Environmental Significance of Neoproterozoic Stromatolites

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Abstract

In geological history, the occurrence of major geological events is often accompanied by drastic changes in earth pattern and environment. The sedimentary record of stromatolites in Neoproterozoic strata is very extensive and provides much important information about the paleoenvironment and sedimentary processes. The Neoproterozoic strata of the North China Craton contain stromatolites, and the stratigraphy is time-constrained. By comparing multiple stromatolite-containing strata of the North China Craton, the development of stromatolites in the Neoproterozoic North China Craton has certain similarities, similarities and differences in rock characteristics and stromatolite types. Through the analysis of global stromatolite development in Neoproterozoic, we can see that stromatolites all over the world are in a stage of a large number of development, and there is a certain correlation between the macro and micro morphology of stromatolites and their formation environment. For example, EPS, etc., the types and activities of stromatolite-forming microorganisms also have corresponding influences on the formation of stromatolites, and the formation process of stromatolites is deeply influenced by environmental factors. The close relationship between the two is worth in-depth comparative study, and it provides important indicative significance for the global Neoproterozoic microbiolites.

Keywords

Neoproterozoic, paleoenvironment, stromatolites.

1. INTRODUCTION

In geological history, the occurrence of major geological events is often accompanied by drastic changes in the earth pattern and environment, and the co-evolution among structure, climate, ocean and ecological conditions plays a key role in the evolution of the Earth system. Neoproterozoic as a significant period of change in the history of earth evolution, a series of events related to earth evolution occurred. In different geological periods, global events selectively acted on microbial development and carbonate sedimentary characteristics. Stromatolites, as biogenic structures widely developed in pre-Cambrian carbonate rocks, are closely related to global events [1]. While the formation of stromatolites is influenced by the earth's environment, it can record a lot of information about the earth's climate, environment and early life evolution [2-3]. The early Neoproterozoic is a relatively stable period of global environment, and stromatolites are flourishing. The study of stromatolites and their close relationship with paleoenvironmental evolution is of great significance for further exploration of paleontological evolution and major global events in this period.

2. STRATIGRAPHIC AGE

In the Neoproterozoic strata, the sedimentary record of stromatolites is very extensive, providing a lot of important information about the paleoenvironment and sedimentary process.

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Stromatolites are developed in the Puyu Formation, Hejiazhai Formation and Luanchuan Group in the Neoproterozoic strata of the southern margin of North China Craton, and locally in the Jingeryu Formation in Yanliao Basin [4]. Stromatolites are produced in Tongjiazhuang, Fulaishan and Shiwangzhuang formations of Tumen Group in Luxi area, east margin of North China Craton. There are many kinds of stromatolites in southern Liaoning, mainly in Nanguanling Formation, Ganjingzi Formation, Yingchengzi Formation and Shisanlitai Formation of Wuxingshan Group [5]. Stromatolites are mainly developed in Badaojiang Formation in Jinnan area. Xuhuai area, southeast margin of North China Craton, has continuous stratigraphic preservation, well-developed stromatolites and high diversification, which makes it an ideal area for the study of Neoproterozoic microbiolites. Among them, stromatolites are widely distributed in Niyuan Formation, Jiudingshan Formation, Weiji Formation, Shijia Formation, Jiuliqiao Formation and Sidingshan Formation of Feishui Group and have been well studied [6].

The zircon U-Pb age from Jiudingshan Formation in Huaibei area is 919±12Ma[7,8], The calcite U-Pb age of the lower part of Weiji Formation is 1010±36Ma[9]; From the bottom to the upper strata of the Feishui Group in Huainan area are Shouxian Formation, Jiuliqiao Formation and Sidingshan Formation, of which the age of Shouxian Formation is <975Ma , and the age of upper Sidingshan Formation measured by chert Sm-Nd is 801±46Ma . The age of Jiuriqiao Formation should be ~975Ma ~800Ma [10]. The absolute age at the bottom of Badaojiang Formation in Jinnan area is 812Ma as measured by Sr and C isotope dating, based on the age (820Ma) of glauconite K-Ar from the Sihe Group in the Zhongjiang region of Korea, estimated that the assemblage is about 800 million years old[10]. These strata are close in age to the bottom of the Hejiazhai Formation in the Wufoshan Group.

