DOI：10.19800/j.cnki.aps.1997.03.002
第 36 卷第 3 期
1997 年 7 月
古 生 物 学 报
ACTA PALAEONTOLOGICA SINICA
Vol.36, No.3
July, 1997

华南黔中震旦纪陡山沱组磷质叠层石礁和与其相关的微生物化石*

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提 要 黔中震旦纪陡山沱组磷质叠层石礁主要分布在温泉、沙坝土和马路坪 3 个矿区，其中的磷质叠层石多半是柱状的，可分为 3 种类形，即 *Gymnosolen* sp.，*Inzeria* sp. 和未定名形。这 3 类叠层石均含丰富的微化石，分别包含 3 个叠层石微群落。研究表明，成礁期间黔中不同矿区似乎存在不同的微环境带，每个微环境带以某些独特的蓝藻菌微群落为特色，而微群落的变化又对叠层石的外形产生深奥的影响。叠层石形态学的变化可能是微群落变化的反应，似乎与环境的变化同时发生。

关键词 叠层石礁 微群落 震旦纪陡山沱组

PHOSPHATIC STROMATOLITE BIOHERMS AND ASSOCIATED MICROBIAL FOSSILS FROM THE SINIAN DOUSHANTUO FORMATION, CENTRAL GUIZHOU, SOUTH CHINA

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Abstract The phosphate-bearing strata containing phosphatic stromatolite bioherms of the Sinian Doushantuo Formation are mainly distributed in Wenquan, Shabatu and Maluping mining areas of central Guizhou. In these bioherms, there are numerous columnar stromatolites which can be classified into three forms, namely, *Gymnosolen* sp., *Inzeria* sp. and an unnamed form. These phosphatic stromatolites often contain abundant well-preserved microfossils and small numbers of microfossil-like objects. Each morphologically distinct stromatolite form was found to have a unique microbial composition or stromatolite microcommunitie. The present data suggest the existence of different small-scale environmental conditions in three mining areas during formation of stromatolite bioherms. Environmental fluctuation may well have affected the composition of microcommunities. Changes in microfossils within phosphatic stromatolites possibly reflect changes in the original microcommunities, and in some instances, such changes happened to have taken place simultaneously with changes in environment and gross morphology of individul stromatolites.

Key words: Stromatolite bioherm, microcommunity, Sinian Doushantuo Formation

1 INTRODUCTION

A bioherm is a circumscribed organo-sedimentary structure whose minimum width is less

* 国家自然科学基金(No.49372073)资助课题。

than or equal to one hundred times its maximum thickness, embedded in rocks of different lithology (Walter, M. R., 1972). Stromatolite bioherms include composite structures of stratiform, nodule-like, columnar-layered, or columnar stromatolites, or some combination of such forms, together with associated clastic or chemical sediments (Semikhatov, M, A. *et al*., 1979).

Phosphatic stromatolite bioherms are found in the phosphate-bearing strata of the Sinian Doushantuo Formation in the Xifeng-Kaiyang region of central Guizhou. In these bioherms, there are numerous columnar stromatolites which can be classified into at least three forms, namely, *Gymnosolen* sp., *Inzeria* sp. and an unnamed form. Differences in stromatolite morphology are marked from north to south. *Gymnosolen* sp. usually forms tabular bioherms which occur within the northern phosphatic sequence in the Wenquan mining area. But lenticular bioherms consisting of *Inzeria* sp. and the unnamed form and some irregular bioherms formed by an individual stromatolite occur within the southern phosphatic sequence in the Shabatu, Maluping, and Niuganchong mining areas, and are thinner than their counterparts to the North. In addition, these phosphatic stromatolites often contain abundant well-preserved microfossils and small numbers of microfossil-like objects. Each morphologically distinct stromatolite form was found to have a unique microbial composition dominated by one morphotype of filamentous microfossils or dubious microfossils. This paper describes morphological features of bioherms, stromatolites and microbial fossils within them, and provides valuable materials for determining the possible relationships among microorganisms, environment and stromatolite morphology.

The specimens of phosphatic stromatolites described here were collected by the author together with his colleagues in the Xifeng-Kaiyang region during geological investigations in 1990.

2 STRATIGRAPHY AND OCCURRENCE

A well-exposed succession of the Sinian system, approximately 1 000m thick, has been established as the stratotype for the Terminal Precambrian of South China in the Yangtze Gorges near Yichang, Hubei Province (Zhao Ziqiang *et al*., 1988). In South China, the Sinian system is generally acknowledged as overlain conformably by the Early Cambrian Meishucun Formation (Yu Wen, 1987). The Chinese geologists are not in agreement on the position of the basal boundary of the Sinian system (Cao Ruiji *et al*., 1982). In this paper, the base of the Nantuo Formation (the Latest Precambrian glacial moraine) is considered as the base of the Sinian, in accordance with views of Cao *et al*. (Cao Ruiji *et al*., 1988). The subdivision of the Sinian system in the Yangtze region, like those in other regions of South China, is tabulated as follows:

Table I Nomenclature and relationships of formations in the Sinian system in the Yangtze region, South China

Lower Cambrian	Meishucun Formation
Sinian System	Dengying Formation
	Doushantuo Formation
	Nantuo Formation
Presinian	Liantuo Formation

Based on the radiometric age data available, Sinian rocks from the Yangtze Gorge section give a Rb-Sr isochron age of 693±29 and 700±5 Ma ($\lambda Rb^{87} = 1.42 \times 10^{-11} Y^{-1}$) separately for the carbonaceous shale, marlite and mud-dolomite in the Doushantuo Formation (Xing Yusheng, 1984) and of 740±16Ma for zircons within the tuff in the upper part of the Liantuo Formation.

