Chinese Science Bulletin

© 2007 Science in China Press

Springer-Verlag

ARTICLES

Benthic foraminiferal fauna turnover at 2.1 Ma in the northern South China Sea

HUANG BaoQi[1,2†], JIAN ZhiMin[2] & WANG PinXian[2]

[1] School of Earth and Space Sciences, Peking University, Beijing 100871, China;
[2] Laboratory of Marine Geology, Tongji University, Shanghai 200092, China;

Quantitative analysis of benthic foraminifera from ODP Site 1146 in the northern South China Sea (SCS) shows that abundance of *Bulimina alazanensis*, sometimes up to about 90%, decreased gradually since 3.2 Ma, especially at 2.1 Ma. Abundance of other benthic foraminiferal species, *Globobulimina subglobosa* and *Cibicidoides wuellerstorfi*, increased after 2.1 Ma. Comparison with changes in oxygen and carbon isotopes of planktonic and benthic foraminifera shows that high abundance values of *B. alazanensis* corresponded with lower values of oxygen isotope, but for carbon isotope, high values of the species were consistent with heavier carbon isotope of benthic foraminifera and lighter carbon isotope of planktonic foraminifera, respectively, and *vice versa*. Considering factors such as uplift of Bashi Strait, expansion of the North Hemisphere Glaciation, strengthening of East Asian winter monsoon and variations in oxygen and carbon isotope of foraminifera, changes of *B. alazanensis* in ODP Site 1146 suggest that the source of deep water masses of the northern South China Sea changed from the warm Pacific deep water with high oxygen content to Pacific Intermediate water with low oxygen content at 2.1 Ma. In addition, the strengthened East Asian winter monsoon resulted in increased primary productivity, high nutrient and suboxic bottom water. Variations in species of *B. alazanensis* seemed to be unable to tolerate environmental stress induced by deep water masses and productivity changes.

paleoceanography, benthic foraminifer *Bulimina alazanensis*, Late Pliocene, northern South China Sea

OCEANOLOGY

1 Introduction

Most studies and discussions about the Late Pliocene were focused on the interval of 3.1—2.5 Ma for the significance of the North Hemisphere Glaciation, but some events taking place at 2.1 Ma could be also found in many places including the Atlantic, Pacific, and Indian oceans, as well as on the African Continent. These changes occurring at 2.1 Ma are mainly related to variations in ocean current, primary productivity, monsoon system and Northern Hemisphere glaciation, which maybe connected with closure of the Indonesia Seaway and the emergence of the Isthmus of Panama. For instance, North Atlantic Deep Water (NADW) beginning to shoal at 2.0 Ma especially during glaciations may have resulted in reduced meridional heat transport, resulting from the final closure of the Panama Seaway[1]. Sea surface temperature (SST) decline at 2.1—1.9 Ma off the coast of Namibia, and the Homo genus occurrence and mammals adapted to grazing and arid conditions increase at about 2 Ma in South Africa were considered to be caused by final closure of the Indonesian Seaway[2]. High primary productivity is recorded from the Indian Ocean between 1.8 Ma and 1.2 Ma, possibly as a result of year-round monsoonal upwelling[3].

Benthic foraminifer is one of the most widely distributed marine organisms. Their species diversity and

Received April 7, 2006; accepted December 19, 2006
doi: 10.1007/s11434-007-0114-3
†Corresponding author (email: bqhuang@pku.edu.cn)
Supported by the National Nature Science Foundation of China (Grant No. 40306007)

dominance are known to be affected by various factors of the deep-sea environments, including water depth, temperature and salinity[4,5]. However, in recent studies, most results suggest that bottom-water oxygen and organic content are the important factors in controlling the production and distribution of benthic foraminifer[6−12]. The organic carbon and oxygen contents of deep-water are controlled not only by productivity of the upper water, but also by ventilation, especially for marginal seas, such as the South China Sea (SCS)[13].