Section Heading

3. ENVIRONMENTAL CORRELATION OF STROMATOLITES IN THE NORTH CHINA CRATON

The Neoproterozoic Jiuliqiao Formation mainly deposited a set of silty limestone and argillaceous limestone, rich in stromatolites, microsomes and macrosomes fossils [11]. The stromatolites of Jiuliqiao Formation mainly develop into columnar stromatolites, and the column bodies are long columnar, layer columnar, and can also be bifurcated. The stromatolites in the lower and upper strata are generally broken, while the stromatolites in the middle strata are generally complete and mostly long branched columns. The gravel between the stromatolite columns, as well as the breaking and bending of the columns, represent the products of the specific water depth environment that the storm can affect, so the change of sea level has an important control effect on the stromatolite [6]. In terms of microstructure, observation and study on the ultra-microstructure of the Jiuliqiao Formation stromatolites show that calcified globule bacteria and algal filaments exist in the Jiuliqiao Formation stromatolites, which are viscous with EPS and easy to capture detrite materials, thus promoting the formation of stromatolites, providing evidence for the existence of microorganisms in the early Neoproterozoic [12]. Formation experienced a process of rising and falling sea level. In the early stage of Jiuliqiao Formation, the sea water in Huainan area was shallow and no stromatolites appeared. In the middle period of sedimentation, Huainan area was a shallow sedimentary environment, where a large number of stromatolite reefs interexisted with storm sediments, and storm effects provided abundant oxygen and life elements for the growth and development of stromatolite-forming microorganisms. In the late sedimentation period, the sea level dropped, the storm weakened, macrobiotic and microplankton appeared, squeezed the growth space of stromatolite microorganisms, and stromatolite disappeared. The morphological characteristics of Jiuliqiao Formation stromatolites and stromatolite reefs reflect the response to environmental changes.

The study of the Jiudingshan Formation stromatolites mainly focuses on the conophyton-like stromatolites. According to the analysis of the Neoproterozoic conophyton-like stromatolites from the Jiudingshan Formation in northern Jiangsu, two types of microbial MATS forming conophyton-like stromatolites are revealed. Respectively are first microbial mat and succedent microbial mat. The initial microbial mat acts as a growth "bud" or mold during the formation of stromatolites. Inherited microbial MATS only serve to raise or enlarge stromatolites, and their development is often restricted by the environment [13]. The phototropism of the pyramidal stromatolites in Jiudingshan Formation is also discussed. The spatial distribution of the pyramidal stromatolites in high and low peaks is perpendicular to each other, and the development of algal MATS or the density of algal filaments in the wings of the pyramidal stromatolites in high peaks is asymmetrical. This phenomenon is related to the fact that cone stromatolites grow in weak dynamic flow environment and have strong phototaxis.

The Shisanlitai Formation is a set of gray and purplish red carbonate rocks with purplish red and gry-green mudstones, in which a large number of stromatolites, mainly Conophyton, are developed and abundant, and a large number of stromatolite reefs, mainly Conophyton, have appeared. The development of stromatolites has entered a flourishing stage, and the environment of the Shisanlitai Formation was in a strong oxidation environment when it was deposited. In the stromatolite assemblages of the Badaojiang Formation, there are many types of Baicalia, but Conophyton types also appear. The morphology of stromatolites is affected by the paleoenvironment, and different water conditions will lead to different morphology of stromatolites.

Stromatolites are widely distributed in the Neoproterozoic North China Craton, and there is a relationship between the structure of stromatolites and the evolution of sedimentary environment. Stromatolites developed in the Hejiazhai Formation of the Neoproterozoic Wufoshan Group, which were abundant and varied, reflecting the changes of water dynamics and sedimentary environment to a certain extent. The tidal flat environment of Hejiazhai Formation in Dengfeng area provides favorable conditions for the development of stromatolites, in which a large number of cone and columnar stromatolites grow in the intertidal and subtidal environments. The Jiudingshan Formation, Jiuliqiao Formation and Hejiazhai Formation are similar in the characteristics of stromatolites, such as the morphology of bedding structure, the characteristics of interlayer gaps, and the types and morphology of stromatolites. This suggests that they may have had similar sedimentary processes and sedimentary environments, and may have been influenced by similar hydrodynamic conditions and sediment sources. In the North China strata, a large number of stromatolite-forming microorganisms calcified, indicating that the Neoproterozoic North China Craton stromatolites are still at the peak of development, and the development trend is the same as that of the global microbiolites in the same period, with a good similarity. The presence of stromatolites does provide important clues to understanding the Cambrian "explosion of life." The surface environment of the earth has a significant influence on the evolution of complex eukaryotes, and the evolution of multicellular eukaryotes is closely related to the changes of atmospheric environment. As a key environmental factor in the evolution of complex multicellular eukaryotes, the role of oxygen cannot be ignored. Although there are different views on the exact value of oxygen content, there is no doubt that high oxygen content is essential for the activity of eukaryotes, providing the necessary support for their evolution [14,15].

