Thermophiles, or heat-loving microscopic organisms, are nourished by the extreme habitat at hydrothermal features in Yellowstone National Park. They also color hydrothermal features shown here at Clepsydra Geyser, either through the pigments that they make or by minerals that they precipitate.

Life in Extreme Heat

The hydrothermal features of Yellowstone are magnificent evidence of Earth's volcanic activity. Amazingly, they are also habitats in which microscopic organisms called thermophiles—"thermo" for heat, "phile" for lover—survive and thrive.

Grand Prismatic Spring at Midway Geyser Basin is an outstanding example of this dual characteristic. Visitors marvel at its size and brilliant colors. The boardwalk crosses a vast habitat for thermophiles. Nourished by energy and chemical building blocks available in the hot springs, microbes construct vividly colored communities. Living with these microscopic life forms are larger examples of life in extreme environments, such as mites, flies, spiders, and plants.

For thousands of years, people have likely wondered about these extreme habitats. The color of Yellowstone's superheated environments certainly caused geologist Walter Harvey Weed to pause, think, and even question scientists who preceded him. In 1889, he (Weed, 1889) wrote:

> *There is good reason to believe that the existence of algae of other colors, particularly the pink, yellow and red forms so common in the Yellowstone waters, have been overlooked or mistaken for deposits of purely mineral matter.*

However, he could not have imagined what a fantastic world exists in these waters of brimstone. Microorganisms, single-celled organisms smaller than the width of a human hair, thrive in waters as acidic as the liquid in your car battery and hot enough to blister your skin. Some create layers that look like molten wax on the surface of steaming alkaline pools. Still others, apparent to us through the odors they create, exist only in murky, sulfuric caldrons that stink worse than rotten eggs.

Today, many scientists study Yellowstone's thermophiles. Some of these microbes are similar to the

Words to Know

Extremophile: A microorganism living in extreme conditions such as heat and acid, that cannot survive without these conditions.

Thermophile: Heat-loving extremophile.

Microorganism: Single- or multi-celled organism of microscopic or submicroscopic size. Also called a microbe.

Microbes in Yellowstone: In addition to the thermophilic microorganisms, millions of other microbes thrive in Yellowstone's soils, streams, rivers, lakes, vegetation, and animals. Some of them are discussed in other chapters of this book.

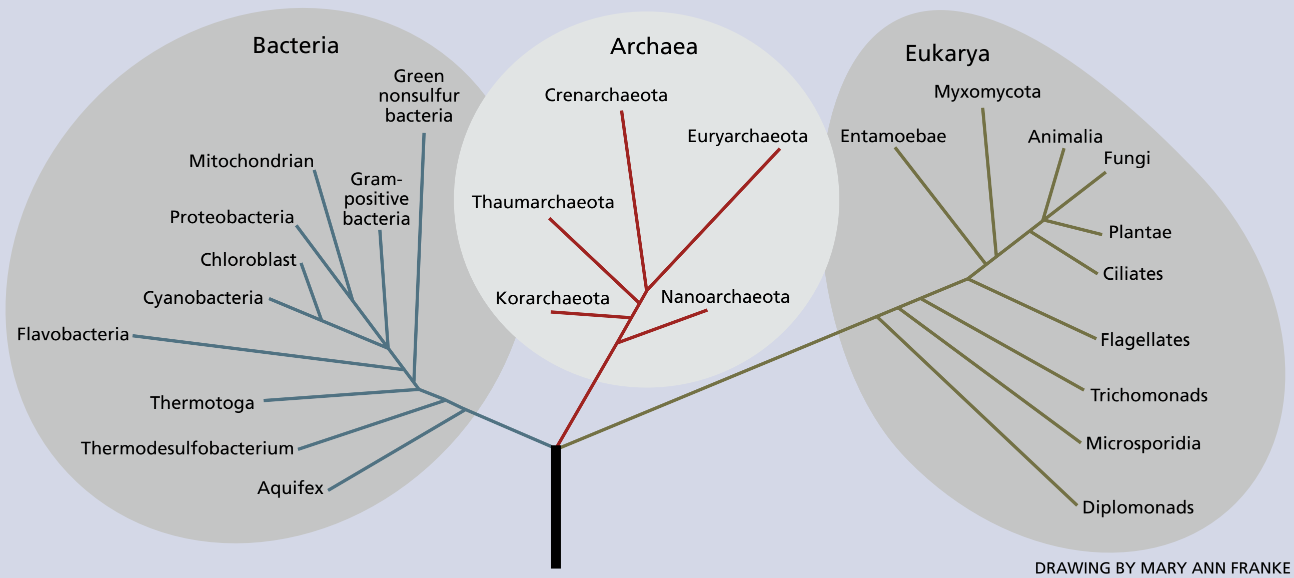
Bacteria (Bacterium): Single-celled microorganisms without nuclei, varying in shape, metabolism, and ability to move.