Previous studies have suggested that the East Asian monsoon controlled the surface currents and the distribution of nutrients, and hence the characters of deep water of the SCS[14 − 17]. Moreover, different water masses of the SCS are sourced from corresponding water masses of western Pacific, so the sill depth of Bashi Strait, as a door between the SCS and Pacific, is of crucial significance[13]. Present depth of the sill is about 2500 m, therefore, waters deeper than 2500 m do not pass through the sill and enter into the SCS.

In this study, we focus on the variations in benthic foraminiferal assemblages and oxygen and carbon isotopes, to discuss characteristic changes of deep-water masses of the SCS, and hence to discuss potential causes of the change at 2.1 Ma in the northern SCS.

2 Material and methods

ODP Site 1146 in the SCS is located on the northern continental slope of the SCS (19°27.40′N, 116°16.37′E) at a modern water depth of 2092 m[18]. Presently, this site sits above the sill depth of the Bashi Strait and present lysocline. Three holes were drilled at Site 1146 with the deepest reaching 642.25 mcd (meters composite depth), according to the shipboard age model extending to approximately 19 Ma. The recovered sediments are mainly hemipelagic muds and silts, and can be divided into three parts: Unit I (0.0—242.68 mcd) is composed of greenish gray nannofossil clay; Unit II (242.68—553.02 mcd) consists of light brownish gray clayey foraminifer and nannofossil ooze and foraminifer clay fossil mixed sediment; and Unit III is dominated by green nannofossil clay (553.02—642.31 mcd)[18]. In this study, we focused on the upper 247 mcd, covering about 4 Ma. The sampling resolution is about 10 ka, and a total of 400 samples were examined.

Samples of approximately 10 cm^3 of sediment were disaggregated by soaking in tap water for several days until the samples were dispersed completely. Then the samples were wetly sieved over a 63 μm screen and dried in an oven under 60℃. The coarse fractions (>154 μm) were split into subsamples containing over 150 benthic foraminifera tests and 250 planktonic foraminifera, which were then picked, counted, and identified according to Loeblich and Tapan[19], Ujiie[20], and Lutze[21] for benthic foraminifera.

In order to discuss primary productivity and oxygen content of bottom waters, we estimated the oxic indicator and dysoxic indicator after Den Dulk[22] and Kaiho[11], with the oxic indicator including *Cibicidoides* spp., *Cibicides* spp., *Globocassidulina subglobosa*, *Laticarinina pauperata*, *Nuttaloides*, *Osangulina*, *Stensioeina*, *Gavelinella*, and *Miliolids* and dysoxic indicator including *Alabamina* spp., *Astrononion pusillum*, *Bolivinita striata*, *Cancris inaequalis*, *Cassidulina* spp., *Ceratobulimina pacifica*, *Favocassidulina favus*, *Bentalina* spp., *Ehrenbergina pacifica*, *Fissurina*, *Stsinforthia*, *Tosaia hanzawai*, *Trifarina*, *Uvigerina*, *Gyroidina*, *Gyroidinoides*, *Hoeglundina elegans*, *Lagena*, *Lenticulina*, *Melonis*, *Nonoin*, *Oridorsalis*, *Pullenia*, *Rosalina*, *Sphaeroidina*, *Valvulineria*, *Bulimina aculeate*, *Elphidium excavatum*, and *Nonionella*.

The age model applied in this study is after refs. [23, 24].

3 Results and discussion

3.1 Faunal turnover of the benthic foraminifera

Our results show that the abundance of *B.alazanensis* in ODP Site 1146 changed dramatically at about 2.1 Ma. Prior to this time, the abundance of *B. alazanensis* was very high reaching 90 %, however, after 2.1 Ma the abundance decreased sharply to zero, and it was absent in most of time since 2.1 Ma (Figure 1). Other species of benthic foraminifera, *Globobulimina subglobosa* and *Cibicidoides wuellerstorfi*, increased after 2.1 Ma. In addition, abundance of suboxic species of benthic foraminifera decreased, while oxic species increased (Figure 1).

