Late Holocene cooling event in the western Pacific*

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Abstract Cores 255, 170, 17940-2, raised from the Okinawa Trough and South China Sea, have been studied for planktonic foraminifers. Among all the species, *Pulleniatina obliquiloculata* is shown to be sensitive to winter sea surface temperature in the late Quaternary in the western Pacific. Its relative abundance fluctuations are significant and correlatable between the cores. The most conspicuous change during Holocene is the *P. obliquiloculata* minimum zone around 4 — 2 ka B.P., which correlates probably to the neoglacial cooling. The widespread occurrence of this cooling event in the western Pacific suggests that *P. obliquiloculata* is promising as a paleoceanographic and climatic monitor, possibly important for reconstructing sea-land correlation of climate.

Keywords: cooling, late Holocene, *Pulleniatina obliquiloculata*, the western Pacific.

Late Holocene cooling event around 4 — 2 ka B.P. has been reported in literature[1-3]. The terrestrial climate records have shown the Late Holocene cooling, named "Nachwärmezeit" or "Neoglacial" in Europe[1]. In China, there was an environmental deterioration since about 4 ka B.P. in China mainland[2], with the driest and coldest climate around 2.8 ka B.P.[3]. Though the temperature drops at 4—2 ka B.P. have been noticed by several authors in the Atlantic and Pacific[4], this event is still quite short of marine records.

The Okinawa Trough and South China Sea (SCS), located between the Pacific and Asian continent, not only provide high-resolution sedimentary records, but also offer an opportunity to decipher sea-land correlation of climate. This paper reports the Late Holocene cooling event revealed by *Pulleniatina obliquiloculata* in three cores there.

1 Materials and methods

Three gravity cores were selected for this study: Cores 255, 170 from the southern Okinawa Trough, taken by the First and Second Institutes of Oceanography, State Ocean

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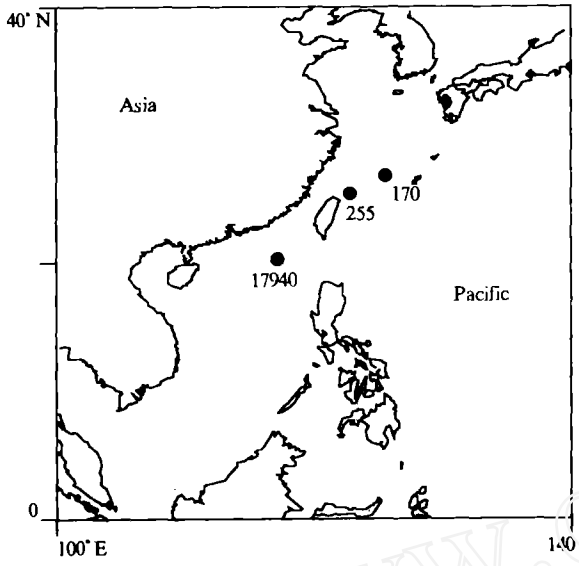

Fig. 1. Location of the three cores used in this study.

Administration (SOA) of China; and Core 17940-2 from the northern slope of the SCS, raised by the German R/V Sonne in 1994, under a German-Chinese joint expedition (fig. 1). A total of 257 samples were analyzed for planktonic foraminifers, with 5—10 cm sampling intervals for Core 255, 3—6 cm for Core 170, and 5—20 cm for Core 17940-2 (table 1).

All samples were processed using standard techniques. The planktonic foraminifers were picked only from the coarse fractions (>154 μm), identified and counted. When planktonic foraminifers were abundant, the sample was split into approximately 300—600 specimens in a workable size.

Table 1 Location and sample information of the three cores used in this study

Core	Longitude	Latitude	Water depth	Core length	Sampling interval	Number of samples taken
255	25°12′N	123°06′E	1575 m	6.55 m	5—10 cm	86
170	26°38′N	125°48′E	1470 m	3.60 m	3— 6 cm	80
17940-2	20°07′N	117°23′E	1727 m	13.30 m	5—20 cm	91

The oxygen isotopic analysis was carried on planktonic foraminifer *Globigerinoides sacculifer* and benthic foraminifer *Uvigerina peregrina* from every sample of Core 255, using a Finnigan/MAT 251 mass spectrometer at the Institute of Marine Geology, Qingdao. The average difference of duplicate analyses was approximately 0.06 ‰. In addition, *Neogloboquadrina dutertrei* (>154 μm) in two samples from Core 255 (at depth 365—375 cm and 585—595 cm) were analyzed for AMS ^{14}C dating at the Rafter Radiocarbon Laboratory of New Zealand.