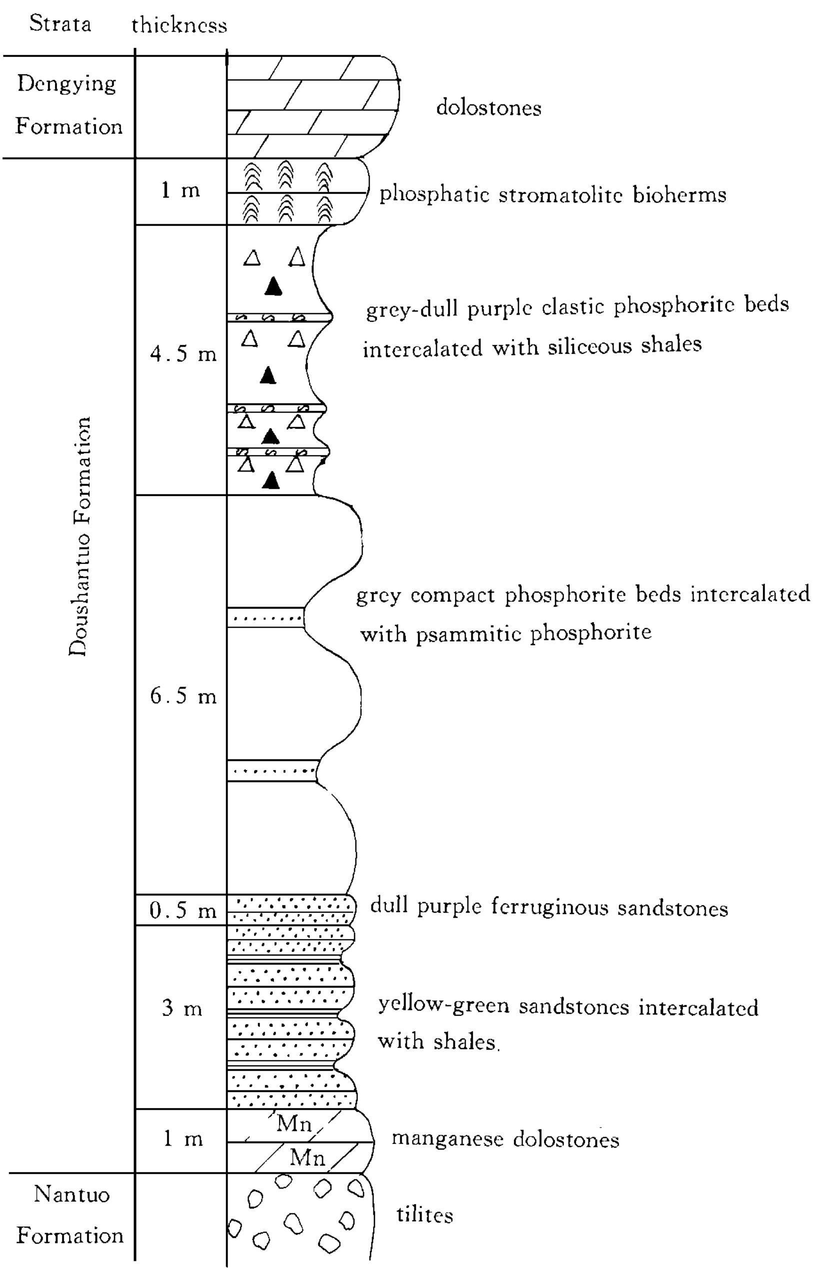
In the Yangtze Gorge region, the Doushantuo Formation ranges from 40 to 200m thick, and includes sandstone, shale, carbonate rocks, chert and phosphorite. However, in the Xifeng-Kaiyang region, central Guizhou, the Doushantuo Formation ranges from 10.5 to 146m thick, and is mainly composed of shale, siliceous rocks, sandstone, dolostone and phosphorite. The phosphatic stromatolite bioherms are restricted to the top and upper part of the phosphate-bearing Doushantuo Formation (Text-figs. 1, 2). These bioherms extend discontinuously and laterally over a considerable distance (more than thirty km) within the Doushantuo Formation. The best preserved phosphatic stromatolite bioherms occur in phosphorites in the Wenquan, Shabatu, and Maluping mining areas in the Xifeng-Kaiyang region (Test-fig. 3). It should be noted that these deposits are usually considered as part of the major phosphorites of South China (Ye Lianjun *et al*., 1989).

