EYE

Extreme Yellowstone Expedition

MICROBIAL MATS AND ALIENS!

LESSON 3

Student Activity Book

MONTANA STATE UNIVERSITY

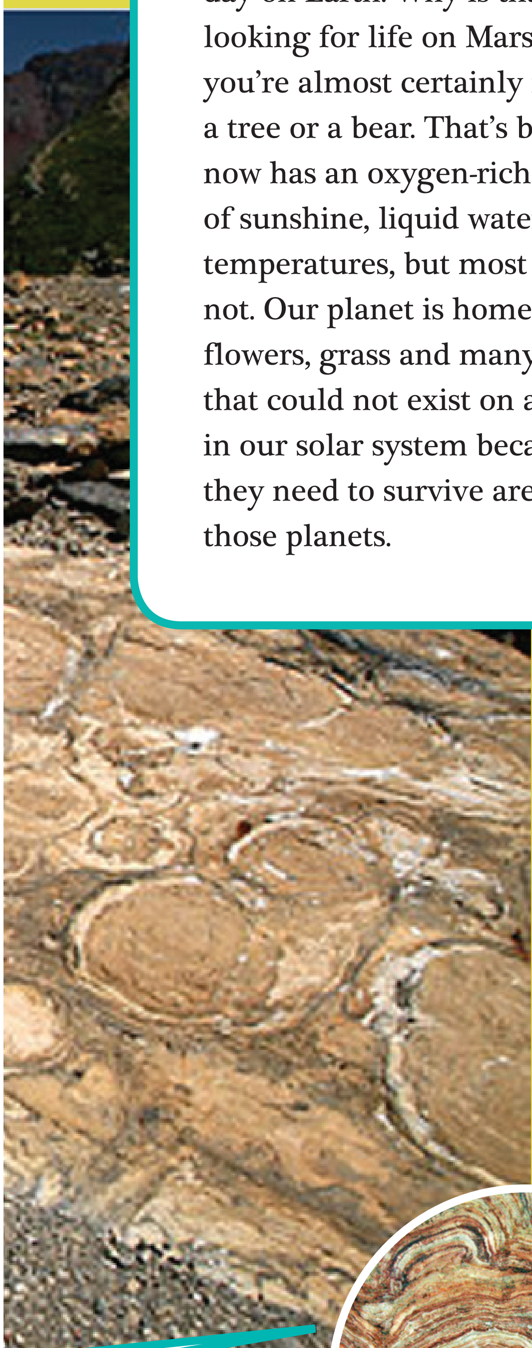
Thermal Biology Institute

BACKGROUND IMAGE: These strange-looking structures in Glacier National Park were created by the fossilization of ancient microbial mats called stromatolites.

INSET: A cross section of a fossilized stromatolite specimen.

Aliens Among Us?

We imagine alien life as looking much different than what we encounter every day on Earth. Why is that? If you are looking for life on Mars or another planet you're almost certainly not going to find a tree or a bear. That's because our planet now has an oxygen-rich atmosphere, lots of sunshine, liquid water and moderate temperatures, but most other planets do not. Our planet is home to birds, reptiles, flowers, grass and many other types of life that could not exist on any other planet in our solar system because the resources they need to survive are not available on those planets.



Though we have not yet discovered living organisms on another planet, the types of life that could survive on other planets would have to survive in conditions that are considered extreme on Earth. Scientists think that if we find life elsewhere in the Universe it is more likely to be an extremophile (a microbe that lives in an "extreme" environment) than a little green man.

Fossilized microbes

Have you ever been to Glacier National Park? Imagine walking on a high mountain trail and seeing a strange pattern of circles on the ground. ***(See background photo.)*** Would you have any idea what you are looking at? They are actually a type of fossil that NASA is searching for on other planets!

The circles are ancient fossilized microbial mats that lived in this area when it was a shallow ancient sea more than 1.3 billion (1,350 million) years ago. Millions of years of Earth's changing climate and shifting tectonic plates have moved what was once a warm shallow sea floor to the top of a modern-day cold mountain.

