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Increased contribution of terrigenous supply from Taiwan to the northern South China Sea since 3 Ma

Shiming Wan [a,b,*], Anchun Li [a], Peter D. Clift [c], Shiguo Wu [a], Kehui Xu [d], Tiegang Li [a]

[a] Key Laboratory of Marine Geology and Environment, Institute of Oceanology, Chinese Academy of Sciences, Qingdao 266071, China
[b] Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing, 100029, China
[c] School of Geosciences, University of Aberdeen, Meston Building, Kings College, Aberdeen, AB24 3UE, United Kingdom
[d] Department of Marine Science, Coastal Carolina University, Conway, SC 29528, USA

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ABSTRACT

Seismic profiles provide evidence that there has been strong transport by deep-water bottom currents and drift deposition on the northern slope of the South China Sea. Earlier geochemical studies suggest that the drift sediments originated primarily from Taiwan. However, the transport process, history and origin of the deep-water bottom deposition in the northern South China Sea, on both glacial–interglacial and tectonic time scales, remain unclear. Here, we show new high-resolution records of clay minerals, grain size and mass accumulation rate (MAR) of terrigenous materials from Ocean Drilling Program (ODP) Site 1144, together with trace element concentrations in siliciclastic sediments from ODP Site 1146. Combined with other published data, we find that the primary source for sediments at ODP Sites 1144–1148 since 3 Ma is from Taiwan, and not from Pearl River as previously thought. Before 3 Ma, however, sediment source to ODP Sites 1146 and 1148 was mainly from the Pearl River. Increased contribution of terrigenous supply from Taiwan to the northern South China Sea since ~3 Ma may be related to the formation of the Taiwan orogen and strengthening of deep-water bottom current transport in the northern South China Sea. Variations in clay mineralogy and sedimentology at ODP Site 1144, located on a sediment drift, shows strong glacial–interglacial cyclicity. This suggests that bottom current deposition is highly dependent on sea-level fluctuations, which control the terrigenous supply to the deep sea.

1. Introduction

The northern South China Sea is an area of active sedimentation with possible input of terrigenous sediment supplies from the Pearl, Red and Yangtze Rivers, as well as the islands of Taiwan and Luzon (Fig. 1) (e.g., Clift et al., 2002; Liu et al., 2003; Wan et al., 2007; Shao et al., 2009). Sediment transport dynamics involve ocean circulation, which is complex in the South China Sea. Model circulation in the South China Sea can be described in three depth ranges: surface circulation above 600 m; mid-depth circulation between 600 and 1200 m; and deep circulation below 1200 m (Chao et al., 1996). The shallow circulation in the South China Sea is controlled by the East Asian monsoon system (Shaw and Chao, 1994). Surface currents flowing towards the southwest are driven by the northeast monsoon in winter, while flow is reversed by the southwest summer monsoon. The clay minerals found at most study sites in the northern South China Sea have usually been interpreted to be transported by monsoon-driven surface ocean currents. As a result downcore variations in clay mineralogy have been used to indicate changes in both the intensity of surface ocean currents and continental weathering linked with the East Asian monsoon (Liu et al., 2003; Boulay et al., 2005; Wan et al., 2007).

However, seismic profiles provide evidence that there is strong NE–SW-trending transport and that deposition of sediments may be controlled by deep-water bottom currents on the northern slope of the South China Sea (Lüdmann et al., 2005; Shao et al., 2007). These bottom currents carry terrigenous materials from the northern slope of the South China Sea southwestward to the central South China Sea, where they form discontinuous drifts with high sedimentation rates (Shao et al., 2007). Sediments recovered at ODP Site 1144, which is located on a sediment drift to the southeast of the Dongsha islands (Fig. 1), show an average sedimentation rate of 46 cm/ky since 1.1 Ma (Bühring et al., 2004). Moreover, the results of trace elements and Nd isotopes analyses suggest that the rapidly accumulated sediments at ODP Site 1144 were primarily derived from the island of Taiwan (Shao et al., 2001, 2009). Some of the sediment may be derived locally from the Plio–Pleistocene erosion of the Dongsha Uplift (Lüdmann and Wong, 1999), but volumetrically the flux from Taiwan would greatly dominate and is more consistent with the clay mineralogy. Although

