



Research Progress of Isolated Carbonate Platform

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ABSTRACT

Isolated carbonate platforms represent a distinct category within the morphological classification of carbonate platforms. Investigating their evolutionary processes encompassing formation, development, and demise holds significant implications for reconstructing basin tectonic evolution, restoring paleogeography, paleo-oceanographic conditions, and paleoclimate, exploring organism-environment co-evolution, deciphering celestial orbital parameter variations, and guiding hydrocarbon source rock evaluation and reservoir development. This study systematically reviews the definition and classification of isolated platforms, establishing an idealized sedimentary facies model based on Wilson's standard facies zones and modern analogs from the Great Bahama Bank. Special emphasis is placed on elucidating controlling factors and methodological approaches governing platform evolution and termination, accompanied by critical assessments of their research significance and practical applications. Notably, isolated carbonate platform research has evolved from traditional qualitative field outcrop analyses to modern multi-method quantitative-semi-quantitative approaches. The emergence of 2D/3D digital geological technologies and numerical simulation models enables three-dimensional visualization of stratigraphic frameworks and facies distribution, facilitating precise geological investigations. Future research should integrate tectonic processes, eustatic fluctuations, and paleoclimatic contexts while prioritizing carbonate producers' response to environmental fluctuations during platform evolution.

KEYWORDS

Isolated Carbonate Platform; Sedimentary Facies Model; Structural Evolution; Digital Geology; Research Methods.

1. INTRODUCTION

The carbonate platform has been studied for nearly half a century. As a term in the strict sense, it is usually defined as a 'platform' developed in the coastal-continental shelf area with flat top, steep edge and large carbonate continuous sedimentary thickness. According to its morphology, it can be divided into rimmed, non-rimmed shelf and carbonate isolated platform (Wilson, 1975; Read, 1985; Tucker, 1990; Burchette and Wright, 1992; Handford and Loucks, 1993; Wright and Burchette, 1996; Fornos and Ahr, 1997; Flügel and Munnecke, 2010; Williams et al., 2011). Although Pomar (2001), Bosence (2005) and Williams (2011) conducted genetic classification based on the types of carbonate platform sediments, basin tectonic background and relative rate of carbonate production and migration, they well solved the defects of classical morphological classification. The latter is still the mainstream classification scheme in academia.

Isolated carbonate platform is favored by geologists because of its unique morphology and geographical location, complex tectonic environment and sediment types. It refers to the type of pure shallow-water carbonate platform that is independent or isolated, generally developed on the continental shelf or the faulted continental crust or transition crust far away from the continental shelf, and surrounded by deep-water sediments (Read, 1985); Tucker & Wright, 1990; Gischler et al., 2003;

navarro et al., 2012). Studying the evolution process of its formation, development and termination for the inversion of basin tectonic evolution (Boni and Selg, 1985; bechstädt et al., 1988; mullins et al., 1991; chen et al., 2001; scheibner et al., 2001; wang Xinqiang and Shi Xiaoying, 2008; yang Huaiyu et al., 2010; hontzsch et al., 2011), restoration of paleogeography (Lehrmann et al., 2007), paleo-marine environment (Föllm et al., 1994); gischler and Lomando, 1999; husinec and Jelaska, 2006; husinec and Read, 2011; rankey and Rodrigo, 2012), Paleoclimate (Fornós and Wayne, 1997, 2006; ehrenberg et al., 2006; jorry et al., 2010; zamagni et al., 2012), exploring the co-evolution of biology and environment (Lehrmann et al., 2003; krull et al., 2004; payne et al., 2011; qiu et al., 2013), variation of orbital parameters of celestial bodies (Yang and Lehrmann, 2003; zühlke et al., 2003) and guide the reservoir evaluation and development of source rocks (Grammer et al., 2001; jones and Xiao, 2006; harris and Vlaswinkel, 2009; ronchi et al., 2010).

Throughout the development process of isolated carbonate platforms, it can be found that the research methods have gradually evolved from the traditional single field outcrop qualitative analysis to the comprehensive analysis of biostratigraphy, sequence stratigraphy, chemical stratigraphy, magnetostratigraphy, cyclostratigraphy, sedimentary facies and sedimentary environment, especially the digital geological technology (Adamset al., 2004). Zampetti et al., 2004; warrlich et al., 2008; verwer et al., 2009) and numerous 2 / 3D stratigraphic framework restoration models (Schlager, 1999; burgess and Wright, 2003; scheibner et al., 2003; paterson et al., 2006; the emergence of Williams et al., 2011) makes the research more accurate and quantitative.

On the basis of consulting many typical isolated platform data in middle and low latitudes, the author intends to introduce the generation mode and type of isolated platform, and establish an ideal isolated platform phase model according to wilson standard phase belt and Greater Bahamas Beach. Summarize the influencing factors and research methods that control the evolution and termination of isolated platforms; the research significance and application of isolated platform evolution are reviewed. Finally, the research on the evolution of isolated platform is prospected and constructive suggestions are put forward.

2. OVERVIEW OF ISOLATED CARBONATE PLATFORM

2.1. Definition and classification

Isolated carbonate platform has attracted much attention as a special type in the classification of platform morphology. It is strictly defined as an independent or isolated, developed on the continental shelf or on the faulted continental crust or transitional crust far from the continental shelf, and surrounded by deep-water sediments. Pure shallow-water carbonate platform type (Read, 1982, 1985; tucker and Wright, 1990), whose sedimentary characteristics and evolution are very different from those of the attached carbonate platform (Gu, 2009).