Old timers of the Earth

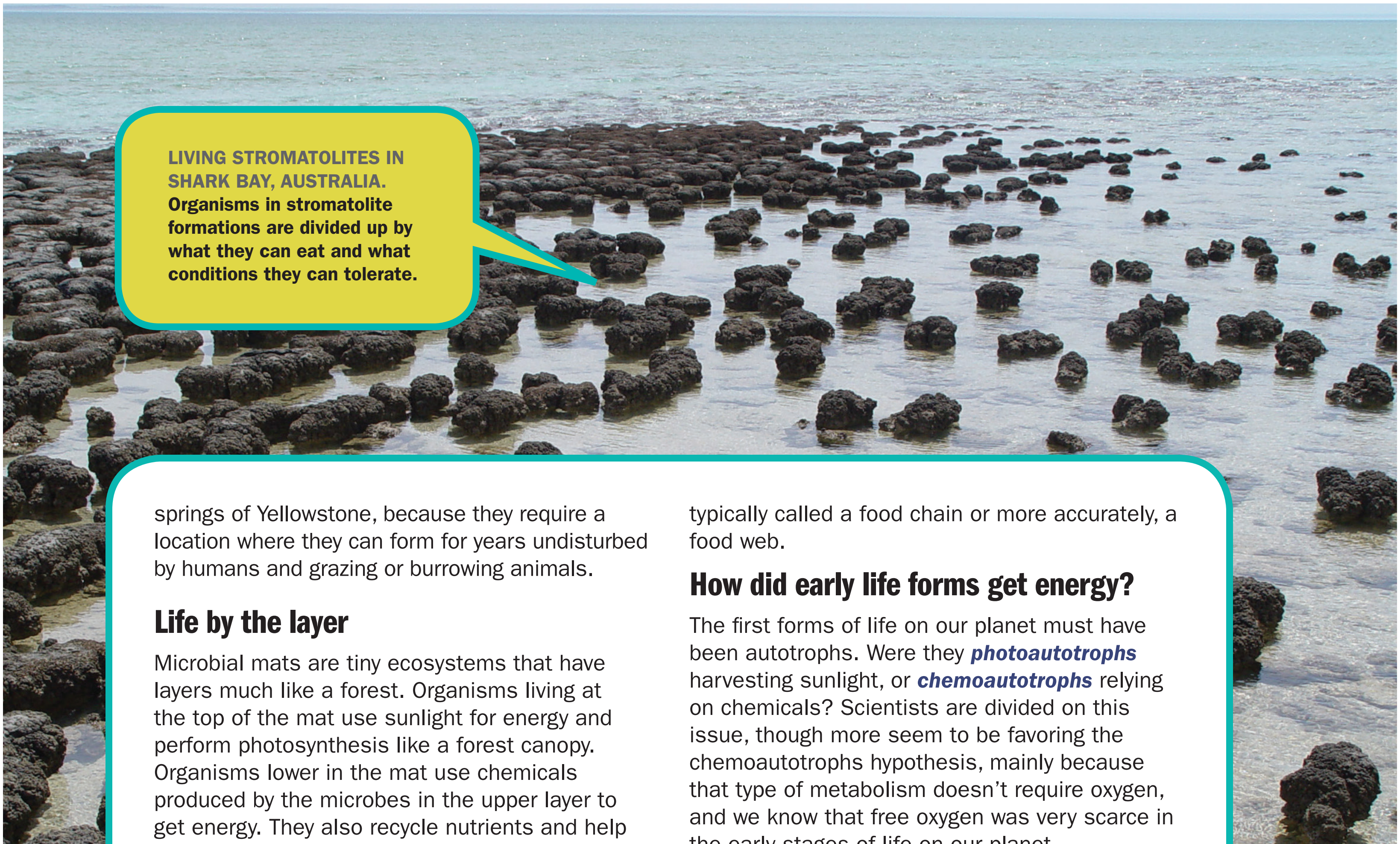
These circular structures are fossils of a ***stromatolite.*** A stromatolite is a structure created by a microbial mat in which a rock-like layer of either sand or precipitated minerals has been trapped.

The microbial mat consists of microorganisms such as bacteria and algae. Stromatolites are formed by microbial communities that consist of many species with different metabolisms competing for or sharing resources. ***(See the fossilized cross section of an ancient Glacier National Park specimen at left.)***

Stromatolites provide one of the most ancient records of life on Earth. Scientists have found fossil remains of stromatolites which date from more than 3.5 billion years ago. If stromatolites are a record of early life on our planet, they might be a record of life on another planet too. Imagine if life formed on Mars millions of years ago when Mars had shallow seas.

