Stromatolites

Daddy are those coral reefs?


The author sitting on stromatolites from Hamelin Pool, Shark Bay Australia

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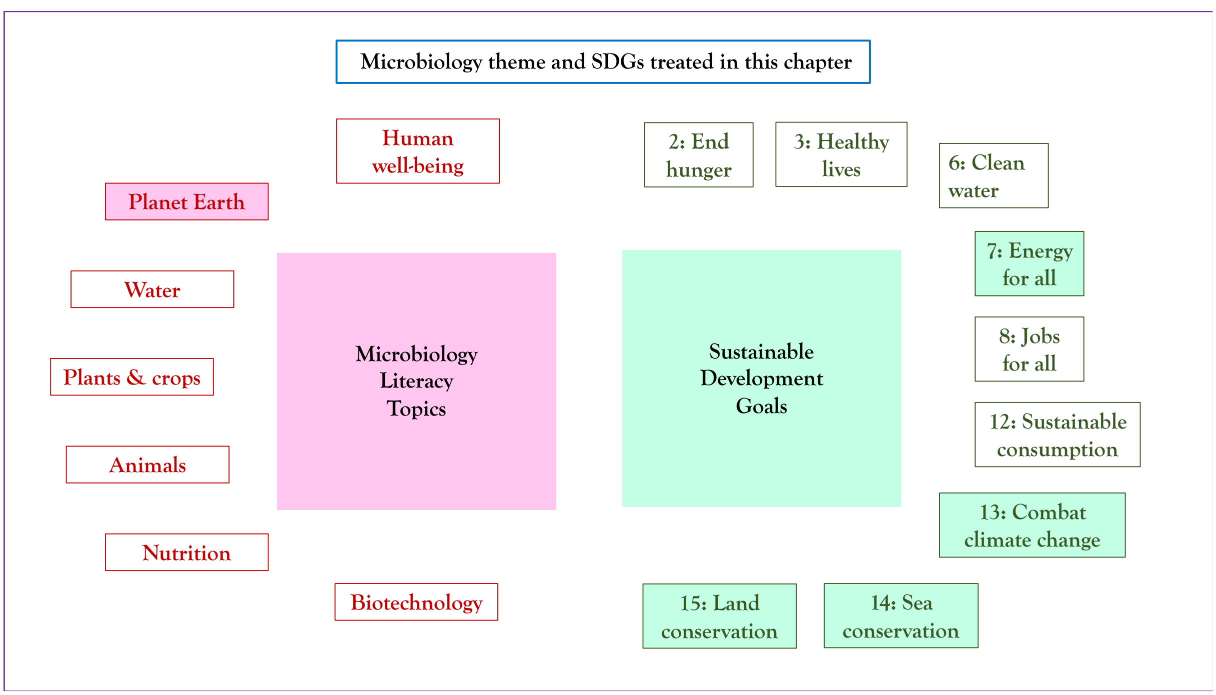
Storyline

The history of life is written in stone. Not by ancient civilizations such as the Mesopotamians or Mayans, but by microorganisms. They began recording this history more than 3.5 billion years ago as they left both unique layered sedimentary structures called “stromatolites” and silicified (petrified) organic remains called “microfossils”. But how can things so small that it requires a microscope to see them, make something visible to the naked eye? How do we know that the microfossils we see in the rocks are the remains of microorganisms? Thankfully, their modern day descendants do exist and living stromatolites are easy to find if you know what to look for.

The Microbiology theme and Social Context

The Microbiology: history of life; microbial communities; microbiomes. *Sustainability issues*: energy, climate change; marine and freshwater ecosystems. *Sustainability issues:* affordable energy; climate change; life under water; life on land.



Stromatolites: the Microbiology

1. ***Fossil record.*** If you are fortunate enough to live in or near a city that has a natural history museum, there is usually an exhibit or hall dedicated to the history of life on Earth. They will have fossil skeletons of creatures that lived millions of years ago. The classic fossil record starts at the base of the Cambrian Period, around 540 million years ago, when animals first developed hard parts that would eventually be preserved in rock. The first plant fossils were discovered in 440 million year old rocks of the Silurian Period. Dinosaurs, of which most of us are familiar with, roamed the Earth from about 250 million years to 65 million years ago. But were there life forms other than animals and plants? How long has life existed on our planet?

