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# Depositional characteristics and processes of alongslope currents related to a seamount on the northwestern margin of the Northwest Sub-Basin, South China Sea

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ABSTRACT

This study infers, from 2D seismic data, the presence of a seamount-related deep-water contourite depositional system, located on the northwestern margin of the Northwest Sub-Basin of the South China Sea. Alongslope aligned erosive features and contourite drifts developed in water depths between 1000 and 1500 m on the present seafloor. A moat formed north of the seamount as a result of bottom current intensification after being deflected by an obstacle morphology, indicating a major eastward flowing current. Due to the Coriolis deflection, an elongated-mounded drift developed to the north of the moat and a modest plastered drift to the south (onlapping the north side of the seamount). Bottom currents away from the seamount are less or minimally intensified, generating contourite channels and furrows over the drift to the north of the moat. Combined with the known oceanographic setting, the bottom currents could belong to the anticyclonic South China Sea Intermediate Water circulation. From the seismic data, the architecture of contourite deposits during progressive burial of the seamount is documented. The first appearance of contourite channels in seismic Unit 1 is inferred to be the onset of the contourite depositional system, which could be traced back to the early Late Miocene. The following aggradational pattern of this system, from the base of seismic Unit 2 onwards, indicates relatively enhanced and stable South China Sea Intermediate Water circulation occurring on the northwestern margin of the northern South China Sea. Subsequently, the behaviour and depositional processes of bottom currents upstream and downstream the seamount are discussed. The depositional model suggests that a complex contourite channel system will replace the former moat–drift system once the seamount is buried. Finally, our findings may provide new challenges for investigating the South China Sea Cenozoic palaeoceanography, which are helpful to understand the sedimentary dynamic processes related to the South China Sea deep-water circulation.



## 1. Introduction

The processes and products, associated with alongslope bottom currents, as well as their interaction with downslope gravity currents, are receiving increasing attention of the scientific community during recent decades (Rebesco et al., 2008, 2014; Hernández-Molina et al., 2011b). This is mainly related to their importance as major components of the deep-water sedimentary system (Knutz, 2008; Mulder et al., 2011), and their role in deep-water hydrocarbon exploration (Moraes et al., 2007; Viana et al., 2007; Viana, 2008). Moreover, technological advances in geophysics and geochemistry during the past two decades, have pushed this research line forward, allowing to focus in detail on diagnostic criteria, classifications and dynamic mechanisms (Hollister, 1993; Faugères et al., 1999; Stow et al., 1998, 2002, 2008; Viana et al., 1998; Faugères and Stow, 2008; Giresse, 2008; Martín-Chivelet et al., 2008; McCave, 2008; Nielsen et al., 2008; Salon et al., 2008; Faugères and Mulder, 2011), as well as to discuss interactions between alongslope and downslope depositional systems (Rebesco et al., 1996, 2007; Massé et al., 1998; Ito, 2002; Rasmussen et al., 2003; Marches et al., 2007; Mulder et al., 2008). This has greatly contributed to distinguishing contourites from other similar erosional and depositional products. These products could be in genetic relationship with processes or mechanisms of wind-driven surface currents, tide waves, storm waves, internal waves, up- or downwellings, clear-water canyon

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currents and turbidity currents (e.g., turbiditic levees or fans) (Faugères et al., 1999; Rebesco et al., 2008; Faugères and Mulder, 2011). Contourite depositional systems (CDSs), more importantly, can be regarded as superb recorders for palaeoceanographic studies. Their lateral and temporal variable 3D geometry may reveal changing patterns and intensities from the palaeoclimatologically influenced deep-water currents (Carter et al., 2004; Surlyk and Lykke-Andersen, 2007; Hernández-Molina et al., 2010; Van Rooij et al., 2010; Llave et al., 2011). Additionally, besides the large-scale contourite drifts generated by the global thermo-haline circulation, increasingly more examples of contourite drifts created under different oceanographic conditions or related to morphological features or restrictions are described (Carter and McCave, 1994; Reeder et al., 2002; Van Rooij et al., 2003; Howe et al., 2006; Martorelli et al., 2010, 2011; Hernández-Molina et al., 2011a; Vandorpe et al., 2014).