Stromatolites used to be much more common on Earth than they are today and they are often found in the ancient fossil record. They were the dominant form of life on Earth for more than two billion years and are thought to be largely responsible for making our atmosphere oxygen-rich (Earth's early atmosphere had little or no oxygen).

Currently, stromatolites occur in only a few places, such as Shark Bay, Australia or in some of the hot



LIVING STROMATOLITES IN SHARK BAY, AUSTRALIA. **Organisms in stromatolite formations are divided up by what they can eat and what conditions they can tolerate.**

springs of Yellowstone, because they require a location where they can form for years undisturbed by humans and grazing or burrowing animals.

Life by the layer

Microbial mats are tiny ecosystems that have layers much like a forest. Organisms living at the top of the mat use sunlight for energy and perform photosynthesis like a forest canopy. Organisms lower in the mat use chemicals produced by the microbes in the upper layer to get energy. They also recycle nutrients and help with functions such as decomposition, just like some of the organisms in a forest's understory.

Each layer of a microbial mat is dominated by microorganisms that thrive in the conditions of that layer and outperform other kinds of life. Organisms compete and cooperate and are divided up by what they can eat and what conditions they can tolerate.

A web of energy

All living things need a way to get food, which gives them energy. Plants can create their own energy using sunlight, but we humans can't, so we have to eat plants, or eat animals that eat plants. We are ***heterotrophs*** (*heteros*=different, *troph*=nutrition) because we must eat other organisms to obtain energy and organic carbon. All animals are heterotrophs, along with some single-celled creatures.

Any organism that can harvest energy directly from the nonliving environment and fix CO_2 into biomass is called an ***autotroph***, a word that means "self feeding" (*autos*=self, *troph*=nutrition).

We can think of energy as "flowing" through lifeforms, starting with the autotrophs (also called producers) and then moving to the heterotrophs (also called consumers), and then maybe to other consumers, and so on. This is typically called a food chain or more accurately, a food web.

How did early life forms get energy?

The first forms of life on our planet must have been autotrophs. Were they ***photoautotrophs*** harvesting sunlight, or ***chemoautotrophs*** relying on chemicals? Scientists are divided on this issue, though more seem to be favoring the chemoautotrophs hypothesis, mainly because that type of metabolism doesn't require oxygen, and we know that free oxygen was very scarce in the early stages of life on our planet.

Different strokes for different trophs

autotrophs – produce food from inorganic (non-living) things such as minerals (*autos*=self, *troph*=nutrition)

photoautotrophs – use sunlight to create food/energy (photosynthesis)

chemoautotrophs – use chemicals to create food/energy (chemosynthesis)

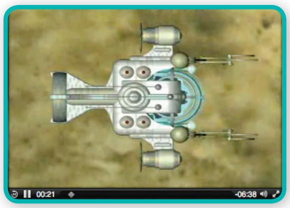
heterotrophs – eat other organisms or organic carbon to obtain energy (*heteros*=different, *troph*=nutrition)

CHEMO VS PHOTO **Being a photoautotroph (using photosynthesis) is a much more productive and efficient way to get energy than being a chemoautotroph. It is estimated that the appearance of oxygenic photosynthesis increased biological productivity by a factor of between 100 and 1,000!**

YOUR MISSION

Watch the stromatolite video and use the transcript of it below to answer the questions on your worksheet. Soon you will be analyzing your own microbial mat sample and you'll need the information contained in the section you just read as well as facts from the video you are about to watch.

Stromatolite Video Transcript



Imagine an exploration mission through a strange and hostile environment. Now place yourself inside the imaginary vehicle, the .1 mm long Stromatolite Explorer. The mission is to probe a microbial mat; a complex and very ancient assemblage of microorganisms less than 5 mm thick. Automated transponders will take chemical readings every quarter of a millimeter as the vehicle descends.

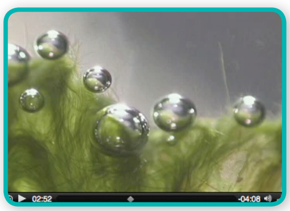
[MUSIC]

Diving into a living mat is like going back in time to explore some of the earliest forms of life on Earth. Microbial mats have been around for over 3 billion years making them Earth's earliest biological communities. Finding the remains of microbial mats on other planets would be powerful evidence that life once thrived there. That's why understanding microbial mats is of such interest to NASA.