3 DESCRIPTION

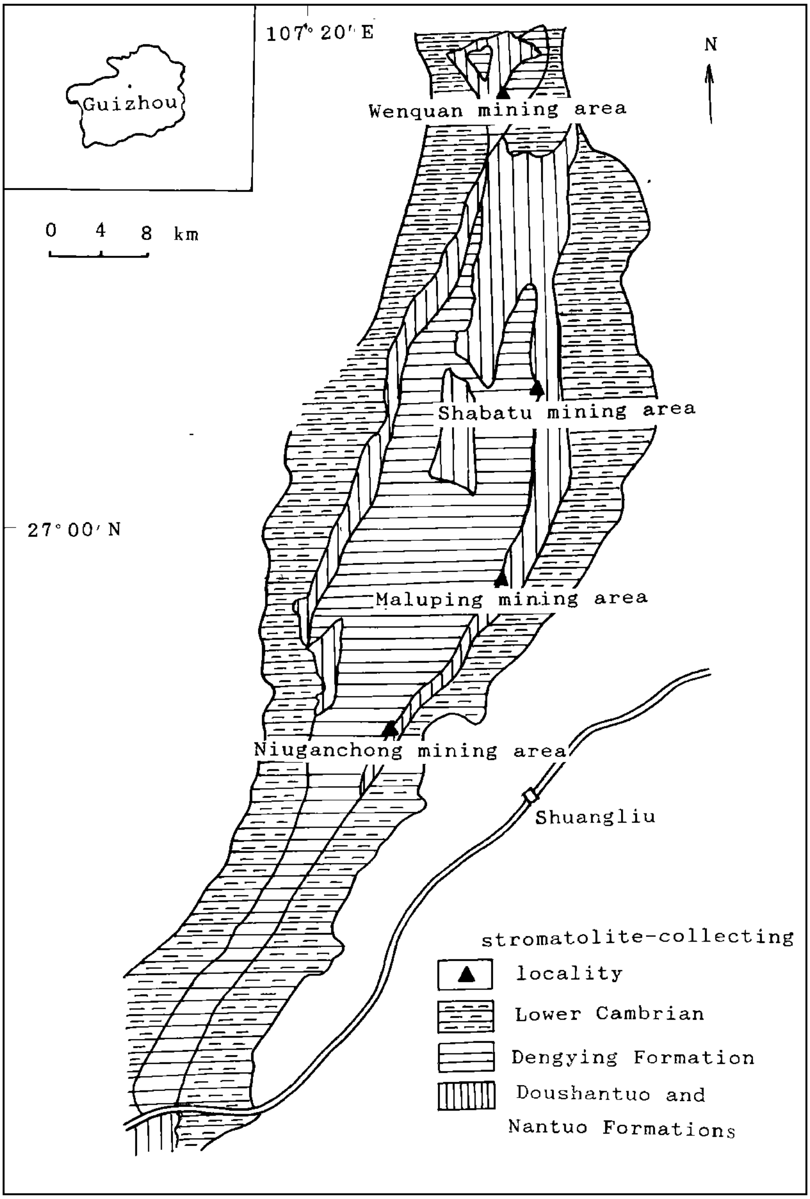
3.1 Bioherms: Bioherms in the Xifeng-Kaiyang sections are generally brown-grey. They are dominated by phosphatic stromatolite columns and phosphatic sand grains. All the bioherms are invariably associated with phosphatic sand grains, which not only fill the intercolumnar spaces, but also occur in laminae of the stomatolites. The stromatolite columns and the intercolumnar sediments are approximately equal in chemical composition (Table Ⅰ). In the Xifeng-Kaiyang region, these bioherms themselves are a kind of rich ore, with P_2O_5 in the stomatolite phosphorite amounting to more than 35%.

In the Wenquan mining area of Xifeng-Kaiyang region, the Doushantuo Formation is chiefly made up of dolostones, sandstones and phosphorites, with a thickness of 16.5 m. The phosphatic stromatolite bioherms consisting of *Gymnosolen* sp. occur in uppermost beds of the formation. Here, these bioherms cover an erosional surface on grey-dull purple clastic phosphorite beds, on which there is a local relief of several centimetres, and are conformably overlain by dolostones of the Dengying Formation. The bioherms are tabular, and range from several tens to about 100m wide and up to 1 m thick. They are approximately circular or elliptical in plan, and have been recognized in isolated outcrops. The erect, subparallel *Gymnosolen* sp. columns within the bioherms grew directly from a flat substrate. Intercolumnar spaces are filled by abundant phosphatic sand grains. Text-fig. 4 shows a reconstruction of growth stages of the bioherms of *Gymnosolen* sp. in the Wenquan mining area.

