Seismic Characteristics and Development Patterns of Miocene Carbonate Platform in the Beikang Basin, Southern South China Sea

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Abstract: The Beikang Basin is located in the southern part of the South China Sea (SCS), which is one of most tectonically complex sea areas. It is a deepwater sedimentary basin that was mainly deposited during the Cenozoic era. Owing to data restrictions, the research on carbonate platforms of this area is still in its infancy. High-resolution seismic data are analyzed to identify the Miocene carbonate platforms and reconstruct the architecture and growth history. The carbonate platforms of Beikang Basin began to develop in the Late Oligocene-Early Miocene, were extended in the Middle Miocene, and declined in the Late Miocene. The carbonate platform mainly developed during two periods: the Oligocene to the Early Miocene, and the Middle Miocene. The carbonate platforms that developed in the Middle Miocene were the most prosperous. The Middle Miocene carbonate platform in the Beikang Basin can be divided into three stages. In the first stage, the platforms had wide range which were thin. During the second stage, the platforms had a smaller range that was controlled by faults. In the third stage, the platforms were gradually submerged. The platform structure developed in the Middle Miocene at the Beikang Basin was controlled by the rate of rising/falling of the sea level and the carbonate growth rate. Based on an analysis of these changes and relationship, the platform can be divided into several patterns: retrogradation, submerged, aggradation, progradation, outward with up-stepping, outward with down-stepping, and down-stepping platforms. At the top of the carbonate platforms in the Beikang Basin a set of carbonate wings or mushrooms usually appeared. These were formed during a period of relative sea-level decline. It is believed that the Miocene carbonate platforms in the Beikang Basin are mainly controlled by tectonic and sedimentary environments, and are also affected by terrestrial detritus.

Key words: carbonate platform, controlling factors, Miocene, Beikang Basin, South China Sea

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1 Introduction

Miocene tropical carbonate deposition was extensive in the southern part of the South China Sea. A large number of carbonate platforms developed on topographic highs that may have been inherited from block-tilting during the Eocene to Early Oligocene rifting phases (Fulthorpe and Schlanger, 1989; Wiliams, 1997; Sales et al., 1997). Various examples of carbonate platform structures and development have been described and discussed for this region, such as the Late Eocene to Early Miocene Malampaya carbonate platform (Fournier et al., 2005), the Nankang carbonate platform (Epting, 1980; Zampetti, et al., 2004; Mat-Zin and Tucker, 1999; Eduard et al., Yan et al., 2018), the Miocene carbonate platform in the Wanan Basin (Fyhn et al., 2009), and the Miocene Natuna carbonate platform (Rudolph and Lehmann, 1989; Dunn et al., 1996). More than 200 carbonate platforms ranging in size from a few to over 200 km^2 in Zengmu Basin have been widely developed. Numerous hydrocarbon reservoirs have been contained in these platforms (Epting, 1989; Zhang and Bai, 1998; Vahrenkamp 1998; Khain et al., 2004; Zampetti et al., 2004; Zhang et al., 2010, Yang et al., 2015).

The structure, evolution, and formation mechanism of the carbonate platform have been topics of great concern to scholars. In recent years, most scholars focused on the Nankang platform, also called the Luconia platform, in the Zengmu Basin and adjacent to the Beikang Basin (Menier, 2014; Eduard, 2015; Eduard et al., 2015). The carbonate platform generally develops in a relatively stable environment, and its development and evolution are comprehensively controlled by many factors such as tectonic ups and downs, paleoclimatic factors, sea-level changes, and the water environment (such as concluding temperature, salinity, turbidity, depth, and current conditions). Therefore, the process of its formation and evolution is often complicated (Lin et al., 2013). The morphology and variability of Miocene carbonate platforms in the South China Sea are a possible analogue

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to present-day carbonate platforms. Miocene and present-day carbonate platforms both exhibit platform fragmentation and contraction, which may be syndepositional and can ultimately lead to the submerging of the entire platform (Menier et al., 2014). Most Miocene Carbonate platforms may be affected by tectonic activity and eustatic variations, and have been explained as being submerged (Vahrenkamp et al., 1998; Zampetti et al., 2004; Fournier et al., 2005; Menier et al., 2014).

The Beikang Basin is a typical deepwater basin located on the southern shelf edge of the South China Sea (Fig. 1). Most of the preliminary studies were conducted on the structure, paleogeographic environment, and evaluation of oil and gas resources based on seismic data (Wang et al., 2001; Wang et al., 2002; Zhang et al., 2003; Liu et al., 2003). Nevertheless, the researches on carbonate platforms of the Beikang Basin remain scarce.

Based on detailed interpretation of high-resolution 2D seismic survey lines of about 20,000 km in the Beikang Basin, the carbonate platforms are identified, their structure characteristics are described, and the controlling factors for platform development are discussed. This study fills a gap in the research area of carbonate platforms in the Beikang Basin, and has important significance for the analysis of carbonate platform development and the prediction of carbonate reservoirs.

2 Geological Settings

The Beikang Basin is a large continental margin fractured basin located in the central part of the Nansha Sea. The area is approximately 6.2×10^4 km^2, and the main water depth ranges from 100 to 2000 m (Zhang et al., 2003). The Cenozoic sedimentary thickness exceeds 13 km. The Beikang Basin is located on the southwest edge of the Nansha Block. The northern part of the basin is in the central area of the Nansha Islands. The other three sides surround the Wanan, Zengmu, Brunei-Saba, and Nansha Trough Basins from west to east (Wang et al., 2001). The Nankang platform in the Zengmu Basin has developed more than 200 Miocene carbonate platforms of various sizes. The current carbonate platform of the Beikang Ansha in the southern Beikang Basin is a post-Miocene Nankang carbonate platform (Lü, 2012; Eduard, 2015).

