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Seismic sequence stratigraphic analysis of the carbonate platform, north offshore Taiping Island, Dangerous Grounds, South China Sea

Jih-Hsin Chang [a,*], Ho-Han Hsu [a], Char-Shine Liu [a], Tung-Yi Lee [b], Shye-Donq Chiu [a], Chih-Chieh Su [a], Yu-Fang Ma [c], Ying-Hui Chiu [a], Hau-Ting Hung [d], Yen-Chun Lin [e], Chien-Hsuan Chiu [f]

[a] Institute of Oceanography, National Taiwan University, Taipei,Taiwan
[b] Department of Earth Science, National Taiwan Normal University, Taipei, Taiwan
[c] Precision Instrumentation Center, National Taiwan University, Taipei, Taiwan
[d] Offshore Exploration & Production Division, Exploration & Production Business Division, Chinese Petroleum Company, Taipei, Taiwan
[e] GeoResource Research Center, National Cheng Kung University, Tainan, Taiwan
[f] Bureau of Mines, Ministry of Economic Affair, Taipei, Taiwan

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ABSTRACT

Taiping Island, also known as Itu Aba, is the largest natural terrestrial landmass in the South China Sea and is centrally located. Using bathymetry and marine multi-channel seismic data, we explored the seismic stratigraphic features of the offshore and isolated carbonate platform north of Taiping Island. The western flank of the carbonate platform is characterized by an intercalation between high-amplitude and low-amplitude reflections, showing the landward and seaward migration of the platform foreslope deposits. In addition, there are two offshore carbonate build-ups that are underlain by normal faults. Six sequence boundaries and five depositional sequences caused by eustatic sea level cycles are identified and correlated with the eustatic sea level change chart. Although the evolution of the seismic sequences is partly controlled by local tectonics, the overall stacking pattern of the sedimentary strata in our study area reveals five third-order cycles and one second-order cycle, which is in accordance with the eustatic sea level chart. Additionally, the formations of the Western Taiping Seamount Group and the Zhenghe-Daoming Trough are preliminarily analyzed based on seismic data.

1. Introduction

The carbonate platforms in the South China Sea are significant for their great explorational interest and tectonic-sedimentary implications for the evolution of the rifted margin. These carbonate platforms are extensively distributed in the South China Sea area and were developed during the Oligocene-Miocene (Fig. 1; Ding et al., 2014a, 2014b; Epting, 1980; Erlich et al., 1990; Fyhn et al., 2009, 2013; Lü et al., 2013; Steuer et al., 2014; Wu et al., 2014). Most of these carbonate platforms are located nearshore or around the shelf break of the South China Sea continental shelf, and only very few offshore carbonate platforms detached from continent have been explored.

Located northwest offshore of Borneo and Palawan, the Dangerous Grounds is a continental slope area characterized by large amounts of offshore and isolated carbonate platforms (Fig. 2). Carbonates were initiated in the Late Oligocene (Fig. 3; Taylor and Hayes, 1980; Ding et al., 2013) and have occupied the area of the continental slope, the crust of which has been rifting to form cuestas (Hutchison and Vijayan, 2010). However, neither the age of the Miocene platform carbonates nor the stratigraphic features and lithologic variations recording the depositional history of the Miocene platform carbonates in the northern Dangerous Grounds have been fully presented in previous studies because of limited published data.

A marine geophysical investigation was conducted during March, 2014, by the Marine Geology and Geophysics (MG&G) research group of the National Taiwan University. The reflection seismic data were acquired in the southwest-northeast strike of the depositional low, suited offshore north of Taiping Island, between the Zhenghe Reefs and the Daoming Reefs, which hereafter will be referred to as the Zhenghe-Daoming Trough (Fig. 4). In this study, a seismically resolvable carbonate platform is verified north of Taiping Island. Based on the concept of sequence stratigraphy, we analyzed the possible relationship between sedimentary developments of the carbonate platform and the eustatic sea level changes. Additionally, volcanic edifices west of Taiping Island (hereafter the Western Taiping Seamount Group) reflecting the regional tectonic framework is also recognized and analyzed (Fig. 4).

