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Pulleniatina obliquiloculata as a paleoceanographic indicator in the southern Okinawa Trough during the last 20,000 years

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Abstract

Pulleniatina obliquiloculata, a tropical species of planktonic foraminifera, is indicative of the Kuroshio current and sensitive to winter sea surface temperature for the late Quaternary in the Okinawa Trough. Its relative abundance fluctuations are significant and correlatable between three gravity cores (cores 255, 170, 253) raised from the southern Okinawa Trough. Four major changes in its abundances with paleoceanographic significance have been recognized during the last 20,000 years: an abrupt increase at the Pleistocene/Holocene boundary, a short-term decrease indicative of a 'Younger Dryas'-type climate reversal at about 11.4–9.6 ka B.P., the *P. obliquiloculata* maximum zone (around 7–6 ka B.P.) corresponding to the mid-Holocene climate optimum and the *P. obliquiloculata* minimum zone (around 4–2 ka B.P.) correlated probably to the Neoglacial cooling. The widespread occurrence of these events in the western Pacific and the correlated variations of its abundance between sea areas suggest that *P. obliquiloculata* is well promising as a paleoceanographic and climatic monitor for high-resolution reconstruction and sea–land correlation.

Keywords: Late Quaternary; Okinawa trough; *Pulleniatina obliquiloculata*; paleoceanography

1. Introduction

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 (Bé, 1977). According to 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 (Cifelli, 1965; Boltovskoy, 1968; Bé and Tolderlund, 1971; Bé et al., 1971). This is a species with short seasonal occurrence, sometimes reaching very high dominance (up to 90% in one sample from the Sargasso Sea; Cifelli and Smith, 1974). This is also confirmed by the recent research results of sediment trap in the northern South China Sea (Zheng Lianfu, pers. commun.). Thus, the abundance of *P. obliquiloculata* should be sensitive to winter temperature.

In the surface sediments of the East China Sea, *P. obliquiloculata* is enriched (over 10% of the plankton assemblage) in areas beneath the Kuroshio and other warm currents (Fig. 1; Wang et al., 1985) and is well known as one of the indicators of the Kuroshio

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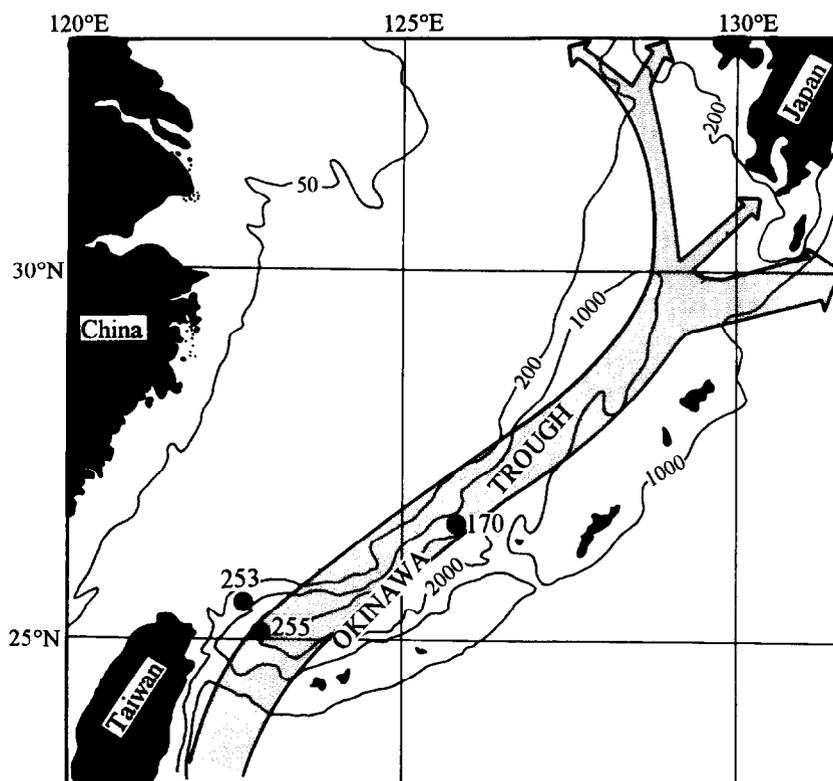


Fig. 2. Location of the sediment cores in the southern Okinawa Trough, East China Sea. Arrow shows the flow of the Kuroshio Current and its branches (modified from Ahagon et al., 1993).