Based on its geological structure and stratigraphic features, the Beikang Basin can be divided into six secondary structural units: the Western Depression, Central Uplift, Southeast Depression, Eastern Uplift, Northeast Depression, and Northeast Uplift (Wang et al., 2001; Liu et al., 2003). In the Beikang Basin, three sets of faults mainly developed: the NE-trending faults formed during the Late Cretaceous-Middle Eocene, NW faults formed during the Late Oligocene-Middle Miocene, and SN strike-slip faults formed during the Late Miocene-

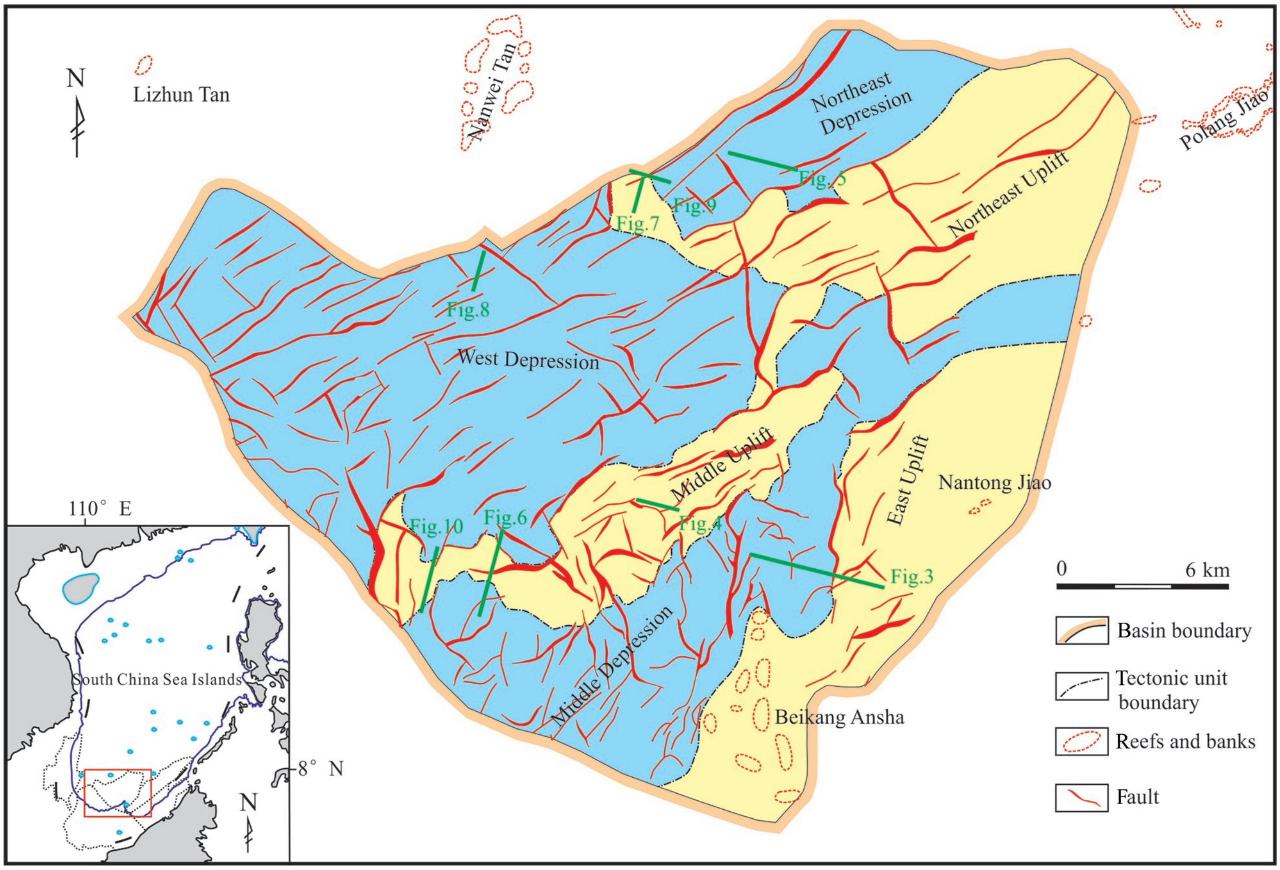

Fig. 1. Location and tectonic units of Beikang Basin in the southern part of South China Sea (after Wang et al., 2001; China base map after China National Bureau of Surveying and Mapping Geographical Information).

Location of Beikang Basin is shown in left corner. Beikang Basin is surrounded by Wanan Basin at west, Zengmu Basin at south, and Nansha Trough Basin at east. Most of Beikang Basin is in deep water (depth of deep water is over 300 m, as shown as inside blue line). Seismic section locations of various carbonate platforms in Fig. 3 to Fig. 10 are shown as green lines.

Quaternary (Wang et al., 2001; Zhang et al., 2003) (Fig. 1). The Miocene carbonate platforms in the Nansha area were controlled by fault activities during their development, which affected the distribution of reefs on the platform and the morphology of the platform (Menier, 2014).

In the seismic section of the Beikang basin, seven reflecting interfaces were identified: T_g, T_5, T_4, T_3, T_3^1, T_2, and T_1 (from bottom to top). T_3^1 is the interface of the Oligocene top, which is the fracture unconformity surface in this region. T_3 is the most obvious unconformity surface in this area, where the strata beneath the interface are strongly deformed and subjected to large-scale denudation owing to the Nansha movement at the end of the Early Miocene (Wang et al., 2002; Zhang et al., 2003) (Fig. 2). At the end of the Early Miocene, the expansion of the South China Sea ended. The Nansha Block dove southward under the Sabah Block, causing the Beikang Basin to lift integrally and enter a marina neritic environment. The carbonate platform and various reefs developed in large numbers during this period (Yang et al., 2017).

3 Data and Methods

The data used in the present research were mainly from a two-dimensional seismic survey that was acquired and processed by the Guangzhou Marine Geological Survey. The data include about 20,000 km of seismic profiles covering almost the entire basin. Most of the seismic profile spacing is 4 × 8 km, with certain spacing at 2 × 4 km in some local areas. The seismic dataset was loaded onto a Geoframe 4.5 (from Schlumberger) workstation for interactive interpretation as post-stack time migrated data (postSTM) with a zero-phase signal. Seismic processing technologies were used to improve the seismic signal-to-noise ratio and resolution before interpretation.

