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Formation Distribution and Geological Significance of Ferric Stromatolites

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ABSTRACT

Ferric stromatolites are microbialites formed by cyanobacteria and other microorganisms under specific geological conditions. Their unique layered structure and iron-bearing composition are of great significance for understanding microbial evolution and mineral genesis. With the continuous advancement and improvement of exploration technologies and research methods, ferric stromatolites will play an increasingly prominent and important role in iron ore resource exploration. Therefore, this paper summarizes the basic concepts of ferric stromatolites, outlines their research value, research methods, formation mechanisms, geological distribution and exploration significance in geology, and draws corresponding conclusions.

KEYWORDS

Ferric stromatolites; Geological distribution; Geological significance.

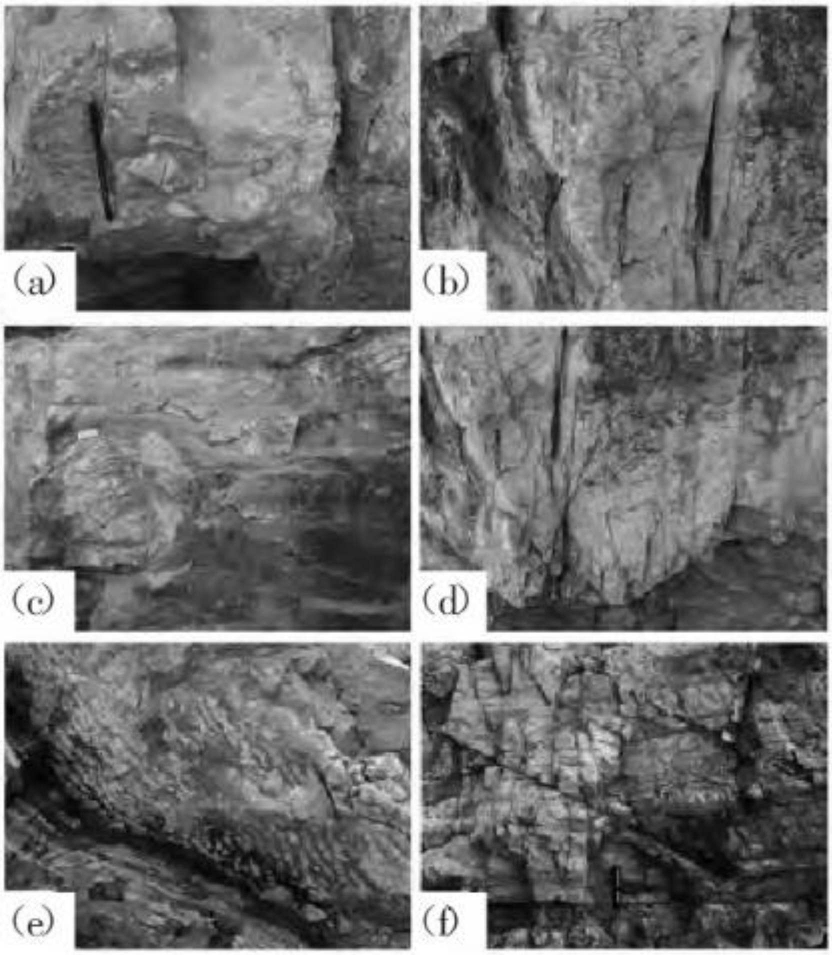
1. INTRODUCTION

Microbialites have become a research hotspot in the fields of geology and energy due to their significance in ecological environment and resource accumulation, as well as the complexity of their calcification mechanisms. Microorganisms are an important component of the Earth's biosphere, accounting for approximately 80% of the total biological biomass. Due to the destruction caused by diagenesis and oxidation, most microorganisms are difficult to be preserved as fossils. However, the importance of microorganisms in the Earth's surface system, especially in environmental transformation, has been increasingly recognized[1]. Microbial mats have been discovered in carbonate rocks dating back 3.5 billion years and preserved in the form of stromatolites[2]. Apart from stromatolites, other evidence of the existence of microorganisms in Earth history is not obvious and hard to be directly identified with the naked eye. Thus, stromatolites are regarded as the only fossil group throughout Earth history. They have witnessed the development of life on Earth and serve as direct evidence for exploring the origin and evolution of life on the planet[3]. In addition, a large amount of organic matter is buried in the bioherms of microbialites (stromatolites), and the formation and enrichment of many ore deposits such as petroleum, phosphorus, iron and copper are often closely related to them[4]. Therefore, it is highly necessary to carry out relevant research on the energy and evolution of stromatolites.

