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PLANKTIC FORAMINIFER FAUNAL SEA SURFACE TEMPERATURE RECORDS OF THE PAST TWO GLACIAL TERMINATIONS IN THE SOUTH CHINA SEA NEAR WAN-AN SHALLOW (IMAGES CORE MD972151)

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ABSTRACT

The South China Sea is the largest marginal sea of southeastern Asia, lying presently under the influences of the Western Pacific Warm Pool and Asian monsoon systems. Sediment cores from this area provide high-resolution records for interpreting millennial- to centennial-scales paleoclimatic changes expressed in the western Pacific. Here we present results of high-resolution paleoceanographic data including planktic foraminifer fauna sea surface temperature (SST) and depth of thermocline (DOT) estimates along with foraminifer stable isotopes, alkenone SST estimates analyzed from a core taken from the southern South China Sea (SCS) near Wan-An Shallow (IMAGES III 1997 cruise core MD972151: 8°43.73'N, 109°52.17'E, 1589m). The intervals of the record presented here cover the past two glacial Terminations (centering at ~12,000 and 128,000 yrs B.P.). Our analyses of SST estimates by using planktic foraminifer transfer functions with paralleling measurements of alkenone SST methods all show events of rapid cooling reversals occurrring during the Termination I concurrent with the Younger Dryas (~13-11 kyr B.P.), and Heinrich events reported previously from GISP2 ice core and North Atlantic core studies. Our reconstructions indicate also that the Termination I in the southern SCS is characterized by a change of monsoon wind systems, with probably much stronger winter monsoon winds in the glacial period. We also found that during the Termination II, there was no such climatic reversal analogous to the Younger Dryas. During oxygen isotope stage 5, our estimates of SST and DOT, and abundances of deep-dwelling planktic foraminifer species all

show large-amplitude variations, indicating an instability of monsoon climate during the interglacial period. Our studies also highlight the climatic teleconnections shown by the linkage of the SCS and other regional records for examples from the East China Sea and Chinese loess.

Key words: planktic foraminifer, paleoceanography, Termination, South China Sea

INTRODUCTION

The South China Sea (SCS) is the largest marginal sea of southeastern Asia. The SCS lies under the influence of the Western Pacific Warm Pool (WPWP) and Asia monsoon systems and is sensitive to climate changes during glacial-interglacial cycles (Chen and Huang, 1998; Pelejero *et al.*, 1999; Wang *et al.*, 1999; Wang and Sun, 1994; Wang, 1999). As of significant terrestrial sediment flux injecting into the SCS by surrounding large rivers, the SCS provides high-resolution sedimentary records for interpreting millennial- to centennial-scales paleoclimatic changes expressed in the western Pacific.

To constrain the past millennial- to centennial-scale variations of western Pacific climate, in this study we investigated a high-resolution, multiple proxy core data generated from an IMAGES core MD972151, which were taken from the southwestern SCS during IMAGES III - IPHIS CRUISE (Leg II) in 1997. This study also aims at documenting climatic change patterns in the SCS during the last two glacial-interglacial cycles, with emphasis on the intervals of the past two glacial Terminations (~12,000 and 128,000 yrs B.P.), when Northern Hemisphere ice sheets gradually retreated and the global climate returned back to warmer states. Previous studies indicated that the Holocene-LGM interval in the SCS appeared to be punctuated by significant climate variability - several short-term cooling reversals, such as the Younger Dryas (YD) and Heinrich events (Chen *et al.*, 1999; Wang *et al.*, 1999; Kienast *et al.*, 2001).

The data analysed and presented in this study includes planktic foraminifer stable oxygen isotopes (Lee *et al.*, 1999), planktic foraminifer assemblages and SST (sea-surface temperature) and DOT (depth of thermocline) estimates, and U^k37 SSTs (Huang *et al.*, 1999; Wang, 1999). The completeness of the data set enables us to better interpret the sequence of high-frequency paleoclimate signals over millennial- to centennial- timescales during the last past glacial-interglacial cycles as well as two glacial Terminations.

The modern ocean conditions of the SCS are revealed by NOAA (1994) modern hydrographies. The distributions of four seasons SSTs in the SCS show that the SCS is dominated by winter/summer monsoons. In the summer time, SSTs in most of the region are above 28°C; and in the winter time, the SSTs ranges from 22 - 27°C and exhibit a ~5°C gradient from the north to south (Ho *et al.*, 1998). Near the site location of core MD972151 around the southwestern SCS, SSTs have ~3°C seasonal variations (Fig. 1). The subsurface hydrographic data provide information about large-scale wind-driven surface circulation patterns. The tropical Pacific DOT patterns (Fig. 2) (Ho *et al.*, 1998; Andreasen and Ravelo, 1997) indicate that the west Pacific is characterized by deep DOT conditions than those in the eastern Pacific (Chen, 1994; Andreasen and Ravelo, 1997; Chen and Prell, 1998), though the DOT in the SCS is relatively shallower than the open sea of the western Pacific, probably indicating dominant fresh water/ salinity or local wind effects. In this study, we used primarily both faunal estimates of SST and DOT as proxies for indicating SCS surface ocean and monsoon wind climate and attempted to correlate our records with climate records from the other regions such as the East China Sea and Chinese loess plateau to advance our understanding on paleoclimate teleconnections.