The Neoproterozoic period experienced important changes in Marine chemistry and eukaryotic evolution. Geochemical analysis of major and trace elements and rare earth elements in carbonates of the Shisanlitai Formation in the Fuzhou Bay Section shows that the Shisanlitai Formation in the study area is a strong oxidizing Marine environment, which may represent atmospheric oxygenation events and seawater oxidation enhancement processes. The source of rare earth elements in the limestone is studied. The rare earth components of the limestone

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mainly inherit from the ancient ocean, and the distribution pattern of seawater rare earth elements is similar to that of the limestone. The sea water has high Y/Ho ratio, negative Ce anomaly, and δEuNASC value of sea water is less than 1, which indicates that the rare earth elements of Neoproterozoic sea water are similar to modern sea water. The content, trace elements, carbon and oxygen isotopes of dolomitic microbial limestone, micrite limestone and endoclastic limestone of Jiudingshan Formation were determined. Since the benthic microbial mat produces abundant oxygen through photosynthesis, it accumulates oxygen at the water-sediment interface and forms an oxygen-rich habitat. This local oxygen-rich oasis may provide a suitable environment for the future evolution of benthic animals [16]. This paper takes the early Neoproterozoic red layer deposits of Jiuliqiao Formation in Huainan area as the research object, and reflects the paleo-marine environment at that time through the analysis of carbon isotope chemostratigraphy and I/(Ca+Mg). I/(Ca+Mg) indicates the depositional environment of oxygen-poor suboxidation. The increase of oxygen level in the atmosphere-ocean system led to the increase of water oxidation level, which provided favorable conditions for the evolution of early Neoproterozoic organisms. Taking Neoproterozoic strata in Huainan and Huaibei areas as the research object, Guilbaud inferred the phosphorus and organic carbon burial fluxes through P and TOC, and learned that the phosphorus restriction condition of the early Neoproterozoic ocean maintained a low level of atmospheric oxygen [17]. According to the analysis of δ13C in the Majatun Formation and the Thirteen Litai Formation, the DOC decrease caused by oxidation began in the early Neoproterozoic, and the DOC decrease caused by oxidation began in the early Neoproterozoic. The dynamic reduction of large Precambrian DOC pools reflects the increase in oxygen content and the emergence of organisms in the Marine environment at this time [18]. It has implications for the carbonate environment where stromatolites were widely deposited in Hejiazhai Formation. In addition, the Neoproterozoic ocean was dominated by prokaryotes, and abundant chert was found in the Jiudinshan Formation in Xuhuai area, which preserved a large number of microbiological fossils, including filamentous and spherical cyanobacteria fossils. Formation generally develop microbiological algal MATS, but no eukaryotes are found in the benthic environment, which indicates that the benthic ecosystem of the shallow sea before the glacial period was mainly composed of prokaryotes. In the carbonate sediments of Tongjiazhuang Formation of Tumen Group in western Shandong Province, organic microne fossils have been found, and the microfossil assemblages are characterized by smooth spherical spiny heads and cyanobacteria filaments [19]. The rich types of stromatolites in the Hejiazhai Formation improve our understanding of the microbiolites in the southern margin of North China. Based on this, we use the study of stromatolites to explore the relationship between the large-scale microbiolites recorded in this period and the oxidation state of the atmosphere, shallow sea and biological development.

4. ENVIRONMENTAL INDICATORS OF NEOPROTEROZOIC STROMATOLITES

4.1. Stromatolites morphology indication

As the record of the oldest life forms on Earth, stromatolites provide indispensable reference information for our in-depth exploration of the Earth's past. Its unique recording method enables us to glimpse the life activities and environmental changes of the early Earth, which is of great significance for understanding the history of the earth. Stromatolites can indicate morphology and sedimentary environment, redox conditions and growth mechanism. Macromorphologically, the forms of stromatolites are rich and diverse. Taking Katav (Kt) and Lnzer (Ln) formations in the central Neoproterozoic Karatau Group in the South Ural region of Russia as examples, a large number of stromatolites are developed in these areas, especially Katav (Kt) formations, whose purple stromatolite reefs are unique. Reveals features of the environment at the time. [20]. Turner pointed out that the Neoproterozoic calcareous microbial

