A ROCK FROM MARS

Although there are alternative explanations for each of these phenomena taken individually, when considered collectively...we conclude that they are evidence for primitive life on early Mars.

-David McKay et al. 1996

Last May I celebrated my 50th birthday while working on a project at Johnson Space Center (JSC) in Houston. The project involved adapting some of the center's materials for use in my courses. To augment our visit there, the staff at JSC had gone all out to provide us with an education by tours and a parade of speakers.

It so happened that on the day that I turned 50, I sat in a conference room (the same room that the Mercury, Gemini, and Apollo astronauts gave their first press conferences after quarantine) to hear Dr. David McKay speak. This was the man who in 1996 led the team that announced the evidence of possible life from examination of a meteorite that had come from Mars.

Figure 1. David McKay at Johnson Space Center, May 2001.

I was thrilled when McKay entered the room and placed a piece of the very same meteorite on the table in front of me. He then began his talk by carefully laying out the evidences for the meteorite coming from Mars and then the telltale signs of life that he and his team detected in it. The most compelling bits of evidence, however, came from scanning electron microscopic examination that revealed structures, which could have been fossils of bacteria (see Figure 2).

Now, if I had seen such things in rock here on earth, I would not have thought twice about their biological origin. Structures appeared to be rods and filaments of cells. Such fossils have been found on earth. Indeed, I have some of them in a siliceous rock of the Gunflint chert from the northern shore of Lake Superior in southern Ontario, Canada (see Figure 3).

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This is a minor revision of an essay that I wrote in 2001.
Unlike neighboring Mars and Venus, whose atmospheres settled down to become stable chemical mixtures of carbon dioxide, the Earth had gotten energized.

-Lynn Margulis and Dorian Sagan, 1986

The Gunflint Chert was discovered by Elso Barghoorn and Stanley Tyler in the 1950's, but the discovery languished in Barghoorn's lab until he was pushed to publish when Preston Cloud threatened to scoop him in the 1960's. The discovery and clear presentation of bacterial fossils in the gunflint chert pushed direct evidence of life back to about 2 billion years ago, well into the Proterozoic Era (see Table 1).

Most fossils come from the last half billion years of earth's 5 billion year history, an eon called the Phanerozoic. As ancient as trilobites and their associates in the Cambrian Period may seem, they appeared after more than 85% of earth's history had elapsed. The dinosaurs came much later than that.

<table>
<thead>
<tr>
<th>EON</th>
<th>BILLIONS OF YEARS AGO</th>
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<tr>
<td>PHANEROZOIC</td>
<td>0 - 0.59</td>
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<tr>
<td>PROTERozoic</td>
<td>0.59-2.6</td>
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<td>ARCHEAN</td>
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<td>HADeAN</td>
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The earliest eon, the Hadean, was marked by a time of heavy meteor bombardment as the planetary bodies accreted, and the earth-moon system appeared. High energy impacts repeatedly liquefied the earth's surface allowing lighter elements to float to the surface and accumulate there. As the bombardment abated, the surface solidified, and atmospheric gasses and liquid water began to accumulate.

The next eon, the Archean, was marked by the presence of land masses, oceans, and a stable atmosphere. It was during this era that life likely began. The Proterozoic Eon saw increasingly complex forms of bacteria arise (By complex, I mean physiological rather than structural complexity).

Perhaps the most important physiological pathway to evolve was that of oxygenic (oxygen-producing) photosynthesis. Recall that the process of photosynthesis used light energy to convert inorganic substances to food. By and large, the energy within food was stored in the carbon-hydrogen bond. Thus, the production of food required an inorganic carbon source like carbon dioxide (CO₂) and a hydrogen source like water (H₂O).

Chlorophyll absorbs light energy to power the process of reducing carbon dioxide (The process of making food is a reduction process in which electrons, or hydrogens, are added to carbon. Conversely, respiration is an oxidation process in which hydrogens or electrons are stripped from food to provide for metabolic energy). Special proteins called enzymes mediate the whole process of photosynthesis and respiration. With a few modifications, the general pathway of photosynthesis is the reverse of the general pathway of respiration.