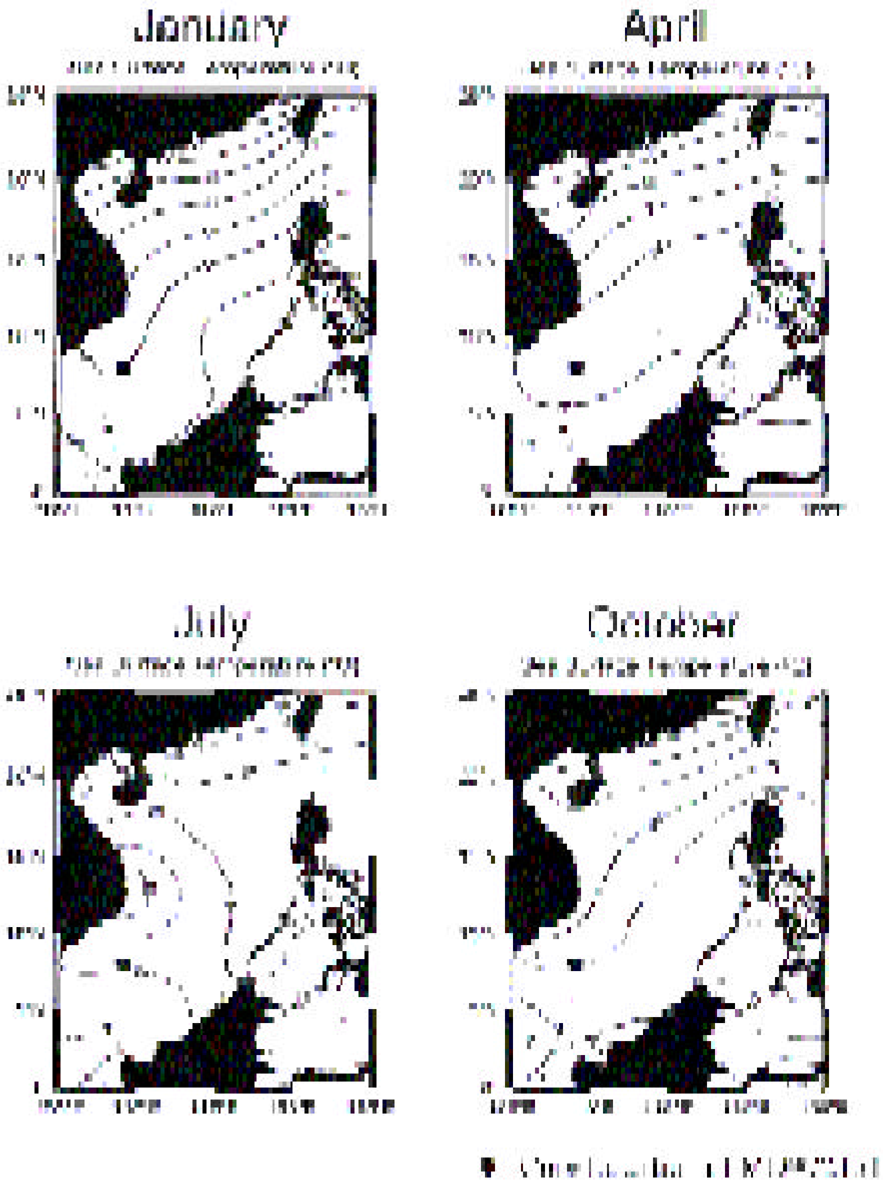

Figure 1. Modern seasonally-averaged sea-surface temperature (SST) in the South China Sea (NOAA, 1994; Ho *et al*., 1998). The dot indicates the location of IMAGES core MD972151.

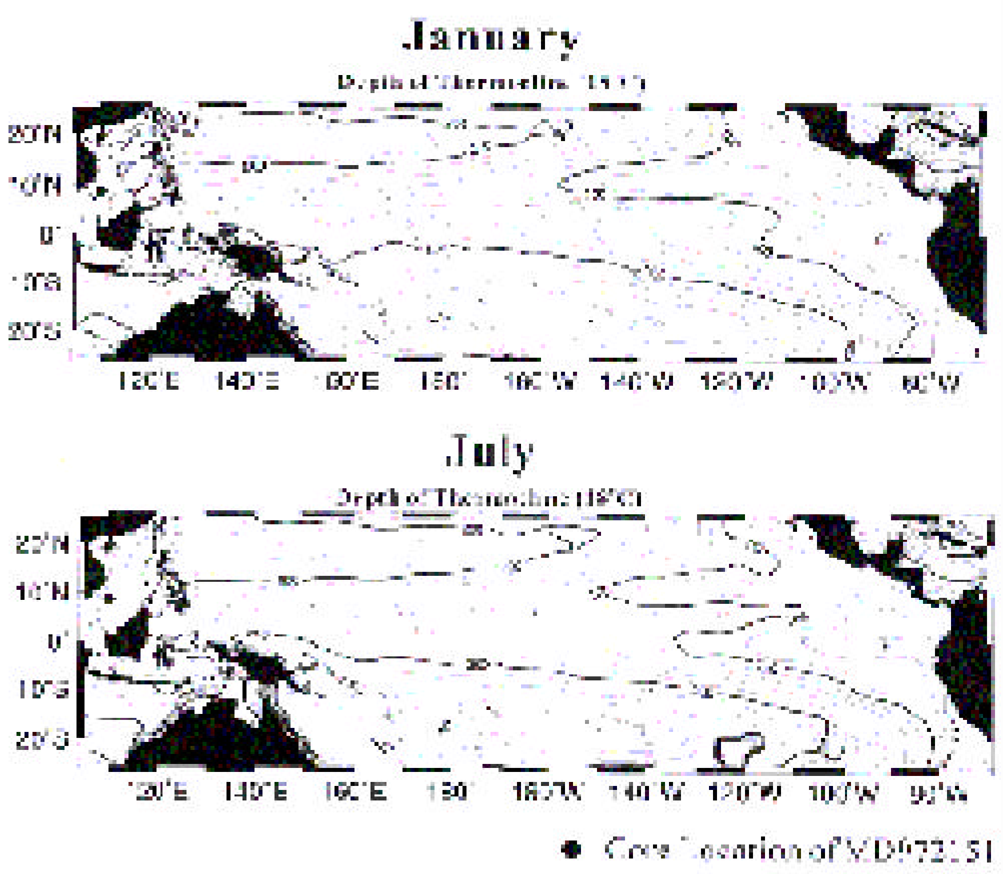

Figure 2. Modern January and July distributions of depth of thermocline (DOT) in the tropical Pacific (modified from Andreasen and Ravelo, 1997). Shallow DOTs are found from the eastern and deep DOTs are from the western Pacific. The dot indicates the location of IMAGES core MD972151.

