WEP Warwick Evans Publishing

International Journal of Natural Resources and Environmental Studies

ISSN: 3006-2012 (Print), ISSN: 3006-0834 (Online) | Volume 5, Number 3, Year 2025
DOI: https://doi.org/10.62051/ijnres.v5n3.14
Journal homepage: https://wepub.org/index.php/IJNRES/index

# Characteristics of Terrestrial Microbial Mat-Example from Liujiagou Formation of Yiyang, Henan

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## ABSTRACT

In recent years, the research on Microbially Induced Sedimentary Structures (MISS) and their biogeological processes has developed rapidly, and has attracted the attention of many scholars. These studies are mainly concentrated in the marine Precambrian. There are few studies on the structure of terrestrial microbial mats. Therefore, this paper takes the terrestrial Liujiagou Formation as the research object, and describes and studies the mat growth structure (nodular protrusions, Kenyan ripples, reticular growth ridges), mat destruction (mainly various forms of dehydration cracks, mainly including: spindle, polygonal mesh, curved, dendritic dehydration cracks), mat decay (gas escape structure and sand volcano) in the study area in detail.

## KEYWORDS

Microbially Induced Sedimentary Structures (MISS); microbiological mat; Liujiagou Formation; terrestrial.

## 1. INTRODUCTION

Microorganisms, in its simplest definition, refers to all organisms at the microscopic level, which generally includes bacteria (including cyanobacteria), fungi, small algae and protozoa. Microbial communities (mainly cyanobacteria and diatoms) secrete mucus such as polysaccharides thereby forming an Extracellular Polymeric Substance (EPS).The EPS forms a protective, sticky substrate and adheres microorganisms to the substrate, resulting in the formation of a biofilm [1]. Biofilm is a thin sub-millimetre layer consisting of a population or community of microorganisms present in the EPS substrate. Biofilms are connected and adhered to the substrate through EPS in the water column and provide stability and accelerate metabolic reactions and act as a barrier to diffusion and a carrier for adsorption [2]. The microbial community settles on the sediment surface and forms a laminar body called microbial mat by bonding, barricading and trapping the sediment during their life activities [3]. Microbial mats are bio-sedimentary structures formed near the sediment-water interface by the interaction of the microbiota and their life activities with the sediment [4], and are an important product of the life activities of the microbiota. It is generally believed that microbial mats are the product of the continued development of microbial membranes, and the organisms that make up microbial membranes are relatively homogeneous, but microbial mats have a broader biodiversity. Although the thickness of microbial mats is small, they constitute a complex microbial ecosystem that is closely related.

From the mid-1990s to the present, with the deepening of research, sedimentologists have increasingly recognised that, in addition to stromatolites, microbes also form a type of primary sedimentary structures that do not protrude from the substratum and are considered to be the product of microbial mats or microbial membranes in conjunction with a variety of exogenous geological

forcings. This type of sedimentary structure is defined as microbially induced sedimentary structures (MISS), which are distinguished from stromatolites by the fact that they are not positive growth structures protruding from the stratigraphic level. MISS are the result of microbial communities interacting with the depositional environment and through the metabolism of microbial life, growth, destruction, decay and other processes that leave various bio-sedimentary structures in the sediments [5]. In this sense it can also be regarded as a kind of relic fossil in a broad sense [6]. At present, the reports and discoveries of MISS in China are mainly concentrated in the Precambrian in the marine phase, and they are found in both clastic and carbonatite strata. However, MISS in terrestrial phases are rarely reported. The Liujiagou Formation in the Yiyang terrestrial phase of West Henan is well preserved with more types of MISS. In this paper, by describing in detail the MISS developed in the Liujiagou Formation, it is found that there are three main types of microbial mat growth, mat destruction and mat decay in the Liujiagou Formation.