The first intimation that life might be older was discovered by a Canadian geologist, C. D. Walcott, who in 1906 described uniquely layered rocks he believed had been made by algae. He called them "Cryptozoon". These structures and others like it were later called "stromatolites" (layered rocks).

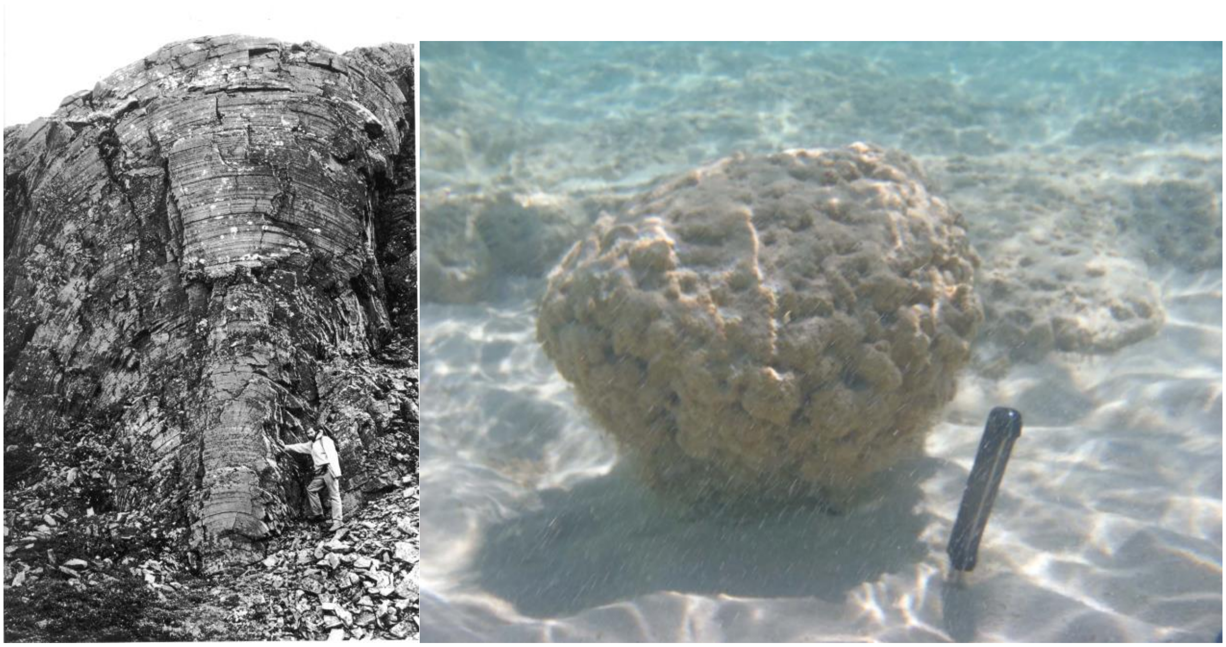


Figure 1. A) 2 billion year-old stromatolite from the Canadian Belt (Campbell and Cecil, 1981), geologist for scale! B) living stromatolites from Hamelin Pool, Shark Bay, Australia. Dive knife for scale.

Stromatolites come in a variety of shapes and sizes, some smaller than a thimble, others meters high (bigger than a house!). The common feature is that they all have repeated layers or laminations of sedimentary rock, usually limestone (Figure 1A). Fossil stromatolites have been found in rock formations all over the world with some of the oldest in Australia and South Africa. They represent the oldest evidence for life on Earth. Their descendants are alive today in places like Shark Bay, Australia (Figure 1B) and the Exuma Islands of the Bahamas.

Back in the early 1950's, geologists Stanley Tyler and Elso Barghoorn thought they had found fossil coal in the Gun Flint Formation, a rock formation of banded iron in northern Minnesota and northwestern Ontario. The rock was made up of super fine grained quartz, called chert, like that found in petrified wood. It also had a lot of organic matter that gave the rock its black color. When the rock was sliced thin so that it could be observed under a microscope, they were amazed to find what looked to be the remains of bacteria. Some were long thick filaments, others were round, and there was one that resembled an inside out umbrella! They were called microfossils. These rocks were dated to be around 2 billion years old as well. Like stromatolites, chert formations with microfossils have been found all over the world, with the oldest, over 3.4 billion years old, in Australia and South Africa. The preserved organic material was further studied by geochemists who further established that indeed these were the remains of microorganisms.

