中国海洋学文集

OCEANOGRAPHY IN CHINA

14

海底演化、资源与环境研究

国家海洋局海底科学重点实验室　编

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2002年·北京

图书在版编目(CIP)数据

中国海洋学文集．14/陈荣华等著．—北京：海洋出版社，2002.4

ISBN 7-5027-5530-6

Ⅰ．中… Ⅱ．陈… Ⅲ．海洋学-文集
Ⅳ．P7-53

中国版本图书馆CIP数据核字(2002)第014157号

责任编辑 齐济美
责任印制 刘志恒

海洋出版社 出版发行
(100081 北京市海淀区大慧寺路8号)
北京海洋印刷厂印刷 新华书店发行所经销
2002年4月第1版 2002年4月北京第1次印刷
开本：787×1029 1/16 印张：7
字数：179.2千字 印数：1～550册
定价：18.00元
海洋版图书印、装错误可随时退换

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Seasonal Variations of the Planktonic Foraminiferal Flux in the Central South China Sea and Its Paleoceanographic Significance *

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Abstract Samples from the shallow and deep time-series sediment traps during 1993 ~ 1995 in the central South China Sea are analyzed for planktonic foraminiferal fluxes and stable-isotopic compositions are analyzed based on the samples. In result, the total planktonic foraminiferal fluxes, the fluxes and relative abundances of *Globigerinoides sacculifer*, *Globigerinoides ruber*, *Neogloboquadrina dutertrei*, *Globigerinita glutinata* exhibit two prominent peaks which occur in the prevailing periods of the northeast and southwest monsoons respectively, while those of *Globigerina bulloides*, *Pulleniatina obliquiloculata* and *Globorotalia menardii* have only one peak in the prevailing periods of the northeast monsoon. In addition, it is found that the fluxes of planktonic foraminiferal species exhibit obvious seasonal and annual variations. The observations indicate that these seasonal and annual variations are mainly controlled by the changes of surface primary productivity and hydrological conditions related to the East Asia monsoon. The $\delta^{18}O$ values of *G. ruber* exhibit obvious seasonal and annual variations which correspond to the sea surface temperature in the central South China Sea. The result indicates that the oxygen isotope compositions of *G. ruber* are mainly controlled by the sea surface temperature. The $\delta^{13}C$ values of *G. ruber* also exhibit the seasonal variations and the trend similar to the sea surface temperature, which indicates that the carbon isotope compositions of *G. ruber* are partly controlled by the sea surface temperature.

Key words foraminiferal flux, seasonal variation, sediment trap, paleoceanography, South China Sea

1 INTRODUCTION

A number of sediment-trap experiments show that the pelagic particulate matters mainly re-

* This project was a Sino-German cooperative project and was also supported by the National Natural Science Foundation of China under contract No. 49776297 and the Key Laboratory of Submarine Geosciences of State Oceanic Administration under contract No. 9903.

sult from the calcareous plankton which generally accounts for more than 50% ~ 60% of the total particle flux[1~2]. Among biogenic particulate materials the planktonic foraminifera is a main component[3], whereas siliceous plankton is a minor one. Therefore, the seasonal and annual changes of planktonic foraminifera are an important role in the study of the ocean flux and relating biogeochemistric process. Since 1987, numerous cooperative studies of the fluxes of the pelagic particulate matters have been carried out between China and Germany by deploying successive sediment-traps in the northern and central South China Sea. Two prominent peaks, roughly corresponding to the prevailing periods of the northeast (from mid October to mid March of the next year) and southwestern monsoons (June to August), are found in the sediment-trap samples[2,4~6]. However, the previous studies seldom refer to the flux changes of the planktonic foraminiferal genus and species as well as the relationship between the East Asia monsoon and ocean hydrographic condition. In this paper, quantitative analysis is done on the fluxes of planktonic foraminifera, carbonate, biopal and organic carbon revealing the paleoceanographic and paleoclimatic information in the sediment traps in the central South China Sea during 1 June 1993 to 2 May 1995.