Archaea (Archaeon): Single-celled microorganisms without nuclei and with membranes different from Bacteria. Once thought to be Bacteria.

Viruses: Non-living parasitic microorganisms consisting of a piece of DNA or RNA coated by protein.

Eukarya (Eukaryote): Single- or multi-celled organisms whose cells contain a distinct membrane-bound nucleus.

Thermophiles in the Tree of Life



DRAWING BY MARY ANN FRANKE

Yellowstone's hot springs contain species from the circled groups on this Tree of Life. Jack Farmer conceived of this version of the tree of life, which first appeared in *GSA Today,* July 2000 (used with permission).

In the last few decades, microbial research has led to a revised tree of life, far different from the one taught before. The new tree combines animal, plant, and fungi in one branch. The other two branches consist solely of microorganisms, including an entire branch of microorganisms not known until the 1970s—the Archaea.

Dr. Carl Woese first proposed this "tree" in the 1970s. He also proposed the new branch, Archaea, which includes many microorganisms formerly considered Bacteria. The ancestor of the Bacteria, Archaea, and Eukarya is inferred to be where the blue, red, and green lines connect. Organisms that branch closest to this ancestor are hyperthermophiles, which thrive in water above 176°F (80°C), indicating life may have arisen in hot environments on the young Earth.

Relevance to Yellowstone

Among the earliest organisms to evolve on Earth were microorganisms whose descendants are found today in extreme high-temperature, and in some cases acidic, environments, such as those in Yellowstone. Their history exhibits principles of ecology and ways in which geologic processes might have influenced biological evolution, and how this, in turn, influenced geology.

first life forms capable of photosynthesis—the process of using sunlight to convert water and carbon dioxide to oxygen, sugars, and other by-products. These life forms, called Cyanobacteria, began to create an oxygen-rich atmosphere that would eventually support human life. Cyanobacteria are found in some of the colorful mats and streamers of Yellowstone's hot springs. The production of oxygen by Cyanobacteria forever changed Earth and created numerous new opportunities for life to evolve, including animals that require oxygen.

About Microbes

Other life forms—the Archaea—predated Cyanobacteria and other photosynthesizers. Archaea can live in the hottest, most acidic conditions in Yellowstone; their relatives are considered among the very earliest life forms on Earth.

Yellowstone's thermophiles and their environments provide a living laboratory for scientists, who continue to explore these extraordinary organisms. Researchers know that many mysteries of Yellowstone's extreme environments remain to be revealed.

Regardless of scientific advances, visitors and explorers in Yellowstone can still relate to something else Weed (Weed, 1889) wrote about Yellowstone, more than a century ago:

> *The vegetation of the acid waters is seldom a conspicuous feature of the springs. But in the alkaline waters that characterize the geyser basins, and in the carbonated, calcareous waters of the Mammoth Hot Springs, the case is otherwise, and the red and yellow tinges of the algae combine with the weird whiteness of the sinter and the varied blue and green of the hot water to form a scene that is, without doubt, one of the most beautiful as well as one of the strangest sights in the world.*

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The travertine terraces in Mammoth Hot Springs host thermophilic Cyanobacteria.

Thermophilic Bacteria

The word "Bacteria" is often associated with disease, but only a few kinds of Bacteria cause problems for humans. The other thousands of Bacteria, although all simple organisms, play a complex role in Earth's ecosystems. In fact, Cyanobacteria were responsible for the oxygenation of our atmosphere. They were the first photosynthesizers, converting light energy into oxygen more than 2.4 billion years ago. Without Bacteria, in particular Cyanobacteria, humans would not be here.

While some Bacteria perform photosynthesis, others depend on chemical energy that is released when compounds like hydrogen or sulfur react with oxygen. This energy is then used to convert carbon dioxide into biomass (chemosynthesis). For example, *Thermus* sp. may also be able to oxidize arsenic into a less toxic form.

Individual Bacteria may be rod or sphere shaped, but they often join end to end to form long strands called filaments. These strands help bind thermophilic mats, forming a vast community or mini-ecosystem. Other groups of Bacteria form layered structures resembling tiny towers, which can trap sand and other organic materials.