2 Results

2.1 Stratigraphy

Based on the $\delta^{18}O$ variations of planktonic and benthic foraminifers and the AMS ^{14}C dating (fig. 2), Core 255 can be subdivided into two parts: the upper part (0—440 cm) belongs to the oxygen isotopic stage 1, and the lower part (440—655 cm) to the stage 2. The average glacial and postglacial sedimentation rates are 22.0 and 36.5 cm/ka, respectively.

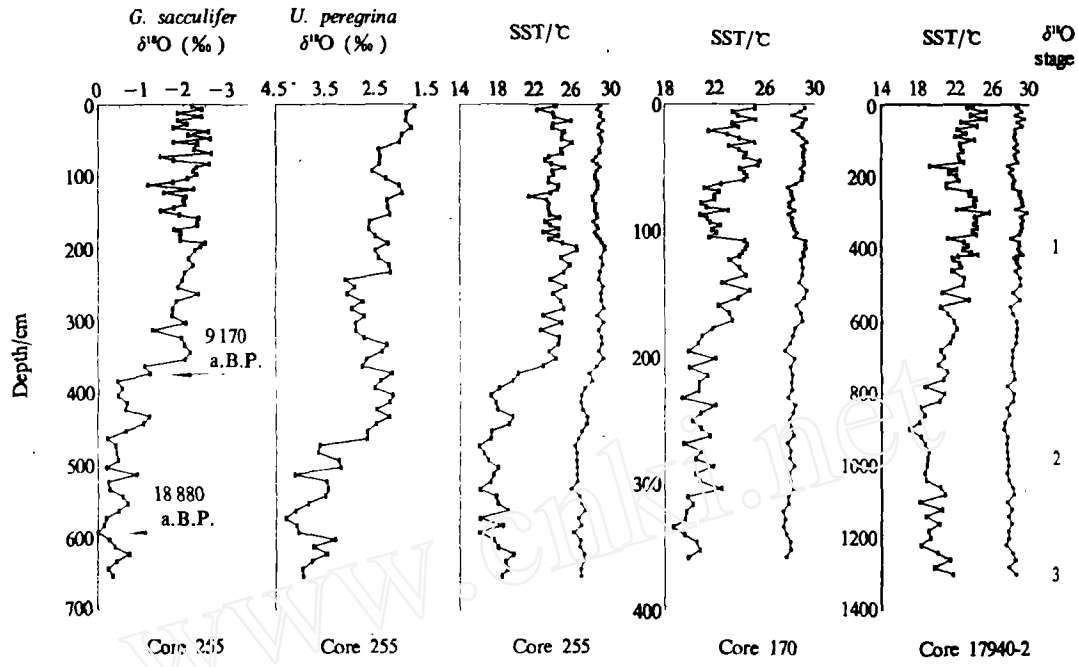

Fig. 2. Oxygen isotope and paleotemperature data of Core 255 and its correlation with Cores 170 and 17940-2. The arrows indicate the AMS ^{14}C age of *Neogloboquadrina dutertrei*. Sea surface temperatures (SSTs, left: winter, right: summer) curves are based on planktonic foraminifers using transfer function technique.

The stratigraphy of Cores 170 and 17940-2 is based on their correlation with Core 255 using the changes in estimated sea surface temperatures (SSTs) and relative abundances of some species (figs. 2 and 3). The oxygen isotopic stage 1/2 boundary is set at depth 238 cm for Core 170 and 820 cm for Core 17940-2 where remarkable changes of SST and of species composition occur while the stage 2/3 boundary is set at depth 1 250 cm for Core 17940-2. The stratigraphy of Core 17940-2 is also confirmed by $\delta^{18}O$ data of the core[1].

