PALEOCEANOGRAPHY, VOL.5, NO.1, PAGES 77-90

LATE QUATERNARY PALEOCEANOGRAPHY OF THE SOUTH CHINA SEA: GLACIAL-INTERGLACIAL CONTRASTS IN AN ENCLOSED BASIN

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Abstract. The sea surface paleotemperature of the South China Sea (SCS) is estimated quantitatively, based on the quantitative analysis of planktonic foraminiferal faunas recovered from piston cores V36-06-3,V36-06-5, and SO49-KL8 on the northern continental slope. The results lead to a reconstruction of the history of paleocirculation patterns during the last 200,000 years. The postglacial and interglacial transbasinal circulation pattern was replaced by a semienclosed basin flow pattern during glacial episodes. Lowered sea level transformed the SCS into a semienclosed basin with the only passageway to the open ocean in its northeastern corner. The East Asian Monsoon, which governs circulation patterns in the SCS both today and during the late Quaternary, created both clockwise (summer) and counterclockwise (winter) surface gyres during glacials. The inflow of tropical surface watermasses from both the Pacific and Indian oceans decreased or was completely cut off from this marginal sea, causing a greater decrease in glacial sea surface temperature than in the open ocean of the same latitude. Inferred increased influence of Pacific Temperate Waters and decreased influence of Tropical-Subtropical Waters are confirmed by changes in the planktonic foraminiferal assemblages. Glacial-interglacial fluctuation in sea surface temperature (SST) (6.8-9.3°C for winter and 2-3°C for summer), as well as the seasonality (4-6°C for postglacial and interglacials and 9-10°C for glacials), are much greater than the adjacent open western Pacific, reflecting the amplification of the climatic signal in the marginal sea.

Paper number 89PA03239
0883-8305/90/89PA-03239$10.00

INTRODUCTION

The South China Sea (SCS), in the western Pacific region, is one of the largest marginal seas in the world (Figure. 1). Because of its rich biological and mineralogical resources, as well as its petroleum prospect, the SCS has long been the focus of marine scientists. A number of comprehensive and detailed oceanographic studies have been carried out in SCS [Zhao, 1982, etc.], including investigations about the oceanographic conditions of the Bashi Strait [Zhu, 1972; Q. Huang, 1984] and the central area watermasses [Han, 1982; Xu, 1982]. Since the 1970s, much micropaleotonlogical and sedimentological work has also been carried out in the region by marine geologists [e.g., Cheng and Cheng, 1962; Tu, 1983; Wang et al., 1985; Feng et al., 1988].

Because the SCS is located between the East Asian landmass and the western Pacific, the sediment sequence and its paleontological record are affected by both the ocean and the continent, thus recording the history of continental climatic change as well as the paleoceanographic change. The study of Quaternary paleoceanography of the SCS began in the early 1980s, along with the recovery of more than a dozen piston cores taken on the

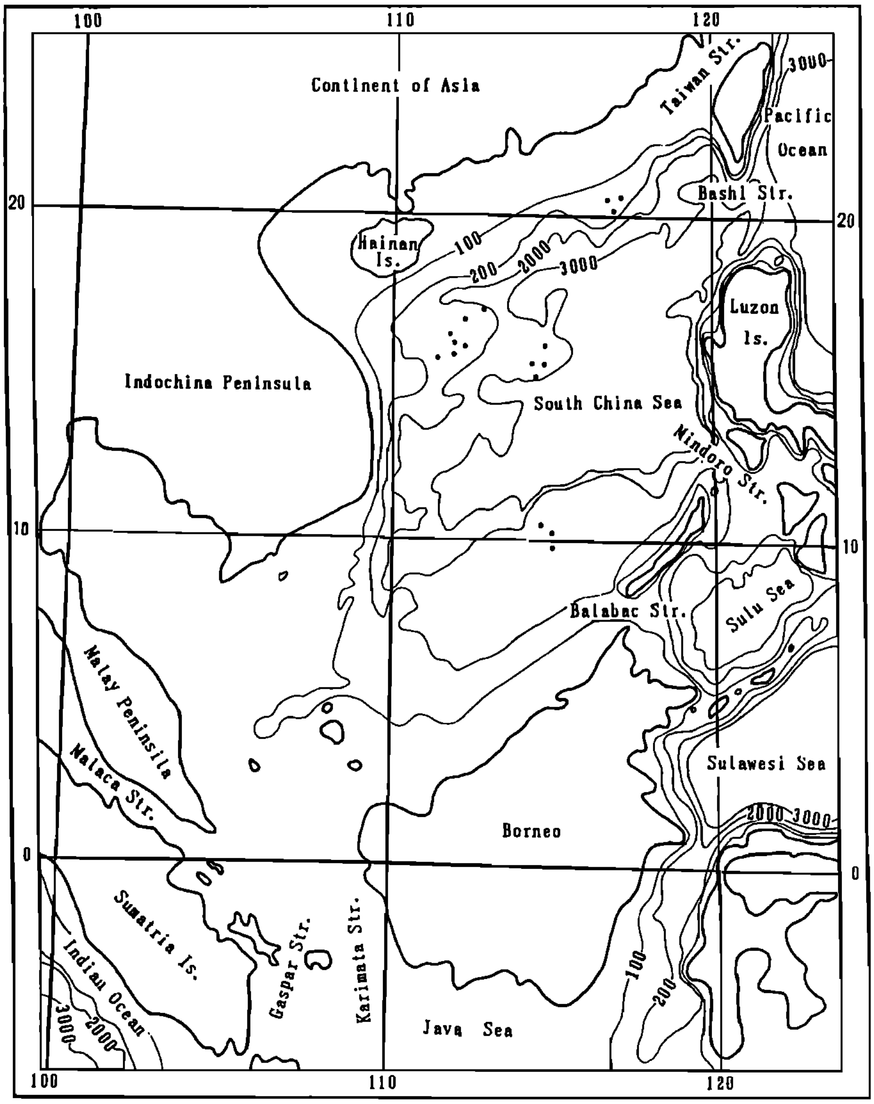


Fig. 1. Geographic position of the South China Sea.

northern continental slope. These cores have been examined for planktonic foraminifera using ecological transfer functions, oxygen isotopes, and sediments. This has led to preliminary interpretations about paleotemperatures of surface waters, paleoceanography, and carbonate cycles [Wang et al., 1986; Samoda et al., 1986; Wang et al., 1988; Feng et al., 1988; Wang and Wang, 1989].

MATERIALS AND METHODS

To investigate late Quaternary changes in sea surface temperature (SST), we studied three cores of different water depths on the northern continental slope of the SCS, namely, V36-06-3, V36-06-5, and SO49-KL8 (Figure 2 and Table 1). There have already been some published results about the first core by the authors in 1986 and 1989 [Wang et al., 1986; Wang and Wang, 1989]. Cores V36-06-3 and V36-06-5 were raised by the R/V *Vema* of the Lamont-Doherty Geological Observatory in 1979 and the core SO49-KL8 by R/V. *Sonne* of West Germany in 1987, under China-United States and China-West Germany joint expeditions, respectively.

