Development of Sedimentary Environment in the Northeastern South China Sea Since the Last Glacial Stage

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Abstract: Core D（21°23′02″N，116°47′13″E, water depth 405 m）was sampled from the upper slope from the northeastern South China Sea (SCS) and applied to analyze the sedimentary environmental change in this sea area since the last glacial stage. The results of grain size analysis, diatom analysis and detrital mineral analysis were well matched. We divided the core D into two layers. The surface sand layer (0 - 2 cm) consisted of residual sediments, which might be originally the sediment in the late Pleistocene and later suffered from being transformed in the post glacial transgression. The lower layer (2 - 130 cm) was quite different from the surface one, which might mainly result from a neritic sedimentary environment in the last glacial stage. Two sedimentary cycles could be detected in the core D: regression during Marine isotope stage (MIS) 4 to transgression during MIS 3 and regression during MIS 2 to transgression during the post glacial.

Keywords: diatom, grain size, sedimentary environment, the last glacial stage, the northeastern South China Sea

Introduction

Several previous investigations in the northeastern South China Sea (SCS) and its adjacent sea areas[1-2] primarily focused on the surface sedimentary environment [3-8], while few researchers have studied the sedimentary environmental change of the northeastern SCS since the last glacial stage [9-11]. In 1979, according to the geomorphologic and surface sedimentary characters, the South China Sea Institute of Oceanology, Chinese Academy of Sciences proposed a sedimentary model in the northeastern SCS [2], which could be compared with that of the Hanjiang Delta and Zhujiang Delta in Guangdong province. So, this model can serve as a fundamental basis for our study. In this paper, we aim to obtain more insights on the sedimentary environmental development in the northeastern SCS since the last glacial stage according to the multiple analytical results of core D.

1 Materials and methods

Core D (21°23′02″N，116°47′13″E；405 m water depth, 130 cm core length) was sampled using a piston corer from the upper slope of the northeastern SCS. A total of 33 sub-samples for diatom analysis

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were sampled at an interval of 4 cm, and 14 sub-samples for grain size as well as detrital mineral analysis were sampled at an interval of 10 cm. The thickness of each sample was 2 cm.

The 33 sub-samples for diatom analysis were prepared based on the method described by Lan [12]. After socked in distilled water for several hours, all samples were scattered with an ultrasonic scatter apparatus for 5 minutes and then filtered with a bolting cloth with holes of 15 μm. The remaining was transferred into centrifugal tubes and centrifuged for 3 minutes with a revolution of 1500 rpm. A cadmium heavy liquid with a specific gravity of 2.4 was used to enable the diatoms to suspend to the upper layer. The supernatant was placed on a cover slip and mixed with the help of a pipette in order to distribute the diatoms evenly on the cover slip. After the material had completely dried, the cover slips were transferred onto permanently labeled slides, mounted with Canada balsam. If possible, more than 300 diatom valves were counted for each sample, otherwise all diatoms on the entire three slides would be counted. Grain size and detrital mineral analyses were conducted for the 14 sub-samples according to the Specification for Oceanographic Survey (GB/T13909-92). Sub-samples for grain size analysis were treated as follows: sampling, drying, weighing, adding Sodium hexametaphosphate and water, and then soaking, filtering through the water sieve with a diameter of 0.063 mm. The grains left on the sieve (> 0.063 mm) were analyzed by a sieve analysis after drying, and the grains under the sieve (< 0.063 mm) were analyzed with a Mastersizer-2000 laser diffraction particle size analyzer (measurement range: 0.02-2000 μm). The results of grain size analysis were plotted on the Wentworth scale (Wentworth, 1922), and the sediments were classified using the Shepard triangular diagram (Shepard, 1954).

2 Results

2.1 Grain size analysis

According to the results of grain size analysis (Tab. 1), the core D could be divided into two layers: A thin surface layer of sand extended from 0 to 2 cm with its grain sizes ranging from 100 to 1000 μm and a mean grain size of 1.94 φ, whereas the sedimentary types of the thick lower layer (2 - 130 cm) were mainly dark gray clayey silts, the grain size ranging from 1 to 100 μm and the mean grain sizes ranging from 6.64 to 7.31 φ with an average of 7.04 φ.

Grain-size cumulative probability curve of the upper layer was quite different from the others (Fig. 1). It was constituted by three log-normal components, the rolling population (amounting to 15.36 %) , the suspension population (amounting to 8.76 %) and the saltation population (amounting to 75.88 %), together with a steep slope, moderate sorting, coarse truncation of 1.0 φ and fine truncation of 3.0 φ, reflecting a high-energy sedimentary environment.