The aim of this study is to characterize the stratigraphic features and propose the ages of the carbonate platform at the northern part of the Dangerous Grounds and its development during the Late Oligocene–Miocene based on an analysis of the seismic data and the concept of sequence stratigraphy. We interpret not only the seismic features of the

* Corresponding author. Tel.:+886 2 3366 1871.
E-mail address: ChangJihHsin@gmail.com (J.-H. Chang).

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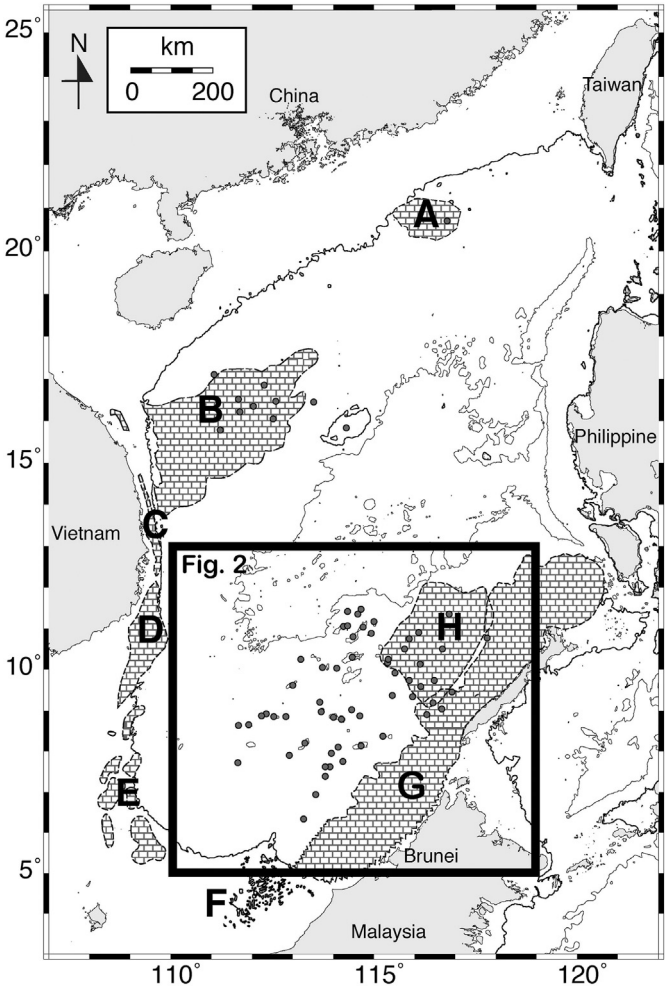

Fig. 1. The simplified bathymetric chart of the South China Sea, with the geographic extents of several published Miocene carbonate platforms (A-H) and the locations of continental slope atolls (gray dots). A: The lower and upper Zhujian carbonate platforms (Sattler et al., 2009). B: The Earliest middle Miocene Xisha carbonate platforms (Fyhn et al., 2013; Wu et al., 2014). C: The Early Miocene Triton carbonate platforms (Fyhn et al., 2013). D: The Phan Rang carbonate platform (Fyhn et al., 2009). E: The Miocene carbonate platform in the Nam Con Son Basin (Lü et al., 2013). F: The Miocene carbonate build-ups of the Central Luconia Province (Hutchison and Vijayan, 2010). G: The Nido carbonate platforms (Steuer et al., 2013). H: Reed Bank that may be covered by carbonate build-ups (Ding et al., 2014a). The locations of continental slope atolls refer to Wang (1998). Thick and thin contour lines are −200 m and −4000 m isobathes, respectively.

carbonate platform foreslope and carbonate build-ups but also present significant seismic stratigraphic boundaries that are caused by eustatic sea level changes. In addition, we revisit the spatiotemporal relationship between the Western Taiping Seamount Group and the Borneo-Palawan foreland basin to discuss their possible tectonic influence on the seismic sequence stratigraphic records in our study area.

