An abrupt cooling event early in the last interglacial in the northern South China Sea

TU Xia (涂 霞)[1], ZHENG Fan (郑 范)[1], WANG Jiliang (王吉良)[2], CAI Huimei (蔡慧梅)[1], WANG Pinxian (汪品先)[2], C. Bühring[3] & M. Sarnthein[3]

1. The South China Sea Institute of Oceanology, Chinese Academy of Sciences, Guangzhou 510301, China;
2. Key Laboratory of Marine Geology, Ministry of Education, Tongji University, Shanghai 200092, China;
3. Institut für Geowissenschaften, Universität Kiel, Germany
Correspondence should be addressed to Zheng Fan (email: zfh@scsio.ac.cn)

Received May 28, 2001

Abstract The high-resolution quantitative analysis of the planktonic foraminifera and the $\delta^{18}O$ records of the section between 96.49—137.6 mcd at ODP Site 1144 on the continental slope of northern South China Sea reveals an abrupt cooling event of sea surface temperature (SST) during the last interglacial (MIS 5.5, i.e. 5e). The dropping range of the winter SST may come to 7.5℃ corresponding to 1.2‰ of the $\delta^{18}O$ value of sea surface water. This event is comparable with those discovered in the west Europe and the northern Atlantic Ocean, but expressed in a more intensive way. It is inferred that this event may have been induced by middle- to low-latitude processes rather than by polar ice sheet change. Since the Kuroshio-index species *Pulleniatina obliquiloculata* displayed the most distinct change at the event, it may also be related to the paleoceanographic change of the low-latitude area in the western Pacific Ocean. This event can be considered as one of "Younger Dryas-style coolings" and is indicative of climate variability of the last interglacial stage.

Keywords: northern South China Sea, last interglacial period, sudden cooling event, MIS 5.5, climate variability.

From one of the ice cores of the Greenland ice sheet at the site GRIP, quick climate changes were first discovered during marine isotope stage (MIS) 5e in the last interglacial period, but were not found at the site GISP[1]. It has become an important problem for paleoclimate studies on whether the climate was stable during the last interglacial period. Its importance should not be underestimated since the climate record during the former interglacial period is helpful for forecasting the future climate of the current interglacial. There are only limited number of sections that can be used for correlation since a high-resolution stratigraphic record is required. The deep-sea sediments have particular relevance to this study, an example is a sudden cooling event lasting less than four hundred years during MIS 5e recently discovered at ODP Site 658[2] from the northern Atlantic Ocean. It is essential to the evaluation of the stability of climate during interglacial period to find out whether similar events are also recorded in other oceans. The sediment high sedimentation rate sequences taken from the South China Sea (SCS) during the ODP Leg 184 have provided ideal research material for tracing the sudden change of climate at stage 5e. The present paper addresses the climate stability during interglacial periods in the north-

ern SCS on the basis of deep-sea records with high-resolution stratigraphy.

1 Material and methods

The samples used for this study were collected from the section between 96.49—137.6 mcd of Site 1144 (20° 3.18′N, 117° 25.14′E) on the northern continental slope of the SCS under 2037 m of water depth. The time span ranges from MIS 6 to the middle of MIS 5. A total of 345 samples was taken at a 10 cm interval in most cases, corresponding to a time resolution of about 160 years in average. All the samples were processed following the standard method of micropaleontology. After quartering the residue, planktonic foraminifera were identified and counted from the coarse fraction over 154 μm. From each sample 300—500 tests of planktonic foraminifera were identified and counted, and the census data were processed using transfer function for paleoceanography. Furthermore, the planktonic foraminiferal species *Globigerinoides ruber* from the upper section above 122 mcd were analyzed for oxygen and carbon isotopes at the Isotope Laboratory of the Kiel University, Germany.