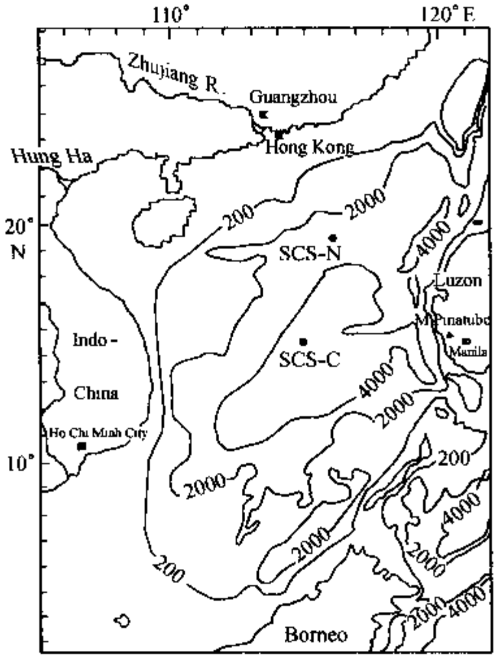


Fig. 1 Locations of the sediment traps in the central and the northern South China Sea in 1993~1995. Water depth isobath unit is in m

2 MATERIAL AND METHOD

The sediment-trap system during 1993 ~ 1994 in the central South China Sea (14° 35. 8′ N, 115°08.6′ E, 4 270 m water depth) consists of two Mark Ⅵ automatic time-series sediment-traps, which were anchored at the depths of 1 191 and 3 728 m respectively. The system during 1994 ~ 1995 in the central South China Sea (14°36.2′ N, 115°07.1′ E, 4 310 m water depth) is composed of three traps, which were fixed at 1 208, 2 243 and 3 774 m (Fig. 1) respectively. Detailed deploying for sediment traps, pretreatment and analyses of samples were done according to References [2]. Forty-seven samples are analyzed in this study, 24 samples of which come from the shallow layer traps and 23 samples from the deep ones. Every sampling interval is 28 d (see Fig. 2).

The fluxes of the planktonic foraminifera are calculated based on the statistic individuals larger than 150 μm, split of the trap sample, area of the trap aperture and the duration of each sample. The unit is ind/ $(m^2 \cdot d)$. The measuring methods of carhonate, biopal and organic carbon are referred to References [2, 4]. The surface primary productivity is estimated with the formula of Berger *et al*.[7]:

$$pp = J/(17/z + 1/100),$$

where pp presents the primary productivity (C) $[g/(cm^2 \cdot d)]$; J is the flux of particulate organic carbon at the depth of z (m).

