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YELLOWSTONE DISCOVERY

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Microbes thrive in extreme conditions

Thermophiles provide unique opportunities for scientific research

By Craig Elliott
For the Yellowstone Association

With so many magnificent geologic features, photogenic large mammals, and other crowd-pleasers to see and study in Yellowstone, it's easy to overlook some of the less-obvious wonders.

But the next time you're on a boardwalk in a thermal basin, take a look down at the rusty-colored bacterial mats and streamers living in the hot-water runoff channels. These are teeming communities of microorganisms, and every day thousands of park visitors walk past them, unaware of the vast potential these unique life forms – called "thermophiles" – may hold.

These aren't just ordinary creatures; thermophiles are microscopic organisms that live at high temperatures. They all require hot water, and some may thrive in acidic conditions while others live in alkaline springs. Others utilize sulfur and arsenic. And they are living and thriving in environments – Yellowstone's hot springs – that are lethal to humans.

Some of these thermophiles are direct descendants of the earliest life forms on Earth. According to DNA analysis, the organism most closely related to the origin of life – Earth's most primitive species – lives in a hot spring in Yellowstone's Hayden Valley.

During the first 3 billion years of Earth's history, scientists believe microorganisms transformed the atmosphere, which had no oxygen, into one that could support complex forms of life. Microorganisms called "cyanobacteria" were the first to use photosynthesis to process carbon dioxide into oxygen and other byproducts. This oxygen production led to the creation of Earth's atmosphere. Other organisms tapped the energy stored in chemicals, such as iron and hydrogen sulfide, in a process known as "chemosynthesis."

Jonmikel Pardo photo

Thermophiles are common in Yellowstone's thermal areas, including Castle Geyser

Cyanobacteria continue to be present in some of the unique bacteria mats and streamers common to Yellowstone's thermal areas. Studies have shown that cyanobacteria and other microbes make up most of the species on Earth, but less than 1 percent of them have been studied in-depth.

Yellowstone's thermophiles can be broken down into three distinct groups: those that live in acidic environments, those that live in alkaline environments, and those that live in neutral, carbonate-rich areas. Thermophile communities can be seen throughout Yellowstone, but remember that samples can only be collected with a scientific permit. These microorganisms are protected by law, just like Yellowstone's large mammals, and removal of them is prohibited.

Acidic Habitat

The Norris Geyser Basin and the Mud Volcano area are good spots to

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- Debris removed from pool
- Encounters lead to bear deaths
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view Yellowstone's acidic thermophile habitat. In fact, thermophiles that live in these environments are considered "extremophiles" because they thrive in boiling water that is also highly acidic. They are also referred to as "thermoacidophiles."

Some of the hot springs in these two areas have a pH near 0, and the water will burn holes in shoes and clothing. Organisms that live in this environment are some of the toughest creatures on Earth. Viruses have also been found in some near-boiling acidic hot springs. The pH in acidic habitat can range up to 5, and these areas are usually underlain by rhyolite rock.

When you're looking for thermophile communities in acidic runoff areas, yellow streamers and mats will show the hottest areas. These areas are between 140 and 181 degrees Fahrenheit. When the temperature is between 131 and 140 degrees in these habitats, thermophiles form reddish-brown mats. The color comes in part from iron oxide, which the thermophiles metabolize from iron.

When the temperature in acidic springs is below 131 degrees, algae species form mats in runoff channels. At lower temperatures, green and purple algae are present.

Alkaline Habitat

Most of the hot springs in the Firehole Valley and West Thumb Geyser Basin are alkaline, so these are good spots to see alkaline habitat for thermophile communities.

When the water temperature is between 163 and 198 degrees Fahrenheit, thermophiles that live in alkaline habitat will form long streamers in quickly-flowing runoff channels. These streamers may be pink, yellow, orange, white, gray, or black, depending upon the minerals in the water and the species involved. Below 167 degrees, thermophiles will form mats in these alkaline areas.

Thermophile mats are vast communities of microorganisms; a 3-inch-square piece of thermophile mat has more microorganisms than the number of people on Earth. These mats also have many of the same characteristics of a forest community. For example, species in the "canopy," or top layers, need or are able to withstand abundant light. "Understory" species can survive with little light and may metabolize chemicals such as iron and hydrogen.

Interaction of the species in these mats can also create a laminated top, giving the mat a covering that appears solid.

Neutral, Carbonate-Rich Habitat

Mammoth Hot Springs is underlain by limestone deposits from ancient seas. When underground hot water circulates to the surface, it brings along calcium carbonate from the limestone, and sulfur from hot, fluid, underlying rock. This means the Mammoth Hot Springs are rich in sulfur and carbonate.

But at high temperatures, sulfur (in the form of hydrogen sulfide) is toxic to cyanobacteria. So these bacteria are found farther downstream at Mammoth, where the sulfur has been removed by other organisms. These downstream cyanobacteria contribute to the orange color in Mammoth's active terraces.