Thermophilic Bacteria in Yellowstone National Park

Name	pH and Temperature	Description	Location
Cyanobacteria *Calothrix*	pH 6–9 30–45°C (86–113°F)	Color: dark brown mats Metabolism: photosynthesis by day; fermentation by night	• Mammoth Hot Springs • Upper, Midway, and Lower geyser basins
Phormidium	pH 6–8 35–57°C (95–135°F)	Color: orange mats Metabolism: photosynthesis	• Mammoth Hot Springs • Upper, Midway, and Lower geyser basins
Oscillatoria	pH 6–8 36–45°C (96–113°F)	Color: orange mats Metabolism: photosynthesis; oscillating moves it closer to or away from light sources.	• Mammoth Hot Springs • Chocolate Pots
Synechococcus	pH 7–9 52–74°C (126–165°F)	Color: green mats Metabolism: photosynthesis by day; fermentation by night	• Mammoth Hot Springs • Upper, Midway, and Lower geyser basins
Green Sulfur *Chlorobium*	pH 6–9 32–52°C (90–126°F)	Color: dense, dark green mats Metabolism: anoxygenic photosynthesis—produces sulfate and sulfur, not oxygen.	• Mammoth Hot springs • Calcite Springs
Green non-sulfur *Chloroflexus*	pH 7–9 35–85°C (95–185°F)	Color: green mats Metabolism: anoxygenic photosynthesis—use organic compounds during photosynthesis.	• Mammoth Hot Springs • Upper, Midway, and Lower geyser basins
Aquificales *Hydrogenobaculum*	pH 3–5.5 55–72°C (131–162°F)	Color: yellow and white streamers Metabolism: reacts hydrogen, hydrogen sulfide, elemental sulfur, or arsenic with oxygen to generate energy.	• Norris Geyser Basin • Amphitheater Springs
Aquificales *Thermocrinis*	pH 5–9 40–79°C (104–174°F)	Color: bright pink or orange streamers; contains carotenoid pigments that act as sunscreen.	• Lower Geyser Basin

Archaea are the most extreme of all extremophiles, and some scientists think they have not changed much from their ancestors. Grand Prismatic Spring at Midway Geyser Basin contains Archaea.

Thermophilic Archaea

Archaea are the most extreme of all extremophiles—some kinds live in the frigid environments of Antarctica; others live in the boiling acidic springs of Yellowstone. These single-celled organisms have no nucleus but have a unique, tough outer cell wall. This tough wall contains molecules and enzymes that may keep acid out of the organism, allowing it to live in environments of pH 3 or less. (For example, most vinegar has a pH of less than 3.) Archaea also have protective enzymes within their cells to keep them from becoming too acidic.

Some scientists think present-day Archaea have not changed much from their ancestors, in particular those that inhabit circumneutral to alkaline pH hot springs. This may be due to the extreme environments in which they live, which would allow little chance for successful changes to occur. If this is so, modern Archaea may not be much different from the earliest forms of life, thus their study can provide important clues into how life was supported on early Earth.

Once thought to be Bacteria, organisms in the domain Archaea share many characteristics with eukaryotic organisms, which includes plants and animals. Many kinds of Archaea live in the hydrothermal waters of Yellowstone. For example, Grand Prismatic Spring at Midway Geyser Basin contains Archaea. However, they are most well known in the superheated acidic features of Norris Geyser Basin and in the muddy roiling springs of the Mud Volcano area.

Whenever you see a hot, muddy, acidic spring, you are probably seeing the results of a thriving community of archaeal cells called *Sulfolobus*. This is the archaeon most often isolated and most well known by scientists. In sulfuric hydrothermal areas, it oxidizes sulfur into sulfuric acid, which helps dissolve the rocks into mud. The *Sulfolobus* community in Congress Pool (Norris) is providing interesting new research directions for scientists: It is parasitized by viruses never before known on Earth.

Archaea can be found in the Mud Volcano area, among other places in Yellowstone National Park.

Thermophilic Archea found in Yellowstone National Park

Name	pH and Temperature	Description	Location
Domain Archaea	pH 0.9–9.8 upper temp.: 92°C (197.6°F)	Color: cream or yellow-colored Metabolism: chemosynthesis, using hydrogen, sulfur, aresenic Form: unicellular, tough cell membrane	• In many of Yellowstone's hydrothermal features
Sulfolobus is the genus most often isolated	pH 0–4, ~50–80°C (104–131°F)	Color: cream or yellow-colored Metabolism: chemosynthesis	• Norris Geyser Basin • Lemonade Creek

Microscopic Eukarya in the extreme environments of Yellowstone. Norris Geyser Basin is one of the best places in Yellowstone to see thermophilic algae.