SO49-KL8 was sampled at 10-cm intervals because of relatively low sedimentation rates (4.2 cm/kyr), while the other two cores were sampled at 20-cm intervals (Table 2). Standard sample preparation procedures have been adopted here. After being soaked in water for 1 or 2 days, unconsolidated samples were washed on 280-mesh (62 microns) screen with tap water. The residuals were dried on a hot plate and

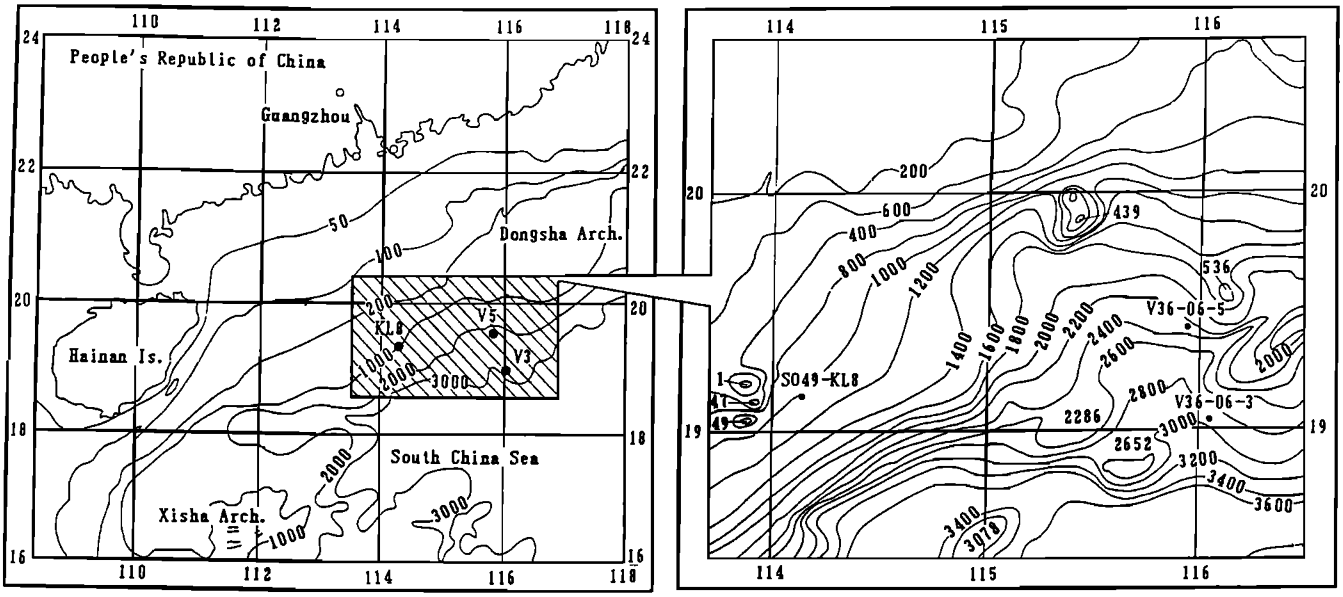


Fig. 2. Location of piston cores V36-06-3, V36-06-5, and SO49-KL8.

TABLE 1. Locations, Water Depths, and Lenths of the Three Cores Used In This Paper

Core	Latitude	Longitude	Depth, m	Length, m
V36-06-3	19°00.5'N	116°05.6'E	2809	12.15
V36-06-5	19°26.0'N	115°01.1'E	2332	10.70
SO49-KL8	19°11.0'N	114°12.0'E	1040	9.55

then sieved dry through 140-mesh (150 microns) screen and only the coarser fractions have been used in quantitative faunal analysis. For planktonic foraminiferal analysis, splitting was carried out if necessary to obtain a statistically appropriate quantity (Table 3). Generally, the benthic foraminifera are far less abundant than the planktonic foraminifera, constituting only less than 5% of total foraminifral fauna in each sample.

Tests of *Globigerinoides sacculifer*, used for stable isotopic analysis, were selected from V36-06-3, with test size of 355-450 microns, while those selected from SO49-KL8 are no-sack-like-chamber-bearing tests and of the same size. The isotopic data of V36-06-3 were provided by N. J. Shackleton, University of Cambridge, United Kingdom, and that of SO49-

TABLE 2. Sample Information of the Three Selected Cores

Core	Sample	Sample Interval, cm	Remark on Exception
V36-06-3	62	20	10 cm between samples 1-2
V36-06-5	55	20	10 cm between samples 1-2
SO49-KL8	98	10	plus two samples at 667.5 and 765.0 cm

TABLE 3. Information of Foraminiferal Faunal Analysis of the Three Cores

Core	Total Number Counted	Number per Sample Maximum	Minimum	Average
	Planktonic Foraminifera			
V36-06-3	33,317	2375	118	537
V36-06-5	14,967	637	121	272
SO49-KL8	38,189	755	216	390
	Benthic Foraminifera			
V36-06-3	1,806	82	5	30
V36-06-5	1,689	70	10	31
SO49-KL8	23,847	1,137	123	443

Benthic foraminifera are analysed for every two samples in each core (See Table 2).

KL8 by Y. Lu of Shanghai Institute of Measurement Technology. The carbonate content analysis results of V36-06-3 used in this paper are from Wang et al. [1986], and those of V36-06-5 are calculated from the CaO content measurements of Feng et al. [1988]. The paleo-SST estimates were made by applying the transfer function technique [Imbrie and Kipp, 1971]. The planktonic foraminiferal transfer function used here is that developed by Thompson [1981] for the western Pacific, namely, FP-12E.

STRATIGRAPHY

The age determination and correlation of the three cores are based on planktonic foraminiferal biostratigraphy, oxygen isotope stratigraphy, and carbonate cycles and are complemented by the estimated SST curves.

In the Indo-Pacific region, the extinction of pink-pigmented test variants of *Globigerinoides ruber* at 120,000 years B.P. provides an accurate datum plane and is one of the most commonly used late Quaternary datums [Thompson et al., 1979]. In V36-06-3 and SO49-KL8, this last appearance datum (LAD) occurs at 11.2 and 5.0 m, respectively. Pink tests of *Gs. ruber* are missing throughout core V36-06-5 (10.7 m in length), and this core is considered to be younger than 120,000 years B.P. (Figure 3).

The $\delta^{18}O$ curve of V36-06-3 and SO49-KL8 exhibit patterns similar to that of cores from the open ocean and the last six isotope stages can be easily recognized (Figure 3). The $\delta^{18}O$ records provide a detailed correlation between these two cores. The most distinct boundaries are 1/2, 4/5, 5/6, and 6/7 with ages of 13,000, 75,000, 128,000, and 195,000 years B.P., respectively [Shackleton and Opdyke, 1973]. The carbonate content of V36-06-3 and V36-06-5 enables us to correlate these two cores and subdivided the latter qualitatively into three parts, corresponding to isotope stages 1, 2-4, and 5 (Figure 3). The $\delta^{18}O$ records correlate well with the paleotemperature records, and the summer and winter SST curves can be divided into cold and warm episodes that correspond to isotope stages (Figure 4). In the same way, the SST curves of SO49-KL8 and V36-06-5 can also be subdivided into warm and cold episodes and, further, be correlated to the oxygen isotope stages identified in V36-06-3. The paleo-SST changes appear to be synchronous in the three closely located sites. SO49-KL8 is subdivided into four warm and three cold episodes, corresponding to isotope stages 1-7. Because of a lack of biostratigraphic datums in V36-06-5, only two stage boundaries, 1/2 and 4/5, can be determined and correlated to those of the other cores (Figure 3 and 4). In short, stratigraphic

