Biolith (biogenic rock) is the second main rock making up the Earth*

Part 1 of my ppt for the plenary presentation at the 1st International Biopetrological Congress on September 23, 2023)

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Concept of Biolith

1. Biogenic carbonates

- Reef rocks
- Non-reef skeletal rocks
- Microbial rocks (= microbiolith)
  - Microbialites
  - Microbial reef rocks (consisting of in situ skeletons of microbes)
  - Rocks consisting of debris of microbialites and microbial reef rocks

2. Microbial ironstones

- BIFs (?)
- Xuanlongshi ironstones (iron oolites, iron stromatolites)

3. Microbial manganic rocks

- Marine manganese nodules

4. Coals, black rocks

Biolith

Rocks formed by organisms

Formation mechanisms of biolith:

(1) Bio-controlled mineral precipitation (forming skeletons of animals, calcareous algae, etc.)

(2) Bio-induced mineral precipitation (forming mineral crusts, miniclots, minilaminae)

(3) Trapping sediments by microbial mats (forming the laminae in some stromatolites)

(4) Fragmentation and deposition (of skeletons and microbialites)

(5) Growth of organic bodies (forming coals)

Bio-controlled mineral precipitation	Bio-induced mineral precipitation
By macro- and micro- organisms	By microbes such as cyanobacteria and bacteria
Form skeletons with special shape and structure	Form micritic miniclots or minilaminae without special shape or structure

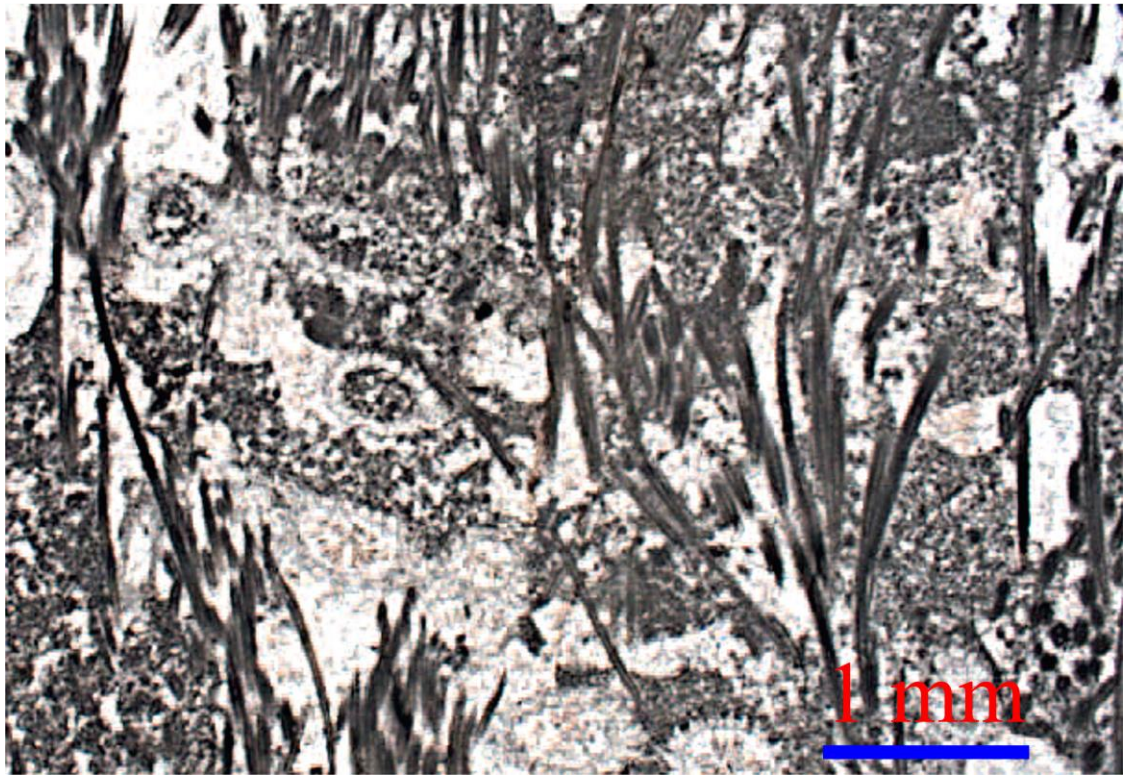
(Bazylinski, Frankel, 2003; Burne, Moore, 1987; Frankel, Bazylinski, 2003)

Biolith formed by bio-controlled mineral precipitation

Reef rock

A coral framestone consisting of in situ coral skeletons, in a modern reef in South China Sea. https://www.westend61.de/en/imageView/DSGF000306/malaysia-south-china-sea-tioman-island-coral-reef

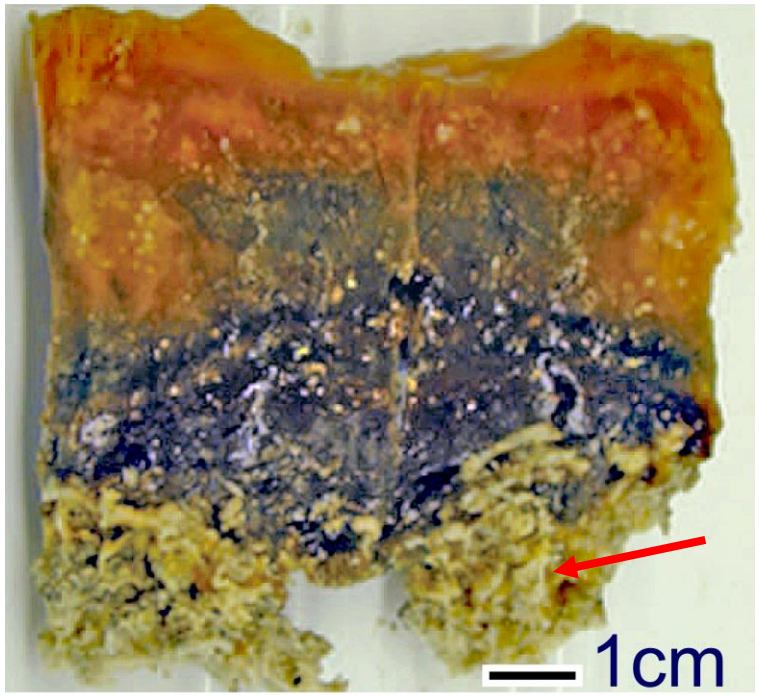
Microbial reef rock



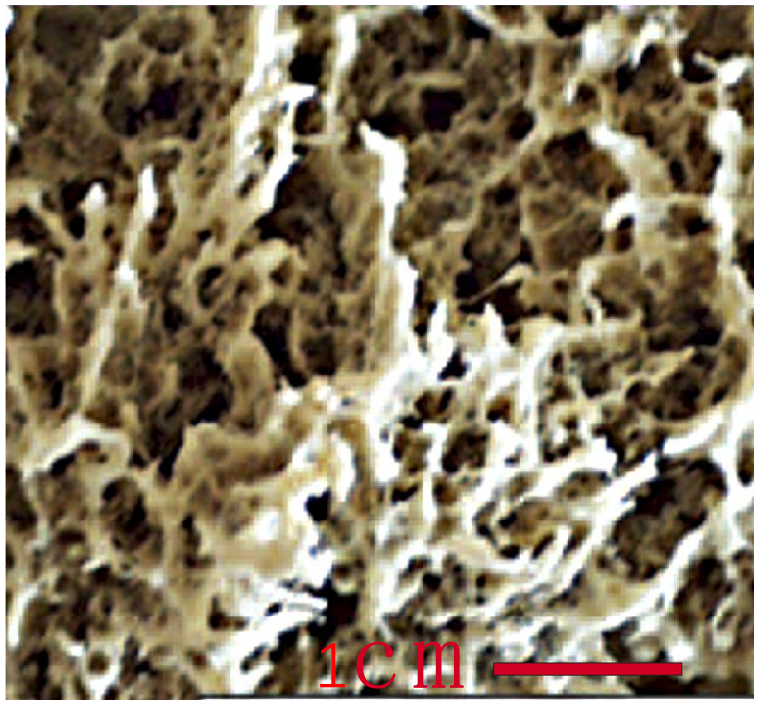
A framelite consisting of skeletons of *Phacelophyton*, a calcified cyanobacterial genus (Liu et al., 2016a, b), from the Upper Ordovician of well TZ24 in the Tarim Basin, Xinjiang, China

Biolith formed bio-induced mineral precipitation

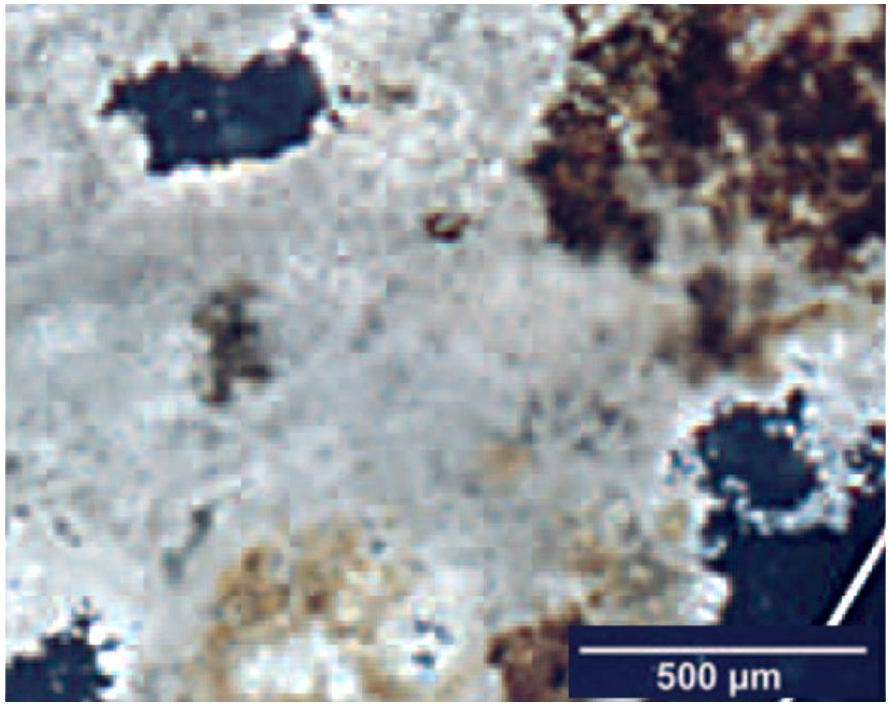
A modern microbialite (thrombolite)



Vertical section of a sample from a modern lake on the Atoll of Kiritimati. Top: microbial mat. Bottom (red arrow): thrombolite interpreted to be formed by the mat. Modified from Fig. 13 of Arp (2012)

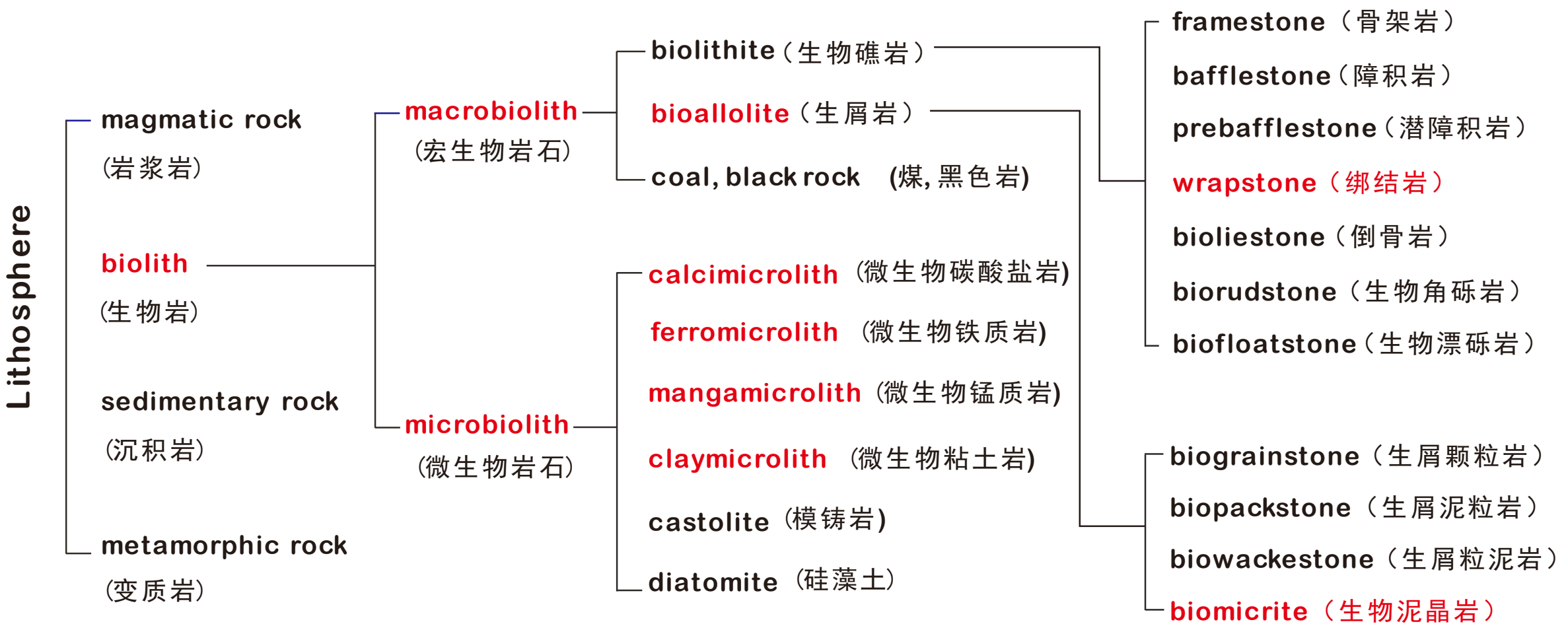


Local enlargement of the thrombolite. Modified from Fig. 13 of Arp (2012)