Thermophilic Eukarya

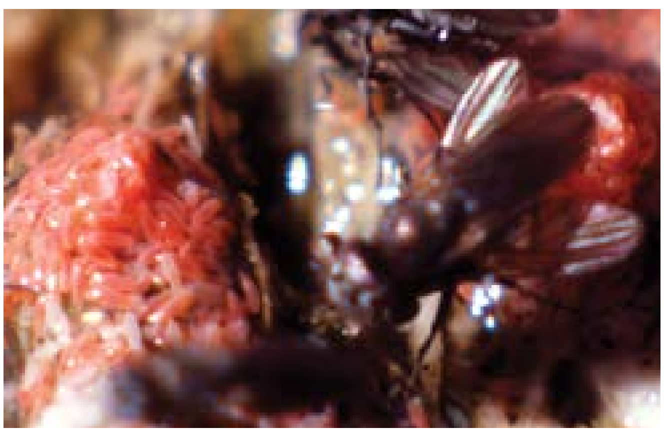
Plants, animals, and mushrooms are the Eukarya most of us know. However, millions of unseen, microscopic members of this kingdom exist throughout our world, including in the extreme environments of Yellowstone.

Norris Geyser Basin is one of the best places to see thermophilic algae, where they form robust bright green microbial mat communities. Bright green *Cyanidioschyzon* grows on top of orange-red iron deposits around Whirligig and Echinus geysers and their runoff channels. Waving streamers of *Zygogonium* are especially easy to see in Porcelain Basin, in cooler regions of spring runoff channels, where their dark colors contrast with the white surface.

From the boardwalk crossing Porcelain Basin, you can also see larger Eukarya, such as ephydrid flies. They live among the thermophilic mats and streamers, and eat algae, among other things. The species that lives in the waters of Geyser Hill, in the Upper Geyser Basin, lays its eggs in pink-orange mounds, sometimes on the firm surfaces of the mats. Part of the thermophilic food chain, ephydrid flies become prey for spiders, beetles, and birds.

Some microscopic Eukarya consume other thermophiles. A predatory protozoan called *Vorticella* thrives in the warm, acidic waters of Obsidian Creek, which flows north toward Mammoth Hot Springs, where it consumes thermophilic bacteria.

Thermophilic eukarya include one form that is dangerous to humans: *Naegleria*, a type of amoeba that can cause disease and death in humans if inhaled through the nose.



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Counterclockwise from top: Ephydrid flies lay eggs in pink-orange mounds, sometimes on the firm surfaces of the mats; waving streamers of *Zygogonium* are easy to see in Porcelain Basin; the fungi *Curvularia protuberata* lives in the roots of hot springs panic grass.

Although they aren't visible like mushrooms, several thermophilic fungi thrive in Yellowstone. *Curvularia protuberata* lives in the roots of hot springs panic grass. This association helps both organisms survive higher temperatures than each could alone. In addition, researchers have recently discovered a virus inside the fungus that is also essential to the grass's ability to grow on hot ground.

Of all the thousands, if not millions, of thermophilic species thriving in Yellowstone's extreme environments, the Eukarya are the group that bridges the world of thermophilic microbes with the larger life forms—such as geese, elk, and bison—that thrive in ecological communities beyond the hot springs.

Thermophilic Eukarya found in Yellowstone National Park

Name		pH and Temperature	Description	Location
Red algae *Cyanidio-schyzon*		pH 0–4 40–55°C (104–131°F)	Color: bright green Metabolism: photosynthetic Form: coating on top of formations; mats	• Norris Geyser Basin • Lemonade Creek • Nymph Creek
Green algae *Zygogonium*		pH 0–4 <32°C (90–131°F)	Color: appears black or dark purple in sunlight Metabolism: photosynthetic Form: filaments and mats	
Protozoa				
Naegleria (amoeba)		Warm Alkaline	Predator of Bacteria; can infect humans when ingested through nose	• Huckleberry Hot Springs • Boiling River
Vorticella (ciliate)			Consumer; single-celled ciliate (feathery appendages swirl water, bringing prey)	• Obsidian Creek
Euglenids *Mutablis*		pH 1–2 <43°C (109°F)	Single-celled; photosynthetic; moves by waving one or two strands called flagella	
Fungi (*Curvularia protuberata*)		≤65°C (149°F) with panic grass <55°C (131°F) without	Grows in roots of hot springs panic grass (*Dichanthelium lanuginosum*), enabling both to survive high temperatures; the plant also produces sugars that the fungus feeds on	
Ephydrid fly (*Ephydra* sp.)		>pH 2 <43°C (109°)	Nonbiting insect that eats microscopic algae as larvae and adult; prey for spiders, beetles, dragonflies, killdeer	• Norris, especially Porcelain Basin • Upper Geyser Basin, especially Geyser Hill • Mammoth Hot Springs
Ross's bentgrass (*Agrostis rossiae*)		38°C (100°F)	One of Yellowstone's three endemic plant species; may bloom in winter; dries out in summer's hot air temperatures	• Banks of Firehole River • Near Shoshone Lake
Warm springs spike rush, with some Tweedy's rush		Warm Acidic	Forms thick floating mats, which also provide habitat for thermophilic algae and other thermophiles	• Obsidian Creek

Note: Algae and Warm springs spike rush photos by Carolyn Duckworth. Fungi photo by Russell Rodriguez and Joan Henson. Ross's bentgrass photo by NPS/Jennifer Whipple.