2. Materials and methods

Three gravity cores have been studied from the Okinawa Trough: cores 255, 253 and 170, taken by the First and Second Institutes of Oceanography, State Ocean Administration (SOA) of China (Fig. 2). A total of 210 samples were analyzed for planktonic foraminifers, with 5–10 cm sampling intervals for cores 255 and 253, and 3–6 cm for Core 170 (Table 1).

2.1. Microfossil analysis

The samples were treated with standard micropaleontologic methods. The planktonic and benthic foraminifers were picked from only the coarser fractions (>0.154 mm), mounted on a reference slide, identified and counted. When planktonic foraminifer were too abundant, the sample was split into a workable size to have approximately 300–600 speci-

mens. *P. obliquiloculata* occurred in almost all of the samples analyzed, with a wide range of abundance.

2.2. $\delta^{18}O$ analysis

Specimens of planktonic foraminifer *Globigerinoides sacculifer* (without 'sac', 350–450 μm) and benthic foraminifera *Uvigerina peregrina* from every sample of Core 255 were picked for oxygen isotopic analysis. The stable isotopic data were measured on a Finnigan/MAT 251 mass spectrometer at the Institute of Marine Geology, Qingdao. The average difference of duplicate analyses was approximately 0.06‰.

2.3. AMS ^{14}C dating

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.

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

Core	Longitude	Latitude	Water depth (m)	Core length (m)	Sampling		Number of samples taken
					interval (cm)	length (cm)	
255	25°12'N	123°06'E	1575	6.55	0–2 m:	5	2.5
					2–3 m:	10	2.5
					3–6.55 m:	10	5
253	25°34'N	123°01'E	839	2.90	0–1.5 m:	5	2.5
					1.5–2.9 m:	10	2.5
170	26°38'N	125°48'E	1470	3.60	0–1.2 m:	3	3
					1.2–3.6 m:	6	3

The samples were treated at the Dept. of Geology, National Taiwan University and measured at the Rafter Radiocarbon Laboratory of New Zealand. Since Core 255 is the only core provided with $\delta^{18}\text{O}$, $\delta^{13}\text{C}$ and ^{14}C dates, our following discussion will be mainly based on Core 255.

3. Results

3.1. Stratigraphy

According to the $\delta^{18}\text{O}$ variations of planktonic and benthic foraminifers (Fig. 3a, b) and the AMS ^{14}C dating (Table 2), Core 255 can be subdivided into two parts: the upper part (from 0 to 440 cm) belongs to the oxygen isotope stage 1, and the lower part (from 440 to 655 cm) to the stage 2. The average glacial and postglacial sedimentation rate were calculated to be 22.0 and 36.5 cm/kyr, respectively.

As to Core 253 and Core 170, where neither oxygen isotope data nor AMS ^{14}C dating are available, the stratigraphy is based on their correlation with Core 255 using the changes in estimated sea surface temperatures (SSTs) and relative abundances of some species (Fig. 3c–e, Fig. 4). The oxygen isotopic stage 1/2 boundary is set at depth 125 cm for

Core 253 and 238 cm for Core 170 where remarkable changes of SST and of species composition occur, whereas the drastic change in SST and foraminiferal assemblage at about 125 cm in Core 253 might suggest a sedimentary discontinuity.

