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A giant, submarine creep zone as a precursor of large-scale slope instability offshore the Dongsha Islands (South China Sea)

Wei Li [a,b], Tiago M. Alves [c], Shiguo Wu [b,*], Michele Rebesco [d], Fang Zhao [e,*], Lijun Mi [f], Benjun Ma [g]

[a] Institute of Geosciences, University of Kiel, Kiel 24118, Germany
[b] Institute of Deep-Sea Science and Engineering, Chinese Academy of Sciences, Sanya 572000, China
[c] 3D Seismic Lab, School of Earth and Ocean Sciences, Cardiff University, Main Building, Park Place, Cardiff, CF10 3AT, United Kingdom
[d] Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS), Borgo Grotta Gigante 42/C, Sgonico, 34010 Trieste, Italy
[e] CAS Key Laboratory of Marginal Sea Geology, South China Sea Institute of Oceanology, Chinese Academy of Sciences, Guangzhou 510301, China
[f] Shenzhen Branch Company, China National Offshore Oil Corporation Ltd, Guangzhou 510420, China
[g] Key Laboratory of Marine Geology and Environment, Institute of Oceanology, Chinese Academy of Sciences, Qingdao 266071, China

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ABSTRACT

A giant submarine creep zone exceeding 800 km^2 on the continental slope offshore the Dongsha Islands, South China Sea, is investigated using bathymetric and 3D seismic data tied to borehole information. The submarine creep zone is identified as a wide area of seafloor undulations with ridges and troughs. The troughs form NW- and WNW-trending elongated depressions separating distinct seafloor ridges, which are parallel or sub-parallel to the continental slope. The troughs are 0.8–4.7 km-long and 0.4 to 2.1 km-wide. The ridges have wavelengths of 1–4 km and vertical relief of 10–30 m. Slope strata are characterised by the presence of vertically stacked ridges and troughs at different stratigraphic depths, but remaining relatively stationary in their position. The interpreted ridges and troughs are associated with large-scale submarine creep, and the troughs can be divided into three types based on their different internal characters and formation processes. The large-scale listric faults trending downslope below MTD 1 and horizon T_0 may be the potential glide planes for the submarine creep movement. High sedimentation rates, local fault activity and the frequent earthquakes recorded on the margin are considered as the main factors controlling the formation of this giant submarine creep zone. Our results are important to the understanding of sediment instability on continental slopes as: a) the interpreted submarine creep is young, or even active at present, and b) areas of creeping may evolve into large-scale slope instabilities, as recorded by similar large-scale events in the past.

1. Introduction

Seafloor undulations are widespread on continental slopes around the world (Cattaneo et al., 2004; Urgeles et al., 2007, 2011). They are defined as undulated morphological features on the seafloor, with lengths ranging from a few to hundreds of meters and heights of centimeters to several meters (Urgeles et al., 2007). Seafloor undulations are commonly associated with sediment-laden currents such as distal turbidites (Berndt et al., 2006), hyperpycnal flows (Rebesco et al., 2009) or contour currents (Wynn and Stow, 2002). Seafloor undulations can also relate to slow, post- or syn-depositional deformation under gravity-driven downslope creep (Lee and Chough, 2001; Cattaneo et al., 2004; Shillington et al., 2012). They are of key importance in such a context, as regions of the continental slope may be classified as stable or potentially unstable depending on the recognition of such features (Urgeles et al., 2007; Shillington et al., 2012). In particular, seafloor undulations may be associated with submarine creep, which consists of gravity-driven deformation under slow rates, reflecting failure of a sediment mass above and along a detachment plane formed in a pre-defined (inherited) plane of weakness (Hill et al., 1982; Lee and Chough, 2001). Submarine creep can be a significant geologic process on many continental slopes; not only can submarine creep generate major displace-

* Corresponding author.
E-mail addresses: swu@sidsse.ac.cn (S. Wu), iocaszhaofang@outlook.com (F. Zhao).