2 Results and discussion

2.1 Stratigraphy

Site ODP 1144 provides ideal material for studies on abrupt climatic changes during the last interglacial because of its highest sedimentation rate known up-to-now in the SCS and the rich and well-preserved foraminiferal fauna. The holes with 519 mcd of penetration have reached only about 1 million years in record[3]. According to the studies in the Indo-Pacific region by Thompson et al.[4], the last occurrence of pink-pigmented *G. ruber* corresponds to MIS 5e and is dated to 120 ka. At ODP Site 1144, pink-pigmented *G. ruber* occurs in samples below 110.33 mcd, making up 10%—15% and sometimes up to 30%—40% in abundance of this species. Therefore, the depth of 110.33 mcd is assigned to MIS 5.5. The $\delta^{18}O$ of planktonic foraminifera *G. ruber* is now under analysis. Although only the upper part above 121.73 mcd had been measured when this paper was prepared, it is already clear that the analyzed upper section has reached MIS 5c (i.e. MIS 5.3), and the boundary between MIS 5 and MIS 6 is located at the depth of 113.5 mcd. The $\delta^{18}O$ below the boundary increases obviously and reaches its maximum at the depth of 120 mcd, corresponding to MIS 6.2 (fig. 1). According to the $\delta^{18}O$ chronology by Martinson et al.[5], the ages of MIS 5.3 and MIS 6.2 are 96 ka and 135 ka respectively. Therefore, the age of the bottom of the section selected for this study is about 150 kaBP.

2.2 Paleotemperature record of surface sea water

The results of planktonic foraminiferal analysis show that the abundances of tropical and subtropical warm-water species, such as *Globigerinoides sacculifer*, *Globorotalia menardii*, and *Pulleniatina obliquiloculata*, are relatively high during MIS 5, whereas those of cool and temperate water species, such as *Neogloboquadrina pachyderma*, *Globigerina bulloides* and *Globoro-*

talia inflata are relatively low. All the species above change to an opposite direction during MIS 6 (fig. 2), indicating the features of SST variations in glacial/interglacial cycles.

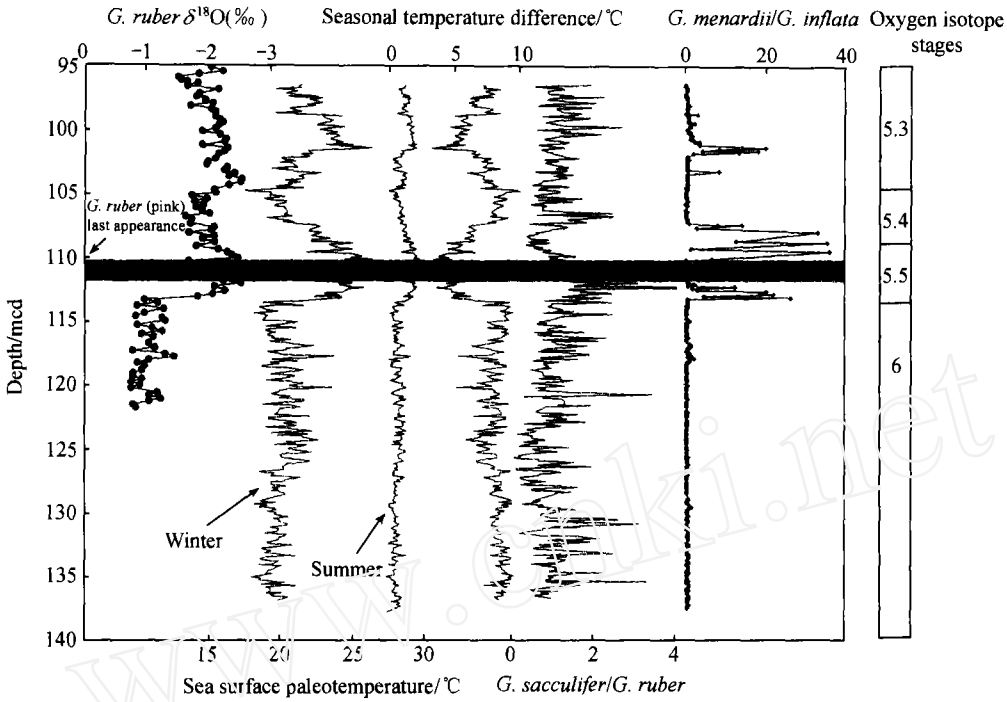

Fig. 1. Downcore variations of SST based on transfer function, oxygen isotope, *G. sacculifer/G. ruber* ratio and *G. menardii/G. inflata* ratio from MIS 5.3 to MIS 6 at ODP Site 1144, northern South China Sea (Shaded bar indicates the abrupt cooling event within MIS 5.5).