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reef ecosystem could respond to environmental changes when he studied the Neoproterozoic calcareous microbial reef in Mount Mackenzie, northwest Canada [21]. Microstructurally, deciphering the evolution of ecological interactions between metabolic types during the early diversification of life on Earth is critical to our understanding of the biosphere. The typical conical stromatolites are thought to be the result of competition between microbes for space, light, and nutrients. [22]. Conophyton stromatolites were abundant in the Neoproterozoic, and Conophyton is well documented from the Vazante Group of the San Francisco Craton (southern Brazil) and from the Mina Verdun Group of Uruguay (El Calabozo Group) with in situ fossil biofilms. Contains well-preserved carbonaceous materials [23]. The light gray layer alternates with the dark gray layer. The dark gray layer consists of three different biofilms that record the layered microstructure of the microbial community. The presence of cryptocrystalline apatite in the lowest biofilm may indicate past metabolic activity of sulphide oxidizing bacteria. It shows that the microorganisms achieve complex metabolic diversification, thus benefiting the entire microbial community. This means that stromatolites from the genus Conophyton may have formed due to the complexity of interactions between microorganisms, rather than just competition between photocooperative users [24]. Stromatolite-dolomitization is crucial for interpreting the traces of early life in the geological record. Neoproterozoic Dengying stromatolites appear dolomitization, preserving the biological evidence of stromatolites [25], using the characteristics of stromatolites, the Marine microbial growth environment of this period was explored.

4.2. The indication of redox conditions in stromatolites

The redox environment is closely related to the growth of stromatolites, so it is very important to study the oxidation of the atmosphere and ocean in Precambrian. In modern oceans, photosynthetic prokaryotes, Prochlorococcus, produce about 20% of the oxygen in the atmosphere through photosynthesis, which means that photosynthetic cyanobacteria play a pivotal role in oxygen generation and have a profound impact on the Earth's atmospheric environment [26]. Photosynthesis not only provides oxygen to the atmosphere and oceans, it also makes possible the emergence of complex life diversity. The growth process of stromatolites is closely related to photosynthesis, and the microbial communities preserved in stromatolites provide important information about atmospheric oxygen content. Cyanobacteria are considered to be a strong indicator of the presence of photosynthetic and phototaxis microorganisms in the Marine environment [27]. In addition, mineral precipitation and micritization in stromatolite-associated microbial MATS are mainly controlled by heterotrophic degradation of extracellular polymers and sulfate-reducing bacteria. Abundant microscopic filamentous and spherical structures have been found in the Neoproterozoic columnar stromatolites of the Jiuliqiao Formation in the southeast margin of the North China Craton. These structures are morphologically similar to EPS, filamentous and globular bacteria, and virus-like particles (VLP), thus providing further biological evidence of the biogenicity of Precambrian stromatolites and will provide clues in the search for more evidence of microbial life in ancient stromatolites. At present, it is generally believed that the Earth's surface layers remained stable between 800 and 1.8 billion years ago, which is called the boring billion years. The early Neoproterozoic period not only saw widespread stromatolites, but also witnessed major changes in ocean chemistry and the emergence of other biological species. Environmental changes affect the development of microorganisms [28]. The close correlation between stromatolite morphology and stratigraphic events is a key step in understanding the long-term evolution of the Earth biosphere. This will help us shed light on the Earth's surface environment and Marine environment in particular, and further analyze the extent of microbial interactions with stromatolites in early Earth. Through these studies, we can provide a crucial reference for the evolution of Marine environment, so as to have a more comprehensive

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understanding of the evolution process of Earth history and environment [29]. Therefore, it is of great significance to study the stromatolites of Hejiazhai Formation. The formation process of stromatolites is deeply affected by environmental factors, and the close relationship between the two is worthy of in-depth comparative study, which provides important indication for the global Neoproterozoic microbiolites.

5. CONCLUSION

The sedimentary record of stromatolites in Neoproterozoic strata is very extensive and provides much important information about the paleoenvironment and sedimentary processes. The Neoproterozoic strata of the North China Craton contain stromatolites, and the stratigraphy is time-constrained. By comparing multiple stromatolite-containing strata of the North China Craton, the development of stromatolites in the Neoproterozoic North China Craton has certain similarities, similarities and differences in rock characteristics and stromatolite types. The Neoproterozoic strata of the North China Craton contain stromatolites, and the stratigraphy is time-constrained. By comparing multiple stromatolite-containing strata of the North China Craton, the development of stromatolites in the Neoproterozoic North China Craton has certain similarities, similarities and differences in rock characteristics and stromatolite types. For example, EPS, etc., the types and activities of stromatolite-forming microorganisms also have corresponding influences on the formation of stromatolites, and the formation process of stromatolites is deeply influenced by environmental factors. The close relationship between the two is worth in-depth comparative study, and it provides important indicative significance for the global Neoproterozoic microbiolites.

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