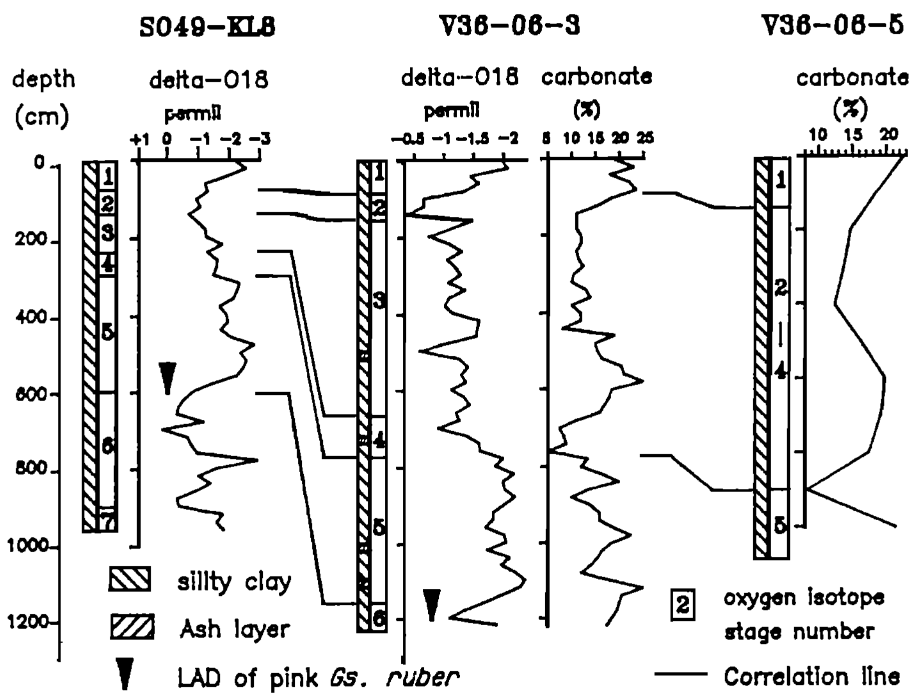


Fig. 3. Stratigraphic correlation of cores V36-06-3, V36-06-5, and SO49-KL8. Isotopic measurements of *Globigerinoides sacculifer* of V36-06-3 are from Wang et al. [1986]. The carbonate content mesurements of V36-06-3 and V36-06-5 are from Wang et al. [1986] and Feng et al. [1988].

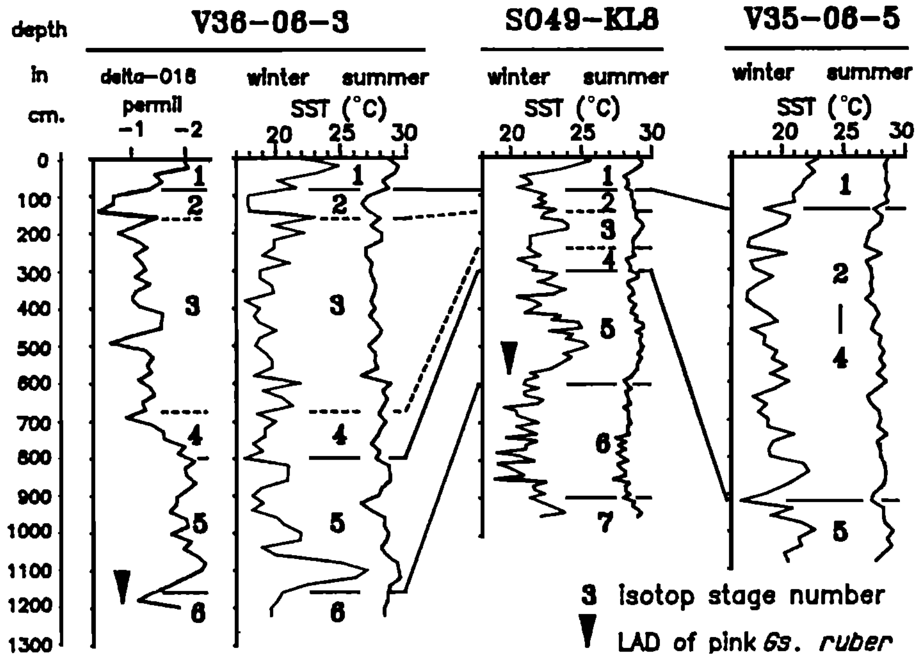


Fig. 4. Paleotemperature curves of cores V36-06-3, SO49-KL8, and V36-06-5. Paleotemperature estimations are made by applying transfer function FP-12E [Thompson, 1981] and isotopic results of *Globigerinoides sacculifer* from V36-O6-3 are from Wang et al. [1986]. Numbers 1-7 are isotopic stage names. See text for ages of main correlation levels.

subdivision of the three cores correlates well with each other and the sediments of last 130,000, 204,000, and about 89,000 years are contained in V36-06-3, SO49-KL8, and V36-06-5, respectively.

PLANKTONIC FORAMINIFERA, PALEO-SST, AND SURFACE CIRCULATION

Planktonic foraminiferal faunas in the three cores are well preserved and biogeographically belong to those of the tropical-subtropical Indo-Pacific region, with *Globigerinoides ruber, Globorotalia inflata, Globigerinita glutinata, Neogloboquadrina dutertrei, Gs. sacculifer, Globigerinella aequilateralis, Globigerina bulloides, Ga. calida, Nq. pachyderma, and Pulleniatina obliqueloculata* predominating in most of the samples (with maximum relative abundance greater than 10%). The taxonomy and analysis of the planktonic foraminifera in V36-06-3 have already been described [Wang et al., 1986; Wang and Wang, 1989], and the same criterion is used for V36-06-3 and V36-06-5 in this paper. For SO49-KL8, not only are the two phenotypes of *Gs. sacculifer* distinguished (with- and without-sack), but a stricter definition is adopted for *Nq. pachyderma*. In SO49-KL8, only the specimens having four roughly equal-sized chambers in the final whorl and a rather low-arch aperture with a thick to moderate rim have been included in *Nq. pachyderma*, as Thompson [1981] adopted a relatively strict criterion for the subdivision of the genus *Neogloboquadrina* in developing transfer function FP-12E. The effect of different data treatment on SST estimation can be seen in the paleotemperature curves (Figure 4), especially in those of winter SST. The amplitude of the glacial-interglacial SST fluctuations in SO49-KL8 (5.2°C) is smaller than that in the other cores (6.6-8.5°C).

Winter and summer SST values estimated are all greater than 14°C and 23°C respectively, falling in the range in which the transfer function FP-12E can provide statistically accurate SST results. Moreover, the differences betweeen the estimated SST of core tops and the present-day SST at the corresponding sites are less than the standard error of estimation (Table 4) [Thompson, 1981]. In addition, the average communalities of the three cores are 0.72, 0.77, and 0.82, meaning the transfer function technique can interprete 85%, 88%, and 91% (square roots of the average communalities) of the total variance in the observed faunal information.

TABLE 4. Comparison of Present-Day SST and Core-Top SST Estimation by Using Transfer Function FP-12E

Core	Present	Core-Top	Difference
Winter Sea Surface Temperature			
V36-06-3	23.7	21.9	1.8
V36-06-5	23.2	23.4	-0.2
SO49-KL8	23.2	24.8	-1.6
Summer Sea Surface Temperature			
V36-06-3	28.8	28.6	0.2
V36-06-5	28.8	28.6	0.2
SO49-KL8	29.0	28.9	0.1

In degrees Celsius

When Thompson [1981] proposed his transfer function FP-12E, six factor assemblages of planktonic foraminifera were defined, namely, tropical dissolution resistant, tropical dissolution susceptible, subtropical, transitional (temperate), polar/subpolar, and gyre-marginal assemblages. The distributions of these factor assemblages coincide with the Kuroshio current, Tropical, Subtropical, Temperate, Polar/Subpolar, and Gyre-marginal watermass, respectively [Thompson, 1981]. This indicates that each of the assemblages is representative of a definite surface watermass. Thus the factor scores of each sample represent the influence of these watermasses on the core site at a particular time. Among the six factors, glacial-interglacial change in the factor scores of the transitional assemblages is the most obvious, which indicates that the influence of Temperate waters was greater in glacials than in interglacials (Figure 5). Several Temperate water species, such as *Gr. inflata*, *Nq. pachyderma* (dextral), also show similar trends (Figure 6). On the contrary, changes in factor scores of tropical dissolution resistant, tropical dissolution susceptible, and subtropical assemblages display an opposite trend. These three factor assemblages represent the influence of Kuroshio, Tropical, and Subtropical waters. Thus the change of factor scores of these three assemblages demonstrates that the influence of warm Kuroshio and Tropical-Subtropical waters decreased in glacials and increased in interglacials (Figure 5). Relative abundance of some tropical and subtropical species, such as *Gs. sacculifer*, *Gr. menardii*, and *Gn. glutinata* also increased in interglacials (Figure 6)