This whole business of food production and food use is an important one to consider. Early life had organic compounds available through nonliving means (abiotic synthesis and additions from comets and meteors). That would have formed a limit to the amount of life possible on the earth and led to intense competition. In that do-or-die period, Bacteria invented (evolutionarily speaking) a variety of other food making pathways which persist today. Some glean energy from reduced inorganic compounds (chemosynthesis; this is the source of food in deep ocean thermal vents). Some use other sources of hydrogens along with a range of bacterial chlorophylls (bacteriochlorophylls) to make food². With the advent of biologically-created food life could expand to much greater mass until particular elements such as nitrogen or phosphorus became limiting.

The switch to oxygenic photosynthesis seems to have begun around the time of the Gunflint fossils and likely evolved from a line of hydrogen sulfide bacteria. As a source of hydrogen, hydrogen sulfide was pretty good. The organism did not have to invest very much energy to wrench the hydrogens from sulfur. Unfortunately, hydrogen sulfide and similar reduced compounds also were in limited supply. For hydrogen-hungry microbes, water, one of the most abundant sources of hydrogen on earth, was an ideal solution. However, water required much more energy to separate its hydrogens from oxygen. Chlorophyll, slightly different from bacteriochlorophylls, could absorb sunlight energy at more energetic wavelengths and, therefore, succeeded in breaking apart water. Then, the microbes had to deal with water's toxic waste product, molecular oxygen.

Rocks from Gunflint times also testify to a change in the atmosphere. Iron, one of the most abundant elements on earth, shows striking differences when in reduced or

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² One of the most common hydrogen sources for this kind of bacterial photosynthesis is hydrogen sulfide (H₂S). In this case, the resulting waste product is sulfur. Such organisms still exist and are abundant in high sulfur environments. They need light, carbon dioxide, and reduced sulfur. Also, they need an environment with little or no oxygen.
oxidizing conditions. Iron in its oxidized form ($\text{Fe}^{3+}$) generally is insoluble and is reddish, or rust-colored. In its reduced form ($\text{Fe}^{2+}$), iron is quite soluble and is black or blue-black. Only when combined with the sulfide ion does reduced iron readily come out of solution. Then, it imparts a black or gray color to the rock. When oxidized, iron imparts a reddish color to rock.

Proterozoic aged rocks (beginning about 2.8 billion years ago) frequently show a peculiar banded iron formation. This is alternating bands of black and red iron-rich rock. The interpretation is that molecular oxygen, released by oxygenic photosynthesis, built up and then combined with available iron. This continued for many millions of years until most of the elements with which oxygen could combine had been swept free. During this period the ocean (and planet earth) would have had a decidedly reddish cast. For a time, the earth was a large red ball.

![Figure 4. Banded iron pebble (ca. 2.4 billion years old) collected by Ben Hayes from South Africa.](image)

**MICROBIAL MATS**

_The Precambrian would have been a fascinating period for the cyanophytologist, since vast areas of stromatolitic rocks are known, hundreds of feet thick and hundreds of miles in extent._

-Thomas Brock, 1973

So, oxygen began to accumulate in the oceans and the atmosphere by Gunflint times. Curiously, the rise in oxygen was accompanied by an increase in the occurrence of stromatolites, pillow-like layered structures. Stromatolites came in a variety of sizes (ranging from a centimeter to meters across), and generally were associated with limestone. In fact, they were the principle components of reefs until the advent of newcomers like red algae and corals.
The stromatolite structure was the consequence of a whole microbial community. The upper-most part of it was populated by cyanobacteria like *Lyngbya*. These produced oxygen while a layer of photosynthetic sulfur bacteria beneath them (and safely out of the way of the oxygen) absorbed light not used by the cyanobacteria. Layers beneath them were populated by chemosynthetic and decomposer bacteria. Similar arrangements of microbes exist in structures called microbial mats. Still, stromatolites were much more than platforms for microbial growth. They were made by the actions of the microbial community itself.

Cyanobacteria like *Lyngbya* often have an outer slime or mucilage coating. Figure 6 illustrates the filament and its slime outer covering with some debris caught in it. Now consider that these organisms take up carbon dioxide during the course of photosynthesis. In so doing, they affect the solubility of calcium carbonate and cause it to precipitate out of solution. So, in calcium carbonate rich waters, active photosynthesizers run the risk of encasing themselves in a tomb of limestone. Cyanobacteria can grow quickly but also many of the filamentous ones (like *Lyngbya*) can crawl out of their slime tubes and move

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3 See *In Hot Water* for an explanation of this phenomenon.
toward the light. Thus, the stromatolite can be made layer by layer by the constituent members of its microbial community.

