

Calcimicrobes in the Dendrolites of the Changshan Formation in the Zhi Dongyu Section

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Abstract: Microbial carbonate rocks are classified into stromatolite, dendrolites, thrombolite, and leiolite based on their mesoscale features. Additionally, there are also oncolite and laminite. Based on field exploration sampling and combined with indoor thin section analysis, dendrolites was observed in the Changshan Formation of the Cambrian period in the Zhi Dongyu section of Shandong. It has a thickness of approximately 75 meters and, together with blocky oolitic grainstone, forms the upper part of a third-order depositional sequence that constitutes a late highstand systems tract (LHST). Macroscopically, obvious branching clots can be observed in dendrolites, while microscopically, the development of various calcifying cyanobacteria such as *Girvanella*, *Epiphyton* and *Hedstroemla* can be seen. In terms of Chronostratigraphy, microbial reefs dominated by dendrolites are relatively rare in the Furong Formation's Changshan Formation. Therefore, this study provides an important example for the subsequent research on dendrolites in the Changshan Formation. Additionally, the discovery of *Epiphyton* in the Changshan Formation contradicts the claim that they were extinct during the Late Ordovician mass extinction. What is more, the abundance of *Hedstroemla* also raises doubts about the previous belief that *Epiphyton* dominate the formation of dendrolites clots, emphasizing the importance of *Hedstroemla* in the formation of dendrolites clots.

Keywords: Dendrolites, *Hedstroemla*, Changshan Formation

1. Introduction

The term "dendrolites" was initially proposed by Riding [1]. Dendrolites has a macroscopic centimetric bush-like fabric, which distinguishing it from leiolite. The lack of lamination distinguishes it from stromatolite. The most remarkable feature of dendrolites is its clots that are entirely related to microbial activity, which sets it apart from thrombolite. *Epiphyton*, a dominant cyanobacterium in the formation of dendrolites, first appeared near the Precambrian-Cambrian boundary and was widely distributed in Cambrian shallow-water reef limestones, briefly reappearing in the Upper Devonian conodont bioherms [1]. Chen Jitao et al. [2] inferred the extinction of *Epiphyton* in the Late Cambrian based on the characteristics of the bioherms in the third member of the Cambrian in the North China Platform. Dendrolites in the Changshan Formation of the Furongian Stage in the Zhidongyu section of the North China Platform exhibits distinct shurb-like clots at the macroscopic level and bush-like *Epiphyton* and *Hedstroemla* at the microscopic level.

The abundant development of *Hedstroemla* indicates its importance in the construction of dendrolites clots, and the presence of *Epiphyton* also challenges the previous assertion of its near extinction in the Furongian Stage. The aim of this study is to clarify the microfacies and macroscopic features of the Cambrian Changshan Formation in the Zhidongyu section of Shandong through field investigations and microscopic identification. This research aims to provide a relatively typical example for understanding the growth patterns and formation mechanisms of dendrolites.

2. Geological Setting

The North China Platform began to undergo deposition roughly in the Late Cambrian Epoch II, and the Cambrian Epoch II strata overlie pre-Cambrian strata from different periods, forming a "giant unconformity" similar to the North American platform [3]. The Furongian Stage of the North China Platform includes the Changshan Formation and Fengshan Formation [4]. The Zhidongyu section is located in

the area of Zhidongyu Village, west of Kongcun Town, in the southern part of Pingyin County, Jinan City. It extends northwest along the highway, with a general dip angle of 0 to 5 degrees. The Changshan Formation is well exposed along the highway and is characterized by microbial reefs dominated by dendrolites. The Changshan Formation consists of a three-level sedimentary sequence, namely the Lower-Middle (L-M) type cyclical sequence composed of thick-bedded marl and thin-bedded laminated marl with mudstone bands, with a thickness of about 10 meters, forming the condensed section (CS) unit of the three-level sequence; the middle part is composed of thick-bedded marl and thin-bedded laminated marl with mudstone bands, with a thickness of about 20 meters, forming the early highstand systems tract (EHST) of the three-level sequence; The upper part consists of dendrolites dominated microbial reef limestone, which is light gray and white in color, with interbedded blocks of 2-3 meters in thickness. It is also composed of several layers of blocky oolitic grainstone with a total thickness of about 75 meters,

forming the late highstand systems tract (LHST) of the three-level sequence. From a stratigraphic and chronological perspective, the occurrence of dendrolites-dominated microbial reefs in the Changshan Formation of the Furongian Stage is relatively rare. Therefore, the analysis of dendrolites in the Changshan Formation of the Furongian Stage in this study will provide an example for the research on dendrolites in the Furongian Stage.