3.2. Planktonic foraminifers and SST

The distribution of modern planktonic foraminifers in the world ocean is mainly governed by water masses (Bé, 1977; Hemleben et al., 1988). In the northwest 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 *G. obliquiloculata*. As shown by our analyses, the percentages of temperate species in the three cores increased during the last glacial and decreased in the postglacial (Fig. 4a–c), while those of the tropical–subtropical species exhibit an opposite trend (Fig. 4d–f). It seemed that the influence of temperate water mass strengthened and tropical–subtropical water mass weakened in the studied area during the glacial stage as compared with the postglacial.

We used the planktonic foraminiferal transfer function FP-12E (Thompson, 1981) to estimate the SSTs for the three cores (Fig. 3). 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°C (Core 255), 7.8°C (Core 253) and 6.8°C (Core 170), while the summer SSTs dropped only 2–3.5°C. Compared with the data from the open north-

Table 2
Results of AMS ^{14}C dating for *Neogloboquadrina dutertrei* in Core 255

Sample depth (cm)	Specimens analyzed (#)	Weight (mg)	Age (yr B.P.)
365–375	900	15.9	9170 ± 110
585–595	1400	26.6	18880 ± 130

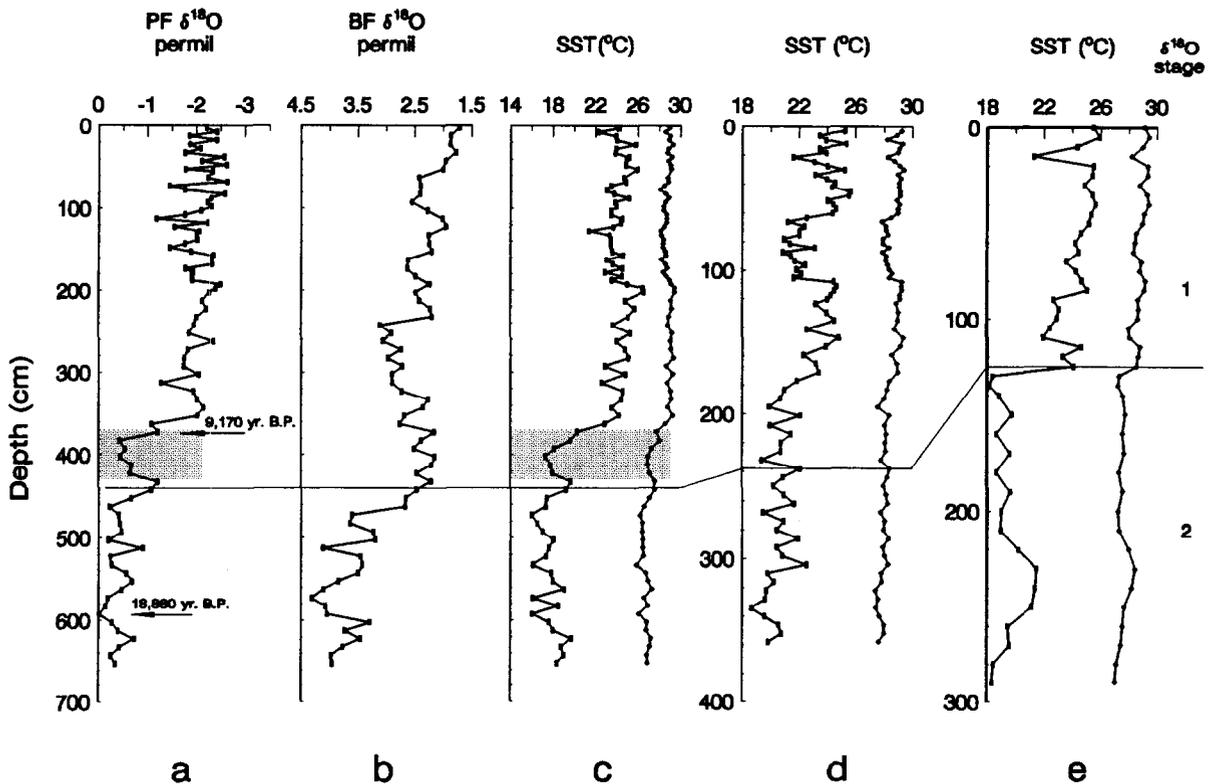


Fig. 3. Stratigraphy and paleotemperature data of Core 255 and its correlation with cores 253 and 170. Oxygen isotope curves of Core 255 (The arrows indicate the AMS ^{14}C age of *Neogloboquadrina dutertrei*): (a) $\delta^{18}\text{O}$ of planktonic foraminifer *Globigerinoides sacculifer* (shaded zone shows the interval comparable with 'Younger Dryas' event); (b) $\delta^{18}\text{O}$ of benthic foraminifer *Uvigerina peregrina*; Sea