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Research paper

Pulleniatina Minimum Events in the Andaman Sea (NE Indian Ocean): Implications for winter monsoon and thermocline changes

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ABSTRACT

The late Quaternary record of *Pulleniatina obliquiloculata* was investigated from two well dated sediment cores from the Andaman Sea (NE Indian Ocean) to examine its paleoceanographic significance and the presence of the *Pulleniatina* Minimum Events (PME) in the western North Pacific. As in the Pacific, our study shows that PMEs exist in the Indian Ocean albeit with a lower intensity. The Holocene PME occurs between 4.5 and 3.0 cal ka BP with a considerable reduction in *P. obliquiloculata* abundance, and which matches well with the Pacific records influenced by the Kuroshio Current. Additionally, two significant minimum events of *P. obliquiloculata* are also seen during the Younger Dryas (YD) and late Last Glacial Maximum (LGM, 20–18 cal ka BP). Overall, the PMEs of the Andaman Sea are not current driven events like in the western Pacific margin either by the weakening of the Kuroshio Current or reduced winter SSTs. The PMEs of the Andaman Sea are characterised by lower abundances of thermocline species indicating the increased depth of the thermocline (DOT) and reduced winter SSTs mainly during the minimum events of the YD and late LGM. The high SSTs during the Holocene PME make this event a mystery. However, the presence of PMEs in the Andaman Sea suggests that these events are not confined to areas influenced by the Kuroshio Current but may be responding to a broad scale oceanographic–climatic process or mechanism which needs to be explored with a detailed study.

1. Introduction

A *Pulleniatina* Minimum Event (PME) refers to the sudden decrease in abundance of the planktic foraminifera *Pulleniatina obliquiloculata* in Holocene sediments of the western Pacific Ocean; such as the one recorded between ~4.5 and 3 ka in deep-sea cores from the western North Pacific (Li et al., 1997; Pflaumann and Jian, 1999; Ujiié and Ujiié, 1999; Wang et al., 1999; Jian et al., 2000; Yu et al., 2000; Huang et al., 2002; Ujiié et al., 2003; Lin et al., 2006; Xiang et al., 2009; Yang and Jian, 2009). In the South China Sea (SCS) another minimum event has been reported during Heinrich Event 1 (H1 PME) (Pflaumann and Jian, 1999; Wang et al., 1999; Yu et al., 2000; Huang et al., 2002; Liu, 2004; Xiang et al., 2009; Yang and Jian, 2009). On the other hand, disappearance of *P. obliquiloculata* mainly during the middle of the last glacial period was also reported from the Atlantic Ocean (Prell and Damuth, 1978). However, to our knowledge, no such minimum events are known in the Indian Ocean region.

In the modern ocean, *P. obliquiloculata* lives in the subsurface waters below the thermocline (e.g., Ravelo et al., 1990). Therefore, variations in its abundance can be interpreted as a change in the thermocline depth (Li et al., 1997). Currently, there are two views on the cause of PMEs in the western Pacific region. Low abundances of *P. obliquiloculata* are considered to be indicative of the weakening/diversion of the Kuroshio Current (Li et al., 1997; Ujiié and Ujiié, 1999). Alternatively, according to plankton tow studies, this warm water, dissolution resistant species is most abundant when winter sea surface temperatures (SST) are relatively high (Bé and Tolderlund, 1971; Ravelo and Fairbanks, 1992). The Holocene PME has also been attributed to the intensification of the winter monsoon and consequently to decreased SST (Jian et al., 2000) which was correlated to the neoglacial cooling in China (Wu and Liu, 2004; Peng et al., 2005). Another characteristic feature associated with the PME of the western Pacific is the high abundance of the thermocline species *Neogloboquadrina dutertrei*, which was interpreted as related to the enhanced influence of gyre-margin water in the Okinawa Trough (Ujiié et al., 2003).

The Andaman Sea is a semi enclosed marginal sea which exchanges water with the Bay of Bengal (BOB) in the northern Indian Ocean and marginal seas of western Pacific mainly via shallow

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channels (Fig. 1a). It is interconnected with the BOB by the Deep Prepares Channel, Ten Degree Channel and the Great Channel. The oceanographic processes in these seas are however comparable only up to a depth of about 1000 m, as the deep water exchange between these two regions (Andaman Sea and BOB) is hampered by several sills which have significant influence on intermediate to deep water circulation in the Andaman Sea. The Sunda Shelf provides a shallow route to the eastern seas and to the Pacific Ocean, which is the southeast extension of the continental shelf of the southeast Asia. As in the Arabian Sea, the Andaman Sea also experiences a seasonal reversal in surface circulation triggered by the Indian monsoon. The Andaman Sea has been well documented as a productive sea owing to the prevailing upwelling during the winter monsoon (Wyrtki, 1973). Biological productivity in the offshore region is ~0.8–1.0 mgC/m^2/d compared to lesser values (<0.6 mgC/m^2/d) observed in the coastal areas (Janekarn and Hylleberg, 1989). The Andaman Sea is characterised by a low surface salinity (Fig. 1b) ranging between 31.8 and 33.4 practical salinity units (psu), due to the influence of fresh water discharge from the Ayeyarwady–Salween river system (Sarma and Narvekar, 2001). The average surface temperature of the Andaman Sea is 29 °C, and is nearly homogenous up to a depth of 50 m leading to stratification, which hinders vertical mixing (Sarma and Narvekar, 2001). The temperature decreases down to 13 °C at a depth of 200 m and 9 °C at a depth of 500–600 m and the total thermocline thickness is about 150 m (Saidova, 2008). Here, we report on the occurrence of more than one PME in the Andaman Sea. In addition, we make an attempt to understand the causes and paleoceanographic significance of *P. obliquiloculata* variability in this marginal sea.