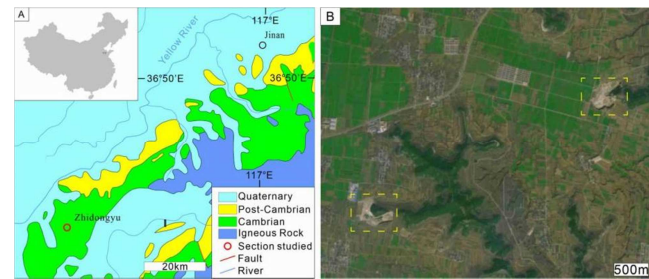


Figure 1. Location map of the Zhi Dongyu section.

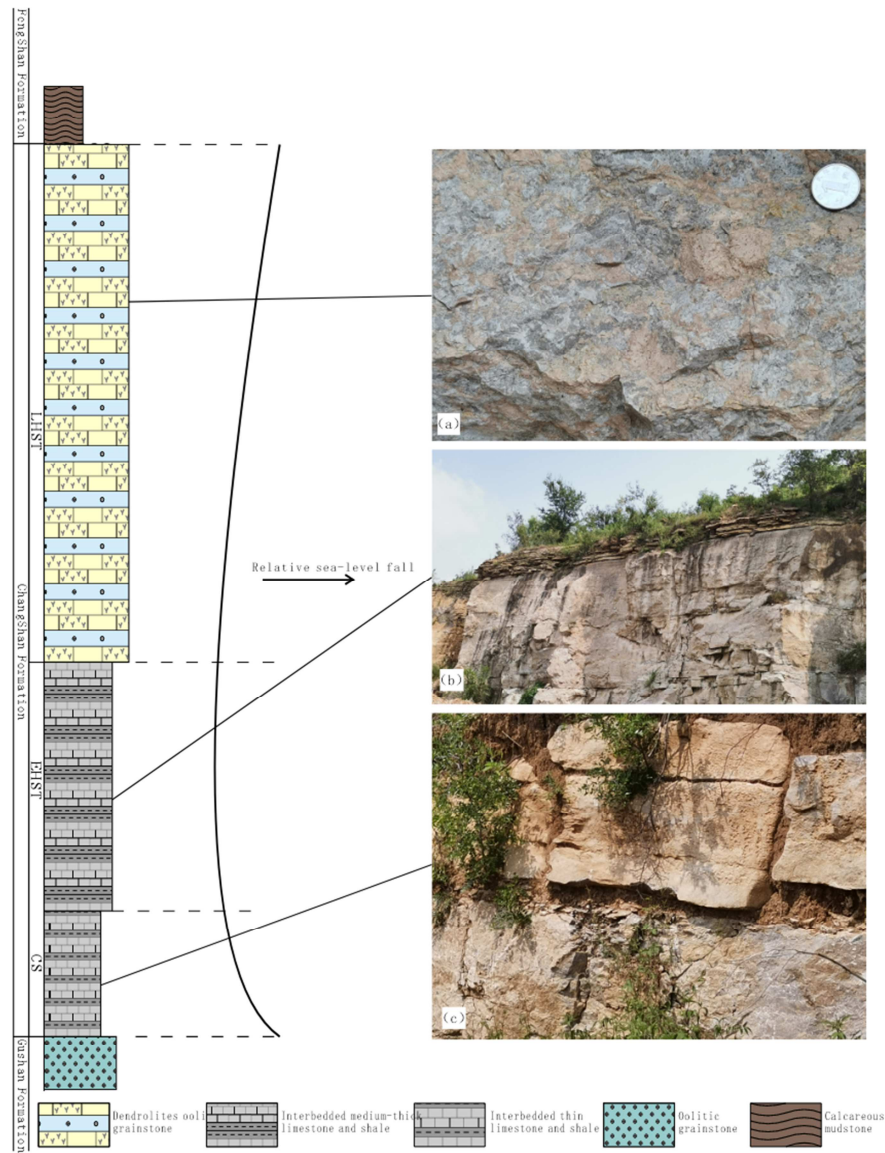


Figure 2. Sedimentary sequence of the Changshan Formation in the Zhi Dongyu section.