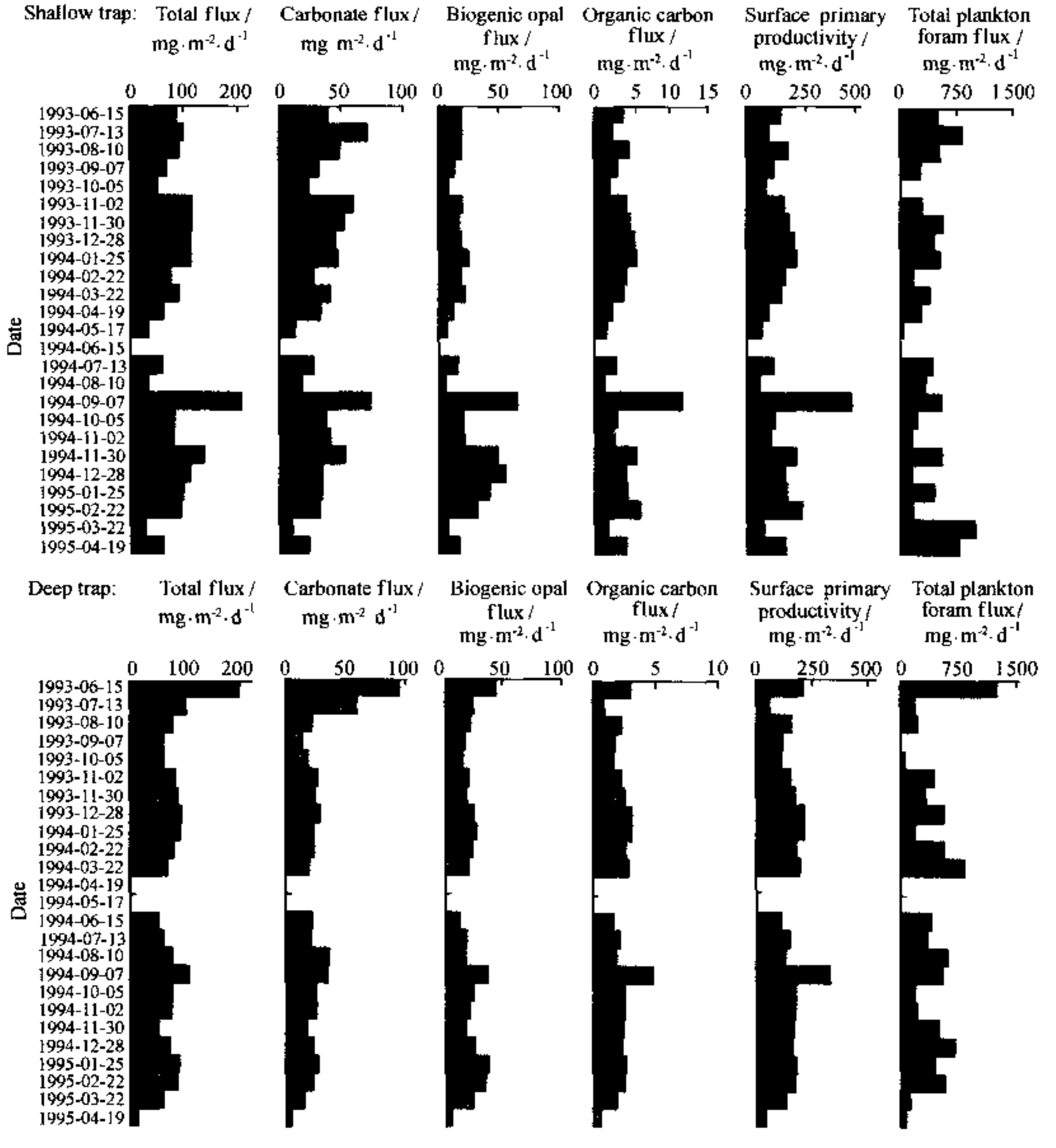


Fig. 2 Distributions of total particulate fluxes, carbonate flux, biogenic opal flux, organic carbon flux, surface primary productivity and total planktonic foraminiferal flux in the shallow traps and deep-layer traps in the central South China Sea

3 DISCUSSION AND CONCLUSIONS

The ranges of the planktonic foraminiferal fluxes in the shallow and deep layers in the central South China Sea are 10−996 and 13∼1 243 ind/$(m^2 \cdot d)$ with the averages of 407 and 415 ind/$(m^2 \cdot d)$, respectively (Fig. 2). Figure 2 shows that: (1) the total flux of planktonic foraminifera in the shallow trap is equivalent to that in the deep trap in the central South China Sea, while the total flux of the planktonic foraminifera in the deep trap reduces sharply compared with the shallow one[2] in the northern South China Sea due to the carbonate dissolution. This might be relative to the small individuals (bigger than 125 μm) included in the calculation of the total flux of the planktonic foraminifera at the northern station. In fact, the carbonate flux in the deep trap at the middle station [average of 27.6 mg/($m^2 \cdot d$)] reduces obviously compared with the shallow one [average of 38.6 mg/($m^2 \cdot d$)], which indicates that the dissolution of pelagic carbonates increases with the water depth, but the effect is small for the individuals bigger than 150 μm. (2) The total flux of tie planktonic foraminifera exhibits obviously seasonal fluctuations in the central South China Sea. The phenomenon occurs in the northern South China Sea and other sea areas, especially in the Arabian Sea[1-5,8-9]. The fluxes of total planktonic foraminifera have peak values during the periods of northeast and southwest monsoon prevailing, the same as the flux of carbonate, organic carbon, opal and surface primary productivity (see Fig. 2), namely, planktonic foraminifera has two "bloom" periods annually, which respectively correspond to the high surface productivity resulted from the winter or summer monsoon-prevailing periods. (3) The total fluxes of planktonic foraminifera in the central South China Sea in period of summer monsoon prevailing are roughly equivalent to those in period of winter monsoon prevailing. But the planktonic foraminiferal fluxes in summer in the northern South China Sea are apparently less than those in winter[10]. That might be due to the central station near the summer upwelling areas off Vietnam, which can be a further evidence on the bloom of the planktonic foraminifera controlled by the surface productivity.

The genera and species of the planktonic foraminifera in the traps of the central South China Sea are identified on the basis of Bé's work[11]. Eleven genera and 26 species are found with the dominancy of *Globigerinoides sacculifer* (average content 38.2%) and *Globigerinoides ruber* (average content 12.4%) which are dominant among them (see Figs 3 and 4). Besides, the species whose percentages are over 10%, are as follows: *Neogloboquadrina dutertrei*, *Globigerinita glutinata*, *Globigerinella aequilateralis*, *Globigerina calida*, *Globigerinoides conglobatus*, *Globorotalia menardii*, *Orbulina universa*, *Globigerina bulloides*, *Globigerinoides tellenus* and *Pulleniatina obliquiloculata*. The fluxes and relative percentages of these genus and species also exhibit an obvious seasonal fluctuation. Most of them reach the highest values when the northeast and southwest monsoons prevailing. For instance, *G. sacculifer*, *G. ruber*, *N. dutertrei* and *G. glutinata*, etc. have a typical two-peaks shape (see Figs 3 and 4). However, at the northern station of the South China Sea, the highest flux and relative percentage of *N. dutertrei* mainly occur in the period of northeast monsoon-prevailing. In fact, *N. dutertrei* represents the species of high productivity in many sea areas of the world, especially in the area of upwelling current[11]. The surface productivity at the northern station is higher in the period of northeast monsoon prevailing than in the period of southwest monsoon prevailing[6], so *N. dutertrei* mainly blooms in winter. Near the summer upwelling area, the surface productivity in the central station is also very high in summer, paralleling with that in winter[6] (see Fig. 1).

