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Research paper

Recurrent slope failure and submarine channel incision as key factors controlling reservoir potential in the South China Sea (Qiongdongnan Basin, South Hainan Island)

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ABSTRACT

High-resolution multi-beam bathymetry, 3D and 2D seismic reflection profiles from the South China Sea are used to investigate the morphology, characteristics, origin and implications to petroleum systems of recurrent slope failure in the Qiongdongnan Basin, northern South China Sea. Seven Late Miocene-Holocene mass-transport deposits (MTDs) and numerous submarine canyons were identified on the continental slope and rise, providing new insights on the evolution of an enigmatic region of the South China Sea. This paper defends that the interpreted MTDs were triggered by a combination of high sedimentation rates and local tectonic uplift. By comparing the stratigraphy of the study area with local sea-level curves, we show that a significant portion of shelf-edge deposits effectively bypassed most of the continental slope during the Miocene-Quaternary to accumulate as large MTDs on its lower part (i.e. on the 'basin-floor'), independently of sea-level changes. Our work has implications to the current sequence stratigraphic models for continental margins, and sheds new light on the reservoir potential of Miocene units in the South China Sea. Hence, regions where base-of-slope fans are expected to occur are, in the study area, occupied by large-scale recurrent MTDs sourced from the shelf edge. Stratigraphically, recurrent slope instability resulted: a) in abrupt episodes of accommodation space creation on the shelf-edge, b) on a moderate reduction in accommodation space at the base of the continental slope, and c) in a complete separation between shelf and distal slope depositional systems, with most stratigraphic markers on 3D seismic data being diachronous across the continental margin. As MTDs also comprise the bulk of channel-fill deposits in large submarine canyons, we propose that the reservoir potential of channel-fill deposits in the South China Sea is closely dependent on the nature of the sediment (i.e. net-to-gross ratio) eroded and transported by these same MTDs.

1. Introduction

Sequence stratigraphy comprises the study of facies relationships and stratal architectures within known chronological frameworks, which are normally delimited on seismic and borehole data by unconformities (and correlative surfaces) of regional expression (Catuneanu et al., 2009). However, sequence stratigraphic analyses on new exploration prospects are seldom undertaken using extensive datasets, relying instead on the interpretation of seismic data complemented (when possible) with wireline and lithological information. Seismic data only images stratal architectures that are vertically separated within the resolution limits of the seismic data, and does not resolve subtle features such as condensed sequences and high-frequency units, particularly at greater depths of investigation (Catuneanu et al., 2009).

Trying to address these caveats, multiple standardized schemes, or stratigraphic models, have been proposed in the literature, from

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which the most widely known are Galloway and Dutton (1979), van Wagoner et al. (1990) and, more recently, Catuneanu et al. (2009). These sequence stratigraphic models assume the existence of four main genetic types of deposits: aggrading, normal regressive, forced regressive and transgressive (see also Hunt and Gawthorpe, 2000). The genetic types are mainly controlled by relative base-level changes, and do not necessarily take into account tectonic and morphological aspects of the continental margins on which strata are accumulated. This poses a second important limitation when interpreting continental margins around the world, particularly those on which slope instability events are common, and complex depositional systems establish the link between deposition in shelf-edge regions and the lower slope (e.g. 'base-of-slope fans' according to van Wagoner et al., 1990). The complex way in which erosional and depositional processes interact in time and space on continental margins resulted in their classification as Exponential, Gaussian and Linear by Adams and Schlager (2000). However, most sequence stratigraphic models do not take into account the morphological variability proposed by Adams and Schlager (2000) which, as shown in this paper, can impose significant controls on the type of depositional facies expected in 'base-of-slope' deposits.

The term mass-transport deposit (MTD) is used in this work to describe all kinds of gravity-induced deposits transported downslope including debris flows, debris avalanches, slumps and slides, with the exception of turbidity currents (Moscardelli and Wood, 2008). MTDs play an important role in reshaping the morphology of continental margins and controlling the sedimentary architectures of sedimentary basins (Posamentier and Kolla, 2003; Gee et al., 2006; Moscardelli et al., 2006; Moscardelli and Wood, 2008). They reflect processes capable of transporting large amounts of sediment onto the deeper parts of continental margins (Weimer, 1989; Frey-Martínez et al., 2005; Gee et al., 2006; Masson et al., 2006; Lee and Stow, 2007; Moscardelli and Wood, 2008; Bull et al., 2009) and comprise heterogeneous volumes of failed sediment of distinct lithologies and degrees of internal disaggregation (Alves et al., 2014). Furthermore, MTDs comprise some of the most important near-seafloor geohazards, posing a direct threat to deep-water equipment and engineering infrastructure, such as pipelines and communication lines (Locat and Lee, 2002; Krastel et al., 2006; Masson et al., 2006).