The winter and summer paleo-SST has been estimated using paleoecology transfer function FP-12E[6] and planktonic foraminiferal census data from Site 1144. The resulting curves fit well with the $\delta^{18}O$ record, as well as the ratios of *G. menardii/G. inflata* and *G. sacculifer/G. ruber.* As seen from fig. 1, the paleo-SST changes are mainly observed in winter time, with the ranges of SST changes from 18—24℃ in winter and 27—29℃ in summer during MIS 6, but 17—27℃ and 27—30℃ respectively during MIS 5. The SST changes between MIS 5 and 6 are estimated as 7℃ for winter and 2℃ for summer. The SST variations, especially in winter, far exceed those in the southern part of the SCS, and even greater comparing with those in the western Pacific Ocean[7].

As indicated in figs. 1 and 2, abrupt changes with different amplitudes are observed not only in the $\delta^{18}O$ curve of planktonic foraminifera, but also in percentage of planktonic foraminifera and paleotemperature curves. It is of interest to note the frequent SST variations occurring during the glacial MIS 6, but variations with enhanced amplitudes occur in MIS 5. For example, the SST during MIS 5.4 was as low as in the glacial period, and the difference with the warmest value during MIS 5.3 may come to 6℃.

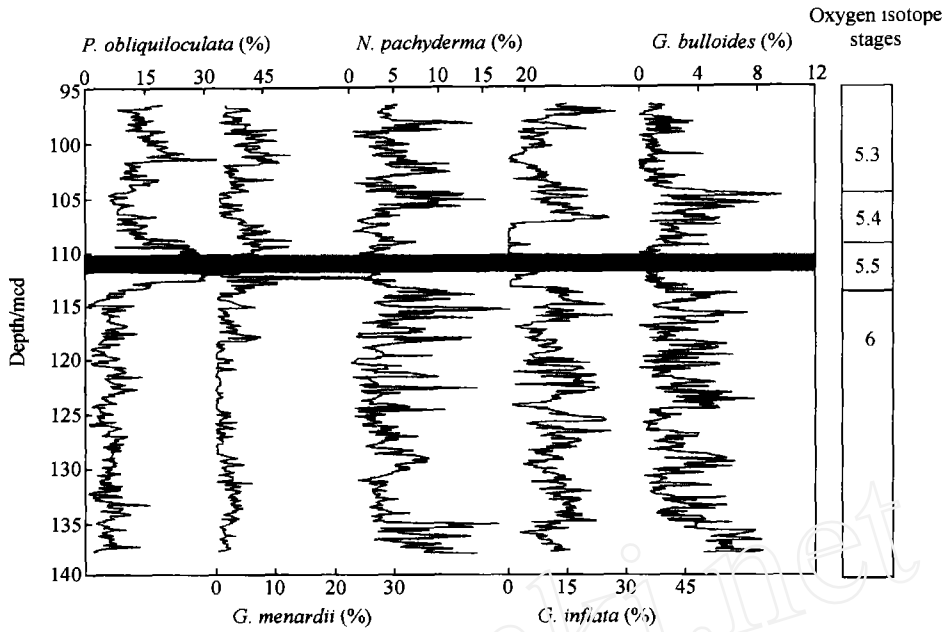

Fig. 2. Downcore variations of some planktonic foraminiferal species from MIS 5.3 to MIS 6 at ODP Site 1144, northern South China Sea (Shaded bar indicates the abrupt cooling event within MIS 5.5).

