SCIENCE OF THE SPRINGS

Reading Guide **ANSWER KEY**

battery acid	pH 0	
	pH 1	Amethyst Geyser, Norris
	pH 2	Black Dragon's Caldron Mud Volcano
	pH 3	
	pH 4	Emerald Spring, Norris
black coffee	pH 5	
	pH 6	
water	pH 7	
	pH 8	Arrowhead Spring, Upper Geyser Basin
	pH 9	
	pH 10	Heart Lak Geyser Basin
	pH 11	
bleach	pH 12	
	pH 13	
liquid drain cleaner	pH 14	

MONTANA STATE UNIVERSITY
Astrobiology Biogeocatalysis Research Center

The Astrobiology Biogeocatalysis Research Center at Montana State University

Our team supports the work of the NASA Astrobiology Institute (NAI), a multidisciplinary umbrella for conducting research on the origin and evolution of life on Earth and elsewhere in the universe.

The origin of life, sustainable energy, and global climate change are intimately linked, and the answers we seek to solve our energy needs of the future are etched into Earth's history. ABRC's work supports NASA's missions, such as Mars exploration and possibilities of habitation of other worlds. Our research also focuses on the future of life on Earth. These efforts support the fundamental groundwork for Goal 3 (Origins of Life) of the NASA Astrobiology Roadmap.

ABRC involves investigators with expertise in geochemistry, experimental and theoretical physical chemistry, materials science, nanoscience, and iron-sulfur cluster biochemistry who work to define and conduct integrated research and education in astrobiology.

We are proud of our interdisciplinary research and teaching, and are committed to communicating and educating the public about our science and helping to train and inspire the next generation of scientists.

The nearby natural laboratory of Yellowstone National Park provides ABRC with unique field research opportunities. Life in the extreme environments of Yellowstone's thermal features is thought to resemble conditions of early Earth. Yellowstone's abundant and unique thermal features give researchers insights into the origin, evolution and future of life.

Whether you are a potential MSU student, a research investigator, a teacher or a citizen, we welcome you to the world of astrobiology. ABRC is committed to sharing our work and its impact with the people of Montana and beyond, through formal and informal education; public outreach; and communications to many different audiences.

Our outreach and education activities are strengthened by many factors, including MSU's proximity to Yellowstone National Park, the expertise and experience of our faculty and close partners, the outstanding commitment from our MSU students to share their work with the public, and a rich network of partners, including the Montana Library Association, Museum of the Rockies, Space Public Outreach Team and Hopa Mountain. We also work closely with the other teams from the NASA Astrobiology Institute.

Please feel free to contact us with any questions, and enjoy exploring our website: **http://abrc.montana.edu**

MONTANA STATE UNIVERSITY | EXTENDED UNIVERSITY

MONTANA STATE UNIVERSITY | Astrobiology Biogeocatalysis Research Center

This learning module was developed by Montana State University Extended University in collaboration with the Astrobiology Biogeocatalysis Research Center at Montana State University. For additional astrobiology education resources, visit http://abrc.montana.edu/outreach/ and for even more research-based educational resources for community and schools, visit http://eu.montana.edu/outreach/resources/

SCIENCE OF THE SPRINGS

Astrobiology in Yellowstone Park

Use the Science of the Springs guidebook to answer these questions:

1. Give an example of an acidic feature at Yellowstone National Park and of something acidic from your everyday life.

Possible answers include: Amethyst Geyser, Norris; Black Dragon's Cauldron Mud Volcano; Whirligig Geyser, Norris; Echinus Geyser, Norris; Emerald Spring, Norris

Battery acid, stomach acid, black coffee, orange juice, citrus fruit, soda

2. Give an example of a basic (pH >7) feature at Yellowstone National Park and of something basic from your everyday life.