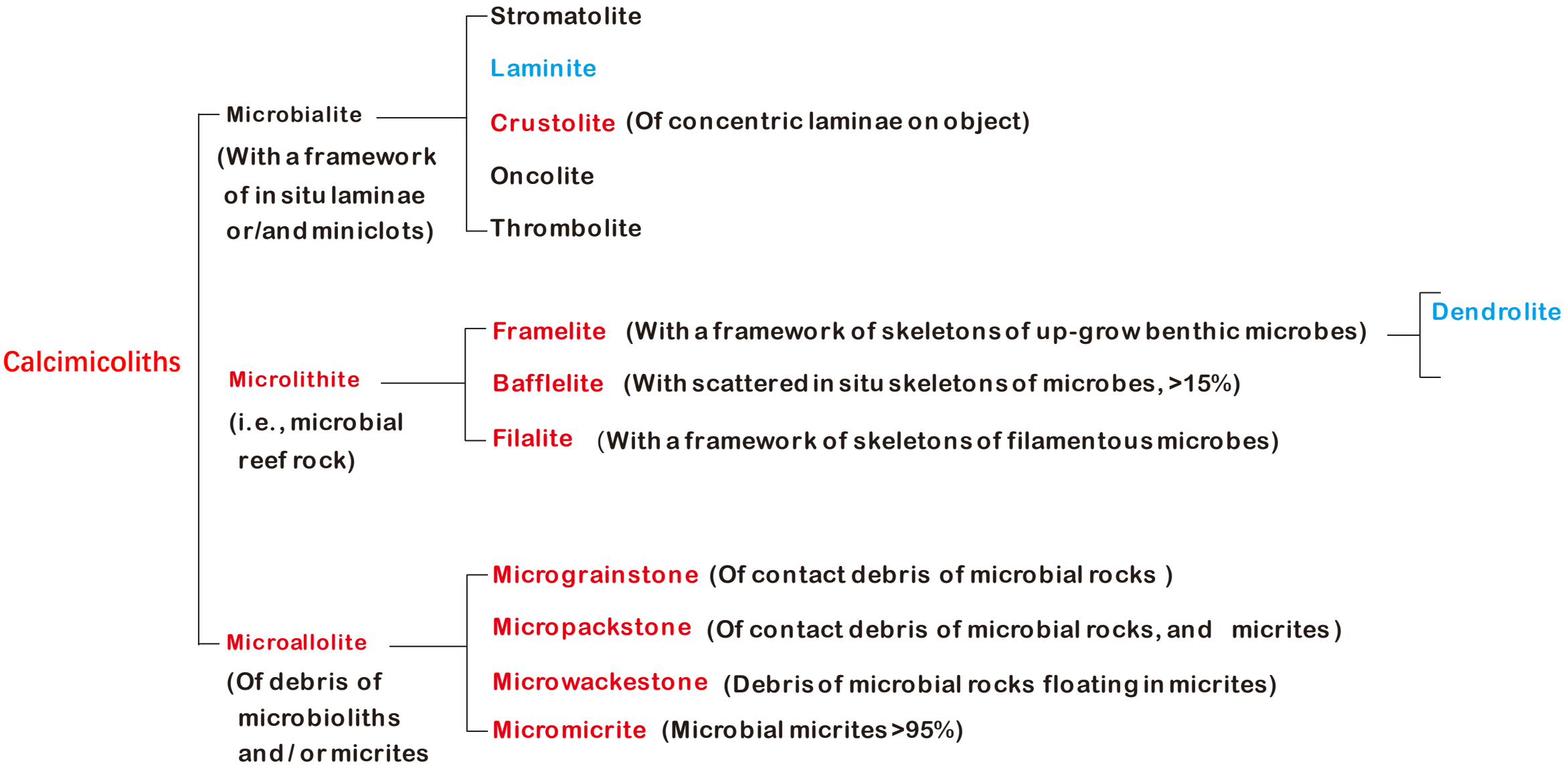


Photomicrograph of a thin section of the thrombolite. Modified from Fig. 13 of Arp (2012)

Classification of bioliths

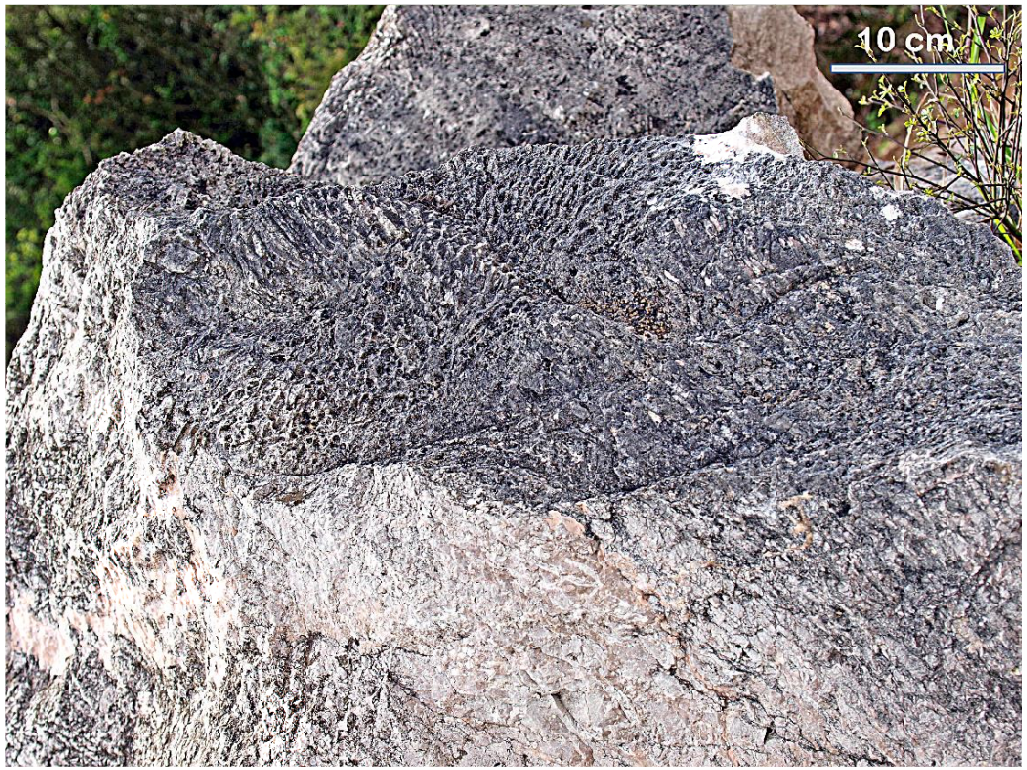


(Wu, 2022; 吴亚生, 2023)　Riding (2000): stromatolite, thrombolite, dendrolite, leiolite



(Wu, 2022; 吴亚生, 2023) Dendrolite (Riding, 2000)

The in-situ skeletons in a framestone must be in contact with each other. Otherwise, it is not a framestone.



A framestone consisting of in-situ skeletons of rugose corals, from an Upper Permian reef in Cili, Hunan Province, China.

A wrapstone consisting of in-situ skeletons of a calcified red alga (*Corallina*), from a Cenozoic reef in Southern China Sea.

A bioliestone consisting of overturned skeletons of some rugose corals, from an Upper Permian reef in Cili, Hunan Province, China.

A dolomitic laminite consisting of dark micritic minilaminae and thick thrombolitic laminae, from the Lower Cambrian Stage 3 in Aksu, Xinjiang, China. The sample no. is S-17.

A stromatolite should have a framework of laminae formed by microbial mats, or have a laminated fabric formed by sheet-like cavities formed by microbial mats.

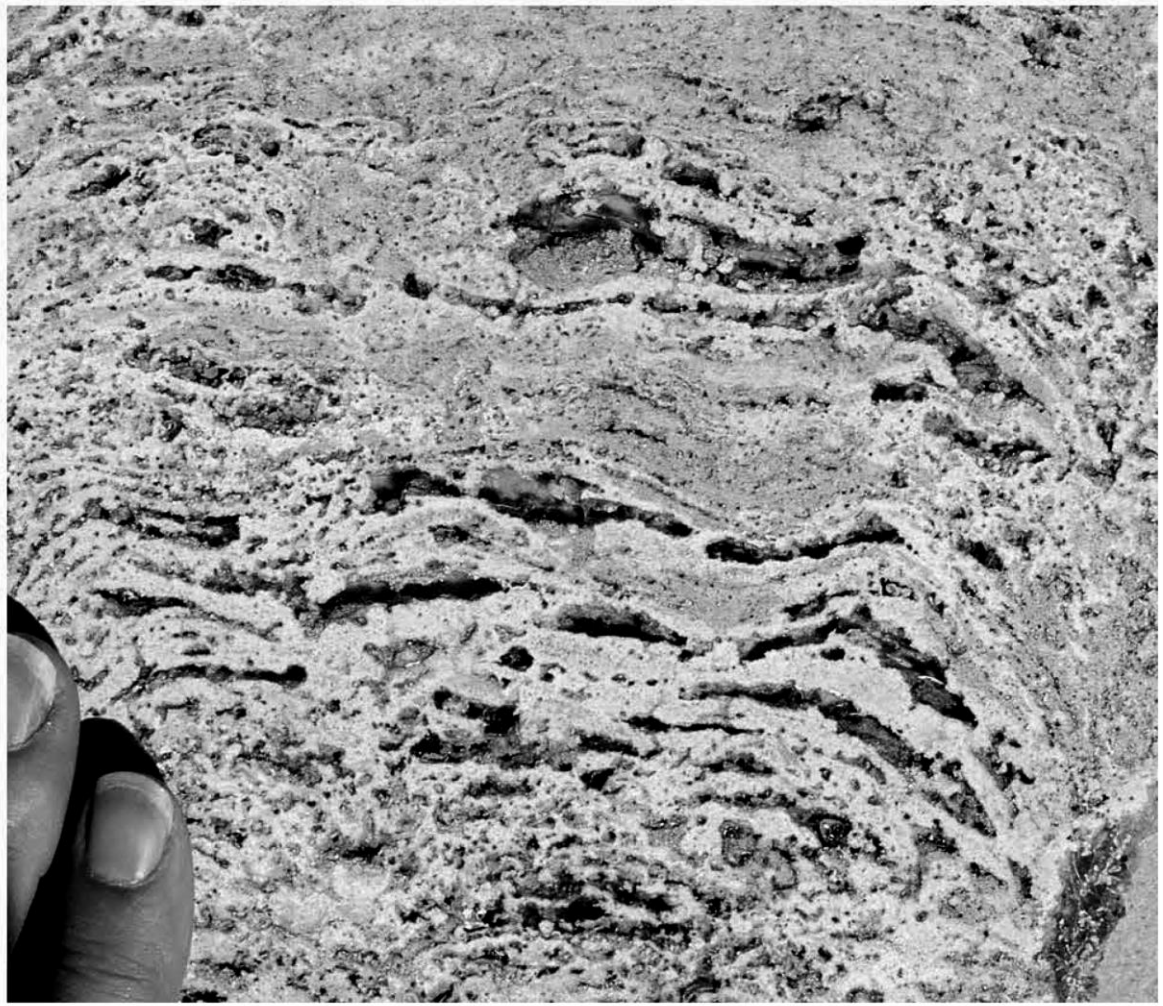
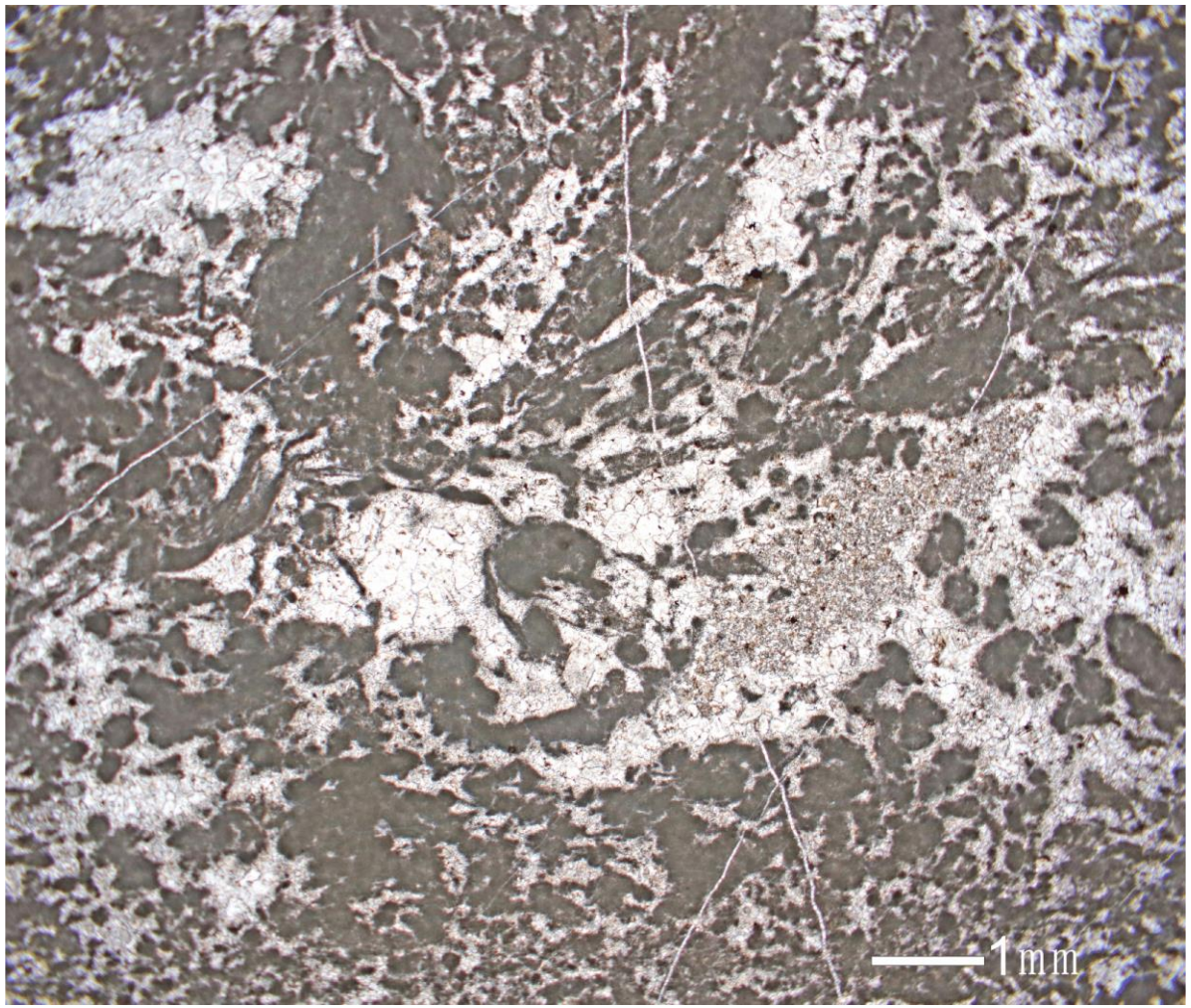


Fig. 9 of Riding (2000): A stromatolite with sheet-like cavities, formed by trapping of sediments by microbial mats.

