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Architecture, development and geological control of the Xisha carbonate platforms, northwestern South China Sea

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ABSTRACT

Newly acquired seismic data allow improved understanding of the architecture and evolution of isolated carbonate platforms on the continental slope of the northern South China Sea. The Xisha carbonate platforms were initiated on a basement high, the Xisha Uplift, in the early Miocene and have remained active up to the present. Their distribution is limited to pre-existing localized, fault-bounded blocks within the Xisha Uplift so individual platforms were small in size at the beginning of the Miocene. However, during the middle Miocene, the platform carbonate factories flourished across an extensive area with 55,900 km^2. The platforms began to backstep in response to a relative sea-level rise in the late Miocene. Platform-edge reefs, patch reefs, pinnacle reefs, atoll reefs and horseshoe reefs, all developed on various platforms. The distribution of platform carbonates shrank significantly during Pliocene-Quaternary time to isolated carbonate platforms, represented today by Xuande Atoll and Yongle Atoll. Tectonics and eustasy were the two main controls on platform development. Tectonics controlled both the initial topography for reef growth and the distribution of platforms, including those that survived the drowning event associated with the late Miocene rapid relative sea-level rise. Eustasy controlled high-frequency carbonate sequence development.

1. Introduction

Carbonate platforms developed widely in tropical and subtropical settings, forming thick and extensive biogenic constructions. Carbonate platforms typically have life spans of millions to tens of millions of years. Their initiation, growth, and demise are governed by a combination of tectonics, eustasy, oceanography and climatic conditions (Fulthorpe and Schlanger, 1989; Sun and Esteban, 1994; Wilson, 2002; Bachtel et al., 2003). During the Late Cenozoic, extensive tropical carbonate platforms and reefs developed in the tectonically complex South China Sea region (Epting, 1989; Wilson, 2002; Sattler et al., 2009). On the southern margin of the South China Sea (Hutchison et al., 2004; Hutchison and Vijayan, 2010), many Tertiary carbonate platforms grew on basement highs created by faulted blocks during the Eocene to Early Oligocene rift phase (Fulthorpe and Schlanger, 1989; Sales et al., 1997; Wiliams, 1997). Carbonate platforms also developed on the northern margin of the South China Sea, both on uplifted fault blocks and on volcanic seamounts. The northern platforms are younger than those on the southern margin (Qiu and Wang, 2001; Wei et al., 2005). Various examples of Indo-Pacific carbonate platforms have been described, and associated facies models presented, e.g., the Miocene Luconia platform (Epting, 1980), the Middle Oligocene Berai Limestone (Saller et al., 1992) and the Miocene Natuna buildup (Rudolph and Lehmann, 1989). However, the stratigraphic architectures of these systems and the geological factors controlling their development are often unclear. Tectonics can be an important factor in the initiation of carbonate platforms, such as the Eocene to the middle Miocene Tonasa carbonate platform of South Sulawesi (Pigram et al., 1989; Wilson et al., 1999, 2000; Bosence, 2005; Hutchison and Vijayan, 2010). Eustatic fluctuations have been considered to have played an important role in platform development and stratigraphic architecture of carbonate platforms likewise e.g. the Maldives (Belopolsky and Droxler, 2003, 2004). In addition, bottom currents can also be a key control on carbonate platform architecture (Betzler et al., 2009; Lüdmann et al., 2012, 2013).

The Xisha Islands (Paracel Islands) are seated on an elevated submarine plateau that rises from the lower slope southeast of Hainan Island and is surrounded by > 1000 m deep seafloor (Fig. 1). The Xisha carbonate factory is an example of the T-factory of Schlager (2005): shallow-water, biologically controlled deposits dominate.

Previous studies of the Xisha carbonate platforms have been limited to analysis of shallow boreholes and examination of modern carbonate