Microbialites are widely developed, dating back to the Early Archean, and flourished most in the Mesoproterozoic, Neoproterozoic, as well as the Early Cambrian and Ordovician[5]. From the remote Archean to the Neoproterozoic, the suitable environment and the absence of metazoans provided extremely favorable conditions for the reproduction of microorganisms such as prokaryotes and eukaryotic fungi and algae, as well as mineral precipitation, creating the most glorious period of stromatolites[6]. The developmental history of stromatolites in Earth history can be divided into five stages: the growth stage from the Archean to the Proterozoic, the peak stage in the Meso-Neoproterozoic, the decline stage in the Neoproterozoic, the recovery stage from the Cambrian to the Early Ordovician, and the large-scale decline stage in the subsequent Phanerozoic[7]. The formation of Precambrian stromatolites was mainly affected by the long-term changes in the chemical properties of seawater and algal competition.

In addition, two atmospheric oxygenation events[8], the breakup of the Kenorland supercontinent, the scarcity of competing biocenoses, the supersaturation of $CaCO_3$ on the shallow marine continental shelf, the low O_2 content and high CO_2 content in the atmosphere and marine surface, as well as the suitable temperature, water depth and light conditions created by the favorable paleoclimatic background during interglacial periods, all constituted favorable conditions for the formation of stromatolites. Conversely, the emergence of herbivores and macroscopic burrowing or boring organisms on the eve of the Nantuo Glaciation, temperature decrease, oxygen increase, the weakening of calcification caused by changes in the physical and chemical conditions of the ocean, led to at least five large-scale abnormal decline events of Precambrian stromatolites, and there was a certain correlation between their decline and metazoans[9]. In the Phanerozoic, the formation of stromatolites was jointly affected by metazoan bioturbation, competition from advanced algae and long-term changes in seawater saturation, but the abnormal carbonate deposition influenced by global changes may have played a more dominant role[10].

The macroscopic morphological characteristics of stromatolites are mainly affected by external factors, and the evolution of their morphological characteristics also reflects the changes in sedimentary environments[11]. Stromatolites are classified by their morphology into layered stromatolites, wavy stromatolites, columnar stromatolites, conical stromatolites, digitate stromatolites (Figure 1)



(a) Digitate stromatolites; (b) Mounded stromatolites; (c) Mounded stromatolites; (d) Wavy stromatolites; (e) Conical stromatolites; (f) Layered stromatolites.

Figure 1 Types of stromatolites

2. SIGNIFICANCE AND METHODS OF FERRIC STROMATOLITES

2.1. Research Significance

Ferric stromatolites occupy a special position in geology and possess extremely high research value. As a type of stromatolite, their formation is often closely related to the activities of cyanobacteria and other microorganisms. Cyanobacteria release oxygen through photosynthesis, oxidize iron elements in seawater and cause their deposition, ultimately leading to the formation of ferric stromatolites. These stromatolites record the traces of early life activities on Earth and are among the oldest biological fossils on the planet[12]. The occurrence of ferric stromatolites in the geological record marks an important stage of life activities on Earth, providing crucial evidence for geologists to study the evolution of early life on Earth. Ferric stromatolites have a wide chronological range of formation, having been discovered from billions of years ago to relatively recent geological periods[13]. They are widely used in the division and correlation of geological ages, serving as an important basis for geologists to determine stratigraphic ages. The morphological, structural and compositional characteristics of ferric stromatolites can often reflect the geological environment in which they formed. For example, the deposition of iron elements is closely related to the redox conditions in the ocean, making ferric stromatolites an important indicator for studying the paleooceanic environment.

The formation of ferric stromatolites is closely linked to the activities of cyanobacteria and other microorganisms, so their research is of great significance for revealing the origin and evolution of early life on Earth. By analyzing the biological fossils and geochemical indicators in ferric stromatolites, geologists can understand the forms, distribution and evolutionary processes of early life on Earth. The morphological, structural and compositional features of ferric stromatolites can reflect the paleogeographic and paleoenvironmental conditions at the time of their formation. Through in-depth research on ferric stromatolites, geologists can reconstruct the paleogeographic pattern and paleoenvironmental characteristics of the early Earth, providing important evidence for understanding the Earth's climate and environmental changes. Iron elements in ferric stromatolites usually exist in the form of iron oxides, which can form iron ores through geological processes[14]. Therefore, the study of ferric stromatolites helps to explore the genetic mechanisms and distribution laws of iron ores, providing an important reference for the exploration and development of mineral resources.

