THERMOPHILES

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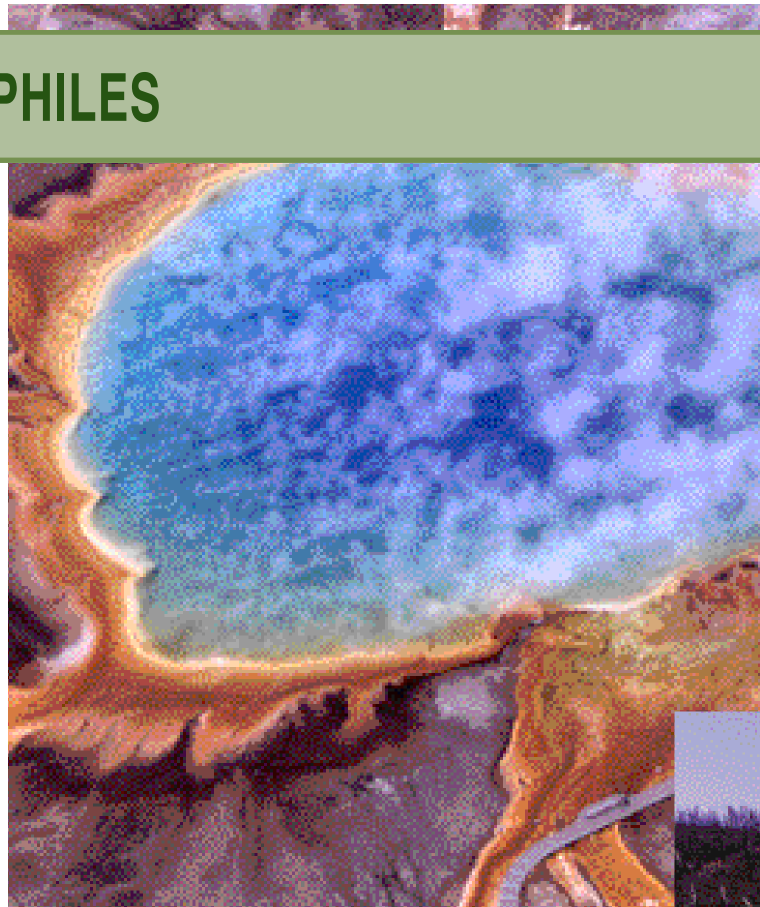
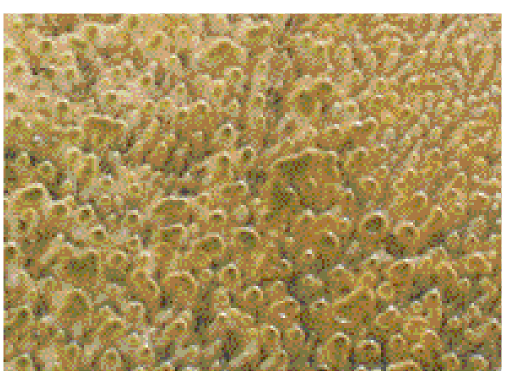
Newchapter



Grand Prismatic Spring (both photos)

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 *(above)* is an outstanding example of this dual characteristic. Visitors are awed by its size and admire its brilliant colors. However, the boardwalk they follow *(lower right corner of photo)* spans a vast habitat for a variety of thermophiles. Drawing on energy and chemical building blocks available in the hot springs, microbes construct substantial communities throughout the park.

All thermophiles require hot water but differ in other habitat needs. Some thrive in only acidic water, others require sulphur or calcium carbonate, still others live in alkaline springs. Depending on these other characteristics, some are described more specifically with terms such as thermoacidophile (heat and acid lover) or extremo- or hyperthermophile (extreme heat lover).



Thermophile community from Geyser Hill, Upper Geyser Basin

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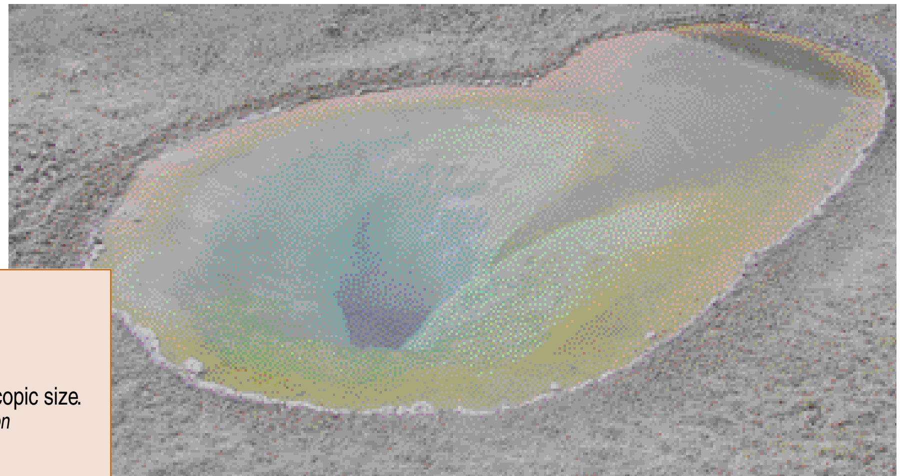
About Microbes