surface temperatures (SSTs) curves based on planktonic foraminifers using transfer function technique (left, winter; right, summer): (c) Core 255 (shaded zone shows the interval comparable with the 'Younger Dryas'-type event); (d) winter (left) and summer (right) SSTs in Core 170; (e) winter (left) and summer (right) SSTs in Core 253.

west Pacific of similar latitudes (Moore et al., 1980, Thompson, 1981), the glacial/postglacial difference in the Okinawa Trough are significantly higher, reflecting the amplification of the climatic signal in the marginal sea. The stronger seasonality during the glacial stage (9°C) compared to the postglacial stage ($\sim 4^{\circ}\text{C}$) implies a much severer environment. The distinct contrast between the glacial and postglacial SSTs was ascribed to changes in surface circulation patterns, such as the southward shift of the north Pacific polar front (Thompson and Shackleton, 1980; Chinzei et al., 1987), the shift of the Kuroshio (Ujiié et al., 1991; Ahagon et al., 1993), and the invasion of coastal waters (Wang et al., 1985) at the LGM.

3.3. Paleoceanographic changes as indicated by *Pulleniatina obliquiloculata*

Among the planktonic foraminifer species *P. obliquiloculata* shows the most significant down-core variations even within the Holocene (Fig. 5). The *P. obliquiloculata* curves of the three cores display similar trends in fluctuations. Four paleoceanographic changes can be recognized in an ascending order:

3.3.1. Pleistocene/Holocene boundary event

All the three cores show a distinct glacial/postglacial contrast. The abundances of *P. obliquiloculata* are much lower in the last glacial (1.9–5.1% in average) than in the Holocene (8.2–10.6% in average).