In the uppermost region of the mat, diatoms reign supreme. These single cells are encased in houses made of glass. Diatoms convert sunlight and carbon dioxide into fuel molecules and oxygen through the process of photosynthesis.

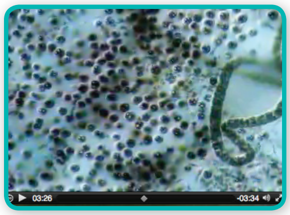
Now the explorer and crew enter the realm of filamentous cyanobacteria. Each strand is a chain of single celled prokaryotes. No nucleus in these cells, just a long strand of DNA.

DEPTH: .5 MM;
OXYGEN: 600 MICROMOLARS;
HYDROGEN SULFIDE: NEGLIGIBLE
PH 9.7



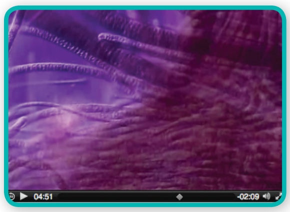
Like other solar-powered photosynthesizers, cyanobacteria produces dissolved oxygen as a byproduct of photosynthesis. Here we see how Earth's atmospheric oxygen originated bubble by bubble.

DEPTH: 2.6MM AND DESCENDING;
OXYGEN: NEGLIGIBLE;
HYDROGEN SULFIDE: 75 MICROMOLARS;
PH 7.2



Because the only light that gets down into the deeper part of a mat is in the form of red to near infrared radiation, the bacteria here, purple sulfur bacteria, use that radiation and the hydrogen sulfate present to perform a kind of photosynthesis that doesn't produce oxygen: anoxygenic photosynthesis.

DEPTH 4.3 MM;
HYDROGEN SULFIDE: 125 MICROMOLARS
OXYGEN: 0

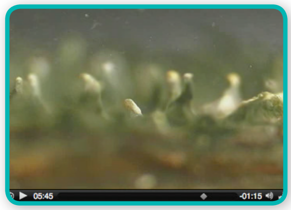


The mat, though relatively thin, shows a steep chemistry gradient from top to bottom. The explorer has descended through layers that contain diatoms, then cyanobacteria, purple sulfur bacteria, and finally sulfate reducing bacteria. Oxygen from photosynthesis at the surface of the mat never makes it to the bottom. So the bacteria down here have evolved to use sulfate to break down or burn organic matter.

ALERT: RESERVE POWER AT CRITICAL LEVEL. INSUFFICIENT SOLAR RADIATION FOR SUCCESSFUL RECHARGE… WARNING.

The mat community contains filamentous cyanobacteria that move between the sulfur-rich deeper layers and the oxygen producing upper layers in a daily cycle. If the crew can remember this, they might have a chance to hitch a free ride back to the surface.

When the sun goes down, the chemical output of the mat community adjusts for life in the dark. A peek at the updated transponder data reveals a new set of readings.



A microbial mat is a community that changes dramatically in the first few millimeters. Descending, the mat changes from a photosynthetic oxygen producing layer to a murky realm where sulfur munching bacteria prevail.

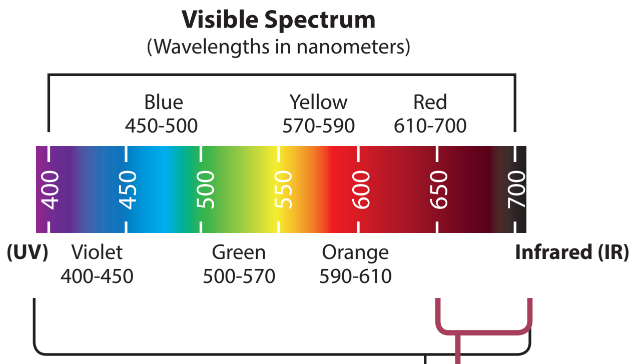
The activities of these simple life forms create an alkaline environment where minerals accumulate and over time a stromatolite will form — one of the telltale signs to look for in our search for life on other worlds.