In the Shabatu and Maluping mining areas of the Xifeng-Kaiyang region, the Doushantuo Formation is dominated by sandstones and phosphorites with laminated structure, with a thickness not exceeding 40 m. It became evident that small phosphatic stromatolite bioherms of *Inzeria* sp., or the unnamed form, are distributed on the top or in the upper part of the phosphorite beds. These bioherms are lenticular, ranging from 20cm to several meters wide, and generally not exceeding 50cm in maximum thickness. They are as a rule isolated and always grew on erosional surfaces of phosphorite beds. Basal parts of these bioherms consist of irregular laminations. Columns of *Inzeria* sp. and the unnamed form are more or less straight, parallel or radially arranged, and grew on these irregular laminations. Some irregular bioherms formed by individual stromatolites also occur within these phosphorites. Text-fig. 5 shows a reconstruction of the appearance during growth of bioherms in the Shabatu and Maluping mining areas.



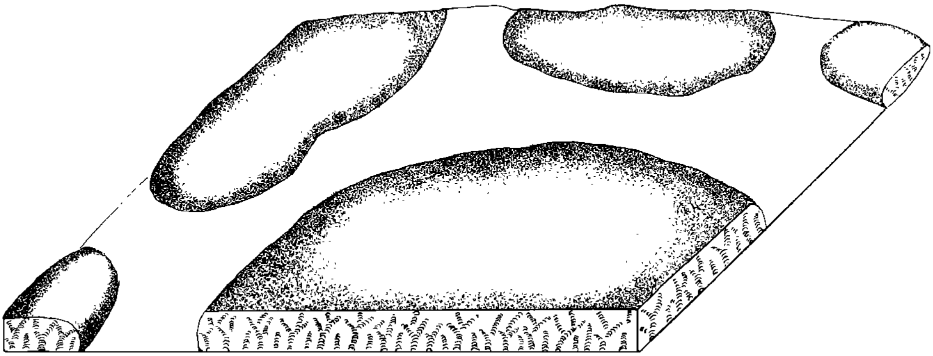
Text-figure 1 Stratigraphic column of Sinian Doushantuo Formation in the Wequan mining area, Xifeng-Kaiyang region



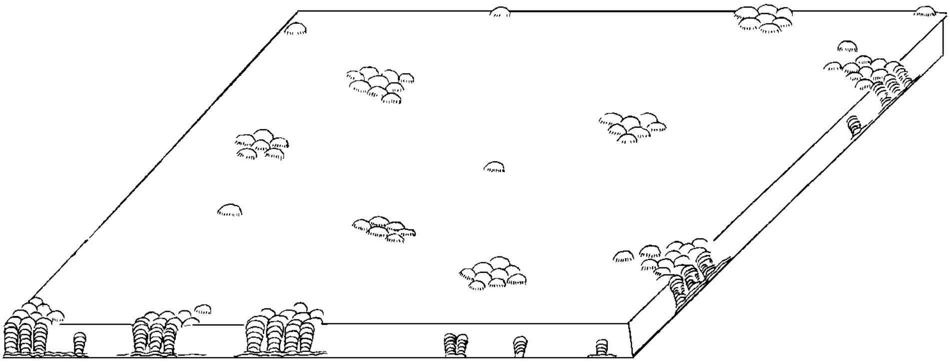
Text-figure 3 Geological map showing location of mining areas in the Xifeng-Kaiyang region

In summary, dimensions of the phosphatic stromatolite bioherms obviously decrease from north to south, and there are all gradations from tabular bioherms of *Gynmosolen* sp. to small, lentcular bioherms of *Inzeria* sp. or an unnamed form, and irregular bioherms formed by individual stromatolites in the Xifeng-Kaiyang region.

3.2 Stromatolites: Phosphatic stromatolites in the Xifeng-Kaiyang region, were identified by the present author as the following genera: *Gymnosolen*, *Inzeria*, and an unnamed genus.



Text-figure 4　Reconstruction of the appearance of bioherms consisting of *Gymnosolen* sp., Doushantuo Formation, Wenquan mining area, Xifeng-Kaiyang region



Text-figure 5　Reconstruction of appearance of lenticular and irregular bioherms, Doushantuo Formation, Shabatu and Maluping mining areas, Xifeng-Kaiyang region

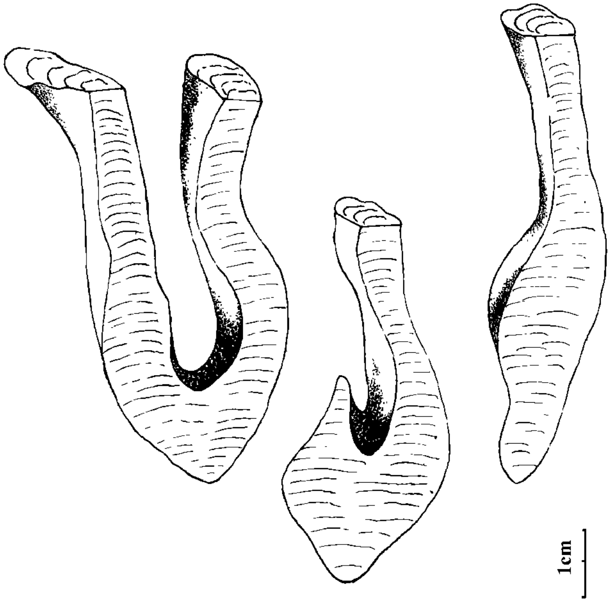
Gymnosolen **Steinmann, 1911**

Gymnosolen **sp.**

(Plate Ⅰ, figs. 1, 2; Text-figure 6)