Microbe:
A minute lifeform; a microorganism.

Microorganism:
An organism of microscopic or submicroscopic size.
Both from American Heritage Dictionary, 4th edition

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.



Hot spring in Upper Geyser Basin

When you look into Yellowstone's colorful hydrothermal pools, imagine you are looking through a window into Earth's past to the beginnings of life itself. The thermophiles that thrive in these pools and their runoff channels are heat-loving microorganisms (also called microbes), some of which are descendants of the earliest lifeforms on Earth.

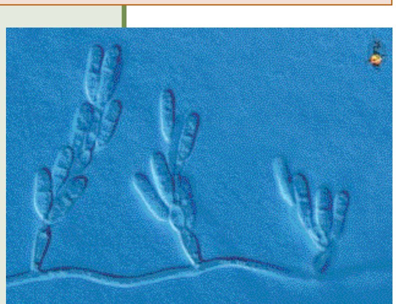
Scientists think that during the first three billion years of Earth's history, microorganisms transformed the original, anoxic (without oxygen) atmosphere into something that could support complex forms of life. Microbes harnessed energy stored in chemicals such as iron and hydrogen sulfide in a process called **chemosynthesis.** And they did this in environments that are lethal to humans—in boiling acidic or alkaline hot springs like the hot springs found in Yellowstone National Park.

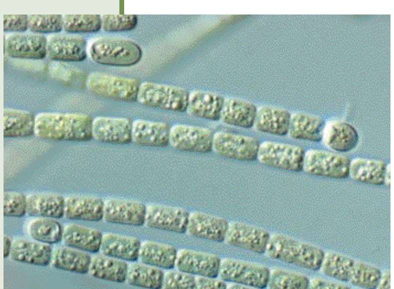
Microorganisms were the first lifeforms capable of photosynthesis—using sunlight to convert carbon dioxide to oxygen and other byproducts. These lifeforms, called cyanobacteria, began to create an atmosphere that would eventually support human life. Cyanobacteria are found in some of the colorful mats and streamers of Yellowstone's hot springs.

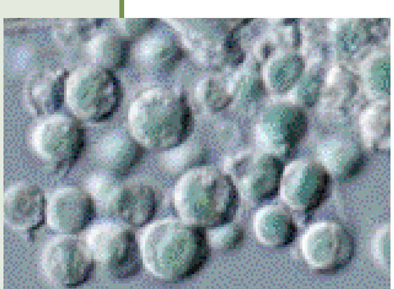
In the last few decades, scientists discovered that cyanobacteria and other microbes comprise the majority of species in the world—yet less than one percent of them have been studied.

Microbial research has also led to a revised tree of life, far different from the one taught for decades *(see next page).* The "old" tree's branches—animal, plant, fungi—are now combined in one branch of the tree. The other two branches consist solely of microorganisms, including an entire branch of microorganisms not known until the 1970s—Archaea.

Yellowstone's thermophilic communities include species in all three branches. These microbes and their environments provide a living laboratory studied by a variety of scientists. Their research findings connect Yellowstone to other ancient lifeforms on Earth, and to the possibilities of life elsewhere in our solar system *(see last section).*