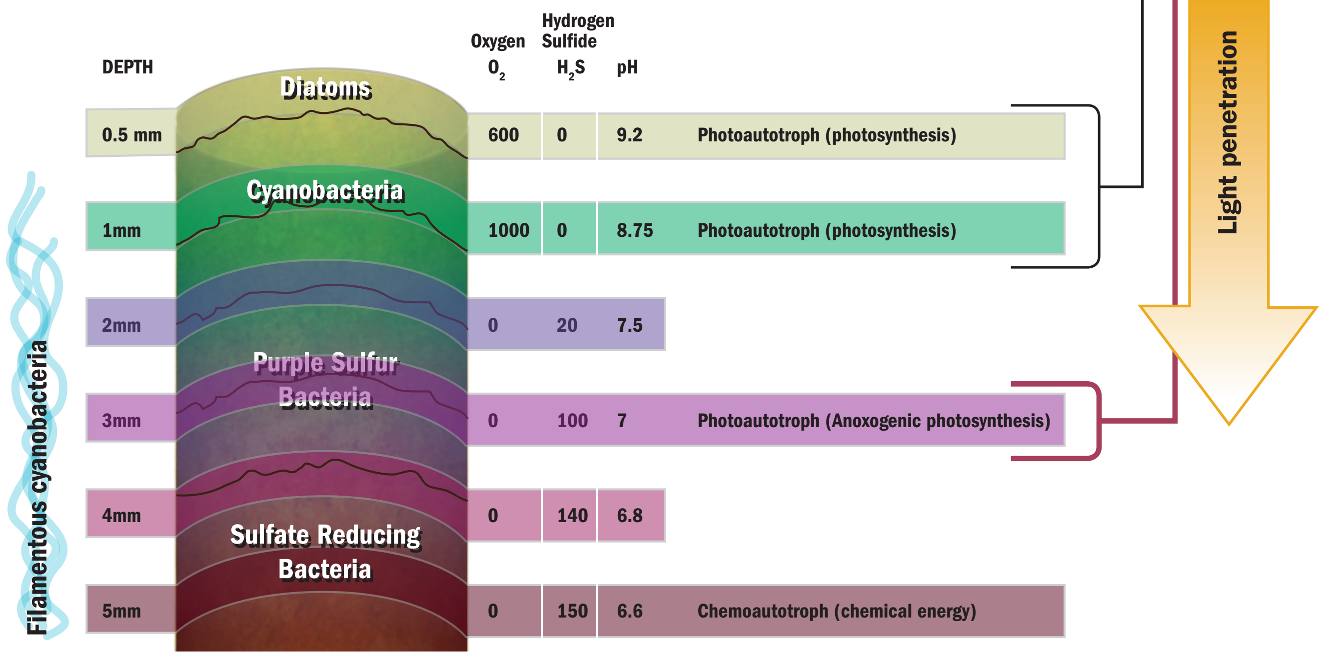
Someday, not so far away when an exploration vehicle from Earth begins probing the soil on a planet such as Mars, it will carry instruments for analyzing biosignatures, minerals and organic matter that may have been left behind by mats that once grew on the shore of Martian seas.

Stromatolite Worksheet

Use the information from the stromatolite video and the graphics below to answer the questions on the next page.

Stromatolites and microbial mats contain energy and light gradients (in a gradient there are increasing or decreasing changes in a variable). The microbes living towards the top of the mat have more resources available to them compared to the lower levels.





How do they make a living?

diatoms
cyanobacteria — **(photoautotrophs)** — photosynthesis

light energy (visible)

$CO_2 + H_2O \rightarrow CH_2O + O_2$ (carbon dioxide + water → sugar + oxygen)

purple sulfur bacteria — **(photoautotroph)** — anoxygenic photosynthesis

light energy (infrared radiation)

$H_2S + CO_2 \rightarrow SO_4 + CH_2O$ (hydrogen sulfide + carbon dioxide → sugar + sugar)

fermentation

$CH_2O \rightarrow C_2H_3O_2 + H_2$ (sulfate → acetate + hydrogen)

sulfate reducing bacteria — **(chemoautotroph)**

chemical energy

$SO_4 + C_2H_3O_2 \rightarrow H_2S + CO_2$
(sulfate + acetate (fermented sugar) → hydrogen sulfide + carbon dioxide)

1. What is a microbial mat? ______________________________

2. Why do we describe microbial mats as “ancient?” ______________________________

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3. If you were examining a stromatolite, would the actual bacteria living in it be ancient? ______________

____

4. How thick is this microbial mat? ______________

5. How long is the imaginary Stromatolite Explorer vehicle? ________

6. To get a sense of the actual size of the stromatolite in the video, draw a square to represent the stromatolite using your answer for Question 4, and a dot to represent the Stromatolite Explorer using your answer for question 5.