MTDs are ubiquitous in the northern South China Sea (Wu et al., 2011) and particular attention has recently been paid to understanding the significance, distribution, and frequency of these deposits in the Qiongdongnan Basin, or QDNB (Sun et al., 2011; Wang et al., 2013; L. Li et al., 2013). This renewed attention results from the discovery of hydrocarbon reservoirs, such as the Ya 13-1 gas field, in the northern part of the basin (Chen et al., 1993; He et al., 2006). Acknowledging the importance of the QDNB as a hydrocarbon producing region, this paper uses high-resolution seismic reflection data and multi-beam bathymetry data to: (1) analyse the morphology of the central part of the QDNB; (2) document the stratigraphic distribution of recurrent MTDs accumulated from the Late Miocene on the continental rise; (3) discuss the factors controlling the deposition of these MTDs, and (4) propose a depositional model for the study area, discussing the implications of our new model to petroleum systems in the QDNB. This study is important to future risk assessments in this area, and our model is useful to better understand the recurrence of slope failure on continental margins dominated by strike-slip tectonics, such as the QDNB. In fact, previous studies on MTDs have demonstrated the significance of high-resolution multi-beam bathymetry and seismic reflection data, as those used in this paper, in improving our understanding of their internal structure and depositional evolution (Gee et al., 2006; Migeon et al., 2011; Völker et al., 2011; Krastel et al., 2012; Li et al., 2014).

2. Data and methods

Multi-beam bathymetry and high-resolution 2D and 3D seismic data were used to map Miocene-Quaternary submarine landslides and study the spatial distribution of MTDs in the QDNB (Fig. 1). The two interpreted 3D seismic volumes were acquired by China National Offshore Oil Corporation (CNOOC) in 2005 (Fig. 2). The seismic volumes were processed to a main frequency bandwidth of 30–45 Hz, and Common Mid Point spacing of 12.5 m. The vertical resolution of the seismic data is ~25 m. In addition to the two 3D seismic volumes, we interpreted 20,000 km^2 of multi-beam bathymetry data acquired in 2008 within water depths ranging from 200 m to 2600 m (Fig. 2). The horizontal and vertical resolutions of the multi-beam bathymetry data are ~100 m and ~1–3.3 m,

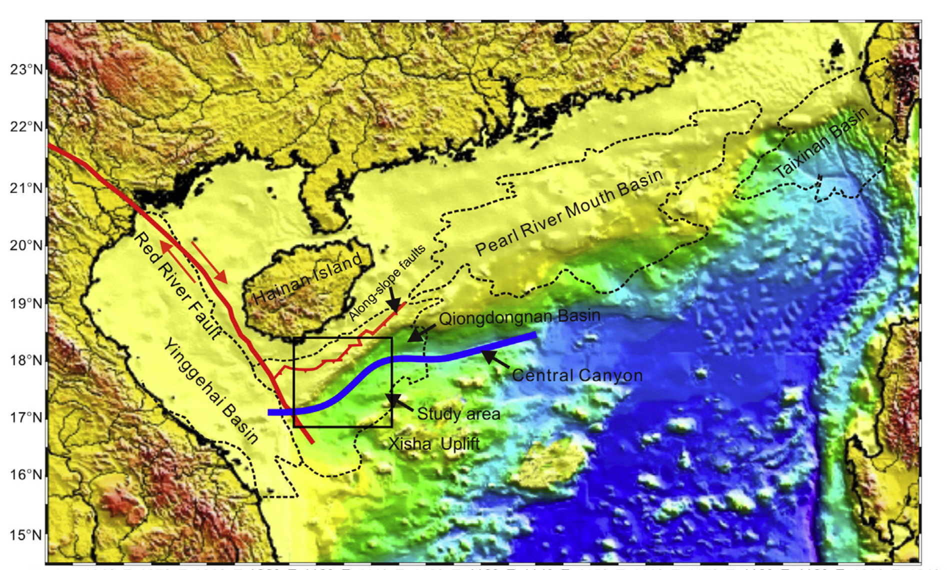

Figure 1. Combined bathymetric and topographic map showing the locations of sedimentary basins in the northern part of the South China Sea. The study area (black box) is located in the central part of the QDNB. The location of major structures and geological features (e.g. Red River Fault, Central Canyon and slope-parallel faults) are taken from Xie et al. (2008) and Gong et al. (2011).