From the estimated paleo-SST curves (Figure 4), several conclusions can be drawn. First, the magnitude of paleotemperature change in the SCS is larger during the last 200,000 years than in open ocean of the western Pacific [Thompson, 1981]. The amplitude of summer SST

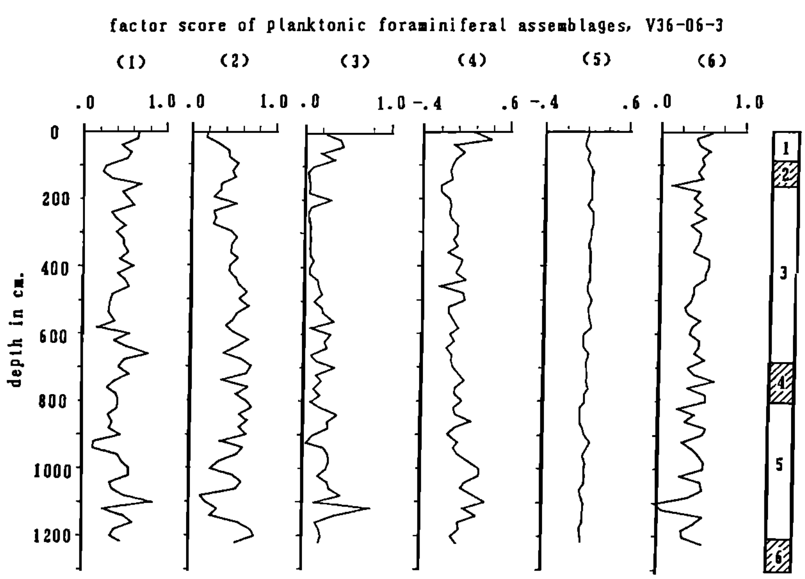
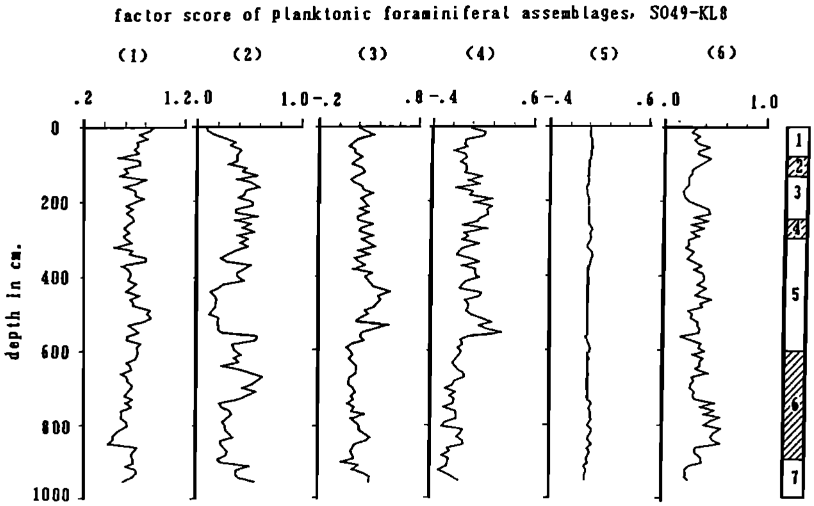


Fig. 5. Factor scores of planktonic foraminiferal faunas from cores V36-06-3, V36-06-5, and SO49-KL8. The six factor assemblages of planktonic foraminifera are those defined in transfer function FP-12E [Thompson, 1981]. The bar at right side indicates the isotopic stage. From left: 1, Tropical Dissolution Susceptible Assemblage (Ass); 2, Transitional Ass; 3, Tropical Dissolution Resistant Ass; 4, Subtropical Ass; 5, Polar/Subpolar Ass; 6, Gyre-marginal Ass.



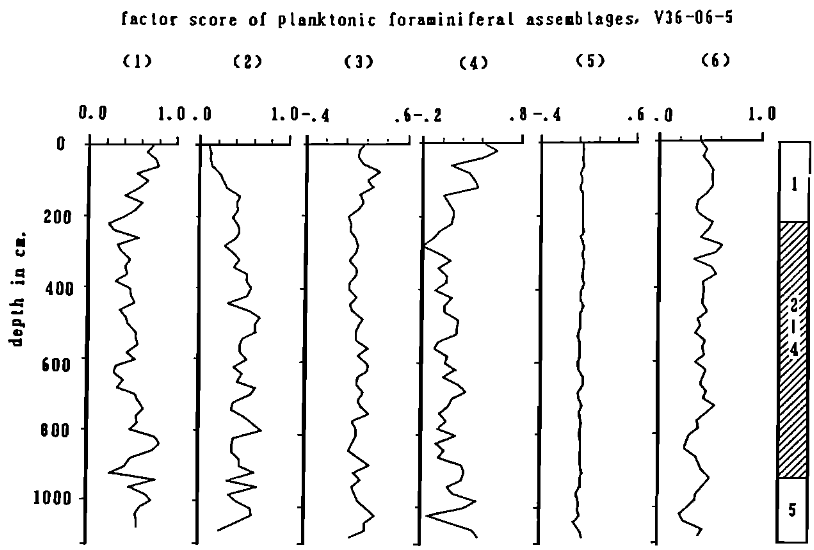


Fig. 5. (continued)

fluctuation is 2-3°C and that of winter SST may be as much as 6.8-9.3°C in the SCS. Using the same transfer function, Thompson [1981] estimated that magnitudes of glacial-interglacial winter SST changes in tropical and subtropical western Pacific were approximately 3°C and up to 5°C in the temperate region. The summer SST change between glacial and interglacial periods was typically 2°C or less in the tropical and subtropical region of the open western Pacific. Glacial-interglacial winter SST fluctuations of as much as 5°C only occur in the temperate region between 30° and 40°N. The magnitude of glacial-interglacial SST changes is clearly much greater in the northern SCS than that in open ocean of the western Pacific.

Present surface circulation in the SCS displays a transbasinal pattern with opposite directions during summer and winter (Figure 7). In summer, when the southwest monsoon prevails, surface waters from the tropical Indian Ocean flow unobstructed into the SCS through the Malacca, Gaspar, and Karimata straits. Surface waters flow northward and into the western Pacific through Bashi and Taiwan straits (Figures 7a and 1). Present summer SST is 28°-29°C in SCS, and its horizontal variation is small due to the inflow of the warm tropical Indian waters (Figure 8a). During