Figure 7. A typical microbial mat in the salt marsh at Assateague Island.

Consider the Gunflint chert again. This was made in an environment rich in silica. Thus, organisms within the mat became preserved as fossils, an exceedingly rare event. Barghoorn, Tyler, and Shopf showed that the microbial community represented in the Gunflint was similar those that must have produced the more common (but barren of microbial fossils) limestone stromatolites.

Figure 8. Top a polished section of the Gunflint chert. Below is a prepared thin section from which I took the photograph of Figure 3.
The Gunflint Chert was the first reported incidence of precambrian microfossils. To date, they have been found in suitable precambrian rocks all over the world. In 1993 J. William Schopf reported the discovery of microbial fossils in the Apex Chert of Australia. These dated to about 3.5 billion years old. Stromatolites of a similar age have been found, also in Australia, although almost certainly they were made by communities that lacked cyanobacteria.

Although rare today due to the pressures of marine grazers like snails and sea urchins, living stromatolites can be found in certain places that tend to exclude or inhibit such animals. Such a place is Shark Bay in Australia. There, an enclosed lagoon becomes hypersaline and tends to exclude organisms that prey on the microbial mat that covers the outside.

Jennifer Elick, a Geologist at Susquehanna University studied Pennsylvanian aged (about 300 million years old) stromatolites from an area near Manhattan, Kansas. There, the shapes and arrangements of the stromatolites allowed her to make broad interpretations of the environment at large. For example, the orientation of the structures suggested that they were subjected to tidal current flow within a, hypersaline environment very much like that of Shark Bay (see Figure 9).

![Figure 9](image1.png)

**Figure 9.** The arrangement of stromatolites at Jennifer Elick's study site in Kansas. The scale in the center is 1 meter long.

![Figure 10](image2.png)

**Figure 10.** A longitudinal section through one of the Kansas stromatolites to show the typical laminations.
RETURN TO MARS

NASA scientists are already working out ways to tell real stromatolites from "foolers" as they tool up to search the returned rocky debris for signs of martian life.

- J. William Schopf, 1999

Thus, it seems that stromatolites as well as all other forms of microbial mats have been around almost since life began. Indeed, no sooner had the earth cooled to allow for the existence of life (around 3.9 billion years ago) than stromatolites and rock bearing microfossils (3.5 billion years ago) began to appear. Such structures testify to the occurrence of microbial communities and relatively complex structures almost as early as they could possibly appear on earth.

This brings us back to that meteor from Mars. The isotopic evidence of the rock indicates that it was formed about 4.5 billion years ago as part of the original Martian crust. Then it received a severe shock around 4 billion years ago (probably through meteor bombardment of Mars). About that time carbonates were laid down within cracks in the rock. The simplest scenario for the formation of carbonates requires liquid water at temperatures that could support life. In addition to the apparent microfossils in ALH84001, the rock has organic compounds and grains of magnetite that are similar to those produced by living iron bacteria. The rock then was ejected from Mars by a meteor impact about 17 million years ago and landed on an Antarctic ice sheet about 11,000 years ago.

Suppose that life did appear on Mars by 4 billion years ago and other rocks were ejected then (as ALH84001 was much later). If the bacteria survived the shock of the ejection and landing and the cold and vacuum of space, then life could have been transferred here from Mars. The scenario is possible and would help to explain the rather sudden appearance of life on earth. As compelling as this scenario might be, it is not sufficient to accept as proof. Indeed, because something is possible does not mean that it happened (an approach that my children tried to take with me many times). As Carl Sagan often said, "Extraordinary claims require extraordinary evidence." I believe that the only suitable evidence could be obtained by collecting samples directly from Mars. The discovery of microfossils or possibly even living microbes could answer the question. That would be the extraordinary evidence needed.

-2001

Sources that I used to write the essay:
QUESTIONS TO THINK ABOUT

1. Who is David MacKay?

2. What is the importance of the Gunflint Chert?

3. How did photosynthesis change the earth?

4. What was the source of food before the advent of photosynthesis?

5. How can we interpret banded iron formations?

6. What are microbial mats and stromatolites? Where would you go to observe microbial mats and stromatolites?

7. How can the study of stromatolites (both present and ancient) support our exploration of Mars?