Cream-colored streamers of bacteria form when source pools at Mammoth Hot Springs are above 151 degrees. Sulfur and calcium carbonate materials deposited on the thermophiles provide the cream color. Below 151 degrees, the thermophiles at Mammoth will form green and purple mats.

Deposits of calcium carbonate also build up the terrace structures, and at the same time trap microbial communities within the newly forming rock matrix.

"Stromatolites" are sediments that have been laminated by microbial activity, and when found in ancient rocks can provide evidence of early microbial ecosystems. Stromatolites also form when Yellowstone's hydrothermal features trap thermophiles within travertine and sinter deposits. Mammoth Hot Springs is a good location for studying ongoing stromatolite activity because of its abundant communities of thermophiles and its quick rate of deposition.

These "biosignatures" of thermophilic communities are preserved in the fossil record and can help scientists recognize similar features in other locations, such as Australia's 350-million-year-old sinter deposits.

Ongoing studies and practical applications

Yellowstone's thermophiles provide valuable clues to early life on Earth, but they are also helping scientists look for signs of life elsewhere in the solar system. Such signs of life would probably appear as evidence of microorganisms, rather than more complex life forms. And such organisms would have to be able to survive in extreme conditions, much like Yellowstone's thermophiles. If stromatolites are ever found in the rocks studied on Mars or other planets, they would provide solid evidence that life once existed elsewhere in the solar system.

NASA is currently studying Yellowstone thermophiles as part of its search for signs of life on Mars. Because cyanobacteria display a biogeochemical signature that can be seen with satellite imagery, scientists are looking for the same signature in Mars' ancient volcanoes and suspected hot springs.

And the study of thermophiles doesn't stop there. Another growing topic, sure to confront Yellowstone's resource managers for the foreseeable future, is that of "bioprospecting." This activity is defined as searching for useful compounds in nature, and Yellowstone's thermophiles are believed to be a virtually untapped treasure trove.

A discovery in Yellowstone was essential to one of the most exciting developments of the twentieth century. In 1966, Dr. Thomas Brock discovered a way to grow one of the thermophiles, *Thermus aquaticus*, living in Mushroom Pool in the Lower Geyser Basin. An enzyme known as "Taq polymerase" was later discovered in *Thermus aquaticus*, and because it can withstand extreme temperatures, this enzyme proved essential in the artificial replication of DNA.

Since 1966, many other species of thermophiles have been identified in Yellowstone, and each produces thousands of uncommon, heat-stable proteins. These heat-stable proteins are becoming increasingly important to advancements in science, medicine, and industry. Thermophile research has already led to practical applications in producing ethanol, treating agricultural food waste, recovering oil, bleaching paper pulp, improving detergents, and a host of other discoveries. And researchers believe that more than 99 percent of Yellowstone's thermophiles are still unidentified.

Yet another topic related to thermophiles concerns the ethical, economic, and legal implications of thermophile research. National Park Service regulations prohibit the commercial use or sale of park specimens themselves, as well as any "harvesting" of microbes beyond the tiny samples needed for scientific analysis.

However, the information and insight gained from these studies can be patented and commercialized, and the benefits and profits can be enormous. For example, the DNA fingerprinting process, made possible by the Taq polymerase enzyme, has earned hundreds of millions of dollars for its patent holder. But Yellowstone received no compensation for that discovery.

When park-based research yields something of commercial value, federal law allows the Park Service to negotiate agreements that would return a reasonable share of the profits. Such agreements are becoming increasingly common in other countries, and in 1997 Yellowstone became the first U.S. national park to enter into such an agreement with a private corporation. However, the issue was taken to court by groups opposed to bioprospecting, and the agreement is on hold pending environmental impact analysis.

As scientists begin to unlock the secrets of thermophiles, Yellowstone will remain an invaluable resource; it is a preserve for one of the greatest concentrations of thermophilic diversity and unique genetic resources on Earth. So the next time you're walking through a thermal area, don't just look at the hot springs and geysers themselves; consider the incredible creatures living there, and the vast potential they represent.

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Much of the information in this article was taken from "Yellowstone Resources and Issues 2004," an annual Park Service publication available through the Association. The chapter from which this article was adapted was written by the NASA Astrobiology Outreach Education Team. Additional information was provided by the Thermal Biology Institute at Montana State University in Bozeman, Montana.

The Mission of the Yellowstone Association

The Yellowstone Association, in partnership with the National Park Service, fosters the public's understanding, appreciation and enjoyment of Yellowstone National Park and its surrounding ecosystem by funding and providing educational products and services.

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Jonmikel Pardo Photo

West Thumb Geyser Basin near Black Pool in 2002, with the Broad Fire in the background