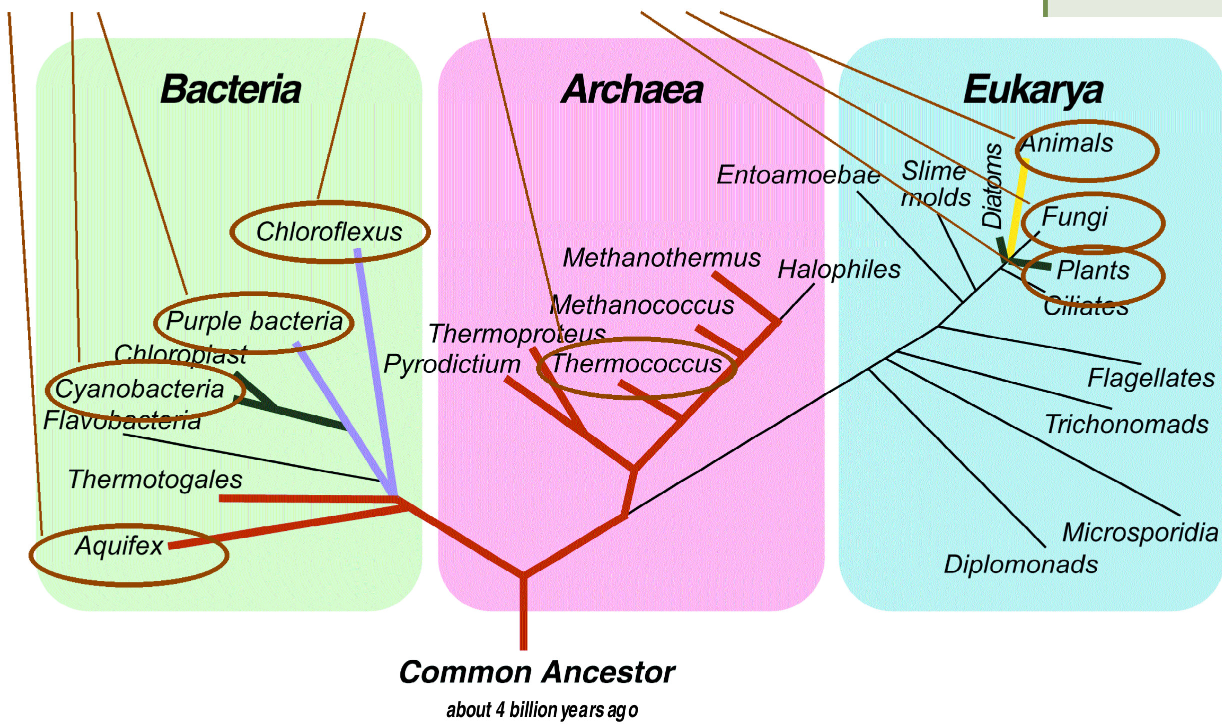






Thermophiles as seen through a microscope. Images courtesy of the Thermal Biology Institute of Montana State University.

Yellowstone's hot springs contain species from these groups on the Tree of Life



The tree shows the divergence of various groups of organisms from the beginning of life on Earth, about four billion years ago. It was originated by Carl Woese in the 1970s. Dr. Woese also proposed the new center branch, Archaea, which includes many microorganisms formerly considered bacteria. The red line links the earliest oganisms that evolved from a common ancestor.

Branches of the tree

- Domains Bacteria and Archaea include single-celled organisms that have simple cell architectures.
- Domain Eukarya includes all organisms comprised of cells containing a nucleus and energy-generating organelles such as mitochrondria and chloroplasts. Animals, plants, fungi, algae, and protozoa are members of Eukarya.

Underestanding the tree

- Mutations (changes in the sequence of DNA) accompany the evolution of living organisms.
- Closely related organisms have fewer mutations in their DNA sequences than more distantly related organisms.
- Closely related organisms are located close to each other on the branches of the tree.
- The earliest organisms are near the tree's root, while the modern organisms are at the ends of the branches.
- Analysis of microorganism DNA shows Bacteria and Archaea are as different from each other as each is different from Eukarya, even though they share a simple cell design.
- Animals, plants, and fungi are late-comers, consistent with their late appearance in the fossil record.

Relevance to Yellowstone

The earliest organisms to evolve on Earth were likely 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 the connections between geology, geochemistry, and biology.

The Tree of Life Continues to Evolve

Three decades of microbial research have occurred since Dr. Woese first proposed this tree of life. Changes to the tree reflect new knowledge and the settling of some controversies. Refinements, changes, and controversies will continue as our understanding of microbes and microbial ecosystems evolves.