Grain-size cumulative probability curves of the lower layer were primarily two log-normal or linear styles. According to the change tendency of the grain size, the lower layer could be divided into three segments as follows.

10 - 62 cm : A rolling population was absent. The content of the saltation population amounts to

18.7 % at most and all of the rest were suspension populations. From bottom upward, the grain sizes became coarser gradually and the contents of sand increased from 1.19 % to 13.66 %, reflecting a sedimentary environment with a low but growing energy.

Tab. 1 Results of grain size analysis of core D in the northeastern South China Sea

Sample No.	Depth / cm	Grain size distribution / %				Statistical parameters / φ			
		gravel	sand	silt	clay	Mz	σi	Ski	Kg
1	0 - 2	3.06	92.42	4.21	0.31	1.94	1.16	-0.13	1.45
2	10 - 12	0.00	13.66	61.53	24.81	6.64	2.34	-0.12	1.45
3	20 - 22	0.00	6.40	66.18	27.43	7.00	2.14	-0.05	1.52
4	30 - 32	0.00	3.17	74.33	22.50	6.87	1.57	0.14	1.13
5	40 - 42	0.00	8.72	66.76	24.52	6.72	2.08	-0.03	1.28
6	50 - 52	0.00	1.82	72.69	25.50	6.99	1.59	0.14	1.06
7	60 - 62	0.00	1.19	68.81	30.00	7.23	1.58	0.12	1.07
8	70 - 72	0.00	0.42	68.35	31.23	7.29	1.59	0.15	1.03
9	80 - 82	0.00	4.16	67.51	28.33	7.14	1.65	0.05	1.17
10	90 - 92	0.00	1.05	67.48	31.47	7.31	1.57	0.12	1.07
11	100 - 102	0.00	3.62	67.17	29.20	7.20	1.61	0.07	1.15
12	110 - 112	0.00	0.90	70.83	28.27	7.18	1.51	0.12	1.07
13	120 - 122	0.00	1.23	69.83	28.94	7.16	1.60	0.12	1.06
14	128 - 130	0.00	1.74	74.94	23.32	6.80	1.66	0.19	1.03

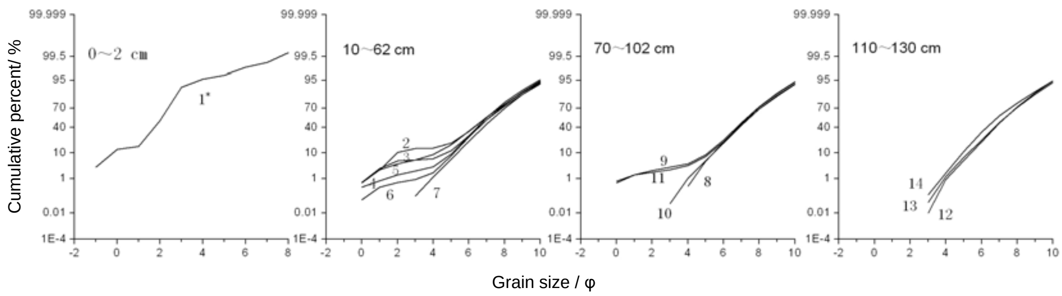

Fig. 1 Grain-size cumulative probability curves of core D in the northeastern South China Sea. The numbers from 1 to 14 refer to the sediment numbers in Tab. 1.

70 - 102 cm : No suspension population has been found in this segment. From bottom upward, the grain size became finer gradually (except for the sample 9) and the total content of silt and clay increased from 96.37 % to 99.58 %, reflecting an extremely low-energy sedimentary environment and the worsening hydrodynamic condition.

110 - 130 cm : All cumulative probability curves were slightly linear and almost overlapped. This segment was mainly composed of suspension population with a mean grain size ranging from 6.80 to 7.18 φ, indicating a low-energy sedimentary environment.