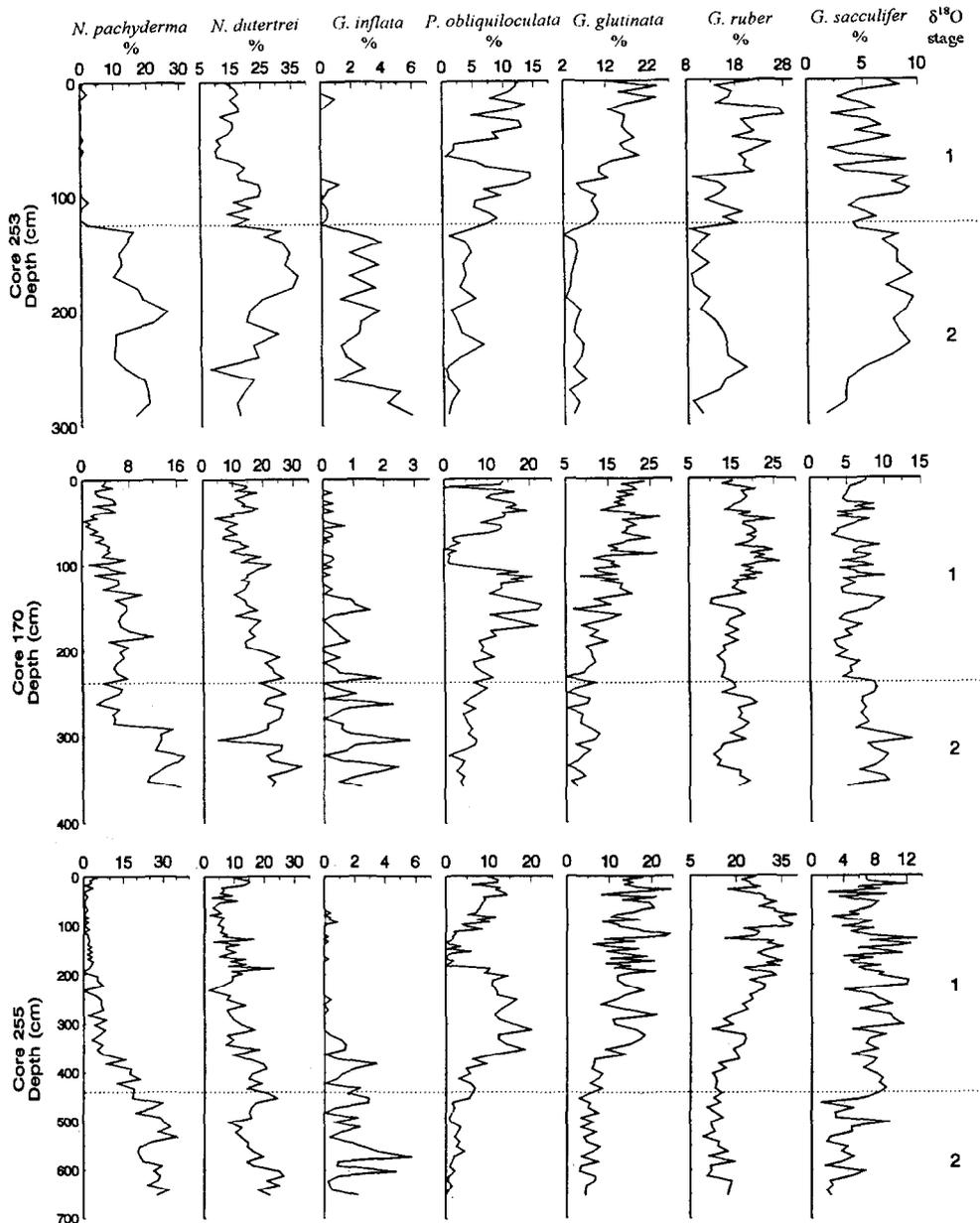


Fig. 4. Down-core variations of relative abundance of some dominant species in planktonic foraminiferal fauna in the southern Okinawa Trough.

age) (Fig. 5; Table 3). This corresponds well to the glacial–postglacial transition in the SSTs (Fig. 3), mainly for winter season, whereas the summer SSTs display little changes from the last glacial to the Holocene. The very low abundance of *P. obliquiloculata* during the last glacial should be related to

low winter SSTs and enhanced seasonality at the glacial. The abrupt increase of *P. obliquiloculata* at the Pleistocene/Holocene turn has also been recorded in cores from the South China Sea (SCS) (Wang et al., 1986; Broecker et al., 1988a), the Sulu Sea (Miao and Thunell, 1994) and elsewhere at the