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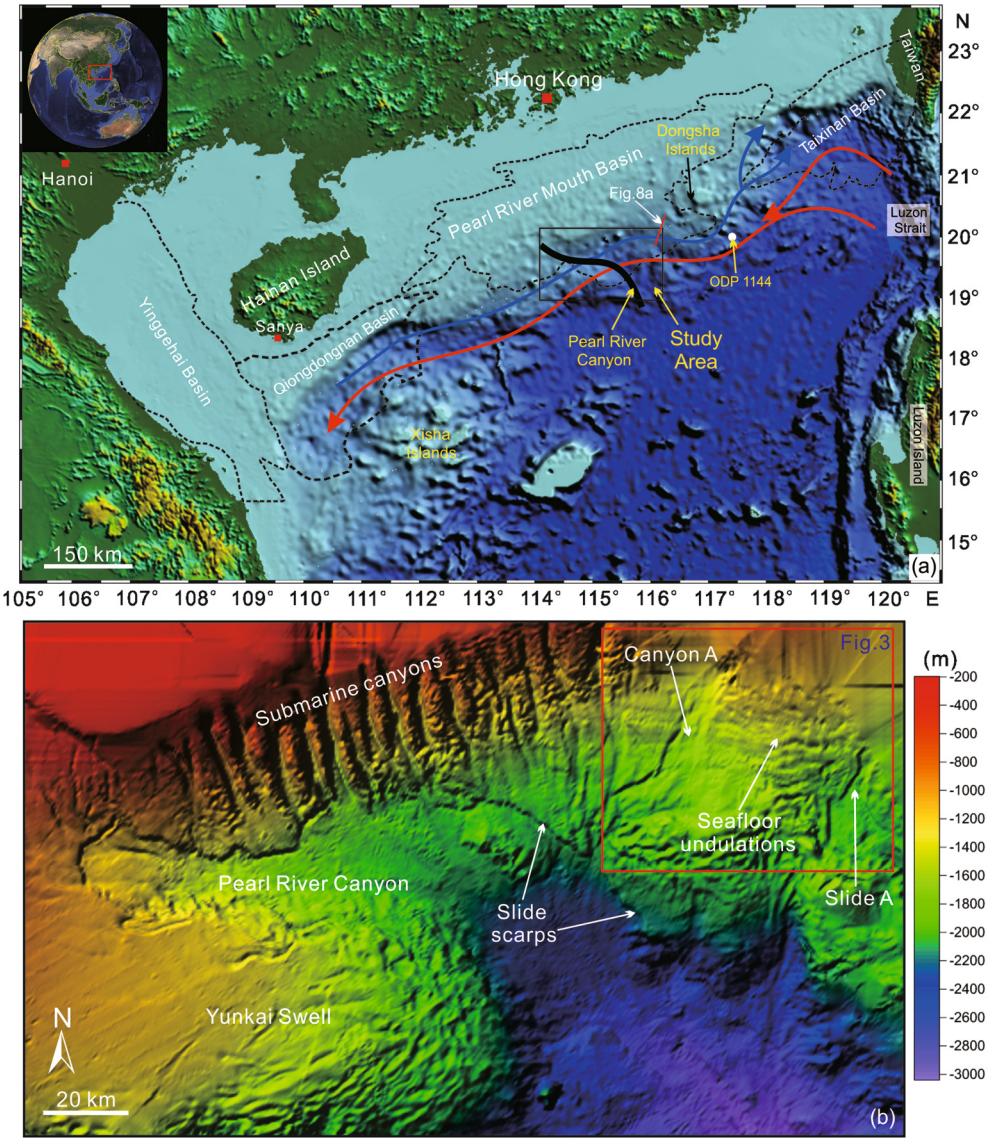

Fig. 1. (a) Topographic map showing the location of major sedimentary basins and geomorphological features (e.g. Dongsha Islands, Xisha Islands, Luzon Strait and Pearl River Canyon) in the northern South China Sea. The black box represents the location of the study area. The blue and red curves indicate the circulation pathways of intermediate (NPIW) and deep-water (NPDM) masses, respectively (modified after Chen et al., 2014; Gong et al., 2015). The seismic profile in Fig. 8a is highlighted by the solid red line. (b) Bathymetric map of the study area illustrating numerous submarine canyons, the steep slide scarps of Baiyun Slide Complex (Li et al., 2014) and the Yunkai Swell (Wang et al., 2014). The red box represents the location of the submarine creep zone interpreted in this study. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

ments in near-seafloor sediment, but it may also be the trigger of recurrent slope failure on continental slopes (Lee and Chough, 2001).

The continental slope of the Pearl River Mouth Basin (PRMB) has been modified by multiple, and recurrent, submarine mass movements (Wu et al., 2011; Li et al., 2014; Zhao et al., 2015). One giant submarine landslide, the Baiyun Slide Complex, occurred ~0.3 Ma b.p. in the southwestern part of the study area (Li et al., 2014). The Baiyun Slide Complex affected an area of about 10,000 km^2 and remobilised ~600 km^3 of sediment. Other parts of the PRMB are dominated by smaller scale mass movements within discrete submarine canyons (He et al., 2014). The southeast portion of the PRMB also records multiple failure events through the Late Miocene–Quaternary (Zhao et al., 2015). Buried MTDs indicate that the continental slope of Dongsha has been unstable for a long time period (>5 Ma). They were chiefly triggered by local tilting of the continental slope in response to tectonic uplift caused by Dongsha Event.

This paper recognises, for the first time, the presence of a giant field of seafloor undulations offshore the Dongsha Islands, in water depths between 1200 and 1550 m (Figs. 1a and b). The identification of these seafloor undulations is important as they may be the morphological expression of an unstable continental slope, with grave consequences for submarine infrastructures. They can also evolve into large-scale slope failures, as recorded in the past in this same area (Li et al., 2014; Zhao et al., 2015). The newly acquired bathymetric, 3D seismic and well data interpreted in this paper provide an ideal opportunity to improve our understanding of the evolution and implications of field of seafloor undulations in the South China Sea, and on other continental margins. Hence, this paper aims to:

a) Investigate the morphology of seafloor undulations offshore the Dongsha Islands;
b) Describe the internal architecture of seafloor undulations on high-quality 3D seismic data;