However, whereas the majority of contourite studies were carried out in the Atlantic and Mediterranean realms (Rebesco et al., 2014), investigations of deep-water alongslope bottom current circulation are scarce in the South China Sea (SCS) (Zhao et al., 2009; Wang et al., 2010; Tian and Qu, 2012; Zheng and Yan, 2012). Distinct contourite deposits have been reported on the slope south of the Dongsha Uplift (ODP 1144, Fig. 1A) (Lüdmann et al., 2005; Shao et al., 2007), on the slopes off southwestern Taiwan (Gong et al., 2012), as well as on the northwestern margin of the SCS Northwest Sub-Basin (Zheng and Yan, 2012; Li et al., 2013; Palamenghi et al., submitted for publication). Some authors have tentatively proposed pathways of deep-sea palaeo-bottom currents in the northern SCS (Fig. 1A) (Lüdmann et al., 2005; Shao et al., 2007; Wang et al., 2010, 2013; Zheng and Yan, 2012; Li et al., 2013). However, the palaeoceanography of a wide range of areas in the SCS is still poorly known.

This paper aims to unravel the Cenozoic seismic palaeoceanography of the SCS Northwest Sub-Basin. This includes the identification of the past and present alongslope depositional processes with respect to the regional and global palaeoceanographic variability. An accurate description of morphological features and internal structures of the discerned units on the northern slope of a seamount, located on the northwestern margin of the Northwest Sub-Basin of the SCS (~650 to ~2000 m in water depth), will be presented (Fig. 1B). These observations may provide new insights in the dynamic SCS deep-water sedimentary processes. Special attention will be given to the influence of the seamount as (basement) obstacle within the local bottom current circulation pattern, as well as its associated erosional and depositional products. Finally, the studied area belongs to the transition zone between continental and oceanic crust, connecting the SCS Northwest Sub-Basin with the Xi'sha Trough (Fig. 1A), and could yield more information regarding the flow direction of deep bottom currents in this area, which is important to consider in further reconstruction of the northern SCS palaeo-bottom current circulation pattern.

## 2. Regional setting

### 2.1. Geological framework

The SCS basin, which is a rhomb-shaped (southwest tapering) semi-enclosed basin, encompasses an area of about $3.5 \times 10^6$ km$^2$ and is divided into three sub-basins (northwest, central/east and southwest) (Sun et al., 2009; Wang and Li, 2009b) (Fig. 1A). The SCS is bordered to the north and west by the Chinese mainland and the Indochina Peninsula, and by the Luzon and Borneo islands to the northeast and to the south, respectively. Its present-day shape and semi-enclosed nature results from the post-spreading tectonic development, e.g., the subduction into Philippine Sea Plate (Wang and Li, 2009a) (Fig. 2). The study area (18°30′ N to 19°10′ N and 113°5′ E to 113°50′ E) is located on the northwestern margin (the continental–oceanic crust transition zone) of the SCS Northwest Sub-Basin, belonging to the southwestern margin of the Pearl River Mouth Basin. It is also adjacent to the Xi'sha Trough in the south and the Qiongdongnan Basin in the west (Fig. 1A).

This area was affected by the initial SCS spreading process, considering the spreading centre (32 to 30 Ma) was confined to the SCS Northwest Sub-Basin (Figs. 1 and 2) (Sun et al., 2006). The local ocean accretion stopped at 23 Ma, after which the spreading centre shifted towards the Central Sub-Basin from 30 to 26 Ma (Wang and Li, 2009b; Xie et al., 2011). The final SCS spreading phase took place in the Southwest Sub-Basin from 24 Ma onwards and lasted until 15.5 Ma (Sun et al., 2006; Wang and Li, 2009b) (Fig. 2).