A thrombolite must have a microscopic clotted fabric.



A thrombolite with a microscopic net-like clotted fabric, from the Upper Ordovician at Taoqupo, Yaoxian, ShanXi Province, China.

Crustolite: consisting of microbiogenic minilaminae encrusting on something.

A crustolite consisting of micritic laminae (red braces) encrusting on the mineral crusts of some cyanobacteria (red arrows). Cenozoic. Haushigou, Qinghai, China.

A framelite consisting of den**dri**tic skeletons of *Epiphyton*.

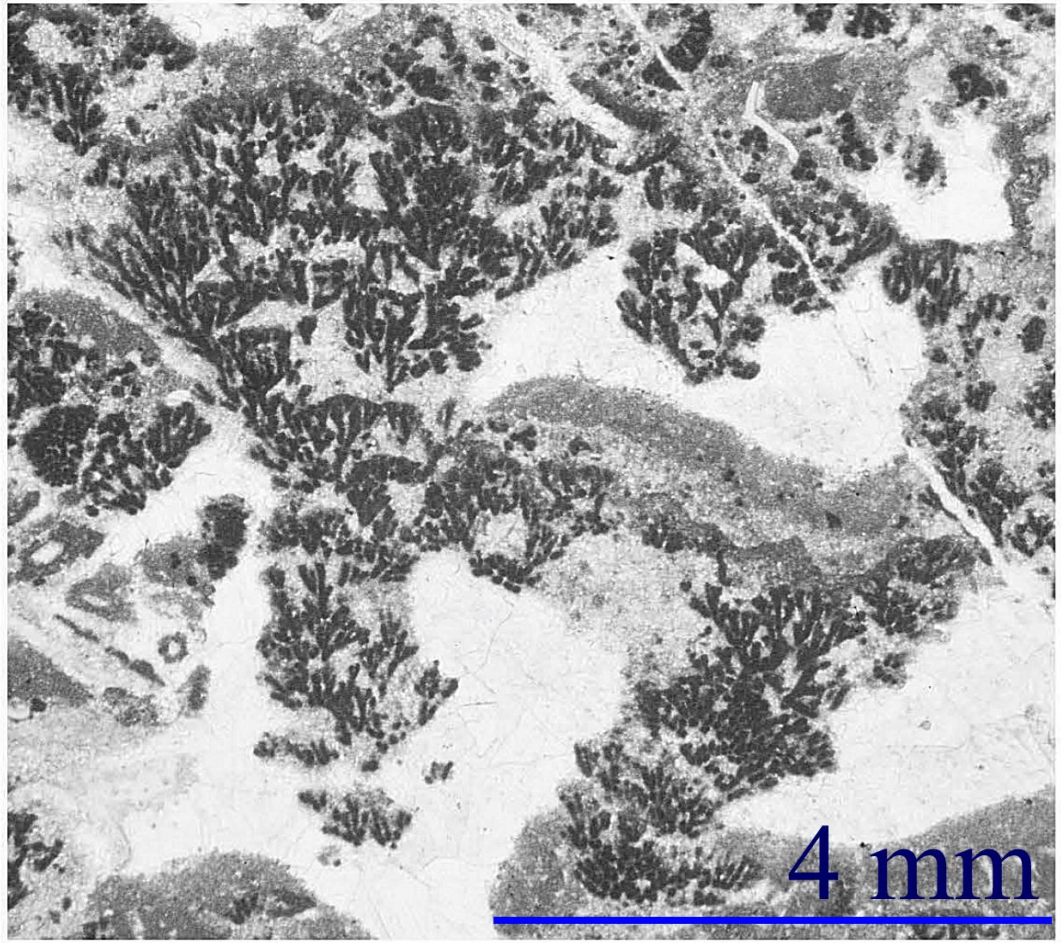
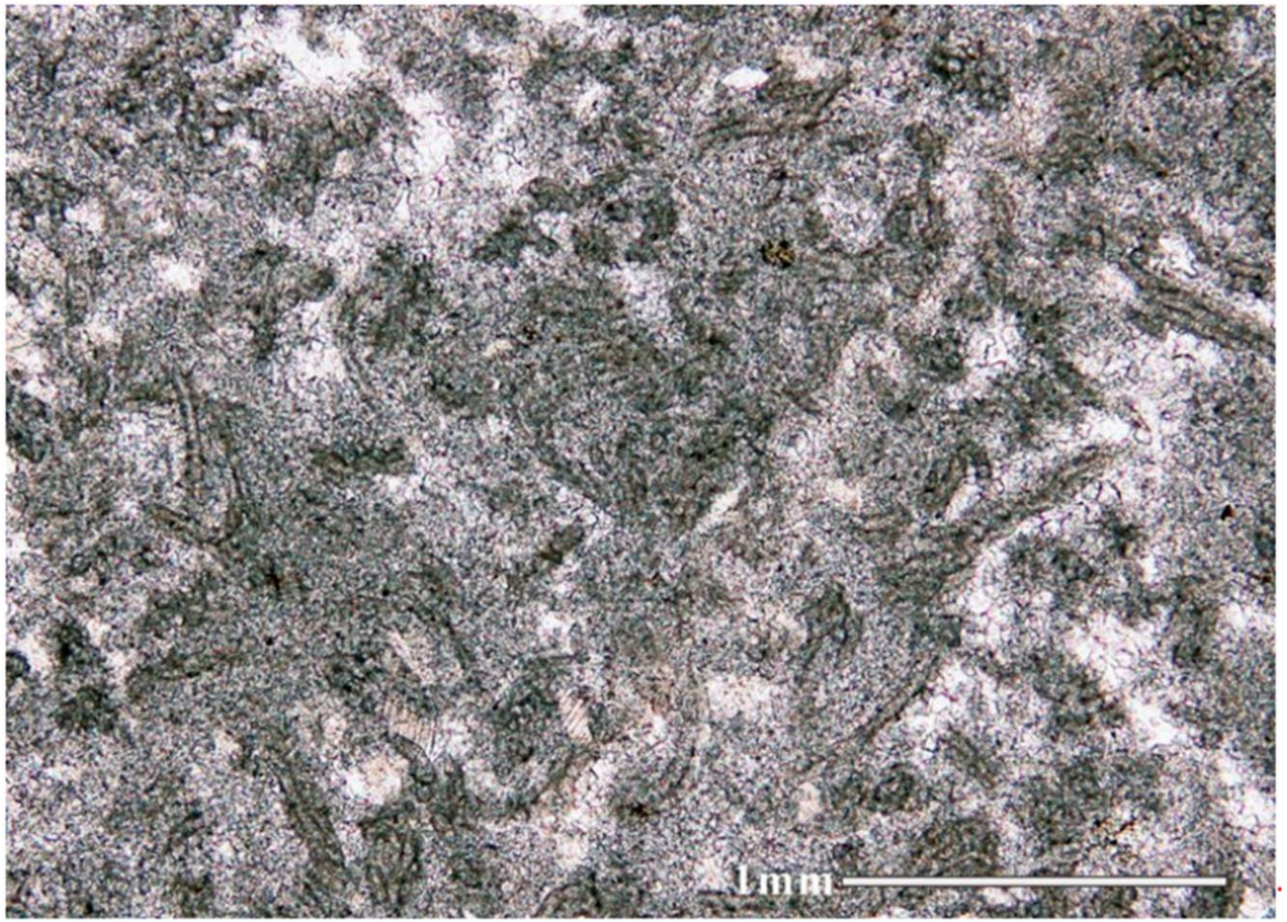
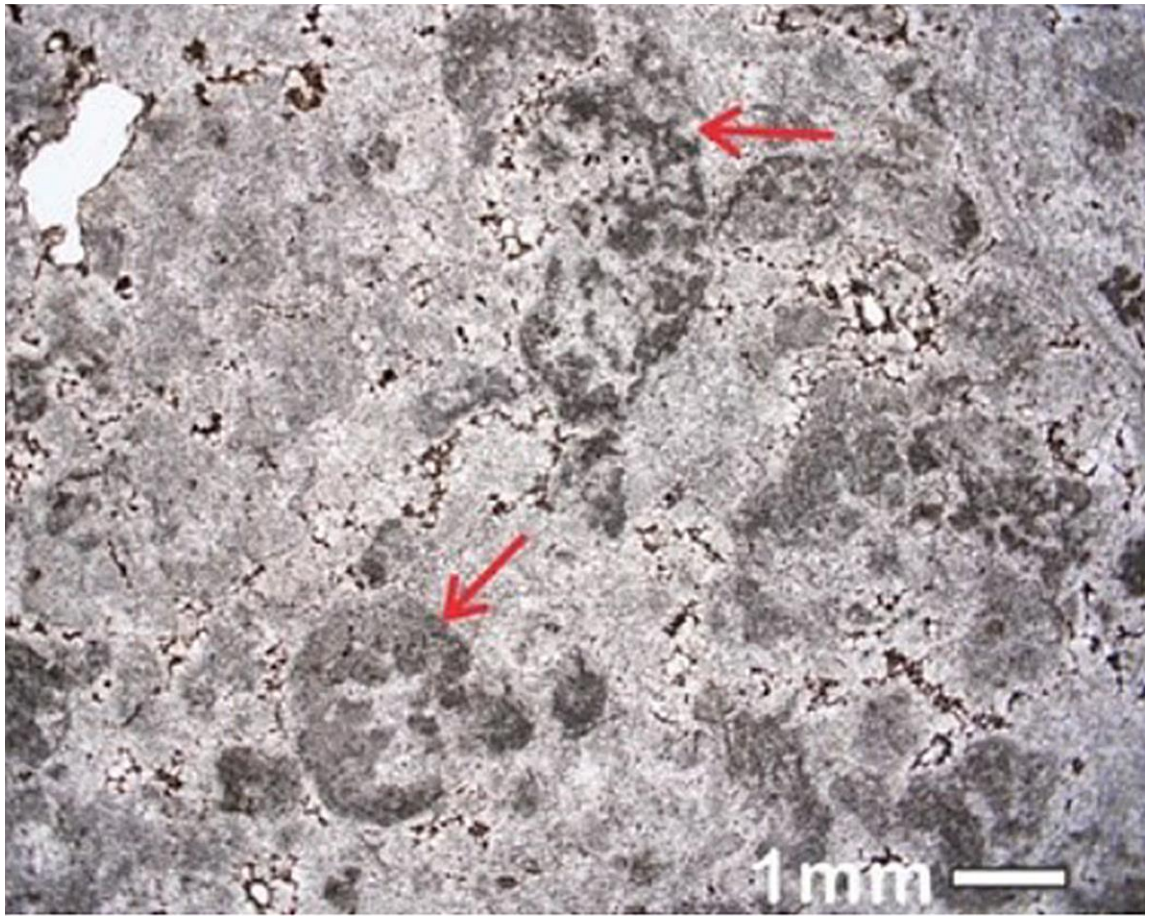


Fig. 13 of Riding (2000). It was assigned to dendrolite by Riding (2000), but here is assigned to framelite.



A filalite consisting of fila**men**tous skeletons of some cyano**bac**teria, from the Lower Cambrian Stage 2 at Sugaitebulake, Aksu, Xinjiang, China



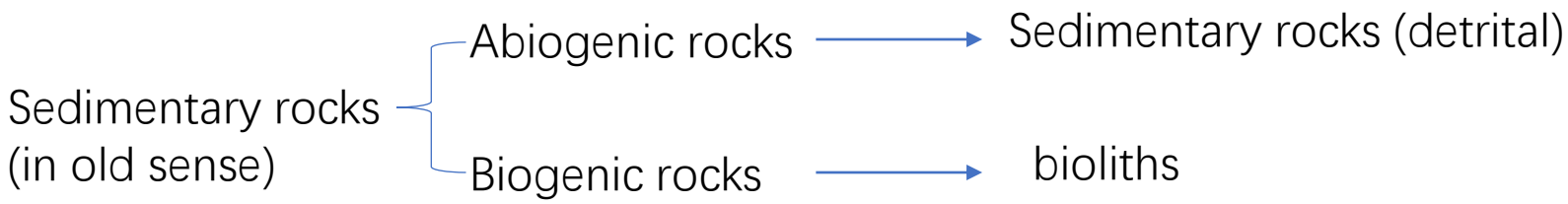
A micrograinstone consisting of skeletal debris of *Renacis*, from the Lower Cambrian Stage 3 at Sugaitebulake, Aksu, Xinjiang, China. (Li et al., 2021)

Biolith is the second important rock, and is one of the four main kinds of rocks making up the Earth

New conception: The lithosphere of the Earth is made up of four main kinds of rocks: magmatic, biolithic, sedimentary and metamorphic rocks. (biolithic rocks = bioliths = biogenic rocks)

Previously the lithosphere of the Earth was believed to be made up of three kinds of rocks: magmatic, sedimentary and metamorphic rocks. Now, however, because of the following three reasons, it is proposed here that the Earth is made up of four main kinds of rocks: magmatic rock, biolith, sedimentary rock, and metamorphic rock.

Reason 1: Organic processes and inorganic processes are quite different, and the bioliths formed by organic processes should not be placed together with the sedimentary rocks formed by inorganic processes, and to sperate bioliths from abiogenic detrital sedimentary rocks is a scientific advance.



Reason 2: Precipitation of minerals from magma caused by decline in temperature, precipitation of minerals from water caused by metabolism of organisms, and precipitation of minerals from water caused by evaporation or decline in pressure and temperature are the three main ways to form the original rocks making up the Earth. The resultant rocks are magmatic rocks, bioliths and chemical rocks, respectively. The chemical rocks mainly include stalactites, evaporites, spring travertines, and mineral accumulations at marine hydrothermal outlets.

Sedimentary rocks in the narrow sense (detrital) and metamorphic rocks are not original, but are derived from existing rocks, and do not significantly increase the total volume of the rocks in the Earth. So, magmatic rocks and bioliths are more important than sedimentary and metamorphic rocks.

Coals, carbonaceous rocks, and black rocks are made up of altered organic remains of plants, and are also important components of the lithosphere. They were previously placed in sedimentary rocks, but here are placed in biolith.

The original rocks in the lithosphere are magmatic rocks, bioliths, evaporates, stalactites, hydrothermal rocks (including hydrothermal chimneys, spring travertines) , coal and black rocks, and the secondary rocks include sedimentary rocks and metamorphic rocks.