Seismic discontinuities and horizons were defined by the truncation, toplap, downlap, or onlap of seismic reflections. Carbonate platforms were identified and described in the seismic profiles. The architectural characteristics of each type of carbonate platform were determined and analyzed through the carbonate sedimentology and sequence stratigraphy. Architectural models were established in relation to the change rate of the sea level and the carbonate growth rate.

4 Results

At the end of the Early Miocene, the Nansha Movement

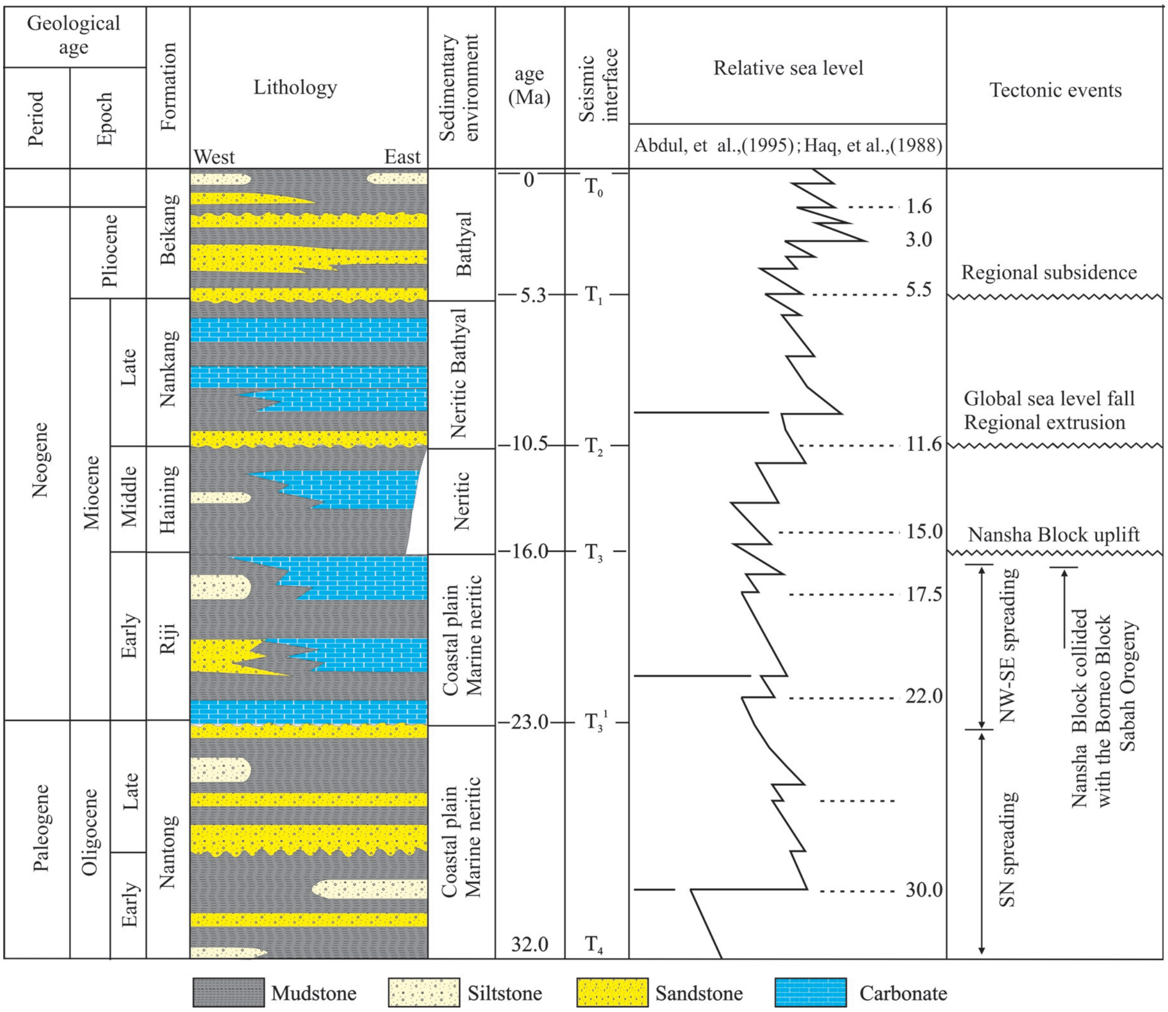

Fig. 2. Stratigraphic column of Beikang Basin in the southern part of South China Sea.
Relative sea level is from Abdul and Wong (1995), Haq et al. (1988). Tectonic events are shown according to researches on regional tectonic evolution (Hutchison, 2004; Madon et al., 2013; Li et al., 2015).

caused the Beikang Basin to rise up and enter a marina neritic environment. Most of the areas were in a semiexposed or semisubmerged state. The carbonate platforms in the Middle Miocene developed widely. In the Late Miocene, owing to rapid subsidence and a sea-level rise, the sedimentary environment in the Beikang Basin changed from a marina neritic to a bathyal or abyssal environment. Most of the carbonate platform was submerged, and a small number of platforms were inherited in fault blocks (Madon et al., 2013) (Fig. 2).

Carbonate rocks in the Beikang Basin mostly developed at the bulge or at the horst. The seismic data can provide geometrical information of the carbonate platforms, which is paramount in determining the internal architecture and facies distribution (Gregor, 2004). In the seismic section, owing to the large wave impedance difference between the carbonate formation and the overlying mudstone, the top of the carbonate shows a parallel or subparallel strong-amplitude reflection axis. The Miocene carbonate platform in the Beikang Basin shows a phased development, while the Middle Miocene carbonate platform can be divided into three phases in the seismic sections. The interface of the three phases in the seismic sections is a strong reflection axis. The platforms in the first stage have a wide range with are thin, and the carbonate mudstone is more developed. In the second stage, the platforms narrow with increased thickness, and are continuously isolated and controlled by faults. In the third stage, the platforms are further reduced until they are submerged and cease to develop (Fig. 3).

