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Research paper

The northeastern South China Sea margin created by the combined action of down-slope and along-slope processes: Processes, products and implications for exploration and paleoceanography

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ABSTRACT

Processes and products associated with the interplay of down-slope and along-slope processes are geographically widespread and yet poorly documented. Using a high-quality 2D database consisting of bathymetry, 2D seismic, piston cores, faunal, and radiocarbon data, six major depositional systems are recognized along the northeastern South China Sea margin, and from the upper slope to abyssal plain, they are erosional features, mass-flow systems, sediment gravity-flow (SGF) systems, mixed contourite-SGF systems, contourite systems and hemipelagic systems.

Sedimentary processes on the studied margin show considerable spatial complexity, yielding a depositional model that must incorporate the interplay of down-slope and along-slope processes. Erosional features and mass-flow systems are common on upper and middle slopes, respectively, where high mass flows probably dominate over bottom currents. In the lower slope and continental rise where mass flows transform into SGFs, yielding SGF system. In the lower segment of the Taiwan canyon, there is a strong interplay of SGFs and bottom currents, forming the mixed contourite-SGF system. On the abyssal plain where SGFs are volumetrically overwhelmed by contour currents, contourite depositional systems are well developed. Our results highlight the complex interaction between down-slope and along-slope processes on continental margins, thus helping to better understand the deep-water sedimentation.

Bottom-current reworked sands lacking 'typical turbidite signatures' are recognized, and are interpreted to be created by the interplay of SGF and bottom currents (including contour currents, bottom currents associated with internal solitary waves and deep-marine tidal bottom currents), which could potentially yield excellent hydrocarbon reservoirs after burial, affording an alternative for interpreting deep-marine non-turbidite reservoirs. Fine-grained bottom-current sediment waves are first recognized in the abyssal plain of the South China Sea and are interpreted to be created by contour currents resulting from the North Pacific Deep Water (NPDW–CCs), providing solid evidence for the intrusion of NPDW into the abyssal plain of the South China Sea. Preliminary bedform-velocity analysis suggests that NPDW–CCs have a maximum flow velocity up to 3 ~ 7 cm/s.

1. Introduction

Over the last few decades, it has been widely accepted that many continental margins such as the Gulf of Cadiz are built by the combined action of down-slope and along-slope deep-marine

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processes (e.g., Hernández-Molina et al., 2006, 2009; Brackenridge et al., 2013; Stow et al., 2013). The interplay of various SGFs including turbidity currents and bottom (contour) currents can produce a wide spectrum of characteristic sedimentary features, including unidirectionallymigrating deep-water channels and bottom-current reworked sands such as the 'Cadiz Sand Sheet', etc. (e.g., Viana, 2008; Salles et al., 2010; Gong et al., 2013; He et al., 2013; Stow et al., 2013). Many previous studies have independently focused on the understanding of down-slope gravity-driven processes or along-slope bottom (contour) processes (e.g., Hernández-Molina et al., 2006; Mulder et al., 2008; Mutti et al., 2009; Ercilla et al., 2008; García et al., 2011; Talling et al., 2012). Because of this, the interplay of down-slope and along-slope processes represents a critical and yet little known topic in the study of deep-marine sedimentation (e.g., Hernández-Molina et al., 2006, 2009; Rebesco et al., 2008; Brackenridge et al., 2013; Stow et al., 2013).

It is now commonly acknowledged that not all deep-marine sands are the result of deposition from turbidity currents (as turbidites) and that bottom-current reworked sands are another widespread component of many deep-marine environments. Previous studies suggested that this mixed or 'hybrid' deep-water sandstones could form significant petroleum reservoirs (e.g., Mutti and Carminatti, 2012; Shanmugam, 2012; Stow et al., 2013). There are many case studies of non-turbidite sands in deep-marine settings, where giant oil and gas fields have been discovered (e.g., the Brazilian margin basins: Mutti and Carminatti, 2012; Gulf of Mexico: Shanmugam et al., 1993; the East North American continental margin: Paull and Matsumoto, 2000; and the North Sea: Shanmugam, 2012, etc.). For example, a large portion of the upper Cretaceous and Tertiary deep-marine sands deposited in Brazilian offshore basins were interpreted as bottom-current reworked sands by Mutti and Carminatti (2012), from which ~88% of oil reserves and >80% of the 2 million barrels of oil (boe) daily production come (e.g. Marlim, Albacora and Roncador oil fields, etc.). As pointed out by Stow et al. (2011, 2013), more work is therefore required on modern analogues (such as the Cadiz Sand Sheet) in order to better understand and characterize the deposition of these hybrid sands and their linked reservoirs.