Stromatolites are an important link in the evolution of life on Earth, mainly formed by ancient algae (cyanobacteria) during their growth. Their existence marks an important turning point in the evolution of life on Earth from simplicity to complexity. Cyanobacteria laid the foundation for the increase of oxygen content in the atmosphere by releasing oxygen through photosynthesis, thereby promoting the emergence of higher life forms. Stromatolites are regarded by geologists as one of the important criteria for dividing geological ages. They record biological, geographic and environmental information of specific periods in Earth history and are an important basis for geological age division. In particular, ferric stromatolites, with their unique chemical composition and morphological characteristics, have become important research objects for the study of paleogeography, paleoclimatology and paleontology.

The iron-bearing composition and its distribution pattern in stromatolites can reflect the changes in paleoclimate and paleoenvironment[15]. For example, the oxidation and deposition processes of iron elements are closely related to the redox conditions in the ocean, which are directly affected by paleoclimate and paleoenvironment. By analyzing the composition and structure of ferric stromatolites, geologists can reconstruct the evolutionary processes of paleoclimate and paleoenvironment. The distribution and morphological characteristics of stromatolites can also provide clues for inferring paleogeographic locations. For instance, by comparing the similarities and differences of stromatolites in different regions, the relative positions and interrelationships of these regions in geological history can be inferred. In addition, magnetic minerals in stromatolites can be used for paleomagnetic research, thereby further determining the paleogeographic location and the evolution of the paleomagnetic field.

Formation of iron ore resources: Ferric stromatolites are not only important research objects for geological evolution and paleoenvironmental reconstruction, but also important clues for the formation of iron ore resources. In the era when cyanobacteria flourished, a large amount of iron elements existed in the ocean. These iron elements were oxidized under the action of cyanobacteria and deposited on the seabed. After long-term geological processes, these sediments gradually formed iron ores. Therefore, the study of ferric stromatolites can reveal the genetic mechanisms and distribution laws of iron ores.

Guidance for resource exploration: The research on ferric stromatolites can also provide guidance for the exploration and development of iron ore resources. By understanding the genetic mechanisms and distribution laws of iron ores, geologists can predict the location of potential ore deposits and provide a scientific basis for the development and utilization of mineral resources. The distribution law of ferric stromatolites is often closely related to that of iron ores [16]. In geological history, the flourishing areas of cyanobacteria and other microorganisms were often the areas where iron elements were enriched, and these areas may form iron ore deposits after long-term geological processes. Therefore, by studying the distribution pattern of ferric stromatolites, potential distribution areas of iron ore resources can be predicted, providing important clues for mineral resource exploration.

2.2. Research Methods

Field investigation: Conduct field surveys to understand the distribution range, morphological characteristics of stromatolites and their relationships with surrounding geological bodies. Then, select representative stromatolite samples for collection based on the survey results.

Microscopic observation: Use optical microscopes and electron microscopes to conduct thin section observations of stromatolite samples, so as to understand the microscopic structure, mineral composition and bedding characteristics of stromatolites.

X-ray diffraction (XRD): It is used to determine the types and contents of minerals in stromatolites, especially the types and morphologies of iron-bearing minerals.

Scanning electron microscopy (SEM): Combined with energy dispersive spectroscopy (EDS), it can further observe the microscopic morphology of stromatolites and analyze their elemental composition.

Geochemical analysis

Major and trace element analysis: Determine the contents of major elements (e.g., Ca, Al, P, Ti, Fe) and trace elements in stromatolite samples through chemical analysis methods (e.g., ICP-MS) to understand the chemical composition of stromatolites and their variation laws.

Isotope analysis: Use isotope techniques (e.g., stable isotope analysis) to study the source and variation processes of elements in stromatolites, such as the source of iron elements and the changes in their redox states.

3. FORMATION MECHANISM OF FERRIC STROMATOLITES

3.1. Microbial Action

Cyanobacteria and other microorganisms play a key role in the formation of ferric stromatolites. Cyanobacteria are among the earliest organisms on Earth capable of photosynthesis, emerging about 3.5 billion years ago. During photosynthesis, cyanobacteria not only release oxygen but also secrete certain mucilage. This mucilage can not only adhere other microorganisms together but also cement tiny mineral particles (including iron elements) in seawater, forming microbial sedimentary rocks, the precursor of stromatolites. With the flourishing of cyanobacteria, a large amount of iron elements are captured and deposited by the mucilage they secrete. The extracellular polymeric substances of cyanobacteria can attract Fe^{3+} ions, providing nucleation sites for the accumulation of iron minerals and further promoting the enrichment of iron elements[17].