The isolated platform can be divided into three categories according to its genesis: 1) It is related to the pillow uplift of the seabed formed by the salt dynamic bottom splitting (García-Mondéjar, 1990; bosence, 2005; navarro et al., 2012), which is generally found in the environment of intra-oceanic rifts, passive continental margins and foreland basins, and is mainly controlled by the rise and fall and dissolution of the bottom-cut salt bodies (Brun and Fort, 2011); 2) It is closely related to the volcanic uplift formed by submarine volcanic eruption (Vera et al., 1997; bosence, 2005), which is characterized by carbonate rocks overlying contracted submarine volcanic rocks, generally forming atolls and surrounded by deep water; 3) It is the result of continental margin stretching, fracture, tilt, rotation, and basin slip, and is controlled by sea level changes (Bosence, 1998a, 2005; li et al., 2012; navarro et al., 2012), mainly found in the passive continental margin environment, which is not too far from the continental shelf and is limited by deep faults. Because the last type of isolated platform involves basin evolution. The tectonic background is of great significance, so this paper mainly aims at this kind of platform.

Due to the inherent imperfection of the classification scheme of carbonate platform morphology (Wilson, 1975; read, 1985; erlich et al., 1993; bosence, 2005) and the expansion of definitions (Wilson, 1975; read, 1985; tucker, 1990; pomar, 2001), which makes the isolated platform have symmetry and asymmetry in morphology, as well as the difference between rimmed and non-rimmed. It can be divided into four types: rimmed symmetric isolated platform, non-rimmed symmetric isolated platform, rimmed asymmetric isolated platform and non-rimmed asymmetric isolated platform(Fig. 1).

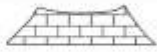
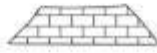
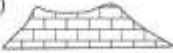
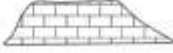
symmetry	Bentness	Isolated platform type	example	profile morphology
symmetry	edging	Edge symmetry	Sahul shelf(Wienberg et al. 2010) Belizean atolls(Gischler et al.2000) Phanh Rang(Fyhn et al.2009)	
	Non-trimmed	Non-rimmed symmetry	Zineir Kaya(Pomar et al.2012)	
dissymmetry	edging	Unsymmetrical ribbed edge	Galala Mountains(Scheibner et al. 2001) Bahamas(Bergman et al.2010) Latemar Massif(Egenhoff et al. 1999)	
	Non-trimmed	Non-rimmed asymmetry	Rakony Mountains(Haas, 1999)	

Fig. 1 Isolated carbonate platform morphology classification scheme

2.2. Ideal sedimentary facies model

The most representative isolated carbonate platform in the world is Great Bahama Bank, which is a rimmed asymmetric platform. It has been widely studied since the 1850 s, and many geological phenomena and theories have been discovered and established. Among them, the sedimentary facies model has become a scale for the study and application of isolated carbonate platforms in middle and low latitudes. By reading a large number of literatures, the author found that most of the isolated platforms are asymmetric, even if they are symmetrical, because they are bound to be affected by tectonic action, ocean current, wind direction, transgression direction and other factors in the process of development and evolution. There are some differences in the distribution of sedimentary facies and internal morphology on both sides of the platform, that is, asymmetry.

Therefore, in order to provide an ideal model (symmetrical rimmed isolated platform) that can be compared and used for reference, the author ignores the influencing factors that lead to the asymmetry of isolated platform. Referring to the Greater Bahamas model, the ideal sedimentary facies model of isolated carbonate platform was established for the first time according to Wilson (1975) standard facies belt (Fig.2).

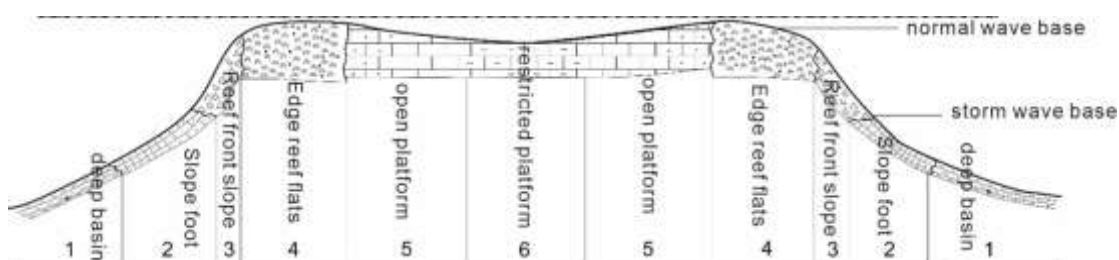


Fig. 2 Ideal sedimentary facies model of isolated carbonate platform

(1) The deep-water basin facies is located below the wave base and the transparent zone, and the water depth is several hundred meters or even more than one kilometer. Lithology is often mixed

sediments of pelagic clay, marl limestone, allochthonous granular marl and breccia, containing pelagic plankton fossils and facies bandwidth.

(2) The slope toe is below the storm wave base and close to the bottom of the aerobic interface. The water depth is between 200-300 m, and the inclination angle is generally greater than 1.5 °, which is much smaller than the slope angle in front of the reef. The lithology is mostly fine-grained carbonate containing chert, and often contains platform redeposited marl limestone. The fossils are mainly shallow-water benthic in the platform, with occasional pelagic organisms. The phase band is narrow.

(3) The pre-reef slope phase is above the storm wave base, and the dip angle is often close to vertical. The lithology is mainly shallow-water platform sediments dominated by allochthonous argillaceous limestone, conglomerate carbonate rock and breccia. The biological fossils are dominated by shallow benthic platform, occasionally containing pelagic organisms. The phase band is very narrow.

(4) The water depth of marginal reef-bank facies is generally a few meters, and the lithology is pure carbonate. It is often composed of various types of shallow water organisms, such as skeleton rock, barrier rock, bond rock and granular limestone. Sometimes it is granular beach, sorting round better calcareous bone debris particles, ooids or (like) spherulites, often composed of granular limestone and argillaceous limestone. The phase band is narrow.

(5) The water depth of the open platform generally varies from several meters to tens of meters, which is connected with the wide sea. The lithology is dominated by argillaceous limestone, granular limestone and argillaceous limestone, and large and medium-sized bedding and patch reefs are developed. The organisms are mainly shallow benthic algae, foraminifera and gastropods. Phase bandwidth.