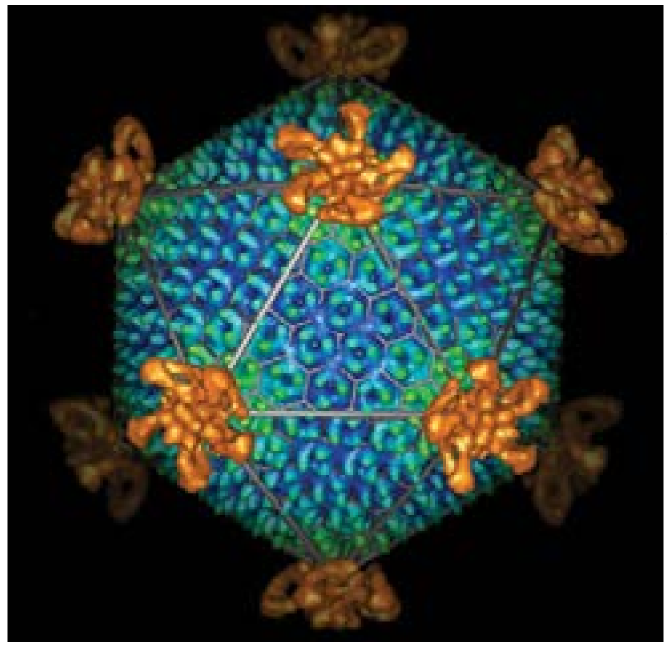
A virus was discovered in Congress Pool, shown here, at Norris Geyser Basin. It was infecting the archaean *Sulfolobus*.

Thermophilic Viruses

Like Bacteria, the word "virus" often conjures up images of sickness and death. However, relatively few viruses cause problems for humans. None of the thermophilic viruses in Yellowstone should cause problems for human health—our bodies are too cold, for one thing.

Unlike microorganisms in the three domains, viruses are not considered to be alive, yet they are still called "life forms." They have no cell structure, only a protein "envelope" that encloses genetic material. They cannot reproduce on their own. Instead, a virus inserts itself into a host cell and uses that cell's nutrients and metabolism to produce more viruses.

Scientists suspect many viruses exist in Yellowstone's hydrothermal features because they would be a logical part of the thermophilic ecosystem. One kind was discovered in Congress Pool, at Norris Geyser Basin. It was infecting the archaeon *Sulfolobus*. Another kind of virus has been identified in pools near Midway Geyser Basin.



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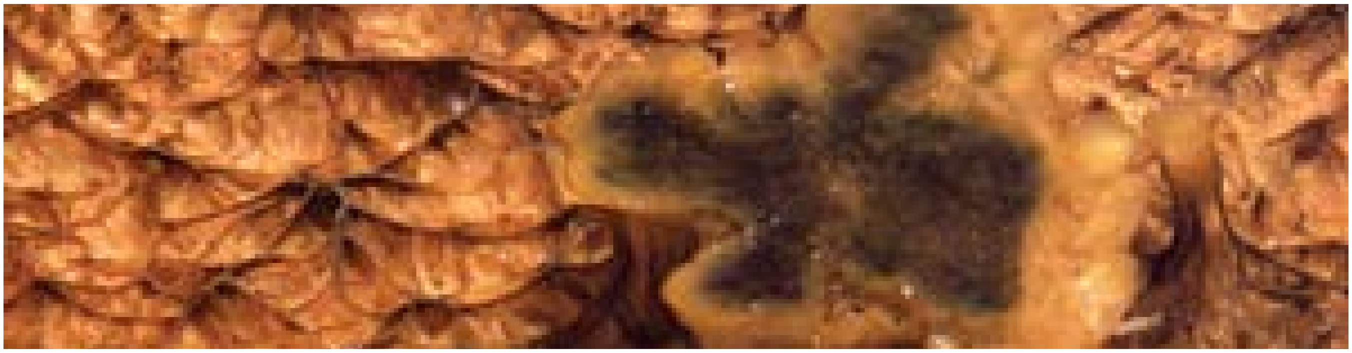
This virus parasitizes *Sulfolobus*.

Thermophilic Viruses found in Yellowstone National Park

Name	pH and Temperature	Description	Location
Viruses (not in a domain)	pH 0.9–5.8; optimum 2–3 55–80°C (131–176°F) optimum 70–75°C	• Protein coats a core of genetic material • Cannot reproduce by itself • Reproduces by using the host cell's metabolism • Not considered living • Predators of other microbes	• In many of Yellowstone's hydrothermal features
Unnamed	Acidic Boiling	• Shape very similar to viruses that infect Bacteria and animals, which could mean this group of viruses existed early in the development of life on Earth	• Unnamed pool near Midway Geyser Basin
Unnamed	Acidic Boiling	• Parasitizes the archaean, *Sulfolobus*	• Norris, Congress Pool



Channels formed with water runoff from geysers create bacterial columns such as this one, located where the runoff channels from Pinwheel and Whirligig geysers meet.