The study area is located in the northeastern South China Sea margin, and is strongly dissected by deep-water channels, submarine canyons, and slope gullies, all of which are active conduits for SGFs (Yu et al., 2009; Gong et al., 2013; Figs. 1 and 2). The study area is also affected by strong and vigorous along-slope bottom (contour) currents associated with North Pacific Intermediate Water (NPIW) and North Pacific Deep Water (NPDW) (e.g., Qu et al., 2006; Yang et al., 2010; Gong et al., 2012, 2013; He et al., 2013). In addition, sandy deposits observed in piston cores (TS01 core, discussed later) recovered from the study area show properties that are not observed in classic turbidites with Bouma divisions. The northeastern South China Sea margin, therefore, provides an ideal opportunity to investigate depositional processes and resultant deposits along a passive continental margin constructed by the combined action of down-slope and along-slope depositional processes.

This study, using newly acquired high-quality data, attempts to: (1) document the main morpho-sedimentary features that characterize the physiographic domains of the northeastern South China Sea margin; (2) investigate the dominant depositional processes in different parts of the margin, both down-slope and along-slope; and (3) address the hydrocarbon exploration and paleoceanographic significance of near-surficial deposits in the study area. Results from this study may help in understanding the depositional processes operating along other continental margins where the interplay of down-slope and along-slope processes and those deep-marine reservoirs lacking typical turbidite signatures occurs.

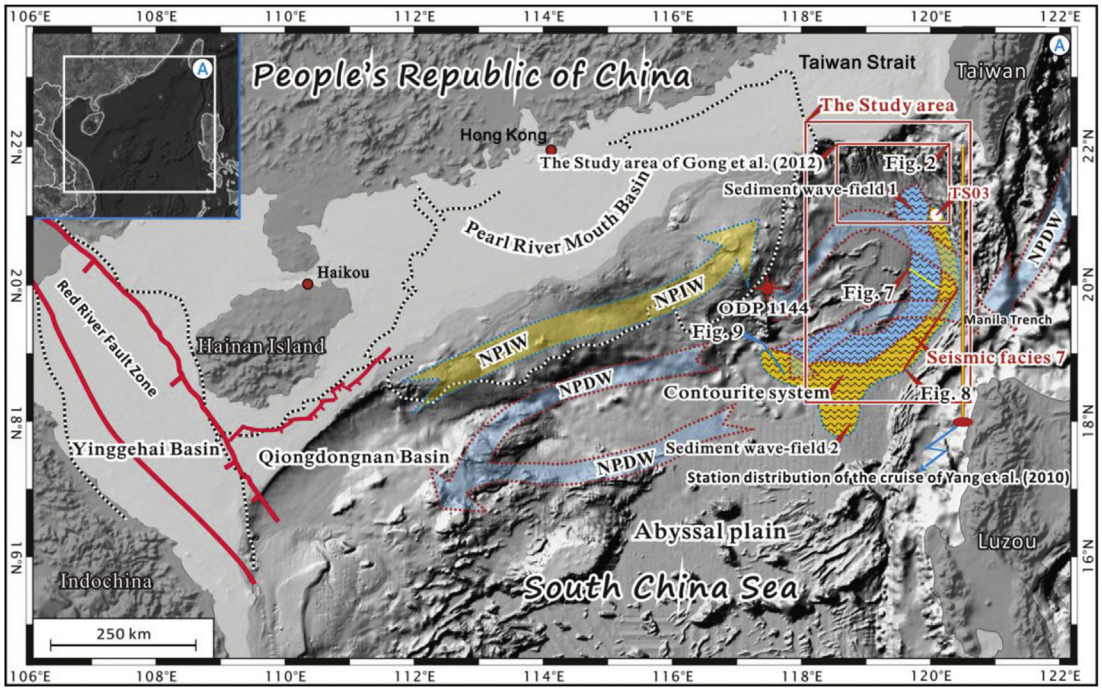

Figure 1. Bathymetric map showing the location of the study area as marked by the rectangle with the solid outline and the pathways of the North Pacific Intermediate Water (NPIW) and North Pacific Deep Water (NPDW) (modified from Gong et al., 2013). The regional plain-view locations of bathymetric map presented in Figure 2, seismic sections shown in Figures 7, 8 and 9 and piston core TS03 are labeled. Also shown are regional plan-view locations of sediment wave-fields 1. Note that the study area of Gong et al. (2012) only represents a small portion of the study area of this research.