2.2 Planktonic foraminifers and SST

The distribution of modern planktonic foraminifers in the world ocean is mainly limited by water masses[5]. In the western Pacific, the temperate water mass is characterized with high abundances of *Globorotalia inflata*, *Neogloboquadrina dutertrei* and *N. pachyderma* (right coiling) whereas the tropical-subtropical water masses with *Globigerinoides ruber*, *G. sacculifer*, *Globigerinita glutinata* and *P. obliquiloculata*. As shown by our analyses, the percentages of temperate species in the 3 cores increased during the last glaciation and decreased in the postglaciation while those of the tropical-subtropical species exhibited an opposite trend (figure 3).

We used the planktonic foraminiferal transfer function FP-12E to estimate the SSTs

1) Wang, L. J., Private communication.

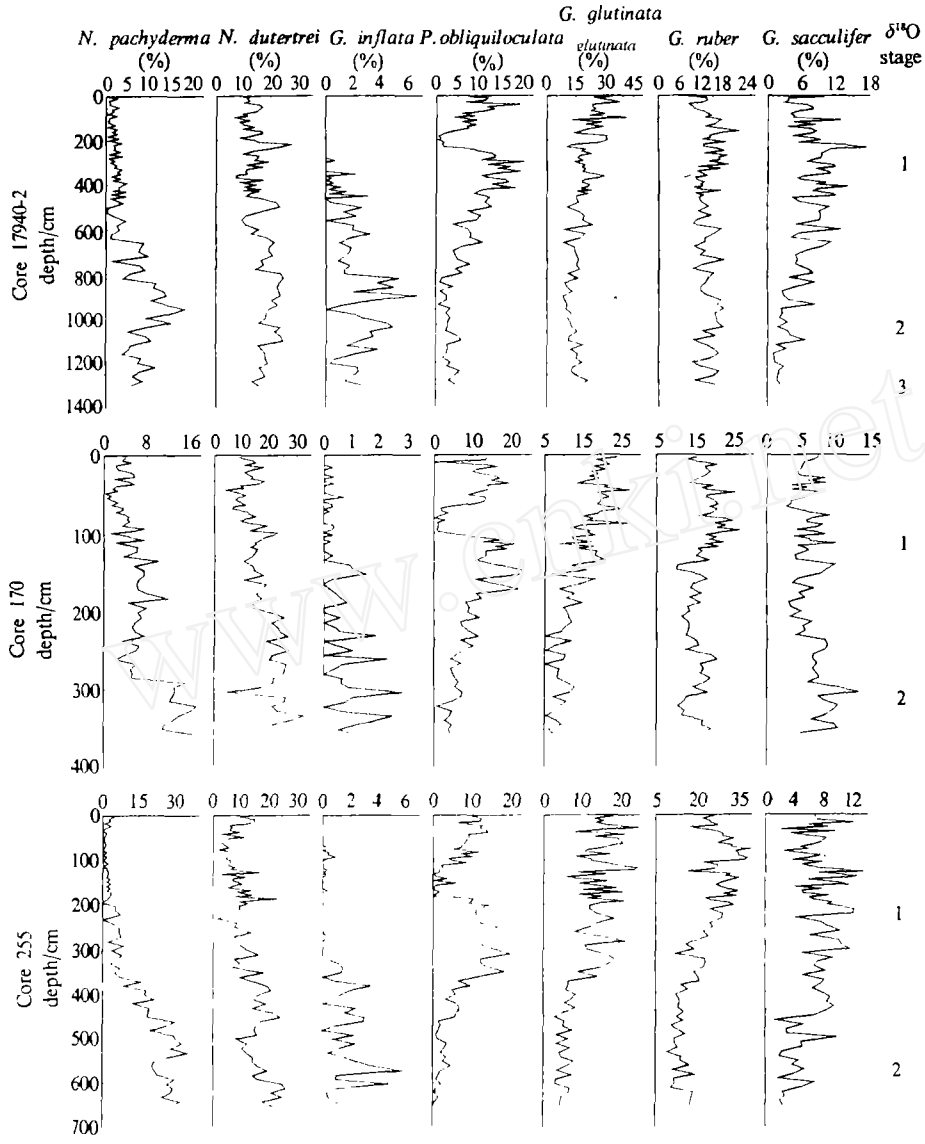

Fig. 3. Down-core variations of relative abundance of some dominant species in planktonic foraminiferal fauna in the Okinawa Trough and South China Sea.

