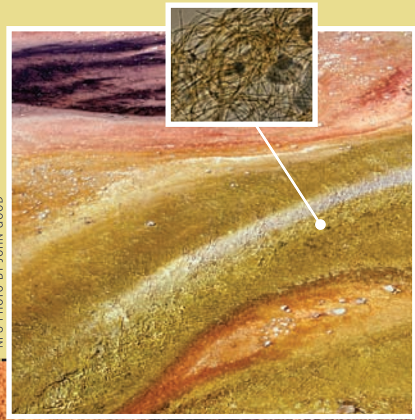
1 CM 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22

SCIENCE OF THE SPRINGS

Astrobiology in Yellowstone National Park

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 Lake Geyser Basin
	pH 11	
bleach	pH 12	
	pH 13	
liquid drain cleaner	pH 14	

MONTANA STATE UNIVERSITY
Astrobiology Biogeocatalysis Research Center

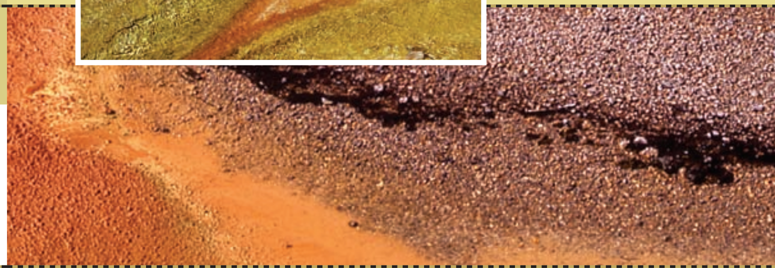


NPS PHOTO BY JOHN GOOD

Chloroflexis is a modern ancestor of the first photosynthetic organism. These interesting microbes use sunlight as an energy source, but do not produce oxygen like plants and algae. Instead, they thrive on carbon dioxide and sulfur compounds.

Q: What's the connection?

YELLOWSTONE HOT SPRINGS & Extraterrestrial Life



What we consider extreme on Earth might be similar to what is normal on other planets or moons.

Not too long ago, scientists discovered organisms that can thrive in the harshest of environments: below freezing, exceedingly hot, very acidic, as well as deep underground and at the bottom of the ocean.

These organisms are called **extremophiles**, and the environments they live in—what we consider extreme on Earth—might be similar to what is normal on other planets or moons. Many scientists think that if we find life elsewhere in the universe, it may resemble these organisms living in Earth's most extreme environments, not the little green men often shown in cartoons and movies.

Extremophiles are microbes: tiny single-celled organisms that you usually need a microscope to see. Yellowstone National Park is one of the best places on Earth to study extremophiles because the Park has such an amazing diversity of them. Yellowstone was established in 1872 as the world's first national park, and it contains half (more than 10,000) of the world's hydrothermal features, including mudpots, hot springs, fumaroles, and geysers. Each thermal feature has its own unique characteristics and hosts a wide array of extremophiles.

Scientists at Montana State University and other institutions examine these life forms and their habitats because it gives them insights into not only what our early Earth might have been like and how life may have formed on this planet, but also because it helps us better consider how life might form and exist on other planets.

Enjoy your journey to Yellowstone's extreme environments!

View extra content using your smart phone.

Throughout this booklet you will see **QR codes** that "unlock" extra videos and content from the Internet. You need a Web-enabled phone with a camera and QR Reader software, which is installed on many phones or free to download. Search online for your phone model and "QR reader." Web links are also listed on the back.

Q: What is Astrobiology?

ASTROBIOLOGY

is the study of life in the universe.

