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Contents

Characterization and origin of microbial carbonate pores in Dengying Formation, North Sichuan Basin, China

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Abstract

The breakthrough of oil and gas exploration in microbial carbonates in Sichuan Basin shows that it has great exploration potential, but the origin of microbial carbonate reservoir is still not perfect. In this paper, the origin of microbial carbonate pores was systematically studied by analyzing the characterization of microbial carbonate pores in Dengying Formation and combining with microbial mineralization simulation experiments. This study suggests that: (ⅰ) The types of microbialite in Dengying Formation include stromatolite, thrombolite, spongiomicrobialite and oncoid, (ⅱ) The pore types of microbial carbonates are diverse and can be divided into pores of microbial genesis and pores of non-microbial genesis.

Pores of microbial genesis can be divided into and microbial dissolution pores. The orgin of this type of pores is related to factors such as microbial community construction and the degradation of microorganisms and EPS. Microbial construction pores are divided into two types: One is the pores formed by the degradation or shedding of the bacteria, and he pore size is micron-sized, which is comparable to the size of bacteria in nature. The other is the framework pore formed by microbial mineralization. Microbial dissolution pores are formed by the dissolution of minerals

by microbial metabolites and degradation products. Microbial mineralization experiments also confirmed the existence of microbial construction pores and microbial dissolution pores. The analysis of EPS components of *Bacillus sp. DB1-9* (sulfate reducing bacteria) confirmed that it contained a variety of amino acids. Molecular simulation showed that amino acids interacted with calcite, which easily caused the calcium ions on the surface of calcite crystals to be adsorbed to the outer layer by amino acids, forming a drag effect so that the calcium ions were free to the solution and then dissolved to form pores.

Pores of non-microbial genesis include intercrystalline pores, dissolution pores (caves) and fractures, which are mainly related to diagenesis. The orgin of pores of non-microbial genesis is controlled by both the primary pores of microbialites and the evolution of fluids during diagenesis. Meteoric water, organic acids and hydrothermal fluids control the formation of dissolved pores. The karstification caused by Meteoric water can be divided into three stages, including the syngenetic-penecontemporaneous karst caused by Tongwan movement I, Tongwan movement II and the early diagenetic karst caused by Tongwan movement III. The dissolution pores formed by karstification are mostly distributed along the layers. The dissolution pores formed by organic acid are divided into intergranular dissolution pores, intracrystalline dissolution pores and microbial dissolution pores. The temperature of brine inclusions in this area is between 110-140 °C, indicating that the Dengying Formation in the study area was filled with organic acids during burial stage. The dissolution pores formed by hydrothermal action are often accompanied by silicification and halo, which are mostly the result of hydrothermal bedding filling in syn-depositional period.

Keywords: Dengying Formation, dolomite, microbialites, microbial pores, hydrocarbon generation potential

Mesoproterozoic stromatolites of the Shennongjia Group in the northern margin of Yangtze Block, China

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Abstract

Stromatolites of Shennongjia Group are mainly conic, columnar, domal, corrugated, stratiform stromatolites and stromatolite bioherms. The columnar and conical stromatolites are well developed. Conical stromatolites are mainly monomers, with a variety of pyramidal types, ranging in diameter from a few millimeters to several meters and formed in the high energy subtidal zone and tidal lagoon environment. Most of the columnar stromatolites are medium to small sizes implied a wide and gentle slope environment at that time. Stratiform (including corrugated) stromatolites are larger scales and extends far away and distributed most widely in almost every horizon in the carbonate rocks. Stratiform stromatolites can be formed in low energy environments such as subtidal and intertidal zones and supratidal belts. Corrugated stromatolites often developed in the hydrodynamic energy condition from weak energy intertidal zone gradually strengthened to the below of the high energy supratidal. Although stromatolite bioherms can be a single or multiform combination, they developed mainly consisted of laminar or small walled columnar and large domal stromatolites. Shicaohe Formation also partially developed large domical stromatolites, the deposited environment from the upper intertidal to supratidal zone. Stromatolite in vertical in Shennongjia Group usually appears as a combination of "Stratiform (Corrugated) - dome - columnar - coniform " or "stratiform - dome - coniform - columnar - dome - stratiform ", which represents the seawater depth from shallow to deep or from shallow

to deep and then to shallow again. These phenomenons generally reflected a stable sea level and accompanied with a high frequency oscillation. Comprehensive researches on the stratigraphy, sedimentary facies, sedimentary environment and the stromatolite types and their characteristics in the Shennongjia Group indicated that the Shennongjia Area is located on a gentle slope of carbonate platform in the passive continental edge, generally, i.e., one of warm and humid climate shallow water zone or /and a clod-drought climate, and had been experienced with eustatic cycles during the Shennongjia Group deposited.