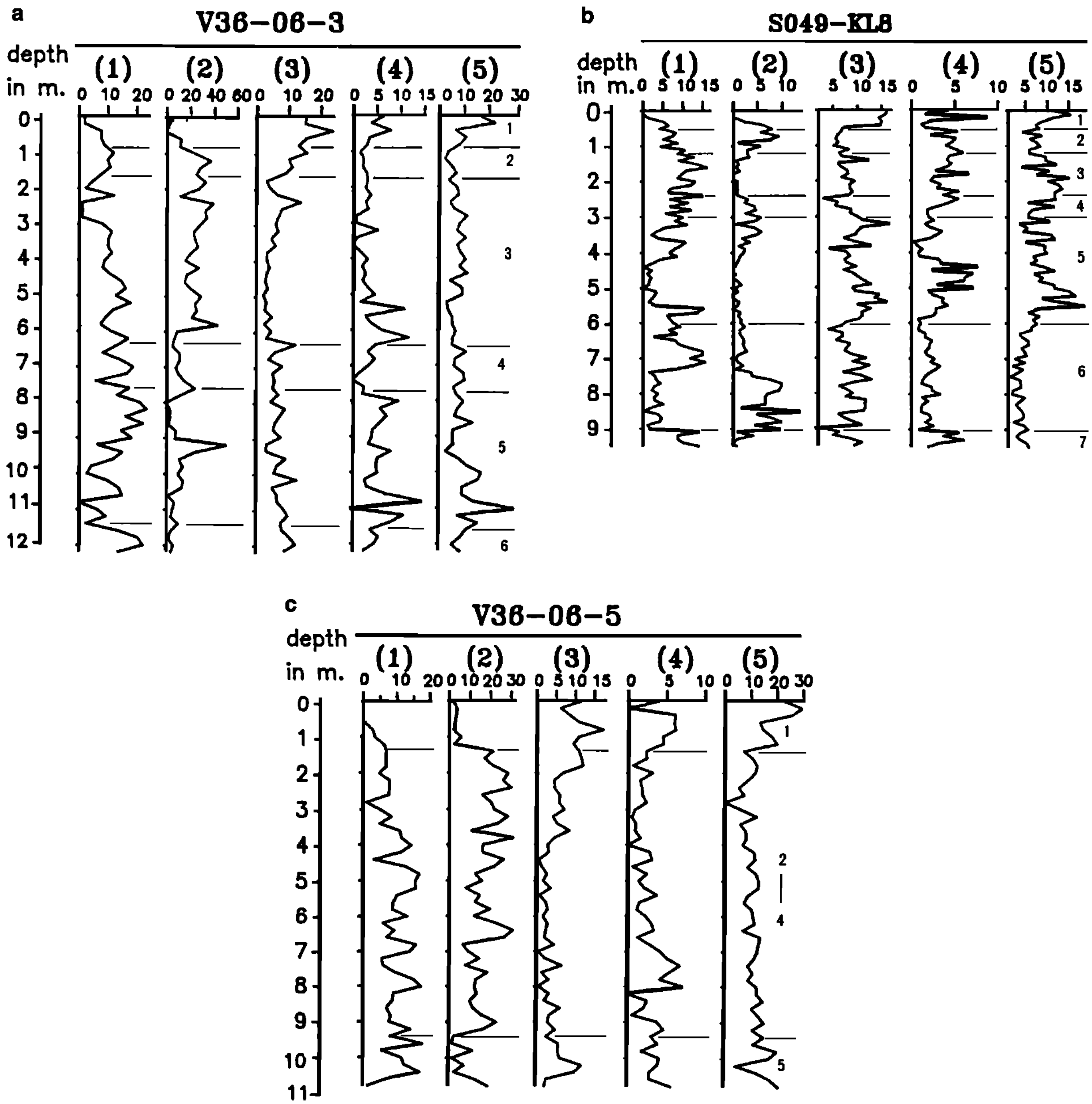


Fig. 6. Relative abundance of selected planktonic foraminiferal species of ecological importance from cores V36-06-3, V36-06-5, and SO49-KL8. 1, *Globorotalia inflata*; 2, *Neogloboquadrina pachyderma*; 3, *Globigerinoides sacculifer*; 4, *Globorotalia menardii*; 5, *Globigerinita glutinata*. Numbers on the right side indicate the isotopic stages.

winter, when the northeast wind prevails, the tropical and subtropical Pacific waters and longshore current enter SCS through Bashi Strait and Taiwan Strait. Most of the surface water flows along the Indo-China Peninsula and then into the Indian Ocean across the Sunda Shelf. Another branch of this current turns back into SCS and forms a couterclockwise gyre (Figure 7b). Because of the inflow of the cooler surface water of the East China Sea and the longshore current, winter SST is rather low, ranging from 16°C in the north to 27°C in the south (Figure 8b).

The sea surface circulation is mainly caused by the wind field and the geotrophic force and is constrained by the configuration of land and

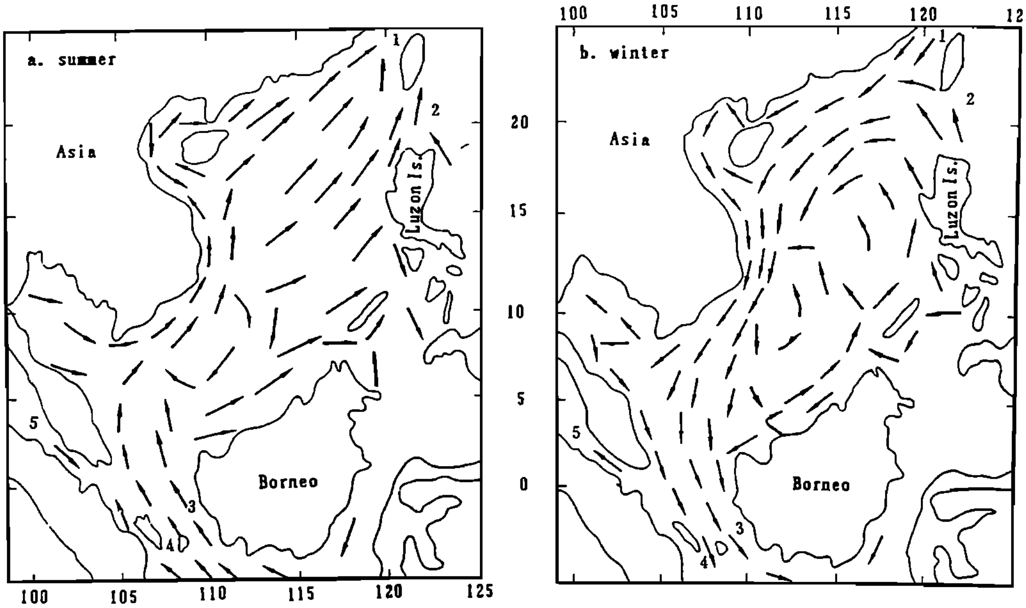


Fig. 7. Present (a) summer and (b) winter surface circulation pattern in South China Sea (redrawn from Chen et al. [1985]). 1, Taiwan Strait; 2, Bashi Strait; 3, Karimata Strait; 4, Gaspar Strait; 5, Malacca Strait.

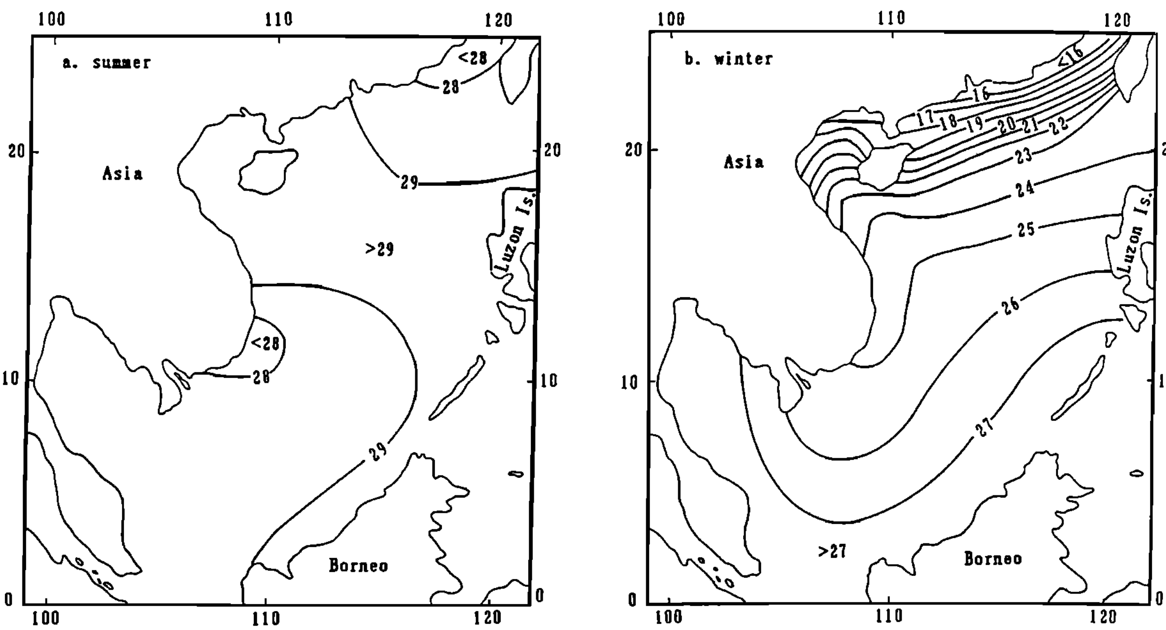


Fig. 8. Present (a) summer and (b) winter sea surface temperature (°C) in South China Sea (redrawn from Chen et al. [1985]).

