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Research paper

Characteristics and occurrence of submarine canyon-associated landslides in the middle of the northern continental slope, South China Sea

Ye He [a], Guangfa Zhong [a, *], Liaoliang Wang [b], Zenggui Kuang [b]

[a] State Key Laboratory of Marine Geology, Tongji University, Shanghai 200092, China
[b] Guangzhou Marine Geological Survey, Guangzhou 510075, China

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ABSTRACT

High-resolution and high-density 2-D multichannel seismic data, combined with high-precision multibeam bathymetric map, are utilized to investigate the characteristics and distribution of submarine landslides in the middle of the northern continental slope, South China Sea. In the region, a series of 19 downslope-extending submarine canyons are developed. The canyons are kilometers apart, and separated by inter-canyon sedimentary ridges. Numerous submarine landslides, bounded by headscarps and basal glide surfaces, are identified on the seismic profiles by their distorted to chaotic reflections. Listric faults and rotational blocks in head areas and compressional folds and inverse faults at the toes of the landslides are possibly developed. Three types of submarine landslides, i.e., creeps, slumps, and landslide complexes, are recognized. These landslides are mostly distributed in the head areas and on the flanks of the canyons. As the most widespread landslides in the region, creeps are usually composed of multiple laterally-coalesced creep bodies, in which the boundaries of singular component creep bodies are difficult to delineate. In addition, a total of 77 landslides are defined, including 61 singular slumps and 16 landslide complexes that consist of two or more component landslides. Statistics show that most landslides are of a small dimension (0.53–18.09 km^2 in area) and a short runout distance (less than 3.5 km). Regional and local slope gradients and rheological behavior of the displaced materials might play important roles in the generation and distribution of the submarine landslides. A conceptual model for the co-evolution of the canyons and the associated landslides in the study area is presented. In the model it is assumed that the canyons are initiated from gullies created by landslides on steeper sites of the continental slope. The nascent canyons would then experience successive retrogressive landsliding events to extend upslope; at the same time canyon downcutting or incision would steepen the canyon walls to induce more landslides.

1. Introduction

Submarine landslides or slope failures, formed by downslope gravity-driven movement of submarine sediments, represent one of the most important deep-water geomorphologic and depositional features on continental margins (Hampton et al., 1996; McAdoo et al., 2000; Canals et al., 2004; Moscardelli and Wood, 2008; Bull et al., 2009). A typical submarine landslide is defined by three basic elements including a headscarp, a glide surface and a displaced mass (Hampton et al., 1996; Lee et al., 2007).

Based on mechanical behaviors and deformation degrees of the displaced materials, submarine landslides are generally classified into four categories, i.e. creeps, slides and slumps, rock or debris falls, and mass flows (Dott, 1963; Crozier, 1973; Almagor and Garfunkel, 1979; Mulder and Cochonat, 1996; McAdoo et al., 2000; Locat, 2001; Canals et al., 2004; Lee et al., 2007; Green and Uken, 2008; Moscardelli and Wood, 2008). Creeps are gradually, continuously, and slowly deformed masses; slides represent downslope displacement of coherent masses of sediment along a planar glide surface; slumps consist of blocks of failed materials rotated along a curved glide surface; rock or debris falls refer to abrupt movement of rocks or debris detached from a steep slope or cliff; and mass flows involve debris avalanches, debris flows and mud flows (Varnes, 1978). Multiple phases or different types of

* Corresponding author. Tel.: +86 21 65982784.
E-mail addresses: yuuke.hy@gmail.com (Y. He), gfz@tongji.edu.cn (G. Zhong), liaoliangwang@163.com (L. Wang), 164696984@qq.com (Z. Kuang).

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landslides can be stacked together to form a landslide complex. All types of submarine landslides may finally transform into turbidity currents (e.g., Locat, 2001).

A large number of submarine landslides have been documented from passive continental margins (Bugge et al., 1987; Maslin et al., 1998; Piper et al., 1999), active continental margins (Lastras et al., 2005), and margins of volcanic islands (Moore et al., 1989; Masson et al., 1998). Submarine landslides on these margins are dominantly distributed on open slopes, and some of them are associated with submarine canyon or channel systems (Booth et al., 1993). Large scale landslides normally occur on the open slopes, while the canyon-associated environments are characterized by small landslides (Chaytor et al., 2009).

Little attention has been paid to those small-scale landslides associated with submarine canyon or channel systems (Green and Uken, 2008). Existing examples are scarce and mostly came from investigations of canyon or channel systems (Twichell and Roberts, 1982; Farre et al., 1983; Pratson et al., 1994; Pratson and Coakley, 1996; Greene et al., 2002; Puga-Bernabéu et al., 2011). Green and Uken (2008) documented the geomorphologic characteristics of 117 landslides around 23 canyons on the Northern KwaZulu-Natal continental shelf of South Africa, and discussed the linkage of the landslides to the hosting submarine canyons.

In the paper, we present a detailed case study of small-scale submarine canyon-associated landslides in the middle of the northern continental slope, South China Sea (SCS). In the region, a series of 19 canyons are developed, which extend downslope in roughly NNW-SSE direction. Lateral spacing between canyons is generally 2–10 km (Fig. 1). Feng et al. (1994) inferred there might be a large submarine landslide of about 400 km^2 in the region. Sun et al. (2008) and Wang et al. (2009) presumed that the area and adjacent slope regions might be made up of a huge active mass transport complex, covering an area over 10,000 km^2. In our study, numerous small-scale submarine canyon-associated landslides but not a huge landslide as previously suggested, are identified by a detailed analysis of the newly-acquired high-resolution, high-density seismic profiles and the high-precision multibeam bathymetry map. Herein, the characteristics and distribution of the submarine landslides are described, and the relationship between the submarine landslides and their hosting canyons is discussed, from which a conceptual model is presented to explain the co-evolution of the landslides and their hosting canyons.