(6) The water depth of the restricted platform is similar to that of the open platform, but the water cycle is limited, and the salinity and temperature are abnormal. The lithology is argillaceous limestone and dolomitic limestone, as well as granular limestone and cohesive rock. The biological abundance is low, which is generally dominated by gastropods and ostracods with wide salinity. Phase bandwidth.

3. INFLUENCING FACTORS CONTROLLING THE EVOLUTION OF ISOLATED PLATFORM

The isolated platform is mainly affected by tectonic action in the evolution process from its formation to its end (Pigram et al., 1989; Wilson, 2000; Bosence, 2005; Fyhn et al., 2009), sea level rise and fall (Betzler et al., 2012), climate change (Fyhn et al., 2009; Husinec et al., 2012), paleo-marine environment (Betzler et al., 2009); Bergman et al., 2010), detrital materials (Wilson, 2000; Fyhn et al., 2013) and carbonate factory (Pomar, 2001; Schlager, 2003; Pomar and Hallock, 2008; Pomar et al., 2012). For a specific research object, only one or several factors may play a leading role, and there is a coupling relationship between them (Eberli, 1991).

3.1. Tectogenesis

The tectonic action is an important factor affecting the development and evolution of the isolated platform. In a sense, it is the fuse of the birth and end of the isolated platform. For example, Bosence (2005) classified the carbonate platform on the basis of tectonic setting. Scheibner (2001) believed that the isolated platform of the Galala Mountains in Egypt was formed by the previous tectonic uplift. Through the study of the Tonasa platform, Wilson (2000) believed that tectonic volcanism was the main controlling factor for the gradual termination of the platform.

In the process of isolated platform development, tectonic uplift events often cause relative sea level decline, resulting in platform exposure and karstification (Ehrenberg et al., 2006; Fyhn et al., 2009), carbonate stopped production (Fig.3A, B); the tectonic subsidence event caused the relative sea level rise and the carbonate factory changed. If the production rate was less than the rate of sea level rise,

the platform was gradually submerged (Fig. 3D, E) (Eberli, 1991; Lehrmann et al., 2007). In addition, uneven subsidence within the platform can also lead to differences in sedimentary thickness (Fig. 3F, $h_1 > h_2$), sedimentary facies and stratigraphic framework in different regions (George et al., 2009; Li et al., 2012); the platform margin collapses due to the development of syndepositional faults that usually control the edge morphology and stratigraphic framework (Fig. 3G, black arrows) (Mullins et al., 1991; Lü et al., 2013).

3.2. Sea level eustasy

Sea level change events in the global and large regional context are also important factors controlling the development and evolution of isolated platforms, which are often associated with (inter) glacial periods (Wright, 1992; Ruppel and Ward, 2013), changes in Earth orbit parameters (Wright, 1992; Yang and Lehrmann, 2003), regional or global tectonic events (Fernandez-Mendiola and Garcia-Mondejar, 1997) and paleo-marine environment (Lü et al., 2013) have coupling relationships.

Similar to the relative sea level change caused by tectonic uplift and subsidence: when the sea level rises, the isolated platform shrinks, and the platform edge reef retreats into the platform (Fig. 3D, E) to maintain the growth rate close to the sea level rise rate. If the period is accompanied by pressure such as the deterioration of the ancient marine environment, the carbonate production rate will gradually decrease, which will lead to the inundation of the platform (Babek et al., 2007). On the contrary, long-term platform exposure and karstification caused by sea level decline can also terminate the development of isolated platforms (Fig. 3A, B). In addition, during the period of frequent global and regional tectonism, the development of isolated platforms is usually controlled by tectonic uplift and sea level (Lü et al., 2013); however, in a stable tectonic setting, Husinec and Jelaska (2006) studied the carbonate strata from the Upper Jurassic to the Lower Cretaceous in the Adriatic isolated platform and found that sea level rise and fall is the main controlling factor of sedimentary facies accumulation pattern in the platform.

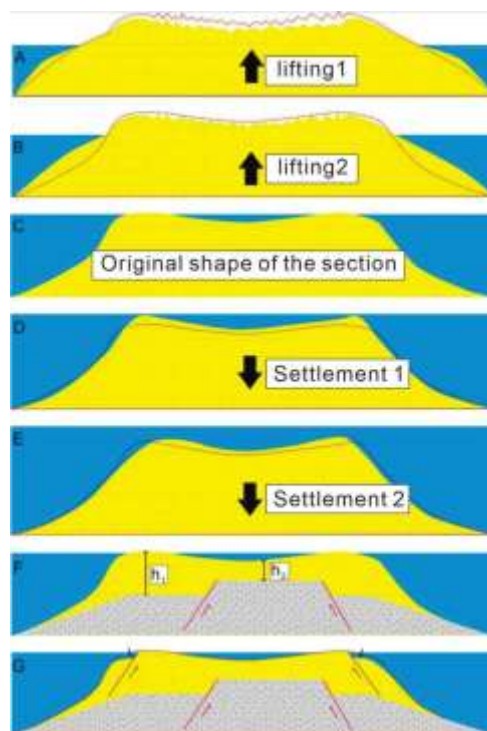


Fig. 3 The sedimentary response diagram of isolated platform to different tectonic processes

3.3. Climate change

The influence of climatic cold and warm factors composed of glacial and interglacial periods on the development and evolution of carbonate platforms by controlling sea level rise and sea surface temperature has attracted more and more attention from geologists (Wright, 1992; Barnett et al., 2002; Yang and Lehrmann, 2003; Ruppel and Ward, 2013), which is intrinsically linked to changes in Earth's orbital parameters (Wright and Vanstone, 2001; Gatt and Gluyas, 2012).

