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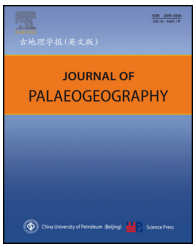

Geochemistry and sedimentary environments

Deep-water carbonate dissolution in the northern South China Sea during Marine Isotope Stage 3

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ABSTRACT

The production, transportation, deposition, and dissolution of carbonate profoundly form part of the global carbon cycle and affect the amount and distribution of dissolved inorganic carbon (DIC) and alkalinity (ALK), which drive atmospheric CO_2 changes during glacial/interglacial cycles. These processes may provide significant clues for better understanding of the mechanisms that control the global climate system. In this study, we calculate and analyze the foraminiferal dissolution index (FDX) and the fragmentation ratios of planktonic foraminifera for the 60–25 ka B.P. time-span, based on samples from Core 17924 and ODP Site 1144 in the northeastern South China Sea (SCS), so as to reconstruct the deep-water carbonate dissolution during Marine Isotope Stage 3 (MIS 3). Our analysis shows that the dissolution of carbonate increases gradually in Core 17924, whereas it remains stable at ODP Site 1144. This difference is caused by the deep-sea carbonate ion concentration ($[CO_3^{2-}]$) that affected the dissolution in Core 17924 where the depth of 3440 m is below the saturation horizon. However, the depth of ODP Site 1144 is 2037 m, which is above the lysocline where the water is always saturated with calcium carbonate; the dissolution is therefore less dependent of chemical changes of the seawater. The combined effect of the productivity and the deep-water chemical evolution may decrease deep-water $[CO_3^{2-}]$ and accelerate carbonate dissolution. The fall of the sea-level increased the input of DIC and ALK to the deep ocean and deepened the carbonate saturation depth, which caused an increase of the deep-water $[CO_3^{2-}]$. The elevated $[CO_3^{2-}]$ partially neutralized the reduced $[CO_3^{2-}]$ contributed by remineralization of organic matter and slowdown of thermohaline. These consequently are the fundamental reasons for the difference in dissolution rate between these two sites.

1. Introduction

Marine Isotope Stage 3 (MIS 3) is a warming period of the last glacial, 59–24 ka B.P. (thousand years before present), which was characterized by rapid climate transitions between cold stadials and warm interstadials at northern latitudes (Dansgaard *et al.*, 1993; Bond *et al.*, 1993). Since the identification of millennial-scale climate oscillations in ice cores from Greenland, much research has carried out on Dansgaard-

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Oeschger (D-O) oscillations in marine and terrestrial records (Voelker, 2002). Oxygen-isotope records of five stalagmites from the Hulu Cave near Nanjing, China, show a remarkable resemblance to oxygen-isotope records from Greenland ice cores, suggesting that the intensity of East Asia monsoon changed in concert with the Greenland temperature during 11–75 ka B.P. (Wang *et al.*, 2001). Ice-core records, loess successions, lacustrine sediments, stalagmite records and deep-sea sediment cores show the climate instability of MIS 3. The palaeoenvironmental changes during MIS 3 have become a main topic in the study of global changes (Zheng *et al.*, 2008).

The world ocean is one of the main constituents of the climate system and affects climate in a multitude of ways (Rahmstorf, 2002). The production, transportation, deposition and dissolution of deep-water carbonate play a significant role in global carbon cycle, because the dissolution of carbonate affects the amount and distribution of dissolved inorganic carbon (DIC) and alkalinity (ALK), and drives atmospheric pCO_2 changes in glacial/interglacial cycles (Jansen *et al.*, 2002; Yu and Elderfield, 2007). As the largest marginal sea of the western Pacific, the South China Sea (SCS), has favorable conditions for carbonate accumulation and preservation (Wang and Li, 2009), providing valuable sedimentary records for palaeoclimate research.