2.2 Diatom analysis

A total of 48 diatom taxa belonging to 17 genera (including varieties and forms) were identified. The diatoms with relatively high occurring frequencies were freshwater to brackish water species *Hantzschia amphioxys* (Ehr.) Grunow; brackish water species *Biddulphia gründleri* A. Schmidt; marine shallow water species *Melosira sulcata* (Ehr.) kützing, *Coscinodiscus excentricus* Ehrenberg, *Pyxidicula weyprechtii* Grunow, *Coscinodiscus radiatus* Ehrenberg, *Coscinodiscus argus* Ehrenberg, *Triceratium favus* Ehrenberg, *Coscinodiscus subtilis* Ehrenberg and *Coscinodiscus fimbriatus* Ehrenberg, oceanic species *Coscinodiscus nodulifer* A. Schmidt and *Hemidiscus cuneiformis* Wallich. Moreover, some other marine shallow water species such as *Actinoptychus undulatus* (Bail.) Ralfs，*Podosira stelliger* (Bail.) Mann，*Cyclotella stylorum* Brightwell，*Campylodiscus brightwellii* Grunow，*Diploneis incurvata* (Greg.) Cleve and *Triceratium reticulum* Ehrenberg have also been detected occasionally.

Based on the diatom assemblage, the quantitative distribution of some dominant diatom species and the diatom abundance of each sample, we grouped diatoms in the core D into 4 diatom zones(Fig. 2).

Diatom zone Ⅰ (112 - 130 cm): Diatom abundance in this zone was relatively high, with an average abundance of 1 389 valves/g. Eight species have been identified, with *Hantzschia amphioxys* as the dorminant species, and majority of the rest diatoms were marine shallow water species such as *Melosira sulcata, Triceratium favus* and *Coscinodiscus spp.*

Diatom zone Ⅱ (72 - 110 cm): A few diatoms have been found in most samples of this zone, but in the 72-74 cm interval the diatom abundance reached as high as 16 462 valves/g and 47 taxa of diatoms belonging to 16 genera (including varieties and forms) were identified, and the main diatom assemblage was *Melosira sulcata-Pyxidicula weyprechtii-Triceratium favus*. Most of them were common species which always showed up in the marine shallow habitat such as *Biddulphia gründleri, Campylodiscus brightwellii, Podosira stelliger* and *Cyclotella stylorum. Hantzschia amphioxys* has never been found in this zone.

Diatom zone Ⅲ (4 - 70 cm): Like the diatom zone Ⅰ, the diatom zone III had an average abundance of 1202 valves/g and eight species have been identified, most of which were *Hantzschia amphioxys* as well as some marine shallow water species.

Diatom zone Ⅳ (0 - 2 cm): Diatom abundance in this zone was 297 valves/g and eighteen species have been identified. A distinct characteristic of the diatom composition in this zone was that all of the three groups of diatoms with distinguishably different habitats could be identified in this zone, including coastal benthic species, marine shallow water species and oceanic species. The dorminnat species were the marine shallow water species *Melosira sulcata* and *Pyxidicula weyprechtii* (amount to 18.5 % and 12.3 % respectively), and the oceanic species *Coscinodiscus nodulifer* and *Hemidiscus cuneiformis* (amount to 18.5 % and 12.3 % respectively).