sea. The SCS is in the area of East Asian Monsoon. The direction and intensity of surface current is mainly affected by the direction and intensity of Monsoon wind. Cullen [1981] thought that the East Asian Mossoon was less intense during the last glacial, but Duplessy [1982] concluded that during glacial episodes the summer monsoon was less intense, while the winter monsoon was much more intense than today. If this is true, the circulation intensity would have changed, although the current direction and circulation pattern would have remained the same. In addition, the change in basin configuration would have played a more important role. According to previous studies, sea level in SCS droped by 100-120 m during glacial periods [Milliman and Emery, 1968; Emery and You, 1981; J. Huang, 1984]. Since most of the straits are shallower than 100 m except the Bashi, Mindoro, and Balabac straits (with sill depths of 2500, 450,and 100-150 m, respectively), the configuration of the SCS would change into a semienclosed basin (Figure 9), with Bashi Strait opening to the open ocean of the western Pacific and the Balabac and Mindoro straits opening to the Sulu Sea. To simplify the discussion, we assume that tion during glacial episodes in the late Quaternary. Today, the northeast monsoon (winter) has more of an effect on northeastern SCS and southwestern central part of the SCS, while the southwest monsoon (summer), which is much weaker than winter monsoon, mainly effects conditions in the southern SCS [Chen et al., 1985]. The duration of monsoon is longer and the wind is stronger in the northern SCS than in southern part [Lei et al., 1988; Ramage, 1971]. If this persisted in the late Pleistocene, it is speculated that glacial surface circulation would display a clockwise (summer) or counterclockwise (winter) semiclosed pattern (Figure 9). As most water passageways became closed or narrowed, surface watermass exchange

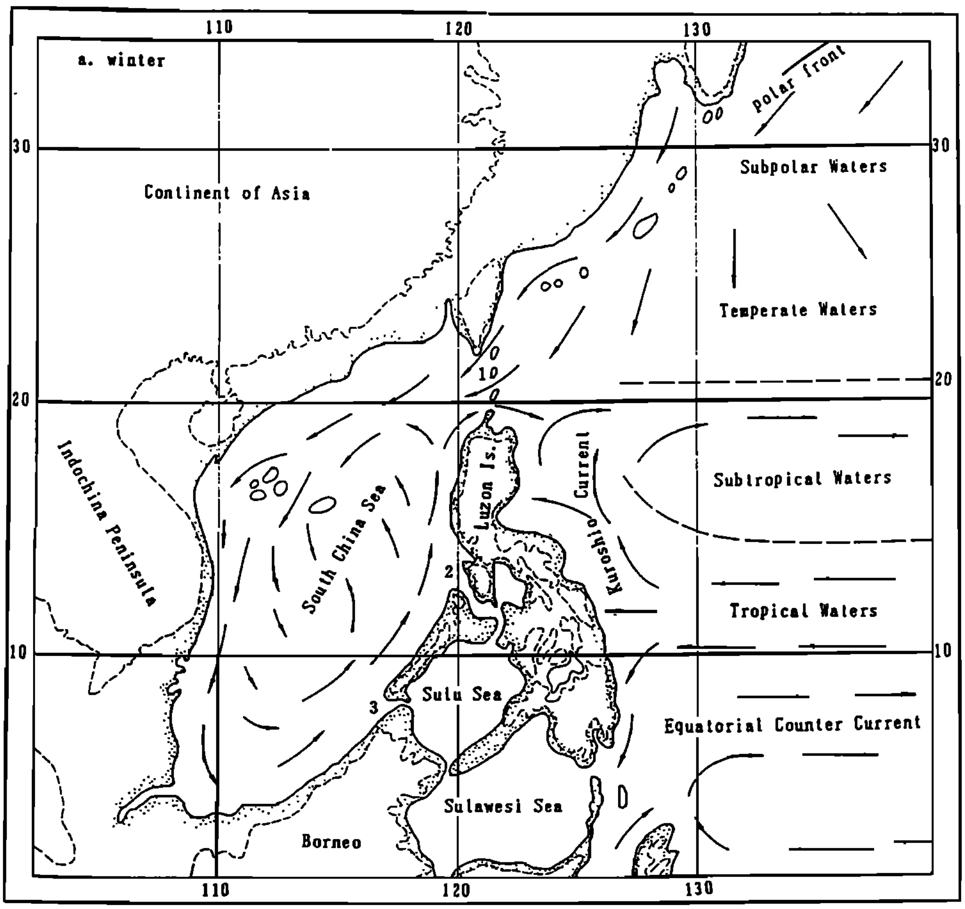


Fig. 9. Inferred glacial surface circulation patterns of the South China Sea, (a) winter and (b) summer. The present-day coast lines are drawn in the thin dotted line and the glacial coast-lines are drawn along the present-day 100 m isobath. The heavy dotted lines indicate boundaries of different surface watermasses, and arrows indicate surface current direction. 1, Bashi Strait; 2, Mindoro Strait; 3, Balabac Strait.

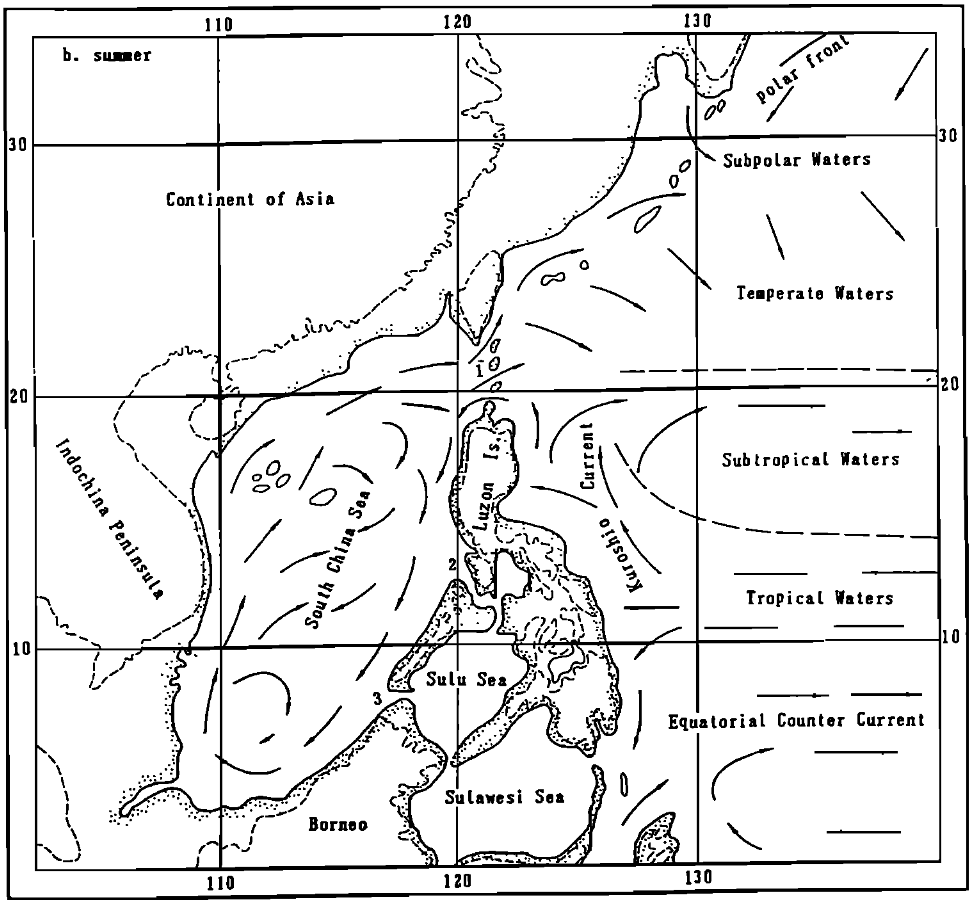


Fig. 9. (continued)

