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Distribution and evolution of Carboniferous reefs in South China

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Abstract

Reefs are sensitive proxies for palaeontological, palaeoenvironmental, and palaeogeographical changes during geological history. In South China, after the collapse of the reef ecosystem during the Frasnian-Famennian and Hangenberg mass extinction events, Carboniferous reefs underwent evolutionary episodes of recovery, decline, and turnover, which were controlled by changes of reef-builders abundance, sedimentary facies, relative sea level, and even global climate. In Tournaisian times, only a few Waulsortian-like banks have been found in Liuzhou, Guangxi without metazoan reefs, which were caused by the lack of reef-builders, such as colonial rugose corals and bryozoans, and the dominant non-carbonate facies (shale, mud stone and sandstone) driven by low relative sea level. The absence of mud mounds in the early Viséan was attributed to the regression event during the Tournaisian-Viséan boundary. During Viséan times, bryozoan-coral reefs in Huishui, Guizhou and Tianlin, Guangxi occurred during a time of increasing biodiversity and carbonate facies resulting from relative sea-level rise. The number of potential reef-builders as colonial rugose coral and bryozoan genera significantly increased in Viséan times in South China. The reef abundance declined during Serpukhovian times in South China and the controlling factors were decreasing abundance of potential reef-builders and developing non-carbonate facies due to a relative sea-level fall. The sedimentary facies were characterized by shale, mud stone, sandstone, and dolostone during this time. A distinct change in reef types occurred after the Mississippian-Pennsylvanian boundary, when phylloid algae and red algae reefs (distributed in Ziyun, Guizhou and Beibuwan, Guangxi) replaced metazoan reefs and became the dominant role in reef ecosystem. This reef turnover event may be triggered by the dramatic relative sea-level fall during the mid-Carboniferous, and continued low relative sea level in South China and global flourish of phylloid and red algae during Pennsylvanian times. Grainstone and dolomitic limestone were the main composition of the platform sedimentary facies in South China during Pennsylvanian times. In addition, global climate cooling and warming, resulted from the waxing and waning of Gondwana glaciation, may also influence the reef evolution in South China, as evidenced from the consistent transgression and regression events and reef evolutionary pattern between South China and globe during the Carboniferous.

Keywords: Reef; Distribution; Evolution; Controlling factors; Carboniferous; South China

1. Introduction

Mass extinction and turnover events during the Middle and Late Palaeozoic caused the extinction and succession of reef-builders, which then resulted in the decline and replacement of reef ecosystems (Copper, 1988; Kiessling, 2001). During the Frasnian-Famennian (F-F) and Hangenberg (Devonian-Carboniferous) mass extinction intervals, reef-builders, such as stromatoporoids and corals, vanished (Copper, 2002a; Wang and Shen, 2004; Wang et al., 2006). In the Mississippian-Pennsylvanian boundary, corals, brachiopods, and fusulinids underwent turnover events (Wang et al., 2006, 2013). In addition, continental merging and multiple glaciations during the Late Palaeozoic affected palaeogeographical, palaeoclimatological, and palaeoceanographical conditions (Scotese and McKerrow, 1990; Fielding et al., 2008). In Mississippian times, Gondwana

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rotated clockwise and moved northward, and its northwestern part joined with the southern part of Laurussia near the equator during the mid-Carboniferous. Then, the two continents continued their collision during Pennsylvanian times which gradually formed the rudiments of Pangaea (Scotese and McKerrow, 1990). The collision of the two continents changed ocean current circulation and heat transport systems (Saltzman, 2003), leading to global lowering of atmospheric $_{P}CO_2$ (Worsley et al., 1994) resulting in climate cooling (Isbell et al., 2003; Fielding et al., 2008). Three major glacial periods have been developed coinciding with positive shifts in inorganic carbon ($\delta^{13}C_{carb}$) and oxygen ($\delta^{18}O$) isotopes during the Carboniferous. These were the Tournaisian, Serpukhovian-middle Bashkirian, and late Kasimovian-Gzhelian (Mii et al., 1999, 2001; Isbell et al., 2003; Buggisch et al., 2008; Fielding et al., 2008; Grossman et al., 2008; Yao et al., 2015a). These changes played important roles in the evolution of the Carboniferous reefs in South China.