3.2 Carbon and oxygen isotope evidence from surface and bottom water

Comparing the changes in abundance of *B. alazanensis* with the variations in $\delta^{18}O$ and $\delta^{13}C$ of *G. sacculifer* and *C. wuellerstorfi* from ODP Site 1148[25], we find that the

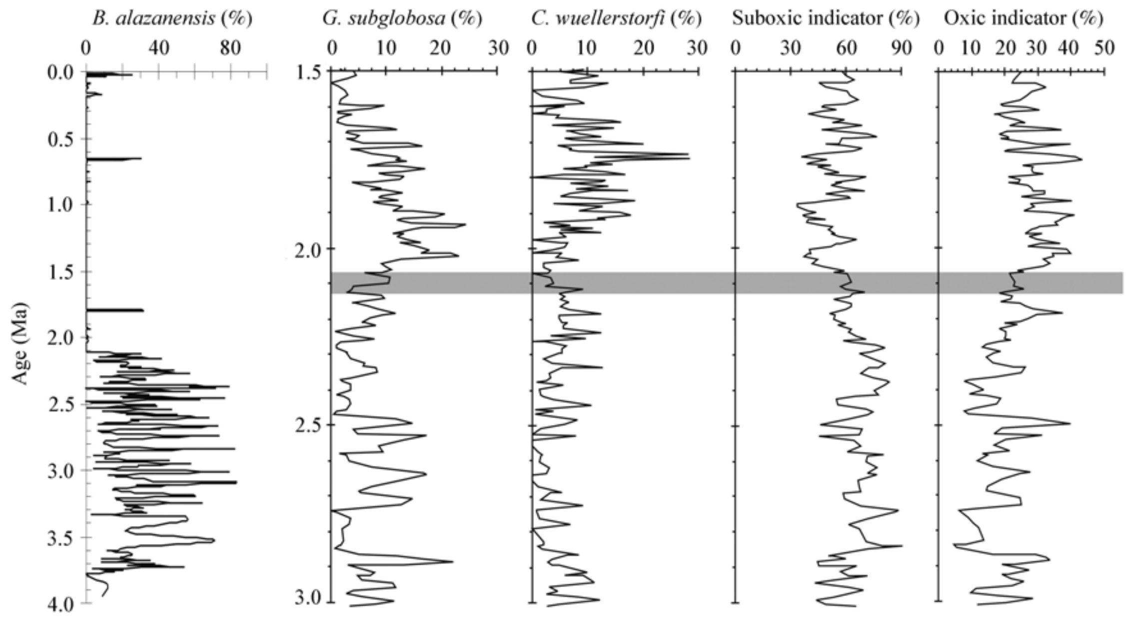

Figure 1 Changes in abundance of benthic foraminifera at ODP Site 1146 from northern SCS.

value of δ^{18}O of *G. sacculifer* was about −3‰ before 2.1Ma, afterwards, the value increased to −2‰; The δ^{13}C of *G. sacculifer* showed an abrupt decrease at about 2 Ma from about 1‰ to 0.5‰. Comparing with planktonic foraminifera, the values of δ^{18}O and δ^{13}C of *C. wuellerstorfi* changed a little, but at 2.1Ma, the values of δ^{18}O increased and those of δ^{13}C decreased sharply (Figure 2).

Compared with the variations in δ^{18}O and δ^{13}C of planktonic and benthic foraminifera between 3.2 and 2.0 Ma from ODP Site 1146, the change in abundance of *B. alazanensis* coincide with the δ^{18}O and δ^{13}C changes of planktonic foraminifera. The abundance of *B. alazanensis* was higher when the values of δ^{18}O and δ^{13}C were greater, indicating interglacial stage, but in glacial periods the abundance of *B. alazanensis* was lower (Figure 3). Similar to the above results, *B. alazanensis* appears to prefer to the warm, low salinity and nutrient, but high oxygen-content waters.