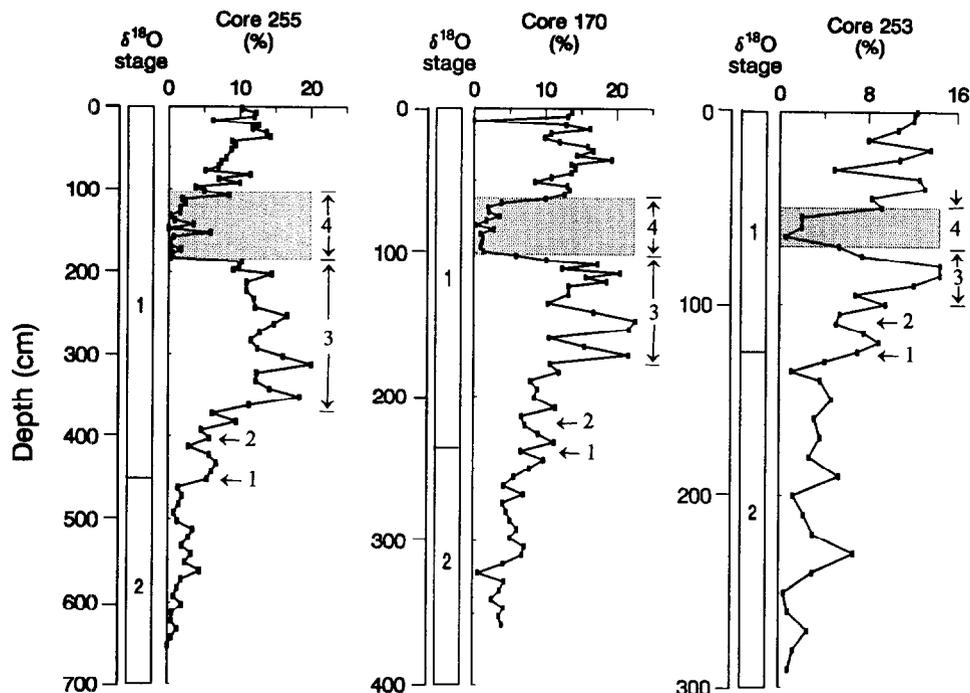


Fig. 5. Down-core variations in *Pulleniatina obliquiloculata* abundance from three cores of the southern Okinawa Trough. Numbers 1–4 refer to the four paleoceanographic changes respectively (see text). The *P. obliquiloculata* minimum zone is shaded.

Table 3

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

	Stage 1	Stage 2	Maximum zone	Minimum zone
<i>Core 255</i>				
Depth (cm)	440–0	655–440	370–185	185–105
<i>P. obliquiloculata</i> average (%)	8.2	1.9	14.8	1.90
<i>P. obliquiloculata</i> extreme (%)	20.0	0.0	20.0	0.0
<i>Core 170</i>				
Depth (cm)	238–0	360–238	177–102	102–63
<i>P. obliquiloculata</i> average (%)	10.6	5.1	15.2	2.7
<i>P. obliquiloculata</i> extreme (%)	21.8	0.7	21.8	0.3
<i>Core 253</i>				
Depth (cm)	125–0	290–125	100–70	70–50
<i>P. obliquiloculata</i> average (%)	8.6	2.8	10.8	2.0
<i>P. obliquiloculata</i> extreme (%)	14.5	0.5	14.5	0.6

Pleistocene/Holocene boundary, unlike the following events which are hardly recognizable in low-resolution stratigraphic records.

3.3.2. 'Younger Dryas'-type event

As seen from Core 255, the abundance of *P. obliquiloculata* obviously decreased at the depth in-

terval of 420–380 cm, shortly above the oxygen isotopic stage 1/2 boundary at 440 cm (Fig. 5), corresponding to the abrupt positive shift of planktonic foraminiferal $\delta^{18}\text{O}$ (about 0.8‰, Fig. 3a) and the winter sea surface temperature drop of about 2.4°C (Fig. 3c). According to the AMS ^{14}C datings, the age of this brief climate return at the depth interval

of 420–380 cm was estimated to be about 11.4–9.6 ka B.P., fairly close to that of Younger Dryas event in the northeastern Atlantic (Duplessy et al., 1981; Broecker et al., 1988b). Thus, the last deglaciation in the Okinawa Trough has also witnessed a short-term climate event comparable with the Younger Dryas, but there is no certainty of their synchrony. This is preferably called as a ‘Younger Dryas’-type event, until a detailed chronology is available.

In fact, the Younger Dryas event has been reported from many places in the western Pacific such as the northern slope of SCS (Wang et al., 1994), the Sulu Sea (Kudrass et al., 1991) and the western equatorial Pacific (Boltovskoy, 1990). Its occurrence in the Okinawa Trough will be another evidence for the global nature of this event.