Possible answers include: Arrowhead Spring, Upper Geyser; Heart Lake Geyser Basin; Minerva Spring, Mammoth; Grand Prismatic; Midway Geyser

Bleach, liquid drain cleaner, baking soda, antacids (Tums), toothpaste (this is why orange juice tastes terrible after you brush your teeth)

3. What is an ***extremophile***? Where do they live? How big are they?

An extremophile is an organism that lives in a place that humans consider extreme. They live in extreme places like very hot water, dry deserts, frozen ice caps, deep in underwater vents. They are tiny (microscopic) bacteria, archaea, and algae.

4. Why are scientists at Montana State University studying Yellowstone's extremophiles?

Scientists at MSU study the extremophiles to learn how things could have lived on early Earth, or have formed on early Earth, and what types of environments could support life on other planets. Studying extremophiles expands the definition of habitability.

5. How is ***Chloroflexis*** similar to a plant? How is it different?

Chloroflexus also uses light to make its food but does not produce oxygen like normal photosynthetic plants. Chloroflexus and plants both use carbon dioxide, but chloroflexus also uses sulfur, unlike plants.

6. What topics might an astrobiologist study? Would *you* like to be an astrobiologist? Why or why not?

An astrobiologist studies life in the universe, whether on our planet or not. They study the origin of life (how did it begin and evolve?); they study the places that organisms could live in the universe (is there life elsewhere?); they study the possible future of life on our planet or others.

7. Describe what Earth was like billions of years ago.

Billions of years ago earth was much hotter, with a temperature around 55-85° C or 131-185° F. Also, early Earth was rocky, gaseous, watery, and devoid of life for a time period. Iron may have been abundant, as well as iron-sulfur compounds.

8. In your own words, describe how ***pyrite*** is important to a theory about how life may have started on Earth.

Pyrite can help chemical reactions that form life's building blocks – the amino acids, so this mineral could have been instrumental in the formation of the first life on Earth. If pyrite helped make amino acids, proteins could have been readily available.

9. Are there microorganisms in Old Faithful? In what kind of extreme environment do they thrive?

Yes there are microbes called methanogens in Yellowstone. They like an environment without oxygen or light. In the geyser they are also subject to intense temperatures and pressures.

11. ***Metallosphaera*** are important to studying what? In what kind of environment do they live?

Metallosphaera are important to studying how the first organisms on Earth may have used iron for food. They live in acidic environments with toxic metals.

12. How do viruses aid extremophiles? Are all viruses bad?

Viruses add genetic diversity to microbes, which helps them evolve and adapt. Some viruses can help organisms like bacteria, they are not all bad.

13. Where do ***methanogens*** live?

Methanogens live in many extreme places, like Old Faithful. They can also live in the bottom of ponds and springs, and at below freezing temperatures. They also live in other thermal features of Yellowstone.

14. What colors can photosynthetic organisms be besides green? What are photosynthetic microorganisms called? How old are these organisms?

Photosynthetic organisms can also be orange. They are sometimes called cyanobacteria. These organisms date back to 3.5 billion years ago.

15. What produced the cascading limestone of Mammoth Hot Springs?

The fossilized microbes of Mammoth produced the limestone. The microbes themselves make the limestone and eventually produce so much limestone that it entombs them.

16. What are two important reasons to study microbes?

Possible answers include: Microbes help us understand evolution and what geologic processes influence it, because it happens on such a fast timescale for them. Microbes also help us understand what types of environments life can withstand. Microbes are important to studying the origin of life on Earth because they were the first life here.

17. Define habitability in your own words.

Habitability is the range of conditions in which life can survive or the minimums and maximums of conditions that are necessary for sustaining life.

18. Even if humans could not live on a different planet, what type of life probably could?

Microbial life could probably survive on a different planet; we have found that microbes can survive almost every environment on Earth, no matter how extreme or strange.

