Yellowstone

Yellowstone National Park
P.O. Box 168
Yellowstone, WY 82190

Steamboat Geyser—
Tallest Active Geyser in the World

Tucked away in the Norris Geyser Basin is Steamboat Geyser, the world's tallest active geyser—its major eruptions shoot water more than 300 feet (91 m).

Only Waimangu Geyser in New Zealand rocketed to greater heights—and it did so for only four years, ending in 1904. In Yellowstone National Park's recorded history, only two other geysers—Excelsior Geyser in Midway Geyser Basin and Sapphire Pool in Biscuit Basin—have exceeded Steamboat in massiveness. Excelsior was very active for about 10 years, ending in 1888, and had one major eruption in 1985. Sapphire Pool was active for several years after the Hebgen Lake Earthquake of August 1959.

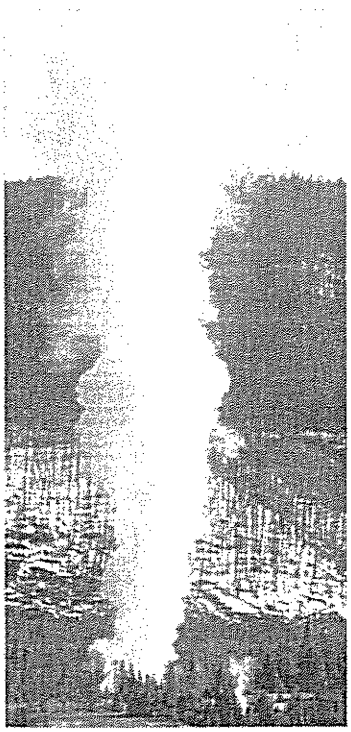
Steamboat's minor and major eruptions, described on the back of this page, are entirely unpredictable.

Steamboat's Major Eruptions

All known major eruptions are listed below. During Steamboat's early years, other major eruptions probably occurred but were not seen because most of each year passed with no observers in Norris Geyser Basin.

YEAR	NUMBER OF ERUPTIONS	INTERVALS
1878	At least 2	
1890	At least 1	12 years
1891	At least 1	Less than 1 year
1892	At least 1	Less than 1 year
1894	At least 1	2 years
1902	At least 1	8 years
1911	At least 1	9 years
1961	At least 1	50 years
1962	At least 7	8–360 days
1963	26	6–32 days
1964	29	5–45 days
1965	22	7–50 days
1966	At least 10	11–77 days
1967	At least 3	15–310 days
1968	At least 3	42–150 days
1969	2	45 days
1978	2	9 years & 148 days
1979	1	199 days
1982	23	4–43 days
1983	12	4–107 days
1984	5	19–93 days
1989	3	107 days to 4.3 years
1990	1	238 days
1991	1 (October 2)	
2000	1 (May 2)	8 years & 212 days
2002	2 (April 26, September 13)	1 year & 359 days, 140 days
2003	3 (March 26, April 27, Oct. 22)	194 days, 30 days, 178 days
2005	1 (May 23)	1 year & 172 days

This is a total of 166 recorded eruptions, with intervals ranging from 4 days to 50 years.



Steamboat Geyser, May 2000

Major Eruptions—Rare & Spectacular

The magnitude and destructive force of a major eruption of Steamboat Geyser are unforgettable. Water intermittently surges from two vents to varying heights. Suddenly water explodes from the larger north vent more than 300 feet (91 m) high. Curtains of water fall to the slope above the geyser and collect in torrents rushing back into the vent, carrying huge amounts of mud, sand, and rock that are shot skyward again and again. Water coats everything with a glistening layer of silica. Trees and cars in the parking lot are often covered with eruption debris. An eruption in February 21, 1982, blanketed the snow upslope from the geyser's vent with an estimated 700 cubic feet (20 cubic m) of debris. Mature lodgepole pines have been broken by the blast, stripped of their limbs by the weight of ice from the water and steam of winter activity, and undermined and then washed away by the geyser's massive discharge. Commonly, the boardwalk at the base of the hill has been covered by the geyser's outwash.

The water phase of a major eruption lasts from 3 to more than 40 minutes. Once the water supply is exhausted, the geyser continues with a powerful steam phase lasting from several hours to a day and a half. Its roar is so great that conversation near the geyser is difficult, and visitors in the Norris Campground, a mile to the north, have been awakened by the noise.

Not-so-minor Eruptions

Steamboat's minor eruptions—the most typical display—reach 6–40 ft (2–12 m) and last 1–4 minutes. Intervals may be as short as 2–5 minutes. The higher and longer minors often excite viewers because a major eruption seems imminent. Usually the geyser calms down again.

Inquire at the Norris Information Station about Steamboat's current activity—is it having a quiet year, emitting only steam, or is it having frequent, high minor eruptions?

Dormancy & Rejuvenation

On September 2, 1961, Steamboat had its first major eruption since 1911. No one knows what caused the long dormancy, but the rejuvenation might have been a delayed response to the Hebgen Lake Earthquake of August 1959.

The Hebgen Lake Earthquake, measuring 7.5 on the Richter Scale, had its epicenter a few miles outside the western boundary of Yellowstone National Park. It caused widespread and spectacular changes in the hydrothermal features along the Firehole River.

Two years later, Steamboat Geyser erupted for the first time in 50 years. Some scientists believe this rejuvenation was a direct result of the shifts in thermal energy caused by the 1959 earthquake; others say it was coincidental.

Steamboat remained active through the 1960s, then was dormant for nine years. In March 1978, swarms of tremors hit the Old Faithful area. Later that month, observers noted Steamboat's minor eruptions had increased volume and were reaching 90 feet (27 m). On March 28, Steamboat had a major eruption. Again, some scientists think it was a response to the earlier earthquake activity, some say it was coincidental.