This tree of life by Jack Farmer first appeared in GSA Today, *July 2000. Used with permission.*

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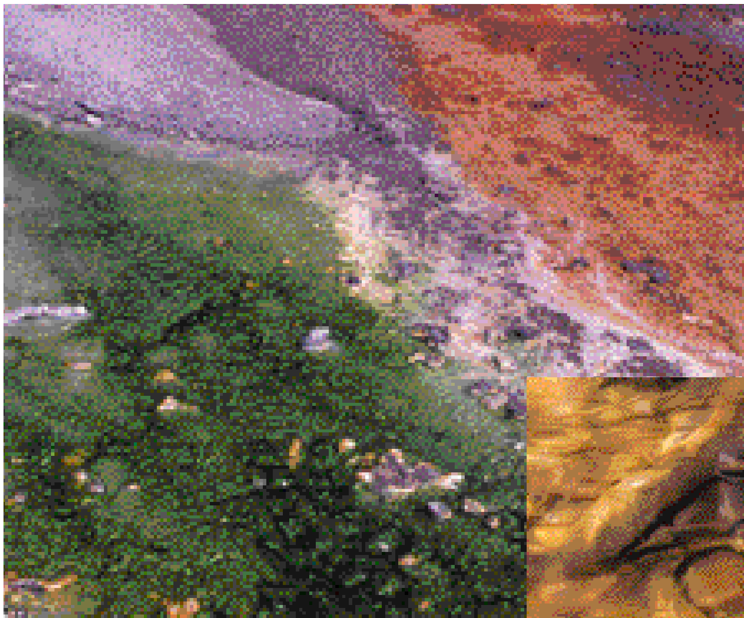
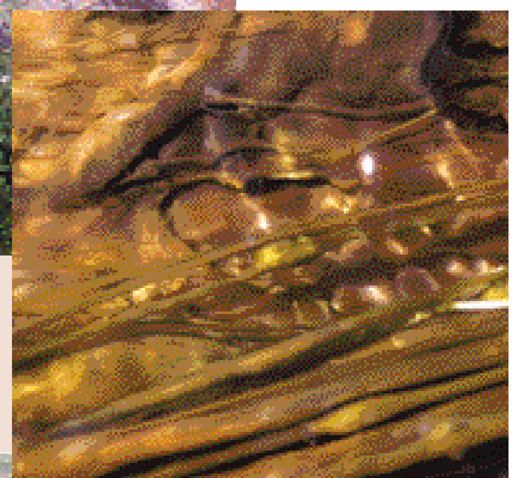
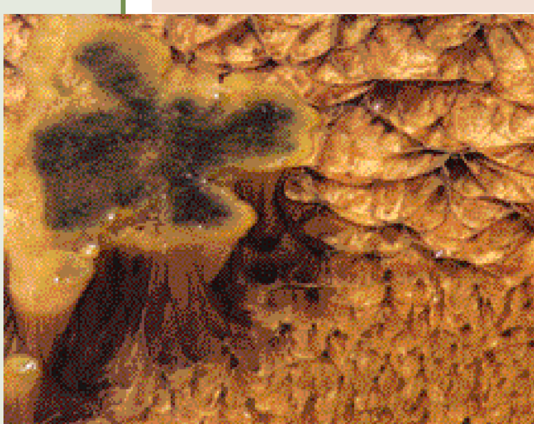
Thermophile Communities

Thermophiles appear in a variety of shapes and colors, as shown on this page. Information about the different thermophile habitats begins on the next page.





Thermophiles grow in communities numbering billions of individuals and often dozens of species. Some communities form a coating on sinter around the rims of hot springs and geysers, such as at Whirligig in Norris Geyser Basin, above. Others connect as ribbons or "streamers" in runoff channels and other moving hot water (right).

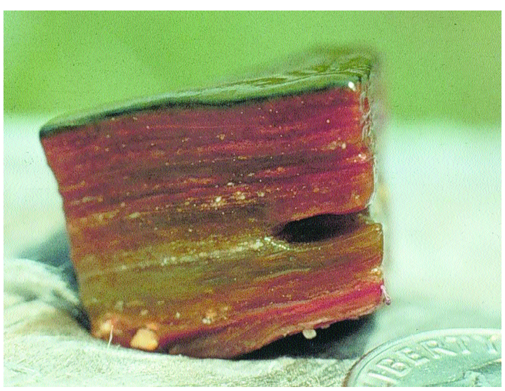


Some thermophile communities grow in columns or pedestals (above)—each seemingly free-standing formation a thriving community of its own connected to the surrounding formations. Still other communities grow into thick mats (right). Within those mats, thermophile species may migrate up or down depending on the air and water temperatures and other conditions, demonstrating that these communities are dynamic and ever-changing.

Above: Hot springs along the Firehole River, Upper Geyser Basin; Below: thermophilic streamers

Streamers

Between 163°F (73°C) and 198°F (92°C), filamentous thermophiles form long, flexible structures called streamers in fast-flowing water of runoff channels. Depending on the thermophilic species and minerals in the water, they may be pink, yellow, orange, white, gray, or black *(photo above)*. The thermophilic species in these streamers are direct descendants of early bacteria.