3. Macroscopic Feature

The dendrolites in the Zhidongyu section are macroscopically characterized by shrub-like clusters growing on a gray-white mud crystalline matrix. The branches of the clusters show obvious directionality, and the interstitial spaces between the mud crystalline matrix are filled with a large amount of pale yellowish-gray mud material. This may represent the paleogeographical pattern of relative sea-level changes between the late-stage local deep-water environment and shallow-water environment of the dendrolites microbial reef.



Figure 3. Macroscopic characteristics of dendrolites in the Changshan Formation of the Zhi Dongyu section.

4. Microscopic Feature

Corresponding to the macroscopic dendrolites clusters growing on the gray-white mud crystalline matrix, the dendrolites in the Zhidongyu section exhibit, at a microscopic level, the growth of *Epiphyton* and *Hedstroemla* shrubs on a dense mud crystalline substrate. Corresponding to the gray-white mud crystalline matrix are the dense mud crystalline substrate and the *Girvanella* growing within it.

4.1. *Epiphyton* Groups

The centimeter-scale dendrolites large clusters of dark mud crystalline bundles shown in Figure 3 correspond to the dense *Epiphyton* groups preserved in high density. Under the microscope, these dark mud crystalline bundles are composed of fossilized branched *Epiphyton*, with the most typical being the type I branched *Epiphyton* described by Woo [5]. They exhibit a typical dichotomous structure, with their filamentous or tubular branches filled with dark mud crystalline matrix, with a diameter of about 60μm and a length of about 500μm. These branched *Epiphyton* form shrub-like colonies (Figure 4-a, Figure 4-c, Figure 4-e), growing in dense mud crystalline or slightly bright crystalline matrix. They are adjacent to *Gordonphyton*, *Girvanella*, and are always filled with bright crystalline calcite cement in the gaps between the dichotomous filamentous structures. In thin section observations of dendrolites, two other commonly identified fossils are recognized within the fossilized fungal assemblages: (1) *Gordonphyton*: (Figure 4-a, Figure 4-b, Figure 4-d), described by Woo [5] as type II *Epiphyton*.

Gordonphyton are characterized by their distinct septa, with a diameter thicker than that of *Epiphyton*, about 80μm, and a length of up to 500μm, forming shrub-like structures. (2) *Korilophyton* (Figure 4-e, Figure 5-a, b, Figure 5-f), described by Woo [5] as type III *Epiphyton*. *Korilophyton* is composed of mud-like short-branched filamentous or tubular structures, with a diameter only half that of *Epiphyton* and *Gordonphyton*, about 30μm, and a shorter length, about 90μm, forming shrub-like structures. They are adjacent to *Hedstroemla* and are similar to *Epiphyton*. *Gordonphyton* and *Korilophyton* also grow on mud crystalline and slightly bright crystalline matrix, with gaps between the dichotomous filamentous structures also filled with bright crystalline calcite cement. Although there are still many uncertainties, such as the issue of the biological affinity of *Epiphyton*, it is generally considered that *Epiphyton* and *Korilophyton* can be analogized to modern true-branched filamentous cyanobacteria such as *Stigonema* [6]. Comparing *Gordonphyton* to the residual calcification of calcium carbonate sheaths of modern pseudo-branched and segmented filamentous cyanobacteria such as *Tolypothrix* is more reasonable [7]. Particularly, in the Changshan Formation of the Zhidongyu section, some completely bright crystallized *Epiphyton* (Figure 4-h) have been discovered. The *Epiphyton* are distributed in the dark mud crystalline matrix in a shrub-like manner, exhibiting clear dichotomous structures, representing a relatively strong hydrodynamic environment and complete diagenesis at that time. Among them, the typical foggy core with bright edges represents the precipitation of dolomite in the organic diagenetic microenvironment [3].