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Keywords: Stromatolite Mesoproterozoic Shennongjia Group Northern Margin of Yangtze Block

Characteristics of Stromatolites and its Significance in Depositional Environment Reconstruction of the Mesoproterozoic Longjiayuan Formation (2nd member), Western Henan

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Abstract

Stromatolites are widely developed in the Precambrian system. As a kind of microbiolites, stromatolites record the growth process of cyanobacteria and microbial communities under photosynthesis in the early oxygen-poor environment, as well as the sedimentation process during the precipitation of calcium carbonate. In the early condition that it is difficult to preserve fossil evidence, stromatolites are of great significance for indicating the sedimentary environment in the Mesoproterozoic. The stromatolites from Longjiayuan Formation (the Second Member) of the Mesoproterozoic Guandaokou Group in Western Henan Province are abundant in form, characteristic and distribution, but there has been no systematic study. This paper makes a detailed study the macroscopic and microscopic characteristics of the stromatolites, and then restores the sedimentary environment of Longjiayuan Formation (2^{nd} member) .The results show that the stromatolites in the study area can be divided into horizontal laminae, ripple, hilly, cone, and column stromatolites according to their

morphology. The sedimentary environment of Longjiayuan Formation (2nd member) is mainly intertidal and subtidal carbonate platform environment, and the morphology of stromatolites is closely related to the hydrodynamic conditions, water depth and changes of the sedimentary environment. Among them, Horizontal laminated stromatolites were developed in the intertidal zone, whilst corrugated and mound stromatolites were developed in the intertidal high-energy zone and low-energy zone. Meanwhile, cone and columnar stromatolites were developed in the subtidal zone. Combined with the macromorphology and micromorphology of stromatolites, it is revealed that Longjiayuan Formation (2nd member) experienced the process of intertidal zone, subtidal zone, intertidal zone, and water body from shallow to deep to shallow. The morphology, environment and related events of Mesoproterozoic stromatolites in North China and different regions of the world during this period are discussed. This study can provide strong evidence for the restoration of the early Mesoproterozoic sedimentary environment in the southern margin of North China and the coupling process of earth environment and microbial evolution during this period.

Key words: stromatolite, Longjiayuan Formation, sedimentary environment, western Henan

Characteristics and depositional environment of the Early Mesoproterozoic Fengjiawan Formation stromatolites in the southern margin of the North China Craton

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Abstract

The lower part of the Early Mesoproterozoic Fengjiawan Formation stromatolites in the southern North China Craton contains abundant microbial dolostones that possess well-preserved primary structures, providing an unique opportunity to investigate the characteristics and paleoenvironmental conditions of the Precambrian microbial carbonates. This study comprehensively investigates the macromorphological, petrographical, mineralogical and geochemical characteristics of the stromatolite-dominated microbialites in the Fengjiawan Formation for the first time. The overall results indicate that the stromatolites were deposited in a shallow open marine environment located on a passive margin setting, with their mineral compositions predominantly composed of dolomite (avg. 94.24 wt%). The stromatolites exhibited diverse macromorphological structures, which are mainly distributed from the bottom

to the top as conical (the lower intertidal to the upper subtidal zone), hemispherical domal (the lower supratidal zone), spherical domal (the upper to middle intertidal zone), and the more abundant columnar (upper to middle subtidal zone) stromatolites. The results revealed that these stromatolites contain a low abundance of microfossils identified as filamentous and spheroidal cyanobacteria microfossils of Gunflintia minuta, Huroniospora, along with Eoentophysalis belcherensis and an undetermined Gastropod shell-like microfossil. Additionally, the studied stromatolites exhibit rare earth element and yttrium (REY) patterns that display weak negative Ce anomalies, weak positive Pr anomalies, and no Eu anomalies, suggesting that the stromatolites were deposited under a suboxic seawater environment. These studied stromatolites were not significantly influenced by both detrital contamination and post-depositional alteration processes. Therefore, the growth of the stromatolite-dominated microbialites in this study was primarily controlled by these depositional conditions, sea level fluctuations and biological processes, which significantly contributed to the excellent preservation of these stromatolite-dominated microbialites.

