the reconstruction was believable in these core during the last 200 years.

As to Core 12694 (Fig. 6b), it was discovered that the BSi content was relatively low and stable and the variation trends of diatom was not similar to other cores because of the BSi contents were not related to diatom (R^2=0.305 9) and we can not reconstruct the diatom by the BSi.

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