for the three cores (fig. 2). The data indicate that the winter SSTs of the last glacial maximum (LGM) were cooler than those at present by as much as 9.9℃ (Core 255), 6.8℃ (Core 170) and 8.7℃ (Core 17940-2) while the summer SSTs dropped only by 1.6—3.5℃. The distinct contrast between the glacial and postglacial SSTs was ascribed to changes in surface circulation patterns at the LGM[6, 7].

2.3 Variations in abundance of *Pulleniatina obliquiloculata*

Among the planktonic foraminiferal species, *P. obliquiloculata* shows the most

significant down-core variations even within the Holocene (fig. 4). The *P. obliquiloculata* (%) curves of the 3 cores display similar trends in its fluctuations.

The abundances of *P. obliquiloculata* are much lower in the last glaciation (1.9%—5.1% in average) than in the Holocene (8.2% — 10.6% in average) (fig. 4, table 2). This corresponds well to the glacial-postglacial transition in the SSTs, mainly in winter season (fig. 2). The abrupt increase of *P. obliquiloculata* at the Pleistocene/Holocene boundary has also been recorded in cores from the southern SCS[9], the Sulu Sea[10] and elsewhere.

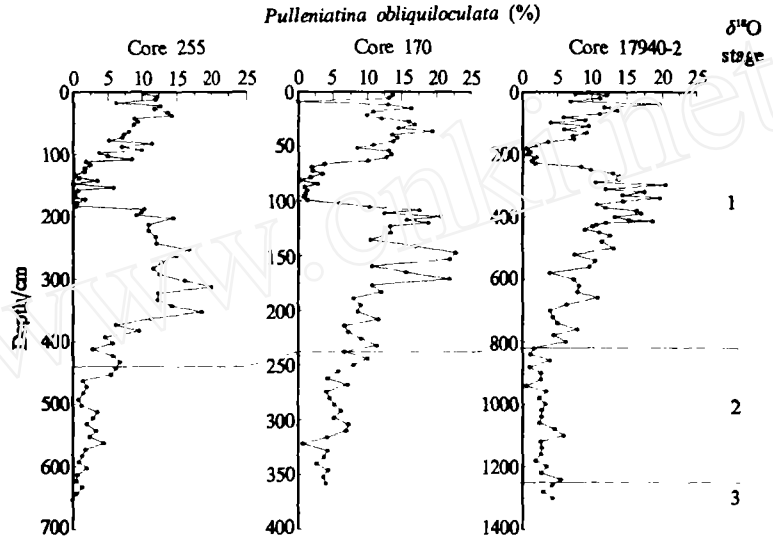

Fig. 4. Down-core variations in *Pulleniatina obliquiloculata* abundance from three cores of the Okinawa Trough and South China Sea. The *P. obliquiloculata* minimum zone is shaded.

After the last deglaciation, the relative abundance of *P. obliquiloculata* in all 3 cores increases abruptly, reaching its maximum around 7 — 6 ka B.P. The abundance of *P. obliquiloculata* rose at depths of 370 — 185 cm, 177 — 102 cm and 500 — 240 cm in Cores 255, 170, 17940-2 respectively, and such interval is called "*P. obliquiloculata* maximum". The average and highest values of abundance are given in table 2. The well correlated stratigraphic position in the 3 cores (fig. 4) suggests that the *P. obliquiloculata* maximum zone is a common phenomenon in the Okinawa Trough and SCS, corresponding to the Mid-Holocene warming[1,2].