In the ocean, iron elements mainly exist in a dissolved state. When cyanobacteria increase the oxygen content in water through photosynthesis, dissolved iron elements are oxidized into solid iron oxides (e.g., hematite). These oxides then deposit on the seabed, becoming an important source of iron elements in stromatolites. Through long-term sedimentation, iron-rich sediments continue to accumulate and combine with sedimentary rocks formed by cyanobacteria and other microorganisms, forming ferric stromatolites. Under specific geological conditions (appropriate temperature, pressure, fluid activity), iron elements in ferric stromatolites will be further enriched to form economically valuable iron ore deposits.

Taking the ferric stromatolites in the second member of the Cambrian Mantou Formation in the Weihui area of Henan Province as an example, these stromatolites developed in the post-beach microbial mound reefs of the intertidal to shallow subtidal zone and contain a large number of iron-mineralized Girvanella filaments[18]. They have a laminated structure of ferric stromatolites, consisting of dark laminae with densely developed Girvanella filaments and light laminae with sparse Girvanella filaments. Geochemical tests show that the main iron-bearing mineral in these stromatolites is hematite, and the iron content is positively correlated with the density of Girvanella filaments. This further proves the important role of cyanobacteria and other microorganisms in the formation of ferric stromatolites.

In summary, the source of iron elements in ferric stromatolites is mainly attributed to the photosynthesis and microbial activities of cyanobacteria and other microorganisms, the chemical processes of the marine environment, as well as subsequent geological processes and mineralization. These processes work together to enable the enrichment of iron elements in stromatolites and the formation of economically valuable iron ore deposits.

3.2. Environmental Conditions

High salinity environment: High salinity environments are extreme and unsuitable for most organisms, but some microorganisms such as cyanobacteria can survive and reproduce in such environments. These microorganisms cement tiny sediment particles in water by secreting mucilage, thus gradually forming stromatolites in high-salinity seawater. High salinity may prevent competition from other organisms, which is conducive to the formation of stromatolites. Under high salinity conditions, salts in seawater such as iron ions (Fe^{2+} or Fe^{3+}) tend to precipitate due to changes in solubility. With the participation of microorganisms, these iron ions may form iron oxides (e.g., hematite) through redox reactions, which in turn become an important component of ferric stromatolites.

Light conditions: Microorganisms such as cyanobacteria rely on photosynthesis for survival, so light is a key factor for their growth. The intensity and direction of light directly affect the growth rate and morphology of stromatolites. For example, due to the phototropism of algal growth, the growth direction of stromatolites is often consistent with the light direction, forming diverse morphologies such as layered, columnar or conical. Light may also indirectly affect the mineral composition of stromatolites by influencing the metabolic activities of microorganisms. Sufficient light is conducive to the active growth of microorganisms, thereby accelerating the mineral precipitation process and increasing the content and types of minerals in stromatolites.

Water flow conditions: Water flow is an indispensable external dynamic factor in the formation of stromatolites. Appropriate water flow can transport and deposit tiny sediment particles, providing a material basis for the formation of stromatolites. However, excessively strong water flow will destroy the formed stromatolite structure, which is not conducive to the growth of stromatolites. The direction and velocity of water flow also affect the morphology and structure of stromatolites. For example, in slowly flowing water, stromatolites may form relatively flat layered structures; while in areas with rapid water flow, stromatolites may exhibit more complex columnar or conical structures.

In high-salinity, well-lit and moderately flowing environments, ferric stromatolites may form diverse morphologies such as layered, columnar or conical. In contrast, in environments with low salinity, insufficient light or excessively strong water flow, the growth of stromatolites may be limited, and their morphologies may be flatter or irregular. Ferric stromatolites formed under different environmental conditions may also differ in mineral composition. For example, stromatolites formed in high-salinity environments may be rich in iron oxides (e.g., hematite), while those formed in other environments may contain different types and proportions of mineral components. In addition, the types and activity of microorganisms will also affect the mineral composition and content of stromatolites.