* Corresponding author. Key Laboratory of Marine Geology and Environment, Institute of Oceanology, Chinese Academy of Sciences, Qingdao 266071, China. Tel.: +86 532 8289 8535; fax: +86 532 8289 8526.
E-mail address: wanshiming@ms.qdio.ac.cn (S. Wan).

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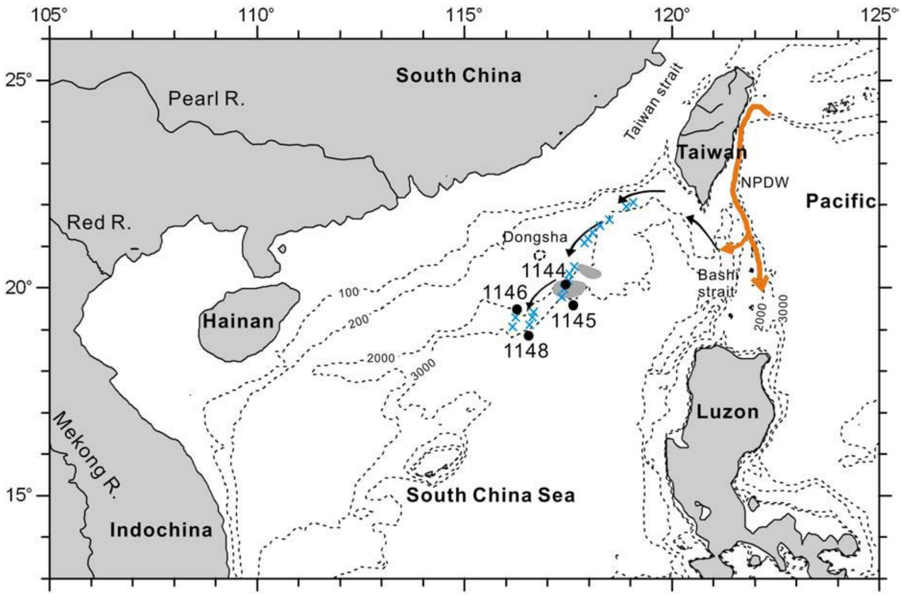

Fig. 1. Location map showing ODP Leg 184 Sites 1144, 1145, 1146 and 1148 in the northern South China Sea. Also shown are the major rivers in Asia, North Pacific Deep Water (NPDW, from Lüdmann et al., 2005) (orange arrows), deep-water current (solid arrows) and sediment drifts (blue crosses, Shao et al. (2007); grey shaded area, Lüdmann et al. (2005)) in the northern South China Sea.

there has been preliminary investigation of the clay minerals and elements geochemistry at ODP Site 1144, little attention has been paid to the sediment source and its link to deep bottom water currents (Boulay et al., 2003; Wei et al., 2004). Prior to this work, few studies have concentrated on the transport of deep-water bottom sediments in the northern South China Sea over glacial–interglacial time scales. In addition, because drilling at ODP Site 1144 did not reach the lower boundary of the drift body, the history and origin of deep-water deposition in the northern South China Sea over tectonic time scales still remain unknown. Drift sediments imaged by seismic profiles extend into the areas around ODP Sites 1146 and 1148 (Shao et al., 2007), where the cored sediment sequences extend at least to the Miocene–Oligocene. A detailed clay mineral and trace element study for sediments at ODP Site 1146 might thus be expected to shed light on the long-term history of deep-water bottom sedimentation in the northern South China Sea.