2. ***Microbialites.*** One of the remarkable things about bacteria is that, when provided the appropriate conditions (i.e., food, water), they can make complex communities. These communities, called biofilms, interact with their environment, creating distinctive deposits called "microbialites". This behavior is believed to be a relic of the early days of Earth, when there was no ozone layer to protect living things from harmful ultraviolet radiation. The microbes are literally burying themselves under a protective layer of sediment. Today you can see living examples of these communities, also called "microbial mats", in extreme environments like salt marshes and hot springs (Figure 2). Like stromatolites, they can leave traces of themselves deep into the sediment, which eventually may be turned to rock. Their organic remains can also be "petrified" through a process called silification. That's how the bacteria were preserved in the Gunflint Chert. Stromatolites are also a type of microbialite as they too are formed as the result of the trapping, binding, and precipitation of sediment.

Figure 2. A) Flat microbial mats in Sippewissett Marsh, Massachussetts,
B) Close up of the mat peeled back showing the pink layer of phototrophic bacteria.

3. ***Microbial diversity.*** Remarkable as it may seem, the communities involved in making microbial mats and stromatolites, are ecosystems, composed of the key functional groups: primary producers, consumers, and decomposers. The primary producers are usually cyanobacteria and anaerobic photosynthetic bacteria such as green and purple phototrophs (Figures 2, 3). Colorless chemoautotrophic bacteria like sulfur oxidizing bacteria can also contribute to carbon fixation.

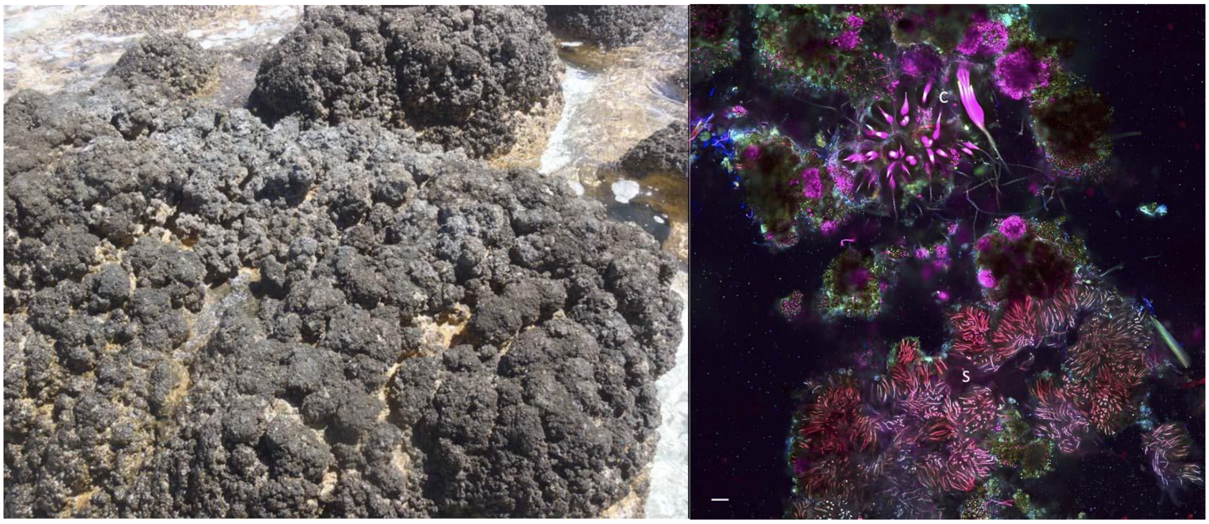


Figure 3 Microbial communities from Shark Bay, Australia. A) Pustular microbial mat found in the intertidal zone. B) Confocal microscopy of the diverse community in the pustular mat, (C) *Chalothrix*, (S) *Scytonema*. Bar 50 μm.