## 2. GEOLOGICAL SETTING

The Liujiagou Formation is located in Yiyang County, Luoyang City, Henan Province, and bel ongs to the North China Stratigraphic Zone-Yuxi Stratigraphic Division, which is the early Ear ly Triassic. The study section is located in the vicinity of Li Gou Coal Mine in Dayulin Villag e, Yiyang County, with good outcrops, dominated by purplish-red medium-fine-grained quartz sandstone and sandstone and mudstone interbedded with siltstone and mudstone, and is in a co nsolidated contact with its underlying stratigraphy, the Sunjiagou Formation, and the overburde ned Shangshanggou Formation, with a total stratigraphic thickness of about 114.07 m. It belon gs to the offshore, coastal shallow lagoonal terrestrial depositional environment [7]. The Yiyan g Liujiagou Formation is rich in sedimentary structures, including wedge-like and plate-like int erbedded laminae, parallel laminae and horizontal laminae, as well as facies structures such as ripple marks, dewatering cracks, and facies protrusions. Among them, dehydration cracks of va rious forms are the most common in the facies structures, which are mainly developed in the p laces where the muddy silty medium-fine grained sandstones interact with each other, and mos t of them are accompanied with wave marks.

## 3. MISS FEATURES OF LIUJIAGOU FORMATION

Nowadays, it is widely used that Schieber (2004) proposed a classification scheme to classify MISS in clastic rocks into five major categories based on the structures formed at different stages of the life development process of microbial mats (Fig. The five categories are: mat growth structure, mat metabolism structure, mat destruction structure, mat decay structure, and mat diagenesis structure. The five categories are: mat growth structure, mat metabolism structure, mat destruction structure, mat decay structure and mat diagenesis structure. Among them, the microbial mat destruction structure is the most common, while the microbial mat metabolism structure and diagenesis structure are not common.

The MISS of the Liujiagou Formation is mainly developed on the contact surface of purple-red or red sandstone and mudstone, distributed in the middle and lower sections of the Formation, and is often accompanied by wave scars, which are of various types, and can be macroscopically classified into mat growth (tumour-like protrusions, reticulated growth ridges, and Kenyan wave scars), mat destruction (dominated by dewatering cracks of various morphologies, including mainly fusiform, polygonal reticulation, curvilinear, and dendritic dewatering cracks), and mat decay (gas escape structures and sand volcanism). Gas escape tectonics and sand volcanism) related tectonics are three major categories [8], of which dehydration cracks of various morphologies are the most typical.

## 3.1. Mat Growth Structures

Microbial mat growth structure is a variety of structures formed on the sediment surface during the development of microbial mats as a result of changes in the life activities of the microbial community and in the mode and rate of growth. Microorganisms in the process of growth, the sediment barrier, capture and bonding effect, resulting in sediment enrichment; coated in the particles of the biofilm upward growth will lead to the upward transport of mineral particles and the reversal of the direction of the particles; biofilm will make the physical cause of the sedimentary structure has been strengthened, and preserved the original form, the formation of biofilm imprints; biological extracellular mucus on the sediment surface of the smooth effect, and microbial mats on the sediment surface closure, fixation, etc. are biostable. The smoothing effect of extracellular mucus on the sediment surface and the sealing and fixing effect of microbial mats on the sediments are important elements of biostabilisation. In addition, thick microbial mats also play a levelling effect on the sedimentary surface. In conclusion, the settlement and growth of microbial mats have led to the formation of many special types of sedimentary structures on the sediment surface. For example, microbial mats settled on the wave scar surface, whose softness and toughness can resist the erosion and the reaction force generated during the burial, have preserved the morphology of the sediment surface, and have generated a variety of wave scars related to the growth of microbial mats.

Elephant skin structure (Fig. 3A) has a ridge height of about 1 mm, and the peak at the cusp is higher than the ridge, with a peak height of 2-3 mm, which is often symbiotic with the wave scar, and develops at both the crest and the trough of the wave, and sometimes flattens the wave scar.

The verrucae are produced by local overgrowth of microbial mats, and are manifested at the level of dense verrucae varying from 0.5 to 1 cm, with low elevations, and are mainly developed in the middle and lower segments of the group (less so in the middle segments).

The Kenyan ripples (Kinneyia ripples) are thought to be ripple-like formations formed due to gases produced by decaying microbial mats that pass through the sub-mat connectivity, which are characterised by flat crests and steep valleys.

Reticulated growth ridges (Fig. 3F) are formed by fine sandy rondelles of the same basal lithology growing on the level intertwined with each other. The average ridge height of the growth ridges in the Liujiagou Formation in Yiyang, West Henan Province, is 1 mm, and at the intersection of different ridges, the ridge height can reach 3 mm, with an average ridge width of 1-2 mm.