The physical and chemical characteristics of the SCS were influenced by upper water structure controlled by East Asian monsoon. In addition, water masses below

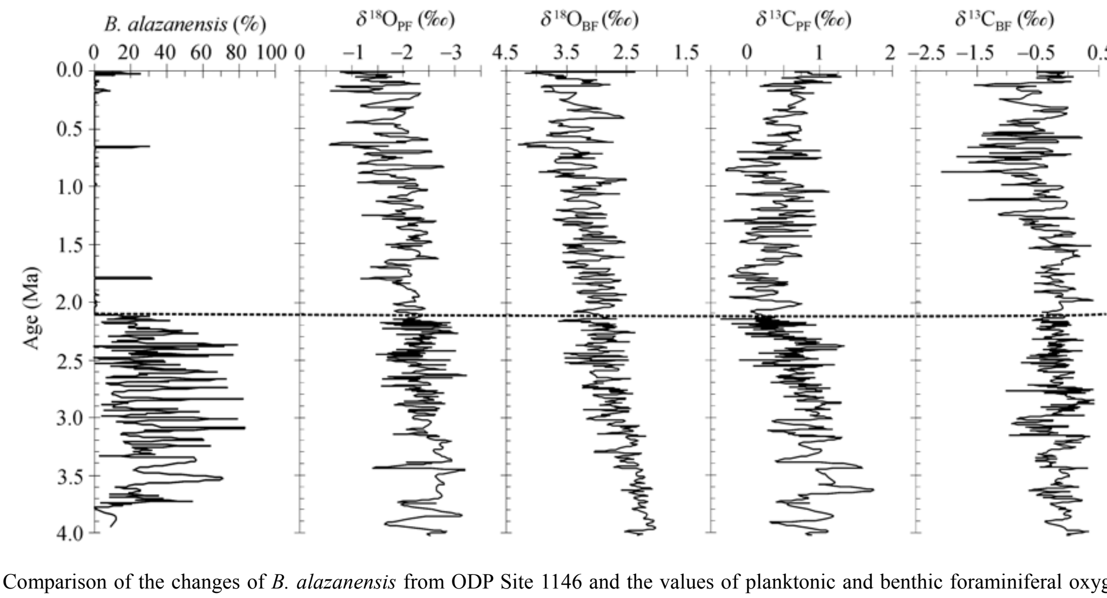

Figure 2 Comparison of the changes of *B. alazanensis* from ODP Site 1146 and the values of planktonic and benthic foraminiferal oxygen and carbon isotopes from ODP Site 1148.