This new and emerging field combines many scientific areas including geology, biology, chemistry, astronomy, physics and even philosophy—to study the origins, evolution, distribution and future of life in the universe. Astrobiologists search for habitable environments in our Solar System and on planets around other stars; they also research the origin, early evolution and diversity of life on Earth. Astrobiology addresses three fundamental questions:

- **How did life begin and evolve?**
- **Is there life elsewhere in the universe?** and,
- **What is the future of life on Earth and beyond?**

Fourteen teams of researchers at universities and NASA centers make up the NASA Astrobiology Institute. The scientists collaborate across distances and disciplines to study these questions. Several teams, including nearby Montana State University, conduct research projects in Yellowstone National Park, where the geothermal features—geysers, hot springs and fumaroles—house microorganisms that can live in extreme environments—environments that may have things in common with those on Mars, Europa and other planets and moons.

NASA Astrobiology Institute researchers study Yellowstone National Park's extreme environments, because they think these areas might resemble the early Earth and be similar to the environments on other planets and moons.

For millions of years, the planet Earth held only rocks, gases and water, with no life of any kind. (artist's rendering)

Q: What was early Earth like?

EARTH'S EARLY Environment

Suitable for extremophiles.

Whirligig Geyser, Norris Geyser Basin
Temp: 68°C, 154°F | pH: 3.4

What was the early Earth like and how did the components form that are needed to support life? The formation of Earth's crust, oceans, and atmosphere is not very well understood.

There was a period about three and a half billion years ago in early Earth that was much hotter than today. Scientists have estimated that the surface temperature of Earth at this time was around 55 to 85°C (131 to 185°F), which is the temperature range for many heat-loving extremophiles.

At Montana State University, researchers find inspiration and insights in nearby Yellowstone National Park, where it's thought that the park's sulfuric pools closely resemble the environment of Earth several billion years ago. At that time, the Earth was essentially rocks, gases and water. So how did life arise from non-life? The answer may lie in studying the Earth's chemistry: specifically compounds containing iron and sulfur.

On the early Earth, iron may have been more abundant or available at the surface. Iron-sulfur compounds such as pyrite, also known as "fools gold," have been shown to spark chemical reactions in a lab. One leading theory is that these iron compounds were important in chemical reactions that formed amino acids—molecules that form proteins and that are one of the building blocks of life. And, if such a reaction did happen on Earth, it's possible that a similar reaction with iron-sulfide compounds may have formed life in other parts of the universe. Because iron- and sulfur-containing minerals are plentiful in Yellowstone, the Park makes an ideal research area for MSU.

Knowledge about how the precursors for life arose and were assembled is essential for understanding the evolution of life on Earth, and possibly life elsewhere in the universe. Such knowledge would prove invaluable for developing chemical signatures to help us detect life beyond Earth.

Guide to Astrobiology-Related Sites in Yellowstone

Map Legend

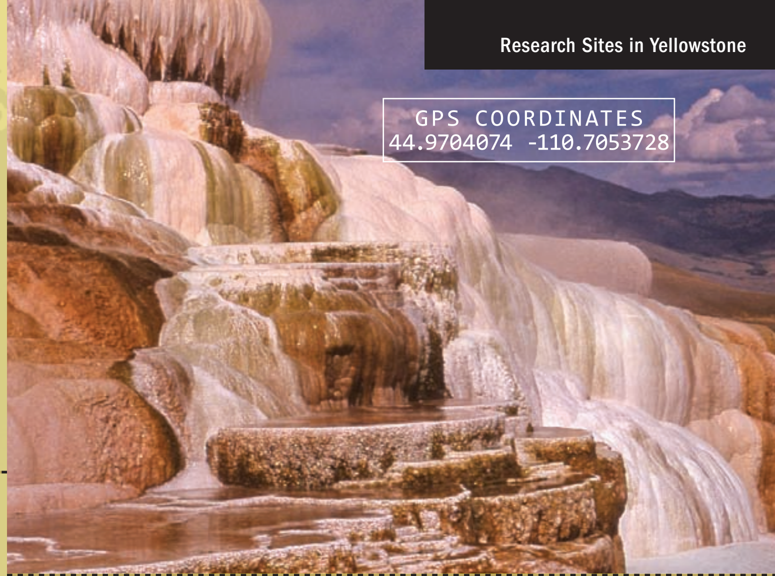
At several locations throughout Yellowstone, you can view informational signs describing astrobiology concepts and research. You can find one sign at Roaring Mountain; two signs each at Mud Volcano, Mammoth, Fountain Paint Pots and Norris; and three signs at Grand Prismatic.