2. Geologic settings

The SCS is one of the largest marginal seas in the western Pacific region. It is resulted from the interaction of the Eurasian, Australian and Pacific plates (Taylor and Hayes, 1980; Ru and Pigott, 1986). The modern SCS oceanic basin is a consequence of crustal rifting and succeeding drifting processes during the latest Eocene or the earliest Oligocene to the middle Miocene (see review in Wang and Li, 2009). Since the late Miocene, the basin has entered a phase of regional thermal subsidence, and its northern and southern passive continental margins have gradually been constructed.

Our study area is located in the middle of the northern continental slope of the SCS, structurally lying in the Baiyun Sag of the Pearl River Mouth Basin, one of the largest offshore oil-bearing basins in China (Fig. 1). The area covers about 3438 km^2, with

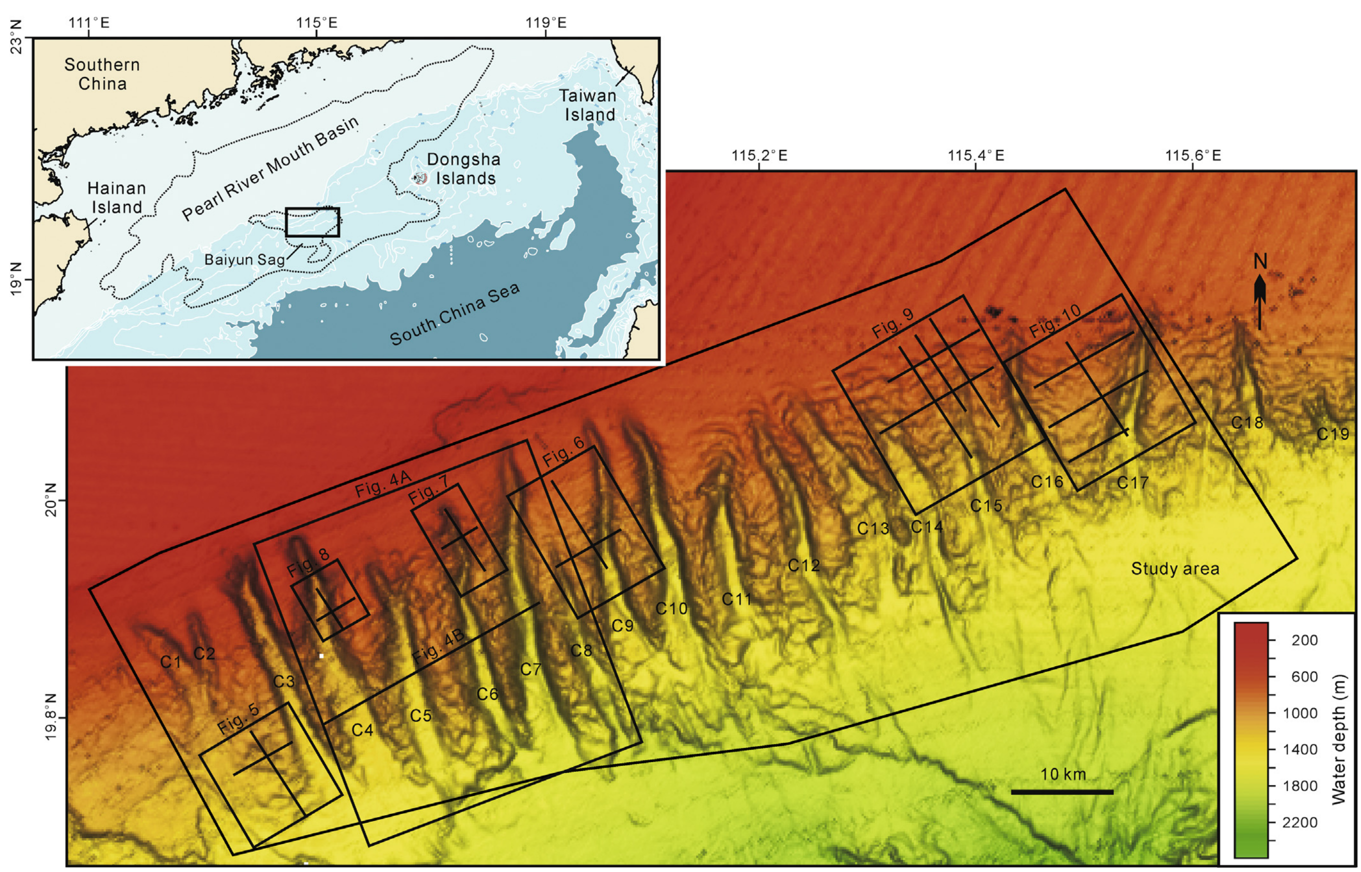

Figure 1. Multibeam bathymetric map (after Ding et al., 2013) showing seafloor reliefs in the middle of the northern continental slope, South China Sea. A total of 19 NNW-SSE-trending submarine canyons are shown, which are labeled from west to east as C1 to C19, respectively. Also shown is the locations of seismic profiles displayed in Figures 4B and 5–10, and the enlarged three-dimensional bathymetric relief map displayed in Figure 4A. The black polygon outlines the study area. Insert shows location of the study area on the northern South China Sea slope.