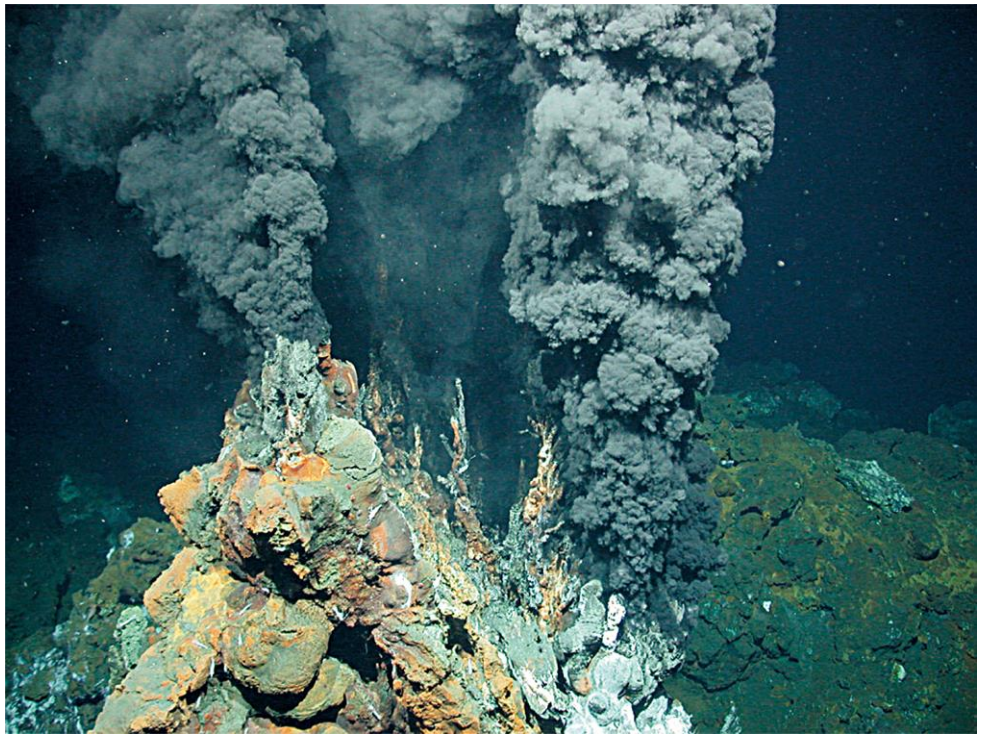
Mineral precipitation from magma caused by temperature decline. opentextbc.ca

Bio-induced mineral precipitation in a lake caused by metabolism of microbes. Modified from Fig. 13 of Arp (2012)

Evaporites formed by evaporation. Qingai Lake, China. dxbei.com

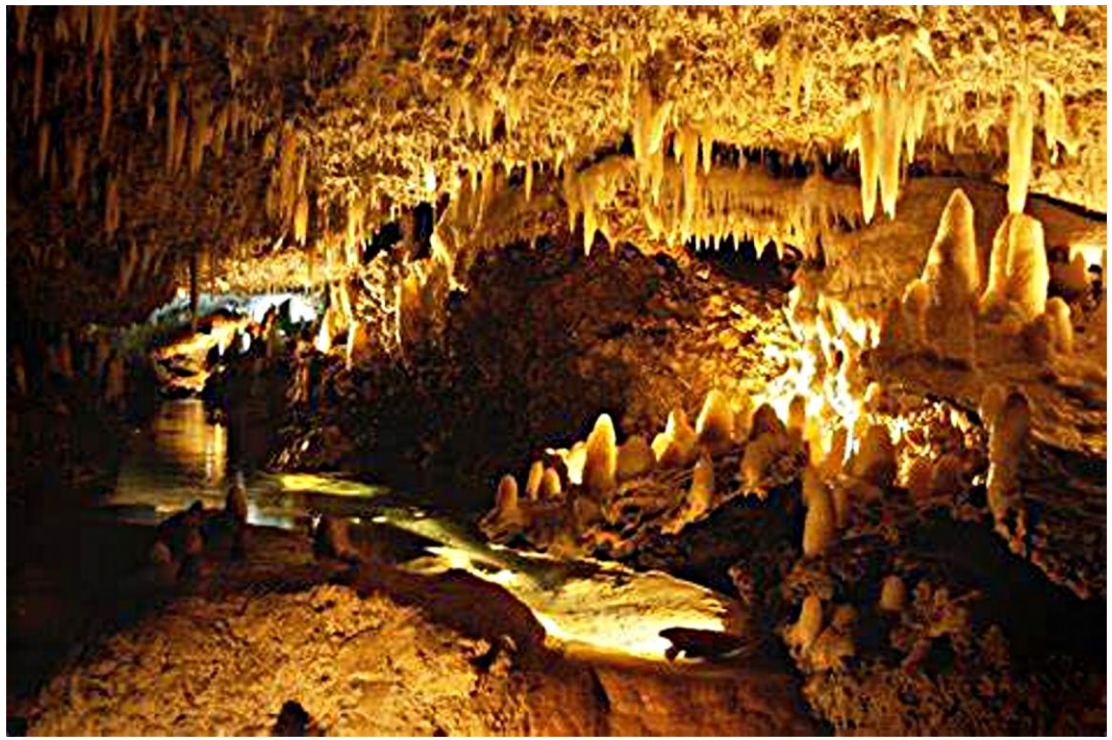
Travertines formed by decline in temperature and pressure. Bridgeport, CA, USA elevation.maplogs.com

Mineral accumulations at oceanic hydrothermal vents, forming hydrothermal rocks such as “chimneys”



[Les ressources minérales des grands fonds marins | Langlois]

Carbonate mineral precipitation in karst caves, forming chemical rocks such as stalactites



https://www.dkfindout.com/uk/earth/caves/stalactites/

Chemical rocks include evaporates, stalactites, hydrothermal rocks (including spring travertines and mineral accumulations at seafloor hydrothermal vents)

Reason 3: The total amount of bioliths in the Earth is very great based on the following facts.

(I) The amount of coals and black rocks are great.

(II) The amount of carbonate rocks are great.

According to data (李大通, 罗雁. 1983), carbonate rocks cover 38.5% of the area of China, and cover 15% of the land area of the Earth (http://www.china-shj.org.cn/post/11294). According to our data, carbonate rocks account for more than 75% of the thickness of the Mesoproterozoic in China.

(III) Carbonate rocks are mainly bioliths, because of the following five reasons:

(1) Except for the ooids in the local area of the Great Bahama Bank, the reefs and non-reef carbonates in modern shallow seas are all bioliths. The carbonates in reefs consist of in-situ skeletons of benthic organisms such as corals and calcified red algae, skeletons of non-benthic organisms such as foraminifers, as well as micrites probably derived from calcified green algae.

(2) Except for oolites, ancient carbonate rocks are all bioliths. The micrites have not been fully studied, probably including a majority of biogenic and a small amount of abiogenic micrites.

(3) As examples, we have studied the Mesoproterozoic carbonate rocks in Jixian, Tianjin, China and those around Shijiazhuang, the capital of Hebei Province, China, and found that they are mainly stromatolites, a kind of biolith. According to our studies, the dolostones of the Lower Cambrian Stage 3 Xiaoerbulake Formation at Sugaitebulake, Aksu, Xinjiang, China are 187 m thick, and are mainly dolomitic thrombolites and laminites, with a small amount of dolomitic stromatolites.

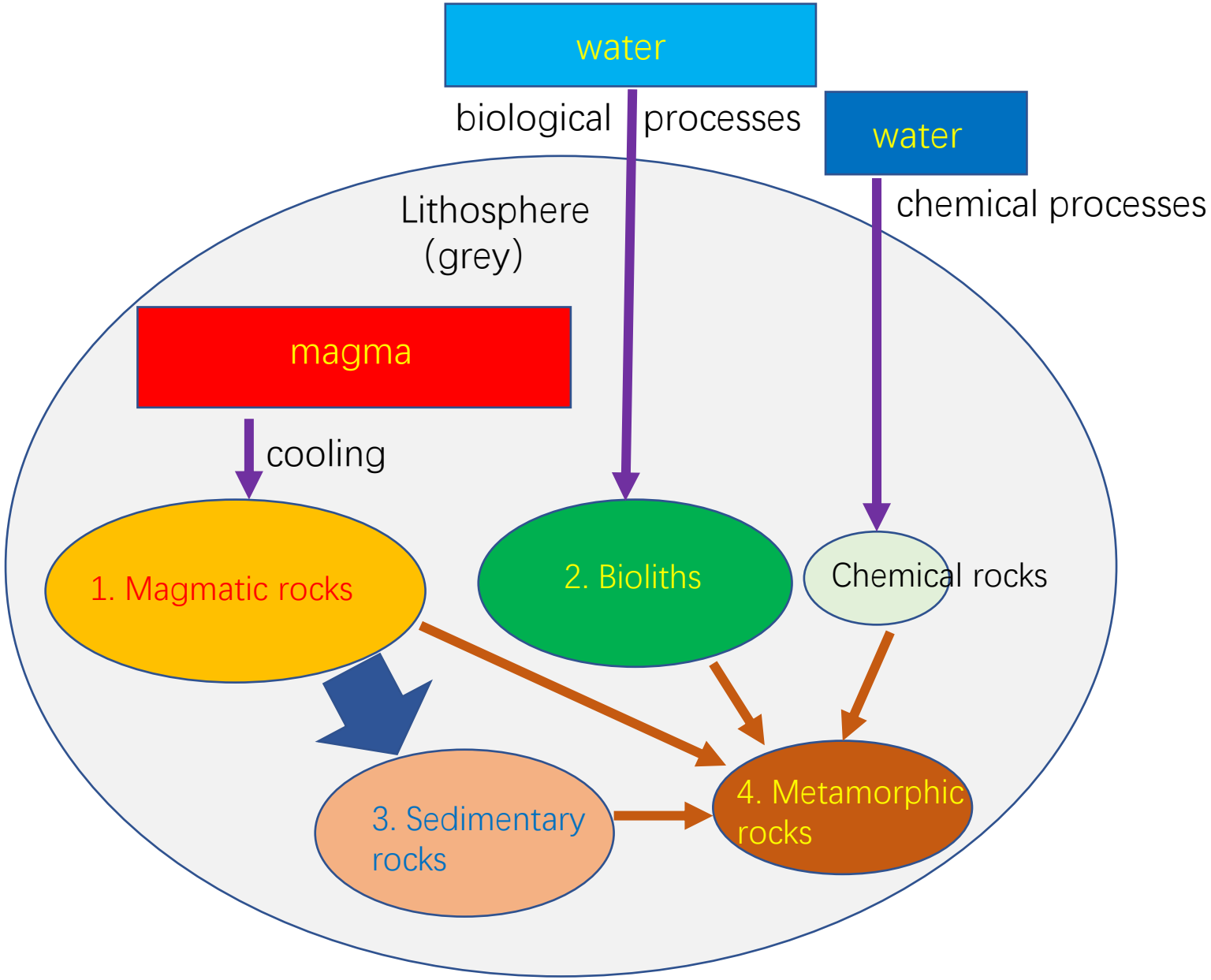
(4) Our studies show that the Ordovician carbonate rocks in the Bachu-Tazhong area in the Tarim Basin in Xinjiang, China mainly consist of microfossils and micrites.

(5) The great amount of banded cherty iron formations (BIFs) is probably of microbial origin.

So, the total amount of bioliths in the Earth is very great, and is probably greater than that of sedimentary rocks. Thus, we conclude that biolith is the secondary important kind of rocks making up the lithosphere. And magmatic rocks, bioliths, sedimentary rocks, and metamorphic rocks are the four main kinds of rocks making up the Earth. Except for the four, chemical rocks are a minor kind of rocks making up the Earth.

Previousely it is said that there are three kinds of rock: igneous, sedimentary, and metamorphic in the earth. But, from now on it should be said that there are four kinds of rock in the earth: magmatic (igneous) rocks, bioliths, sedimentary rocks, and metamorphic rocks.

Schematic diagram showing the main rocks in the lithosphere:



References

Arp, G., Helms, G., Karlinska, K., Schumann, G., Reimer, A., Reitner, J., Trichet, J. 2012. Photosynthesis versus exopolymer degradation in the formation of microbialites on the atoll of Kiritimati, Republic of Kiribati, Central Pacific. Geomicrobiology Journal, 29 (1): 29–65. https://doi.org/10.1080/01490451.2010.521436.

Bazylinski, D.A., Frankel, R.B. 2003. Biologically controlled mineralization in prokaryotes. Reviews in Mineralogy and Geochemistry, 54(1): 217-247.

Burne, R.V., Moore, L.S. 1987. Microbialites: Organosedimentary deposits of benthic microbial communities. Palaios, 2(3) : 241 − 254.

Frankel, R.B., Bazylinski, D.A. 2003. Biologically induced mineralization by bacteria. Reviews in Mineralogy and Geochemistry, 54(1): 95-114.

Li, Y., Jiang, H.X., Wu, Y.S., Pan, W.Q., Zhang, B.S., Sun, C.H., Yang, G. 2021. Macro- and microfeatures of Early Cambrian dolomitic microbialites from Tarim Basin, China. Journal of Palaeogeography, 10 (1): 19-38. https://doi.org/10.1186/s42501

Liu, L.J., Wu, Y.S., Yang, H.J., Riding, R. 2016a. Ordovician calcified cyanobacteria and associated microfossils from the Tarim Basin, Northwest China: systematics and significance. Journal of Systematic Palaeontology, 14(3): 183-210.

Liu, L.J., Wu, Y.S., Jiang, H.X., Riding, R. 2016b. Calcified rivulariaceans from the Ordovician of the Tarim Basin, Northwest China, Phanerozoic lagoonal examples, and possible controlling factors. Palaeogeography, Palaeoclimatology, Palaeoecology, 448, 371-381.

Riding, R. 2000. Microbial carbonates: The geological record of calcified bacterial–algal mats and biofilms. Sedimentology, 47 (s1): 179–214.

Wu, Y.S. 2022. Classification of biogenic carbonate rocks. Biopetrology, 1(1): 19-29.
http://biopetrology.com/yswcob

李大通, 罗雁. 1983. 中国碳酸盐岩分布面积测量. 中国岩溶, 1983, (02): 61-64.

吴亚生，2023. 生物岩的分类. 古地理学报, 25(3): 511-523.

生物岩是组成地球的第二大类岩石

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生物岩的概念

1. 生物碳酸盐岩

生物礁岩

非礁碳酸盐岩

微生物岩石

微生物岩

微生物礁岩 (由原地的微生物骨骼组成)

微屑岩（由微生物岩和微生物礁岩的碎屑组成）

2. 微生物铁质岩

条带状铁矿 (?)