DATA AND METHODS

In this research, we presented data from a giant piston core MD972151 (8°43.73'N, 109°52.17'E, 1589m) (Fig. 1), recovered from the southwestern slop near the Wan-An Shallow of the SCS during the IMAGES cruise in 1997 (Chen *et al.*, 1998). The recovery length of the core is 26.72m. The water depth of the core is well above the depth of the regional lysocline (Rottman, 1979; Shieh and Chen, 1984). The dominant lithology of the core are olivine to dark clay and slightly silty with nannofossil, foraminifer and diatom oozes (Chen *et al.*, 1998). Sampling for planktic foraminifer faunal and stable isotope analyses was carried out at approximately 4-cm intervals. Each sediment sample was cut to represent ~1cm interval of the core. A total of 209 samples that were taken from the top to 931cm (~ interval of the Termination I) and 1851 cm to 2577cm (~ interval of the Termination II) of the core were investigated in this study.

All wet sediment samples were completely freeze-dried. Dried samples were then gently collapsed and washed through a >63μm sieve under a weak spray of water. The remaining coarse fractions were then oven-dried at 50°C and dry sieved. For all planktic foraminifer faunal census data, we made splits of the >149μm size fractions containing approximate 300 complete specimens. A total of 23 faunal species were identified and the relative abundances of the species are expressed as percentages of total faunal assemblages (Parker, 1962; Bé, 1967; Kipp, 1976). The faunal identifications of these samples were made in the Laboratory of Earth Environments and Climate Changes, in National Taiwan Ocean University. We included in this report two separate data sets of stable oxygen isotope (*G.sacculifer*) (Lee *et al.*, 1999) and alkenone SST analyses (Wang, 1999; Huang *et al.*, 1999), which were done in the Department of Geoscinece, National Taiwan University.

Descriptive statistics of the relative abundances of 23 species of planktic foraminifer fauna were calculated for the two Termination intervals of 209 downcore faunal abundance data (Tab. 1). This set of faunal abundance data is dominated by five species, which constitute over 75% of the planktic foraminifer compositions. Ranking the species abundances from high to low, these five are: *G.ruber* (26.1%), *N.dutertrei* + *G.pachyderma* (right coiling) (17.2%), *G.sacculifer* (14.4%), *P.obliquiloculata* (9.6%), and *G.glutinata* (8.0%).

We used a global planktic foraminifer SST transfer function (Ortiz and Mix, 1997) to obtain SST estimates for these core intervals. This transfer function was written based on 1121 coretop data from global oceans, and was assessed and proven reliable using coretop and sediment trap samples (Ortiz and Mix, 1997). We also used a tropical Pacific Ocean DOT function, which was constructed based on 189 coretop data from the tropical Pacific Ocean (25°N ~ 25°S) (Andreasen and Ravelo, 1997) to estimate DOT changes in this study.

The time-stratigraphy of this core was established based on $\delta^{18}O$ record and correlation with a SPECMAP stack (Pisias *et al.*, 1984; Imbrie *et al.*, 1984; Prell *et al.*, 1986). Twelve AMS ^{14}C dating using planktic foraminifer specimens have been used to calibrate the $\delta^{18}O$ age model for the top part of the core (Lee *et al.*, 1999; Stuiver and Reimer, 1993).

RESULTS AND DISCUSSION

In these two glacial-interglacial interval data sets of planktic foraminifer faunal abundances of core MD972151 (Tab.1), we found that the data are dominated by five species which constitute over 75% of total planktic foraminifer compositions: *G.ruber*, *G.pachyderma* (R.) +*N.dutertrei*, *G.sacculifer*, *P.obliquiloculata*, *G.glutinata*. In the interval of the Termination I, the faunal patterns of these five dominant species show glacial-interglacial fluctuations mostly paralleling to the $\delta^{18}O$ curve of the core (Fig. 3). For example, *N.dutertrei*, a species indicating strong upwelling and/or high nutrient conditions, has abundances increased in the last glacial maximum (LGM) than those in the Holocene. *G.sacculifer*, a warm surface water species, has high abundances during the Holocene than LGM. The abundances of *P.obliquiloculata*, a species indicating warm watermass and/or deep thermocline conditions in the open sea environments of the western Pacific (Andresean and Ravelo, 1997; Chen and Prell, 1998), were higher in the LGM and lower in the Holocene, probably indicating different subsurface hydrographies during the Holocene and LGM in the SCS. It is worthy to notice that there is a *Pulleniatina* minimum event happened at ~4500 to ~3000 yrs B.P.. The same event was reported from core studies for Ryukyu Arc region (Ujiié and Ujiié, 1999) and for the SCS (Jian *et al.*, 1996). Initially this event was interpreted as short-term oscillations driven by regional tectonic mechanisms (Ujiié and Ujiié, 1999). Our finding of the same event in the southern SCS suggests that the *Pulleniatina* minimum event might persist at more regional scales. It is therefore inferred from our data that this *Pulleniatina* minimum event maybe a more basin-wide scale event of the western Pacific, instead of a local event of the Ryukyu Arc region. Another *Pulleniatina* minimum event happened in our record at ~17,000 to ~15,000 yrs B.P. which is concurrent with the timing of the first Heinrich event.

Table 1. Descriptive statistics of 23 planktic foraminifer species percentages from last two glacial-interglacial cycles of 209-samples in the South China Sea Core MD972151.