2. Geological setting

2.1. Tectonic evolution northwest offshore Borneo and Palawan

The nature of the continental margin northwest of Borneo and Palawan was influenced by the seafloor spreading of the oceanic basin (Hinz and Schlueter, 1985; Briais et al., 1993) and the convergence event between the rifted continental crust of the Dangerous Grounds and northwest Borneo (Madon et al., 2013)(Fig. 3). Since the Late Cretaceous, the proto-South China Sea occupied the south region of the Chinese terrace. Subsequently, the proto-South China Sea was subducted beneath the northwest Borneo during the Paleogene, and part of the continental crust of the Dangerous Grounds region was subducted beneath the northwest Borneo in the latest early Miocene (Hesse et al., 2009). During the Oligocene to Miocene, seafloor spreading of the South China Sea occurred, resulting in the migration of the rifted continental crust of the Dangerous Grounds away from the southern margin of China (Hesse et al., 2010). The collisional event of the Sabah Orogeny caused by the collision between the rifted continental crust of the Dangerous Grounds and Sabah is generally thought to coincide with the end of the seafloor spreading of the South China Sea (Madon et al., 2013). The northwest Borneo fold-thrust belt is still tectonically active and resulted in many submarine thrust wedges along with the foreland basin of the northwest Borneo Trough (Hesse et al., 2010).

2.2. Oligocene-Miocene carbonate platforms in the South China Sea

The Oligocene-Miocene carbonate platforms in the South China Sea are significant because of their great explorational interests and their tectonic-sedimentary relationships with the rifted margin during the spreading of the South China Sea oceanic basin. They are extensively distributed in the South China Sea (Fig. 1A). In the northernmost part of the South China Sea, the Miocene Zhujian Formation in the Pearl River Mouth Basin is characterized by numerous drowning surfaces and deposits of a drowned carbonate platform (A in Fig. 1; Sattler et al., 2009). Southwestward, the Miocene Xisha carbonate platform is located in the northwestern South China Sea (B in Fig. 1; Wu et al., 2014). Toward the south, the Miocene Triton and Phanh Rang carbonate platform is located offshore south of Vietnam and covers more than 15000 km^2 (C and D in Fig. 1; Fyhn et al., 2009, 2013). These carbonate platforms continue to extend southward and also occur on the structural highs of the Nam Con Son Basin (E in Fig. 1; Lü et al., 2013). In the Central Luconia offshore Sarawak, numerous Miocene carbonate buildups have been seismically mapped (F in Fig. 1; Hutchison and Vijayan, 2010). Located offshore west of Palawan and Borneo, the Nido carbonate platforms were widely drilled and were believed to be formed upon the migrating Late Oligocene-Miocene flexural forebulge in response to the Borneo-Palawan thrust wedge (G in Fig. 1; Steuer et al., 2013).

In addition to those above mentioned, the platform carbonates isolated from the continental shelf of the South China Sea are recently receiving increasing attention, for example the carbonate platforms in the drifted Reed Bank, a fragment of rifted continent crust detached from landmass (H in Fig. 1A; Ding et al., 2014a). The carbonate platforms of the Reed Bank area were deposited in either shallow water, lagoon or open marine environment during Late Oligocene-Miocene (Ding et al., 2014b). After the cessation of the South China Sea seafloor spreading (20.5~16Ma, Barckhausen et al., 2014; Chang et al., 2015), part of these reefs continued to grow, and formed the rugged bathymetry in the Reed Bank area.

Southwest of the Reed Bank, the Zhenghe Reefs (*Tizard Bank and Reefs*), Daoming Reefs (*Loaita Bank and Reefs*), Zhongye Reefs (*Thi-Tu Reefs*), Jiuzhang Reefs (Union Bank and Reefs), and Shuangzi Reefs (North Danger) are the Holocene active reefs in the northern part of the Dangerous Grounds (Fig. 4). Among them, Taiping Island in the Zhenghe Reefs is perhaps the most significant in this area for its size. However, because of long-lasting territorial claims among surrounding countries and the great distance from Taiwan, field investigations of Taiping Island have been difficult to perform and the regional depositional evolution during the Late Oligocene-Miocene is not well studied.

2.3. The geology of Taiping Island

Taiping Island, also known as Itu Aba Island, is the largest natural landmass among the Nansha Islands (also known as the Spratly Islands) in the northern part of the Dangerous Grounds (Fig. 2) and is covered by bioclastic sediments. A fully cored borehole that is 523.35 m in

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