7. Why are microbial mats and stromatolites of interest to NASA? ______________________________

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8. The conditions in the mat change dramatically as you get deeper. What happens to pH, oxygen, and hydrogen sulfide levels as you go deeper into the mat?

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9. Describe the cycling of matter and flow of energy in a stromatolite (how are the microbes making a living) and mention specifically what the organisms are exchanging. (Use the arrows at the bottom of p.6 to help you answer this question.) ______________________________

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10. Stromatolites are a complex community that form their own little ecosystem. What genetic and environmental factors shape the distribution and growth of organisms in a stromatolite? If you are having problems coming up with ideas, think about whether or not sulfate reducing bacteria could live at the top levels of the mat — why or why not?

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11. How did ancient stromatolites and the bacteria in them help Earth’s atmosphere to become full of oxygen?

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12. It can take a stromatolite 100 years to grow 5 cm. Some of the stromatolites in Shark Bay, Australia are 2,000-3,000 years old. What would be the size range of stromatolites that old? ______________

MAT SAMPLE OBSERVATIONS

Directions

- Use your core sampler (straw) to take a sample of your microbial mat (cupcake).
- Insert the straw slowly and gently into the center so you do not disturb the composition of your mat.
- Remove the sample by slowly squeezing the empty end of the straw.
- If the sample is not intact, take another.
- Complete the observation form and pretend that your sample was taken from a real living stromatolite.

1. How many layer colors make up your mat? ________

2. Make a sketch of your core in the box at right. Measure the height of each section and label your drawing with your measurements.

3. If this were a real microbial mat, give some reasons why the layers of the mat are different colors.

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4. Assuming that this stromatolite was similar to the one in the previous activity, explain whether or not the sample could have come from any of the following places.

Place	**Could the sample have come from here? (Yes/No)**	**Why or why not?**
A dark cave		
A dry desert		
A fast flowing river where lots of animals swim, drink and cross		
A reservoir of toxic mine waste in Butte, Montana called the Berkeley Pit (pH 2.5)		

5. Why do you think that your mat might have different sized layers than a classmate's mat?

Note: *When answering, think about resources and remember that you are answering the question as if it were a real stromatolite, not a piece of cake.*

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6. Oxygen can be toxic to purple sulfur bacteria and sulfate reducing bacteria, although both bacteria can sometimes tolerate small levels. Before the Earth had oxygen, these types of bacteria could have done fairly well living by themselves. Once the Earth's atmosphere became oxygen rich, what advantage would living in a microbial mat or stromatolite give to the sulfate reducing bacteria?

Hint: *Think about what would have happened to the population of microorganisms that use photosynthesis once Earth had oxygen and how would that impact sulfate reducing bacteria?*

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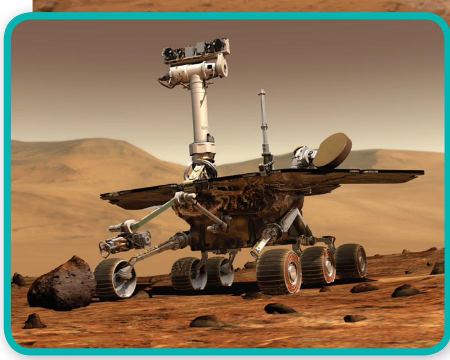
In 2007 the Mars Rover named Spirit, while traveling backwards across the Gusev Crater, dragged its locked wheel, uncovering a white rock layer under the dust. When x-ray spectroscopy looked at this rock, the data showed that the rock was 90% silica. Scientists believe that this kind of rock could have been deposited by a volcanic vent or a hot spring; similar to the low sulfur area of Mushroom Spring in Yellowstone National Park.

Mushroom Spring, Yellowstone National Park



This is a slice of a microbial mat collected by scientists from Mushroom Spring in Yellowstone (pH 7.9, temp 154°F (68°C))