2.3 The cooling event within MIS 5.5

The oxygen isotopic curve of MIS 5.5 shows an obvious double-peak feature where $\delta^{18}O$ is as light as −2.5‰, separated by valley with $\delta^{18}O$ of −1.25‰. The early peak is located at 112 mcd and the later one at 110 mcd. The $\delta^{18}O$ of the early peak is slightly lighter than the later one, the base of which just corresponds to the last appearance of *Globigerinoides ruber* (pink) dated to approximately 120 ka BP (late MIS 5.51). According to SPECMAP oxygen isotopic stratigraphy[5], the two peaks are assigned to MIS 5.53 and MIS 5.51, respectively (fig. 1), thus the older peak to 123.5 ka. As seen from fig. 1, the relative abundances of the tropical warm water species of planktonic foraminifera *P. obliquiloculata* and *G. menardii* in MIS 5.53 are higher than those in MIS 5.51, whereas the percentages of cool water species *G. inflata* and *G. bulloides* are lower in MIS 5.53 than in 5.51. Moreover, the downcore variations in *G. sacculifer/G. ruber* ratio display the same double-peak feature, and again a higher value in MIS 5.53 than in 5.51, implying a higher SST at 5.53. All this agrees well with oxygen isotopes at MIS 5.53, but is at odds with the records in the open ocean where MIS 5.51 experienced the highest warming within the last interglacial, and is also not supported by oxygen isotope records from other sites within the SCS. A $\delta^{18}O$ peak at MIS 5.51 clearly lighter than at 5.53 is observed at the nearby ODP Site 1145 (19° 35′N, 117° 37′E; personal communication by K. McIntyre, 2001), and at Cores 17954 (14° 48′N, 111° 32′E) and 17955 (14° 07′N, 112° 11′E)[1)][8]. It indicates that the main part of

1) Heilig, Stephanie, Palăo-Ozeanographie vor Vietnam im Wandel von Glazial zu Interglazial, Diplomarbeit, Universität zu Kiel, 1996, 57 S.

MIS 5.51 is missing at ODP Site 1144, and a hiatus of several thousand years occurs just below the (truncated) upper peak in $\delta^{18}O$ curve, resulting in the conspicuous absence of the warmest time interval. The extreme values of MIS 5.53 may also present a sort of climatic overshoot phenomenon along with glacial termination II.

When the $\delta^{18}O$ and planktonic foraminiferal records are compared with the transfer function paleo-SST curves, an abrupt cooling event within MIS 5.5 becomes striking (fig. 1). The $\delta^{18}O$ values increased and the content of the cool-warm water species *G. inflata* came to the highest in the period between the two peaks, i.e. stage 5.52 (fig. 2), with the winter SST ranging from 19 to 20℃ in contrast to 25—26.5℃ at MIS 5.51 and 5.53. In other words, MIS 5.52 witnessed a drastic cooling about 7.5℃ in winter and about 1.5℃ in summer, and the surface water $\delta^{18}O$ becomes 1.2‰ heavier. The range of variation is almost comparable with that of glacial / interglacial cycles (fig. 1).

Actually, the MIS 5.52 cooling event was reported many years ago, such as in the alkenon paleo-SST and benthic oxygen isotope records from ODP Site 658 (20° 45′N, 18° 35′E), northern Atlantic Ocean[2, 9,10]. The event was ascribed to a Younger Dryas-style cooling which occurred at each termination during the last 650000 years[11]. Similar coolings within MIS 5.5 have been discovered in many other areas, such as the sudden drop event of pollen percentage of non-arboreal in the Maar lake of central France[12]. The finding from ODP Site 1144 in the SCS is in accordance with the records above, though the nature and cause of this event are still unclear. It merits our attention that the response of $\delta^{13}C$ of benthonic foraminifera to this event is far stronger than that of $\delta^{18}O$ in cores at ODP Site 658, and the range of variation in surface water $\delta^{18}O$ at ODP 1144 is also much greater than that recorded by the bottom water $\delta^{18}O$ at ODP 658, probably as a result of the strong decrease in SST, hence indicating an increase in local sea surface salinity (SSS) and a decrease in summer precipitation. All this infers that this event was probably brought about by middle- to low-latitude processes rather than by ice-sheet expansion. Among the species of planktonic foraminifera, the most distinct change is the sudden drop of *P. obliquiloculata* abundance from more than 30% to about 10% at the cooling event (fig. 2). Since this is a species Kuroshio-index species in the northwest Pacific Ocean[13], the sudden decline of relative abundance of *P. obliquiloculata* might indicate a decreasing influence of the Kuroshio in this area[14], resulting from a significant change in low-latitudinal paleoceanography, possibly sea-level induced.