Foraminifer Species	Avg.(%)	St. Dev. (%)	Min.(%)	Max.(%)
Orbulina universa	1.32	0.65	0.00	4.76
Globigerinoides conglobatus	0.48	0.57	0.00	3.65
Globigerinoides ruber	**26.04**	5.17	8.73	42.47
Globigerinoides tenellus	1.72	1.02	0.00	6.22
Globigerinoides sacculifer	**14.44**	5.40	3.78	32.64
Sphaeroidinella dehiscens	0.12	0.24	0.00	1.21
Globigerinella aequilateralis	2.20	1.12	0.31	6.40
Globigerina calida	5.85	2.03	0.93	11.18
Globigerina bulloides	4.62	2.25	0.42	11.62
Globigerina falconensis	0.13	0.27	0.00	1.53
Globigerina digitata	0.08	0.17	0.00	0.91
Globigerina rubescens	1.56	1.18	0.00	6.63
Neogloboquadrina pachyderma (L)	0.00	0.08	0.00	0.48
Neogloboquadrina dutertrei	**17.23**	6.88	3.65	35.73
Globoquadrina conglomerata	1.06	1.00	0.00	3.79
Pulleniatina obliquiloculata	**9.61**	5.48	0.00	29.44
Globorotalia inflata	0.99	1.13	0.00	5.45
Globorotalia truncatulinoides (L)	0.16	0.55	0.00	4.37
Globorotalia truncatulinoides (R)	0.32	0.56	0.00	2.63
Globorotalia crassaformis	1.15	1.41	0.00	6.12
Globorotalia scitula	0.34	0.42	0.00	3.23
Globorotalia menardii	3.29	2.76	0.00	12.46
Globigerinita glutinata	**8.01**	4.94	1.12	22.91

Note: *Neogloboquadrina dutertrei* include *Neogloboquadrina dutertrei* and *Neogloboquadrina pachyderma* (R).

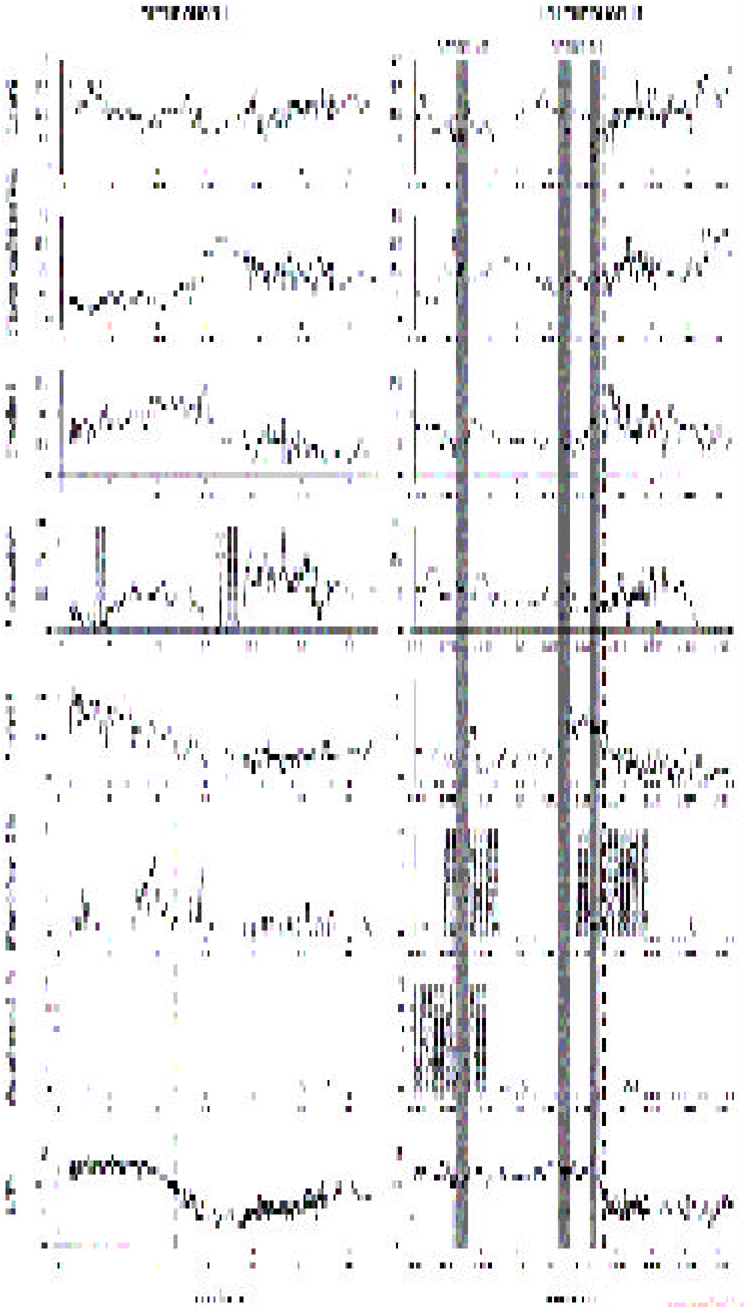

Figure 3. The variations of relative abundances of five dominant planktic foraminifer species and two deep-dwelling species against age of the last two Terminations in MD972151. The planktic foraminifer $\delta^{18}O$ data from the same core are plotted for comparison and age model construction. The two Termination boundaries are indicated by dashed lines. Hatched shadows indicate events of *Pulleniatina* minima in the Holocene (Ujiié and Ujiié, 1999) and increased abundances of deep-dwelling species *G.truncatulinoides* (left coiling) and *G.truncatulinoides* (right coiling) in stage 5d and 5e (Jian *et al.*, 2000). The shaded lines indicate dust peak events in stage 5d and 5e reported from loess profiles in central China (An and Porter, 1997).

During the interval of the Termination II, these species showed no clear glacial-interglacial change patterns but much higher amplitude variations. We also found that there is a high abundance interval of *G.truncatulinoides* (left coiling), a deep-dwelling/cold water species in stage 5d. This event has been reported from South China Sea core studies (Jian *et al.*, 2000). Slightly increased abundances of *G.truncatulinoides* (right coiling) that also implies stronger surface water mixing conditions are also observed from the intervals of 5d and 5e (Jian *et al.*, 2000). All these features suggest the existence of episodic cold/stronger mixing events in the Termination II. Brief cold events inferred from the oscillations of coarse-fraction content in Chinese loess profiles of central China (An and Porter, 1997) also suggested an instability of monsoon climate during the interval of the Termination II, particularly in stage 5d and 5e. The coincidence of rapid cooling episodes expressed in marine and terrestrial records suggests teleconnections and instabilities of East Asian regional climate during the Termination II and early stage 5.