The study area shares the same Mesozoic basement with the Cenozoic rift basins developed on the SCS northern continental margin (Sun et al., 2012), especially, the Pearl River Mouth Basin (on the shelf and slope area offshore the Pearl River Mouth, occupying an area of about $14.7 \times 10^4$ km$^2$) and the Qiongdongnan Basin (west of the Pearl River Mouth Basin, covering an area of $4.5 \times 10^4$ km$^2$) (e.g., Li et al., 2009; Wang and Li, 2009b; Xu et al., 2012) (Fig. 1A). This basement mainly consists of Mesozoic granites and to a lesser extent, volcanic rocks (Gong et al., 1989; Jin, 1989; Chen, 2000). Its structural evolution involved two major stages (Ru and Pigott, 1986; Chen et al., 1994; Li et al., 2009; Wang and Li, 2009b; Zhu et al., 2009). An initial rifting stage with intensified faulting activities lasted from ~65 till ~30 Ma in the Pearl River Mouth Basin and ~23 Ma in the Qiongdongnan Basin (Fig. 2). Subsequently, a post-rift subsidence stage started from the Late Oligocene onwards in the Pearl River Mouth Basin and from the Early Miocene onwards in the Qiongdongnan Basin (Fig. 2). This latter stage can be further subdivided into a steady subsiding sub-stage (from ~30 to ~11.6 Ma in the Pearl River Mouth Basin and from ~23 to ~11.6 Ma in the Qiongdongnan Basin) and a rapid subsiding sub-stage from the early Late Miocene onwards (Xie et al., 2011) (Fig. 2).

Numerous seismic and sequence stratigraphic studies concerning this region have been carried out (Huang, 1999; Wu et al., 2000; Pang et al., 2007; Li et al., 2009), resulting in many different seismic stratigraphic interpretations. For the use of this paper, the seismic stratigraphic setting proposed by Xie et al. (2011) is principally applied, including a correlation with the seismic stratigraphy by Li et al. (2009), resulting in the identification of 8 regional seismic unconformities, T2 to T9 and Tg (Fig. 2). The unconformities T7 (30 Ma) and T6 (23 Ma) have been widely accepted as representing the breakup unconformity and separating the lower syn-rift from the upper post-rift mega-sequences in the Pearl River Mouth Basin and Qiongdongnan Basin, respectively (Li et al., 2009; Wang and Li, 2009b; Xie et al., 2011). The shift from the rifting to the subsidence stage caused the transformation of the northern SCS from a neritic continental shelf to a continental slope, at the end of Oligocene (23 Ma), accompanied by a change of a proximal sediment provenance in the Oligocene to a mainly distal one in the Miocene (Chen et al., 1993; Xie et al., 2006; Li et al., 2009). During the SCS regional transgression, a deep-water sedimentary environment was gradually introduced in the Pearl River Mouth Basin from the Early Miocene onwards (Chen et al., 1994; Wang et al., 2003; Shao et al., 2004; Li et al., 2009; Xie et al., 2011), and in the Qiongdongnan Basin from the Late Miocene onwards (Su et al., 2009, 2013; He et al., 2013) (Fig. 2).

### 2.2. Oceanographic framework

The SCS oceanography is largely influenced by its physiographic characteristics (Zhao et al., 2009; Wang et al., 2013; Xie et al., 2013). The connections with neighbouring seas are all rather shallow (<100 m), e.g. the Taiwan Strait to the East China Sea and the Balabac Strait to the Sulu Sea (Fig. 1). The only two exceptions are the Mindoro Strait (~420 m), which forms the connection with the Sulu Sea, and the Bashi Channel (~2400 m) towards the West Philippine Sea (Wang et al., 1999; Qu et al., 2006; Zhao et al., 2009). The Bashi Channel is thus the deepest SCS connection to open seas, and was formed due to the