Because of their high fluxes and relative percentages in the period of northeast monsoon-prevailing, *G. bulloides*, *P. obliquiloculata* and *G. menardii* are typical species of winter (see Figs 3 and 4). Among the three species, the seasonal changes of *P. obliquiloculata* and *G. menardii* are in agreement with the result of study in other sea areas by planktonic hauls and sediment traps[3,11]. *G. bulloides* mainly distributes in the sub-polarity, upwelling areas at low latitude and boundary current areas[11]. For example, it is the dominant species of the summer upwelling areas in the Indian Ocean[12], while not as the symbol species of southwest monsoon-prevailing period in the South China Sea in summer. This also indicates that its distribution in the Late Quaternary strata in the South China Sea does not reflect the change of the surface productivity but might reflect the change of the hydrographic conditions such as surface water temperature[13].

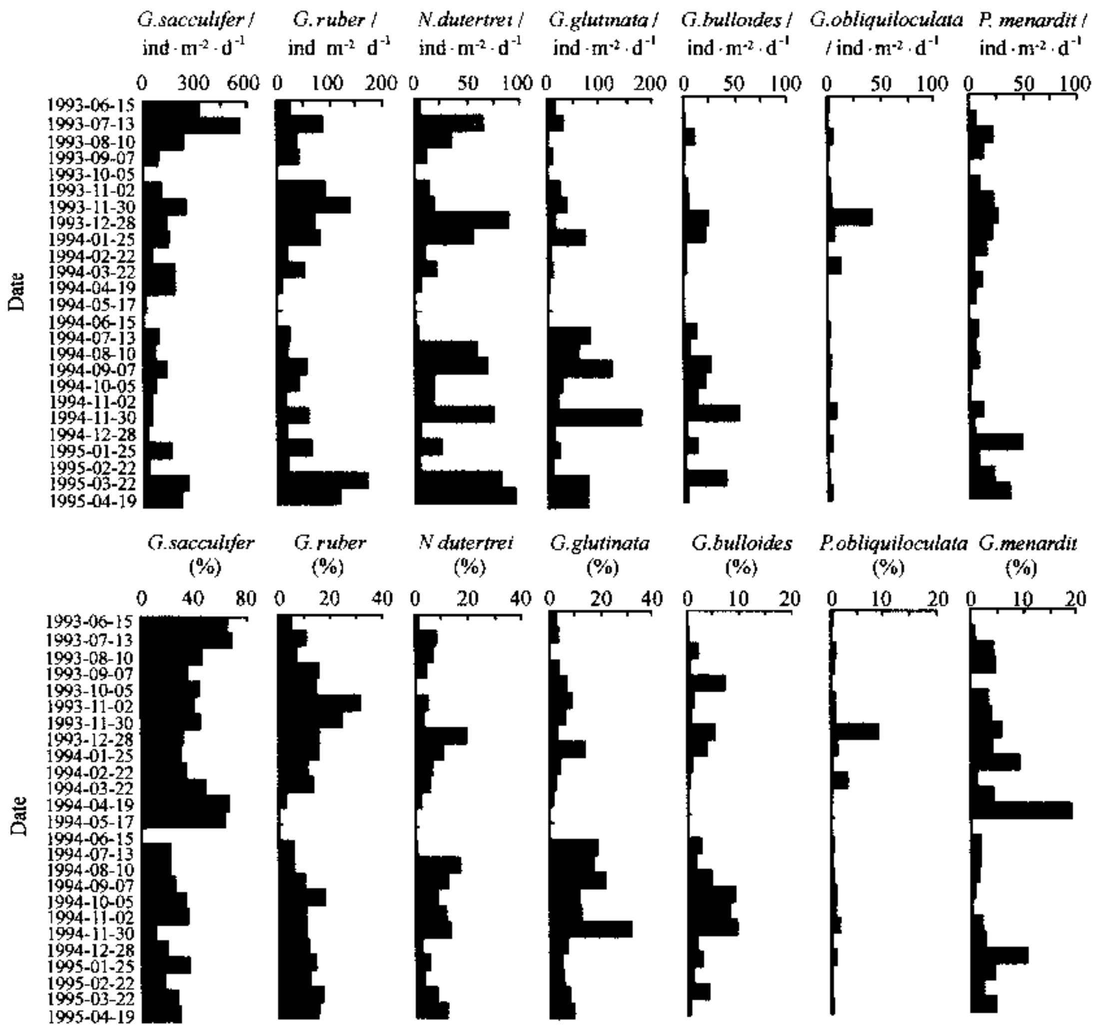


Fig. 3 Distributions of important species and relative abundances of planktonic foraminifera in the shallow sediment trap in the central South China Sea