Researchers collected this sample of a thermophile mat, which shows the multiple layers of communities. Photo courtesy Thermal Biology Institute, Montana State University.

Mats

Thermophiles form mats in water below 167°F (75°C). Species of four genera dominate the mats listed in the box at right. Many other bacteria and Archaea also occur, each adapted to different temperatures and light conditions within the mat. They are fueled by the photosynthetic species and are involved in decomposition of the mats. The interactions of the species form a mat that is laminated and seems solid *(photo above)*.

The thermophilic mat community can be compared to a forest community. Its canopy species either need or can withstand abundant light, and its understory species live with less or no light and may metabolize chemicals such as hydrogen and iron.

Where to see

Most hot springs in the Firehole Valley and West Thumb Geyser Basin

Characteristics

- pH 7–11
- underlain by rhyolite rock
- water rich in silica, which forms sinter and geyserite deposits

Thermophiles

- Above 167°F (75°C), bacteria and Archaea reside in boiling pools and as streamers in runoff channels.
- Above 167°F (75°C), streamers may be pink, yellow, orange, or gray. They are comprised of many thermophile species, including *Thermocrinis*, descended from an ancient bacteria that metabolizes hydrogen and oxygen.
- Below 167°F (75°C), thermophiles form mats that line cooler hot springs and runoff channels. The main species in these mats are *Synechococcus* (a cyanobacteria), *Chloroflexus* (filamentous green bacteria), and two filamentous cyanobacteria—*Phormidium* and *Calothrix*.

Interesting facts

- At this elevation, the surface boiling point is 199°F/93°C.
- The microorganisms in a 3x3″ chunk of thermophile mat outnumber the people on Earth.

4

Thermophile Habitats: Acidic

Mud Volcano area

Where to see

- Mud Volcano *(photo at right)*
- Norris Geyser Basin

Characteristics

- pH 0–5
- underlain by rhyolite rock

Thermophiles present

- Above 140°F (60°C), filamentous bacteria form yellowish streamers and mats.
- Below 140°F (60°C), filamentous bacteria and Archaea form red brown mats (see below).
- Below 131°F (55°C), algae and fungi form mats in runoff channels.
- Sulfur-consuming microbes such as *Sulfolobus,* an Archaeum, produces sulfuric acid, which breaks down rocks into clay mud.

Interesting facts

- Acid pools in Norris Geyser Basin often appear turbid due, in part, to the high concentrations of microorganisms in the water.
- Some of these hot springs have a pH near zero; their water will burn holes in shoes and clothing.
- Archaea living in near-boiling acid hot springs are some of the toughest known lifeforms.
- Viruses have been discovered in some near-boiling acidic hot springs.
- Roaring Mountain is an acidic thermophile community; the Archaeum *Sulfolobus* produces sulfuric acid, which accelerates erosion of the mountainside.

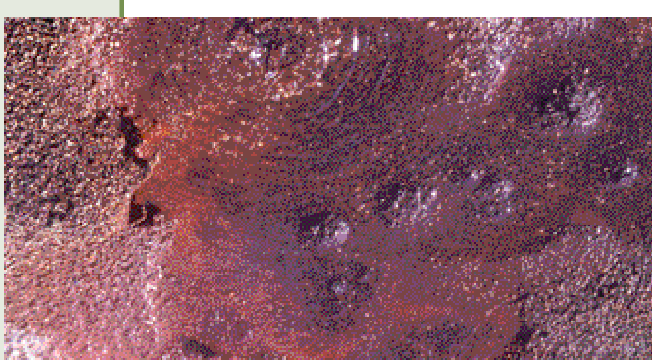
Thermophiles that live in these acidic hot springs are considered extremophiles because they live in boiling water that is highly acidic. They are sometimes referred to as thermoacidophiles. *Sulfolobus acidocaldarius,* an Archaeum that abounds in such springs, is well named. It is a sulfur-eating *(Sulfo-)*, lobe-shaped *(-lobus)* microorganism adapted to life in acidic *(acido-)* hot *(-caldarius)* places. Other Archaea such as *Thermoproteus* and *Acidianus* also live in these springs.

Streamers and Mats

Yellowish streamers and mats grow in the hottest acidic runoff channels, between 140°F (60°C) and 181°F (83°C). One of these genera, *Hydrogenobaculum,* may metabolize hydrogen and sulfur compounds.

Below 140°F (60°C), filamentous bacteria—including *Thiomonas, Acidimicrobium, Desulfurella*—and the Archaeum *Metallosphaera* form red-brown mats *(see photo below).* The color comes in part from iron oxide, metabolized from iron by the thermophiles. High levels of arsenic also contribute to the color.