Description: Columns subcylindrical, frequently branched, 1 – 2.5cm or more in diameter, more than 10 cm high. Surface generally smooth, occasionally with low bumps. Branching pattern complicated, slightly to markedly divergent, sometimes split into thinner branches with subparallel axes above a thickening of branching column. Horizontal profile subcircular. Surface of column discontinuously enveloped. Laminae relatively flat, irregular, 0.5 to 1mm thick. In thin section columns poorly or indistinctly laminated; "sand-rich layers" visibly alternate with "sand-poor layers", with microfossils or microfossil-like textures generally occurring in "sand-poor layers".

Comparison: Some important features of this stromatolite described here make it identical with *Gymnosolen* Steinmann, such as shape of the columns, its branching pattern and discontinuous wall structure. The relatively poor preservation of microstructure in the phosphatized *Gymnosolen* sp. in the Wenquan mining area does not permit its assignment to a species. The present form differs from *Gym-*



Text-figure 6 *Gymnosolen* sp., Doushantuo Formation, Wenquan mining area, Xifeng-Kaiyang region

nosolen confragousus Semikhatov, in column thickening before branching and in having flat laminae.

Occurrence: Wenquan mining area.

Inzeria Krylov, 1963

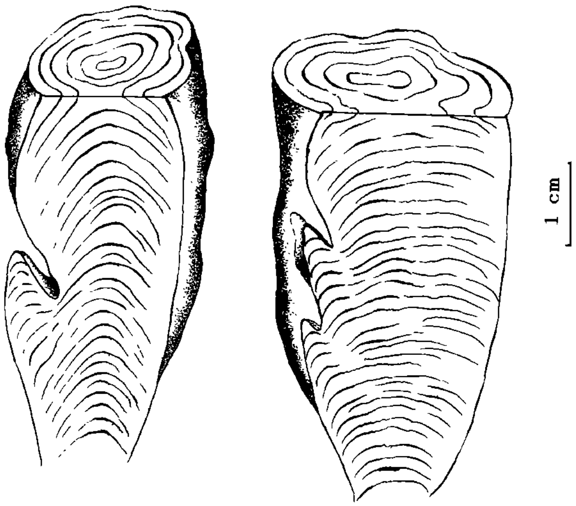
Inzeria sp.

(Plate I, fig. 3; Text-figure 7)

Description: Columns erect, subcylindrical or clavate, 4cm in diameter, 7—10cm high. Surface smooth, not showing clear ribs, often with niches containing projections. Branches generally starting from niches as short buds, roughly parallel or slightly divergent. Laminae fade into a generally smooth marginal zone showing local overhangs and discontinuous enveloping. Laminae fine and close in arrangement, generally ranging from 0.05 to 0.3mm thick, and varying from hemispherical, steeply convex to obtusely conical. Laminations containing abundant phosphate sand grains and well-preserved microfossils inside.

Comparison: This form is reminiscent of *Inzeria anhuiensis* Cao *et al*. (Cao *et al*., 1985, p. 23—24, pl. 7) from the Sidingshan Formation of Late Precambrian age in northern Anhui province. It differs from the latter in the relatively regular laminae associated with sand-sized grains.

Occurrence: Shabatu mining area.



Text-figure 7　*Inzeria* sp.，Doushantuo Formation，Shabatu mining area，Xifeng-Kaiyang region

Unnamed form

(Plate Ⅰ，fig. 4)

Description: Columns erect，subcylindrical，7—10cm in diameter，20cm high. Surface relatively smooth，not ragged. Columns rarely branched. On the margin of column，laminae curved abruptly and form a multilaminate wall. Laminae fine and close in arrangement，rectangular，generally ranging from 0.3 to 0.8mm thick，convex or wavy，often asymmetrical，further decurrent on one side. In thin section，lamination indistinct，containing abundant sandy phosphate grains. Microfossils preserved in laminations.

Comparison: This form is too fragile to be cut into slabs for three-dimensional reconstruction. More difficult is identification of genera that are discrete taxonomic entities.

Occurrence: Maluping mining area.

3.3　Microfossils: All the microfossils studied here were preserved in stromatolite laminae of phosphorites. At present，there is no sufficient evidence to indicate whether the microfossil-like objects are definitely biogenic or actually of non-biological origin. So these microfossils and filamentous objects needn't be named. They may be grouped into several types based on their morphological features. The five types described here are well-preserved and relatively abundant within the stromatolite laminae.

Type A

(Plate Ⅱ，figs. 1—4；plate Ⅲ，fig. 1)

Description: Filaments non-septate，uniseriate，cylindrical，broadly curved，2 to 5μm in diameter (averaging 3.3μm，as measured in 12 specimens) and up to 200μm long. Most filaments intertwined in growth，thus forming filamentous clusters of microcolonies. A few solitary filaments organically preserved by permineralization of fine-grained phosphate. Some filamentous clusters not clearly discernible in outline because of their association with abundant phosphatic or organic particles (Plate Ⅱ, fig. 2). Surface texture generally smooth, but granulated in degraded filaments.