between SCS and the western Pacific decreased, especially in summer when less tropic water could flow into the SCS, and that between SCS and the Indian Ocean would be completely cut off due to the close of the passageways to the Indian Ocean, through which the warm Indian tropic waters enter the SCS in summer during interglacials. In addition, the glacial-interglacial contrasts in SST are affected by the southward displacement of western Pacific Temperate waters to the vicinity of the Bashi Strait. Previous studies showed that the watermass distribution of the western Pacific changed considerably between glacial and interglacial episodes [Thompson, 1981]. Thompson discovered that polar/subpolar waters were displaced about 10° to the south during glacial episodes. He also pointed out that there was a poleward expansion of the subtropical fauna during interglacials. Therefore it is reasonable to conclude that during glacial periods, Temperate waters, now at 25-35°N, should have reached as far as 20°N, where the Bashi Strait is located (Figure 9).

As discussed before, the Bashi Strait is the only water passageway to the open ocean during glacials. Therefore cooler Temperate waters would have entered the SCS, while the inflow of warmer Kuroshio, Tropical, and Subtropical waters would have decreased. Such changes in watermass influence are well recorded by the planktonic faunas discussed before (Figures 5 and 6). The change is more distinct during winter. In addition to the cooler Temperate waters, cold water associated with the long-shore current was driven into the SCS by the northeast wind, resulting in much lower glacial winter SST at the core sites compared with that in the open western Pacific (Figure 9a).
In summer months, the southwest wind and the clockwise circulation sent the cold longshore current out of the SCS. However, as there was no longer a passageway for warm tropical Indian Ocean waters to flow into the SCS, glacial summer SST were also lower than at the same latitude in the adjacent Pacific (Figuer 9b). This reflects an amplification of the glacial-interglacial climatic signal in the marginal sea.

SEASONAL SST DIFFERENCE (SEASONALITY)

Along with the above speculations about glacial-interglacial changes in circulation patterns, another conclusion derived from the paleo-SST estimates is that seansonal SST differences (seasonality) appear to have been much greater during glacials than interglacials (Figure 10). In addition, glacial seasonality in the SCS (9-10°C) is significantly greater than that previously estimated by Thompson [1981] for the tropics (2°C) or subtropics (5°C). This strong seasonality is due to the glacial-interglacial change in circulation and watermass exchange between the SCS and the western Pacific.

Large seasonality is a characteristic of the SCS. At present, there is a gradient in seasonal SST difference in the SCS (Figure 11) that decreases from north to south. This gradient is produced by the longshore current and the seasonal change in surface water flow caused by the East Asian Monsoon. During post-glacial and interglacial periods, the SST estimation shows that the seasonal SST difference was 4-6°C, identical to that at present. However, during glacial periods, the longshore current moved southward, as the coast line moved out to the 100-120 m isobaths. Together

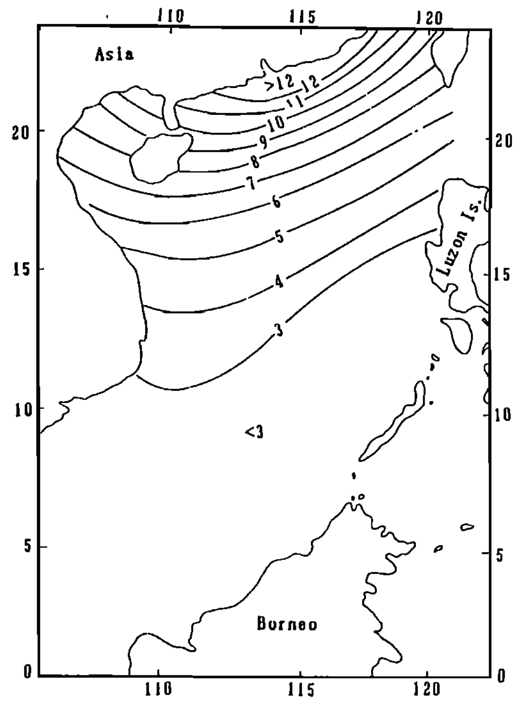


Fig. 11. Present seasonal sea surface temperature difference (°C) in the South China Sea [from Chen et al., 1985].

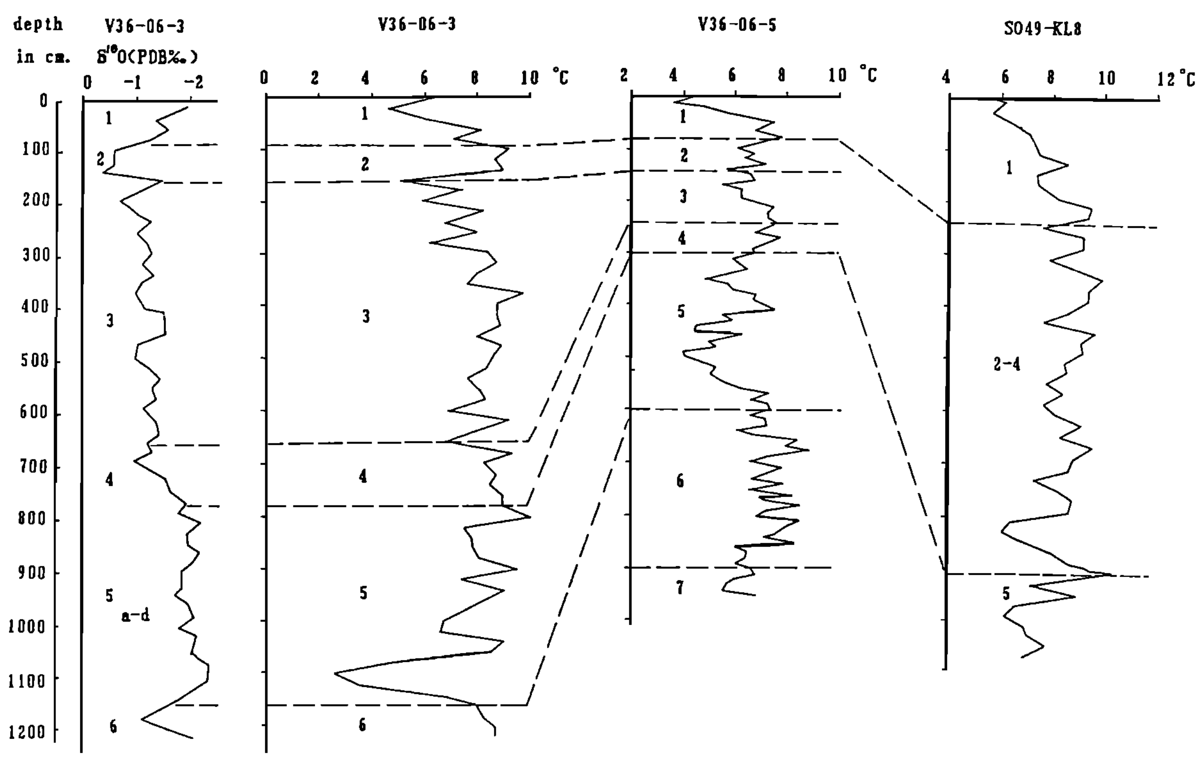


Fig. 10. Seasonal sea surface temperature difference (seasonality) revealed by temperature estimation of cores V36-06-3, V36-06-5, and SO49-KL8. Numbers and dotted lines indicate the oxygen isotopic stage and boundaries between them.

with the increase of the influence of the long-shore current along the northern continental slope, the increased influence of Pacific Temperate waters and the decrease or cut-off of the tropical waters of both the Pacific and the Indian Ocean combined to caused a sharp SST reduction in winter and a moderate one in summer and hence the stronger glacial seasonality at the core sites (Figure 10).