宣龙式铁矿(铁质鲕粒岩, 铁质叠层石)

3. 微生物锰质岩

大洋锰质结核

4. 煤、黑色岩

生物岩

（由生物作用形成的岩石）

生物岩的形成机制:

(1) 生物控制矿物结晶作用 (形成动物、钙藻的骨骼),

(2) 生物诱导矿物结晶作用 (形成矿物壳、显微凝块、显微纹层等),

(3) 微生物席对沉积物的捕集作用 (形成一部分叠层石),

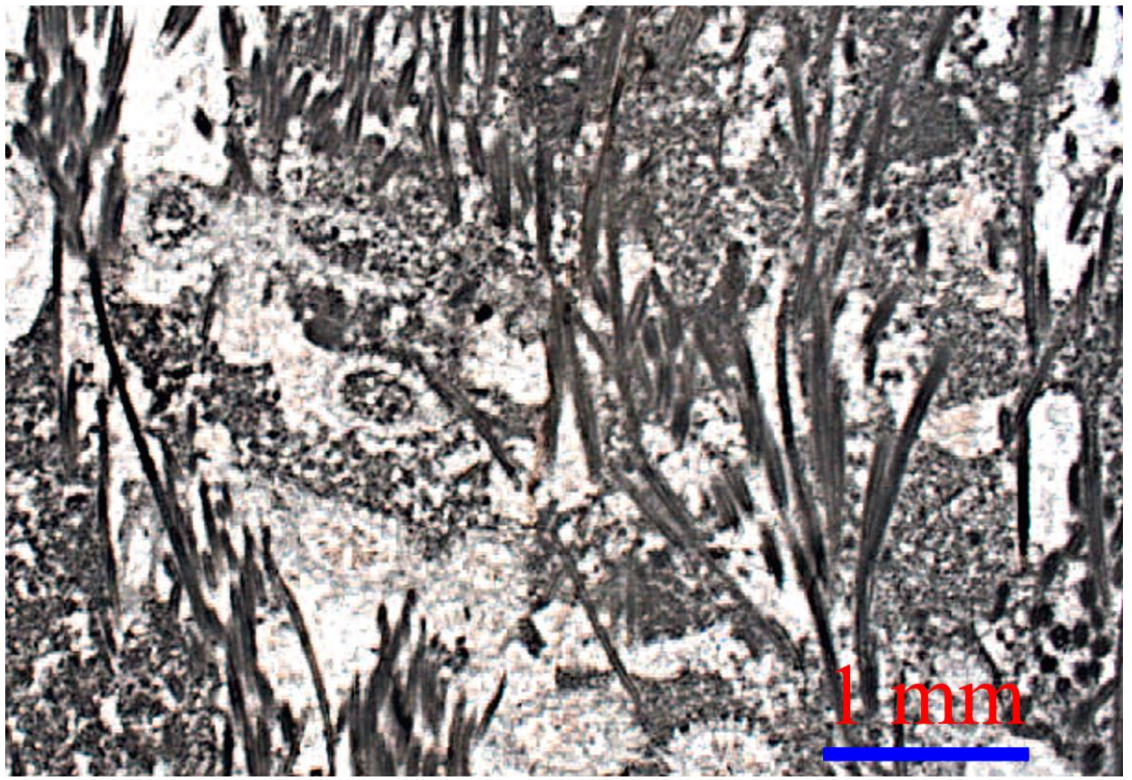
(4) 部分生物岩的破碎和沉积、成岩作用,

(5) 生物体的生长(形成煤等)

生物控制矿物结晶作用	生物诱导矿物结晶作用
既可以是宏体生物的也可以是微体生物的作用控制的	由微生物的作用诱导的
形成有特殊形状和结构的骨骼	形成矿物壳、显微凝块、显微纹层，没有特定形状和结构

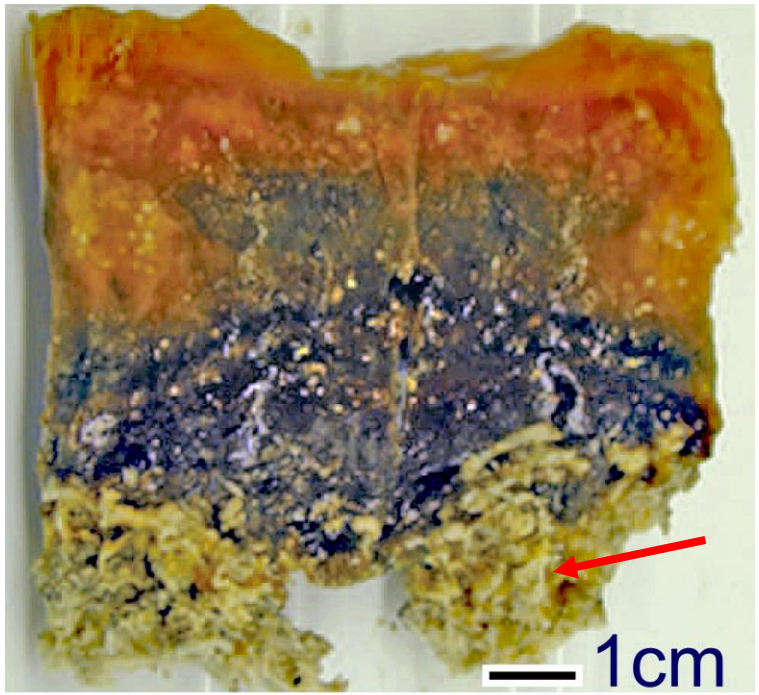
（1）宏体生物控制矿物结晶作用形成礁岩（左）、微生物控制矿物结晶作用形成的微生物礁岩（右）

礁岩（珊瑚骨架岩）

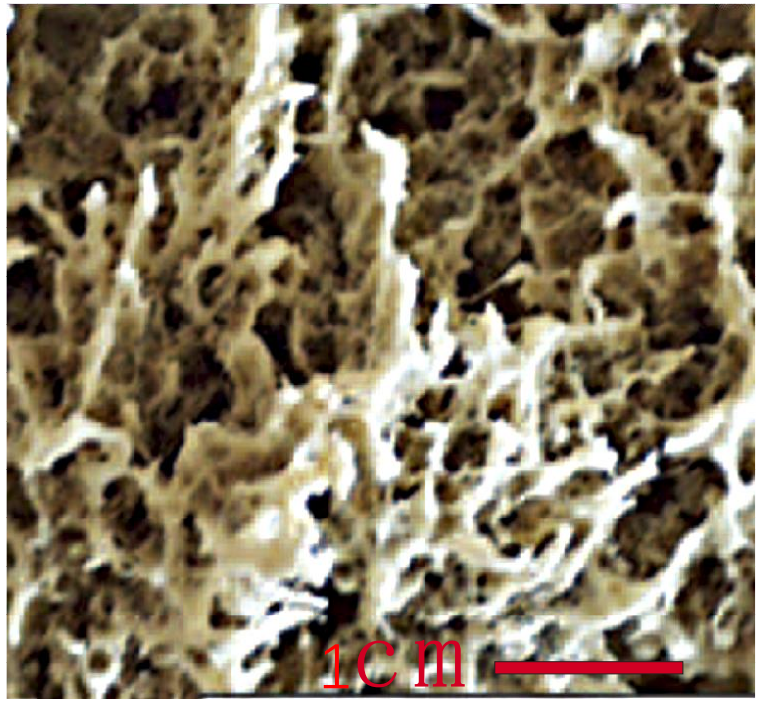


微生物礁岩（微骨架岩），由丛藻（一种钙化蓝细菌）的原地骨骼构成的微骨架岩。引自（Liu et al., 2016

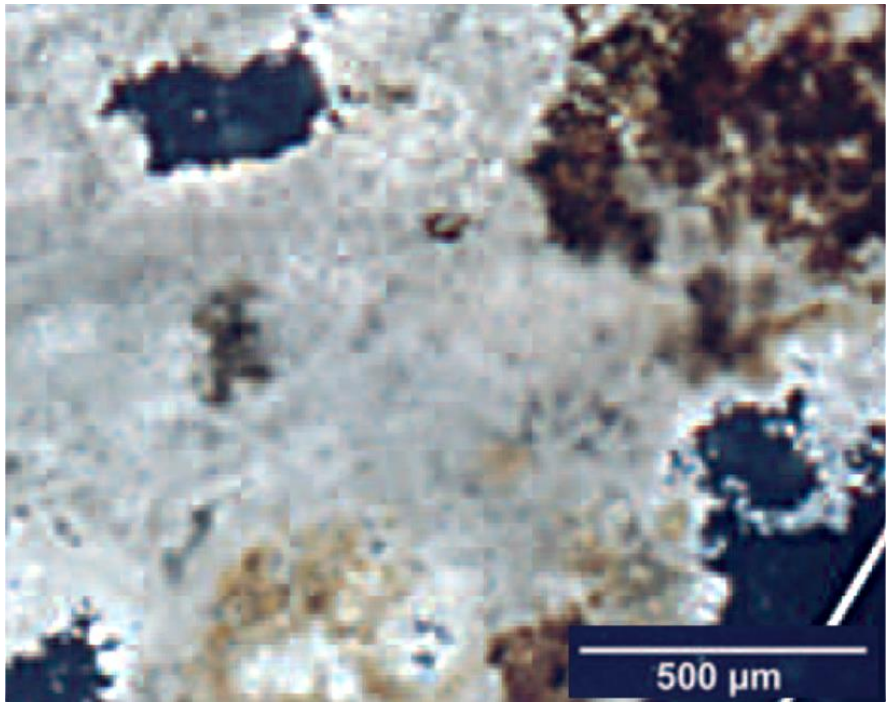
一种由微生物诱导矿物结晶作用形成的现代凝块石



基里巴斯群岛湖泊微生物席下的凝块石。一个手标本的垂直切面。黄色：微生物席；底部白色（红色箭头）：凝块石。引自Fig. 13 of Arp (2012)

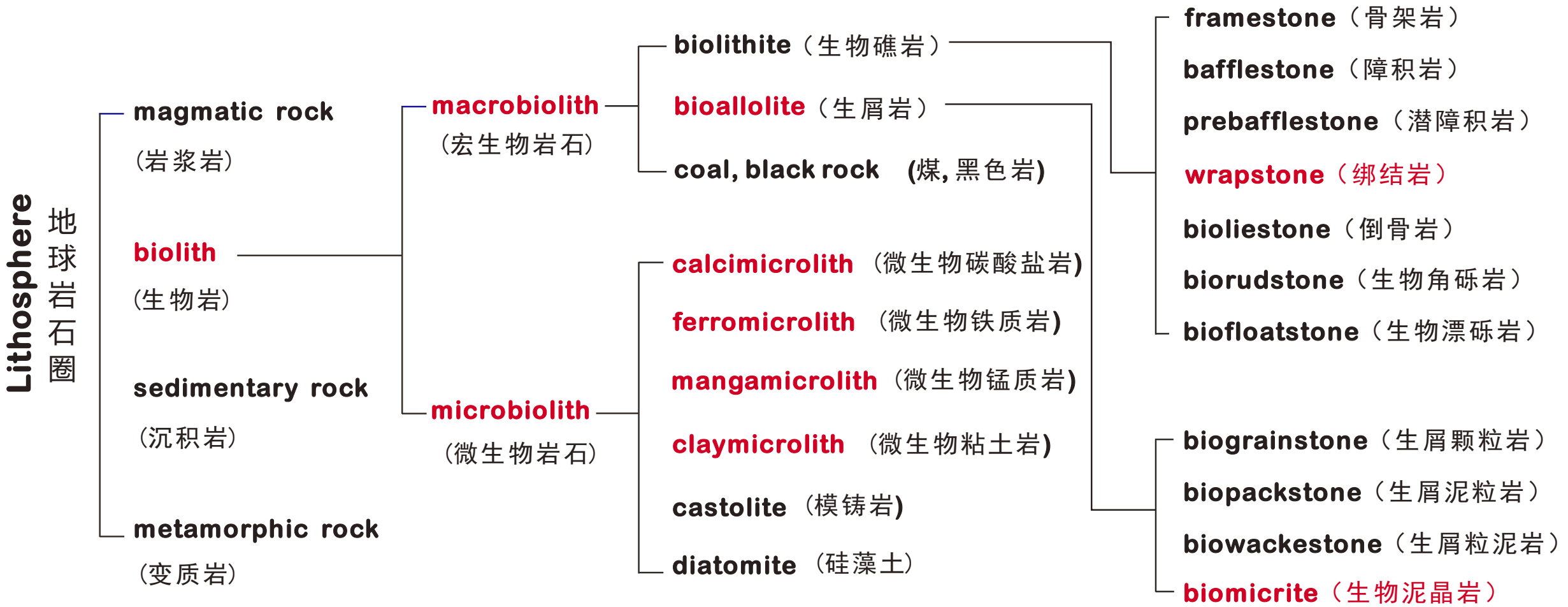


凝块石的近观。引自Fig. 13 of Arp (2012)



凝块石的薄片显微照片。引自Fig. 13 of Arp (2012)

