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In situ observation of contour currents in the northern South China Sea: Applications for deepwater sediment transport

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ABSTRACT

Deepwater currents and related suspended sediment concentration were obtained by an Acoustic Doppler Current Profiler (ADCP) mooring system in the northern South China Sea from September 2011 to May 2013 to characterize the occurrence of contour currents and to evaluate their sediment transport capacity. Magnitude of the current velocity generally varied in the range of 0–2 cm/s, with a dominant flow direction of ∼250° (southwestward). The observed contour current, defined as the along-slope component of the deepwater currents, has a tunnel-like vertical structure with the largest velocity occurring in the middle of the "tunnel" and decreasing outwards. Both the magnitude and the depth range of the maximum velocity display evident inter-seasonal variations, with the strongest velocity in summer and the weakest in spring, while the thickness of the contour currents was the highest in winter and the lowest in spring. We also found that passing-through of the deep-reaching mesoscale eddies significantly affected the magnitude and direction of the contour currents. The suspended sediment concentration (SSC) estimated from echo intensities of the ADCP is the highest at the near-bottom (>400 μg/L) and decreases upwards to <10 μg/L at water depth shallower than 1750 m. High SSC is mostly observed during periods of low magnitude of the contour currents, suggesting resuspension of sediment from the seafloor is not the major controlling factor of these high-SSC events. Our observation also suggests that the major role that contour currents play is to transport sediment from the sources through keeping sediment suspended above the lower continental slope of the South China Sea.

1. Introduction

A contour current is a persistent along-slope flow of water mass in the deep sea that is controlled mostly by topography (Rebesco et al., 2008; Zenk, 2008). Deflection against a side wall of deep-sea basin is an elementary property of the contour currents (Zenk, 2008). At the continental margin, the contour current usually runs parallel to the topographic isobaths, but it is not necessary that a contour current has to be in contact with the side wall or the seafloor (Zenk, 2008). In physical oceanography, the contour current is frequently considered as a particular type of bottom current, although most contour currents investigated so far occur at intermediate levels (Zenk, 2008). Contour current has drawn attentions of the marine geologists since the pioneering work of Heezen and Hollister (1964), because it has the capability to affect the sea floor by re-suspending, transporting, and/or controlling the deposition of sediments (Rebesco et al., 2008). Contourite, the marine sediment that has been deposited from or significantly affected by the contour currents, is known to construct large accumulation of sediments in the deep-sea environment and to cover large areas of the present-day seafloor beneath the modern bottom-current systems (Stow et al., 2008). *In situ* oceanographic observation of modern contour currents is the most fundamental method for investigating contourite depositions in the deep sea (Howe, 2008). However, such measurements are seldom undertaken in most cases of contourite researches for reasons of cost. The deficiency of observational datasets makes the concept of "contour current" not well accepted in the community of the physical oceanographers, largely jeopardizing the further development of the research of the contourites.

The South China Sea (SCS) is the largest marginal sea in the western Pacific, with a maximum water depth of >5000 m. The only significant deep connection between the SCS and the open ocean is the Luzon Strait located between Taiwan and Luzon, with the deepest sill at around 2400 m (Qu et al., 2006). Recent field ob-

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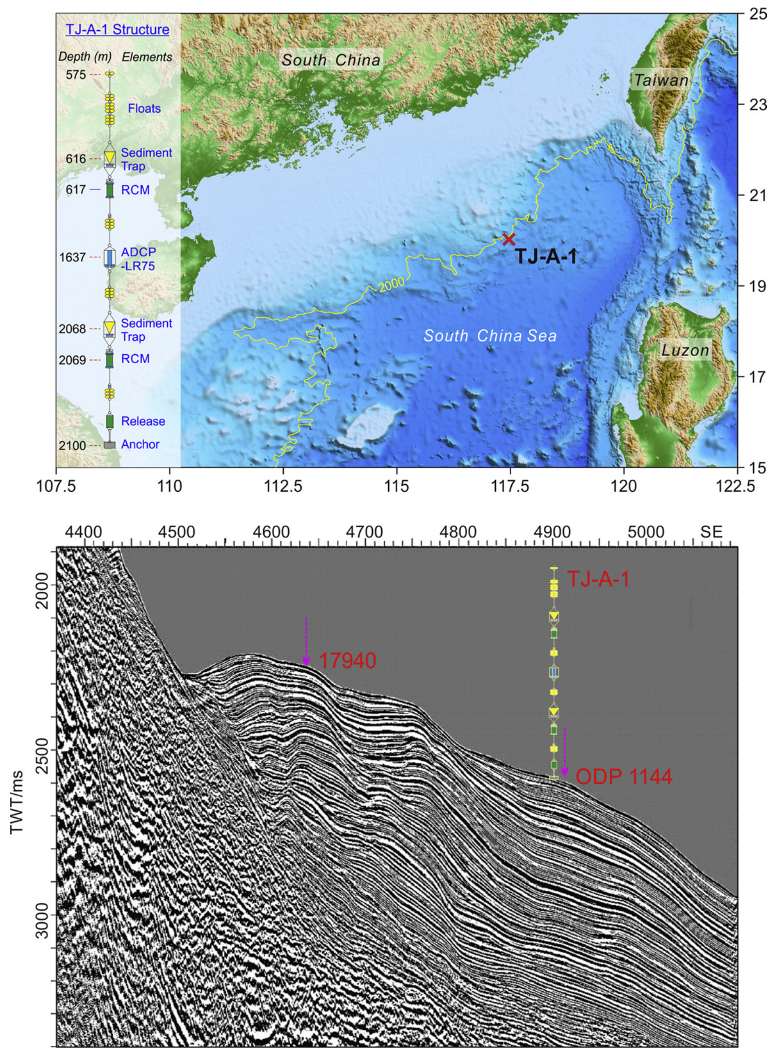