Thermophilic Communities

Thermophilic communities are as diverse as the communities that humans live in. Community formations, colors, and locations vary depending on the types of microbes, the pH, and the temperature of their environments. Here, we discuss the microbe communities most easily seen in Yellowstone.

Millions of individual microbes can connect into long strands called filaments. Some Bacteria and algae form thin and delicate structures in fast moving water such as the runoff channels of hot springs and geysers. Other microbes form thick, sturdy structures in slower water or where chemical precipitates quickly coat their filaments.

A bacterium called *Thermocrinis* forms structures and is descended from ancient Bacteria that metabolized hydrogen and oxygen. Its filaments entwine, forming mats. Flowing water carries other microbes, organic matter, and minerals that become caught in the streamers and add to the mat.

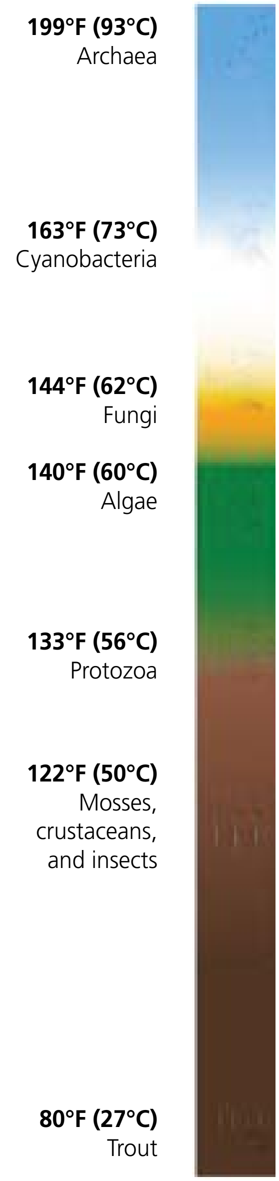
Photosynthetic activity of Cyanobacteria such as *Lyptolyngbya* form columns or pedestals. Oxygen bubbles rise in the mat, forcing the microbes upward. The higher formations capture more organic matter and sediment than the lower mats, which help build the columns. Called stromatolites or microbialites, these structures are similar to ancient microbial communities preserved in formations around the world.

Mats can be as thin as tissue paper or as thick as lasagna. Multiple layers of microorganisms make up inch-thick mats. Dozens of types of microbes from all three domains can exist in these layers. Each layer is a community, and each layer interacts with the other layers, forming a complex, larger community full of millions of microorganisms and their life processes.

Changes in Communities

Visible and invisible changes occur in thermophile communities as light, temperature, and chemical concentrations change—both short term (within one day) and long-term (seasonally). As day brightens to noon, Cyanobacteria sensitive to light may move away from the surface; microbes less sensitive to light may move to the top layers of the mat. When light levels cause shifts in organisms, the community is responding to a light gradient.

Temperature and chemical gradients most often affect thermophilic communities in runoff channels of geysers and in shallow outflows from hot springs. The runoff channels from Pinwheel and Whirligig geysers meet. The outer edges of both are too hot for visible thermophile communities to develop. But as Pinwheel's water cools in the shallower channel edge, *Cyanidioschyzon* (an alga) can grow, forming a bright green community. Whirligig's runoff is hotter, which prevents



Thermophilic community inhabitants are controlled, in part, by water temperature and pH. The chart provides general guidelines for maximum for each type.

Cyanidioschyzon from growing, but another type of thermophile thrives by oxidizing the abundant iron in the water, thereby forming the orange/red colored community.

At the Chocolate Pots, which you can see from pullouts along the Gibbon River just north of Gibbon Meadows, iron-rich water flows from the vents. Cyanobacteria—such as *Synechococcus*, and *Oscillatoria*—thrive in this feature. The bacterial filaments form mats, in which orange-red iron oxide (rust) is captured. The iron may also be caught on the Bacteria as the microbes move about within the mat. An olive green color indicates where the orange iron and green bacteria are enmeshed. Darker streaks indicate the presence of manganese.