CONCLUSIONS

Two main results about the paleoceanography in the SCS in the last 200,000 years can be concluded from the present study:

1. Due to the southward displacement of surface watermasses in the open western Pacific and the cut-off of Indian Tropic waters, as well as the change in surface circulation pattern related to the Monsoon, glacial-interglacial fluctuations of SST (6.8-9.3°C for winter and 2-3°C for summer) and the glacial seasonal SST difference (9-10°C) are much greater than those in the tropical Pacific Ocean at the same latitude (5°C for winter and 2°C for summer, 4-5°C for seasonality, respectively).

2. In SCS, postglacial and interglacial transbasinal surface circulation patterns were replaced by a semiclosed, clockwise (summer) or counterclockwise (winter) pattern during glacial periods, when the SCS changed into a semienclosed marginal sea at low sea level stand (-100 to -120 m).

The glacial-interglacial contrasts in paleoceanography of the SCS give a good example of amplification of the glacial-interglacial climatic signal in marginal seas.

Acknowledgements. The authors benefited a lot from informative discussions with James P. Kennett, who kindly read through the manuscript and made important improvement in quality of both text and figures. We thank Nicholas J. Shackleton and Lu Yijiang for providing the isotope data. Thanks are expressed to Bian Yunhua for participating in micropaleontological work; to Jin Xianglong, Li Quanxing, and Feng Wenke for making available of the samples; and, also, to Wu Meiying for redrawing some of the figures. The authors are indebted to R. Thunell and B. Corliss for critically reviewing the manuscript. This study was supported by a grant from the National Natural Science Foundation of China and a grant from the Chinese National Commission for Education.

REFERENCES

Chen, S., T. Chen, X. Xu, Z. Chen, and S. Sui (Eds.), *The Vast South China Sea*, (in Chinese) 218 pp., China Science Press, Beijing, 1985.

Cheng, T., and S. Cheng, The planktonic foraminifera of the northern South China Sea (in Chinese, with English abstract), *Oceanol. Limnol. Sin*, *6*(1), 38-77, 1962.

Cullen, J. L., Microfossil evidence for changing salinity pattern in the Bay of Bengal over the last 20,000 years. *Paleogeogr. Paleoclimato. Paleoecol.*, *35*(2-4), 315-356, 1981.

Duplessy, J. C., Glacial to interglacial contrasts in the northern Indian Ocean, *Nature*, *295*(5849), 494-498, 1982.

Emery, K. O., and F. You, Sea-level changes in the western Pacific with emphasis on China, *Oceanol. Limnol. Sin.*, *12*(4), 297-310, 1981.

Feng, W., W. Xue, and D. Yang, *The Geological Environment of Late Quaternary in the Northern South China Sea* (in Chinese, with English abstract), 261 pp., Guangdong Science and Technology Publishing House, Guangzhou, 1988.

Han, W., Study on the chemical elements of seawater of the Central Water of the South China Sea (in Chinese, with English abstract), in *Symposium on Research Reports on the Sea Area of South China Sea* vol. 1, edited by X. Zhao, pp. 159-175, China Science Press, Beijing, 1982.

Huang J., Changes of sea-level since the late Pleistocene in China, in *The Evolution of the East Asian Environment*, vol. 1, edited by R. O. Whyte, pp. 309-319, Hong Kong University, Hong Kong, 1984.

Huang, Q., Physical oceanography of the Bashi Channel (in Chinese, with English abstract), *Nanhai Stud. Mar. Sin.*, *6*, 53-67, 1984.

Imbrie, J., and Kipp, N. G., A new micropaleontological method for quantitative paleoclimatology: Application to a late Pleistocene Caribbean core, in *The Late Cenozoic Glacial Ages*, edited by K. K. Turekian, pp. 71-181, Yale University, New Haven, 1971.

Lei, Z, W. Zhu, F. Xia, X. Gao, Y.Huang, and S. Han, *Handbook of China Seas Environments* (in Chinese), 638 pp., Shanghai Jiaotong University Press, Shanghai, 1988.

Milliman, J. D., and K. O. Emery, Sea levels during the past 35,000 years, *Science*, *162*, 1121-1123, 1968.

Ramage, C. S., *Monsoon Meteorology*, 218 pp., Academic, San Diego, Calif., 1971.

Samoda, J., P. Thompson, and C. Chen, Foraminiferal analysis of South China Sea core V36-08 with paleoenvironmental implications, *Proc. Geol. Soc. China*, *29*, 118-137, 1986.

Shackleton, N. J., and N. D. Opdyke, Oxygen isotope and palaeomagnetic stratigraphy of equatorial core V28-238: Oxygen isotope temperatures and ice volumes on a 100,000 year and 10,000 year scale, *Quat. Res.*, *3*, 39-55, 1973.

Thompson, P., Planktonic foraminifera in the western North Pacific during the past 150,000 years: Comparison of modern and fossil assemblages, *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, *35*, 241-279, 1981.

Thompson, P.R., A. W. H. Bé, J.-G. Duplessy, and N. J. Shackleton, Disappearence of pink-pigmented *Globigerinoides ruber* at 120,000 yr B.P. in the Indian and Pacific Oceans. *Nature*, *280*, 554-558, 1979.

Tu, X., Distribution and habitats of foraminifera in bottom sediments of the northeastern South China Sea (in Chinese, with English abstract), *Tropic Oceanol.*, *2*(1), 11-19, 1983.

Wang, L. and P. Wang, An attempt at paleotemperature estimation in South China Sea using transfer function, *Chin. Sci. Bull.*, *34*(1), 53-56, 1989.

Wang, P., Q. Min, and Y. Bian, Foraminiferal biofacies in the northern continental shelf of the South China Sea, in *Marine Micropaleontology of China*, pp. 151-175, China Ocean Press, Beijing, 1985.

Wang, P., Q. Min, Y. Bian, and W. Feng, Planktonic foraminifera in the continental slope of the northern South China Sea during the last 130,000 years and their paleooceanographic implications, *Acta Geol. Sin*, *60*(3), 1-11, 1986.

Wang, P., Y. Bian, L. Wang, and W. Feng, A brief note on palaeoceanography of the northern part of the South China Sea over the past 130,000 years, in *The Paleoenvironment of East Asia From the Mid-Tertiary*, vol. 1, edited by R. O. Whyte et al., pp. 782-786, Hong Kong University, Hong Kong, 1988.

Xu, X., The distribution of temperature, salinity and the characteristics of the watermass in the central part of South China Sea (in Chinese, with English abstrct), in *Symposium on Research Reports on the Sea Area of South China Sea*, vol. 1, edited by X. Zhao, pp. 119-127, China Science Press, Beijing, 1982.

Zhao, X.(Ed.), *Symposium on Research Reports on the Sea Area of South China Sea* (in Chinese, with English abstracts), vol. 1, 308 pp., China Science Press, Beijing, 1982.

Zhu, Z., Watermass exchange between the South China Sea and the Pacific (in Chinese), *J. Ocean Inst. Univ. Taiwan*, *2*, 11-24, 1972.

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(Received February 7, 1989;
revised October 2, 1989;
accepted October 4, 1989.)