Remarks: In the Xifeng-Kaiyang region, Type A has been detected only in the phosphorites from *Inzeria* sp. Because of its distribution, in particular its almost exclusive restriction to stromatolite laminae, Type A may be considered as belonging to some benthic mat-building microorganisms. The present specimens are similar to *Eomycetopsis robusta* reported from the Late Precambrian Qinggou Formation in the Hunjiang district of Jilin Province, China (Yin Leiming, 1987), a unit which was regared by Yin as correlative with upper Riphean and Vendian strata based on microfossil assemblages. In contrast to *E. robusta*, the present specimens often form filamentous clusters or microcolonies.

Occurrence: Shabatu mining area.

Type B

(Plate Ⅱ, figs. 7, 8)

Filamentous fossil-like objects simply tubular, unbranched, solitary or gregarious, often with marked organic matter inside, 10—30μm in diameter (averaging 14.2μm, as measured in 12 specimens) and up to 400μm long, twisted and strongly curved. Septa absent. Surface texture generally smooth. Grains of pyrite not yet observed at ends of filamentous objects.

Remarks: These fossil-like filamentous objects are so simple in form that it is difficult to establish their biogenic origin on the basis of morphology alone. The present bodies are regarded here as only dubious microfossils; they seem possibly comparable with oscillartoriacean cyanobacteria.

Occurrence: Wenquan and Shabatu mining areas.

Type C

(Plate Ⅱ, figs. 9, 10; plate Ⅲ, figs. 2, 3)

Description: Filaments non-septate, unbranched and tubular, straight or slightly curved, 8 to 40μm in diameter (averaging 21.4μm, as measured in 12 specimens) and up to 500μm long; wall with thickness of 2—5μm, occasionally radiating from a "holdfast-like" base in the stromatolite laminae. Surface texture generally smooth. Cross sections of filaments round or ellipsoidal.

Remarks: Most filaments are empty sheaths. The present specimens may represent the chemically altered remnants of external polysaccharide sheathes of *Lyngbya* or *Phormidium*-type blue-green algae. It seems reasonable to assume that the trichomes of these microorganisms may have had significant gliding motility. In general form, Type C is similar to *Siphonophycus sinensis* Zhang from the Sinian Doushantuo Formation in the eastern Yangtze Gorge, China (Zhang Zhongying, 1986), but that species differs in having filaments with granular surface texture.

Occurrence: Maluping, Wenquan and Shabatu mining areas.

Type D

(Plate Ⅱ, figs. 5, 6)

Description: Dark brown chains consisting of spheroidal to polyhedral cells or grains with empty or opaque centres. Chains unbranched, uniseriate, slightly to strongly curved. Diameter of elements in each chain relatively uniform, ranging from 10 to 12μm, solitary or intertwined fragments up to 100μm in length.

Remarks: The several attached cells(?) aligned in short rows probably represent an early stage in formation of a long chain of cells. The present specimens do not allow any satisfactory comparison with other described microfossils from the Sinian Doushantuo Formation in South China.

Occurrence: Shabatu mining area.

Type E

(Plate Ⅲ, figs. 2—4)

Description: Thalli probably large irregular spheroids roughly discernible in outline and visible to the naked eye, ranging from 400 to 500μm in diameter, with relatively thin and multi-holed walls based on observation of thin sections. Surface with circular holes 5—10μm in diameter, uniform and penetrating through the wall.

Remarks: In the genus *Thallophyca* described by Zhang Yun (1989) from phosphate rocks of the Doushantuo Formation in Guizhou province, the thallus consists of two distinct parts: a cortex part composed of elongated cells, forming a 50 to 100μm-thick outer layer surrounding the thallus, and a medullary part which consists of spheroidal, ellipsoidal or spindle-shaped cells often arranged in seriate rows. In sectional morphology, Type E is similar to the cortex portion of *Thallophyca* Zhang Yun (1989), but it has no distinct medullary bodies.

Occurrence: Maluping mining area.

4 MICROFOSSIL COMPOSITION OF THE STROMATOLITES

The three morphologically distinct columnar stromatolites contain different microbiotic assemblages dominated by filamenous microorganisms or objects. Locally, some large spherical acritarchs occur in certain stromatolites. However, they are difficult to see because the unicells and colonial structures are poorly preserved and are dissected in preparation. Changes of microbiotic assemblages in the phosphatic stromatolites of different morphotype are expressed mainly by changes in the types and relative abundance of filamentous microorganisms and objects. Type A and Type D are almost exclusively found within laminae of *Inzeria* sp. stromatolites, and Type E forms are important microfossils in the unnamed stromatolite. The three morphologically distinct columnar stromatolites, however, commonly contain Type B and Type C.