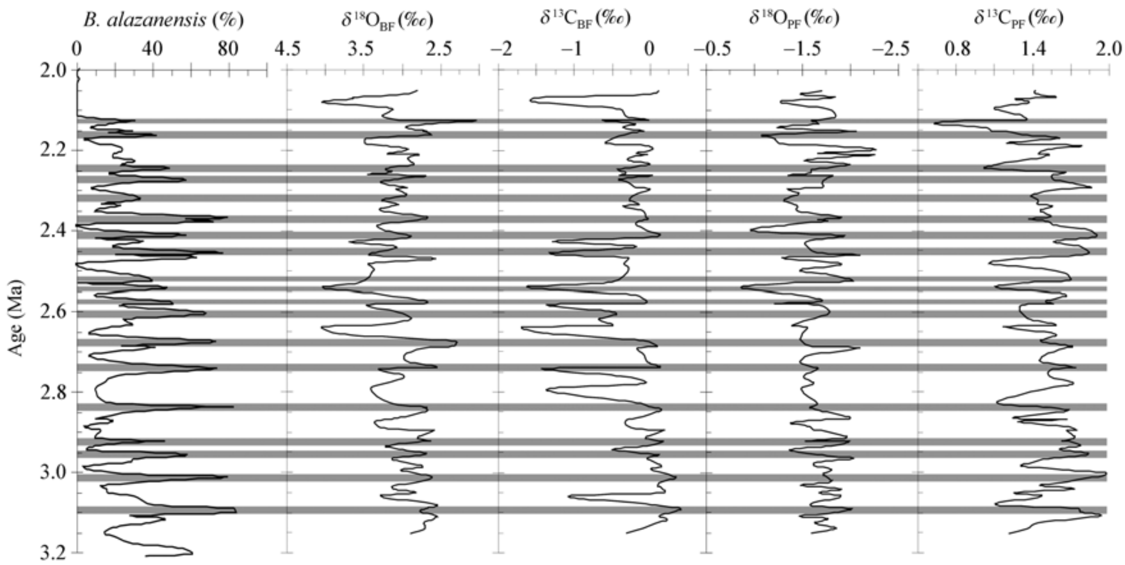

Figure 3 Comparison of the abundance of *B. alazanensis* and values of oxygen and carbon isotopes during 3.2—2.0 Ma from the ODP Site 1146.

surface of the SCS were sourced from western Pacific through the Bashi Strait with a depth at about 2500 m. Previous studies showed that Bashi Strait reached 2500 m at about 4 Ma[26], therefore, the changes of *B. alazanensis* have no direct relation with rise of the strait. This is also supported by results of benthic foraminiferal studies which showed the same changes in abundances of *B. alazanensis* at ODP Site 1143 from the southern SCS[27].

Results of benthic foraminifera studies on modern sediments in the SCS and western Pacific Waters show that assemblages of *G. subglobosa*, *Astrononion novozealandicum* and *B. aculeata* -*E. bradyi* are the main species of mid-water masses, deep-water masses and bottom water masses, respectively, in the SCS. However, assemblages of *Uvigerina* and *E. exigua* are the main species of <2500 m and >2500 m in the western Pacific[6]. Results of factor analysis of benthic foraminifera in the ODP Site 1146 show that *B. alazanensis* was the control species before 2.1Ma, but during 2.1—1.6 Ma, *Stilostomella* sp., *G. subglobosa*, *Nodogenerina* sp., *Oridorsalis umbonatus* and *C. wuellerstorfi* are the main species[28]. Species of *G. subglobosa, O. umbonatus* and *C. wuellerstorfi* indicate nutrient-poor and high dissolution oxygen content in water. Some studies detected that Late Pliocene return flow resided at about 2500 m (as compared to about 1500 m today) due to a strengthened Pacific Intermediate Water from north to south[29], and warmer temperatures of Pacific Deep Water presented by low oxygen and salinity water mass in the East Pacific at 2.1 Ma, maybe related to the onset of Northern Hemisphere Glaciation at 2.4 Ma, as well as a reconstructing of the Pacific current patterns due to the emergent Isthmus of Panama[7]. In modern ocean benthic foraminiferal communities, *B. alazanensis*, is mainly distributed along the shelf and slope in locations such as the northern Gulf of Mexico, the European and African margins, and the Atlantic seaboards of Europe and Africa. The genera of *Bulimina* distribute mainly in the southern Pacific, where the oxygen content of the waters is over 3.6 mL/L higher than the SCS (www. nodc.noaa. gov/general/getdata.html). In the Indian Ocean, the species is associated with warm deep-water[3]. In addition, studies of planktonic foraminifera in ODP Site 1146 showed that sea surface temperature decreased gradually and primary productivity increased gradually since 4 Ma, especially at 2.1 Ma, and the changes are thought to result from the expanding of North Hemisphere Glaciation and strengthened East Asian winter monsoon[30].

