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Sediment waves on the South China Sea Slope off southwestern Taiwan: Implications for the intrusion of the Northern Pacific Deep Water into the South China Sea

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ABSTRACT

Using an integrated multi-beam bathymetry, high-resolution seismic profile, piston core, and AMS ^{14}C dating data set, the current study identified two sediment wave fields, fields 1 and 2, on the South China Sea Slope off southwestern Taiwan. Field 1 is located in the lower slope, and sediment waves within it are overall oriented perpendicular to the direction of down-slope gravity flows and canyon axis. Geometries, morphology, and internal seismic reflection configurations suggest that the sediment waves in field 1 underwent significant up-slope migration. Field 2, in contrast, is located more basinward, on the continental rise. Instead of having asymmetrical morphology and discontinuous reflections as observed in field 1, the sediment waves in field 2 show more symmetrical morphology and continuous reflections that can be traced from one wave to another, suggesting that vertical aggradation is more active and predominant than up-slope migration.

Three sediment wave evolution stages, stage 1 through stage 3, are identified in both field 1 and field 2. During stage 1, the sediment waves are built upon a regional unconformity that separates the underlying mass-transport complexes from the overlying sediment waves. In both of these two fields, there is progressive development of the sediment waves and increase in wave dimensions from the oldest stage 1 to the youngest stage 3, even though up-slope migration is dominant in field 1 whereas vertical aggradation is predominant in field 2 throughout these three stages.

The integrated data and the depositional model show that the upper slope of the study area is strongly dissected and eroded by down-slope gravity flows. The net result of strong erosion is that significant amounts of sediment are transported further basinward into the lower slope by gravity flows and/or turbidity currents. The interactions of these currents with bottom (contour) currents induced by the intrusion of the Northern Pacific Deep Water into the South China Sea and preexisting wavy topography in the lower slope result in the up-slope migrating sediment waves in field 1 and the contourites as observed from cores TS01 and TS02. Further basinward on the continental rise, turbidity currents are waned and diluted, whereas along-slope bottom (contour) currents are vigorous and most likely dominate over the diluted turbidity currents, resulting in the vertically aggraded sediment waves in field 2.

The results from this study also provide the further evidence for the intrusion of the Northern Pacific Deep Water into the South China Sea and suggest that this intrusion has probably existed and been capable of affecting sedimentation in South China Sea at least since Quaternary.

1. Introduction

Deepwater sediment waves are one of the most distinct and frequently described submarine bedforms (Wynn, 2000; Cattaneo et al., 2004; Wynn and Masson, 2008; Stow et al., 2009; Cartigny et al., 2011; Andrew, 2011). Over the last five decades, sediment waves have been observed and documented throughout the world,

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from shelf, to continental slope and rise, and to abyssal-plain environments (Ediger et al., 2002; Lewis and Pantin, 2002; Lom-Keil, et al., 2002; Mosher and Thomson, 2002; Wynn and Stow, 2002). Based on their processes of formation, sediment waves can be classified into four different groups, and these are:

(1) *Turbidity current sediment waves derived from down-slope processes.* This type of sediment waves has been widely documented (Damuth, 1979; Lewis and Pantin, 2002; Migeon et al., 2004). They are commonly formed by confined flows within submarine canyons and/or channels or by expanding flows in channel-lobe transition zones and thus have limited distribution (Mulder and Alexander, 2001; Faugères et al., 2002; Wynn et al., 2002; Arzola et al., 2008).

(2) *Bottom current sediment waves induced by along-slope processes.* The generation of bottom current sediment waves is related to bottom current activities, and they commonly cover very large areas of many slope and basin-floor settings where the persistent actions of bottom currents are active (Faugères et al., 2002; Lewis and Pantin, 2002; Masson et al., 2002; MacLachlan et al., 2008). Bottom current sediment waves could provide records of long-term bottom current circulation patterns, and the changes in the internal geometries and morphology of this type of sediment waves have been suggested as the evidence for the changes in bottom current activities (Cunningham and Barker, 1996; Lom-Keil, et al., 2002; Masson et al., 2002).

(3) *Sediment waves induced by sediment instability and failure (soft-sediment deformation features).* This type of sediment waves usually has undulating or wavy morphology and occurs where slope gradients and sedimentation rate are high (Wynn and Stow, 2002). The development of this type of sediment waves can be triggered by a variety of mechanisms, including slope failure, shear force instabilities, earthquake shaking, gravitational instabilities, gas escape, and constant strain (Faugères et al., 2002; Holbrook et al., 2002; Lee et al., 2002; Heifetz et al., 2005).