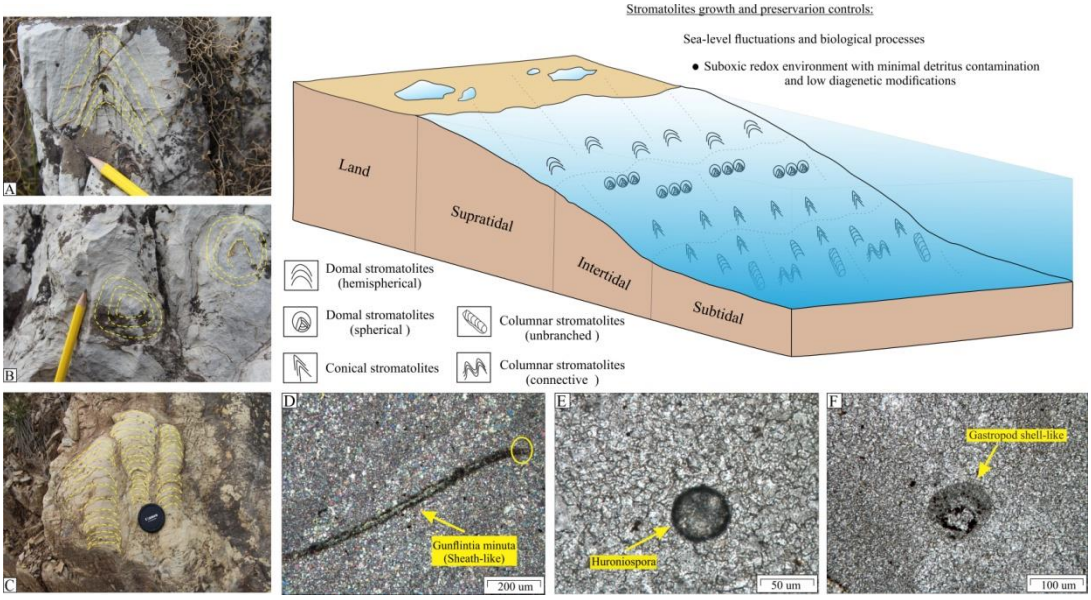

Fig.1 Fengjiawan Formation stromatolites in the southern margin of the North China Craton

Keywords: Stromatolites; Microfossils; Paleoenvironments; Growth mechanisms; Early Mesoproterozoic; Southern North China Craton

Stromatolites from Middle Cambrian Pingjing Formation in Youyang, Chongqing

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Abstract

Recently, we found abundant Middle Cambrian stromatolites in Youyang County located in southeast Chongqing during field investigation and in local area there are reefs formed by stromatolites. Stromatolites are from Pingjing Formation of Cambrian Miaolingian.and extend intermittently 100 km from northeast to southwest and provide new excellent materials of Cambrian stromatolites.

In Youyang Pingjing Formation completely belongs to Miaolingian and conformably overlies the Shilengshui Formation and overlain by the Gengjiadian Formation of Furongian. It could be divided into two members, both of which contain a diverse assemblage of stromatolites.

Based on the cause and structure, we recognized six types of stromatolites morphologies including stratiform, wave-like, columnar, hemispheroidal. Columnar stromatolites are subdivided into cylinder, cone-shaped and inverted cone-shaped morphologies.

In outcrop scale, columnar stromatolites can form reefs, showing biostromal megastructures. They are constructed of vertically stacked columnar stromatolites with locally intercalated bioturbated wackestones and bioclastic grainstones. There are several horizons of thrombolites or dendrolites characterized by cm-scale mesoclots, which are surrounded by matrices in Pingjing Formation. They vary in size and usually occur above or below columnar stromatolites and together form reefs.

The distribution pattern of sedimentary environment about stromatolite has been deeply studied. All results showed that stromatolite growth are mainly influenced by

hydrodynamic condition and different morphology of stromatolite correspond to certain environment. The stromatolite morphologies of Pingjing Formation are not unique and are similar to many of the most common Proterozoic forms, and have well documented morphologies that formed in a depositional environment that has modern and ancient analogues. Based on the relationship between the surrounding rock and different morphology of stromatolites. The stromatolites of the Pingjing Formation could be judged to live in tidal flat environments, and concentrated in intertidal zone relatively. On the basis of sedimentary feature stromatolite facies could be divided into various facies zone, including Intertidal zone to subtidal zone, Middle intertidal zone, upper intertidal zone and supratidal zone.