Below 131°F (55°C), *Cyanidium* and *Galdieria* form mats in acidic runoff channels. Both species are algae, in the domain eukarya *(see the tree of life, page 51).* They contain a nucleus and chloroplasts for harvesting light energy and generating oxygen as a byproduct. These mats are not as well laminated as cyanobacterial mats in alkaline springs, possibly because filamentous bacteria—an important "thread" in the alkaline mat—is absent. Instead, the acidic mats may be held together by fungi that consume algal products. Many bacteria and Archaea also inhabit the mat and are involved in its decomposition. At lower temperatures, *Chlorella,* a green alga, dominates the mat; *Zygogonium,* a filamentous alga, thrives at even lower temperatures and is recognized by its dark purple color.



Iron and arsenic contribute dark orange colors to some thermophiles in Norris Geyser Basin

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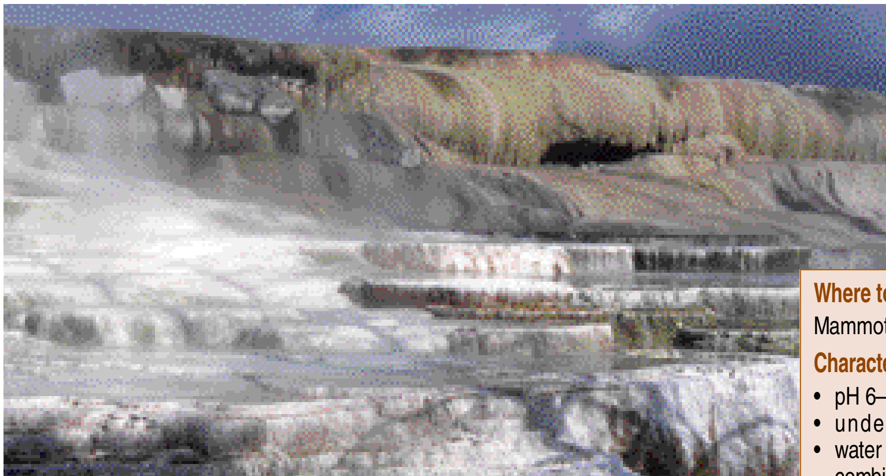
Thermophile Habitats: Neutral, Carbonate Rich



Travertine terraces at Mammoth Hot Springs

Where to see

Mammoth Hot Springs

Characteristics

- pH 6–8 (neutral to slightly acidic)
- underlain by ancient limestone deposits
- water rich in calcium carbonate and sulfur, a combination unique to Mammoth Hot Springs

Thermophiles

- 151°F (66°C) to 167°F (75°C), bacteria form streamers in runoff channels.
- Below 151°F (66°C), *Chloroflexus* (bacteria) forms green mats and filamentous bacteria form cream-colored streamers.
- Below 136°F (58°C), *Chromatium* (bacteria) form purple mats.
- 77–129F (25–54C), *Chlorobium* (bacteria) form green mats.

Interesting facts

- The combination of hydrogen sulfide and high temperature is toxic to cyanobacteria. Downstream, after hydrogen sulfide has been removed by other organisms, cyanobacteria thrives and contributes to the orange color of active terraces.
- Other thermophiles can obtain energy from the hydrogen sulfide.
- Scientists are studying the role that thermophiles might play in calcium carbonate deposition.

See Chapters 3 and 10 for more about the geology of Mammoth Hot Springs.

Underneath Mammoth Hot Springs, the dominant rock is limestone deposited by ancient seas. Calcium carbonate from the limestone and sulfur from an underground source are brought to the surface by circulating hot water. Thus, the hot springs are rich with the sulfur and carbonate. Sulfur, in the form of hydrogen sulfide, is toxic to cyanobacteria at high temperatures but nutritious for purple and green photosynthetic bacteria. Calcium carbonate precipitates from the hot spring waters, building up the terrace structures and entombing microbial communities within the newly forming rock matrix *(see page 57 for more about this)*.

Streamers

When source pools are above 151°F (66°C), their runoff supports the cream-colored streamers of filamentous bacteria *(below)*. The cream color comes from calcium carbonate minerals and sulfur deposited on filamentous thermophiles. These bacteria are descended from the earliest bacteria and metabolize sulfide in combination with oxygen.

Mats

The carbonate- and sulfide-rich springs of Mammoth contain rare examples of laminated microbial mats formed by green bacteria in the absence of cyanobacteria. These bacteria use hydrogen sulfide in chemosynthetic reactions, producing sulfur instead of oxygen as a by-product. Cream-colored streamers may form above these mats where oxygen mixes in from the air.