4.1 Submerged platform

When the relative sea-level rise rate is high or the carbonate growth rate is low, a submergence platform will be formed (Fig. 4). In the Late Miocene, many carbonate platforms were submerged, and global sea levels continued to decline during this period (Fig. 2). However, the main reason for submergence in the platform was accelerated post-rift subsidence (Abdul and Wong, 1995; Wu et al., 2014; Wu and Zhang, 2015). After the Middle Miocene, the subsidence and sedimentary center of the Beikang Basin shifted from the northeast to the southwest. The sedimentation rate in the southwest of the basin was higher, ranging from 300 to 460 m/Ma, and the sedimentation rate in the east was 300 to 140 m/Ma. The strong subsidence resulted in a rapid increase in the relative sea level, which eventually caused the submergence of carbonate platforms in the Beikang Basin.

4.2 Retrogradation platform

At relatively high rates of relative sea-level rise, the growth or accumulation rate of carbonate rocks at the edges of the original platforms rapidly decreased or completely stopped. Carbonate rocks or reef growth were barely in sync with the sea-level rise, and the sedimentation of carbonate rock gradually migrated into the platform with a gradually decreased range. Then, the original edge of the platform was submerged, and a retrogradation platform was formed (Figs. 4 and 5). Owing to the rapid subsidence after the Middle Miocene, the relative sea level rose rapidly. Retrogradation platforms were relatively common in this period, and most of the platforms experienced a period of retreat before they were submerged. The retrogradation platforms developed in an obvious regressive sequence.

4.3 Aggradation platform

At relatively high rates of relative sea-level rise, and the carbonate platform growth rate was consistent with or stable pursued the relative sea-level rise rate. The sedimentary environment of the platform margin and platform inner area basically remained unchanged. Carbonate deposits were given priority to vertically accumulate, and progradation did not develop, thus forming an aggradation platform (Fig. 5). In the Beikang Basin, the aggradation platform was more likely to develop at sites where the production rate of carbonate rocks was high, and the top of the platform was relatively flat, which was controlled by the local water environment. When the relative sea level rose at the same rate, different

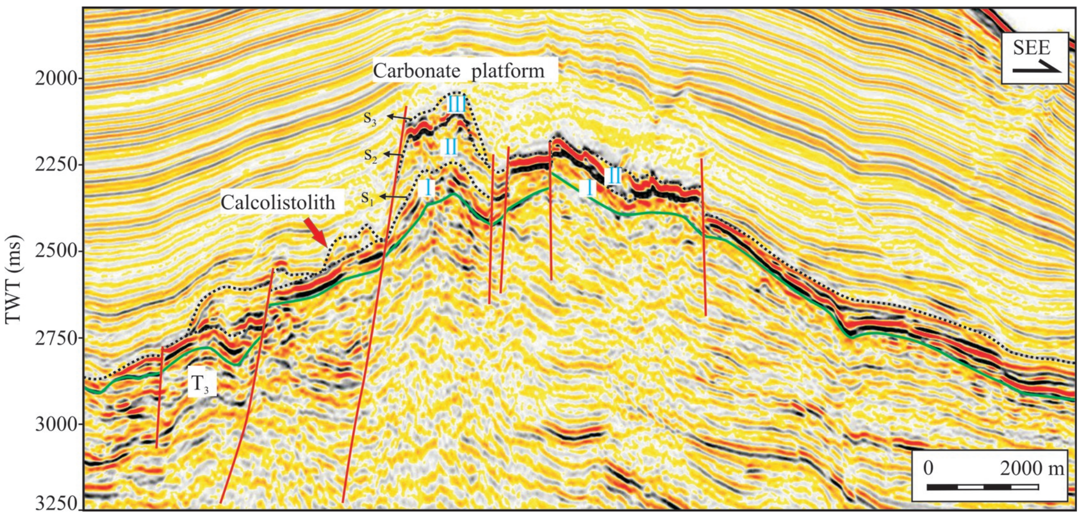

Fig. 3. Seismic profile across Middle Miocene carbonate platform exhibiting three-stage development.
T3 is top of Early Miocene, which is most obvious regional unconformity surface. Some carbonate platforms partly show one- or two-stage development. S1 is top of first-stage carbonate platform, S2 is top of second-stage carbonate platform, and S3 is top of third-stage carbonate platform.

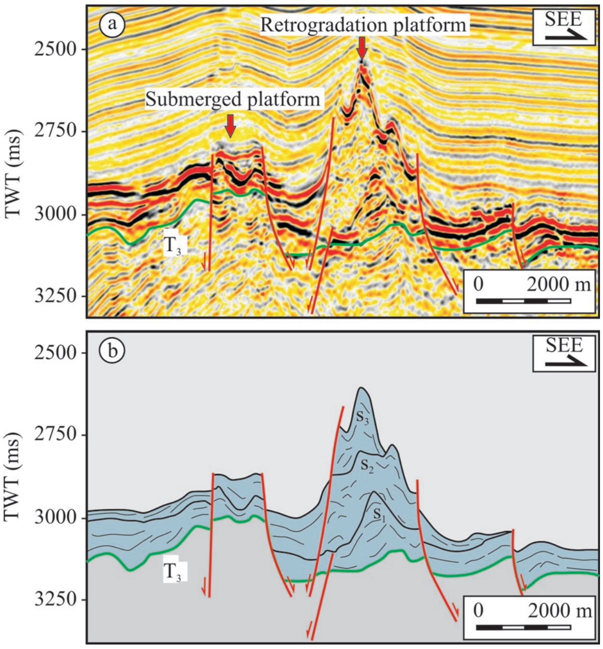

Fig. 4. (a) Seismic profile and (b) interpretation showing Miocene submerged platform and retrogradation platform.