The Cambrian stromatolites in Youyang appeared under the background of transgression in which took place four times regression and four times transgression. From the morphological change and multistage cyclic stratigraphy containing intercalation of dolomite it could be judged that strata containing much stromatolites underwent at least four times complete eustasy. The appearance order of stromatolites is generally hemispheroidal, columnar, wave-like, stratiform, or wave-like, hemispheroidal, columnar, wave-like, stratiform, which, combined with interbeds between stromatolites, showed water depth experienced at least three times changes. While Pingjing Formation is characterized of progradation sequence, stromatolite beds match the facie feature of regression generally, with repeated fluctuation. The global rise and fall of sea level in Middle and Late Cambrian expressed during the sedimentary period of Pingjing Formation and controlled the growth of stromatolites, which proved that the change of sea level or hydrodynamic condition is the key factor of stromatolites growth types.

Stromatolites in Youyang belonging to microbialites appeared in Cambrian Epoch 3. Their large scale showed that microbialites also flourished in South china. These microbialites are mainly composed of thrombolites or dendrolites, which is similar to other regions, or large-scale column stromatolites, which is partly different from other regions because in some areas of Youyang stromatolites can occupy a large part of reef. Generally, it is reasonable to judge that the stromatolites in Youyang should form in warm shallow water with elevated temperatures and reduced marine oxygenation which caused dysoxia-hypoxia in marine environments limiting the metazoan reef-builders. It is noteworthy that the difference in stromatolite development in South china and other regions reflect the difference of local palaeo-environment, which deserves a further study.

In Youyang Furongian is represented by Gengjiadian Formation and Maotian Formation that are mainly composed of dolomitic limestone and limestone containing little stromatolites, which is different from the Cambrian Epoch 3 in other area. The transition across the boundary is also judged to be caused by some global geological events across the Cambrian Epoch 3–Furongian boundary events. The detailed research will be made in the future to know the specific process and reasons.

Dendrolite bioherms on a limestone conglomerate bed in the Sesong Formation (Miaolingian–Furongian), Taebaeksan Basin, Korea: stratigraphic and paleoenvironmental implications

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Abstract

Dendrolite bioherms are found in the Furongian Sesong Formation in central eastern Korea (Taebaeksan Basin). The dendrolites rest on top of a limestone conglomerate bed that appears to have been deformed after its deposition. The exposed outcrop section displays a variety of sandstone facies and limestone conglomerates interbedded with them. The deformed limestone conglomerate beds comprise a mixed matrix of sandstone and grainstone, along with limestone clasts ranging from millimeters to decimeters in size that contain remnants of microbialites. Three distinct dendrolite bioherms were identified in this study. The bioherm comprises upward branching and downward tapering bush-like dendroids which are predominantly micritic and peloidal, with crystalline cement filling the spaces between the micritic masses. The interspace between dendroids is filled with matrices of bioclast, quartz sand grains, and limestone intraclasts. The occurrence of dendrolites in a primarily siliciclastic succession is unusual. Further comprehensive investigation of their microscopic structures, comparison with other dendrolites, and paleogeographic distribution would enhance our knowledge of the depositional environment of dendrolites and their evolutionary trait. Besides, the atypical structure observed within the limestone conglomerate-sandstone interbedded interval beneath the dendrolite bioherms is remarkable and may offer valuable insights into the sedimentation and deformation processes that took place.

Detailed sedimentary facies and architectural analysis were carried out to unravel the depositional processes and environments.

A Preliminary Study of Taphonomy of the Calcimicrobialite in Zhangxia Formation of Middle Cambrian in the Taihang Mountain Area of Hebei Province

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Abstract

The Taihang Mountain Area is an important geological unit in North China, known for its geological features. Such characteristics make them perfect candidates for the Taphonomy of Calcimicrobialite. The taphonomy of Calcimicrobialite is a multidisciplinary field, which involves the role of microbes and its long burial process. Previous studies have mainly focused on the occurrence, types, and community structures of Calcimicrobialite, but there were much less attention given to study the benthic microbial community taphonomy represented by microbial rocks. This study aims to investigate the taphonomy of calcimicrobialite in Zhangxia Formation of Middle Cambrian in the Taihang Mountain Area of Hebei Province, through conducting comprehensive research on the five primary geological profiles located in the western region of Shijiazhuang, Taihang Mountains, namely DongZhuanggou sections Qingyangou sections, profound insights have been obtained.The deposition of carbonate rocks encompasses sedimentation processes that are non-biological, biologically induced, and biologically controlled. To further understand these mechanisms and influencing factors, this study will utilize the concept of triple subdivision of carbonate facies and apply innovative principles and techniques for analyzing carbonate microfacies. This analysis will facilitate the identification of distinct carbonate microfacies types and provide preliminary insights into the formation processes and controlling factors of carbonate microfacies. It is challenging to discover intact fossils in carbonate rocks from carbonate platform facies, However, the implementation of microfacies techniques allows for the analysis of fossil fragments in laminated rocks and dark microcrystalline sediments, enabling the examination of their quantity, types, and microbial characteristics. This presents an opportunity for the examination of paleontological fossil assemblage characteristics, paleobioclasm features, and fossil preservation quality in a scientific context. The research will also investigate the impact of bioturbation on the preservation process of microbial rocks during the Middle Cambrian. Microfacies analysis methods and techniques will be utilized to focus on the concentration layers