Many of the signs were made possible by a generous grant to the Yellowstone Park Foundation from the NASA Astrobiology Institute and Lockheed Martin Space Operations.

This map features sites in Yellowstone where astrobiologists are conducting research. These sites are just examples, and many of these organisms and habitats occur in places throughout the Park.

Q: Where do we find answers?

RESEARCH SITES IN YELLOWSTONE



Minerva Spring, Mammoth Hot Springs
Temp: 45°C, 113°F | pH: 8

As you travel throughout the Park, you may see scientists and students in action. If you visit Norris, Mammoth, Old Faithful or Grand Prismatic Spring, think about some of the astrobiology research topics listed here.

Norris Some of the water channels around Norris are colored orange because of *Metallosphaera*. This organism uses iron for energy and can become coated with rust. They are extremely resistant to toxic metals and thrive in acidic environments. They give scientists insight into early life on Earth.

Norris Viruses from high-temperature acidic environments in Yellowstone, such as Norris Hot Springs, and others around the world are studied to understand how their structure and function informs us about the evolution of life. Viruses are not considered to be living, but contain packets of genetic material that can be transferred from one organism to another. The influx of this material increases genetic diversity and may influence changes within the microbial community allowing the organism to better adapt to its environment.

Old Faithful Methanogens are thought to be among the oldest forms of life on Earth because they live in environments with no oxygen and no light. They are the dominant life form at the bottom of most ponds and springs, producing methane gas as a biological signature. Methanogens can also live in below freezing temperatures and may be a good candidate for life on Mars or Jupiter's moon Europa. Methanogens are found in Old Faithful and are abundant in many other thermal features of Yellowstone.

Grand Prismatic Photosynthetic microorganisms may have been largely responsible for making Earth's atmosphere oxygen-rich; they are some of the oldest fossilized organisms found on earth (3.5 billion years old). Studying these fossils helps researchers understand photosynthesis and the ancient microbial world. Mats of photosynthetic cyanobacteria are usually orange and occasionally green and are found in the channels around Grand Prismatic.

Mammoth Hot Springs Millions of microbes are thriving in Mammoth Hot Springs. As the microbes die, they can become entombed in limestone. The unique chemical impression of these fossilized microbes could help scientists identify signatures of life on other planets.

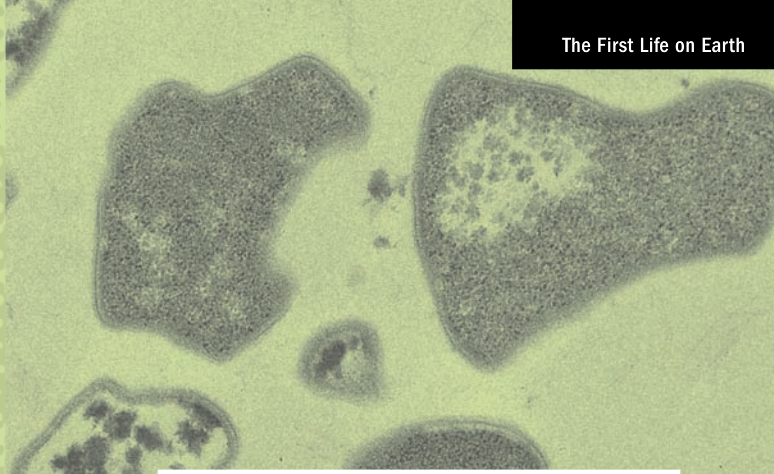
Q: Why study microbes?

THE FIRST LIFE ON EARTH

Microbes were the first life on Earth, and were the only life form for well over half the time life has been on Earth.

Microbes have relatively simple environmental and nutritional requirements and have been found nearly everywhere on our planet. Microbes are important to study because they can help us understand evolution and give us evidence for ways in which geologic processes might have influenced evolution.