Thin sections for optical microscopy were prepared from each of the three types of stromatolites under study. Upwards of 1 200 microorganisms were counted. Differentiable taxa found in the stromatolite assemblages are listed in Table Ⅱ. The first assemblage, found within *Gymnosolen* sp., is dominated by the filamentous Type B, but also includes filaments of Type C. The second assemblage, found within *Inzeria* sp., is dominated by the filamentous Type A, but also includes filaments of Type B, Type C and Type D. The third assemblage, found within the unnamed form, is dominated by larger filamentous sheaths of Type C, but also includes larger spheroids of Type E and rare filamentous Type B.

Table Ⅱ Taxonomic percentage distribution of several sample populations of stromatolite microfossils described in this paper

	Gymnosolen sp. (N 400)	*Inzeria* sp. (N 500)	Unnamed form (N 300)
Type A	—	74	—
Type B	72	6	12
Type C	28	12	80
Type D	—	8	—
Type E	—	—	8

5 ENVIRONMENT

In the Xifeng-Kaiyang region, extensive phosphorites and stromatolite bioherms of the Doushantuo Formation were formed on a continental shelf (Ye Lianjun *et al*., 1989). Ripple marks and evidence of scouring and wave erosion are commonly visible on bedding planes of the phosphorite. Intraclast phosphatic sand grains, generally 5—45μm in diameter, formed in the high-energy sediments and are usually found in direct association with the stromatolites. Ooliths and stratiform stromatolites were also observed in the phosphorite, and gypsum has been locally observed in the top of the Doushantuo Formation. Typical *Conophyton* stromatolites, which were commonly formed in quiet subtidal settings, have not been found in the phosphorite of the Doushantuo Formation. However, in many places in South China, such as at Jiangshan in Zhejiang and at Suixian in Hubei, *Conophyton* stromatolites often occur in the Sinian Dengying and Doushantuo Formations. Both the above data and the local sedimentology demonstrate formation of the phosphatic stormatolite bioherms as occurring in phosphorite sediments in very shallow zones of wave action on a platform margin.

In the Wenquan mining area, tabular bioherms consisting of *Gymnosolen* sp. extend continuously and laterally over a considerable distance. These stromatolite columns are relatively long and narrow, but fragments of columns are rarely observed in the bioherms. Phosphatic sandy grains, generally 5—20μm in diameter, are directly associated with stromatolites and are well rounded. It seems that these bioherms were formed under conditions of relatively low energy.

In the Shabatu mining area, bioherms commonly contain some broken and fallen trunks of stomatolites belonging to *Inzeria* sp. Interspace between stromatolite columns is filled with coarse sandy phosphatic grains and fragments of columns or phosphorite. These evidences indicate a higher energy level in the Shabatu mining area during stromatolite formation than was present in the Wenquan mining area during formation of stromatolite bioherms therein.

In the Maluping mining area, large columns of stromatolites belonging to the unnamed form are in general distinctly inclined towards NE 40° or even in a lodging manner. These stromatolites suggest characteristic strong currents and turbulent conditions. In the Niuganchong mining area, stromatolite columns were seriously damaged by strong currents before diagenesis (Plate Ⅲ, fig. 5). Thus data obtained from studies on these phosphatic stromatolites suggest that environments roughly changed southwards in the Xifeng-Kaiyang region from relatively low energy to high energy.

6 DISCUSSION

There are two principal hypotheses on morphogensis of stromatolites. One holds that the morphology of stromatolites depends entirely on conditions of their formation (Logan *et al*., 1964), while the other holds that the microbiota actually influences stromatolite morphology (Awramik, 1976, 1984). Attributes of stromatolites are evaluated at five structural and textural levels, from largest to smallest: 1) bioherms; 2) individual stomatolites; 3) laminae; 4) microstructure; and 5) microbiotas. Macrostructural elements of stromatolite morphology are controlled, or at least strongly influenced, by environmental factors external to the growing microbial mat, and microstructural elements are controlled mainly or entirely by the makeup of the microbial assemblages (Semikhatov *et al*., 1979).

In the present individual stromatolites, distribution of filaments, particularly their almost exclusive restriction to stromatolite laminae, and the arrangement of these filaments, both prostrate and erect, as occasionally seen within the laminae, are all evidences suggesting the existence of some benthic mat-building microorganisms. Sedimentological and microstructural studies of the present phosphatic stromatolites (thin sections) document that the sediments are mainly aphanitic phosphorites and fine sand-sized phosphorite clasts or grains. The aphanitic phosphorites, which possibly replaced the original calcium carbonate before diagenesis, are a precipitate resulting from growth and metabolic activity of the stromatolite-building microorganisms, with some of these organisms apparently capable of trapping and binding phosphorite clasts or grains. These microorganisms were probably responsible for the biological growth of the phosphatic stromatolites, instead of representing only detrital accumulations or microorganisms.