Previous studies of planktonic foraminifera in the SCS focused on their assemblages and distribution, or on the related palaeoenvironmental changes (Huang and Jian, 1999; Huang *et al.*, 2000; Li and Jian, 2001; Jin *et al.*, 2003). Investigations of carbonate dissolution concentrated on carbonate-dissolution cycles and on the way in which carbonate percentages changed in response to climate variability (Li *et al.*, 2001; Chen *et al.*, 2002). The study on glacial carbonate cycles in the western Pacific marginal seas shows that the percentage of $CaCO_3$ is extremely low in high-latitude seas and increases towards low-latitude basins, revealing a close relationship between this percentage and water temperature and depth (Wang, 1998). Cycles of carbonate dissolution reflect the rise and lowering of carbonate compensation depth (CCD). According to opposite variable trends of CCD cycles in the Pacific and Atlantic, carbonate cycles can be divided into a "Pacific type" and an "Atlantic type" (Wang *et al.*, 1986). Since the Middle Pleistocene, the curve of the calcium-carbonate content in the SCS shows that several strong carbonate dissolution events occurred in the transitional phase from interglacials to glacials (Li *et al.*, 2001). The deep-sea carbonate ion concentration ($[CO_3^{2-}]$) and the pH provide important clues for the investigation of the preservation of carbonate and global carbon cycles, which can be calculated with planktonic foraminiferal assembles or the $\delta^{11}B$ value and the B/Ca ratio of benthic foraminifera (Yu *et al.*, 2010).

In SCS of MIS 3, Yang *et al.* (2008) investigated the relationship between the abundance of planktonic foraminiferal species and the sea surface temperature or the depth of thermocline in the western SCS during MIS 3. Chen *et al.* (2011) concluded that the two different types of carbonate cycles in the northern and southern SCS are related to the changes of East Asian monsoon. But there is no clear conclusion so far concerning the variability of the deep-water carbonate content in the northern SCS during MIS 3.

The objective of the present study was to investigate the variability in foraminiferal dissolution in the northern SCS, and to explain the processes responsible for the temporal and spatial variations of the deep-water carbonate dissolution. Based on fragmentation ratios and foraminiferal dissolution index (FDX) of planktonic foraminifera in Core 17924 and at ODP Site 1144, we compare the carbonate dissolution found in both cores and discuss the relationship between carbonate dissolution and deep-water chemical variability in the northern SCS.

2. Material and methods

The analyses concern Core 17924 sediments collected during the 1994 SONNE95 cruise. This site is located in the northeastern part of SCS (19°24.7′N, 118°50.8′E, 3440 m water depth) (Fig. 1). Seventy-one samples were taken at 10 cm intervals from a subsection from 503 to 1270 cm.

All initial masses of the samples were measured by separating them in glass beakers and drying them in an oven (60 °C) for 24 h. Then, the samples were immersed in distilled water for 48 h before they were washed through 63 μm sieves. Finally, the residual coarse particles >63 μm were dried for analysis of the coarse fraction of foraminifera.

The coarse fraction of each sample was obtained through 154 μm sieves, and the residual coarse particles of >154 μm were split with a microsplitter in order to obtain aliquots which contain 200–400 tests of foraminifera each. Planktonic foraminiferal species were identified and counted following the taxonomy of Hemleben *et al.* (1989). We identified 24 planktonic foraminiferal species in Core 17924.

The age of Core 17924 has been established via five AMS-^{14}C datings, which yielded 18 ka B.P. (260 cm), 29 ka B.P. (550 cm), 57 ka B.P. (1130 cm), 60.44 ka B.P. (1207.5 cm), and 67 ka B.P. (1247.5 cm) (Lv, 2004). The age of the samples at other levels was calculated by interpolation.

ODP Site 1144 is located on the northeastern continental slope of the SCS (20°3.18′N, 117°25.14′E) and provided a 522-m-long composite section from a sediment drift at a water depth of 2037 m (Wang *et al.*, 2000). In the present study, we compared sediments from 22.84–72.32 m (21.51–63.63 ka B.P.) at ODP Site 1144 (Bühring *et al.*, 2004) with the contemporaneous sediments at Core 17924. The planktonic foraminiferal data are taken from Huang and Yang (2006).

Investigation of deep-water carbonate dissolution researches commonly involves measurement of the coarse fraction (Bassinot *et al.*, 1994), the percentage of carbonate (Farrell and Prell, 1989), the relative content of planktonic foraminiferal fragments (Le and Shackleton, 1992), the foraminiferal dissolution index (FDX) (Berger, 1975) and the percentage of solution-resistant species (Jian *et al.*, 1999) in sediments are commonly used as foraminiferal dissolution indexes to reconstruct deep-water carbonate dissolution. However, it is difficult to determine the degree of dissolution changes accurately by only one of these indexes. In order to distinguish the carbonate dissolution zones precisely, several indexes should be combined and analyzed comprehensively.

Dissolution potential of planktonic foraminiferal species varies. Planktonic foraminifera of different size, structure, morphology, and wall structure show variable resistance to