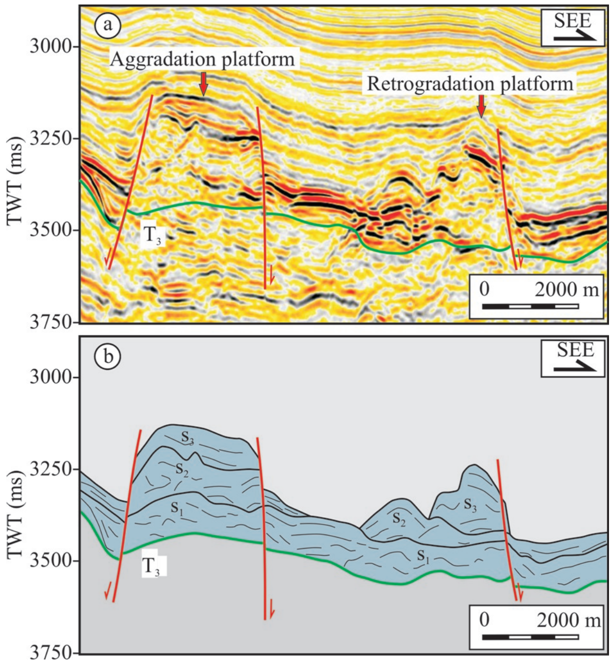

Fig. 5. (a) Seismic profile and (b) interpretation showing Miocene aggradation platform and retrogradation platform.

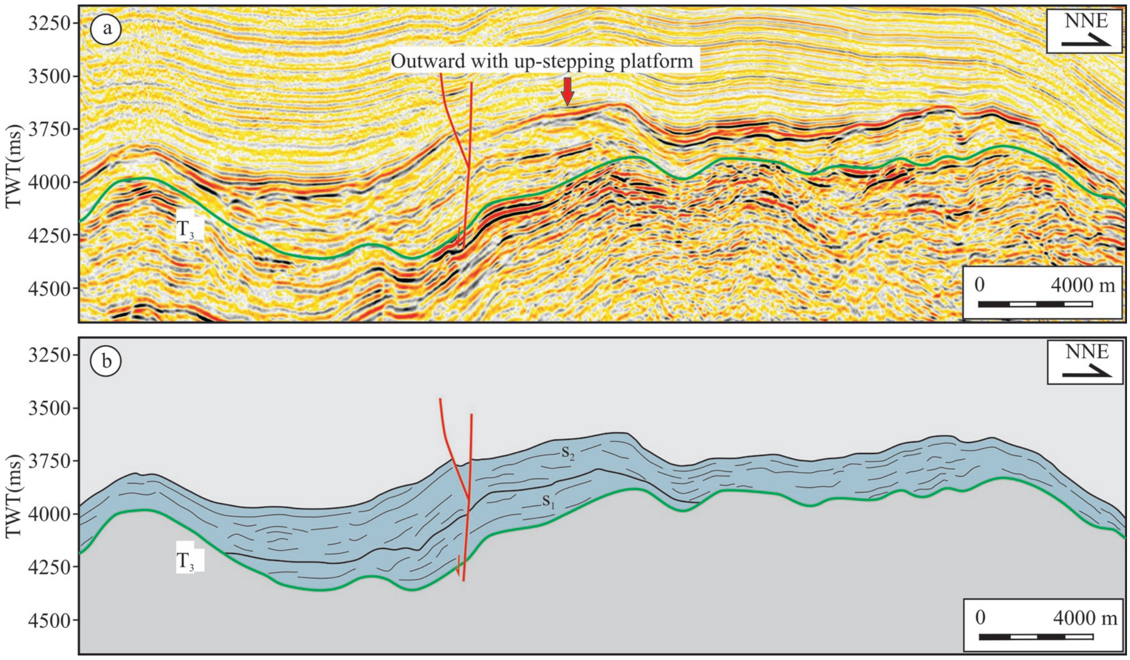

Fig. 6. (a) Seismic profile and (b) interpretation showing Miocene outward with up-stepping platform.

platform local water environments (such as temperature, salinity, and cleanliness) caused differences in the production rates of carbonate rocks at various sites, and the high growth rate of the platforms formed aggradation platforms (Fig. 5). At a low growth rate, retrogradation platforms and submerged platforms were easily formed (Figs. 4 and 5).

4.4 Outward with up-stepping platform

When the growth rate of carbonate rocks was relatively fast and slightly greater than the relative sea-level rise rate or the growth rate of the accommodated space, vertical aggradation was likely to occur in the interior of the platform, while progradation occurred at the platform edge. The aggradation and progradation increased the range of the carbonate platform, and at the same time resulted in a thick accumulation sequence of the platform, thus forming an outward with up-stepping (upward-stacking) platform (Fig. 6). In the Beikang Basin, this type of platform mainly developed on the larger uplifts farther from the continental margin, with less tectonic activity and a better water environment. In addition, the growth rate of carbonate rocks was higher, and the sea level rose steadily. At this time, the accommodating space of the platform was filled, and progradation developed. This increased the thickness of the platform and expanded the range.

4.5 Progradation platform

During the development of the outward progradation platform, the relative sea level rose slowly or did not change. In this situation, the relative sea-level rise rate was lower than the carbonate growth rate or restacking rate, and there was not enough accommodating space available on the platform for carbonate filling. In addition, excess carbonate rocks were transported toward the platform slope for outward progradation (Fig. 7). This type of platform was less developed in the Beikang Basin, and there was asymmetry at the platform edge in different directions. This may be owing to different flow or climate factors during the lateral migration of carbonate sediments. In general, the windward slopes were steeper and the leeward slopes were more gradual.

4.6 Outward with down-stepping platform

The periodicity of sea-level changes and the differences in tectonic subsidence caused relative sea-level changes. During the relative sea-level decline, especially at low water levels, some of the platform might have been exposed, while the sea level outside the platform edge became shallower. The increase in the production rate of carbonate rocks caused the original platform to expand outward and form an outward with down-stepping platform (Fig. 8). This type of platform was less developed in the Beikang Basin with a smaller range. Because of the exposure of the platform top, this type of platform was usually eroded by atmospheric fresh water.