生物岩分类

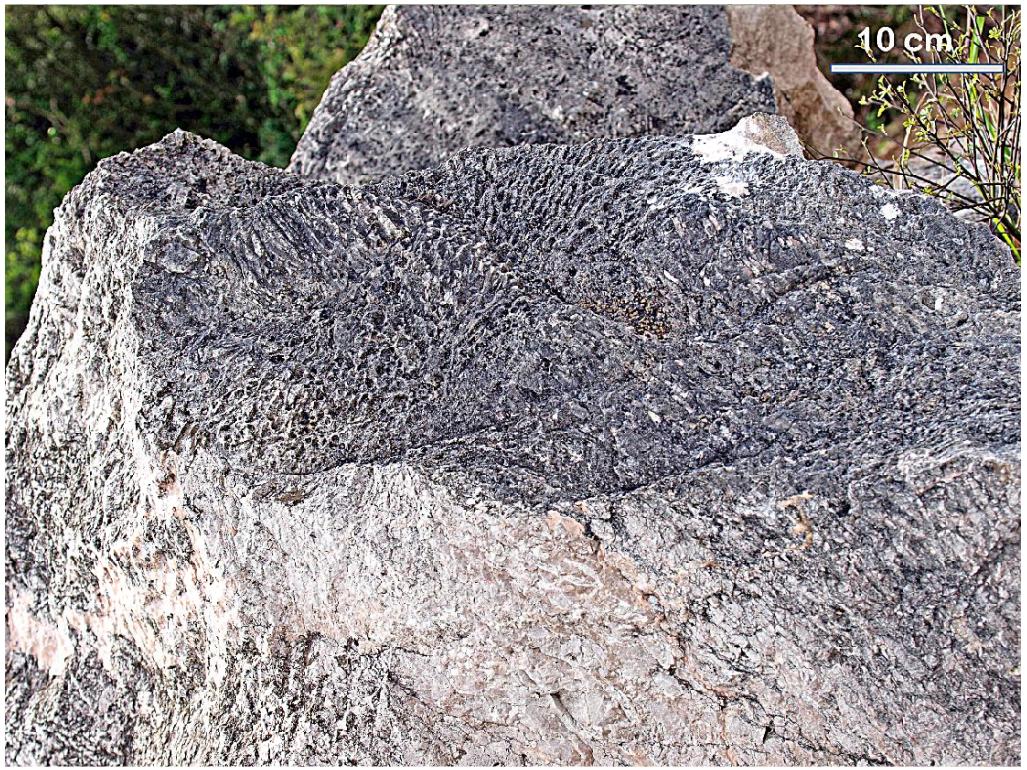


(Wu, 2022; 吴亚生, 2023)　Riding (2000): stromatolite, thrombolite, dendrolite, leiolite

- 微生物碳酸盐岩或叫钙质微生物岩石
  - 微生物岩
    - 叠层石(柱状、具有暗色泥晶显微纹层构成的岩石骨架，或具有窗格孔构成的纹层结构）
    - 层纹石(层状、具有暗色泥晶显微纹层构成的岩石骨架，或具有窗格孔构成的纹层结构）
    - 包壳石(主要由包裹生长的微生物席成因的纹层组成）
    - 核形石(主要由包裹生长的微生物席成因的纹层组成的球形颗粒）
    - 凝块石（原位的暗色泥晶显微凝块构成岩石骨架）
  - 微（生物）礁岩
    - 微（生物）骨架岩（原地底栖微生物骨骼构成岩石骨架）（树状石）
    - 微（生物）障积岩（原地底栖微生物骨骼含量>15%）
    - 微（生物）绑结岩（皮壳状微生物骨骼层层包裹其它物体）
    - 微（生物）丝状岩（原地丝状微生物骨骼构成岩石骨架）
  - 微（生物）屑岩
    - 微（生物）颗粒岩（微礁岩、微生物岩的碎屑相互接触，泥晶占孔隙50%以下）
    - 微（生物）泥粒岩（微礁岩、微生物岩的碎屑相互接触，泥晶占孔隙50%以上）
    - 微（生物）粒泥岩（微礁岩、微生物岩的碎屑不相互接触，基质为泥晶）
    - 微（生物）泥晶岩（微生物成因的泥晶>95%）

(Wu, 2022; 吴亚生, 2023)　　Dendrolite (Riding, 2000)

骨架岩中的生物骨骼必须相互连接。



这是一种由丛状珊瑚（属于四射珊瑚类）的原地骨骼构成的骨架岩，来自湖南慈利上二叠统生物礁。

这是一种由一种红藻(*Corallina*)的皮壳状骨骼构成的绑结岩，来自中国南海的新生代生物礁。岩心照片。

这是一种由倒伏的丛状珊瑚（属于四射珊瑚类）的骨骼组成的倒骨岩，来自湖南慈利的上二叠统生物礁。

一种细-粉晶云质层纹石，由暗色泥晶显微纹层与凝块石构成的浅色细-粉晶粗纹层的交互构成，来自新疆阿克苏下寒武统第三阶肖尔布拉克组，标本号S-17。

叠层石必须具有微生物席形成的纹层组成的骨架，或者有微生物席形成的纹层状孔洞。

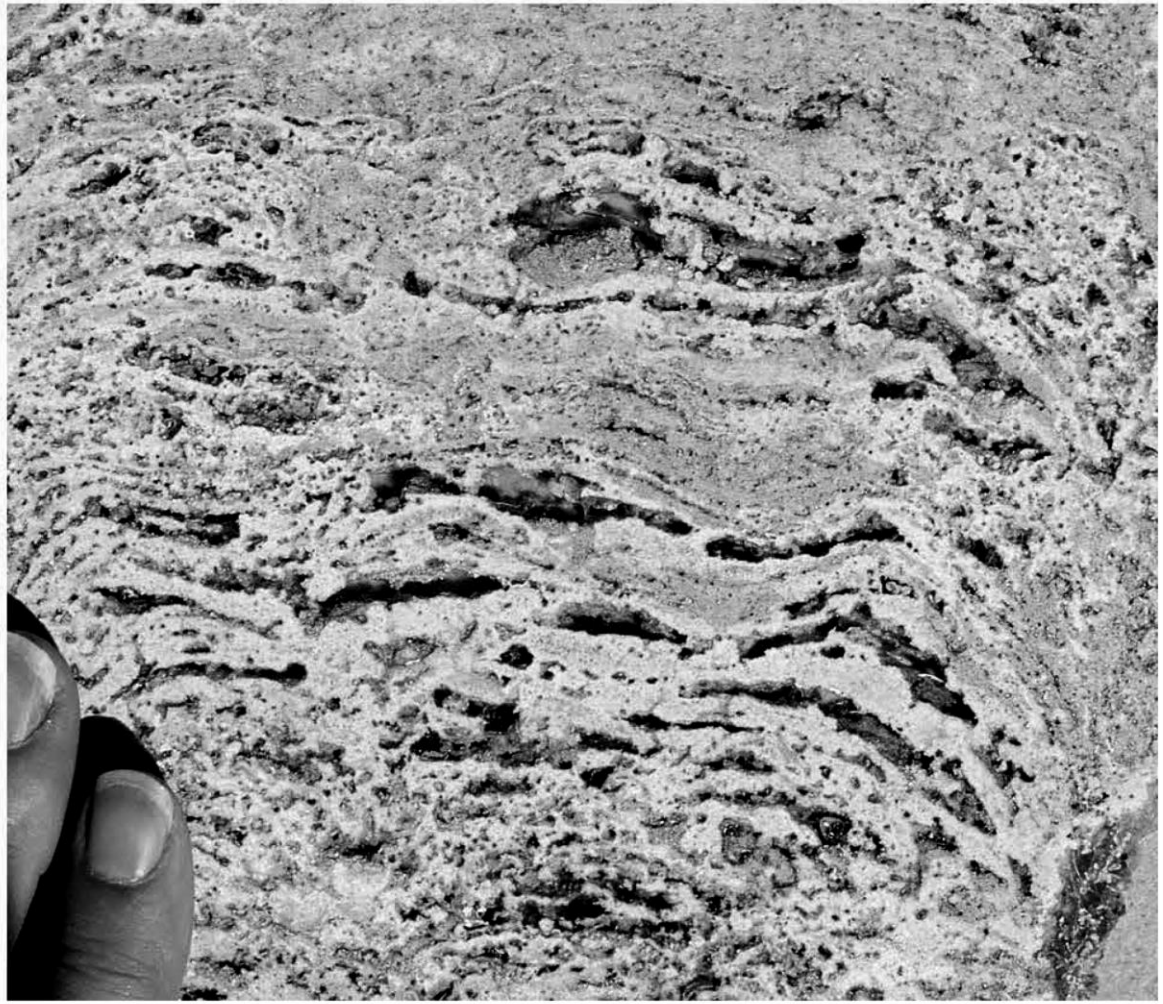
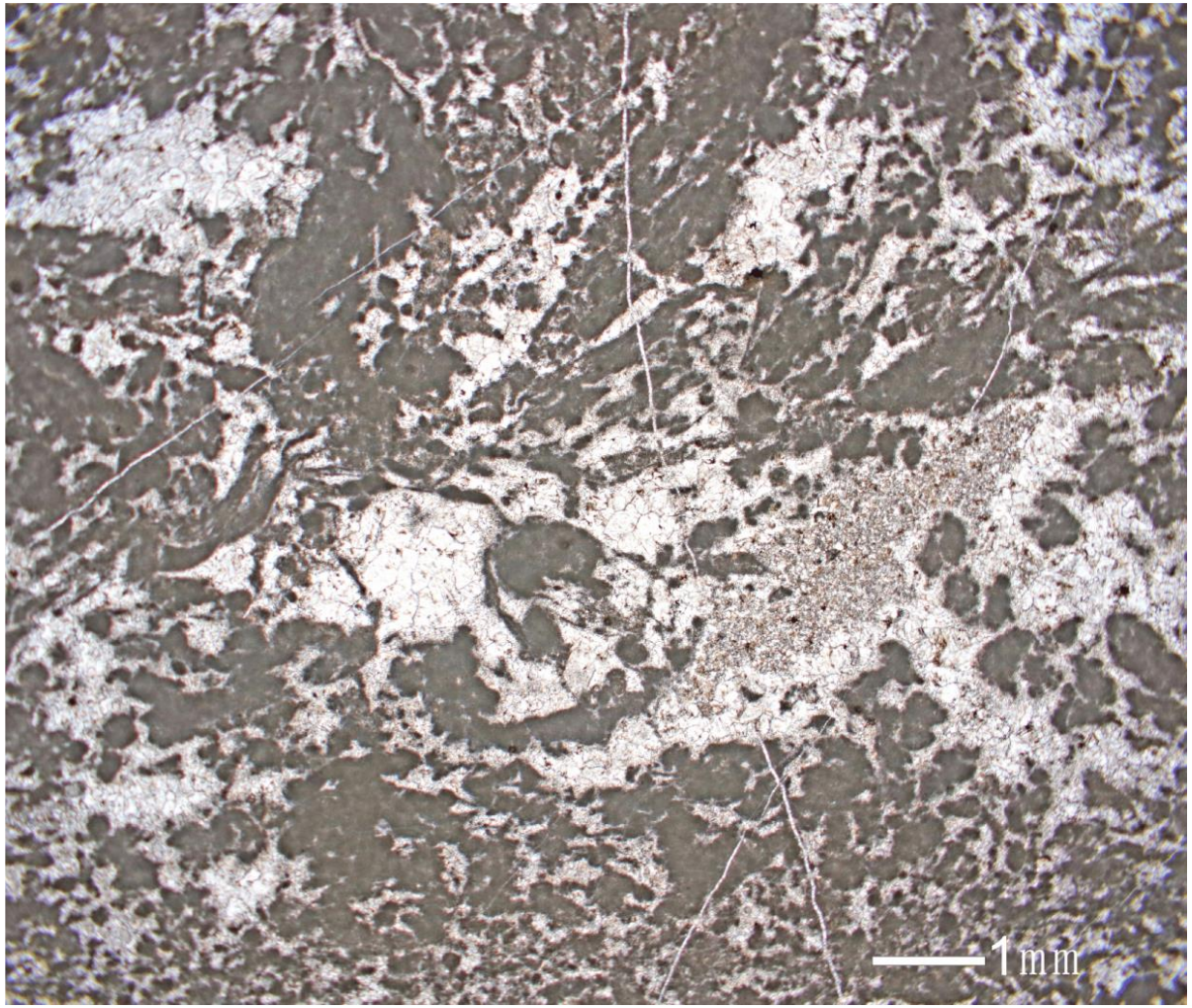


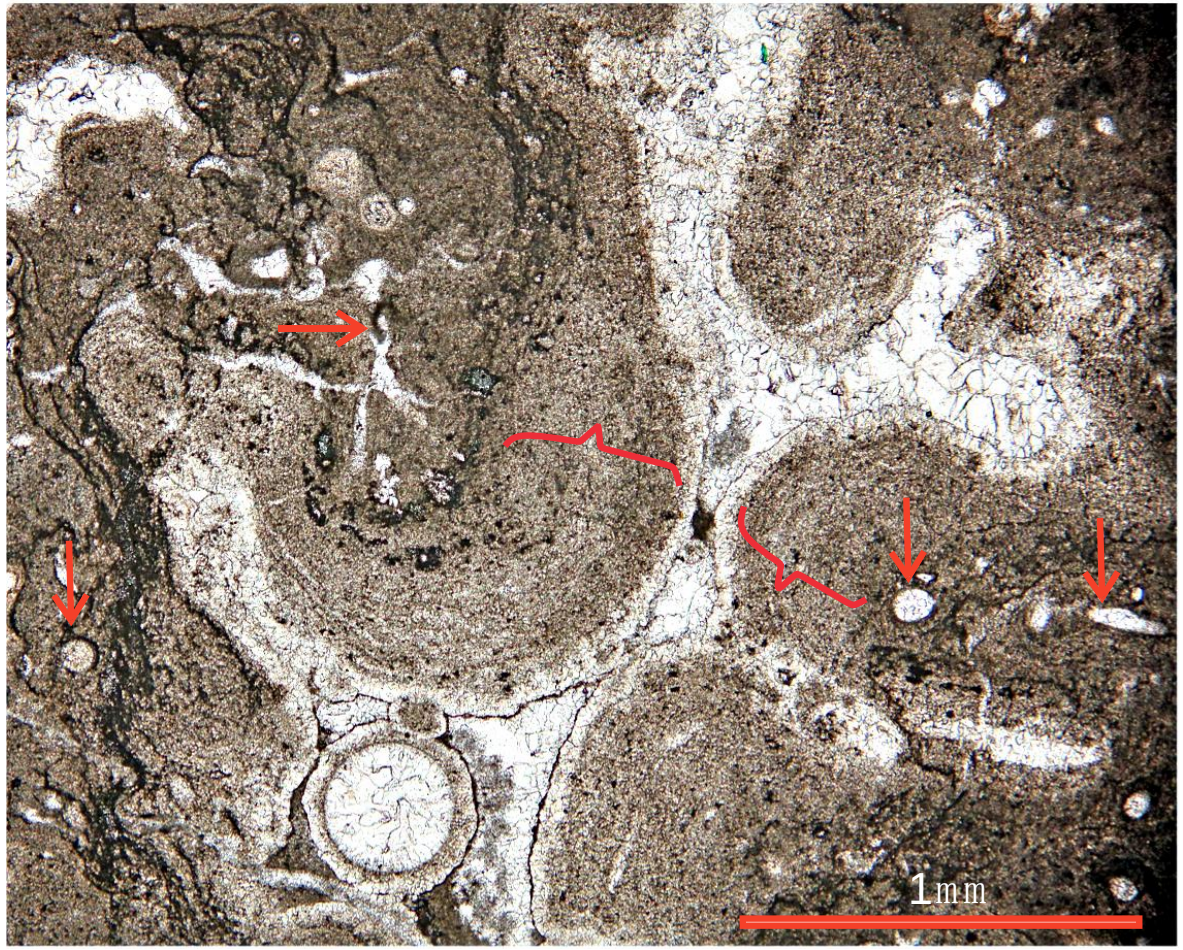
Fig. 9 of Riding (2000): 一种具有纹层状孔洞的现代叠层石，由微生物席捕集沉积物形成。