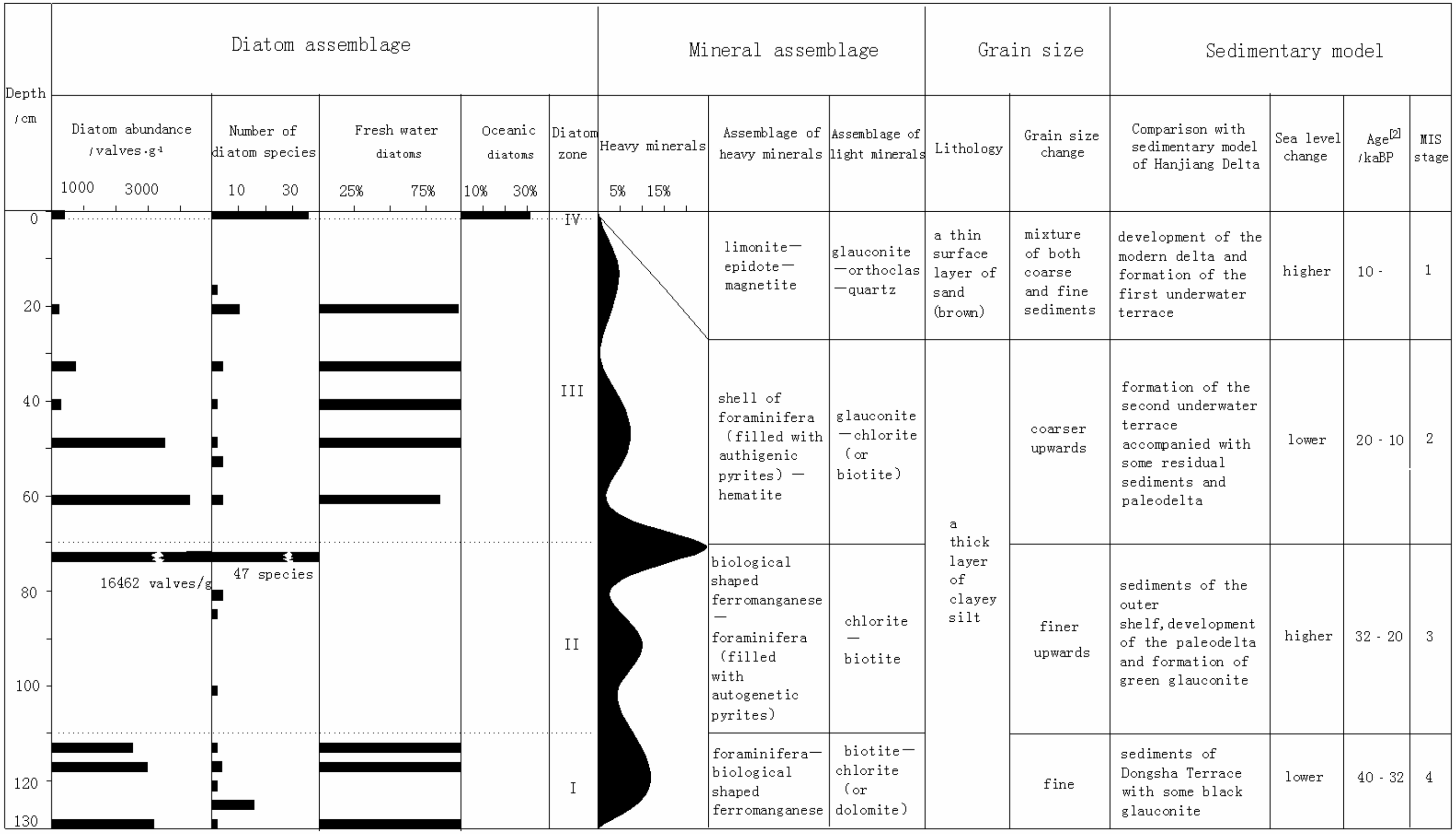

Fig. 2 Model of sedimentary environmental development in the vicinity of Core D in the northeastern South China Sea since the last glacial stage

2.3 Detrital mineral analysis

Twenty-one heavy minerals have been identified. Except for authigenic pyrite (appearing occasionally and always filling in the shell of foraminifera) and chlorite, terrestrial detrital minerals were commonly found, dominated by oxide and other silicate and hydroxide. Thirteen light minerals have been identified, including glauconite, chlorite, biotite, orthoclase and so on. The content percentages of the light and heavy minerals were shown in Table 2. Note that the percentage of heavy minerals reached as high as 24.52 % at the interval of 70 - 72 cm.

Tab. 2 Percentage of light and heavy minerals in Core D from the northeastern South China Sea / %

Depth/cm	0 - 2	10 - 12	20 - 22	30 - 32	40 - 42	50 - 52	60 - 62	70 - 72	80 - 82	90 - 92	100 - 102	110 - 112	120 - 122	128 - 130
Heavy mineral	0.25	4.21	3.14	0.57	5.64	6.75	1.91	24.52	2.62	12.01	4.48	8.81	11.78	1.31
Light mineral	99.75	95.79	96.86	99.43	94.36	93.25	98.09	75.48	97.38	87.99	95.52	91.19	88.22	98.69

3 Discussion

3.1 Sedimentary environment analysis

3.1.1 Surface layer sedimentary environment

Based on uranium-series dating result proposed by the South China Sea Institute of Oceanology, Chinese Academy of Sciences, the sedimentation rate of the surface layer in the northeastern SCS is 1.6×10^{-3} mm/a [2]. Presumably, the surface layer of core D might be the sediments as a result of the sea level rise since ca. 12.5 kaBP. This assumption is quite consistent with the results of grain size analysis and diatom analysis that the coarse sand dominated the sediments with a wide range of grain size distribution and the marine shallow water diatom taxa dominated the diverse-habitationed diatoms. The absence of *Hantzschia amphioxys* provides another testimony to prove that the surface layer might sediment in a shallow to bathyal sedimentary environment.