4.7 Down-stepping platform

When the descent rate of the relative sea level was large and the growth rate of the carbonate platform was small, a down-stepping platform was formed (Fig. 9). This type of platform formed in environments where the relative sea level declined sharply and the production rate and stacking rate of the carbonate rocks were not high. Therefore, the platform development was thin, and it was vulnerable to atmospheric freshwater showering and denudation. In the Late Middle Miocene of the Beikang Basin, the top of the platform formed a thin layer of carbonate rock owing to periodic sea-level drops and resembled a "wing-like" or "mushroom-like" shape. Some scholars called these "carbonate wings" or "carbonate mushrooms," respectively (Eduard, 2015). The periodic fluctuation of the relative sea level made the platform edge form multiple carbonate wings (Fig. 10). These carbonate wings were likely to be the down-stepping platform that formed when the relative sea level dropped because the formation was thinner and larger than the original platform, so it was shaped like a wing or mushroom.

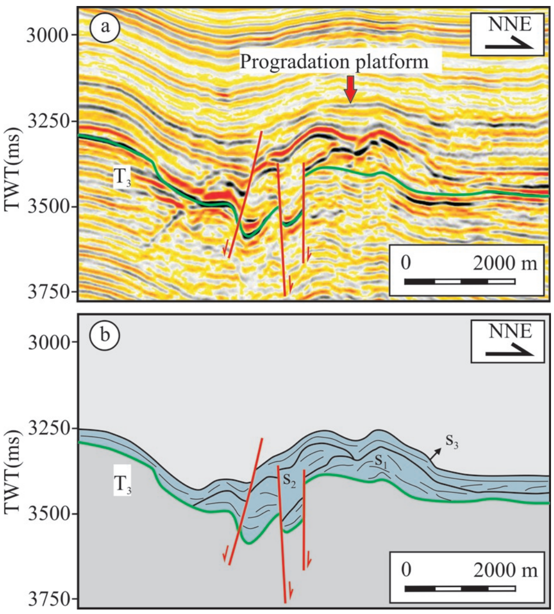

Fig. 7. (a) Seismic profile and (b) interpretation showing Miocene progradation platform.

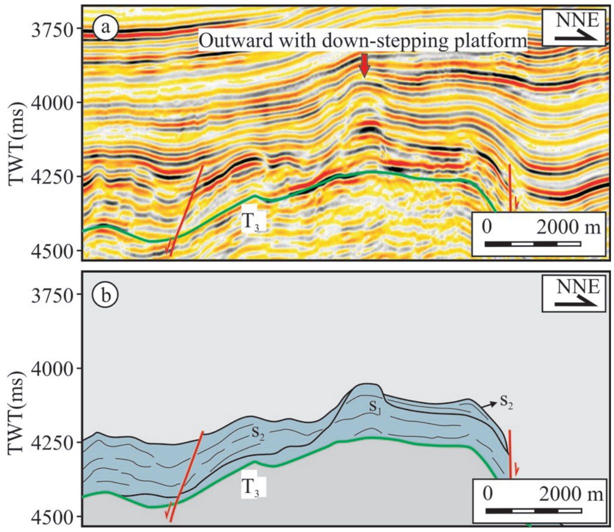

Fig. 8. (a) Seismic profile and (b) interpretation showing Miocene outward with down-stepping platform.

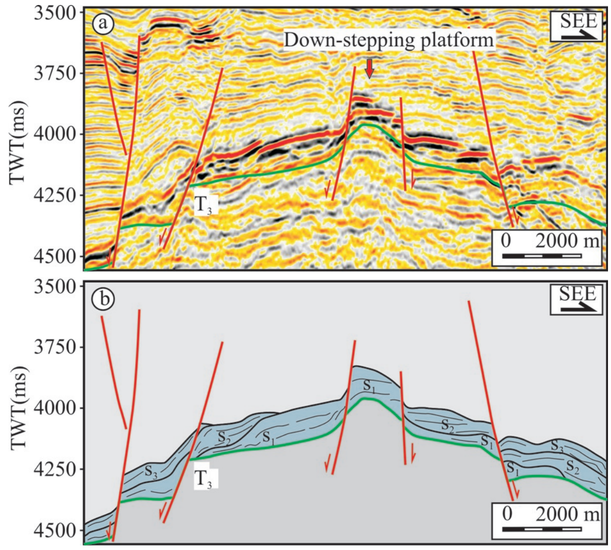

Fig. 9. (a) Seismic profile and (b) interpretation showing Miocene down-stepping platform.

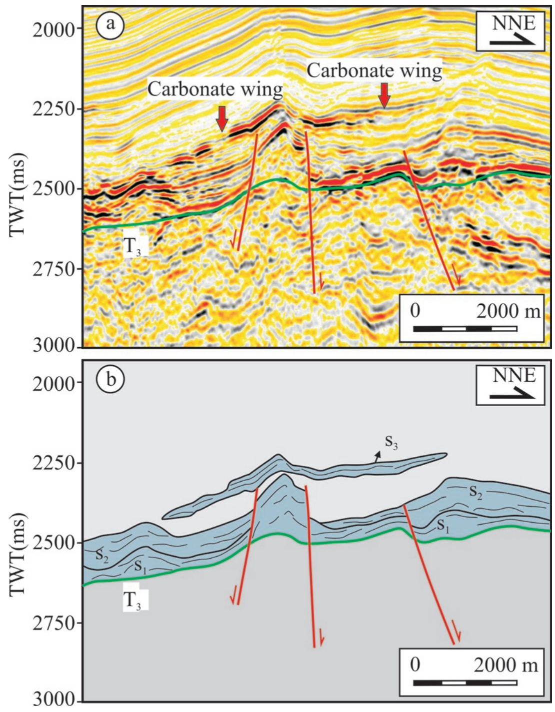

Fig. 10. (a) Seismic profile and (b) interpretation showing Miocene carbonate wings in Beikang Basin.

5 Discussions

5.1 Structure patterns

The Beikang Basin has a wide range of Miocene platforms that are mostly isolated. Based on the sequenced stacking structures developed on the platforms, these platforms can be divided into seven structural patterns that are mainly controlled by the relative sea-level change rate and the carbonate platform growth rate (Fig. 11). The relative sea-level change rate is the result of the global sea -level change rate and tectonic subsidence/rise rate. The platform growth rate is mainly related to the production rate of carbonate sediments and the amount of reaccumulation of carbonate rocks (Tucker and Wright, 1990).