A large number of studies have shown that there are many differences in sequence cycles and sedimentary accumulation patterns between the glacial and interglacial periods on the carbonate platform (Wright, 1992; Barnett et al., 2002; Yang and Lehrmann, 2003). The glacial period caused by the change of the Earth's eccentricity can lead to the rapid and high-amplitude rise and fall of the sea level (such as the Visean period of the Devonian) (Paterson et al., 2006). The cyclic strata are characterized by high frequency (known as the fourth-order sequence or high-frequency sequence). The thickness is generally between 2-30 m, dominated by subtidal cycles, and often ends at the top of the sequence with an exposed surface (Wright, 1992; Barnett et al., 2002); in the interglacial period, the cyclic strata are dominated by the Milankovitch cycle (or Milankovitch cycle), and the continuity of the strata is more complete than that of the glacial period, which is characterized by asymmetric upward shallowing sequence (rare symmetrical sequence), and the top of the sequence often develops retrograde microbial laminae (Wright, 1992). Yang and Lehrmann, 2003; Husinec and Read, 2011).

3.4. Paleo-ocean environment

The favorable paleo-marine environment can provide favorable factors for the development of carbonate platform, which mainly includes the sea surface temperature (Isern et al., 1996; Mutti and Hallock, 2003; Bergman et al., 2010), salinity (Bergman et al., 2010; Husinec and Read, 2011), nutrients (Mutti and Hallock, 2003), wind (Minero, 1991) and ocean currents (Betzler et al., 2009; Betzler et al., 2012; Reijmer et al., 2012).

Seawater surface temperature and nutrients (referring to inorganic nutrients such as nitrogen and phosphorus necessary for shallow water biological life activities) mainly affect carbonate production rate and particle type through carbonate factories. Jams (1997), Mutti and Hallock (2003) found that

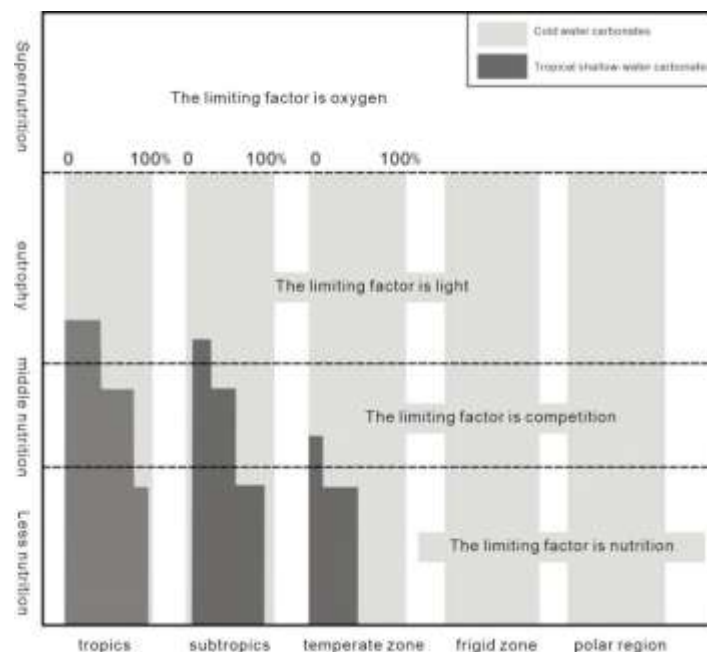


Fig.4 Distribution of tropical shallow / cold water carbonates based on temperature and nutrients (Mutti and Hallock, 2003).

Photozoan carbonates are mainly distributed in the west coast of tropical and subtropical ocean basins (Fig.4), while Heterozoan carbonates are found in high latitudes or polar regions, low temperature zones on the east coast of ocean basins (Fig.4), or areas where ascending ocean currents (rich in nutrients) are prevalent. Isern et al. (1996) studied the response of carbonate platforms and corals to sedimentary types of different temperature zones in the Queensland Plateau in northeastern Australia since 10 Ma. It is believed that temperature, as a non-negligible factor, is an important prerequisite for controlling the spatial and temporal distribution of carbonates. In addition, their study also shows that the growth rate of corals decreases rapidly below 24 ° (lower than the long-term sedimentation rate) and eventually leads to the submergence of the platform edge.

Lees (1975) studied the continental shelf carbonate between 60 ° N and 60 ° S, and considered that temperature and salinity may have a superposition effect, which is explained by the S.T.A.R. partition map: that is, in different zones in the map (representing different ranges of salinity and temperature), the types of sediment assemblages are also different. Husinec and Read (2011) also separately analyzed the effect of salinity on the Milankovitch cycle during the interglacial period, and believed that the Milankovitch cycle with microbial lamina as the top was formed in the shallow water with gradually increasing salinity under semi-arid conditions. In a humid, normal or brackish environment, the microbial lamina at the top of the cycle layer is often drilled and rooted by passive plants to form a special bioturbation layer.

The influence of wind on carbonate platform is mainly through two ways: one is the influence of waves generated by wind on the edge and interior of the platform, and the other is the influence of rising ocean current generated by monsoon on the edge of the platform. In the windward edge of the platform, the impact of wind and waves can produce acyclic vertical sequence, but in the reef environment, due to the protection of marginal reefs, limited asymmetric upward shallowing sequences are often developed, and it is the place where muddy materials are most likely to accumulate (Minero, 1991; egenhoff et al., 1999). The nutrients carried by the upwelling caused by the summer monsoon can lead to the development of cool-water carbonates (Reijmer et al., 2012) on the carbonate platform in tropical shallow water, which reduces the productivity of carbonates and leads to the phenomenon of accretion and gradual retreat (submergence) on the edge of the platform (Betzler et al., 2009; betzler et al., 2012).

3.5. Fragmentary material

Detrital materials can be divided into terrigenous siliceous debris and volcanic debris, both of which are important factors affecting the production rate of carbonate factories and sequence development (Wilson and Lokier, 2002). (1) The excessive physical burial of detritus causes the death of most unescapable carbonate producers, thus changing the production mechanism of carbonate factories and reducing the production rate; 2) In the case of a certain water depth, the increase of debris suspended solids reduces its visibility, resulting in the overall upward movement of the producer combination; 3) The input of debris flow often changes the chemical environmental conditions of seawater, such as reducing salinity, fluctuating PH value, and increasing nutrients, which will destroy the ecology of producers. Although the input rate and frequency of detrital flow, the size of detritus and the abundance of nutrients are different, the mechanism of terrigenous siliceous debris and volcanic debris affecting the development of carbonate platform is similar, and their large input often leads to the gradual inundation of isolated platform (Wang Xinqiang and Shi Xiaoying, 2008; yang Huaiyu et al., 2010; lu Gang et al., 2013).