After the last glacial maximum (LGM), a global warming occurred. The shoreline moved landwards and part of the residual sediments from the outer shelf were taken to the core D and a thin surface layer came into being in the surface layer of core D. This kind of residual sediments distribute widely in many surface layer sediments of the continental shelf of China seas [13-15].

3.1.2 Lower layer sedimentary environment

This layer was quite different from that of the upper layer. We presume that sedimentary breaks might exist based on the results of diatom analysis. Two sedimentary cycles were recognized according to the results of grain size and diatom analysis. Therefore, the core D was divided into three segments: the lower segment (110 - 130 cm) , the middle segment (70 - 110 cm) and the upper segment (2 - 70 cm) .

The lower segment (110 - 130 cm): This segment was characterized by a large number of freshwater to brackish diatom species *Hantzschia amphioxys* and the fine-grained sediment, reflecting a relatively low sea level and a short distance to the shore. We presume this segment to be a coastal to neritic sedimentary environment during the Marine Isotope Stage (MIS) 4.

The middle segment (70 - 110 cm): Most of the diatoms were marine shallow water species and no freshwater to brackish diatom species *Hantzschia amphioxys* had been identified. At the interval of 72 - 74 cm, both the diatom abundance and the species diversity simultaneously reached the peak of 16 462 valves/g and 47 taxa respectively. Cumulative probability curves changed from a linear style to a two log-normal style. Compared with the lower segment, grain sizes of this segment were smaller and turned gradually finer upward. As a result. We presume this segment to be a neritic sedimentary environment during MIS 3 with a relatively deep water depth and a higher sea level.

The upper segment (2 - 70 cm): The result of diatom analysis was quite similar to that of the lower segment with a majority of *Hantzschia amphioxys*, and its abundance reached the peak of 3427 valves/g at the interval of 60 - 62 cm. Cumulative probability curves were primarily a two log-normal style, and grain sizes grew bigger upward. We presume the sea level had dropped and the 60-62 cm interval might be the sediment during MIS 2 when the sea level had fell to its lowest position.

Additionally, amount of authigenic pyrite has been identified in the lower layer, implying a reducing environment at that time[11, 16-17].

In conclusion, we believe the lower layer resulted from a neritic sedimentary environment in the last glacial stage.

3.2 Sedimentary cycles

Combined with the sedimentary model proposed in 1979 by the South China Sea Institute of Oceanology, Chinese Academy of Sciences, we compiled the results of grain size analysis, diatom analysis and mineral analysis to draw a preliminary conclusion that two sedimentary cycles and four sedimentary stages could be detected in the core D.

Cycle 1 : regression during Marine isotope stage (MIS) 4 to transgression during MIS 3

During the period of MIS 4 (ca. 40 - 32 kaBP) lots of freshwater to brackish diatom species *Hantzschia amphioxys* showed up in the core D as the sea level fell. Afterwards, with the advent of MIS 3 (about 32 - 20 kaBP), as a result of global warming, a transgression occurred, so the grain sizes became finer gradually and marine shallow water diatom taxa replaced *Hantzschia amphioxys.*

Cycle 2 : regression during MIS 2 to transgression during the post glacial

As the global sea level falling happened during MIS 2 (about 20 - 10 kaBP), a large number of freshwater to brackish diatom species *Hantzschia amphioxys* appeared in the core D and reached the peak at the 60 - 62 cm interval. The climate turned warmer quickly after the post glacial stage. Accordingly, the sea level rose to the present water depth in a short time. During this period the sedimentation rate was quite low and only a 2 cm thin layer of sediment has been formed in the core D.

4 Conclusion

a) The characteristics of the surface upper layer of core D in the northeastern SCS were quite different from those of the lower layer. The grain size analysis showed that coarse sands and fine sands coexisted while coarse sands dominates the sediments. The diatom analysis showed that marine shallow water species and oceanic species coexisted while the marine shallow water species dominated the diversely habitating diatoms. We presume the surface layer is a residual sediment. As a result of the neritic sedimentary environment since the last glacial stage, regular change of the grain sizes and the presence of freshwater to brackish water diatom species *Hantzschia amphioxys* characterized the lower layer.

b) The results of diatom, grain size and mineral analyses were well matched with each other, revealing that two sedimentary rhythms and four stages could be detected in the core D.

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References

[1] Liu Z S, ZHAO H T, FAN S Q, et al. Geology of the South China Sea [M]. Beijing: science press. 2002, 14.