NASA researchers work in Yellowstone to study extreme forms of microbial life. Home to the world's largest caldera—a crater formed by a violent volcanic explosion or the collapse of a volcanic cone—the Park contains the most numerous and diverse geothermal features on Earth. Each thermal feature has its own unique characteristics and they are all host to a wide array of microbes. Scientists are currently trying to understand the biodiversity and patterns of distribution displayed among the Park's microbial life.



Echinus Geyser, Norris Geyser Basin
Temp: 80°C, 176°F | pH: 3.3-3.6

Q: Where can we find life?

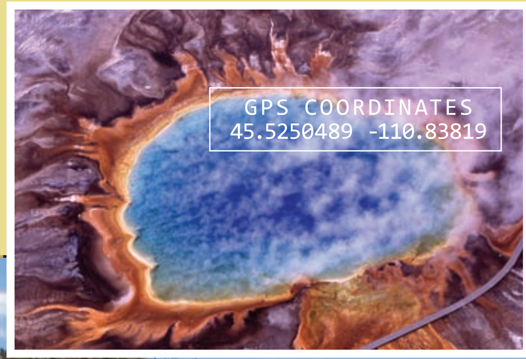
YELLOWSTONE and Other Extreme Environments

One of the questions asked by astrobiology researchers is: "What are the limits of life?" In other words, we know that humans can only survive at certain temperatures and under specific environmental conditions, but other types of organisms thrive in much more extreme environments. If we know more about these environments, we can develop theories about life in other parts of the Solar System.

Habitability means determining an environment's potential to develop and sustain life. Scientists think that for an environment to be habitable it must have liquid water, a carbon source, and an energy source.

Life exists in thermal features throughout Yellowstone—even those that are at near-boiling temperatures, or as acidic as battery acid. Likewise, living organisms have been found in salty brine oceans at -10°C (14°F) under frozen Antarctic ice; miles below the Earth's subsurface in mine shafts; at the bottom of the ocean around volcanic vents; and in water laced with toxic chemicals like arsenic and lead. NASA scientists study microbes in these extreme environments to determine the limits of life and delineate the signs of life. If organisms can live in these habitats, might there be life in other locations in the Universe?

Grand Prismatic, Midway Geyser Basin
Temp: 63-86° C, 147-188° F | pH: 8.4



NASA Astrobiology Institute

NASA's Astrobiology Program supports scientists across the country through a variety of research programs. For more information and resources visit http://astrobiology.nasa.gov. The NASA Astrobiology Institute (NAI) is comprised of the following 14 interdisciplinary teams at universities and science centers. Visit http://astrobiology.nasa.gov/nai/teams to learn more about each one.

- Arizona State University
- Carnegie Institution of Washington
- Georgia Institute of Technology
- Jet Propulsion Laboratory—Icy Worlds
- Jet Propulsion Laboratory—Titan
- Massachusetts Institute of Technology
- Montana State University
- NASA Ames Research Center
- NASA Goddard Space Flight Center
- Pennsylvania State University
- Rensselaer Polytechnic Institute
- University of Hawaii
- University of Washington
- University of Wisconsin

The NAI also has six international partners. Visit http://astrobiology.nasa.gov/nai/international-partners for more information.

- Australian Centre for Astrobiology (ACA)
- Centro de Astrobiología (CAB)
- Astrobiology Society of Britain (ASB)
- Société Française d'Exobiologie (SFE)
- The European Exo/Astrobiology Network Association (EANA)
- Russian Astrobiology Center (RAC)

If you were unable to "unlock" the QR codes in this pamphlet, here are the web links they open.

Astrobiology at Montana State University [video]
www.youtube.com/watch?v=lNiUjCdk9tc

Yellowstone's Extreme Environments [slideshow]
www.youtube.com/watch?v=sBB5KcvhARA

Studying the Origins of Life [video]
www.youtube.com/watch?v=n3-S3tbJPp8

This pamphlet was produced by the Montana State University Astrobiology Biogeocatalysis Research Center.
For more information visit http://abrc.montana.edu