3.3.3. *Pulleniatina obliquiloculata maximum*

Close to the middle Holocene, the relative abundance of *P. obliquiloculata* in all three cores increases abruptly after the ‘Younger Dryas’-type event, reaching its maximum around 7–6 ka B.P. The abundance of *P. obliquiloculata* raised at depths of 370–185 cm, 177–102 cm and 100–70 cm in cores 255, 170 and 253, respectively, and such intervals are called here as ‘*P. obliquiloculata maximum*’. The average and highest values of abundances in cores are given in Table 3. The well correlated stratigraphic position in the three cores suggests that the mid-Holocene *P. obliquiloculata maximum* zone is a common event in the Okinawa Trough. A number of samples are being analyzed for AMS ^{14}C to precisely date this zone.

The high percentage of *P. obliquiloculata* in the middle Holocene is not restricted to the Okinawa Trough, but was also found in the SCS and elsewhere when sedimentation rate and stratigraphic resolution is high enough. The terrestrial climate records have long shown the mid-Holocene warming under names of ‘Wärmezeit’, ‘Hypsithermal’, ‘Altithermal’, amongst others (Lamb, 1977). This ‘Holocene climate optimum’ was defined as from 7 to 6.5 ka B.P. by Frenzel et al. (1992). This was also reported from China as ‘mid-Holocene climate optimum’ around 7–6 ka B.P. (Shi et al., 1993). Deep-sea records of this warming are rare due to the limited stratigraphic resolution and are reported from the East China Sea here for the first time.

It is of great importance to investigate the lead-lag relationships between the marine and terrestrial events.

3.3.4. *Pulleniatina obliquiloculata minimum*

The next conspicuous event during the Holocene in the Okinawa Trough is the drastic decline of *P. obliquiloculata* in percentage immediately following the ‘maximum’ and lasting around 4–2 ka B.P. This interval is called ‘*P. obliquiloculata minimum*’, corresponding to the depths of 185–105, 102–63 and 70–50 cm in cores 255, 170 and 253, respectively. The average values of *P. obliquiloculata* abundance are only about 1–1.5% and the lowest values approximate to zero in the three cores (Table 3). The same trends of abundance variations in *P. obliquiloculata* have been already found in the SCS (Core TSDY, Rottman, 1979; RC12-350, Jian et al., 1997), but the event is much more distinct in the Okinawa Trough cores.

Again, the *P. obliquiloculata minimum* as a marine climate event is correlatable to land records, corresponding generally to the ‘Nachwärmezeit’ or ‘Neoglacial’ in Europe (Lamb, 1977). In China, there was an environmental deterioration since about 4 ka B.P. in Chinese continent (Shi et al., 1993), with the most drier and colder climate around 2.8 ka B.P. in China (Chu, 1973). The *P. obliquiloculata minimum* is believed to be a marine counterpart of this stage, although the precise dating is yet to be provided.

Upwards, the fluctuations of *P. obliquiloculata* percentage show a similar pattern in these cores, particularly between cores 255 and 170 (Fig. 5). A detailed examination of the curves would be very much informative for late Holocene paleoclimatology. This requests, however, ^{14}C datings for the uppermost part of the cores.

4. Conclusions

As limited by the available AMS ^{14}C dating at present, we can not point out the precise ages of these paleoceanographic events disclosed by *P. obliquiloculata*. But similar events of *P. obliquiloculata* can also be found elsewhere in the western Pacific, showing that the broad regional, if not universal, role of *P. obliquiloculata* as a paleoceanographic indicator.