3.3. Genetic Differences Between Ferric Stromatolites and Other Types of Stromatolites

Ferric stromatolites tend to form in iron-rich seawater or sedimentary environments. These environments may have specific redox conditions, water flow velocities, light intensities, etc., which are conducive to the oxidation, deposition and enrichment of iron elements. In addition to being rich in iron elements, ferric stromatolites may also have unique morphological and structural characteristics. For example, their surface may exhibit a red or yellowish-brown color due to the presence of iron oxides. Structurally, ferric stromatolites may also have a denser bedding structure and higher density[19].

Other types of stromatolites form in a wider range of environments, which may include different seawater depths, light conditions, water flow velocities, etc. For example, some stromatolites may form in shallow seas or intertidal zones and be affected by tidal action; while others may form in deep-sea environments and be influenced by ocean currents and biological activities.

4. DISTRIBUTION AND EXPLORATION SIGNIFICANCE OF FERRIC STROMATOLITES

4.1. Distribution of Ferric Stromatolites

The global distribution of ferric stromatolites is a complex issue, as their formation is affected by a variety of geological, biological and environmental factors, and their distribution is often characterized by regionality and locality. However, based on existing data and knowledge, a general overview of the global distribution of ferric stromatolites can be made: as a special type of stromatolite, ferric stromatolites are mainly distributed in iron-rich seawater or sedimentary environments. These environments usually have specific geological conditions, redox environments and hydrodynamic conditions, which are conducive to the oxidation, deposition and enrichment of iron elements[20]. Therefore, the distribution of ferric stromatolites is often closely related to specific geological structures, sedimentary basins and paleogeographic environments.

North China is one of the important distribution areas of stromatolites in China, which may also contain ferric stromatolites. The Jixian National Geopark in Tianjin is endowed with abundant stromatolite resources, which may contain iron-bearing components[21]. The ferric stromatolites in the second member of the Cambrian Mantou Formation in the Weihui area of Henan Province are a typical example, indicating that similar ferric stromatolites may be distributed in other regions of China. Globally, ferric stromatolites may also be distributed in other countries and regions. Ferric stromatolites are likely to form in areas with iron-rich seawater or sedimentary environments and suitable geological and biological conditions.

4.2. Mineral Resource Exploration

Ferric stromatolites can serve as a direct indicator for iron ore exploration[22]. In the process of geological exploration, the existence and scale of iron ore deposits can be preliminarily judged by identifying and analyzing the distribution range, morphological characteristics and mineral composition of ferric stromatolites. The distribution law of ferric stromatolites can provide important directional guidance for iron ore exploration. By studying the genetic mechanisms and distribution characteristics of ferric stromatolites, the formation conditions and spatial distribution laws of iron ore deposits can be inferred, thereby guiding the deployment and implementation of exploration work[23].

Using ferric stromatolites for iron ore exploration can significantly improve exploration efficiency. By identifying and analyzing the characteristic information of ferric stromatolites, potential iron ore resource areas can be quickly locked, reducing the blindness and uncertainty of exploration work and improving exploration efficiency[24].

Promoting scientific research: The research on ferric stromatolites can also promote the development of related disciplines. In-depth research on the genetic mechanisms, evolutionary history and biological mineralization of ferric stromatolites can reveal scientific issues such as the evolution of early life on Earth, environmental changes and mineralization, providing new ideas and methods for the development of geology, biology, mineral resources science and other disciplines.

5. CONCLUSIONS

Ferric stromatolites are mainly formed by the interaction between the activities of microorganisms (e.g., cyanobacteria) and geological processes. Through their life activities such as photosynthesis and redox reactions, these microorganisms enrich and deposit iron elements in the environment, forming layered stromatolites. Therefore, ferric stromatolites are not only direct products of biological activities but also important records of environmental changes and biological evolution in geological history.

Ferric stromatolites often act as direct or indirect indicators of iron ore deposits. Their existence is closely related to the enrichment and distribution of iron ore resources. Thus, in iron ore resource exploration, ferric stromatolites can be used as an important prospecting marker to help explorers quickly locate potential iron ore deposits.

As an interdisciplinary research object of geology, biology, mineral resources science and other disciplines, ferric stromatolites have broad scientific research value. Issues such as their genetic mechanisms, evolutionary processes and their relationship with the formation of iron ore deposits are all hotspots and difficulties in current scientific research. We can conduct a general discussion and analysis of their distribution characteristics and influencing factors based on existing data and knowledge, and future research will further reveal the global distribution laws and geological significance of ferric stromatolites.