Combining the results of this and previous studies on ODP Site 1146[28,31], we suggest that the benthic foraminiferal faunal turnover reflects deep-water masses changed to cool and high primary productivity from warm, low salinity and productivity, and low dissolution oxygen content water during Late Pliocene.

4 Conclusions

There was a benthic foraminiferal faunal turnover at about 2.1 Ma from ODP Site 1146 in the northern South China Sea. The relative abundance of *B. alazanensis* decreased abruptly from about 80 % to zero at this transition during 3.2—2.0 Ma. Comparison of the results of assemblage of benthic foraminifera, changes of oxygen and carbon isotopes and abundance of planktonic foraminifera, and the variations in relative abundance of *B. alazanensis* shows that water masses entering the SCS changed from warm western Pacific deep-water with high dissolution oxygen content to cold Pacific Intermediate Water with low dissolution oxygen content at about 2.1 Ma. With the expanding of the North Hemisphere Glaciation and strengthening of the East Asian winter monsoon, primary productivity increases in surface and bottom water rich in nutrient and anoxic, which pressed the production of *B. alazanensis*, and resulted in its abundance decreased from 3.2 Ma and disappeared at about 2.1Ma.

The authors would like to thank Dr. M Cane for helpful discussions and insightful comments.

1 Raymo M E, Ruddiman W F, Shackleton N J, et al. Evolution of Atlantic-Pacific d13C gradients over the last 2.5 m.y. Earth Planet Sci Lett, 1990, 97: 353—368[DOI]
2 Marlow J R, Lange C B, Wefer G, et al. Upwelling intensification as part of the Pliocene-Pleistocene climate transition. Science, 2000, 290: 2288—2291
3 Gupta A K, Thomas E. Latest Miocene-Pleistocene productivity and deep-sea ventilation in the northwestern Indian Ocean (Deep Sea Drilling Project Site 219). Paleoceanography, 1999, 14: 62—73[DOI]
4 Culver S. New foraminiferal depth zonation of the northwestern Gulf of Mexico. Palaios, 1988, 3: 69—85
5 Wang P, Min Q, Gao J. A Preliminary study of foraminiferal and ostracod assemblages in the Huanghai Sea. In: Wang P, et al. eds. Marine Micropaleontology of China. Beijing: China Ocean Press; Berlin-Heidelberg-New-York Tokyo: Springer-Verlag, 1985. 115—133
6 Jian Z, Wang L. Late Quaternary benthic foraminifera and deep-water paleoceanography in the South China Sea. Mar Micropaleontol, 1997, 32 (1-2): 127—154[DOI]
7 McDougall K. Benthic foraminiferal response to the emergence of the Isthmus of Panama and coincident paleoceanographic changes. Mar Micropaleontol, 1996, 28: 133—169[DOI]
8 Loubere P. The surface productivity and bottom water oxygen signals in deep water benthic foraminiferal assemblages. Mar Micropaleontol, 1996, 28(3-4): 247—261[DOI]
9 Loubere P. Benthic foraminiferal assemblage formation, organic carbon flux and oxygen concentrations on the outer continental shelf and slope. J Foramin Res, 1997, 27 (2): 93—100
10 Den Dulk, Reichart M, Memon G J, et al. Benthic foraminiferal response to variations in surface water productivity and oxygenation in the northern Arabian Sea. Mar Micropaleontol, 1998, 35: 43—66[DOI]
11 Kaiho K. Effect of organic carbon flux and dissolved oxygen on the benthic foraminiferal oxygen index (BFOI). Mar Micropaleontol, 1999, 37: 67—76[DOI]
12 Murray J W. The niche of benthic foraminifera, critical thresholds and proxies. Mar Micropaleontol, 2001, 41: 1—7[DOI]