We used CABFAC Q-mode factor analysis to smooth the data noise and to identify statistically independent "components" from these species abundance data. Four factors explain over 97% of the total variance of our planktic foraminifer compositions (Tab.2; Fig. 4). The first factor is mainly composed of *P.obliquiloculata*, which shows pattern of variations similar with that of species abundances: high loadings during the LGM and low loadings during the Holocene. The second factor is composed of *G.ruber* and *G.glutinata*, which may represent local SCS warm surface water masses, and/or stable stratification conditions. The variations of the factor loadings follow the same oscillation trends as shown by the species abundances: high loadings during the Holocene and low loadings during the LGM. This pattern of variations points out the glacial-interglacial contrast in the SCS during the interval of the Termination I. The third factor is composed of *G.sacculifer*, which also represents the warm SCS surface waters, reaches high loadings in a broad interval of the Termination I. The fourth factor is represented by *N.dutertrei*, and shows the same pattern of variations as shown by the species abundances: high loadings during the LGM and low loadings during the Holocene. This suggested that the southern SCS was much colder and probably more abundant in nutrient concentrations in the glacial intervals, when the climate was dominated by winter monsoon (Chen and Huang, 1998). During the interval of the Termination II, only factor 4 was slightly higher in glacial stage 6 than in interglacial stage 5. The other factors show no clearly glacial to interglacial variations, but interrupted by much high-frequency, short-term cooling events which reflect probably more variable monsoon climate during this time interval.

Downcore fauna estimates of SST and DOT by using previously published transfer functions (Ortiz and Mix, 1997; Andreasen and Ravelo, 1997) from core MD972151 also exhibit high-frequency variations (Fig. 5). By focusing on the variations of faunal SST and alkenone SST (Huang *et al.*, 1999; Wang, 1999) of the past two Termination intervals, we found that during the Termination I, both SSTs exhibit variations of cooling reversal events similar to the Younger Dryas and Heinrich Event. Though different amplitudes of SST variations estimated by these two methods, our results indicate that a cooling of ~1-2^{o}C in the Younger Dryas and of ~2-3.5^{o}C in the first Heinrich event in the southern SCS. DOT estimates also show shallower depth conditions for these two events, which are indications of stronger wind effects. In contrast, during the interval of the Termination II, there was no distinguishable climatic reversal event occurring in the transition, but there were many high-frequency and high-amplitude cooling events interrupted in interglacial stage 5d and 5e (Fig. 5). Our results indicate a cooling of ~1-3^{o}C in these short-term coolings, while alkenone estimates again exhibit relatively smaller amplitudes of changes. During the cooling events, we also observed that the DOTs were much shallower which indicates probably stronger wind effects that in turn could result from deep-mixing conditions. All these events seem to be correlative with dust peak events reported from loess profiles in central China (An and Porter, 1997), and increased abundances in deep-dwelling faunal species *G.truncatulinoides* (L.) and *G.truncatulinoides* (R.) (Jian *et al.*, 2000).

Table 2. Factor-Score Assemblage Matrix (F) of 209-downcore faunal percentage data from a South China Sea Core MD972151. (VARIMAX solution by CABFAC factor analysis).

Foraminifer Species	Factor 1	Factor 2	Factor 3	Factor 4
Orbulina universa	0.026	0.003	0.021	-0.024
Globigerinoides conglobatus	-0.004	0.022	0.007	0.000
Globigerinoides ruber	0.376	0.680	-0.250	-0.400
Globigerinoides tenellus	-0.016	0.048	-0.004	-0.033
Globigerinoides sacculifer	-0.189	0.281	0.875	0.020
Sphaeroidinella dehiscens	-0.003	0.002	0.009	-0.001
Globigerinella aequilateralis	0.025	0.043	-0.023	-0.060
Globigerina calida	0.143	0.045	0.020	-0.079
Globigerina bulloides	0.058	0.190	-0.044	0.009
Globigerina falconensis	0.003	-0.002	0.005	-0.002
Globigerina digitata	0.000	0.002	0.001	-0.002
Globigerina rubescens	0.049	0.013	-0.020	-0.032
Neogloboquadrina pachyderma (L)	0.001	0.000	0.001	0.001
Neogloboquadrina dutertrei	0.252	-0.304	0.305	-0.775
Globoquadrina conglomerata	0.035	0.024	0.032	0.032
Pulleniatina obliquiloculata	0.847	-0.116	0.221	0.445
Globorotalia inflata	0.041	-0.023	0.001	-0.035
Globorotalia truncatulinoides(L)	0.011	-0.003	0.007	0.005
Globorotalia truncatulinoides(R)	-0.012	0.003	0.036	0.001
Globorotalia crassaformis	0.055	-0.036	0.043	-0.011
Globorotalia scitula	0.017	-0.005	-0.004	-0.007
Globorotalia menardii	-0.013	0.149	0.139	0.086
Globigerinita glutinata	0.082	0.534	0.059	0.139
Variance (%)	28.02	31.64	15.03	22.87
Cumulative Variance (%)	28.02	59.66	74.69	97.56

Note: *Neogloboquadrina dutertrei* include *Neogloboquadrina dutertrei* and *Neogloboquadrina pachyderma* (R).