The values of oxygen isotope of *G. ruber* tests exhibit obviously seasonal and annual varia-

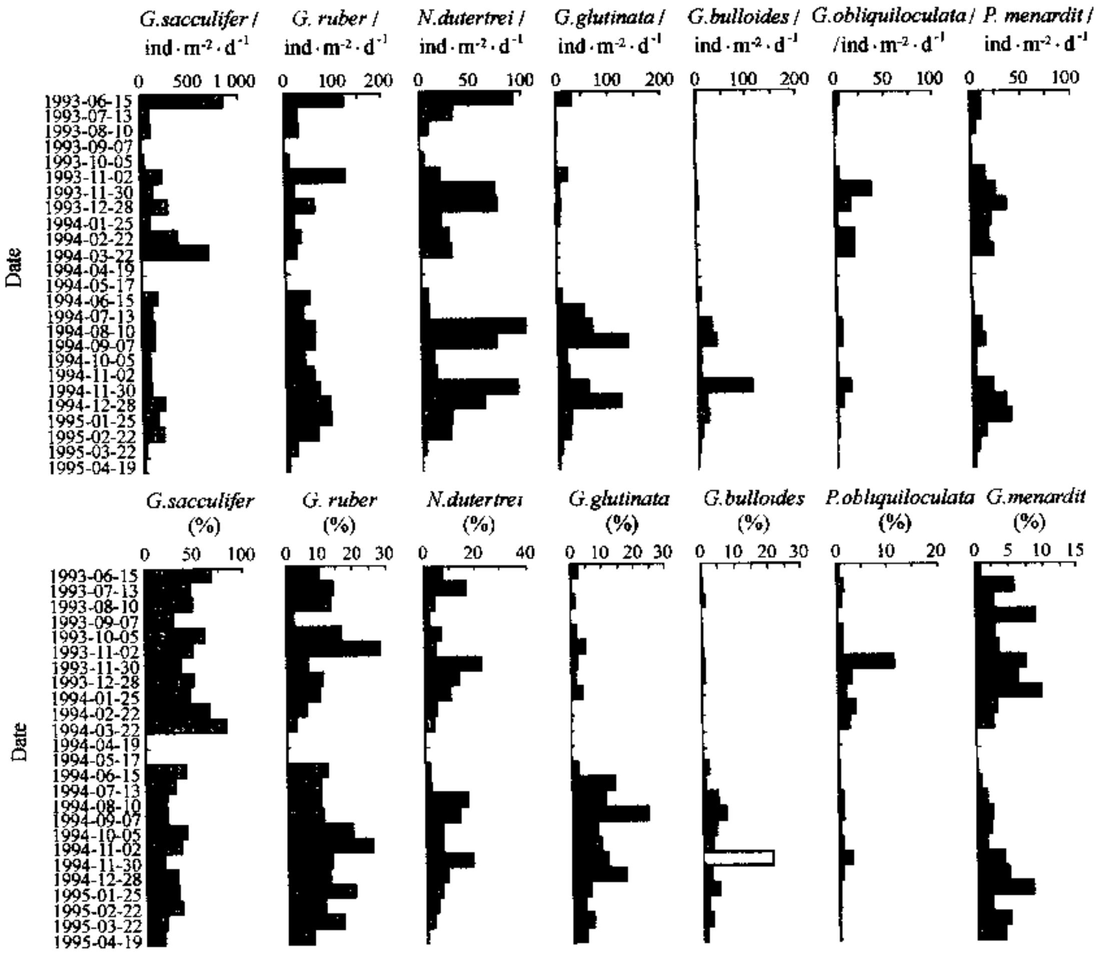
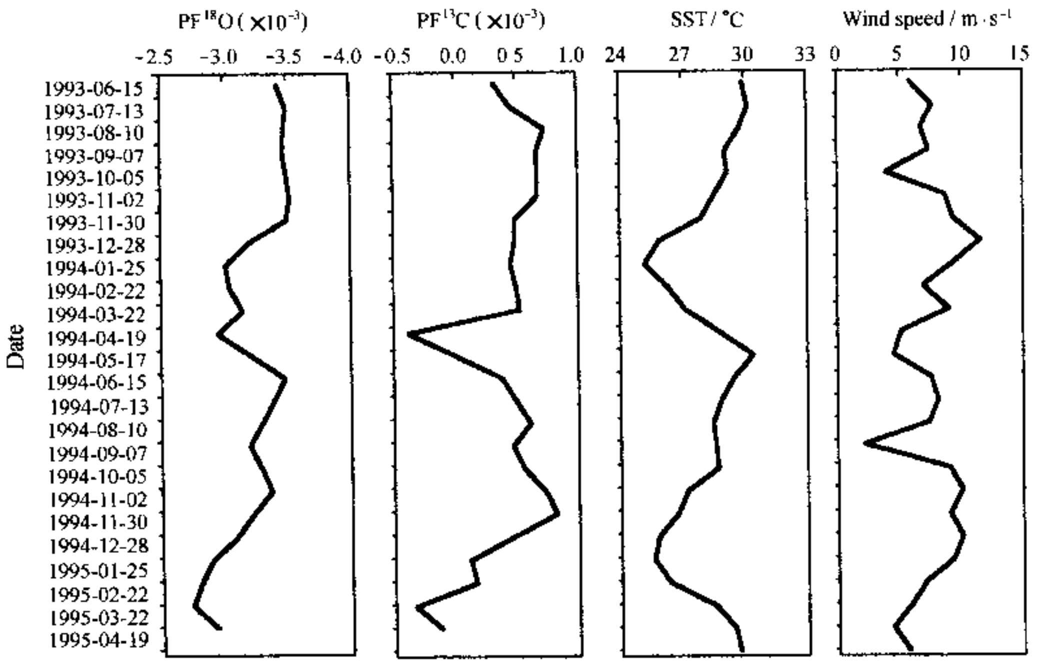