3.6. Carbonate factory

The carbonate factory was proposed in the 1990 s. It is a dynamic system that points out that the space and process of carbonate production are controlled by biology and environment in a certain range of seawater depth (Schlager, 2003). Wright and Burgess, 2005). Since the carbonate factory is a

continuous system (Wright and Burgess, 2005), Schlager (2000, 2003) started from the environment, mode and sedimentary framework of carbonate production. Three types of end-member benthic carbonate factories since the Phanerozoic are summarized: tropical shallow-water factory, cool-water factory and mud-mound factory (also called benthic automicrite factory, Pomar and Hallock, 2008).

The mechanism, type and rate of carbonate production in the three end-member carbonate factories are different. Under the restriction of certain water kinetic energy conditions (representing the migration of carbonate sediments), it is bound to affect the development and evolution of carbonate platforms. Pomar (2001a, 2001b) proposed the concept of "ecological space," which refers to the ability of carbonates to grow upward above the hydrodynamic base level. It is closely related to the size, type, production rate of carbonate factories, the development and evolution of organisms, and the physical and chemical conditions of seawater. Through the study of different types of carbonate platforms in the Mediterranean region, it is found that the sedimentary profile, the distribution of sedimentary facies and the internal framework of the platform are controlled by the production and migration of carbonates (Pomar, 2001a; pomar et al., 2012).

Numerous studies have shown that tropical shallow-water carbonate factories are generally associated with flat-topped rimmed platforms (Schlager, 2003), while cold-water carbonates are prone to form carbonate ramps (Pomar, 2001a; pomar et al., 2012), and the lime mud mound carbonate factory prevailed after the mass extinction. It often produces lime mud mounds on the platform or continental shelf slope, and when it grows to the wave base surface, it is no different from the flat-topped rimmed platform (Schlager, 2003). In addition, high-frequency and low-amplitude sea level changes tend to increase the inhomogeneity of flat-topped rimmed platforms associated with tropical shallow-water carbonate factories, while the carbonate ramps generated by cold-water carbonate factories are just the opposite (Poamr et al., 2012).

Therefore, the development and evolution of carbonate platforms, including isolated platforms, are not only controlled by factors such as tectonics, global sea level changes and paleoclimate, but also focus on the synergistic control of carbonate producers and the environment.

4. RESEARCH METHOD OF ISOLATED PLATFORM EVOLUTION

4.1. Selection of research object

The isolated platform covers four important components: interior, margin, flank / slope and basin. Different research objects reflect different directions or advantages of the evolution of isolated platforms. For example, the slope of the platform edge can more accurately reflect the change of sea level in the low water level period or the late high water level period than the inside of the platform (Scheibner et al., 2001; qiu et al., 2013), and the high-frequency low-amplitude fourth-order or fifth-order sea level changes are superior to the former (Yang and Lehrmann, 2003; zühlke et al., 2003; husinec and Jelaska, 2006). However, there are many factors controlling the development and evolution of isolated platforms, and most of them have coupling relationships. Therefore, the author believes that it is best to conduct vertical and horizontal comparative studies between the stratigraphic framework and sedimentary sequences of the platform interior-edge-slope-basin.

4.2. Study means

For carbonate (isolated) platforms, the commonly used research methods in the world include sedimentary facies analysis, biostratigraphy, sequence stratigraphy, cyclostratigraphy, chemical stratigraphy and magnetic stratigraphy. In particular, the emergence of digital geological technology and many 2 / 3D numerical simulation models makes the development and evolution process of stratigraphic framework and sedimentary sequence in isolated platforms visualized, which greatly promotes the quantification of research.

4.2.1. Facies analysis

Sedimentary facies analysis is the pioneer of sequence stratigraphy and cyclostratigraphy. Its vertical arrangement and horizontal correlation can provide the most solid foundation for tracing the evolution history of carbonate platform. The traditional sedimentary facies analysis is based on the color, lithology, thickness, original sedimentary structure, organisms and their combinations of outcrop rocks (Gischler, 1994; wang Liangzhen and Zhang Jinliang, 1999; qiu et al., 2013). Since the sedimentary characteristics of different sedimentary facies have been mentioned above (Fig.2), only the differences between marginal reefs and their front and back slope facies which are difficult to distinguish are described here.

Machel and Hunter (1994) studied the reefs of the Middle-Upper Devonian from the aspects of water kinetic energy, lithology, mud crystal content, porosity, biological assemblage and facies fossils, and established a detailed sedimentary model. It is believed that it can better distinguish the difference between the pre-reef and post-reef slope facies, although this model fails to explain a small number of reefs developed on gentle slopes related to paleotopography (Flügel and Munnecke, 2010). The figure shows that the core difference between the reef and its front and rear slope facies is the shale content (Minero, 1991; egenhoff et al., 1999), differences in pore composition and organisms (e.g. benthic foraminifera, Schafer and Senowbari-Daryan, 1981) and their assemblages.

With the study of sedimentary environment and diagenesis history, carbonate microfacies dominated by microscopic thin sections have been paid more and more attention in sedimentary facies analysis (Wilson, 1975; Flügel, 2004; Flügel and Munnecke, 2010). Flügel (1972) first analyzed the Late Triassic carbonate platform and reef sedimentary environment by using the standard of microscopic structure and biological assemblage, and was supplemented and improved by Wilson (1975) to obtain 24 standard carbonate microfacies suitable for the rimmed shelf, and finally expanded from Flügel (2004, 2010) to 26 and 30 standard carbonate microfacies suitable for carbonate ramps. Although this method is simple and practical, there are also problems. For example, a standard microfacies can appear in several or even all facies belts. Inheriting Wilson standard facies belt does not distinguish the pre-reef slope from the post-reef slope (Machel and Hunter, 1994). The distribution of microfacies types of carbonate platforms with different sedimentary models is also different.