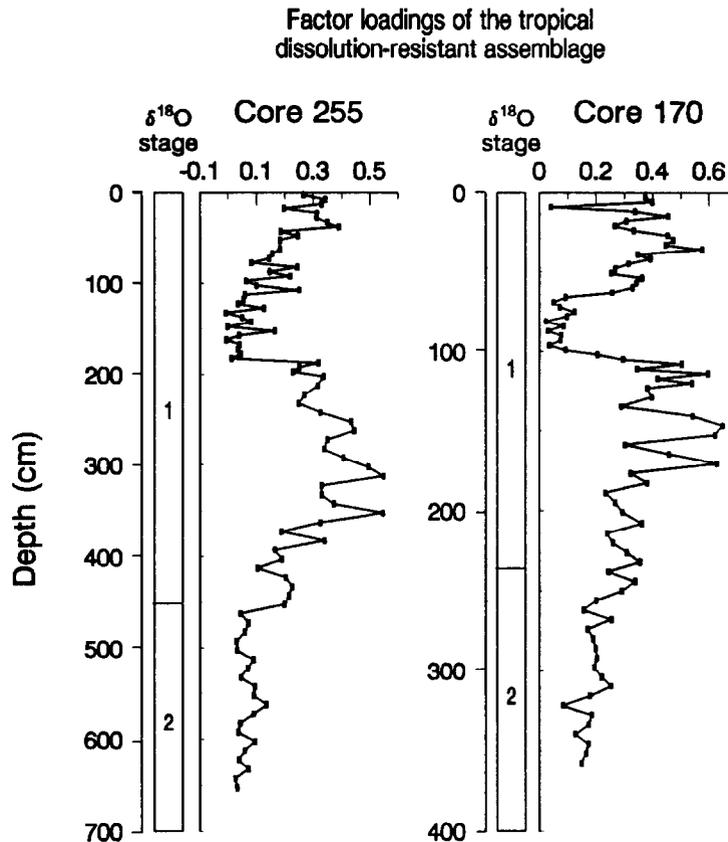


Fig. 6. Down-core variations in factor loading of the tropical dissolution-resistant assemblage defined by Thompson (1981) in cores 255 and 170.

P. obliquiloculata is one of the well known indicators of warm water masses such as the Kuroshio Current. In the Okinawa Trough its maximum zone and minimum zone reflected an increase and decrease of the Kuroshio influence, respectively, caused probably by a temporary shift of the Kuroshio track (Ujiié et al., 1991; Ahagon et al., 1993). In the transfer function FP-12E developed for the West Pacific and adopted in the present study, the Kuroshio factor is represented by the 'tropical dissolution-resistant assemblage' dominated by *P. obliquiloculata* (Thompson, 1981), and the downcore variations of the factor loading in cores well coincide with those of *P. obliquiloculata* (Fig. 6). This confirms the role of *P. obliquiloculata* as a Kuroshio indicator. However, this explanation can hardly be applied to areas away from the Kuroshio Current, such as in the southern SCS.

As shown above, the variations of *P. obliquiloculata* abundance are correlative to those of SSTs, mainly winter SSTs (Fig. 3c–e, Fig. 5). 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 in summer SSTs since the last glacial stage in the studied sea area, most of 'summer species' including *G. ruber* and *G. sacculifer* (Hemleben et al., 1988) displayed only a minor change in abundance, correspondingly. As the winter SSTs there has changed greatly since the last glacial, the 'winter species' *P. obliquiloculata* increased significantly in abundance from the glacial to the Holocene, with maximum abundances 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 a cooling of the winter SST.

Certainly, the above discussion does not exhaust the paleoceanographic implications of *P. obliquiloculata*. According to plankton tows studies (Bé and Tolderlund, 1971; Bé et al., 1971; Ravelo et al., 1992), *P. obliquiloculata* lives in subsurface water below thermocline in modern ocean. Therefore, the variations of its abundance can also be ascribed to the change of the thermocline depth. Much more work is required to understand the oceanographic factors that control the variations of *P. obliquiloculata* abundance. Nevertheless, *P. obliquiloculata* is beyond all doubt a sensitive paleoceanographic indicator for the region with high potential in sea–land climate correlation.

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