Cream-colored streaming thermophilic communities at Mammoth

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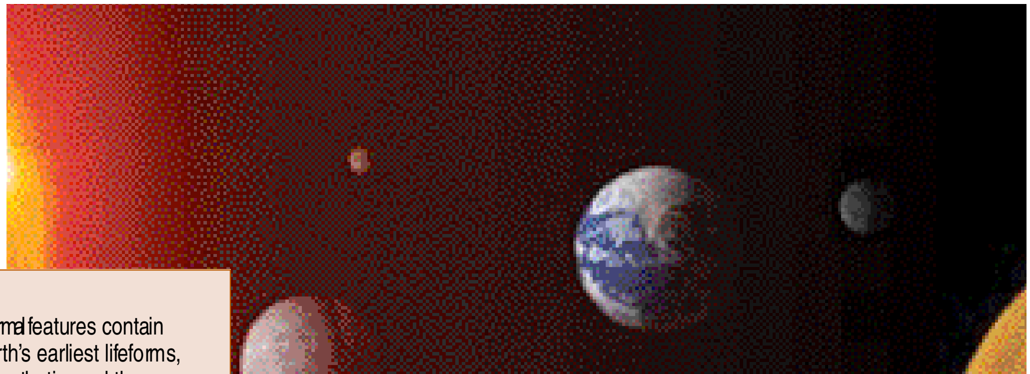
Thermophiles In Time and Space



What's the Connection?

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

Life began very early in Earth's history *(see timeline, below),* perhaps before 3.8 billion years ago. By the close of the Archaean Eon, some 2.5 billion years ago, microorganisms had evolved to remarkable levels of metabolic sophistication. Thermophiles in Yellowstone's hot springs are living connections to the primal Earth of billions of years ago. They are also studied by scientists searching for life on other planets, where extreme environmental conditions may support similar lifeforms.

Chemosynthesis: An Ancient Process

Studies suggest that the common ancestor of all modern organisms may have lived in a high-temperature environment like a Yellowstone hot spring. Descendents of these early organisms currently inhabit Yellowstone's hot springs, where they live by chemosynthesis—combining inorganic chemicals to liberate energy, which is then used for growth. Such energy sources likely fueled Earth's earliest lifeforms, and remain a mainstay for organisms living in hydrothermal environments where sunlight is unavailable.

Photosynthesis: Key to the Present

Photosynthesis was key to creating an atmosphere that would eventually support plants and animals. All types of photosynthesis are represented in Yellowstone's thermophile mat communities. The simplest and earliest type of photosynthesis, anoxygenic photosynthesis, was probably conducted by green and purple bacteria by splitting hydrogen sulfide and producing sulfur. Today, such communities exist in Mammoth Hot Springs.

Oxygenic photosynthesis—generating oxygen by splitting water—is conducted by microbes such as cyanobacteria, which form mats in

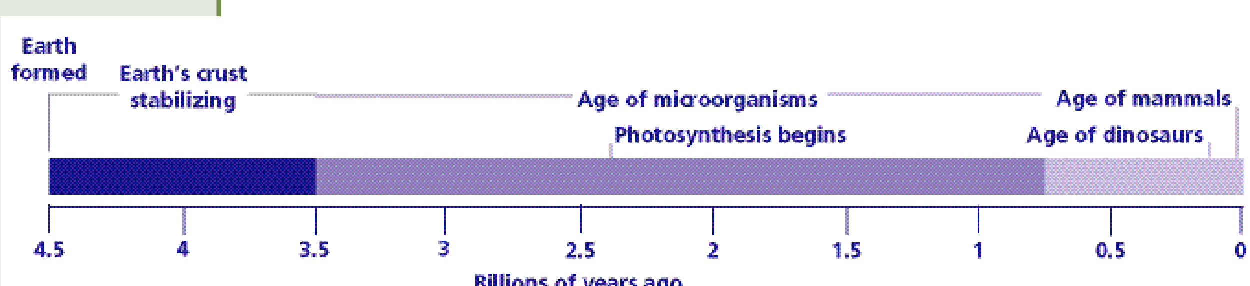


Photo above from NASA/JPL; time line provided by the Thermal Biology Institute, Montana State University springs wherever sulfide is low or has been removed by other organisms, such as in Norris Geyser Basin. Algae also conduct oxygenic photosynthesis and are found in acidic hot springs such as at Norris.