Fig. 4 Distributions of important species and relative abundances of planktonic foraminifera in the deep sediment trap in the central South China Sea

tions, similar to those of sea surface temperatures. The range of $\delta^{18}O$ values of *G. ruber* tests is between $-2.73 \times 10^{-3} \sim$ $3.52 \times 10^{\ 3}$, a little lighter in 1993～1994 than that in 1994～1995 (see Fig. 5). This indicates that the sea surface temperatures are a little bit higher in 1993～1994 than in 1994～1995 in the central South China Sea. The differences of $\delta^{18}O$ values are much smaller in the central station of the South China Sea than in the northern station of the South China Sea, and the differences of sea surface temperatures between summer and winter are larger in the northern station of the South China Sea than in the central station of the South China Sea, corresponding to the observation of the sea surface temperature of the South China Sea. The result indicates that the fluctuations of $\delta^{18}O$ values are mainly controlled by the sea surface temperature. In other words, the sea surface temperature is mainly controlled by the monsoons, especially the northeast monsoon (see Fig. 5).

The values of carbon isotope of *G. ruber* tests also exhibit seasonal and annual variations. But the fluctuations of $\delta^{13}C$ values of *G. ruber* tests are not corresponding well with the sea sur-



FigA. 5 Relationships of wind speed, sea surface temperature, ^{18}O and ^{13}C records in the central South China Sea

face temperature (Fig. 5). The result indicates that the fluctuations of $\delta^{13}C$ values are partly controlled by the sea surface temperature. In addition, the flux and relative percentage of each genus and species of the planktonic foraminifera have interannual variations too. For example, the flux and relative percentage of *G. bulloides* and *G. glutinata* in 1994 ~ 1995 are higher than those in shallow trap and deep trap in 1993 ~ 1994. However, an opposite trend is observed in the flux and relative percentage of *P. obliquiloculata* and *G. sacculifer* (see Figs 3 and 4). Because the optimum temperature ranges of the former two species are apparently lower than those of the latter two species[11], annual changes might reflect the surface temperature in the central South China Sea in 1994 ~ 1995 slightly lower than that in 1993 ~ 1994. This has been verified by the surface temperature observation of the central South China Sea. The $\delta^{18}O$ analysis also indicates that the sea surface temperatures are a little bit lower in 1994 ~ 1995 than those in the central South China Sea in 1993 ~ 1994.

Summarily, the total planktonic foraminiferal flux, the flux and relative percentage of each genus and species, $\delta^{18}O$ values are mainly controlled by the surface productivity as well as the hydrographic conditions such as surface temperature. Thus apparently seasonal and annual variations are exhibited. For paleoceanography and paleoclimate research, it is very important significance to further understand these variances of planktonic foraminifera and its isotope.

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Late Quaternary Sedimentary Diatom in the Okinawa Trough and Its Paleoceanographic Significance *

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Abstract The diatom abundance, relative content of dominant diatom species, micro-diatom species and its abundance, and distributive characteristics of tropic pelagic species abundance are described in Cores KL22 and KL18 from the northern Okinawa Trough. Some problems about the stratichronology of the cores and the ancient Kuroshio Current are also discussed. The results show that the main Kuroshio Current has not run through the study region since Late Pleistocene; and the sudden increases of diatom abundance and tropic pelagic species abundance in the cores are records of the paleoclimatic cooling events of Younger Dryas (YD) and Heinrich I (H1).