The Devonian and Permian were periods of global reef expansion and were characterized by coral-stromatoporoid reefs and algal-sponge reefs respectively, widely distributed in North America, Russia, Siberia, Europe, Australia, and South China (Copper, 2002b; Fan and Wu, 2005). In contrast, the Carboniferous was a period of global low reef abundance. Carboniferous reefs were constructed mainly by calcimicrobes, calcareous algae, sponges, and bryozoans, generally lacking large metazoan frameworks (Wahlman, 2002; Webb, 2002), and the reefs were present in North America, Siberia, Europe, and South China (Gong et al., 2010). In South China, the Carboniferous reefs were relatively rare and only a few coral-bryozoan-algal-microbial reefs have been documented in Guizhou Province and Guangxi Zhuang Autonomous Region (Gong et al., 2012), mainly of the Viséan, late Bashkirian-middle Kasimovian, and late Kasimovian-Gzhelian times (Gong et al., 2010, 2012). The Viséan reefs are relatively more diverse and widely distributed. The late Bashkirian-middle Kasimovian reefs are sparser and moderate in their distribution. The late Kasimovian-Gzhelian reefs are the most diverse but spatially limited.

Reefs are complicated ecosystems and their growth and demise are closely related to changes in (1) the abundance of potential reef-builders, (2) temperature, (3) relative sea level, and (4) palaeogeography. Wang and Shen (2004) suggested that the extinction and recovery of coral reefs from the Late Devonian to Mississippian were coupled with the diversity changes of colonial rugose corals. Temperature changes of marine water constrain the temporal and spatial distributions of reefs (Copper, 2002a). With global warming, reefs expanded from the equator to high latitudes, such as in the Wenlock and Emsian-Givetian stages (Copper, 2002a). On the contrary, reefs were restricted to low latitudes during climate cooling periods, e.g., Latest Ordovician and Late Devonian (Copper, 2002a). Eustatic changes also restrict the formation and termination of reefs. The rise or fall of relative sea level all can cause the growth and demise of reefs (Aretz and Chevalier, 2007; Aretz et al., 2010). Also, terrigenous supply, carbonate platform scales, and platform-basin patterns play a decisive role in the development of reefs. The wide distribution of carbonate platforms during a stable tectonic stage is conducive to reef expansion (Wang et al., 2014).

The Carboniferous period forms a link in the reef evolution from the Devonian to Permian. Systematic study of types, distribution, and evolution of the Carboniferous reefs may provide not only new information about the evolution of Palaeozoic reefs, but also potentially new insights into the sedimentary facies and relative sea-level changes in South China and global climate of the Carboniferous. To date, the studies of the Chinese Carboniferous reefs were focused mainly on the description of individual reefs (Gong et al., 2012). Their evolution and controlling factors were rarely discussed. In this study, based on the published literature and new data on reefs, the types, abundance, size, reef-builders and -dwellers, sedimentary facies, and distribution of the Carboniferous reefs in South China have been systematically reviewed (Fig. 1), in order to assess the relationships between reef evolution and reef-builder abundance, sedimentary facies, relative sea-level, and global climate changes. The reefs mentioned in this paper use the definition of Riding (2002) that is 'essentially in place calcareous deposits created by sessile organisms', which include organic reef/biostrome and carbonate mud mound (Kershaw, 1994; Flügel, 2004).

2. Geological setting

Carboniferous reefs in South China were distributed mainly in Guizhou Province, Guangxi Zhuang Autonomous Region, and Hunan Province in southern part of China (Fig. 2a). A total of seven reef locations have been found, four in Guangxi (Liuzhou, Langping, Laibin and Beibuwan areas), two in Guizhou (Yashui and Houchang areas), and one in Hunan (Lianyuan-Lengshuijiang area) (Fig. 2b). Mississippian reefs are distributed in Liuzhou, Langping, Laibin, Yashui, and Lianyuan-Lengshuijiang areas. Pennsylvanian reefs are present in Huishui, Lianyuan-Lengshuijiang, Langping, Beibuwan, and Ziyun areas (Fig. 2b).

Strong lithofacies differentiation resulted from several active rifts of the Carboniferous in South China (Feng et al., 1998; Qie and Wang, 2012). The Qian-Gui (QG) basin configured by rifting was formed in the Early Devonian, and developed during the Carboniferous (Mei and Li, 2004). In the Mississippian, a widespread Dian-Qian-Gui-Xiang (DQGX) platform developed around QG basin including isolated carbonate platforms. Slope facies can be distinguished between platform and basin facies (Feng et al., 1998) (Fig. 3A, B). During the Pennsylvanian, the QG basin was replaced by the Luodian, Baise, and Tiandeng basins surrounded by a more large-scale carbonate platforms, including Southwestern (SW), Central South (CS) and Central Lower Yangtze (CLY) platforms (Feng et al., 1998) (Fig. 3C, D). The Carboniferous carbonate platform was characterized by large thickness of carbonate sequences (Jiao et al., 2003). In addition, during the Carboniferous, the South China Block was located near the equator and the climate was warm. The carbonate sequence and warm climate all provide suitable conditions for the development of reefs. The regional palaeogeographical maps show that the Carboniferous reefs in South China were distributed mainly at platform margins or on slopes (Fig. 3).