Stromatolites: Signatures of Life

Stromatolites are sediments laminated by microbial activity. Found in ancient rocks, stromatolites are perhaps the most abundant and widespread evidence of early microbial ecosystems.

Stromatolites also form in Yellowstone's hydrothermal features as thermophiles are entombed within travertine and sinter deposits. Thermophile communities leave behind evidence of their shapes as biological "signatures." Scientists compare the signatures of these modern and recent stromatolites to those of ancient deposits elsewhere (e.g., 350-million-year-old Australian sinter deposits) to better understand the environment and evolution on early Earth. Mammoth Hot Springs is a particularly good location for these studies because of rapid deposition rates and abundant thermophile communities.

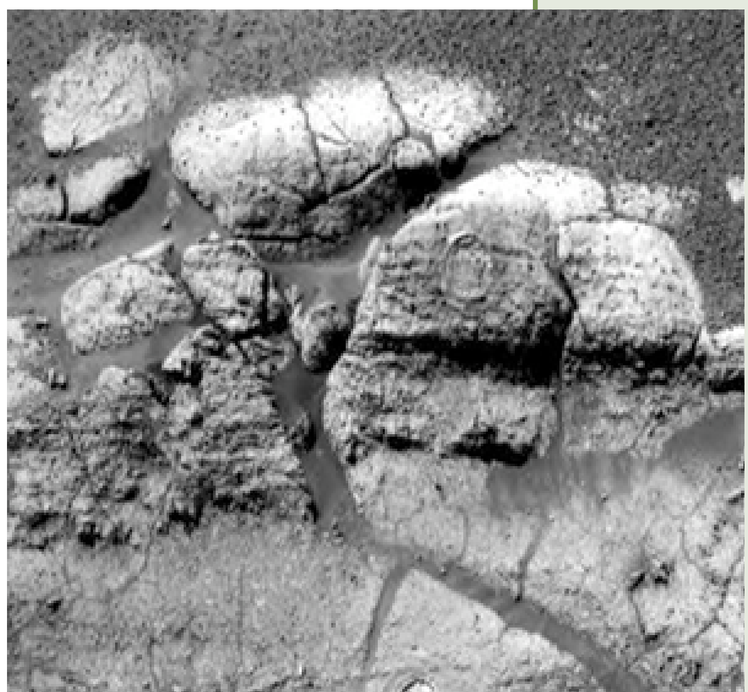
From Earth to Mars—and Beyond?

Yellowstone's hydrothermal features and their associated communities of thermophiles are studied by scientists who are searching for evidence of life on other planets. The connection is extreme environments. If life originated in the extreme conditions thought to have been widespread on ancient Earth, it may well have developed on other planets—or even 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 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 preclude photosynthesis. Chemical energy sources, along with extensive groundwater systems (such as on Mars) or below-crust oceans (such as on Jupiter's moons) could provide habitats for life.

The study of stromatolites on Earth may also be applied to the search for life on other planets. If stromatolites are eventually found in the rocks of Mars or on other planets, we would have unequivocal evidence that life once existed elsewhere in the universe.

Yellowstone National Park will continue to be an important site for studies at 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 lifeforms in ancient rocks and on distant planets.



Opportunity, the Mars Exploration Rover, took this image on March 1, 2004. Data indicate the layer rock is made up of types of sulfate that could have only been created by interaction between water and martian rock over extended amounts of time. Life on Earth is sustained by extended interaction between water and the environment. Evidence of a similar relationship between water and rock on Mars does not necessarily mean that life did develop on Mars, but it does bring the possibility one step closer to reality.

Photo and text adapted from www.nasa.gov, image by Nasa/JPL

For additional information about the scientific value of thermophiles, see Chapter 9, "Bioprospecting."

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For More Information

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Additional information available on numerous websites. Search topics include thermophiles, extreme life, and astrobiology.

Additional Information from Yellowstone National Park

Yellowstone National Park website, www.nps.gov/yell, includes an array of park information about resources, science, recreation, and issues.

Yellowstone Science, published quarterly, reports on research and includes articles on natural and cultural resources. Free; available from the Yellowstone Center for Resources, in the Yellowstone Research Library, or online at www.nps.gov/yell.

Yellowstone Today, published seasonally and distributed at entrance gates and visitor centers, includes features on park resources such as hydrothermal features.

Area trail guides detail geology of major areas of the park. Available for a modest donation at Canyon, Fountain Paint Pot, Mammoth, Norris, Old Faithful, and West Thumb areas.

Site Bulletins, published as needed, provide more detailed information on park topics. Free; available upon request from visitor centers.