Fig. 1. Up: Bathymetric map of the northern SCS showing location of the Station TJ-A-1 and vertical structure of the mooring (left side). The contour line at 2000 m is shown in yellow line. Down: Reflection seismic profile showing structure of the sediment drift, with locations of ODP Site 1144 and Core 17940 (Shao et al., 2007).

servations (Tian et al., 2006) as well as numerical modeling (Lan et al., 2013) have confirmed that water exchange in the Luzon Strait is featured by a sandwich-like vertical structure: westward into the SCS in the upper layer (<500 m), eastward into the Pacific Ocean in the intermediate layer (500–1500 m), and westward flow again in the deep layer (>1500 m). The westward deepwater current is closely related with intrusion of the North Pacific Deep Water (NPDW) into the SCS (Qu et al., 2006). Mooring observation in the Luzon Strait reveals that deep water flows into the Strait through the Bashi Channel and the Taltung Canyon, then turns southward along the Luzon Trough, and finally enters the SCS through two gaps on the southern Hengchun Ridge (Zhao et al., 2014). Upon entering the SCS, the deepwater current (2000–2500 m) is enhanced by the SCS deep western boundary currents, and it flows firstly northwestward and then turns southwestward along the continental margins (Qu et al., 2006). In the deeper part of the SCS beneath the Luzon sill at 2400 m, the water circulation is quasi-barotropic, with average horizontal current velocity reaching maximum speed of 1.09 and 1.35 cm/s along the northern and western boundaries, respectively (G. Wang et al., 2011). In the northern SCS, the deepwater circulation can occasionally be affected by the activities of deep-penetrating mesoscale eddies (Z. Zhang et al., 2013; Y. Zhang et al., 2014). Passing-through of a pair of eddies in early 2012 led to an increase of the mean magnitude of velocity from 1.7 cm/s to 3.0 cm/s at >3500 m water depth (Z. Zhang et al., 2013). The same pair of eddies brought ~0.52 Mt of suspended sediment from southeast of Taiwan to the northern SCS basin (Y. Zhang et al., 2014).

Reflection seismic profiles in the northern SCS show that intrusion of the NPDW into the SCS has led to the formation of a series of discontinuous sediment drifts along the trajectory of the bottom currents (Shao et al., 2007). Among all the contourite drifts in the northern SCS, the high-accumulation-rate sediment drift at southeast of the Dongsha Islands, on which several deep-sea sediment cores are located, including ODP Site 1144, Core MD05-2905 and Core 17940, has drawn attentions of many researchers (Fig. 1; Sarnthein et al., 1994; Wong et al., 1994; Shao et al., 2001, 2007; Laj et al., 2005; Lüdmann et al., 2005). The sediment drift possesses the highest ever-known linear sediment rate (LSR) in the SCS deep basin, with the average LSR for the last 12 kyr reaching 56–58 cm/kyr on the upper and middle part of drift (L. Wang et al., 1999; Bühring et al., 2004). Based on results of the reflection seismic profiles, two hypotheses were proposed to interpret the formation of the sediment drift at southeast of the Dongsha Islands. Lüdmann et al. (2005) proposed that sediment re-suspended off Southeast Taiwan was brought into the interior of the SCS by the bottom currents, when encountering the continental slope off the Dongsha Islands, the currents started flowing upward the slope and slowing down, leading to the formation of this sediment drift (Lüdmann et al., 2005). It was suggested by Shao et al. (2007),