2. Materials and methods

The sediment cores SK 168/GC-1 (11°42.463′N; 94°29.606′E, water depth: 2064 m, core length: 4.20 m) and AAS 11 GC 1 (9°N; 94°17′E, water depth: 2909 m; core length: 4.28 m) were collected from the Andaman Sea (Fig. 1). SK 168/GC-1 was collected during the 168th cruise of ORV Sagar Kanya from the Alcock Seamount Complex and core AAS 11/GC-1 was collected during the 11th expedition of RV AA Sidorenko. About 10 g of dried samples were soaked in Milli-Q water overnight and washed through a 63 μm mesh sieve. Later the dried filtrate was sieved through a 125 μm mesh sieve. The coarse fraction (>125 μm) was split into several aliquots to reduce the total number of planktic foraminifera to a minimum of 300 individuals which were used for quantitative and qualitative analyses of planktic

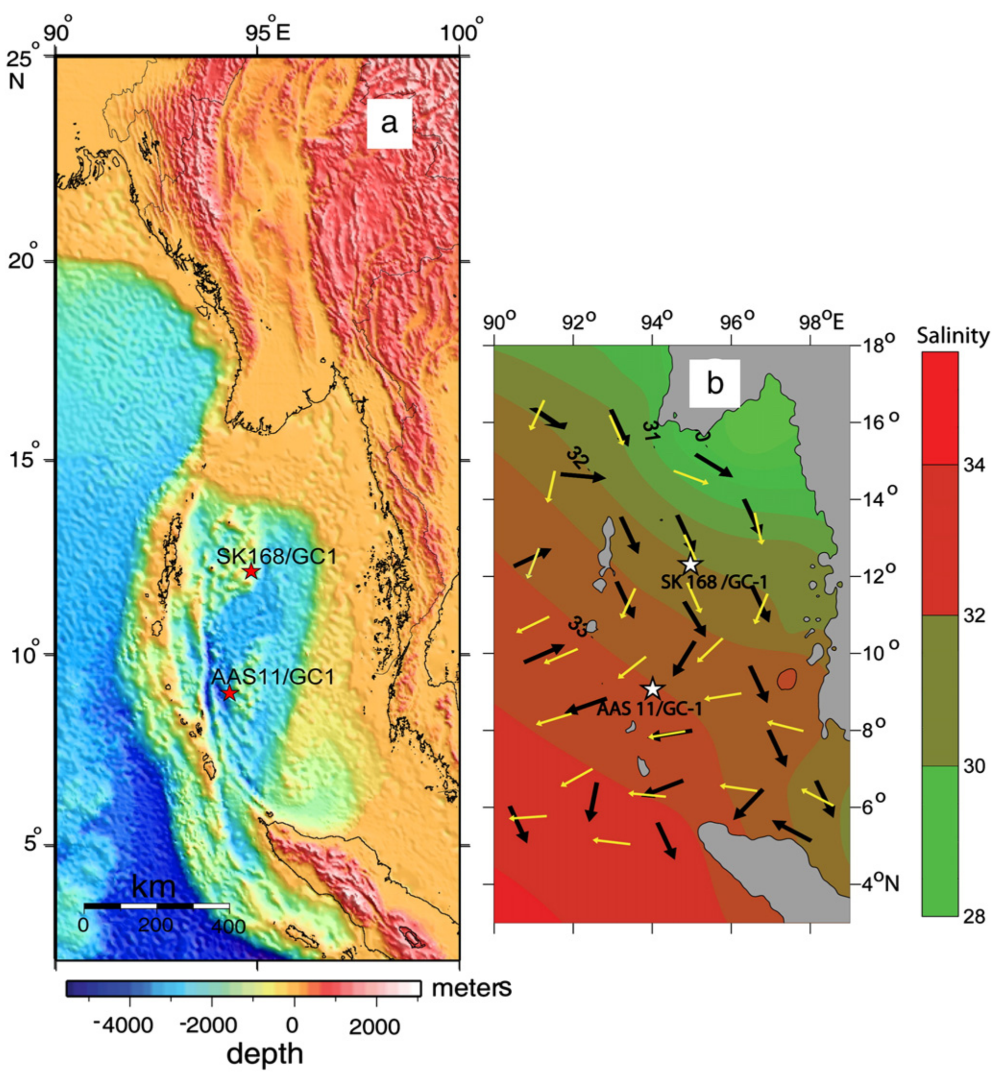

Fig. 1. Location of cores SK 168/GC 1 and AAS 11/GC 1, Andaman Sea, in the eastern Indian Ocean (modified from Sijinkumar et al., 2010): a) bathymetry of Andaman Sea along with core locations; b) salinity (annual salinity at the surface, World Ocean Atlas, 2009, www.nodc.noaa.gov) and monsoon currents in Andaman Sea; black arrow — summer monsoon, yellow arrow — winter monsoon, (modified from Brown, 2007 reference therein).