3 Conclusions

The results of planktonic foraminiferal analyses in cores from ODP Site 1144 show great changes in SST and SSS in the northern SCS from MIS 6 to 5, as well as within MIS 5.5. The enhanced SST variations and increased seasonality resulted presumably from ocean current driven by winter monsoon winds, leading to the advection of water masses from temperate zone similar

to that during glacial periods. A cooling event occurred in the stage MIS 5.52 during the last interglacial period, when SST suddenly dropped about 7℃ and $\delta^{18}O$ increased by 1.2‰. This cooling is comparable with Younger Dryas-style event recorded in the Atlantic Ocean and elsewhere, but is more intensively expressed in the northern SCS[15,16]. This event may have possibly been induced by middle- to low-latitude processes rather than by ice sheet changes, and provides one more evidence for climate variability during the last interglacial.

Acknowledgements This work was supported by the National Natural Science Foundation of China (Grant No. 4999560). Dr. Jian Zhimin is acknowledged for his assistance in completing the final version of the manuscript.

References

1. Grootes, P. M., Stulver, M., Johnson, J. W. C. et al., Comparison of oxygen isotope records from GISP2 and GRIP Greenland ice cores, Nature, 1993, 366: 552 — 554.
2. Maslin, M., Sarnthein, M., Knaack, J. J. et al., Intra-interglacial cold events: An Eemian-Holocene comparison, The Geological Society of London, Special Publications, 1998, 131: 91— 99.
3. Wang, P., Prell, W., Blum, P. et al., Proceedings of the Ocean Drilling Program, Initial Reports, 2000, 184.
4. Thompson, P. R., Bé, A. W. H., Disappearrence of pink-pigmented *Globigerinoides ruber* at 120,000yr BP in the Indian and Pacific Oceans, Nature, 1976, 280: 554 — 558.
5. Martinson, D. G., Piasias, N. G., Hays, J. D. et al., Age dating and the orbital theory of the ice ages: Development of a high-resolution 0 to 300000-year chronostratigraphy, Quaternary Research, 1987, 27: 1— 29.
6. Thompson, P. R., Planktonic foraminifera in the West North Pacific during the past 150,000 years: Comparison of modern and fossil assemblages, Palaeogeogr. Palaeoclimatol. Palaeoecol., 1981, 35: 241 — 279.
7. Tu, X., Zheng, F., Chen, M. et al., Planktonic foraminifera in continental slope of southern South China Sea and their implications to paleotemperature of surface sea water, Tropic Oceanology (in Chinese with English abstract), 2000, 19(3): 40—49.
8. Wang, L., Sarnthein, M., Erlenkeuser, H. et al., East Asian monsoon climate during the late Pleistocene: High-resolution sediment records from the South China Sea, Marine Geology, 1999, 156: 245— 284.
9. Eglintin, G., Bradshaw, S. A., Rosell, A. et al., Molecular record of secular sea surface temperature changes on 100-year timescales for glacial terminations I, II, and IV, Nature, 1992, 356: 423— 426.
10. Maslin, M., Sarnthein, M., Knaack, J.-J., Subtropical Eastern Atlantic climate during the Eamian, Naturwissenschaften, 1996, 83: 122 —126.
11. Sarnthein, M., Tiedemann, R., Younger Dryas-style cooling events at glacial terminations I-VI at ODP Site 658: Associated benthic $\delta^{13}C$ anomalies constrain meltwater hypothesis, Paleoceanography, 1990, 5(6): 1041—1055.
12. Thouveny, N., de Besulien, J.-L., Bonifay, E. et al., Climate variations in Europe over the past 140 kyr deduced from rock magnetism, Nature, 1994, 371: 503— 506.
13. Li, B., Jian, Z., Wang, P. et al., *Pulleniatina obliquiloculata* as a paleoceanographic indicator in the South Okinawa Trough during the last 20000 years, Marine Micropaleontology, 1997, 32: 59— 69.
14. Wang, J., Saito, Y., Oba, T. et al., High-resolution records of thermocline in the Okinawa Trough since about 10000 aBP, Science in China, Ser. D, 2001, 44(3): 193—200.
15. Wang, P., Bian Y., Li, B. et al., "The Younger Dryas" in the west pacific marginal seas, Science in China, Ser. D, 1996, 39(4): 522—532.
16. Jian, Z., Chen, M., Lin, H. et al., Stepwise Paleo-ocanographic change of the last deglaciation in the southern South China Sea: Records of stable isotope and microfossils isotope and microfossils, Science in China, Ser. D, 1998, 41(2): 187—194.