Therefore, the author suggests that the sedimentary facies analysis should be combined with the macroscopic characteristics of the field, the microscopic identification of the indoor thin section and the chemical index.

4.2.2. Biostratigraphy

Biostratigraphy is a science that studies the evolution and development history of paleontology and its spatial and temporal distribution. In the study of the evolution of isolated carbonate platforms, one or more fossils are often used to determine the depositional age of the strata (Lehmann et al., 2000; chen et al., 2001; scheibner et al., 2001; husinec et al., 2012; qiu et al., 2013). However, in most cases, it is used to judge the change of sedimentary environment, especially some organisms that are very sensitive to the environment, such as macrobenthic foraminifera (Gischler et al., 2003). Fugagnoli, 2004; bassi, 2005; hontzsch et al., 2011; zamagni et al., 2012) and coralline algae (Bassi, 2005).

In addition, since carbonates are mainly biogenic (Flügel, 2004, 2010), the evolution of carbonate producers related to the development and evolution of carbonate platforms and their response to environmental changes have received increasing attention from geologists (Pomar, 2001a; pomar, 2001b; pomar et al., 2012). Pomar (2001a) and Pomar et al. (2012) proposed the biological assemblages related to the light band according to the division of water depth and light band. Through the study of the producers of carbonate platforms in the Miocene Balearic Island and other Mediterranean areas, he believed that the ecological changes were the main factors controlling the morphological evolution of carbonate platforms (Pomar, 2001b; pomar et al., 2012). Therefore,

excluding the influence of tectonic and volcanic factors, the study of biostratigraphy led by carbonate producers can provide a new perspective for uncovering the evolution history of carbonate platforms.

4.2.3. Sequence stratigraphy

Sequence stratigraphy based on sedimentary facies plays an important role in the study of (isolated) carbonate platform evolution. The commonly used sequence stratigraphic units include third-order sequence, high-frequency sequences and meter-scale cycles (Mitchum and Van Wagoner, 1991). Lehmann et al., 2000).

The determination of the third-order sequence boundary is very important for the division of sequences (Chen et al., 2001). It is generally a maximum regression surface or unconformity surface (Qiu et al., 2013), and can also be a transition layer from a few meters to more than ten meters, and is characterized by high frequency, thinner than the average cycle of small sequences, and increased frequency of upward exposed surfaces (Elrick, 1996). Chen et al., 2001; capentier et al., 2010). There is a transgressive-regressive (T-R) cycle between sequence boundaries, and the maximum flooding surface (mfs) is often used as the boundary. The division of the third-order sequence in the isolated platform slope facies can be traced back to the third-order sea level change history (Qiu et al., 2013). If the outcrop sequence boundary (or mfs) extends widely, the sequence boundary of platform interior-edge-slope-basin can also be compared to judge the evolution process of platform morphology (Elrick, 1996; lehmann et al., 2000).

For high-frequency sequence and meter-scale cyclic sequence, if the tidal margin cyclic sequence accounts for a large proportion, it can often judge the change of accommodation space dominated by long-term ground subsidence and high-frequency fluctuation of sea level (Elrick, 1996; chen et al., 2001; capentier et al., 2010), and often described in Fischer plots (Sadler et al., 1993; chen et al., 2001; capentier et al., 2010).

The Fisher diagram is a method that uses the number of small cycles (at least 50) as a variable to express the curve of the cumulative thickness of small cycles deviating from the average cycle thickness, and can reflect the vertical accumulation pattern of sedimentary facies and the long-term accommodation space change (Sadler et al., 1993; chen et al., 2001). If the thickness of minor cycles exceeds the average thickness, positive deviation will occur, representing the increase of long-term accommodation space, and vice versa (Sadler et al., 1993; chen et al., 2001). However, the premise of its use is that the small cycle must be topped by an upwardly shallowing exposed surface, while the upwardly shallowing subtidal cycle can only reflect the minimum value of the long-term spatial variation (Capentier et al., 2010).

4.2.4. Cyclic stratigraphy

The basis of cyclostratigraphy is based on Milankovitch 's theory (Ding, 2006; shi Guangyu and Liu Yuzhi, 2006). The core of this theory is that the glacial-interglacial cycle period is 2 to 100,000 years, and its period is related to the period of the Earth 's orbital eccentricity (period of 400,000 years and 100,000 years) (Paterson et al., 2006), the yellow-red angle (period of 41,000 years) and the precession (period of 19,000 to 23,000 years) (Shi and Liu, 2006).

The most typical Milankovitch cycle recognized so far is found in the Latemar limestone of the Middle Triassic dolomite mountain in northern Italy (Goldhammer et al., 1987; preto et al., 2001; zühlke et al., 2003; meyers, 2008). It has a 1: 5 cyclic stacking pattern, that is, five small upward-shallowing cycles form an upward-thinning sequence and are interpreted as the superposition of the Earth 's orbital eccentricity on the precession (Zühlke et al., 2003). However, this theory is faced with defects such as the lack of precise age constraints (Preto et al., 2001; zühlke et al., 2003; meyers, 2008).

Cyclostratigraphy is of great significance for explaining the influence of high-frequency sea level fluctuations caused by changes in Earth 's orbital parameters during the interglacial period on the development and evolution of (isolated) carbonate platforms (such as sedimentary facies

accumulation patterns and internal stratigraphic frameworks). In addition, it also excludes the possibility of disturbance of carbonate platforms by structural and environmental factors.