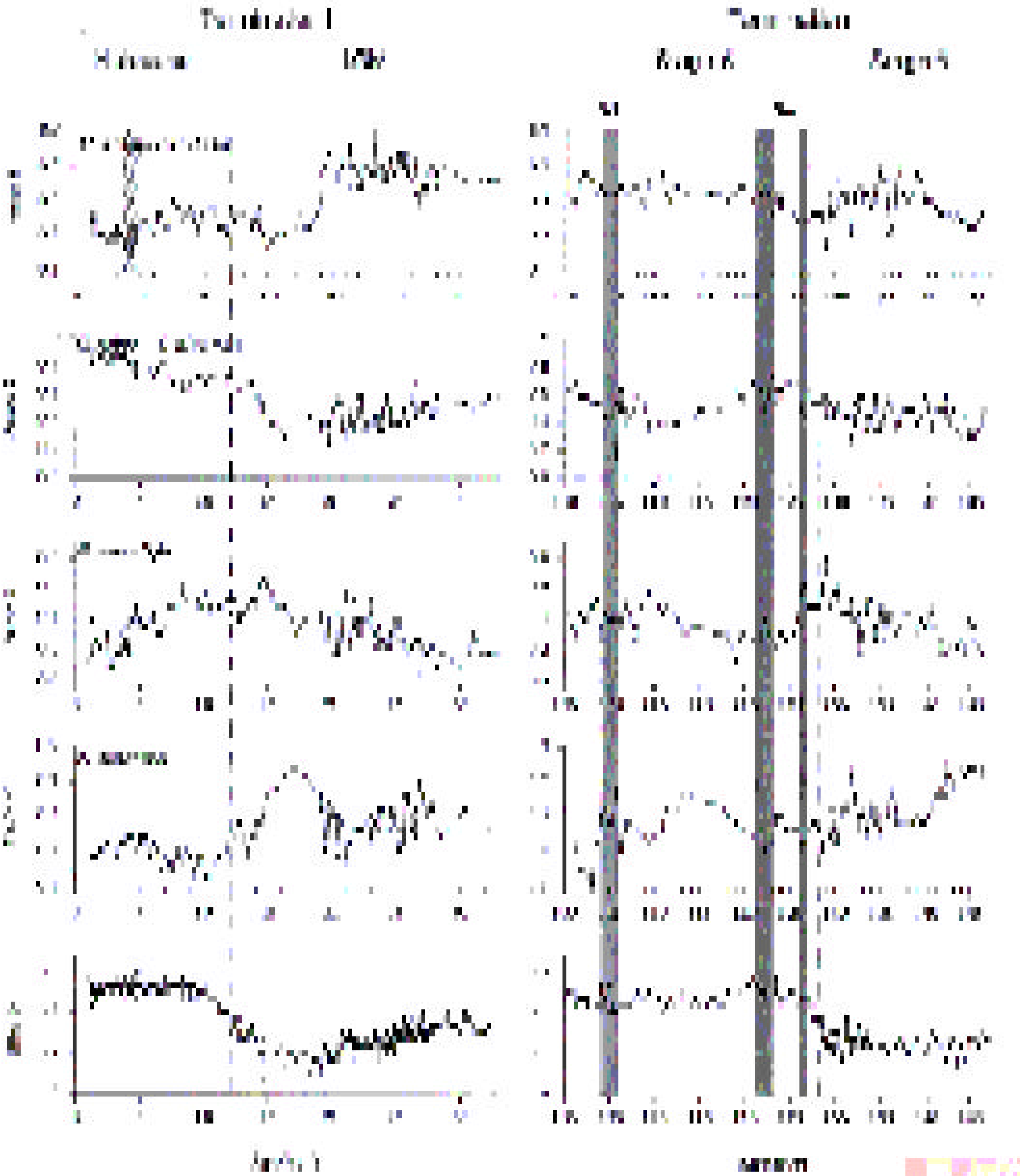

Figure 4. The variations of four important faunal factors from core MD972151 of the last two Terminations and of planktic foraminifer *G.sacculife* $\delta^{18}O$ plotted against age. The factors were computed using a Q-mode factor analysis with a VARIMAX solution (Klovan and Imbrie, 1971). Termination boundaries are indicated by dashed vertical lines. The shaded lines indicate intervals of the Younger Dryas and Heinrich events (in left panel) and dust peak events in stage 5d and 5e reported from loess profiles in central China (An and Porter, 1997).