[2] South China Sea Institute of Oceanology, Academia sinica. Report of a multidisciplinary investigation in the South China Sea (No. 2) [M]. Beijing: science press. 1985, 2-128.

[3] Luo Y L. A preliminary study on the surface sediment types and their grain size characteristics of the northeastern part of the South China Sea. Tropic Oceanology. 1985. 4 (1): 33-41.

[4] Huang B Q, Jian Z M. Late Quaternary changes of paleoproductivity in the northeastern South China Sea [J]. Marine geology & Quaternary geology, 2000, 20 (2): 65-68.

[5] Xu J, Huang B Q, Chen R H, et al. Distribution of foraminifera in surface sediments of northeastern South China Sea and its environmental implications [J]. Journal of Tropical Oceanography, 2001, 20 (4): 6-13.

[6] Meng Y, Yan S Z, Chen R H, et al. Composition analysis of the biogenic and mineral clastics In the surface sediment of the northeastern South China Sea and its paleoenvironmental significance [J]. Marine geology & Quaternary geology, 2001, 22(3): 17-22.

[7] Chen R H, Wang D J, Xu J, et al. Calcium and siliceous microfossil in the surface sediments of the northeastern South China Sea and their relationships with the sedimentary environment [J]. Marine geology & Quaternary geology, 2003, 23 (4): 15-21.

[8] Chen R H, Xu J, Meng Y, et al. Microorganisms and carbonate lysocline depth and CCD in the surface sediment

of the northeastern South China Sea [J]. Acta Oceanologica sinica, 2003, 25(2): 48-56.

[9] Duan W W, Chen F, Wei K Y, et al. Calcareous nannofossil in the northeastern South China Sea since the last 15ka and its significance of paleo-oceanography [J]. Marine geology & Quaternary geology, 1998, 18(1): 13-22.

[10] Wei K Y, Lee M Y, Duan W W, et al. Late glaciation-Holocene paleo-oceanography of the northeastern South China Sea: core RC26-16 [J]. Marine geology & Quaternary geology. 1999, 19(3): 19-27.

[11] Yang Q H, Zhang F Y, Lin Z H, et al. On mineralogical and geochemical records of paleosedimentary environmental variation in the northeastern South China Sea since the late Pleistocene [J]. Acta Oceanologica sinica, 2004, 26(2): 72-80.

[12] Lan D Z, Cheng Z D, Liu S C. Diatoms in late quaternary sediments from the South China Sea [M]. Beijing: China Ocean Press. 1995.

[13] Wang P X, Min Q B, Bian Y H, et al. Preliminary study on Quaternary transgressional stratigraphy in East China [J]. Acta Geologica Sinica, 1981, (1): 1-13.

[14] Wang P X, Zhang J J, Zhao H Q, et al. Foraminifera and Ostracoda in bottom sediments of the East China Sea [M]. Beijing: China Ocean Press. 1988, 298-301.

[15] Wang Z H, Guo Z Y, Chen Z Y, et al. Relict sediment and its environmental implication in Pingbei area, East China Sea continental shelf [J]. Journal of East China Normal University (Natural Science). 2002, 1: 81-86.

[16] Chu F Y, Chen L R, Shen S X, et al. Origin and environmental significance of authigenic pyrite from the south Yellow (Huanghai) Sea sediments [J]. Oceanologia et Limnologia Sinica, 1995, 26(3): 227-233.

[17] Wang L, Wang P. Late Quaternary paleoceanography of the South China Sea: glacial-interglacial contrasts in an enclosed basin [J]. Paleoceanography, 1990, 5 (1): 77-90.

南海东北部末次冰期以来沉积环境演变

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摘 要：利用南海东北部上陆坡处所取的 D 孔（21°23′02″N，116°47′13″E,水深 405 m）进行硅藻分析，结合粒度分析与碎屑矿物分析结果，探讨该海域末次冰期以来沉积环境演变过程。结果表明：粒度与硅藻分析结果较为吻合，共同显示 D 孔可分为上下两层，上层（ 0 - 2 cm）的砂质沉积层为经冰后期海进过程改造的晚更新世残留沉积层；下层（2 - 130 cm）主要是末次冰期形成的浅海沉积。整个柱样可反映出海洋同位素 MIS 4 期海退至 MIS 3 期海进与 MIS 2 期海退至冰后期海进的沉积韵律。

关键词：硅藻；粒度分析；沉积环境；末次冰期；南海东北部