The relative sea-level fell gradually with a tectonic uplift caused by block collisions as well as the expansion of the South China Sea during the Early Miocene (Fig. 2, Abdul and Wong, 1995; Haq et al., 1988; Hutchison, 2004). Generally, carbonate platforms initially developed at a low-middle growth rate during this period. In addition, some down-stepping and outward with down-stepping developed on the ridges, caused by normal faults at the northwest and middle parts of the Beikang Basin. The relative sea level began to rise at the end of the Early Miocene (Fig. 2). Simultaneously, various carbonate platforms grew rapidly and were distributed widely, mostly at a middle-high growth rate. These included aggradation (which is more distributed and could be the majority pattern in this period), outward with up-stepping, and progradation carbonate platforms. When the growth rate of carbonate platforms was relatively low, this was mainly affected by the sedimentary environment, and more submerged and retrogradation carbonate platforms developed. In particular, after the Middle Miocene, most aggradation platforms in the early period became retrogradation or submerged platforms owing to rapid increases in the water depth caused by accelerated subsidence.

5.2 Tectonic activity

There are many factors that control the development of

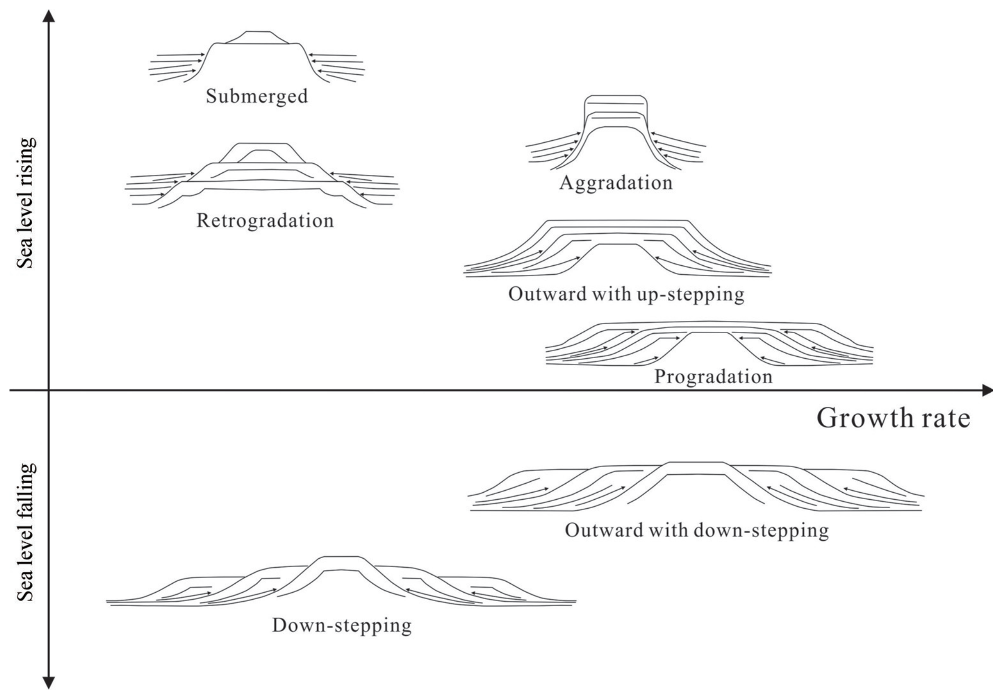

Fig. 11. Structure of Miocene carbonate platform in relation to relative sea-level change rate and carbonate growth rate in Beikang Basin.

carbonate platforms, including tectonic movement, sea level changes, climate changes, and water environment changes. These factors ultimately lead to changes in the relative sea level and the rate of carbonate rock growth, thus controlling the development of the carbonate platforms. The relative sea-level changes caused by tectonic movements and sea-level changes control the accommodating space available for carbonate rock deposition.

The Miocene carbonate platform in the Beikang Basin was greatly affected by tectonic movement. The relative sea-level changes caused by tectonic uplift and tectonic subsidence controlled the development, prosperity, and extinction of the platform. The distribution of tectonic uplifts and fractures also controlled the distribution of carbonate platforms. The tectonic evolution of the Beikang Basin can be divided into three stages: (1) initial rifting in the Paleocene-Middle Eocene (65 Ma–32 Ma), when the Beikang Basin began to form and migrated southward with the expansion of the South China Sea at the end of the Middle Eocene (32 Ma); (2) rifting-depression transition and compression uplift in the Late Eocene-Middle Miocene (32 Ma–10.5 Ma), when the basin was uplifted owing to the collision and extrusion on the Nansha Block and influenced by strike-slip activity on the Jinjar-West Baram Line, most faults stopped their activity, and a partial area began to subsidence stably with the suspension of the expansion of the South China Sea in the Middle Miocene (after 15.5 Ma); and (3) regional subsidence in the Late Miocene-Quaternary (10.5 Ma–present), when the basin was in a state of calm and relaxation with rapid sedimentation and subsidence (Zhang et al., 2003; Hutchison, 2004; Madon et al., 2013; Cullen, 2014; Barckhausen et al., 2014; Liu, et al., 2018).

5.2.1 Initial development stage

In the Early Miocene (23 Ma), the South China Sea expanded its ridge and moved southward, and the Nansha Block collided with the Cagayan Islands arc (Briais et al., 1993; Hutchison, 2004). As a result of the tectonic uplift, the water in the Beikang Basin became shallow and was in a marine neritic environment. Owing to the global warming after the Mi-1 Glaciation during the Early-Middle Miocene, low-latitude reef-building organisms flourished (Zachos et al., 2001; Wu et al., 2011). In addition, the South China Sea became warmer because of the expansion heating event caused by the upwelling of the mantle (Li et al., 2006; Wu et al., 2015). Under these favorable conditions, a carbonate platform began to develop (Fig. 2). During this period, the Beikang Basin was still in a semiexposed or semisubmerged state, and thus the development of carbonate platforms was relatively limited and thin. Unstable tectonic setting led to a lack of large-scale development of carbonate platforms. In addition, a foreland basin system developed in the southeastern part of the South China Sea owing to block collisions (Hutchison, 2004; Steuer et al., 2014; Xie et al., 2018). Carbonate platforms on the forebulge of the foreland basin system were generally developed and widespread. For example, the Liyue Basin and Zengmu Basin developed large numbers of carbonate platforms (Wu and Zhang, 2015).