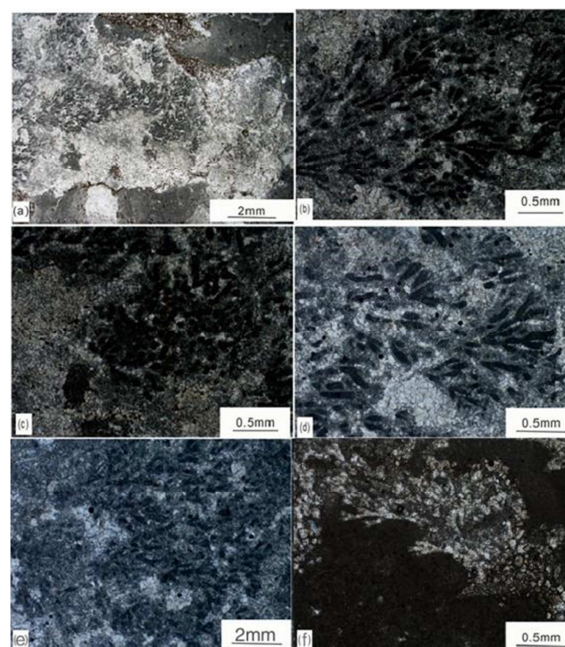


Figure 4. *Epiphyton* in the dendrolites of Changshan Formation of the Zhi Dongyu section. (a): Bushy *Epiphyton* and *Gordonphyton* combination in the Changshan Formation. (b): Bushy *Gordonphyton* in the Changshan Formation. (c): Bushy *Epiphyton* in the Changshan Formation. (d): Magnification of Figure b, showing clear separation of *Gordonphyton*. (e): Bushy *Korilophyton*. (f): Mineralized *Epiphyton*.

4.2. *Hedstroemla*

In addition, within the small and medium-sized centimeter-scale cluster-like bundles of dark mud crystalline composition in the dendritic stones, *Hedstroemla*, described by Woo [5] as type IV *Epiphyton* are also developed. They are characterized by: (1) branched tubes; (2) fan-shaped bundles in longitudinal section; (3) radial upright growth; (4) adjacent tubes may share common walls or septa [1]. These calcified *Hedstroemla* have a diameter of about 20-30 μ m and form chamber-like colonies (Figure 5-a, Figure 5-b) and

shrub-like structures (Figure 5-c), adjacent to Korilophyton (Figure 5-a, Figure 5-b). In the observation of dendrolites in the Changshan Formation, *Hedstroemla* account for nearly half of the calcified cyanobacteria. *Hedstroemla* are a well-established analogy to modern calcified cyanobacterial fossils known as *Rivulariaceae* [1], which are advanced nitrogen-fixing cyanobacteria with heterocysts [8]. A typical characteristic is the radially arranged, hair-like filamentous structures facing the surface of the *Rivulariaceae* colony [9].

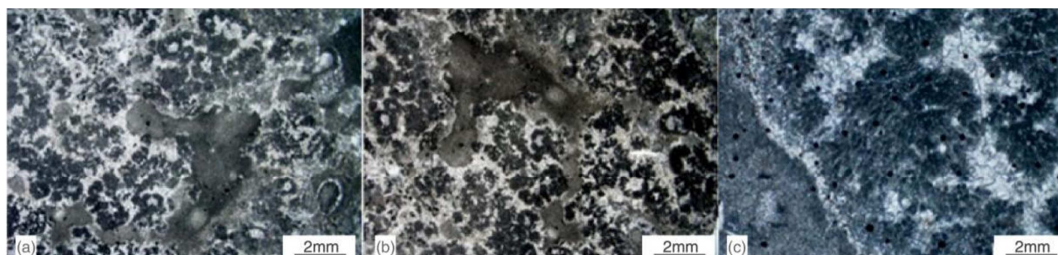


Figure 5. *Hedstroemla* in the dendrolites of in the Changshan Formation of the Zhi Dongyu section. (a) (b): Large colonies of *Hedstroemla* and a small amount of *Korilophyton* in the Changshan Formation. (c) Bushy colonies of *Hedstroemla* in the Changshan Formation.

4.3. *Grivanella*

Additionally, within the dense dark mud crystalline and slightly bright crystalline matrix, *Grivanella*, which symbiotically coexist with branched *Epiphyton*, can be observed (Figure 6-a, Figure 6-b, Figure 6-c). These *Grivanella* are densely distributed in a bundle-like manner,

with thin (1-2 μ m) dark mud crystalline walls forming non-branched tubular or filamentous structures. The diameter of the tubes is relatively thin (less than 10 μ m), but they are relatively long. Together with the dense mud crystalline matrix, they form the growth substrate for *Epiphyton* and *Hedstroemla*. They are classified as *Subtifloria*, analogized to modern *Microcoleus* [1] or *Coleofasciculus* [10].