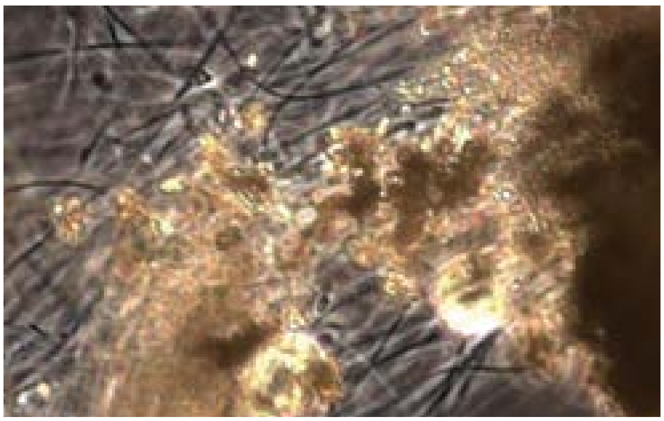
COURTESY CAROLYN DUCKWORTH

Bison and elk find food and warmth on the less extreme edges of thermophilic environments in winter.

Thermophiles by Place and Color in Yellowstone National Park

Location	Characteristics	Thermophiles by Temperature	Thermophiles by Color
Upper, Middle, and Lower Geyser Basins and West Thumb Geyser Basin			
	• pH 7–11 (alkaline) • underlain by rhyolitic rock • water rich in silica, which forms sinter and geyserite deposits	• >75°C (167°F), Bacteria and Archaea • >75°C (167°F), *Thermocrinis* and other bacteria form streamers of pink, yellow, orange, or gray • <75°C (167°F), *Synechococcus*, *Lyptolyngbya*, and *Calothrix* (cyanobacteria) plus *Roseiflexus* (filamentous green bacterium) form mats that line cooler hot springs and runoff channels	• Pink, yellow, orange, gray filaments—*Thermocrinis* bacteria • Orange mats—Cyanobacteria, especially on sunny summer days (carotenoids protect the organisms from the bright sun) • Olive-green mats—Cyanobacteria
Norris Geyser Basin and Mud Volcano Area			
	• pH 0–5 (acidic) • underlain by rhyolite rock	• >75°C (167°F), *Sulfolobus*, an archaean, and viruses that parasitize *Sulfolobus* • >60°C (140°F), filamentous bacteria in yellowish streamers and mats • <60°C (140°F), filamentous bacteria and archaea form red brown mats • <56°C (133°F), *Zygogonium*, other algae, and fungi form mats in runoff channels	• Pink–pinkish-orange mats and streamers—*Thermus aquaticus* and other *Thermus* sp. • Green streamers and mats—*Cyanidium* • Orange—iron and/or arsenic, oxidized by thermophiles • Gray, muddy pools—*Sulfolobus*
Mammoth Hot Springs			
	• pH 6–8 (neutral to slightly acidic) • underlain by ancient limestone deposits • water rich in calcium carbonate and sulfur	• 66–75°C (151–167°F), *Aquificales* (Bacteria) filaments near hot springs vents • <66°C (151°F), *Chloroflexus* (green nonsulfur bacteria) and Cyanobacteria mats, and filamentous bacteria streamers • <58°C (136°F), *Chromatium* (Bacteria) form dark mats (uncommon) • 25–54°C (77–129°F), *Chlorobium* (Bacteria) mats; *Calothrix* streamers; *Synechococcus*	• Orange—*Chloroflexus* and Cyanobacteria in summer • Green—*Chloroflexus* and Cyanobacteria in winter; *Chlorobium* in cooler water • Cream—filamentous bacteria

Note: Photos by Carolyn Duckworth.



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Top: Structures formed by the bacteria *Thermocrinis.* Bottom: Millions of individual microbes can connect into long strands called filaments, shown here with the help of a microscope.

Scientists think that mixing of iron-rich waters with shallow precipitation-derived waters creates the unique conditions that give rise to the large iron and manganese oxide mounds at Chocolate Pots. These formations are not commonly encountered in the park.

Communities formed by thermophilic microbes sustain communities of larger organisms within Yellowstone's hydrothermal areas. These communities in turn affect even larger communities of the park's mammals. For example, bison and elk find food and warmth on the less extreme edges of thermophilic environments in winter. In turn, coyotes, wolves, and bears seek prey in these areas—especially in late winter and early spring when bison and elk are weaker than at any other time of year.

Whether it's the strike of a grizzly's paw or a shift in heat beneath the Earth, these communities change through both common and strange processes. Biologists continue to discover more about the individuals involved in thermophilic communities, and ecologists follow the threads of these intricate webs.

