Theoretical Article

Definition of biopetrology

Ya-Sheng Wu*

[1]Key Laboratory of Cenozoic Geology and Environment, Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 100029, China.
[2]Innovation Academy for Earth Science, Chinese Academy of Sciences, Beijing 100029, China.
[3]University of Chinese Academy of Sciences, Beijing 100049, China.
*Corresponding author: wys@mail.igcas.ac.cn.

Abstract

Biopetrology is a new interdisciplinary science dealing with the features, formation, environment, and economic significance of bioliths, i.e., the biogenic rocks. Currently it includes the five different but related research fields: biomineralization, modern reefs, ancient reefs, modern microbial rocks, and ancient microbial rocks. Research of biomineralization and modern bioliths provides the base for the study of ancient bioliths. Because present-day biosphere and environments are different from the ancient, the research results of modern bioliths and biomineralization cannot be directly applied to the ancient. The research results of the ancient bioliths can provide ideas for designing the research of modern bioliths and biomineralization. The related disciplines include biology, microbiology, paleontology, paleomicrobiology, sedimentology, sedimentary petrology, mineralogy, and geochemistry. Biopetrological research needs the knowledge of these disciplines.

Key words: **Biopetrological, biolith, microbial rocks, biomineralization, reef, biogenic rocks**.

1 Definition of biopetrology

In the 13th issue of the WeChat Public Account on August 5, 2021 (Wu, 2021), Ya-Sheng Wu proposed to define a new discipline to accommodate the study of all biogenic minerals and rocks. The new discipline is intended to cover the five research fields: biomineralization, modern reefs, ancient reefs, modern microbial rocks, and ancient microbial rocks. The microbial rocks include all rocks formed by the calcification of microbes, or by the trapping or induced precipitation by microbes. All biogenic rocks, including reef rocks, non-reefal biogenic rocks, and microbial rocks, can be placed under the name biolith, a geologic term established in the first half of the 19th century in Germany literature referring to the rocks formed from the remains or skeletons of organisms, or by the activities of organisms (Ehrenberg, 1853), and was sparsely used in the 20th (Rivadeneyra et al., 1996) and 21th centuries. Biopetrology, a term that has been used in several papers on coal by a few Indian

Funding This study was supported by the National Natural Science Foundation of China (Grant No. 41972320), National Major Science and Technology Projects of China (Grant No. 2016ZX05004–004) and the Strategic Priority Research Program (B) of Chinese Academy of Sciences (Grant No. XDB26000000) to Ya-Sheng Wu.

Cite it as: Wu, Y.S. 2022. Definition of biopetrology. Biopetrology, 1(1): 3-8. http://biopetrology.com/yswdob.

scholars in this century, but never been used in papers on other kind of rocks, is here formally suggested as the name of the new discipline. Biopetrology studies the feature, formation, environment, and economic significance of bioliths.

The research on biomineralization includes the experimental studies on the biomineralization of macroalgae, plants and animals, such as green algae, red algae, corals and bivalves, and those on the formation mechanism and features of minerals, fossils, and rocks by microbes.

The research on modern reefs deals with the biotic communities, physical-chemical conditions, fabrics, and mineral and chemical compositions of the rocks in reefs. Mineral construction is a general term referring to a mineral body consisting of the in situ mineral skeletons of macroorganisms or microbes, or of the micritic laminae or micritic clots formed by microbe-induced precipitation. The carbonate constructions formed by the in situ skeletons of macroorganisms are called reefs, and those formed by in situ micritic laminae and / or clots called microbialites (Burne and Moore, 1987). The mineral construction consisting of the skeletons of microbes were regarded as thrombolites or dendrolites in previous literature (Yan et al., 2017). In my opinion, however, the formation of the skeletons of microbes is different from that of the laminae in stromatolites and the clots in thrombolites: although both form by biomineralization, the two biomineralizations are different. Thus, we prefer to call the mineral constructions consisting of the in situ skeletons of microbes (i.e., fossils) microbial reefs. A reef must be a topographic elevation on the sea floor. A sheet-like mineral body, even though it consists of in situ skeletons, is not a reef, but a biostrome (Cumings and Shrock, 1928).

The research on ancient reefs studies the fabrics, mineral and chemical compositions, formation mechanisms, paleoceanographic conditions, fossils, paleocommunities, diagenesis history, and ore resource significance of ancient reefs.

The research on modern microbial rocks focuses on the physical-chemical conditions, microbial communities, fabrics, mineral and chemical compositions, and formation mechanisms of modern microbial rocks. The term microbial rock used here is different from microbialite, which was defined by Burne and Moore (1987) to refer to the microbial rock formed by the action of benthic microbial communities. Microbial rock refers to all rocks that are formed by microbes, whether by benthic or planktonic microbes, whether the rocks are composed of in situ fossils, crusts, laminae, clots formed by microbes, or composed of sediments formed from the fossils, crusts, laminae, and clots formed by microbes with action of water or currents.

The research on ancient microbial rocks deals with the macro-, meso-, and micro- fabrics, mineral and chemical compositions, formation mechanisms, paleoenvironments and mineral ore resource significances of ancient microbial rocks.