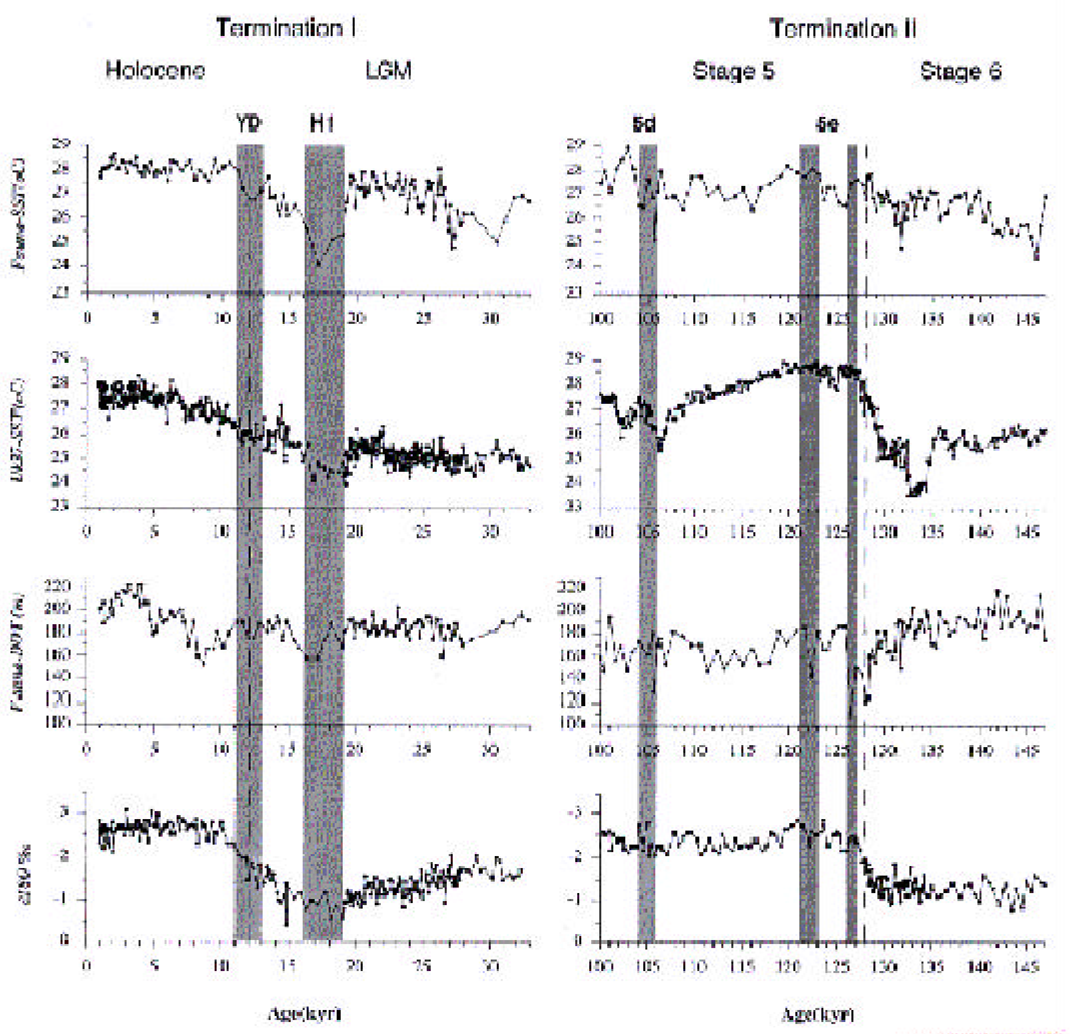

Figure 5. Variations of faunal estimates sea-surface temperature (SST), depth of thermocline (DOT), and U^k37 plotted against age during the last two Terminations. The SST estimates were computed based on a global transfer function (Ortiz and Mix, 1997), and the DOT estimates were based on a tropical Pacific Ocean transfer function (Andreasen and Ravelo, 1997). Termination boundaries are indicated by dashed vertical lines. The shaded lines indicate intervals of the Younger Dryas and Heinrich events (in left panel) and dust peak events in stage 5d and 5e reported from loess profiles in central China (An and Porter, 1997).

CONCLUSIONS

In this study we presented high-resolution data of planktic foraminifer stable isotopes, faunal abundances with SST and DOT estimates, and alkenone SSTs from an IMAGES core MD972151 in the southern SCS. While presenting our data for the past two Termination intervals, we identified four planktic foraminifer factors from the downcore data to indicate past surface water mass variations in the SCS. These four factors are factor 1 (*P.obliquiloculata*), factor 2 (*G.ruber* and *G.glutinata*), factor 3 (*G.sacculifer*), and factor 4 (N.dutertrei). These factors can be interpreted in terms of different water masses and/or stratification conditions in the SCS. We further analysed the data by calculating SST and DOT estimates by using planktic foraminifer transfer functions and comparing the faunal SSTs with paralleling measurements of alkenone SSTs. Our results show events of rapid cooling reversals occurred during the Termination I and the events are concurrent with the Younger Dryas (~13-11 kyr B.P.), and Heinrich events reported previously from GISP2 ice core and North Atlantic core studies. We also found that during the Termination II, there was no such climatic reversal analogous to the Younger Dryas. During the interval of the Termination II, our estimates of SST and DOT, and abundances of deep-dwelling planktic foraminifer species all show large-amplitude variations. These indicate an instability of monsoon climate during the last interglacial period. Our studies also highlight the climatic teleconnections shown by the linkage of our MD972151 records and other regional paleoclimatic records in certain events: (1) a *Pulleniatina* minimum event happened at ~4500 to ~3000 yrs B.P. reported from core studies for Ryukyu Arc region (Ujiié and Ujiié, 1999) and for the SCS (Jian *et al.*, 1996) from the East China Sea; (2) increased abundances of deep-dwelling species *G.truncatulinoides* (left coiling) and *G.truncatulinoides* (right coiling) in stage 5d and 5e. This event has been reported from East and South China Sea core studies (Jian *et al.*, 2000); and (3) dust peak events in stage 5d and 5e reported from loess profiles in central China (An and Porter, 1997).

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REFERENCES

An, Z., and Porter, S.C. (1997) Millennial-scale climate oscillation during the last interglaciation in central China: *Geology*, **25**, 603-606.

Andreasen, DJ., and Ravelo, A.C. (1997) Tropical Pacific Ocean thermocline depth reconstructures for the last glacial maximum: *Paleoceanography*, **12**, 395-413.

Be, A.W.H. (1967) Foraminifera, families: Globigerinide and Globorotaliidae: In: J.H. Fraser (editor), *Fiches d'Identification du Zooplancton*, Cons. Int. Explor. Mer, Charlottenlund, Sheet 118.

Chen, M.-T. (1994) Estimating thermocline from planktonic foraminifer fauna data: the development of paleocological transfer functions for reconstructing low-latitude pacific upper-layer conditions: *Journal of the Geological Society of China*, **37**, 443-474.

Chen, M.-T. and Huang, C.-Y. (1998) Ice-volume forcing of winter monsoon climate in the South China Sea: *Paleoceanography*, **13**, 622-633.

Chen, M.-T., Beaufort, L. and the Shipboard Scientific Party of the IMAGES III/MD106 - IPHIS Cruise (Leg II) (1998) Exploring Quaternary Variability of the East Asia Monsoon, Kuroshio Current, and western Pacific warm pool systems: High-Resolution investigations of paleoceanography from the IMAGES III (MD106)- IPHIS Cruise: *The Journal of Tterrestrial, Atmospheric and Oceanic Sciences*, **9**,129-142.

Chen, M.-T., Wang, C.-H., Huang, C.-Y., Wang, P., Wang, L., Sarthein, M. (1999) A late Quaternary planktonic foraminifer fauna record of rapid climatic changes from the South China Sea: *Marine Geology*, **156**, 85-108.

Chen, M.-T., and Prell, W.L. (1998) Faunal distribution patterns of planktonic foraminifers in surface sediments of the low-latitude Pacific: *Paleogeography, Paleoclimatology, Paleoecology*, **137**, 55-77.