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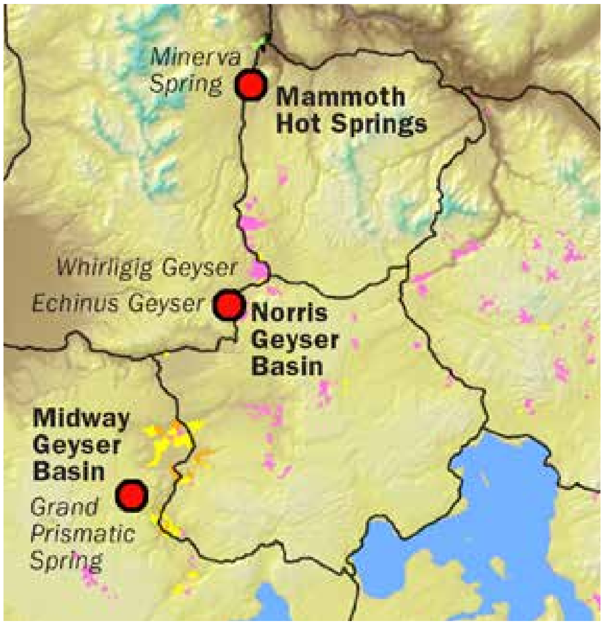


Extreme Conditions

For each of the thermal features below, report the ***temperature*** and ***pH***. What kinds of extreme conditions would an extremophile living there need to withstand?

1. Whirligig Geyser, Norris Geyser Basin

Temperature: 68° C or 154° F

pH: 3.4

Extreme conditions: Extremophiles would need to withstand extreme heat and high acidity.

2. Minerva Spring, Mammoth Hot Springs

Temperature: 45° C or 113° F

pH: 8

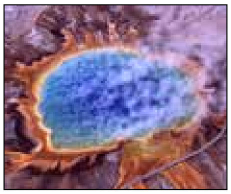
Extreme conditions: Extremophiles would need to withstand moderate heat and moderate basicity.

3. Echinus Geyser, Norris Geyser Basin

Temperature: 80° C or 176° F

pH: 3.3-3.6

Extreme conditions: They would need to withstand extreme heat and high acidity.



4. Grand Prismatic Spring, Midway Geyser Basin

Temperature: 63-68° C or 147-188° F

pH: 8.4

Extreme conditions: Extremophiles would need to withstand high heat and moderate basicity.

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Learn More About Extremophiles

Extremophiles are not unique to Yellowstone. While Yellowstone is a special extreme environment due to its multitude of hydrothermal features, extremophiles exist in every extreme environment on Earth. What other extreme environments can you think of?

Every type of extremophile has a different name, based on the extreme condition in which it lives.

Thermophiles (the name means heat-loving) are found all over in Yellowstone, because most of the features are very hot.

On the other hand, ***psychrophiles*** love very cold temperatures and live in places such as Antarctica and under glaciers. These extremophiles are also found in Montana in Glacier National Park.

Many of the features of Yellowstone are acidic. Extremophiles that live in acid are called ***acidophiles***. The opposite of these are ***alkalophiles*** that live in the basic (pH >7) features of Yellowstone.

There are even microbes that live out of the water, in the rocks of Yellowstone National Park. Rock-loving extremophiles are called ***endoliths***. Similar to these are ***xerophiles,*** which live in very dry environments, like the sand of the Sahara Desert. There are even microbes living at the very bottom of the ocean where the water is so heavy and the pressure is so great that it crushes most animals instantly. These pressure-loving microbes are called ***barophiles***. This deep in the ocean, there is no oxygen. Many microbes live without oxygen: they are called ***anaerobes***. Anaerobes are found in places without oxygen. You have anaerobes in your intestine!

Microbes are found every place on Earth. However, we only call them extremophiles when the conditions are extreme.

Microbes can fall under more than one of the categories named above. For instance, the bacteria in your stomach are both anaerobes and acidophiles, because that environment is very acidic (pH 2) and has no oxygen. Microbes are the most versatile and numerous life forms on the planet! Can you imagine them living on other planets?

Matching Game

Draw a line connecting the extremophile to its environment.

Matching Game

Acidophile – acidic

Alkalinophile – basic

Thermophile – hot

Psychrophile – cold

Xerophile – very dry

Barophile – heavy pressure

Endolith – rocky

Halophile – salty

Anaerobe – no oxygen