凝块石必须具有暗色泥晶显微凝块组成的骨架。



一种具有网状凝块结构的凝块石，暗色泥晶显微凝块组成岩石的骨架，来自陕西耀县陶曲坡奥陶系。

包壳石: 由层层包裹在它物上的微生物成因的泥晶显微纹层组成。



一种包壳石，由层层包裹在一些蓝藻的矿物壳（红色箭头）上的泥晶纹层（红色括号）组成，来自青海新生代湖相地层。（标本由中国石油杭州地质研究院朱超提供）

一种由表附藻（*Epiphyton*）的树枝状骨骼组成的微骨架岩

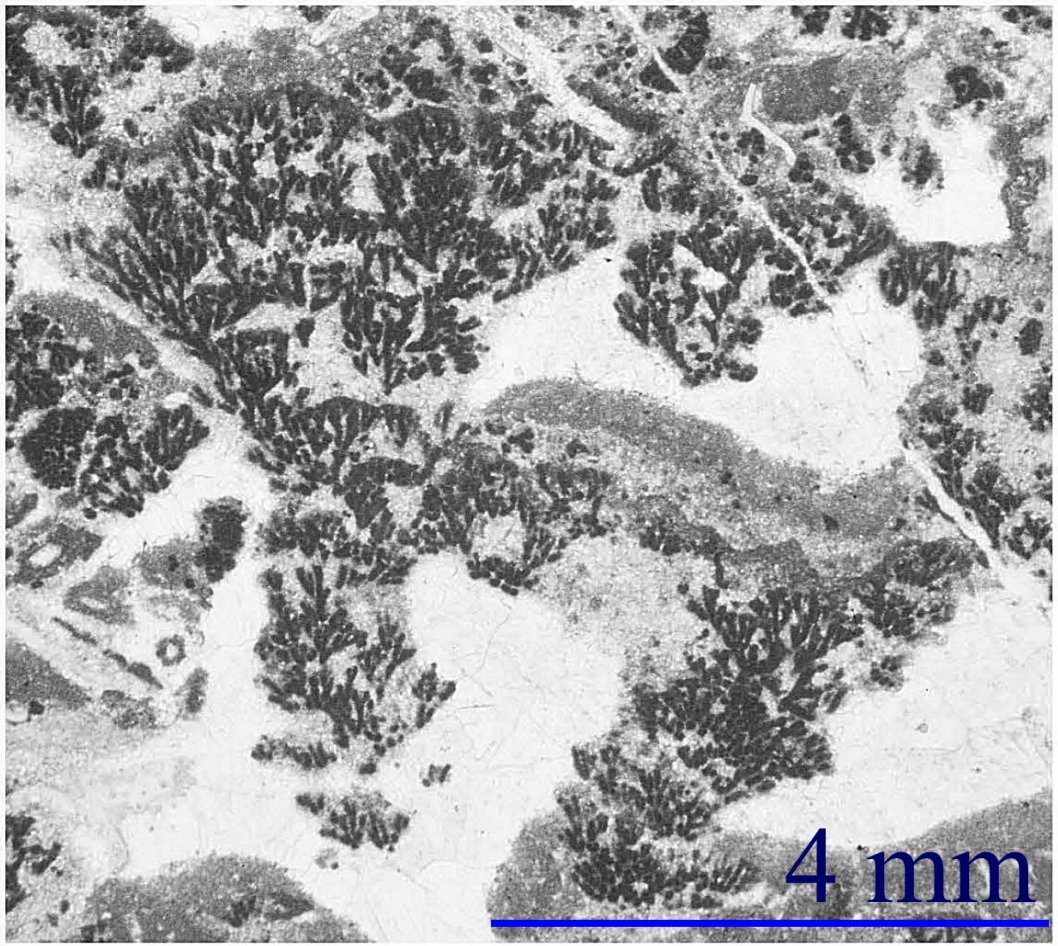
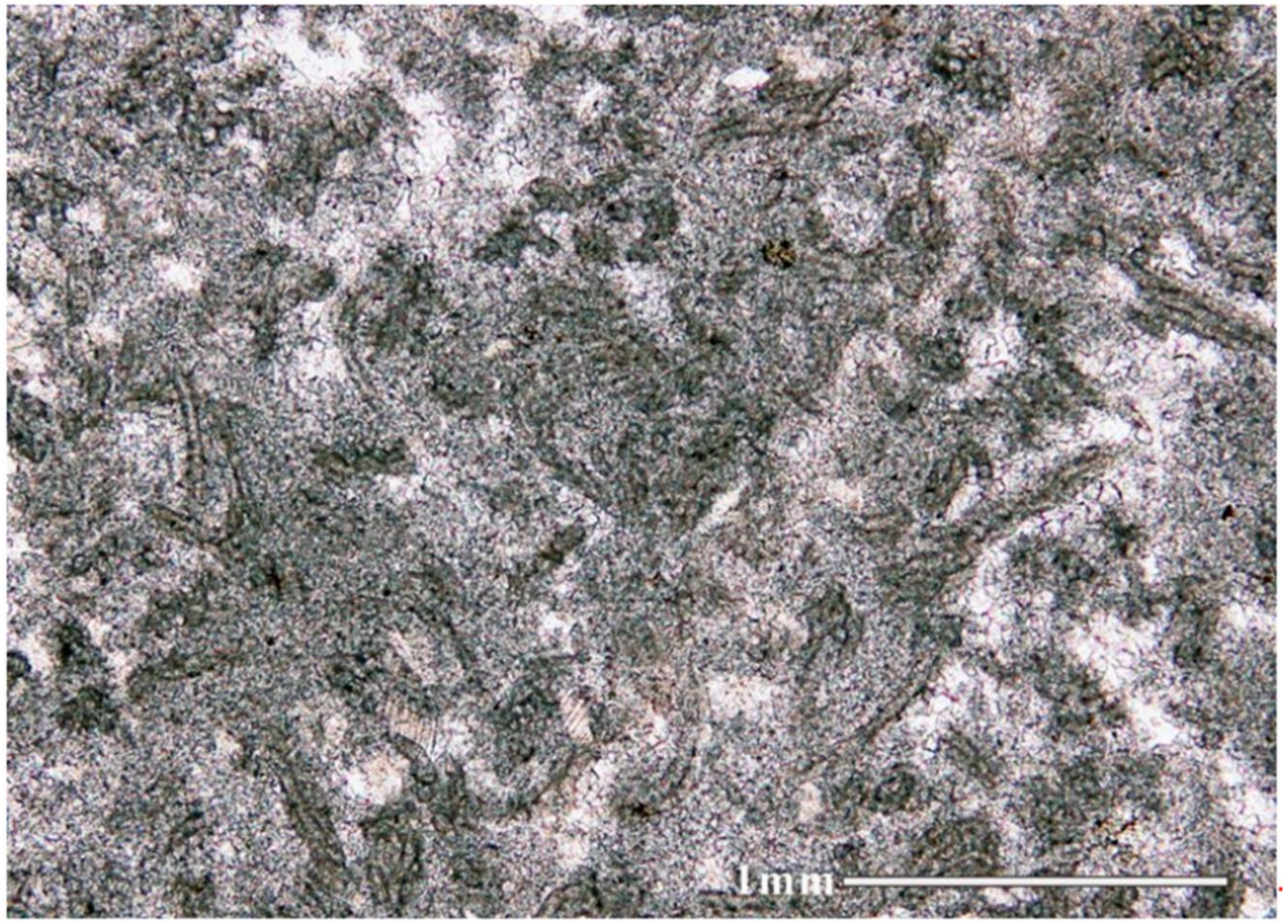
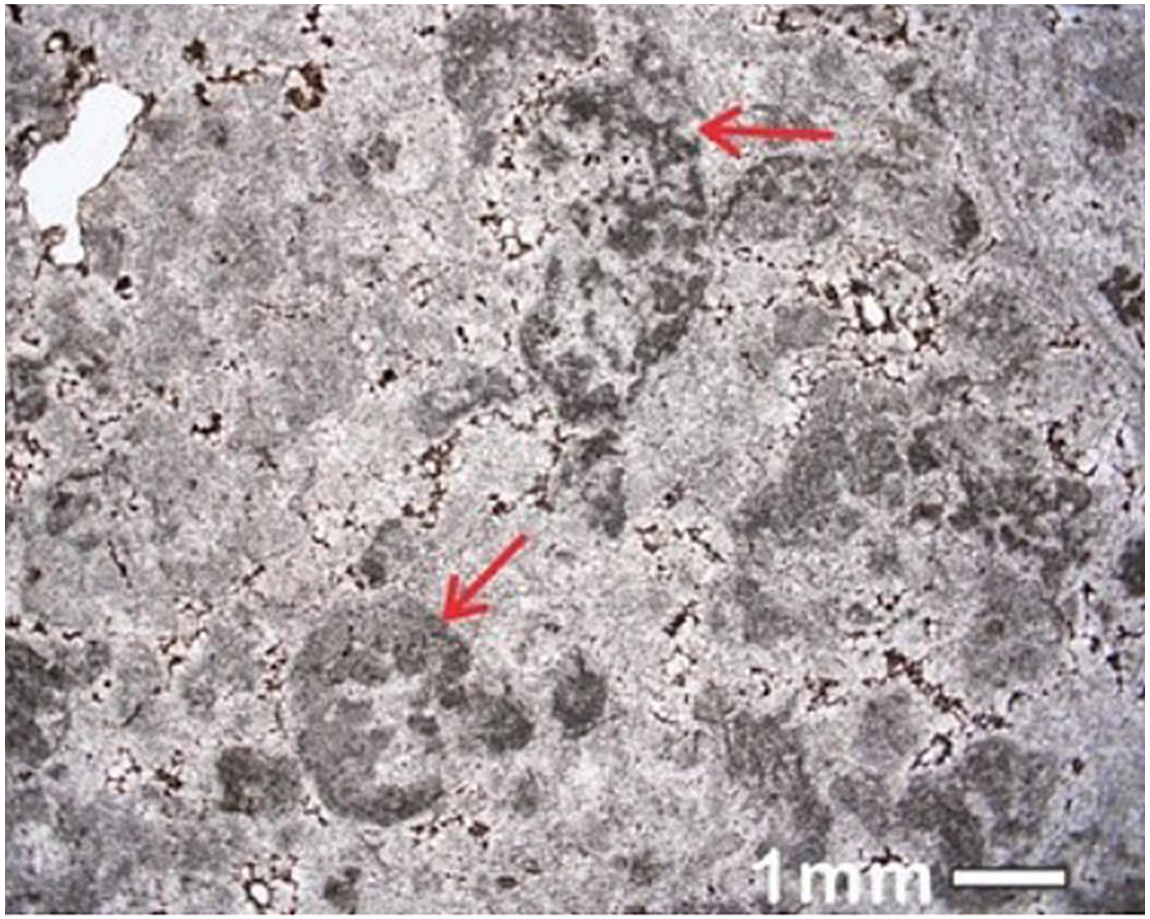


Fig. 13 of Riding (2000) 把这种岩石归入树状石（dendrolite），此处归入微骨架岩。



一种由一些蓝藻的丝状骨骼构成的丝状岩，来自新疆阿克苏下寒武统第二阶玉尔吐斯组。



一种由肾形藻（*Renacis*）骨骼的碎屑组成的微颗粒岩，来自新疆阿克苏下寒武统第三阶肖尔布拉克组。

生物岩是地球上的第二大岩，是组成地球岩石圈的四大岩之一

重要新认识：地球是由岩浆岩、生物岩、沉积岩（仅包括碎屑沉积岩）和变质岩这四大岩组成的。

以前认为地球是由岩浆岩、沉积岩、变质岩这三大岩组成的。由于以下三个原因，这里主张地球是由岩浆岩、生物岩、沉积岩（仅指碎屑沉积岩）、变质岩这四大岩组成的。

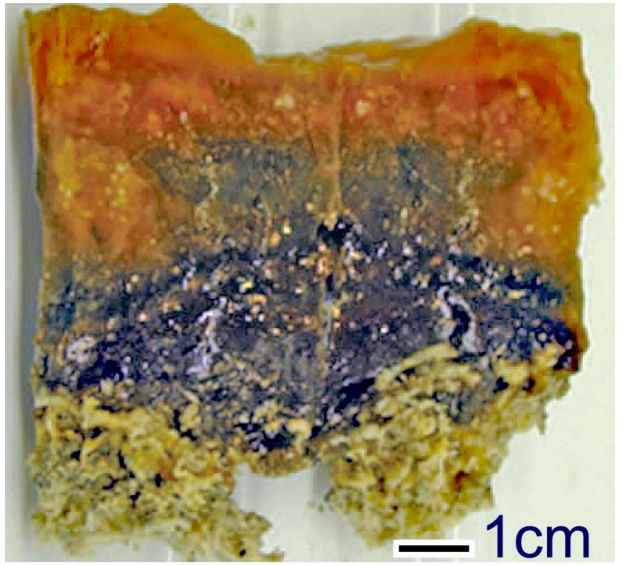
原因一，有机作用和无机作用是截然不同的作用；由生物作用形成的生物岩，不应该与无机作用形成的碎屑沉积岩归在一起。将生物作用形成的生物岩从传统的沉积岩中分离出来，是科学研究的进步。

沉积岩(旧涵义的)
- 非生物成因的沉积岩 → 沉积岩（狭义的，=碎屑沉积岩）
- 生物成因的“沉积岩” → 生物岩

原因二，形成地球上的原始岩石的作用只有三种：（1）岩浆冷凝引起的矿物结晶作用，（2）生物作用导致的矿物在水中的结晶作用，（3）无机作用，包括蒸发作用、压力和温度下降引起的矿物自/在水中的结晶作用。这三种作用形成的岩石分别是：岩浆岩、生物岩、化学岩（包括溶洞中的钟乳石、石笋，盐湖中的蒸发岩，泉华，海底热液出口处的矿物堆积——例如黑烟囱）。