## 3.2. Mat Decay Structures

Decay structure refers to a variety of structures formed in the sediment surface layer by the gas generated by the decay and decomposition of buried microbial mats [9]. The gas generated by the decay of microbial mats affects the sedimentary layer under the mats and the microbial mats themselves, forming gas domes, where a large number of gas bubbles can produce a wrinkle-like structure due to strong action, with flat crests and steep valleys, as in the case of the Kinneyia Wave Scratch. Our study of modern microbial mats also demonstrates this. If the surface of a microbial mat is not tough enough to resist the pressure generated by gas bubbles, the aeroclastic structures can break up and produce gas escape structures, such as the typical Astropolithon and small sand volcanos. The production of gas bubbles can also come from photosynthesis, such as the photosynthesis of the ball-shaped cyanobacteria on the tide to produce gas bubbles, when the gas rupture and other structures should be classified as the category of growth structures.

The mat-rotting structures developed in the Liujiagou Formation include gas escape structures formed when the gas produced by microbial growth or rotting and burying broke through the mat layer to form gas holes and then filled or flattened (Fig. 3N) and sand volcanoes (Fig. 3O). The sand volcanoes developed in the study area are small, with a height of 2 mm and a diameter of 4 mm, and are mostly coeval with corrugated escape structures.

### 3.3. Mat Destruction Structures

Microbial mat damage structure refers to a series of related structures, such as cracks, deformation and curling structures, formed after the microbial mat formation due to the physical and chemical damage caused by the exposure of the sedimentary surface layer or other factors, and the rupture (fragmentation), curling, deformation, folding, dehydration, or being transported to redeposit. The most typical of such structures are the various cracking structures, which produce various forms of dewatering cracks, ranging from isolated fusiform cracks to reticulated dewatering cracks, depending on the length of exposure time [10]. Such formations are sometimes simply referred to as sand cracks (sand cracks) due to their development in sandstones. This type of formation is the most found and easily recognisable category in the stratigraphy.

Fusiform dehydration cracks are mainly distributed in the middle and lower sections of the Liujiagou Formation, both at the wave marks and non-wave marks, and a large number of overlapping fusiform cracks formed through multiple dehydration processes also occur in this formation.

Curved dewatering cracks are a special kind of polygonal mesh dewatering cracks, which are mainly distributed in the lower section of the Formation and are less developed. The sand ridges are curved to a greater extent, forming irregular net-like, ring-like, near-ring-like or ‘8’ shapes interactively, and the width of the sand ridges varies from 0.2 to 1 cm.

The dendritic dewatering cracks are located in the middle section of the Liujiagou Formation, which is another special form of polygonal reticulated dewatering cracks, shaped like a dendritic structure, with a thick trunk and tiny branches forming a net. The sand ridges are millimetre wide and can be more than ten centimetres long.

The rolled-up edges of the structures (Fig. 3L) are less than 1 mm thick and small, and should belong to the in situ burial; the microbial mat fragments (Fig. M) have an average shaft length of 2-3 cm, and are in the form of elliptical or irregular flakes.

### 3.4. Distribution of MISS

The MISS developed in the Yiyang Liujiagou Formation is dominated by microbial mat-destruction related structures, especially the most dehydrated cracks. The different morphologies of dehydration cracks mainly depend on the length of mat exposure dehydration time and the thickness of the mat layer. Firstly, the morphology, the shorter exposure time will form incomplete cracks such as fusiform, and with the longer exposure time will form bird's-foot-like to complete type of reticulation cracks. In general, topographic relief and proximity to the shore determine the length of exposure time, and microbial mats that are landward and away from the shore are exposed for a long period of time and are prone to form complete dehydrated shrinkage cracks [12]. Secondly, the height and width of the sand ridges (cracks) are mainly related to the thickness of the microbial mat. In addition, the curvilinear dehydration cracks may be caused by the fact that the residual water in the wave valley during the exposure period can provide a more favourable growth environment for microbial mat development, and the formed microbial mats are thicker. Here, the distribution of MISS in the Liujiagou Formation is summarised as follows:

(1) From the lower section of the Liujiagou Formation, there are mat growth structures (tumour-like protrusions), mat decay structures (sand volcanoes and Kenyan wave scars), and mat destruction structures (a variety of dehydration cracks). Most of the mat growth structures occur in the muddy interlayers between quartz sandstones, on the demarcation line of quartz sandstones of different colours and between the layers of quartz sandstones rich in mud and gravel, which proves that the mat growth structures are easy to be deposited in the environment of hot climate and high humidity. The rocks in this section are mostly red and purplish-red, and the sedimentary materials are mainly sandy and silty sandy, and the stratigraphy developed from the bottom up is dominated by interlocking stratigraphy. Gradually changed to parallel laminations, which indicates that the

topography of the lake from steep to slow, wave action can not reach the shore, most of the medium - fine-grained sandstone slowly deposited, the formation of a set of parallel laminations of purplish red - red fine-grained quartz sandstone, with the change of the environment, a large number of microorganisms (cyanobacteria) are active, but also because there is no posthabitat animals gnawing and destruction, intermittent exposure time is longer, there is enough water replenishment, moderate sedimentation rate and basal settling speed, and the ability to be buried in time, etc., which made the sandstone particles bonded and captured to form microbial mats and preserved them.

(2) Compared with the lower section, the middle section of the Liujiagou Formation has more ripples, and a thicker layer of red fine-grained sandstone with part of the mud and gravel has appeared, and there are various shapes of dewatering cracks on the level of the mat-growing structure (microbial mat layer) and mat-destroying structure, and there are more mat-destroying structures than mat-growing structures, which indicates that the mat-growing structures are not easy to be preserved, and the mat-growing structures are supposedly inhibited because of the different degrees of damage caused by the changes in the natural environment. It is believed that the natural environment changes have caused different degrees of damage and inhibited the formation of mat growth structures. In addition, the development of mat destructive structures has gradually changed from fusiform dewatering cracks to reticulate dewatering cracks, which indicates that the exposure time of the microbial mats was gradually increasing, and the lake was gradually becoming shallower. In the upper part of the section, the colour of the stratum gradually deepened from old to new rock layers, changing from red to purple-red, and several groups of fine-grained-medium-grained-fine-grained small-scale cyclic deposits were formed in the change of grain size, with less mat growth (verruca) and basically disappeared of the decay structure; most of them are small and medium-sized mat destroying structures, such as some wide polygonal reticulation cracks and fusiform dewatering cracks superimposed after many times. It indicates that the Binhu continued to become shallow in this stage, the sediments were more easily oxidised, and a large amount of $Fe^{2+}$ in the sandstones was oxidised to $Fe^{3+}$, which was purplish-red in colour, and only some mat-damaged structures with more aggregates were preserved in the upper part of this section [13].

(3) The upper section of the Liujiagou Formation is a set of medium-thickly bedded greyish-red medium-coarse-grained quartz sandstones containing a large amount of mud and gravel, with wedge-shaped interbedded laminations. The sandstone is poorly sorted, mostly medium-grained sandstone; the mud gravel is poorly rounded, and many mud gravel holes are left behind by the shedding of muddy sediment in some mud gravels, which should be the sediment brought by the river of the near source, and the water body becomes deeper, the oxidation ability becomes weaker, and the overall colour is greyish-red. This proves the process of dry climate and lake to land transformation at that time, i.e. deltaic environment [14].Summary

## 4. CONCLUSION

The MISS of the Lower Triassic Liujiagou Formation is mainly developed in the middle and lower sections, and is macroscopically divided into three major categories: microbial mat growth, microbial mat destruction, and microbial mat decay tectonics, with mat destruction tectonics predominating, and especially various forms of dewatering fractures being the most numerous. From old to new strata, the dehydration cracks with various forms are gradually changed from fusiform to reticulated cracks, which indicates that the depositional environment was mainly shallow water phase, indicating that the depositional environment was coastal shallow sea or coastal shallow lake at that time; combining with the results of the previous research in the southern part of North China, which has entered the terrestrial phase of deposition from the Late Permian, it is believed that the Yiyang Liujiagou Formation is a subphase of deposition of the lakeshore and coastal shallow lake.

## CONFLICTS OF INTEREST

The authors declare that they have no conflict of interest.

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