Of the five research fields, the research of modern and ancient reefs was included in the extant discipline "sedimentology". However, the research on biomineralization, modern and ancient microbial rocks has not been categorized in any existing disciplines. Perhaps some scholars tend to place them in sedimentology. It is preferable, however, to place them in a different disciplinary, since their formations are not controlled by wind, water or currents, but by microbes.

Although some kinds of bioliths are formed by the transportation and deposition of biogenic carbonate grains, most bioliths were formed independent of the common sedimentary processes, and their research should be performed according to different theories and using different methods. Thus, it's necessary to put the research of bioliths in an independent discipline.

2 The relationships among the five research fields

There are some relationships among the five research fields. Modern reefs mainly consist of the in situ skeletons that were mainly formed by the biomineralization of extant plants and animals. Thus, the study of the biomineralization of modern organisms can provide a basis for understanding the formation of modern reefs. Ancient reefs consist of the in situ skeletons formed by the biomineralization of ancient plants and animals. Although most ancient plants and animals are extinct, most of them have extant descendants or relatives. The research of the biomineralization of their recent descendants or relatives can help understand the formation of the skeletons in ancient reefs.

The study of the biomineralization of modern microbes can provide a basis for understanding modern and ancient microbial rocks. The study of modern microbial rocks can provide a basis for understanding ancient microbial rocks. The study of ancient microbial rocks can provide the ideas about how to design the experiments on modern microbial biomineralization.

Ancient reefs and microbial rocks have suffered diagenetic alterations, and their original fabrics and mineral-chemical compositions have been destroyed to varying degrees. Modern reefs and microbial rocks have suffered little diagenesis, and are the best materials for studying the original fabrics and compositions. The research of modern reefs and microbial rocks can provide good references for understanding ancient reefs and microbial rocks.

Compared with the long history of the Earth, however, modern time is a short moment. In the long geological history, the environments kept in change and the biosphere kept in evolution. Therefore, even though the results of modern research can be used as references for the research of ancient reefs and microbial rocks, they are very limited, since many ancient phenomena do not have present-day references. Thus, the study of ancient bioliths not only needs to learn from modern bioliths, but also requires lots of simulation and experiments, and a lot of reasoning and deduction.

Since there are natural connections between the five fields, they should not be considered in isolation, but are best integrated within a new interdisciplinary science, biopetrology.

3 Related disciplines of biopetrology

(1) Biology, microbiology, paleontology and paleomicrobiology

Paleontology studies the fossils in strata to interpret the taxonomy, ecology, geography, evolution, and other aspects of ancient organisms. According to the size of the fossils dealt with in paleontology, this discipline is divided into macropaleontology and micropaleontology. The macropaleontology is divided into paleobotany, invertebrate paleontology, and vertebrate paleontology.

Biopetrology studies the rocks formed by macroorganisms and microbes. For studies of the rocks formed by modern organisms, it is necessary to study modern organisms, because we need to know what kind of organisms have formed the rocks. So, we need to conduct taxonomic research.

For ancient bioliths, it is necessary to study ancient organisms to determine what kinds of macroorganisms or microbes have formed the ancient bioliths. Thus, paleontological research is needed. In the past, micropaleontology mainly studied foraminifers, sporopollen, ostracods, and other small fossils, with very little content for cyanobacterial and bacterial fossils.

Existing knowledge reveals that bioliths are mainly formed by microbes, animals, and algae; coal is mainly formed by higher plants; and oil shale and petroleum are mainly formed from microbes. The history of biological evolution shows that during the 4 billion years of the Precambrian, the biological world on Earth was dominated by microbes. It was not until the late Proterozoic that metazoans appeared. The Phanerozoic is an era when both metazoans and microbes were present. Microbes in the Phanerozoic era act as primary producers, as food for metazoans.

The amount of the microbioliths formed on the vast surface of the earth in the Precambrian is much greater than the bioliths formed in the Phanerozoic. Therefore, the study of microbial fossils is as important as, or even more important than, the study of metazoans.

In the future, we need to strengthen the research on ancient microbes. In order to facilitate the research on ancient microbes, it is suggested here to separate the research of ancient microbes into a branch of paleontology parallel to paleobotany and paleozoology, here termed paleomicrobiology.

(2) Sedimentology and sedimentary petrology

Sedimentology studies the transportation and deposition of detrital sediments by currents, wind, iceberg, and gravity, and the transformation of sediments to rocks through compaction, cementation, and mineral transformation. Previously the research of the rocks formed by chemical precipitation and the reefs were included in sedimentology. I prefer to separate them from it. The science studying the characteristics, formation mechanism, environmental and ore resource significances of sedimentary rocks is called sedimentary petrology.

Sedimentology is an important branch of earth sciences. Sedimentary petrology is an important branch of geology. When the formation mechanism of the sedimentary rocks is dealt with, the weathering and sedimentation processes need to be studied. The emphasis on the research of sedimentation and the development of the research on sedimentation led to it develop into an independent discipline, sedimentology.