Key words sedimentary diatom, Late Quaternary, Okinawa Trough

1 MATERIAL AND METHODS

Cores KL22 and KL18, collected during Leg 50 of RV *Sonne* by China-Germany joint survey in 1987, are used in our study on the characteristics of Late Quaternary diatom in the northern Okinawa Trough (Fig.1 and see Table 1). The two cores are very close, 1.5 km apart from each other. Totally 57 samples of 4 cm thick and 8 cm interval are analyzed.

For each sample, 1 g dry sample is taken to be decalcified by 10% HCl, dispersed by 15% H_2O_2 boiling 15 min, washed by distilled water, concentrated by caldium heavy liquid with specific gravity of 2.4, and then made into fixed slides. For each sample, over 200 valves or 18 cm×18 cm standard slides are identified and counted, and then conversed into individuals of diatom valve per gram sample.

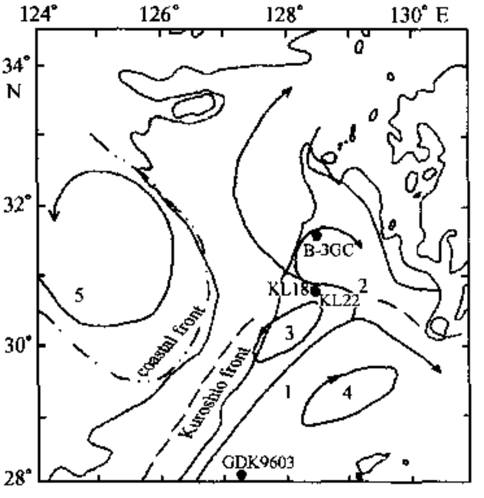

Fig. 1 Sketch map of study cores and circulation in the Okinawa Trough
1. Kuroshio Current, 2. Kuroshio branch, 3. eddy northwest of the turn of Kuroshio, 4. warm eddy northwest of Amami Island, 5. cyclonic eddy south of Cheju Island

* This study was supported by the Key Laboratory of Submarine Geosciences of State Oceanic Administration.

Table 1　General situation of study cores

Core	East longitude	North latitude	Water depth/m	Core depth/cm	Sample amount
KL22	128°28.0′	30°48.0′	787	123～700	48
KL18	128°27.3′	30°48.8′	770	0～118	9

2　RESULTS

2.1　Distributive characteristics of diatom

2.1.1　Diatom abundance

The diatom cells in Cores KL22 and KL18 are extremely abundant. The absolute abundance is between 1×10^5 and 4×10^5 grains/g for most samples. It suddenly increases to more than 2×10^6 grains/g at 575～579 and 239～243 cm. The lowest value is 4 700 grains/g at 54～58 cm (Fig.2).