Fermenting bacteria, serving as consumers, may break down complex organics to simpler organics. Sulfate reducing bacteria take the simple organics and oxidize them to carbon dioxide, completing the carbon cycle, reducing sulfate (produced by the anaerobic phototrophs) to hydrogen sulfide gas. That's why when you disturb microbial mats you often get a whiff of rotten eggs (actually hydrogen sulfide). The microbial diversity can be incredible with thousands of different species co-existing. Microbial mats commonly have chemical gradients that create specific micro-niches on the millimeter scale. The most notable gradients are of oxygen, sulfide, and pH. These communities can be considered "bioreactors" as they cycle oxygen, sulfur, nitrogen, and metals like manganese and iron. The microbial communities that build stromatolites not only trap and bind the sediment that surrounds them, but also precipitate calcium carbonate that cements the structure (Figure 3).

4. ***Stromatolite sampling campaigns: travel, logistics, exciting discoveries.*** Shark Bay is located in Western Australia about an 8-hour drive north from the city of Perth. A World Heritage Site, the stromatolites are protected so you need special permits to collect samples. Getting to the different sites requires a lot of off-road driving, so a four-wheel drive vehicle is essential. You have to be aware of livestock, like sheep and goats (mostly farmland around the bay), and of course kangaroos, of which there are plenty, and the occasional emu.

Carbla Point is the classic field location but there are many different types of microbial mats and stromatolites around the bay. Microbial mats can be found along the shore line, where they are exposed to air at low tide. Pustular mats, that resemble heads of broccoli, are also found in this intertidal zone (Figure 3). They start off soft, with colonies of the cyanobacterium *Entophysalis major*, but eventually harden and are then colonized by other cyanobacteria, such as *Scytonema* and *Calothrix* (Figure 3B).

Larger stromatolites are found in deeper water and are submerged most of the time. You have to snorkel or SCUBA dive to study them. The currents aren't too bad, but you have to watch out for sea snakes: they have a very potent venom and a single bite could be lethal! Thankfully, they usually keep to themselves. It is amazing to see the many different types of microbial communities and the variety of microbialites they produce. It is like going back to a time when there weren't plants and animals. The amount of sediment they produce, in the form of carbonate, is also very significant especially in light of climate change.

Relevance for Sustainable Development Goals and Grand Challenges

- **Goal 7. Affordable and clean energy.** Many of the organisms that created the earliest stromatolites were photosynthetic. They were the first primary producers to harvest the energy from sunlight and to turn carbon into living things.
- **Goal 13. Climate Change.** Over the course of life's history, the Earth has never been completely frozen over or have the oceans evaporated.
- **Goal 14 Life under water.** Although living stromatolites today are limited to certain marine and freshwater environments, they were far more abundant in the past.
- **Goal 15 Life on land.** You can find microbial communities on land if you know what to look for.

Pupil Participation

1. Class discussion of how bacterial communities are involved in the carbon and sulfur cycles. Talk about oxygenic photosynthesis and anoxygenic photosynthesis, and how they are actually related (one uses H_2O the other H_2S).

2. Exercises

a. Microbes beneath your feet – taking a walk along the beach and in the salt marsh. If you live near the shore, you should be able to find microbial mats living in or near the salt marsh. This is especially true in areas that are flooded at high tide but exposed to air at low tide. You may have to scratch the surface to remove the protective layer of sand to expose the microbial community below (see Figure 2).

b. Finding microbial mats in your backyard. Microbial mats don't just live in extreme environments, but can be found in places where plants and grass find it hard to live. They can be found living in roof gutters (they like the alternation of wet and dry), or in tire tracks on the side of roads or off-road.

The Evidence Base, Further Reading and Teaching Aids

"These boulders are alive" from Nova, Making North America: Life, https://www.pbs.org/video/these-boulders-are-alive-goefio/

"What are Stromatolites?" https://www.youtube.com/watch?v=N-G7IJCkyvg

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Glossary

Chemoautotrophy – an organism that fixes carbon dioxide and generates energy from the oxidation of inorganic compounds like hydrogen sulfide
Confocal Microscopy – fluorescence microscopy that uses lasers
Cyanobacteria – photosynthetic bacteria that produce oxygen in the process
Heterotroph- organism that uses organic compounds for energy and growth
Microbial community – diverse populations of different microbial species living in the same place at the same time
Microbialite – distinctive sedimentary deposit formed by the trapping, binding, and precipitation of sediment by microorganisms
Microfossil – the remains of microorganisms preserved in chert
Phototroph – an organism that is capable of photosynthesis
Stromatolite – layered, often dome-shaped, microbialite produced by microorganisms