碎屑沉积岩和变质岩不是原生岩石，而是改造已经存在的原生岩石形成的；其形成并不明显增加地球岩石的总体积。因此，就构成地球岩石而言，岩浆岩和生物岩比沉积岩和变质岩更重要。煤、炭质岩、黑色岩是由生物体转变而来的，或者主要由转变了的生物体组成，它们是地壳的重要组成内容。它们以前被归入沉积岩中，这里将它们归入生物岩中。

岩浆冷却导致的矿物从岩浆中结晶形成岩浆岩。opentextbc.ca



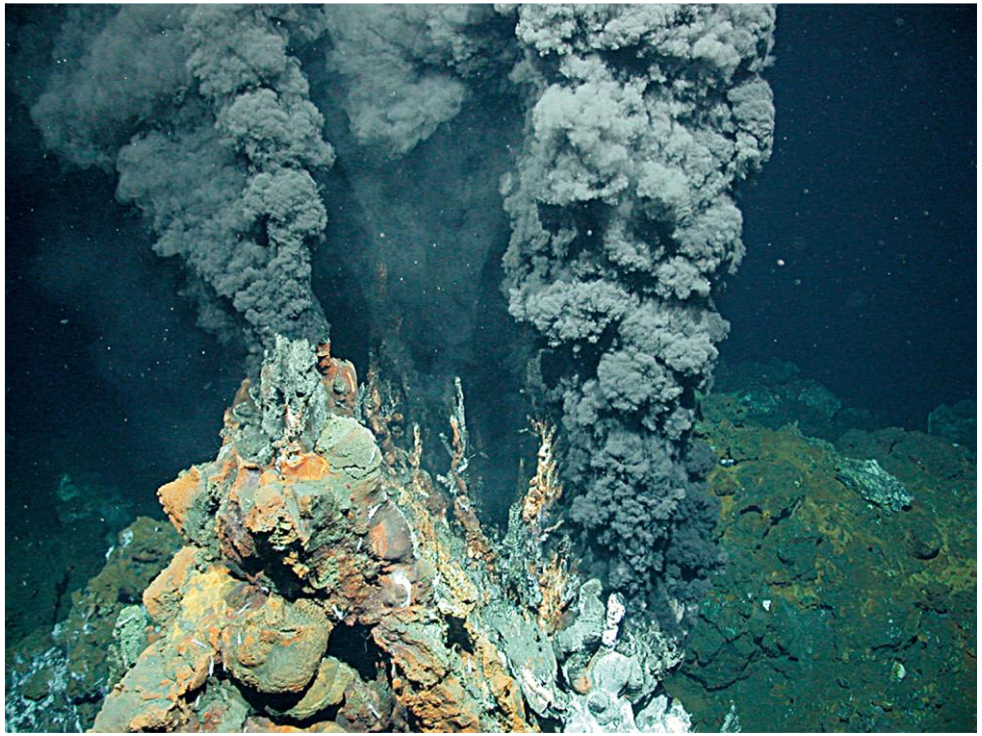
基里巴斯群岛上的湖泊里，微生物新陈代谢引起矿物结晶，形成矿物壳组成的凝块石。照片引自Fig. 13 of Arp (2012

青海湖的湖水蒸发作用导致矿物结晶，形成化学岩。dxbei.com

泉水流出地表，温度和压力的下降导致矿物从水中结晶，形成泉华. elevation.maplogs.com

Hot Spring – Bridgeport, CA, USA

海底热液喷口处由压力和温度下降导致的矿物堆积，形成“黑烟囱”



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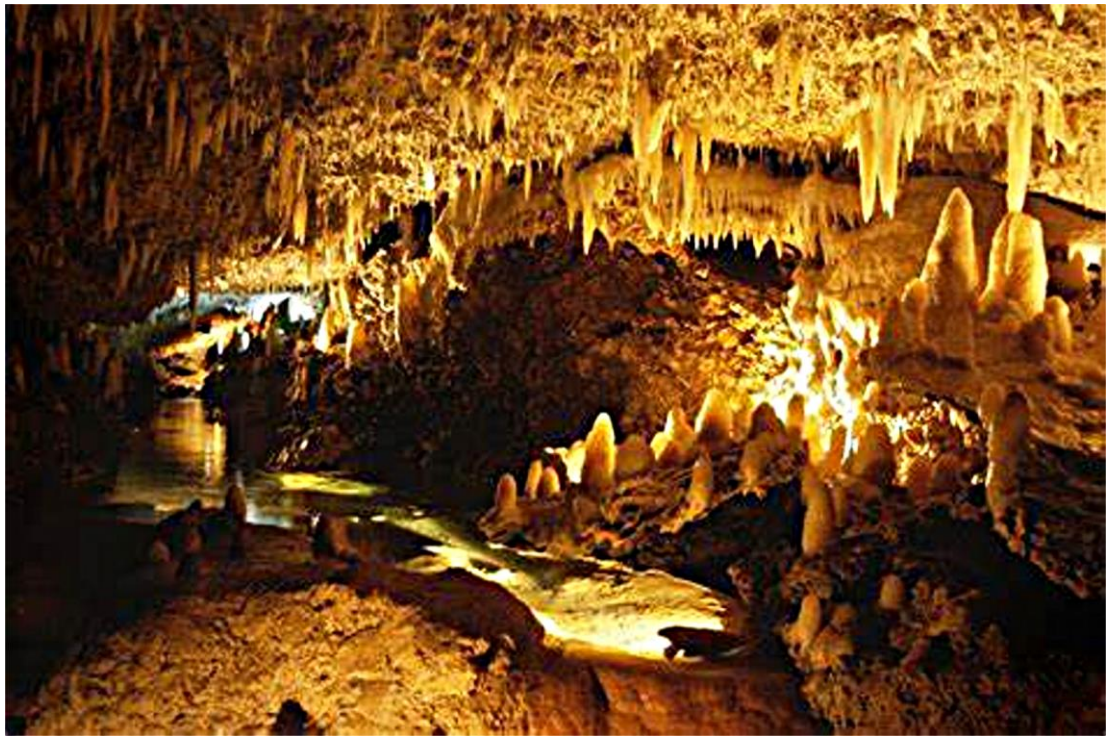
溶洞内滴水由蒸发作用导致的碳酸钙结晶，形成钟乳石、石笋等



https://www.dkfindout.com/uk/earth/caves/stalactites/

化学岩包括蒸发岩（地表水体的蒸发作用导致矿物结晶形成的）、热水岩（包括泉华、海底热液口堆积——包括黑烟囱）。

原因三，地球上生物岩的总体积很大。

（1）地球上，煤、炭质岩、黑色岩的数量巨大。

（2）地球上，碳酸盐岩的数量巨大：

根据统计，中国国土面积的38.5%被碳酸盐岩地层覆盖（李大通, 罗雁. 1983）；全球陆地表面积的15%被碳酸盐岩地层覆盖（http://www.china-shj.org.cn/post/11294）。地壳内碳酸盐岩的总体积应与其露头总面积成正比。根据笔者统计，碳酸盐岩地层占到中国华北中元古代地层总厚度的75%以上。因此，地壳内的碳酸盐岩数量巨大。

因为以下原因，笔者认为碳酸盐岩主要是生物岩：

（1）现代碳酸盐形成区，除了大巴哈马滩局部有无机成因的鲕粒沉积在形成，其余几乎全部是生物成因的碳酸盐颗粒和泥晶。泥晶的成因不是十分明确，但可能大多数是生物成因的、少数是无机成因的;

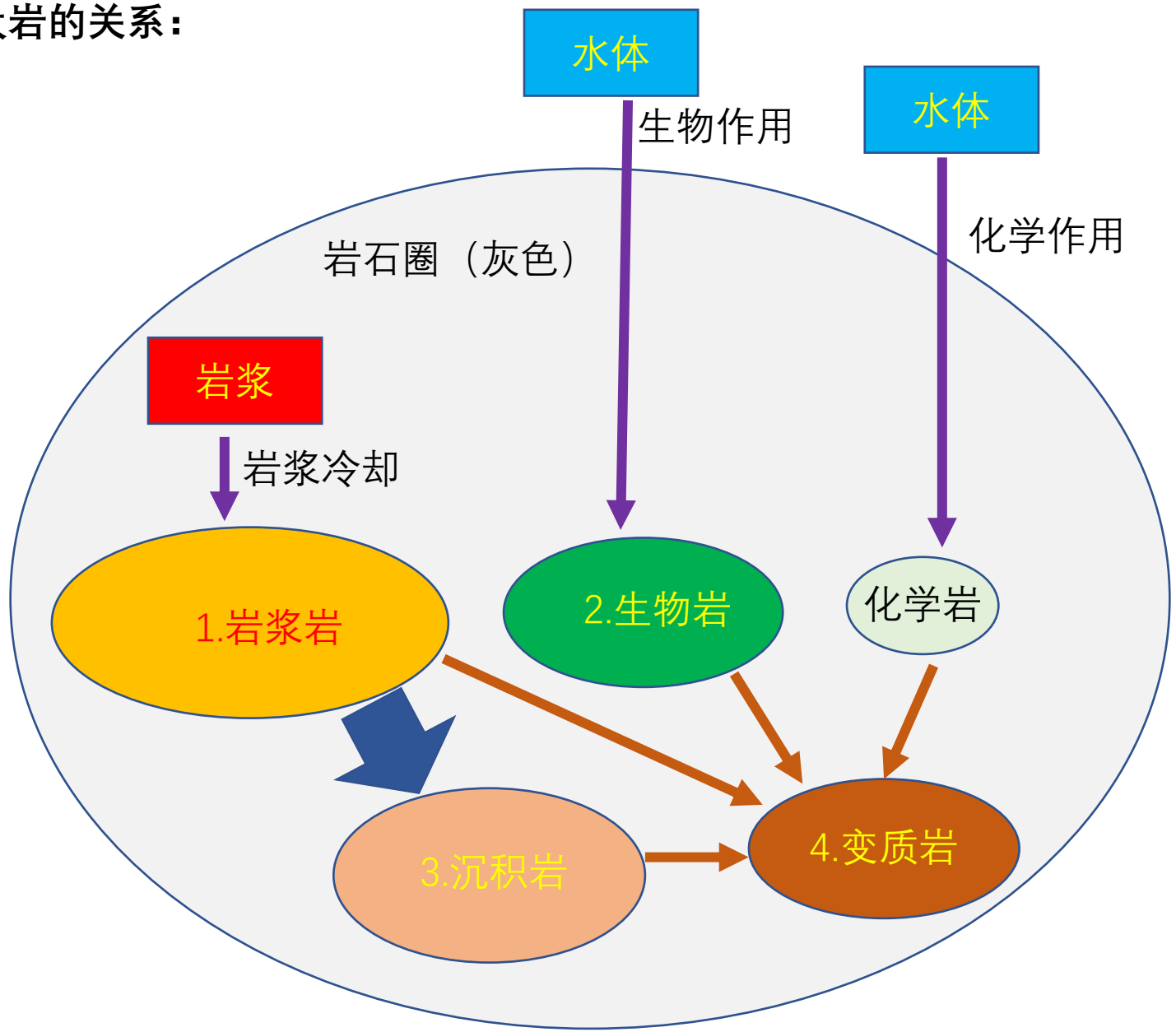
（2）大量的研究表明，古代地层中的碳酸盐岩中，鲕粒岩等无机成因的也是少数，生物成因的生物碳酸盐岩占大多数;

(3) 根据研究，天津蓟县的中元古代碳酸盐岩主要是叠层石——一种典型的生物碳酸盐岩；根据我们的研究，石家庄周围的中元古代碳酸盐岩主要是叠层石；新疆阿克苏苏盖特布拉克下寒武统第三阶肖尔布拉克组187m厚的白云岩地层，微生物岩石的厚度占90%以上，包括凝块石和叠层石；新疆巴楚-塔中的奥陶系碳酸盐岩主要是生物岩；

(5) 数量巨大的条带状硅铁建造的铁可能是微生物成因的；

因此，得出结论：地球上的生物岩数量巨大，由于其为原生岩石，其重要性大大超过了碎屑沉积岩，因此是组成地球岩石圈的第二大岩石，是组成地球岩石圈的四大岩之一。

组成地球岩石圈的4大岩的关系：



参考文献

Arp, G., Helms, G., Karlinska, K., Schumann, G., Reimer, A., Reitner, J., Trichet, J. 2012. Photosynthesis versus exopolymer degradation in the formation of microbialites on the atoll of Kiritimati, Republic of Kiribati, Central Pacific. Geomicrobiology Journal, 29 (1): 29–65. https://doi.org/10.1080/01490451.2010.521436.

Bazylinski, D.A., Frankel, R.B. 2003. Biologically Controlled Mineralization in Prokaryotes. Reviews in Mineralogy and Geochemistry, 54(1): 217-247.

Burne, R.V., Moore, L.S. 1987. Microbialites: Organosedimentary deposits of benthic microbial communities. Palaios, 2(3) : 241 − 254.

Frankel, R.B., Bazylinski, D.A. 2003. Biologically induced mineralization by bacteria. Reviews in Mineralogy and Geochemistry, 54(1): 95-114.

Li, Y., Jiang, H.X., Wu, Y.S., Pan, W.Q., Zhang, B.S., Sun, C.H., Yang, G., 2021. Macro- and microfeatures of Early Cambrian dolomitic microbialites from Tarim Basin, China. Journal of Palaeogeography, 10 (1): 19-38. https://doi.org/10.1186/s42501

Liu, L.J., Wu, Y.S., Yang, H.J., Riding, R. 2016. Ordovician calcified cyanobacteria and associated microfossils from the Tarim Basin, Northwest China: systematics and significance. Journal of Systematic Palaeontology, 14(3): 183-210.

Liu, L.J., Wu, Y.S.,Jiang, H.X., Riding, R. 2016. Calcified rivulariaceans from the Ordovician of the Tarim Basin, Northwest China, Phanerozoic lagoonal examples, and possible controlling factors. Palaeogeography, Palaeoclimatology, Palaeoecology, 448, 371–381.

Riding, R. 2000. Microbial carbonates: The geological record of calcified bacterial–algal mats and biofilms. Sedimentology, 47 (s1): 179–214.

Wu, Y.S. 2022. Classification of biogenic carbonate rocks. Biopetrology, 1(1): 19-29.
http://biopetrology.com/yswcob
李大通, 罗雁. 1983. 中国碳酸盐岩分布面积测量. 中国岩溶, 1983, (02): 61-64.
吴亚生，2023. 生物岩的分类. 古地理学报, 25(3): 511-523.

(The end)