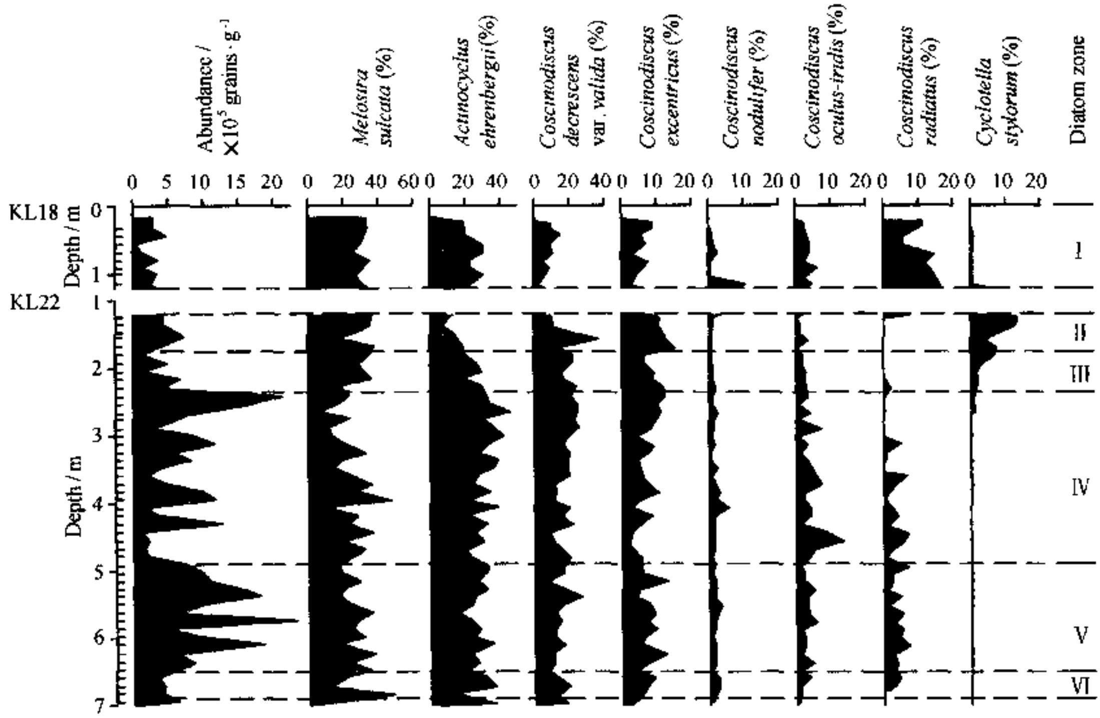

Fig. 2　Distribution of dominant species of Late Quaternary diatom in Cores KL22 and KL18 from the northern Okinawa Trough

2.1.2　Dominant diatom species and their distribution

One hundred and twenty-five diatom species and varieties belonging to 43 genus are identified in Cores KL22 and KL18, including 12 freshwater species, 7 brackish water species and 106 sea water species and varieties. There are 8 dominant species as follows:

(1) *Melosira sulcata*. It is a species with maximum relative content in Cores KL22 and KL18. Except that it is 5.38% and 9.48% at 263～267 and 407～411 cm respectively, the contents are all over 10.00% for the other samples, most of them over 25.00%, with a maximum of

48.85%.

(2) *Actinocyclus ehrenbergii*. The contents of the species are nearly the same as the former species. Except that it is less than 10.00% at 135~139 cm, the contents for the other samples are all over 10.00%, with a maximum of 45.29%. It is seen from Fig. 2 that the content is between 20.00% and 30.00% for Section 0~118 cm, less than 20.00% for Section 123~190 cm and more than 20.00% for Section below 190 cm.

(3) *Coscinodiscus decrescens*. The relative contents of the species are over 15.00% for Section 147~363 cm with a maximum of 37.31% and less than 10.00% for most of the other samples.

(4) *Coscinodiscus excentricus*. The relatively high contents of the species mainly concentrate in Section 123~280 cm, mostly over 8.00% with a maximum of 14.93%. They are commonly less than 8.00% for the other samples.

(5) *Coscinodiscus nodulifer*. The contents of the species are less than 5.00%, except at 114~118 and 407~411 cm, 10.30% and 5.21% respectively.

(6) *Coscinodiscus oculus-iridis*. The contents of the species are over 5.00% for Section 440~475 cm with a maximum of 13.62% and also at Samples 90~94, 287~291, 359~363 and 575~579 cm. They are relatively low for the other samples.

(7) *Coscinodiscus radiatus*. The species mainly distributes in Section 0~118 cm with contents of between 5.00% and 16.00%. The contents for the other samples are relatively low.

(8) *Cyclotella stylorum*. It is a nearshore low-salinity species and concentrates in Section 123~190 cm with contents of between 6.00% and 14.00%.

2.2 Micro-diatom

Micro-diatoms, diatoms with cell diameter being not greater than 20 μm, are analyzed and counted for 35 samples.

2.2.1 Micro-diatom abundance

Micro-diatom is rather abundant, with an abundance of over 1×10^4 grains/g for most samples and over 5×10^4 grains/g at 395~399 and 635~639 cm, but less than 3 000 grains/g in Section 54~75 cm.

2.2.2 Micro-diatom species and their distribution

Totally 27 micro-diatom species and varieties belonging to 16 genus are identified. Among them, the relative content of *Melosira sulcata* is over 92.00% in all samples. Five species, *Delphineis surirella*, *Cyclotella striata*, *Cyclotella stylorum*, *Thalassiosira oestrupii* and *Thalassionema nitzschioides* var. *parva* are found in most samples (see Table 2). Nine species, *Rhaphoneis amphiceros*, *Coscinodiscus robustus*, *Coscinodiscus nodulifer*, *Xanthiopyxis globosa*, *Cymbella parva*, *Rhaphoneis crinigera*, *Thalasiosira eccentrica*, *Plagiogramma pulchellum* and *Synedra tabulata*, only occur in Section 470~690 cm. The other species distribute scatteredly.

2.3 Distribution of tropic pelagic species

Seven tropic pelagic species, *Coscinodiscus nodulifer*, *Rhizosolenia bergonii*, *Nitzschia marina*, *Hemidiscus cuneiformis*, *Roperta tesselata*, *Coscinodiscus africanus* and *Pseudoeunotia*