This present paper reports new high-resolution records of clay mineral assemblages, grain size and mass accumulation rate (MAR) of terrigenous materials at ODP Site 1144, as well as the trace element geochemistry of silicate sediments at ODP Site 1146, together with other published data, in order to (1) constrain the sediment source to the study sites and their temporal changes, (2) to test whether monsoon-driven surface ocean currents or deep-water current have controlled the sediment records in the northern South China Sea, and (3) to discuss the history and origin of deep-water deposition in the northern South China Sea over both glacial–interglacial and tectonic time scales.

2. Materials and methods

ODP Site 1144 (20°3.18′N, 117°25.14′E) is located at a water depth of 2037 m, on a sediment drift in the northern South China Sea (Fig. 1). Coring at ODP Site 1144 recovered a mid- to upper Pleistocene and Holocene sequence of rapidly accumulated, homogenous gray-green hemipelagic clays with a basal age of ~1.1 Ma (Wang et al., 2000). ODP Site 1146 (19°27.40′N, 116°16.37′E) is located to the southwest of ODP Site 1144, in a water depth of 2092 m, within a small rift basin on the mid-continental slope of the northern South China Sea (Fig. 1). The overall drilled sediment sequences span approximately 20 Ma. For this study, a total of 149 and 275 samples were sampled at 3.0–1.5 m intervals in 0–502.02 meters composite depth (mcd) at ODP Site 1144 and in 0–642.44 mcd at ODP Site 1146, respectively. The age model for ODP Site 1144 was based on high-resolution $\delta^{18}O$ data from *Globigerinoides ruber* (Bühring et al., 2004). The chronostratigraphic framework for ODP Site 1146 was established on the basis of the magnetostratigraphy and biostratigraphy (Wang et al., 2000) and interpolated linearly between control points.

Clay mineral studies were carried out on the <2 μm fraction, which was separated based on conventional Stokes' settling velocity principle after the removal of carbonate and organic matter (e.g., Wan et al., 2007, 2010a,b). Carbonate and organic matter were removed by acetic acid (15%) and hydrogen peroxide (10%), respectively. Clay minerals were identified by X-ray Diffraction (XRD) using a D8 ADVANCE diffractometer with CuKα (alpha) radiation (40 kV and 40 mA) in the laboratory of the Institute of Oceanology, Chinese Academy of Sciences (IOCAS). Three XRD runs were performed for each sample, following air-drying, ethylene–glycol salvation at 60 °C for 12 h and heating at 490 °C for 2 h. Identification of clay minerals was made according to the position of the (001) series of basal reflections on the three XRD diagrams (Moore and Reynolds, 1997). Semi-quantitative estimates of peak areas of the basal reflection for the main clay mineral groups of smectite (including mixed-layers) (15–17 Å), illite (10 Å), and kaolinite/chlorite (7 Å) were carried out on the glycolated samples using Topas 2P software with the empirical factors of Biscaye (1965). Relative clay mineral abundances were given in percent. For consistency purposes, all the clay mineralogical results referred to in this study were calculated based on the same methodology of Biscaye (1965).

The illite chemical composition was estimated using the ratio of the 5 Å and 10 Å illite peak areas ratio of ethylene-glycolated samples (Esquevin-Index; Esquevin, 1969). Ratios above 0.4 indicate Al-rich illites, which are formed under strong hydrolysis. Ratios below 0.4 represent Fe–Mg-rich illites (biotites and micas) are characteristic for physically eroded, unweathered rocks (e.g., Esquevin, 1969; Ehrmann, 1998). Furthermore, the illite crystallinity was calculated as the full width at half maximum (FWHM) of the illite 10 Å peak. Generally, high values indicate poor crystallinities (highly degraded), whereas low values indicate good crystallinities (relatively unaltered). These two parameters may be used to track source regions and transport paths (e.g., Ehrmann, 1998; Wan et al., 2008, 2010a,b; Xu et al., 2009).

Geochemical analysis of trace elements concentrations was performed on bulk organic- and carbonate-free sediments. Organic