Microfossil assemblages in the present stromatolites are obviously different from the original microcommunity because of the meager preservation of the original microorganisms. However, under similar conditions of preservation, these microfossil assemblages can still reflect, more or less, the original compositions of the microcommunities. Changes in microfossils within phosphatic stromatolies possibly reflect changes in the original microcommunities, and in some instances, such changes seem to have taken place simultaneously with changes in environment and gross morphology of individual stromatolites. The present data suggest the existence of different small-scale environmental conditions in the Xifeng-Kaiyang region during formation of stromtolite bioherms. Environmental fluctuation may well have affected the composition of microorganism communities.

From the material above, the author draws the following conclusions: Microorganisms within the phosphatic stromatolites under study are mainly composed of filamentous cyanobacteria, including three assemblages or stromatolite microcommunities occurring in each of the three different mining areas. The first stromatolite microcommunity (in the Wenquan mining area) consists mainly of Type B and Type C; the second one (in the Shabatu mining area) is mainly made up of Type A, with some elements of Type D, Type B and Type C; while the third one (in the Maluping mining area) is composed of Type

C, with some elements of Type E and Type B. These differences are possibly related to the formation of *Gymnosolen* sp., *Inzeria* sp. and the unnamed form respectively. Golubic (1976) indicated that subtle differences in climate and local ecology were frequently responsible for significant changes in microbial composition, their interaction within a community, and in the resultant stromatolite morphology. Only dominant or very abundant organisms can be expected to play any significant role in influencing the microenvironment or the structure of stromatolites. To some extent, the present investigation lends support to this explanation. Morphotypes of individual stromatolites changed laterally from *Gymnosolen* sp. to *Inzeria* sp., to an unnamed form along an ecological gradient of increasing energy, and that shift in energy may have been associated with changes in stromatolite morphology.

ACKNOWLEDGEMENTS The author gratefully acknowledges the full support rendered by the National Natural Science Foundation of China (49372073).

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[1996 年 12 月 25 日收到]

Explanation of Plates

All the type materials are deposited in Nanjing Institute of Geology and Palaeontology, Academia Sinica.

Plate Ⅰ

Phosphatic stromatolites from the Sinian Doushantuo Formation in the Xifeng-Kaiyang region, vertical sections.

1. *Gymnosolen* sp., Wenquan mining area, scale bar＝1cm (specimen No. GXW-01).
2. Fragments of bioherm consisting of *Gymnosolen* sp., Wenquan mining area.
3. *Inzeria* sp., Shabatu mining area, scale bar＝1cm (specimen No. GXS-01).
4. Unnamed form, Maluping mining area, scale bar＝1cm (specimen No. GKM-01).

Plate Ⅱ

1－6. Thin sections of *Inzeria* sp., showing filaments of Type A and Type D, from the Sinian Doushantuo Formation, Shabatu mining area, Xifeng-Kaiyang region. Filaments of Type A (see 1－4), scale bar＝20μm (specimen No. GKS-02_a, GKS-$O2_b$). Microfossils of Type D (see 5 and 6), scale bar＝30μm (specimen No. GKS-02_a).

7. Filament of Type B, preserved in *Inzeria* sp. from the Sinian Doushantuo Formation, Shabatu mining area, Xifeng-Kaiyang region, scale bar＝30μm (specimen No. GKS-02_a).
8. Filament of Type B, preserved in *Gymnosolen* sp. from the Sinian Doushantuo Formation, Wenquan mining area, Xifeng-Kaiyang region, scale bar＝30μm (specimen No. GXW-03_a).
9. Thin section of an unnamed form showing filaments of Type C which could be clumped together with a dense amount of organic material and phosphate, from the Sinian Doushantuo Formation, Maluping mining area, Xifeng-Kaiyang region, scale bar＝80μm (specimen No. GKM-03_a).
10. Filament of Type C, preserved in an unnamed stromatolite, from the Sinian Doushantuo Formation, Maluping mining area, Xifeng-Kaiyang region, scale bar＝20 μm (specimen No. GKM-03_a).

Plate Ⅲ

1. Thin section of *Inzeria* sp., showing several filamentous clusters or microcolonies of Type A (arrowhead pointing to the filamentous cluster), from the Sinian Doushantuo Formation in the Shabatu mining area, scale bar＝40μm (specimen No. GKS-02_b).
2. Thin sections of unnamed stromatolite, showing microfossils of Type C (middle) and Type E (lower) from the Sinian Doushantuo Formation in the Maluping mining area; filaments of Type C that are both prostrate and erect within laminae; scale bar＝100 μm (specimen No. GKM-03_b).
3. Microfossils of Type C and Type E, from the Sinian Doushantuo Formation in the Maluping mining area, scale bar＝80μm (specimen No. GKM-03_a).
4. Photograph showing indistinct outline of Type E (large spheroid), preserved in an unnamed stromatolite, from the Sinian Doushantuo Formation in the Maluping mining area, scale bar＝80μm (specimen No. GKM-03_b).
5. Photograph showing an unidentified stromatolite column seriously damaged (arrowhead pointing to rupture plane) by strong currents before diagenesis, from the Sinian Doushantuo Formation in the Niuganchong mining area, Xifeng-Kaiyang region, scale bar＝1cm (specimen No. GKM-01).