4.2.5. Chemical stratigraphy

C, O, Sr isotopes, rare earth elements (REE), major and trace elements (such as K, Ca, Mg, U, Th) and other chemical analysis are more and more widely used in the study of carbonate platform. To some extent, it has become a stratigraphic division and correlation (Kürschner et al., 1992; Babek et al., 2007), event deposits (Veizer et al., 1997; Azmy et al., 2009), paleogeographic evolution (Nothdurft et al., 2004; Armendariz et al., 2008), paleo-marine environment (van Geldern et al., 2006), paleo-ocean chemical composition evolution (Webb and Kamber, 2000; Nothdurft et al., 2004).

The C, O and Sr isotopes of carbonates have been a research hotspot in recent years. They are not only used for stratigraphic division and correlation and event studies (such as mass extinction, anoxic events, marine thermal events, etc.) (Kürschner et al., 1992; Babek et al., 2007) were also used to study the co-evolution of environment and organisms related to sea level changes (Korte et al., 2004). Rare earth elements (REE) are often targeted at some fossil shells (such as brachiopods, conodonts, etc.), nodules (flints) or microbial rocks. After excluding the influence of late diagenesis and terrigenous debris, they can reflect the chemical evolution history of ancient seawater during the development of carbonate platforms (Webb and Kamber, 2000; Nothdurft et al., 2004). The content of K and Th is related to the content of siliceous debris. After the carbonate platform is submerged, the values of K and Th will increase. This feature is often used in the comparison of platform strata and the indication of paleoenvironment (Babek et al., 2007). U is associated with the diagenesis of organic matter and phosphate. When the platform is exposed, U is enriched due to groundwater activity, which often corresponds to or below the submerged unconformity surface (U is an easy-to-migrate element). In addition, the Mg / Ca ratio is also an important chemical indicator, which has been shown by geologists to be a direct factor controlling the deposition of bone and non-bone debris particles and the activity of carbonate producers (Pomar and Hallock, 2008).

4.2.6. Magnetostratigraphy

In recent years, magnetostratigraphy based on magnetic susceptibility has been widely used in the stratigraphic division and correlation of (isolated) carbonate platforms, which mainly reflects the changes of sedimentary environment (Zhang Shihong et al., 1999; da Silva and Boulvain, 2006; Mabilille and Boulvain, 2007; da Silva et al., 2009).

The magnetism of carbonate rocks is generally weak, but the change of magnetic susceptibility can be related to the sea level change related to the input of terrigenous debris. In the transgression stage, seawater dilutes the concentration of magnetic minerals, and the magnetic susceptibility is negative. A large number of detrital materials enter the seawater during regression, resulting in an increase in the concentration of magnetic minerals and a positive bias in magnetic susceptibility (Zhang et al., 1999). Da Silva and Boulvain, 2006). In addition, studies have shown that in a limited environment (such as a lagoon environment), the production of ' bacterial magnetite ' (bacterial magnetite) increases, resulting in an increase in the content of magnetic minerals, and the magnetization rate will also be positively biased (McNeill et al., 1988).

Da Silva et al. (2009) also compared the magnetic susceptibility of the coastal carbonate platform and the isolated platform in the same period, and found that the magnetic susceptibility of the former was positively biased during the regression, while the latter was just the opposite. The magnetic susceptibility of the former gradually increases from the adjacent sedimentary facies to the upward shallowing sequence, while the latter decreases. Therefore, there are three main factors affecting the magnetic susceptibility of carbonate: 1) terrigenous debris input will lead to an increase in magnetic susceptibility; 2) High carbonate yield and water kinetic energy environment are not conducive to the deposition of magnetic minerals; 3) Later diagenesis will homogenize the magnetic susceptibility.

4.2.7. Simulation of stratigraphic framework

Due to the increase of deposition rate and the decrease of sediment transport rate, the carbonate strata will be incomplete (manifested as the presence or absence of sedimentary 'cracks' and weathering erosion unconformity in the strata) (Burgess and Wright, 2003), coupled with the incomplete outcrop of the field profile and the complexity of the internal framework (Scheibner et al., 2003; Adams et al., 2004; Verwer et al., 2009), which makes it very challenging for people to fully and accurately understand the evolution process of (isolated) carbonate platform. In a sense, it can be said that it is impossible. Fortunately, with the advent of digital geological techniques and numerous 2 / 3D stratigraphic numerical modeling models, the study of (isolated) carbonate platforms has become more accurate and quantitative (Burgess, 2001; Paterson et al., 2006; Warrlich et al., 2008; Burgess, 2011; Amour et al., 2013).

The existing stratigraphic simulation models can be divided into forward model and inversion model (Scheibner et al., 2003). The forward model is to input a series of parameters (including the accommodation space controlled by sea level and tectonic subsidence, carbonate production, migration and original sedimentary topography) to simulate the sedimentary process, and then the output results correspond to the actual field data. The inversion model uses the forward model to simulate a specific result (Scheibner et al., 2003).

From the perspective of the development process of stratigraphic simulation, the previous models basically simulated the two-dimensional sedimentary process of the whole basin or part of the basin for the purpose of oil and gas exploration, and then added the time scale to form a 'three-dimensional' model (Blendinger et al., 2004). With the emergence of digital geological technology (such as LIDAR, DGPS, satellite images, etc.) (Warrlich et al., 2008), three-dimensional simulation with different purposes has emerged. It is a static simulation technology that restores the state of carbonate platform as much as possible (such as tectonic faults, stratigraphic rotation, three-dimensional geological morphology, etc.) (Blendinger et al., 2004). They lay the foundation for accurate quantitative research.

However, some scholars believe that the distribution patterns reflected by different stratigraphic levels are not the same, and the simulation should be based on different scales (Falivene et al., 2006; Amour et al., 2013). They called for the combined use of simulation models of different scales of carbonate strata to achieve more accurate research.

The author believes that simulation is based on different uses and can be flexibly selected. For example, it is obviously unnecessary to study the scale of oil and gas exploration and to use small-scale simulation models. In addition, the simulation should also respect the first-hand geological data in the field, and it is unreasonable and unscientific to blindly apply the model.