of microbiological fossils within the Zhangxia Formation. A crucial analysis will be conducted to examine the taphonomy characteristics of bioclasts in carbonate rocks, including differentiation, preservation quality, taphonomic deviation, homogenization effect, disruption caused by bioturbation, and preservation features of microbiological fossils. Additionally, trace fossils adjacent to layers exhibiting significant diagenetic halos will be examined to understand their influence and transformation mechanism on sedimentary matrices. Furthermore, an analysis of the formation of grainy structures will be conducted based on the distribution layers of trace fossils. Mathematical and statistical methods will be employed to quantitatively study and analyze various aspects of microbial fossil-rich layers, such as the quantity, types, sizes, wear, fragmentation rates, completeness, and degree of mineralization in terms of bioclasts. The application of these scientific techniques will facilitate a deeper comprehension of the hydrodynamic conditions during the diagenesis process, ancient water flow, turbidity currents, storm events, oxygen conditions, paleosalinity, and contribute to a deeper understanding of microbial taphonomy and paleoenvironmental issues.

Key words: Calcimicrobialite; Taphonomy; Zhangxia Formation, Cambrian; Taihang Mountain Area.

Features and formation environment of Early Cambrian microbialites from Tarim Basin, China

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Abstract

Microbial carbonate is a hot spot in sedimentary research field, and it is also one of the main targets oil and gas exploration in recent years. The Early Cambrian Xiaoerblak Formation in the Tarim Basin is a thick sequence of microbial dolostones that has good exploration prospect. Because of it underwent complex diagenetic alteration, however, studies and understanding on the features, types, distribution, and formation environments of the microbial carbonates in this formation were greatly limited, which has blocked the exploration work. Here we made a systematic study on the microbialites of the Xiaoerbulak Formation through detailed field work on four outcrop sections in Aksu area and microscopic analysis on 280 thin sections, microscopically classified the microbialite fabrics, and analyzed the formation environments of this formation.

Six kinds of microbialites were recognized in the formation: laminite, thrombolite, thrombolitic laminite, *Renalcis* framestone, foamite dolostones and stromatolite. The Sugaitblak section consists of thrombolite, laminite, thrombolitic laminite and *Renalcis* framestone, and other rocks; while the Shiairik section mainly consists of laminite, thrombolite and foamite dolostones, and the Jianbizhenmutag and Sawapuqi sections mainly consist of laminites. On the microscopic scale, the microbialite fabrics can be divided into 4 types: clotted fabric (vermicular clotted fabric, reticular clotted fabric, spotted clotted fabric and clumpy clotted fabric), laminated fabric (wavy laminated fabric, compound laminated fabric), foaming fabric and skeletal fabric. Under scanning electron microscope, a series of microbial fabrics such as calcified filamentous, EPS and microbial mats were observed in laminated fabric. Both clotted fabrics and

laminated fabrics showed obvious carbon peaks (1350 cm^{-1} and 1600 cm^{-1}) on Raman spectrum, which indicates the once presence of microbes.

The formation environments of the different microbialites were determined. The laminites with birdseye and fenestral structures and thrombolites with honeycomb pores formed mainly in the supratidal-intertidal zone of restricted platform; the laminites without birdseye structures mainly in the intertidal-subtidal zone of restricted platform; the thrombolites without honeycomb pores and thrombolitic mounds mainly in deep-water subtidal zone of restricted platform; and the laminites with intraclasts laminations, *Renalcis* framestone and foamite dolostones mainly in the open platform grain banks. According to the characteristics in outcrop and thin sections, ten types of lithofacies were identified, and the sedimentary facies include tidal flat facies of restricted platform, deep subtidal facies of restricted platform and grain bank facies of open platform. The lower part of the Sugaitblak section and Shiairik section are the tidal flat facies of restricted platform, and the upper part is a transition from deep subtidal facies to grain bank facies. The Jianbizhenmutag and Sawapuqi section are mainly grain bank facies of open platforms with intermittent development of tidal flat facies of laminites. The water gradually deepened from south to north, and the hydrodynamic energy gradually becomes stronger.

Key Words: Tarim Basin, Cambrian, Microbialites, Fabrics, Formation Environment