Bioliths are the rocks formed by biological processes. The formation of bioliths does not require the intervention of sedimentation. However, in many cases, biologically formed rocks are destroyed and modified by sedimentation. Therefore, when the bioliths are studied, the knowledge of sedimentology is often needed.

Reefs are formed by the in situ skeletons of organisms. If a reef is formed in a deep or restricted quiet water, the reef can avoid the impact of waves and currents, and be preserved intact. However, if it forms in an open shallow water, waves and storms will break the skeletons in the reef, and even carry it for a short distance. Therefore, in many cases, the study of reefs is not just a matter of biopetrology, but also needs sedimentological analysis.

Like all other sediments, after their formation, reefs will be affected by other geological processes such as cementation and dissolution. The study of these two processes belongs to the content of sedimentary petrology. Therefore, the research of bioliths also needs the knowledge of sedimentary petrology.

(3) Mineralogy

Bioliths are composed of the minerals formed by macroorganisms and microbes. Gastropods can form shells accommodating their bodies. The calcified green algae of Dasycladales can form a coating of aragonite needles on their surfaces. The metabolism of some genera of cyanobacteria and bacteria can induce the precipitation of minerals, to form microbialites and microlithites.

Aragonite is an unstable mineral, and is apt to change to calcite. Thus, the aragonites in ancient bioliths have generally converted to calcites. In addition, the aragonite and calcite minerals in ancient bioliths often suffered the alteration by dolomitization and recrystallization. Since the formation and evolution of ancient bioliths commonly involve the crystallization and transformation of minerals, the research of bioliths requires the knowledge of mineralogy.

(4) Geochemistry

All bioliths are composed of minerals, which are composed of chemical elements. Therefore, the study of bioliths deals with not only their fabrics and mineral composition, but also their chemical composition.

Biopetrology studies not only the characteristics and differences of the original chemical compositions of various bioliths, but also the evolution of their chemical compositions in geological time. If the evolution of their chemical compositions is understood, we can use it to determine the formation and evolution history of bioliths. Therefore, the geochemical study is a very important aspect of the research of bioliths.

In summary, biopetrology is related to biology, microbiology, paleontology, paleomicrobiology, sedimentology, minerology, petrology, and geochemistry (Fig. 1).

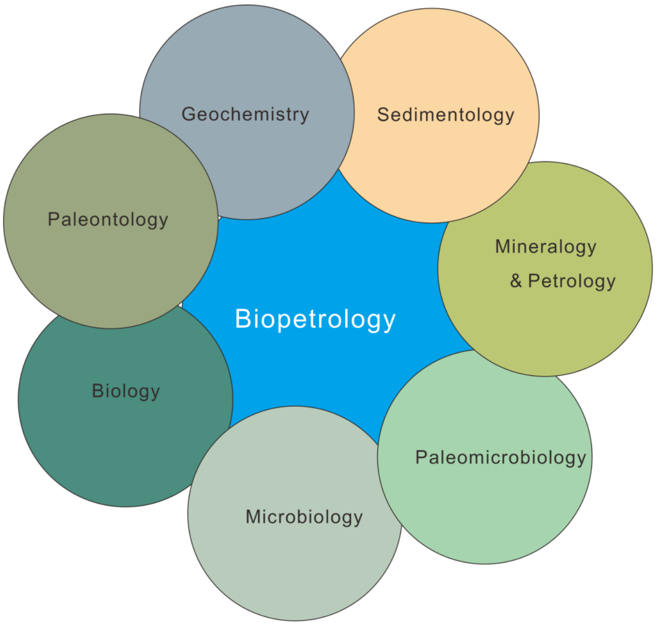

Fig. 1 The related disciplines of biopetrology. The overlaps of circles represent the overlaps in their research scopes.

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Comment by Santanu Banerjee:

It is an excellent review regarding terminologies in Biopetrology.

Comment by Yue-Feng Shen:

It is really exciting to have Biopetrology as a new discipline to enlarge our biological and geological world. Biopetrology and its related disciplines could improve our understanding of both biological and geological world.

Comment by Hong-Wei Kuang:

It creates a new geological cross-discipline, proposes a new classification of biogenic rocks, and for the first time integrate microbes and macroorganisms, modern biology, biosedimentation, and biomineralization, and diagenesis.

Comment by Hua-Xiao Yan:

The author puts forward his unique views on the classification of bioliths. This paper is excellent.

Comment by Giorgio Bianciardi:

An excellent presentation of the numerous fields of application in which biopetrology is involved and an up-to-date on the definitions that allow a complete and analytical framework of the disciplines involved, in a complete definition of the terms necessary for an understanding of the field of biopetrology. It deserves to be published.

Innovation scored by: Wyn Hughes, Santanu Banerjee, Yue-Feng Shen, Hong-Wei Kuang, Hua-Xiao Yan, Fritz Neuweiler.

Innovation score (0-5): (5+5+3+5+5+1.5)/=4.1

Detailed reviewed by: Yue-Feng Shen, Wyn Hughes, Dong-Jie Tang, Santanu Banerjee, Xue-Song Tian.

Revised by: Yue-Feng Shen, Wyn Hughes.

Published on: 6 January, 2022