(4) *Interactions between down- and along-slope processes generated sediment waves* (IDASPWs). Many continental margins are built up by the interactions between down- and along-slope processes (e.g. Gulf of Mexico, Antarctic Peninsula, Demerara continental rise, Bay of Biscay, and Gulf of Cadiz) (Robesco et al., 1996; Gonthier et al., 2002; Kenyon et al., 2002; Faugères et al., 2002; Hernández-Molina et al., 2006). The interactions between down- and along-slope processes account for many bedforms and sediment waves formed in deep-water settings (Hernández-Molina et al., 2006; Mulder et al., 2008). Similar to contourites, IDASPWs play a critical role in paleoceanographic studies, in that their architecture and geometries are argued as the direct responses to paleoceanographic circulation patterns (Stow, 2002). Despite their importance, IDASPWs are relatively poorly understood depositional features.

Previous work on the first three types of sediment waves has considerably improved our knowledge of their geometries, morphology, and forming processes (Normark et al., 1980; Migeon et al., 2000; Wynn, 2000; Wynn and Stow, 2002; Hernández-Molina et al., 2006; Wynn and Masson, 2008). There is, however, still much to learn about IDASPWs, particularly their initiation, evolution, and paleoceanographic implications (Migeon et al., 2000).

The large sediment wave fields developed in the South China Sea Slope off southwestern Taiwan and the rich amount of data in this area provide an ideal opportunity to bridge the gap (Figs. 1 and 2). The present study focuses on two sediment wave fields,

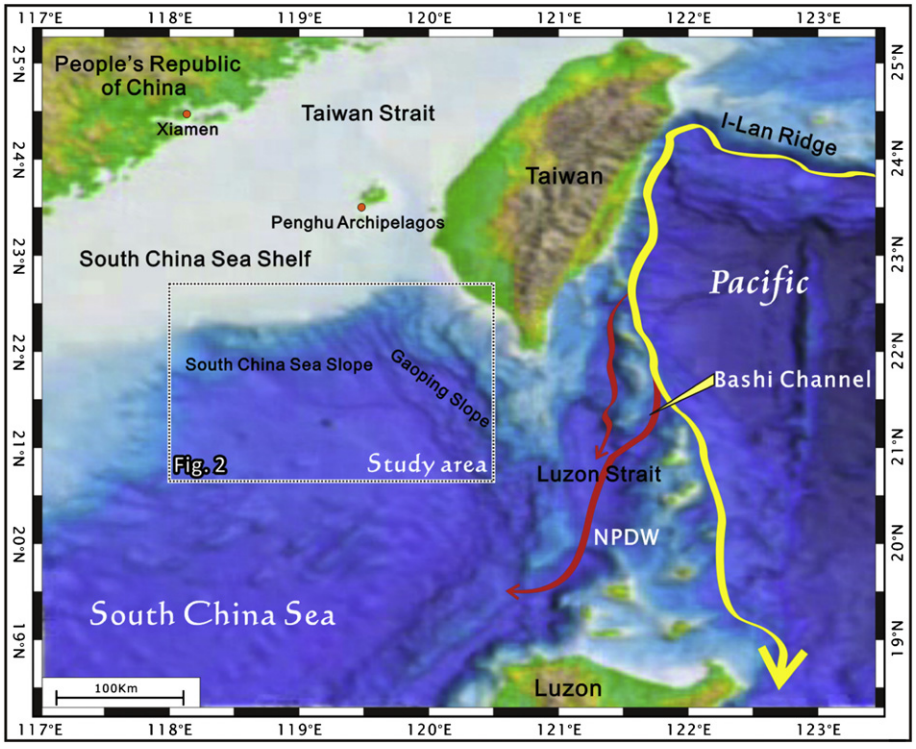

Figure 1. Bathymetric map showing the location of the study area as well as the pathways (red arrows) for the intrusion of the Northern Pacific Deep Water into the South China Sea via the Bashi Channel and the Luzon Strait. The pathway of the Northern Pacific Deep Water is modified from Xie (2009). The inset rectangle illustrates the location of Figure 2. Map modified from the images provided by the Institute of Oceanography, National Taiwan University. NPDW = the Northern Pacific Deep Water (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.).