Ho, H.W., Chen, M.T., Zheng, L. and Huang, C.Y. (1998) A preliminary analysis on the distribution patterns of recent surface-sediment planktic foraminifers and upper-layer ocean environments in the South China Sea: *Journal of the Geological Society of China*, **41**, 43-72.

Huang, C.-Y., Wang, C.-C. and Zhao, M. (1999) High-resolution Carbonate Stratigraphy of IMAGES Core MD972151 from South China Sea: *The Journal of Terrestrial, Atmospheric, and Oceanic Sciences*, **10**,225-238.

Imbrie, J., J. Hay, D. Martinson, A. McIntype, A. Mix, J. Morley, N. Pisias, W. Prell and N. Shackleton (1984) The orbital theory of Pleistocene climate: Support from a revised chronology of marine $\delta^{18}O$ record: In *Milankovitch and Climate*, edited by A. Berger. Reidel, Dordecht, 269-305pp..

Jian, Z., Li, B., Huang, B. and Wang, J. (2000) *Globorotalia truncatulinoides* as indicator of upper-ocean thermal structure during the Quaternary: evidence from the South China Sea and Okinawa Trough: *Palaeogeography, Palaeoclimatology, Palaeoecology*, **162**, 287-298.

Jian, Z., Li, B., Pflaumann, U. and Wang, P. (1996) Late Holocene cooling event in the western Pacific: *Sci. China Ser.*, **39**, 543-550.

Kienast, M., S. Steinke, K. Stattegger, and S.E. Calvert, 2001. Synchronous tropical South China Sea SST change and Greenland warming during deglaciation: *Science*, **291**, 2132-2134.

Kipp, N.G. (1976) New transfer function for estimating past sea-surface conditions from sea-bed distribution of planktonic foraminiferal assemblages in the North Atlantic: In: R.M. Cline and J.D. Hays (editors), *Investigation of Late Quaternary Paleoceanography and Paleoclimatology*, Memoir of Geological Society of America, **145**, 3-41.

Klovan, J.E. and Imbrie, J. (1971) An algorithm and FORTRAN-IV program for large-scale Q-mode factor analysis and calculation of factor scores: *Mathematical Geology*, **3**, 61-77.

Lee, M.-Y., Wei, K.-Y. and Chen, Y.-G. (1999) High Resolution Oxygen Isotope Straigraphy for the Last 150,000 Years in the Southern South China Sea:Core MD972151: *The Journal of Tterrestrial, Atmospheric, and Oceanic Sciences*, **10**, 239-254.

National Oceanic and Atmospheric Administration (NOAA) (1994) World Ocean Atlas 1994: National Oceanographic Data Center, NOAA, Washington, D.C., U.S.A..

Ortiz, J.D., and Mix, A.C. (1997) Comparison of Imbrie-Kipp transfer function and modern analog temperature estimates using sediment trap and core top foraminiferal faunas: *Paleoceanography*, **12**, 175-190.

Parker, F.L. (1962) Planktonic foraminiferal species in Pacific sediments: *Micropaleontology*, **8**, 219-254.

Pelejero, C., Grimalt, J.O., Heilig, S., Kienast, M. and Wang, L. (1999) High-resolution Uk37 temperature reconstructions in the South China Sea over the past 220 kyr: *Paleoceanography*, **14**, 224-231.

Pisias, N.G., Martinson, D.G., Moore, T.C., Shackleton, N.J., Prell, W., Hay, J., and Boden, G. (1984) High resolution stratigraphic correlation of benthic oxygen isotoic records spanning the last 300,000 years: *Marine Geology*, **56**, 119-136.

Prell, W., Imbrie, J., Martinson, D.G., Morley, J.J., Pisias, N.G., Shackleton, N.J., and Streeter, H.F. (1986) Graphic correlation of oxygen isotope stratigraphy application to the late Quaternary: *Paleoceanography*, **1**, 137-162.

Rottman, M.L. (1979) dissolution of planktonic foraminifera and pteropods in South China Sea sediments: *Journal of Foraminiferal Research*, **9**, 41-49.

Shieh, K.-S., and Chen, M.-P. (1984) Recent planktonic foraminifera in surface sediments of the South China: *Bulletin of the Central Geological Survey*, **3**, 81-106.

Stuiver, M. and Reimer, P.J. (1993) Extend ^{14}C data base and revised CALIB 3.0 ^{14}C age calibration program: *Radiocarbon*, **35**, 215-230.

Ujiié, H. and Ujiié, Y. (1999) Late Quaternary course changes of the Kuroshio Current in the Ryukyu Arc region, northwestern Pacific Ocean: *Marine Micropaleontology*, **37**, 23-40.

Wang, C.-C. (1999) High-resolution Paleomonsoon/Paleoceanography fluctuation of the South China Sea in the last 150kyrs: records of IMAGES MD972151 core: Master Degree Thesis (In Chinese), Department of Geology, National Taiwan University, Taipei, Taiwan, ROC, 83pp.

Wang, L., Sarnthein, M., Erlenkeuser, H., Grimalt, J.O., Grootes, P.M., Heilig, S., Ivanova, E., Kienast, M., Pelejero, C. and Pflaumann, U. (1999) East Asian monsoon climate during the Late Pleistocene: high-resolution sediment records from the South China Sea: *Marine Geology*, **156**, 245-284.

Wang, L., Sarnthein, M., Groots, P.M. and Erlenkeuser, H. (1999) Millennial reoccurrence of century-scale abrupt events of East Asian monsoon: A possible heat conveyor for the global deglaciation: *Paleoceanography*, **14**, 725-731.

Wang, P. (1999) Response of weastern Pacific marginal seas to glacial cycles: paleoceanographic and sedimentological features: *Marine Geology*, **156**, 5-39.

Wang, P. and Sun, X. (1994) Last glacial maximum in China: comparison between land and sea: *Catena*, **23**,341-353.