Thermophiles in Time and Space

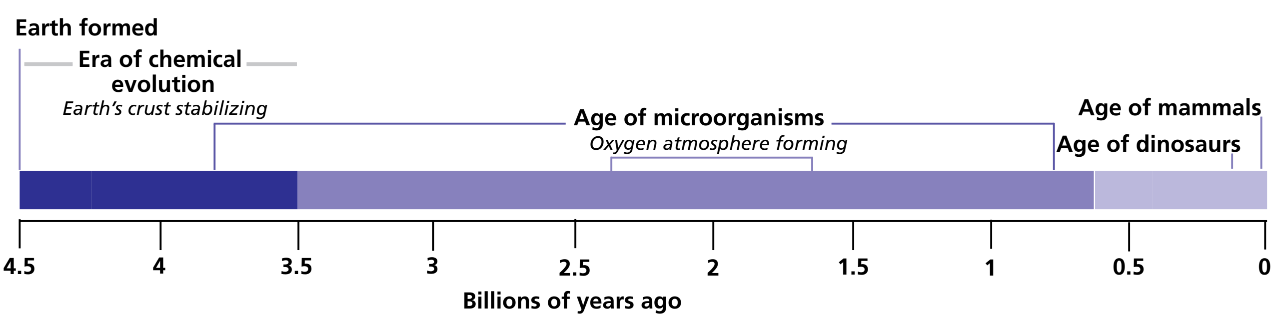
To Mars—and Beyond?

The hydrothermal features of Yellowstone and their associated thermophilic communities are studied by scientists searching for evidence of life on other planets. The connection is extreme environments. If life began in the extreme conditions thought to have been widespread on ancient Earth, it may well have developed on other planets with similar conditions—and these conditions might still exist today.

The chemosynthetic microbes that thrive in some of Yellowstone's hot springs do so by metabolizing inorganic chemicals, a source of energy that does not require sunlight. Such chemical energy sources provide the most likely habitable niches for life on Mars or on the moons of Jupiter—Ganymede, Europa, and Callisto—where uninhabitable surface conditions

What's the Connection?

- Yellowstone's hydrothermal features contain modern examples of Earth's earliest life forms, both chemo- and photosynthetic, and thus provide a window into Earth's ancient past.
- Yellowstone's hydrothermal communities reveal the extremes life can endure, providing clues to environments that might harbor life on other worlds.
- Yellowstone's environments show how mineralization preserves biosignatures of thermophilic communities, which could help scientists recognize similar signatures elsewhere.
- Based on life on Earth, the search for life on other planets seems more likely to encounter evidence of microorganisms than of more complex life.



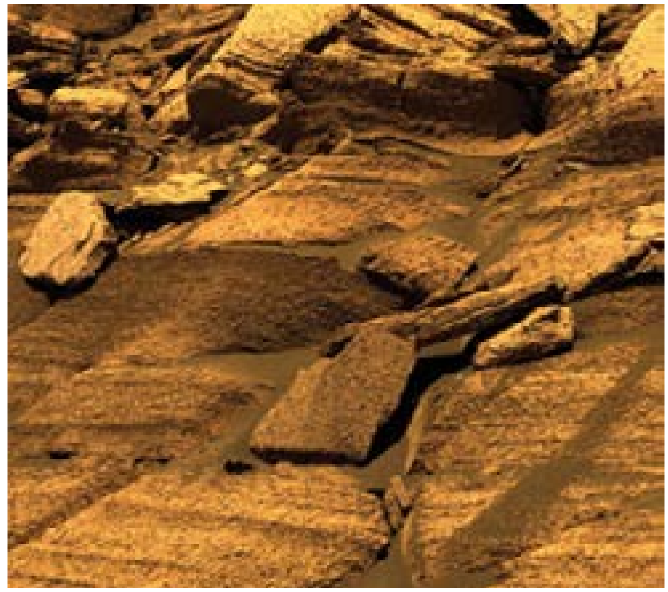
preclude photosynthesis. Chemical energy sources, along with extensive groundwater systems (such as on Mars) or oceans beneath icy crusts (such as on Jupiter's moons) could provide habitats for life.

Similar Signatures

Thermophile communities leave behind evidence of their shapes as biological "signatures." For example, at Mammoth Hot Springs, rapidly depositing minerals entomb thermophile communities. Scientists compare these modern signatures to those of ancient deposits elsewhere, such as sinter deposits in Australia that are 3.5 billion years old. These comparisons help scientists better understand the environment that supported life on early Earth, and give them an idea of what to look for on other planets.

Yellowstone National Park will continue to be an important site for studies of the physical and chemical limits of survival. These studies will give scientists a better understanding of the conditions that give rise to and support life, and of how to recognize signatures of life in ancient rocks and on distant planets.

Reviewers
Dr. Eric Boyd, Montana State University Department of Microbiology and Immunology
Dr. Erin White, Park Hydrologist
Annie Carlson, Research Permit Coordinator



NASA/JPL

These layers of rock on Mars have minerals and features developed by interactions between liquid water and rocks over time. This evidence does not prove life developed on Mars, but it brings the possibility one step closer to reality. Photo and caption adapted from www.nasa.gov, image by NASA/JPL.