5.2.2 Flourish development stage

At the end of the Early Miocene (15.5 Ma), the expansion of the South China Sea stopped, and the collisions between the blocks also gradually stagnated. The stable tectonic and sedimentary environment made the Middle Miocene carbonate reefs and platforms prosperous in the Beikang Basin (Briais et al., 1993; Hutchison, 2004; Madon et al., 2013; Li et al., 2015). Owing to changes in the sedimentary environment and sea level, the Middle Miocene carbonate platforms exhibited multiple stages of development (Fig. 3). The Middle Miocene carbonate platforms in the Beikang Basin mostly developed on stretch fault blocks formed by continental margin cracking or bulges formed by block collisions. The fault activity caused the fault blocks to rotate, and the drop disks of the faults bended and subsided, resulting in an asymmetric development of the platforms (Fig. 3).

5.2.3 Submerged stage

After the Middle Miocene (after 10.5 Ma), rapid sedimentation caused by sedimentary loading made the water depth of the Beikang Basin increase rapidly, eventually leading to the large flooding of carbonate platforms (Haq, et al., 1988; Abdul and Wong, 1995; Hutchison, 2004; Wu et al., 2014; Wu et al., 2015; Yang et al., 2017). After the Miocene, large-scale subsidence occurred in the central and western Beikang Basin, and the sedimentation rate was 300–460 m/Ma. While the settlement in the east was relatively weak, the sedimentation velocity was 300–140 m/Ma. Therefore, the carbonate platforms in the middle and western parts of the Beikang Basin were almost completely submerged, covering the shallow-sea and semimarine clastic rocks (Liu and Guo, 2003; Chen et al., 2017). While some of the eastern platforms were not submerged and showed inherited development, some of the platforms developed to the present day, including the Beikang Ansha and Nantong Jiao (Fig. 1).

5.3 Sedimentary environment

The sedimentary environmental factors that control the development of carbonate platforms mainly include the water environment and climate factors. Among these, the water environment includes nutrient salts, transparency, and the water temperature, while the climate factors include monsoons and climate-induced hydrodynamic changes. The sedimentary environment influences the type and quantity of carbonate deposits, and changes in the rate of carbonate rock growth (Schlager, 1992).

The Beikang Basin has been located in the low-latitude tropical and subtropical regions since the Miocene, so the main source of carbonate rocks is the secretion of carbonate rock organisms, and the growth and prosperity of these organisms are greatly affected by the sedimentary environment. Most of the secretory carbonates live in the light-transmitting layer, and the depth is 0–15 m. The temperature and light transmittance are most suitable for the growth of these organisms (Bosscher and Schlager, 1992, 1993; Read, 1985). Within certain water-depth conditions, waves, storms, tidal waves, or other hydrodynamic activities cause carbonate sediments to float and move to other shallow-water areas or adjacent slopes outside shallow water, thus forming a buildup on the continental shelf and the platform (Osleger, 1991; Wilson and Roberts, 1995). Therefore, the paleowind and ancient ocean currents affect the asymmetric development of the two wings of the platform, and the eutrophication of the seawater leads to the submergence of the platform (Fournier et al., 2005).

5.4 Terrigenous debris injection

The injection of terrigenous debris makes the water become turbid, eventually leading to the death of carbonate organisms and the rapid demise of the platform. Therefore, whether terrigenous debris injection is also an important factor affecting the development of carbonate platform. In the Miocene period, the southern part of the Beikang Basin was located at the edge of the continental shelf, close to the sediment source, and the development of the carbonate platform was greatly affected by the injection of terrigenous debris. The water depth in this area is shallow and subsidence is not obvious. The injection of terrigenous debris was probably the main reason for the stoppage of the platform development. In the northern and central Beikang Basin, owing to the long distance from the sediment source, the development of the carbonate platform was less affected by terrigenous debris.

Compared with the Beikang Basin, carbonate platform development in some other basins in the southern South China Sea was greatly affected by terrigenous debris injection. For example, most of the carbonate platforms on the Nankang Terrace in the adjacent Zengmu Basin are covered by siliciclastic debris from the progradational delta after the Miocene, and thus most of the platforms are submerged (Eduard, 2015). In addition, after the late Miocene in the Wanan Basin in the southwestern South China Sea, owing to a significant injection of terrigenous debris in the Mekong River, the platform stopped growing and entered a submerged stage (Lü et al., 2013).

6 Conclusions

The Miocene carbonate platform in the Beikang Basin mainly developed during two periods: Oligocene-Early Miocene and Middle Miocene. Meanwhile, the carbonate platforms developed the most prosperous in the Middle Miocene. The Middle Miocene carbonate platform in the Beikang Basin can be identified in three stages on seismic profiles. The platforms in the first stage have a wide range and are thin. In the second stage, the platforms were controlled by faults and have a smaller range. In the third stage, the scope of the platform gradually narrowed until it was submerged.

The Miocene platform structure in the Beikang Basin is determined by the rising/falling rate of the sea level and the carbonate growth rate. Based on the relationship between these two factors, the platform structure can be divided into seven major types: retrogradation, submerged, aggradation, progradation, outward with up-stepping, outward with down-stepping, and down-stepping platform. At the top of the carbonate platform, there is a set of “wing-like” or “mushroom-like” carbonate rocks, which are mostly formed during the period of relative sea level decline.

The development of the Miocene carbonate platform in the Beikang Basin was mainly controlled by the tectonic and sedimentary environments, and was also affected by the injection of terrigenous debris.

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