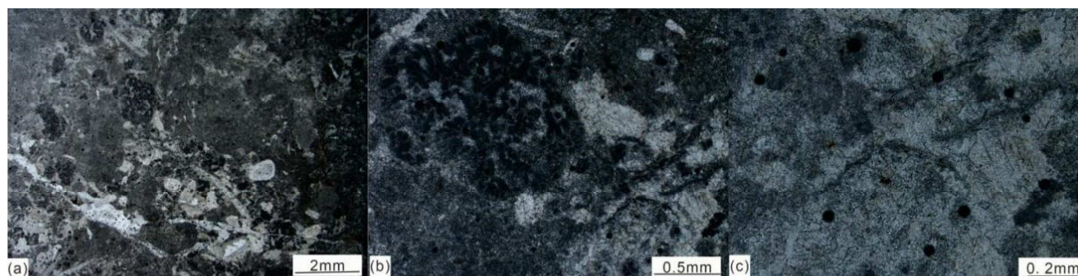


Figure 6. *Grivanella* in the dendrolites of Changshan Formation of the Zhi Dongyu section. (a): Symbiosis between *Epiphyton* and *Grivanella* in the Changshan Formation. (b): Magnification of Figure a. (c): Magnification of Figure b.

5. Discussion

Similar to the research conducted by Suosaari [11] on the living dendrolites microbial mats in the high-salinity brackish lake Hamelin Pool in Shark Bay, Western Australia, and Bradley [12] on dendritic cones in hot spring deposits, the dendrolites structures in the Changshan Formation of the Cambrian in the Dongyao Quarry section are also dominated by diverse filamentous microbes [13]. The growth of tree-shaped microbial mats, co-dominated by *Epiphyton* and *Hedstroemla*, occurs on the dense mud crystal and substrate provided by *Gevanella*. The presence of in *Epiphyton* the Changshan Formation contradicts the notion that they gradually went extinct during the Late Cambrian. There has

been a long-standing debate regarding the biological affinity of *Epiphyton* [7], particularly whether they can be classified as cyanobacteria or filamentous cyanobacteria. This study combines previous research [7] and microscopic observations of the obvious directional growth of *Epiphyton* (which may represent *phototaxis* similar to cyanobacteria) to interpret them as a type of filamentous cyanobacteria. The black spots observed in the dense mud crystal represent possible remnants of pyrite, indicating the involvement of sulfate reduction in the cyanobacterial calcification process. Therefore, the possible mechanism of dendrolites formation involves the dominant role of bushy *Epiphyton* and *Hedstroemla* in the formation of tree-shaped microbial mats. The microbial community captures and binds calcium carbonate through extracellular polymeric substances (EPS), microbial films, and microbial

mats. Under diagenetic processes, this leads to in situ carbonate precipitation, ultimately forming dendrolites structures. During this process, microbial-induced organic mineralization leads to cyanobacterial calcification. The specific mechanism involves the microbial regulation of the surrounding microenvironment's pH through photosynthesis [14], inducing the precipitation of calcium carbonate. It is widely believed that this process requires the assistance of a carbon-concentrating mechanism (CCM), which enhances the efficiency of photosynthetic organisms in utilizing carbon dioxide, triggered when carbon dioxide levels drop below 10 PAL (present atmospheric level). However, as the first period of the Phanerozoic Eon, the Cambrian had a higher carbon dioxide content, reaching up to 25 times the present atmospheric level [7]. In this scenario, the abundant occurrence of calcifying cyanobacteria can be attributed to the increase of divalent calcium ions in seawater due to a major unconformity between the Pre-Cambrian and Cambrian periods [7]. As Dupraz [15] said, "The biggest challenge is to translate all these processes and products from fossil records, especially through diagenetic filters." Further details on the evolution of dendrolites need to be discussed in the future.

6. Conclusions

The development of dendrolites in the Changshan Formation of the Cambrian period in the Zhidongyu section is relatively rare. Macroscopically, the dendrolites exhibit distinct shrub-like clusters. At the microscale, *Epiphyton* and *Hedstroemla* play a dominant role in constructing tree-shaped microbial mats, thereby forming dendrolites structures. The abundance of *Hedstroemla* contradicts the claim that they were extinct during the Late Ordovician mass extinction, suggesting their ability to thrive under certain environmental conditions. The widespread distribution of *Hedstroemla* emphasizes their importance in dendrolites structures, providing additional evidence to the previous notion that *Epiphyton* were solely responsible for the formation of dendrolites colts.

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