5. THE SIGNIFICANCE AND APPLICATION OF STUDYING THE EVOLUTION OF ISOLATED PLATFORM

As mentioned above, the stratigraphic framework of the isolated carbonate platform is complex and changeable, which determines the diversity of its research methods and research directions. While uncovering the origin, development and evolution of the isolated platform, the primary and secondary factors of its morphological evolution, paleo-marine environment, paleoclimate, tectonic process, sea level change, and paleo-seawater chemistry have also been determined. Therefore, it plays an important role in inverting the tectonic evolution of the basin, restoring the paleogeography, paleo-ocean environment and paleoclimate, exploring the co-evolution of biology and environment, and guiding the reservoir evaluation and development of source rocks.

5.1. Inversion basin tectonic evolution

As a part of the basin, the development and evolution process of the isolated carbonate platform is strictly corresponding to the tectonic evolution history of the basin (Boni and Selg, 1985; bechstädt et al., 1988; mullins et al., 1991; chen et al., 2001; scheibner et al., 2001; lu Gang et al., 2013, pending publication). The third-order and fourth-order sea level changes based on sedimentary facies and sequence stratigraphy (Qiu et al., 2013), coupled with the reflection of the Fisher diagram on the accommodation space and the comparison between the stratigraphic frameworks, can clearly reflect the history of basin evolution (Wang and Shi, 2008; yang Huaiyu et al., 2010; hontzsch et al., 2011; lu et al., 2013).

5.2. Restoration of ancient geography, ancient climate, ancient marine environment

Paleogeography, paleoclimate and paleo-ocean environment are the backing of the development and evolution of isolated carbonate platform. Unlike violent tectonic movements, volcanoes and sea level changes that can directly lead to the generation or end of the platform, they often subtly affect the development of the carbonate platform.

Comparison of stratigraphic and paleontological data and paleo-seawater chemical evolution of isolated carbonate platforms are often used to restore paleogeographic features (Webb and Kamber, 2000; nothdurft et al., 2004; lehrmann et al., 2007). The paleoclimate and paleoenvironment restoration are often related to the shape (symmetry, edging, etc.) and internal framework and accumulation pattern of the isolated platform itself, which can restore the wind direction at that time (Egenhoff et al., 1999; reijmer et al., 2012), ocean currents (Betzler et al., 2009), temperature (Mutti and Hallock, 2003), salinity (Husinec and Read, 2011) and climate change (Barnett et al., 2002); ruppel and Ward, 2013).

5.3. Exploring the co-evolution of biology and environment

Isolated carbonate platform, as a good place for biological growth and reproduction and sensitive to environmental changes, has become a hot research object to study the co-evolution of biology and environment (Lehrmann et al., 2003; krull et al., 2004; payne et al., 2011; qiu et al., 2013), and they are often associated with mass extinctions.

For example, after the mass extinction (e.g., P-T), the morphology of the tropical shallow-water carbonate platform will change from a rimmed isolated platform to a non-rimmed biological mound, and its biological type will change from shallow-water tropical organisms to microorganisms (Schlager, 2003). With the help of paleontological strata (e.g., macrobenthic foraminifera and bacillary algae) and C, O, S and other isotope methods, it can reflect the mass extinction step or recovery mode related to the environment.

5.4. Guiding the evaluation of hydrocarbon source rock development

Hydrocarbon source rock reservoirs are generally associated with third-order sea-level decline and carbonate diagenesis (Sun and Esteban, 1994; kusumastuti et al., 2002), and the carbonates formed during the transgression were denser due to compaction and resistance to atmospheric water (Sun and Esteban, 1994). Therefore, high-quality source rock reservoirs are often located below the exposed unconformity surface in the high water level stage. Therefore, it is necessary to explore the evolution process and diagenesis history of isolated carbonate platform (Ronchi et al., 2010).

Many carbonate platform numerical simulation models based on oil and gas exploration can make the source rock reservoir three-dimensional (Blendinger et al., 2004), which lays a solid foundation for guiding its development and evaluation.

6. RESEARCH TREND AND PROSPECT OF ISOLATED PLATFORM EVOLUTION

From the development process of isolated carbonate platform research, it can be seen that the research method has gradually evolved from the traditional qualitative analysis of single field outcrop to the comprehensive analysis of sedimentary facies analysis, biostratigraphy, sequence stratigraphy, cyclic stratigraphy, chemical stratigraphy, magnetostratigraphy and sedimentary environment, especially the digital geological technology (Adamset al., 2004). Zampetti et al., 2004; warrlich et al., 2008; verwer et al., 2009) and numerous 2 / 3D stratigraphic framework restoration models (Schlager, 1999; burgess and Wright, 2003; scheibner et al., 2003; paterson et al., 2006; the emergence of Williams et al., 2011) makes the research more accurate and quantitative.

Therefore, the author makes the following two constructive prospects:

(1) In terms of research ideas: The factors affecting the evolution of isolated carbonate platform are multifaceted, and have a superimposed effect, so the complex multi-solution is inevitable. Since most of the carbonates are biogenic, we should first pay attention to the response of carbonate producers to the paleoenvironment and its influence on the type of carbonate production, production rate and migration on the basis of fully considering the influence of tectonic uplift and subsidence, sea level change and paleoclimate background on the evolution of carbonate platform.

(2) In terms of research methods: With the development of many stratigraphic framework simulation models, the setting of internal parameters and the scope of application remain to be discussed. The author believes that the study of the evolution process of the isolated carbonate platform should be based on the respect of the first-hand geological data in the field, and the strata at different levels should be simulated to restore the truth as accurately as possible.

In addition, a single research method cannot prove the scientific rigor of the ' conclusion '. The combination of sedimentary facies analysis, biostratigraphy, sequence stratigraphy, cyclic stratigraphy, chemical stratigraphy, magnetostratigraphy and simulation models is the general trend. It is believed that with the further study of the evolution of the carbonate platform, the evolution process of the accumulation framework style and contact relationship of the internal-edge-slope-basin will be accurately and quantitatively displayed with time.

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