13 Jian Z M, Wang L J. Late Quaternary benthic foraminifera and deep-water paleoceanography in the South China Sea. Mar Micropaleontol, 1997, 32: 127—154[DOI]
14 Wiesner M G, Zheng L, Wong H K, et al. Fluxes of particulate matter in the South China Sea. In: Ittekkot V, Schöfer P, Honjo S, et al, eds. Particle Flux in the Ocean. London: John Wiley & Sons Ltd., 1996. 293—312
15 Wang L J, Sarnthein M, Erlenkeuser H, et al. East Asian monsoon climate during the Late Pleistocene: high-resolution sediment records from the South China Sea. Mar Geol, 1999, 156: 245—284[DOI]
16 Huang B, Jian Z, Cheng X, Wang P. Foraminiferal responses to upwelling variations in the South China Sea over the last 220000 years. Mar Micropaleontol, 2003, 47: 1—15[DOI]
17 Cheng X R, Huang B Q, Jian Z M, et al. Foraminiferal isotopic evidence for monsoonal activity in the South China Sea: a resent-LGM comparison. Mar Micropaleontol, 2005, 54: 125—139[DOI]
18 Wang P X, Prell W L, Blum P. Proceedings of the Ocean Drilling Program, Initial Reports Volume 184, CD-ROM Contents Site 1146, 2000. 1—82
19 Loeblich A R, Tappan J H, foraminiferal genera and their classification. New York: Van Nostrand Reinhold Company Inc, 1988. 970
20 Ujiie H, Bathyal benthic foraminifera in a piston core east off the Miyako Islands, Ryukyu Island Arc Bull Coll Sci Univ Ryukyus, 1990, 49: 1—60
21 Lutze G F. Depth distribution of benthic foraminifera on the continental margin of northweat Africa. 'Meteor' Forschungsergeb. Reihe C, 1980, 32: 31—80
22 Den Dulk M, Reichart G J, Van Heyst S, et al. Benthic foraminifera as proxies of organic matter flux and bottom water oxygenation? A case history from the northern Arabian Sea. Palaeogeogr Palaeocli Palaeoecol, 2000, 161: 337—359[DOI]
23 Huang B, Cheng X, Jian Z, et al. Response of upper ocean structure to initiation of the North Hemisphere glaciation in the South China Sea. Palaeogeogr Palaeocli Palaeoecol, 2003, 196 (3-4): 305—318[DOI]
24 Li B, Wang J, Huang B, et al. South China Sea surface water evolution over the last 12 Myr:A south-north comparison from Ocean Drilling Program Sites 1143 and 1146. Paleoceanography, 2004, 19: 1—12
25 Zhao Q H, Jian Z M, Wang J L, et al. Neogene oxygen isotopic stratigraphy, ODP Site 1148, northern South China Sea. Sci China Ser D-Earth Sci, 2001, 44 (10): 934—942
26 Huang C Y, Xia K, Yuan P B, et al. Marine investigations from passive continental margin in NE South China Sea to plate convergent zone off eastern Taiwan: comparisons with Taiwan geology. J Asian Earth Sci, 2001, 19: 619—639[DOI]
27 Hess S, Kuhnt W. Neogene and Quaternary paleoceanographic changes in the southern South China Sea (Site 1143):the benthic foraminiferal record. Mar Micropaleontol, 2005, 54: 63—87[DOI]
28 Huang B, Jian Z, Wang P. Paleoceanography evolution recorded in the northern South China Sea since 4 Ma. Sci China Ser D-Earth Sci, 2005, 48 (12): 2166—2173
29 Kwiek P B, Ravelo A C. Pacific ocean intermediate and deep water circulation during the Pliocene. Palaeogeogr Palaeocli Palaeoecol, 1999, 154: 191—217[DOI]
30 Huang B, Jian Z, Zhao Q, et al. Variations in deep-water masses from northern South China Sea since the Late Pliocene. Earth Science (in Chinese), 2005, 30 (5): 529—533
31 Murray J W. Ecology and Palaeoecology of Benthic Foraminifera. New York: John Wiley & Sons Inc, 1989. 43—287