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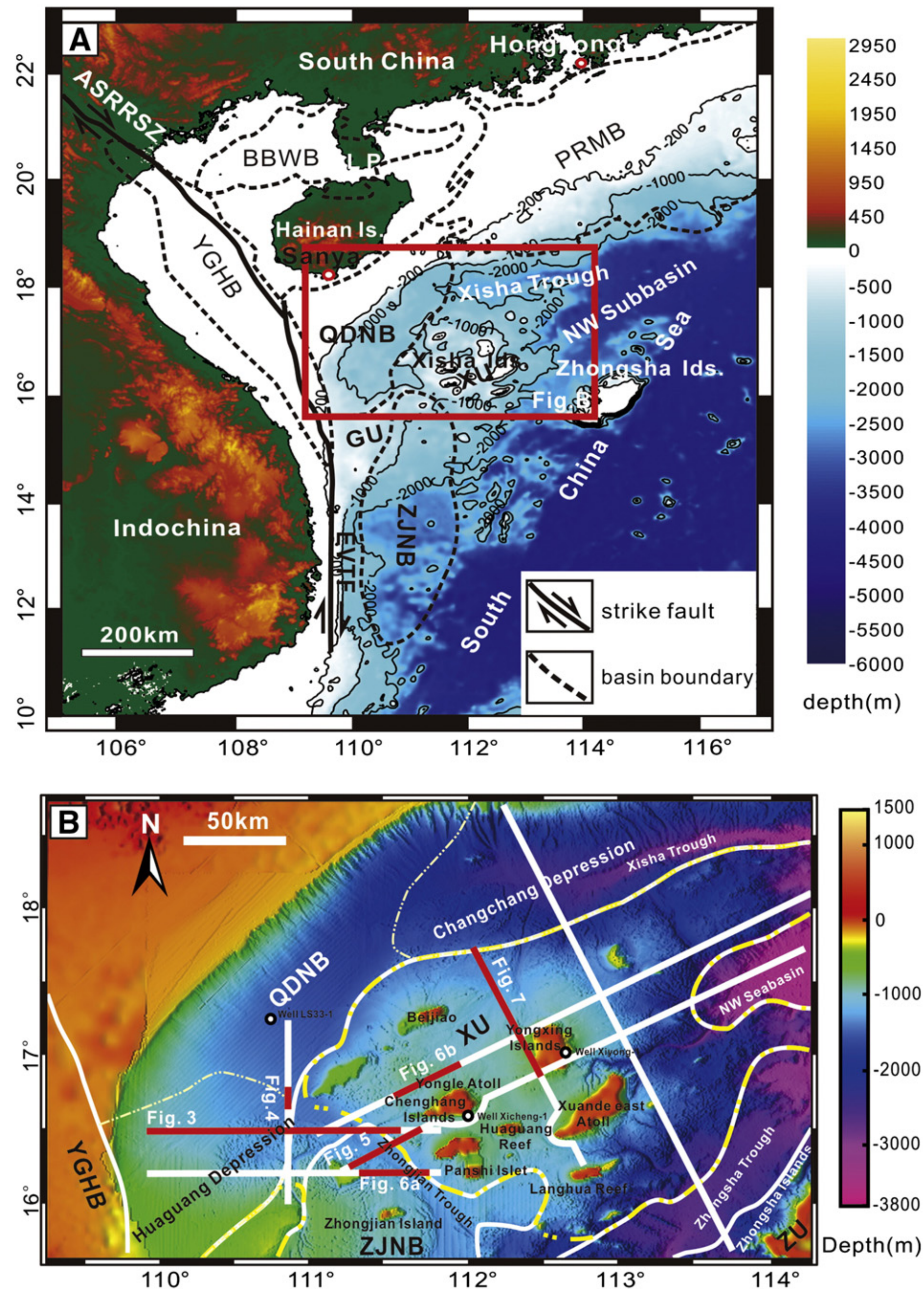

Fig. 1. A: Tectonic divisions of sedimentary basins in the northern South China Sea. Dashed lines indicate basin boundaries. The rectangle indicates study area. ASRRSZ: Ailaoshan-Red River Shear Zone; BBWB: Beibuwan Basin; PRMB: Pearl River Mouth Basin; QDNB: Qiongdongnan Basin; YGHB: Yinggehai Basin; ZJNB: Zhongjiannan Basin; XU: Xisha Uplift; GU: Guangle Uplift; ZU: Zhongsha Uplift; EVTF: East Vietnam Transform Fault. B: Bathymetric map of the Xisha Islands (Paracel Islands) and adjacent sea areas. The location of the map is shown in Fig. 1A. White lines indicate seismic tracks. Locations of wells mentioned in the text are also shown.

deposits on the islands (He and Zhang, 1986; Zhao et al., 2011). However, in the course of rapidly advancing deep-water hydrocarbon exploration, both commercial and academic seismic surveys have been conducted in deep-water settings of the northern South China Sea. In particular, 2D/3D seismic data have been recently acquired in order to evaluate the potential of reef carbonate reservoirs (Wu et al., 2009; Ma et al., 2010). These data provide new insights into the architectures and evolution of the northern South China Sea carbonate platforms.

The objectives of this paper are twofold: 1) to illustrate the architecture and evolution of the Xisha carbonate platforms; and 2) to understand the main factors controlling the development of carbonate factories in marginal seas. We focus on the impact of early tectonic movements, eustatic change, and terrigenous input, on the development of reefs and carbonate platforms in the Xisha region (Fig. 1).

2. Geological setting

The South China Sea is the largest marginal sea off East Asia. It is surrounded by the South China block, Taiwan, the Luzon arc, Palawan, Borneo, and the Indo-China Peninsula and was formed by seafloor spreading from 32 to 17 Ma (Taylor and Hayes, 1983; Tsai et al., 2004).

Main structural elements in the study area are the Xisha Uplift and adjacent depressions (Fig. 1). The Xisha Uplift was subaerially exposed prior to the Miocene, but subsided during the late Oligocene to early Miocene period of seafloor spreading (Fig. 1). Crustal thickness in the Xisha Uplift varies from 27 km to 6.8 km (Taylor and Hayes, 1983; Xia et al., 1998; Qiu et al., 2001; Yao et al., 2004). The Xisha Uplift had experienced rifting since the late Cretaceous and its crest in the early Miocene was broken into small, fault-controlled uplifted blocks and intervening