Ferric stromatolites have a close relationship with iron ore deposits, and as an important marker of iron mineralization and a geological phenomenon, they have important application prospects in iron ore resource exploration. In the future, with the continuous advancement and improvement of exploration technologies and research methods, ferric stromatolites will play an increasingly prominent and important role in iron ore resource exploration.

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REFERENCES

[1] Warren L A, Kauffman M E. Microbial geoengineers[J]. Science, 2003, 299(5609): 1027-1029.

[2] Wen Z F, Zhong J H, Guo Z Q, et al. Petrological characteristics and hydrocarbon reservoir properties of Tertiary stromatolites in the western Qaidam Basin[J]. Petroleum Exploration and Development, 2004, 31(3): 49-53. (in Chinese)

[3] Chen L Q. Stromatolite decline events[J]. Fossils, 2007(4): 21-23. (in Chinese)

[4] Lee J H, Chen J T, Chough S K. The middle-late Cambrian reef transition and related geological events: a review and new view[J]. Earth-Science Reviews, 2015, 145: 66-84.

[5] Fang Q F, Zhang H Q. A review of the effects of Earth system evolution on stromatolite decline[J]. Advances in Earth Science, 2014, 29(9): 1003-1010. (in Chinese)

[6] Riding R. Skeletal stromatolites[M]. Berlin: Springer-Verlag, 1977: 57-60.

[7] Su L, Chen L Q. Stromatolite decline events and molar-tooth carbonate event episodes: important clues to understanding the Precambrian carbonate world[J]. Geological Science and Technology Information, 2008, 27(6): 17-23. (in Chinese)

[8] Shi X Y, Zhang C H, Jiang G Q, et al. Microbially induced structures in Mesoproterozoic carbonates of the North China Platform and their hydrocarbon generation potential[J]. Geoscience Frontiers, 2008, 22(5): 669-682. (in Chinese)

[9] Cao R J, Yuan X L. Stromatolites[M]. Hefei: University of Science and Technology of China Press, 2006. (in Chinese)

[10] Chang Y G, Bai W B, Qi Y A, et al. Microfossil assemblages of Cambrian stromatolites in western Henan and their sedimentary environments[J]. Advances in Earth Science, 2014, 29(4): 456-463. (in Chinese)

[11] Li Q Q, Zheng D S. Characteristics and sedimentary environment analysis of stromatolites in the second member of the Mesoproterozoic Longjiayuan Formation in western Henan[J]. Geoscience Frontiers, 2022. (in Chinese, in press)

[12] Decho A W. Microbial exopolymer secretions in ocean environments: their role(s) in food webs and marine processes[J]. Oceanographic and Marine Biology: an Annual Review, 1990, 28: 73-154.

[13] Reid R P, Visscher P T, Decho A W, et al. The role of microbes in accretion, lamination and early lithification of modern marine stromatolites[J]. Nature, 2000, 406: 989-991.

[14] Noffke N, Gerdes G, Klenke T. Benthic cyanobacteria and their influence on the sedimentary dynamics of peritidal depositional systems (siliciclastic, evaporitic salty, and evaporitic carbonatic)[J]. Earth-Science Reviews, 2003, 62: 163-176.

[15] 15. Noffke N, Gerdes G, Klenke T, et al. Microbially Induced Sedimentary Structures: A New Category within the Classification of Primary Sedimentary Structures[J]. Journal of Sedimentary Research, 2001, 71(5): 649-656.

[16] Noffke N. Geobiology- a holistic scientific discipline[J]. Palaeogeography, Palaeoclimatology, Palaeoecology, 2005, 219: 1-3.

[17] Schieber J, Banerjee S, Bose P K, et al. Atlas of Microbial Mat Features Preserved in the Siliciclastic Rock Record[M]. Amsterdam: Elsevier, 2007.

[18] Noffke N. The criteria for biogeneicity of microbially induced sedimentary structures (MISS) in Archean, sandy deposits[J]. Earth-Science Reviews, 2009, 96: 173-180.

[19] Gerdes G, Klenke T, Noffke N. Microbial signatures in peritidal siliciclastic sediments: a catalogue[J]. Sedimentology, 2000, 47(2): 279-308.

[20] Shi X Y, Wang X Q, Jiang G Q, et al. Microbially induced mat structures in the Mesoproterozoic of the Helan Mountain area: sedimentary indicators of microbial community activity in the remote past[J]. Geological Review, 2008, 54(4): 575-586. (in Chinese)