The most conspicuous event during the Holocene in the Okinawa Trough and SCS is the drastic decline of *P. obliquiloculata* in percentage immediately following the "maximum", with a duration of about 4 — 2 ka B.P. This interval is called here "*P. obliquiloculata* minimum", corresponding to the depths of 185 — 105 cm, 102 — 63 cm and 240 — 160 cm in Cores 255, 170, 17940-2 respectively. The average values of *P. obliquiloculata* abundance are only about 1.7% — 2.7% and the lowest values approximate

Table 2 Average and peak values of *Pulleniatina obliquiloculata* relative abundance in the three cores examined

P. obliquiloculata %		Stage 1	Stage 2	Maximum zone	Minimum zone
	depth/cm	440 — 0	655 — 440	370 — 185	185 — 105
255	average (%)	8.2	1.9	14.8	1.90
	extreme (%)	20.0	0.0	20.0	0.0
	depth/cm	238 — 0	360 — 238	177 — 102	102 — 63
170	average (%)	10.6	5.1	15.2	2.7
	extreme (%)	21.8	0.7	21.8	0.3
	depth/cm	820 — 0	1 250 — 820	500 — 240	240 — 160
17940-2	average (%)	9.5	3.0	13.5	1.7
	extreme (%)	20.4	0.6	20.4	0.7

to zero in the 3 cores (table 2). The same trends of variations in the abundance of *P. obliquiloculata* can also be found in the western equatorial Pacific[4], the southern SCS[11] and the northwestern Pacific off Japan[12], showing the broad regional existence of *P. obliquiloculata* minimum zone during the Late Holocene, but the event is much more distinct in the 3 cores studied.

3 Discussion and conclusions

In the surface sediments of the East China Sea, *P. obliquiloculata* is enriched (over 10% of the plankton assemblage) in areas beneath warm currents such as the Kuroshio[13] and is well known as one of the indicators of the Kuroshio[12]. Its maximum and minimum zones can reflect an increase and a decrease of the Kuroshio influence, respectively, caused probably by a temporary shift of the Kuroshio track[14]. However, this explanation can hardly be applied to areas away from the Kuroshio Current, such as the southern SCS.

Pulleniatina obliquiloculata is a tropical planktonic foraminifer, and in the global ocean "its highest abundance in the surface sediments occurs in a relatively narrow belt between about 10°N and 10°S. This belt coincides generally with the equatorial current systems in the Atlantic, Indian and Pacific Oceans"[5]. Based on the foraminiferal analyses of plankton tows in the North Atlantic, high concentrations of *P. obliquiloculata* are found in the Gulf Stream System, mainly in winter samples[5]. This is also confirmed by a recent research of sediment trap in the northern SCS[1]. Thus, the abundance of *P. obliquiloculata* should be sensitive to winter temperature.

As shown above, the variations in the abundance of *P. obliquiloculata* are correlative to those of SSTs, mainly winter SSTs (figs. 2 and 4). This implies that *P. obliquiloculata* abundance can be regarded as a proxy of winter sea surface temperature at least for the Late Quaternary. Because of the little change of summer SSTs since the last glaciation in the studied area, most of "summer species" including *G. ruber* and *G. sacculifer* displayed only a minor change in abundance, correspondingly. As the winter SSTs there has changed

1) Zheng, L. F., Private communication.

greatly since the last glaciation, the "winter species" *P. obliquiloculata* increased significantly in abundance from glaciation to Holocene, with maximum abundance at the Mid-Holocene optimum when winter SST was high. Likewise, the *P. obliquiloculata* minimum zone about 4—2 ka B.P. is believed to be related to the cooling of the winter SST[1)], although the precise dating is yet to be provided. In addition, the UK37 record in Core 17940-2, which is taken as an index of the annual SST, does show corresponding coolings during Late Holocene[2)].

The SST may not be the only reason for the change of *P. obliquiloculata* % during the Late Holocene. According to plankton tows studies[15], *P. obliquiloculata* is a deep-dwelling species which lives in subsurface water below thermocline in the modern ocean. The variations of its abundance can also be ascribed to the change of the depth of the thermocline. Therefore, more work is to be done to understand the oceanographic factors that control the variations of *P. obliquiloculata* abundance. Nevertheless, the Late Holocene *P. obliquiloculata* minimum zone as a marine climate event is correlatable to land records, corresponding in time to the "neoglacial" cooling. *P. obliquiloculata* is beyond all doubt a sensitive paleoceanographic indicator for the region with high potential in understanding sea-land climate correlation.

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