In the last decade of the 20th century, Steamboat quieted again. Then, on May 2, 2000, a major eruption occurred. No major earthquake activity preceded this eruption nor eruptions in 2002 and 2003. Nevertheless, scientists continue to study Steamboat to find out if it is among the seismically-sensitive geysers.

The Cistern Spring Connection

Cistern Spring, at the base of the hill, exhibits changes related to its gigantic neighbor.

After 1959, Cistern Spring's temperature gradual rose, possibly receiving some of this heat from Steamboat. Cistern began increasing discharge in 1965 when Steamboat's frequency of major eruptions was beginning to decrease. This surge in heat and water was so great that all vegetation immediately south of Cistern was killed and a colorful silica terrace rapidly grew several feet high. This terrace continues to rise and expand.

Since that time, Cistern has also drained during and/or after a major Steamboat eruption.

Steamboat's Future

Steamboat Geyser's future is unpredictable. Fifty years with no major eruptions occurred in the past, and it is just as likely that 50 or more years will pass as quietly as before. The dynamic nature so characteristic of this geyser basin, and of the geology of Yellowstone as a whole, will determine the answer.

For more information

www.nps.gov/yell
volcanoes.usgs.gov/yvo/steamboat.html

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GEOLOGICAL HISTORY OF THE GRAND CANYON OF THE YELLOWSTONE

Visitors to the Grand Canyon of the Yellowstone River witness an inspiring display of depth, color, and ruggedness. Rangers are often asked three questions: Why is there a canyon? Why are the walls of the Canyon so colorful? Why are there waterfalls here? Answers lie in understanding the geological events responsible for this amazing landscape.

The Big Picture

The story begins about 16 million years ago, when hot material rising through Earth's mantle reached the surface. This so-called ***hotspot*** is responsible for many features seen in Yellowstone National Park, including the Canyon and its colorful rocks. The hotspot initially lifted the landscape and spewed volcanic material onto the surface near the juncture of Nevada, Idaho, and Oregon, about 300 miles southwest of Yellowstone. But Earth's outer shell is not fixed; it consists of plates that move a fraction of an inch to a few inches per year (the same rate your fingernails grow!). Moving southwestward about 1 inch per year, the ***North American Plate*** thus drifted 300 miles over the fixed hotspot in the last 16 million years. Like a candle burning through a moving sheet of waxed paper, a line of volcanoes formed across southern Idaho to Yellowstone. The Hawaiian Islands are a similar chain of volcanoes, formed as the Pacific Plate moves over another hotspot. Lying directly over a hotspot, the Yellowstone region is thus similar to the Big Island of Hawaii, with its high elevation and young volcanic rocks.

Three factors, each related to the hotspot, conspire to form the Grand Canyon of the Yellowstone.

A) Like a hot-air balloon rising, ***the hotspot elevates the Yellowstone Plateau***. At 8,000 feet elevation, this broad region is 2,000 to 3,000 feet higher than most of the surrounding land.
B) The hotspot melts some of the rock of Earth's crust, forming a ***magma chamber*** about 3 miles below the surface. Magma periodically flows out on the surface and hardens into lava flows.
C) Water from rain and snow seeps into the ground where it encounters hot rocks above the magma chamber. The hot water expands and rises, returning to the surface as the ***geysers, hot springs, mudpots,*** and ***steam vents*** seen in the park.

These factors help us answer the three questions posed above.

Why is there a Canyon?

Deep canyons form not just because a river cuts deeply into the ground, but also because the land moves slowly upward. The Grand Canyon in Arizona is a good example. There are two ways we can envision the Colorado River carving that canyon. Think of the land as a giant layer cake. You could take a sharp knife and carve downward through the soft layers. Another way is to hold the knife steady and lift the cake. That is what has been happening for the past 6 million years in northern Arizona – the Colorado Plateau has slowly moved upward, but the Colorado River erodes to stay at about 2,000 to 3,000 feet elevation. So, too, is this occurring with the Grand Canyon of the Yellowstone. The Yellowstone River wants to stay at low elevation, but the hotspot gradually uplifts the Yellowstone Plateau. So to keep up, the river continuously cuts downward, forming the Canyon.

Why are there such fantastic colors on the walls of the Canyon?

From the rim of the Grand Canyon of the Yellowstone, artist Thomas Moran first painted his wonderful images of Yellowstone in 1871. These paintings, and those of countless artists since, were inspired by the wonderful red, orange, and yellow colors along the Canyon walls. Most of the rocks in the Canyon area are ***rhyolite***, light-colored lava flows that contain some iron. There is a fair-sized thermal area in the Canyon area, much like the better known one around Old Faithful. Looking down into the Canyon you may see steam vents; near Clear Lake, a short hike south of the Canyon, there are active mudpots. When iron is subjected to hot water, it turns into iron-oxide, which is ***rust***. All those reds, yellows, and oranges on the Canyon walls are beautiful examples of rust and other iron compounds, formed as the rising thermal waters interacted with the rhyolite.

Why are there waterfalls here?

There are two prominent waterfalls in the upper part of the Grand Canyon of the Yellowstone. The ***Upper Falls*** are 109 feet high; the ***Lower Falls*** drop 308 feet (nearly twice the height of Niagara Falls). Like many prominent waterfalls, the falls of the Yellowstone River exist because ***rock layers change laterally from soft to hard***. Consider two potatoes, one raw and one that has been boiled for half an hour. The raw potato is hard; if you tried to stab it with a fork, it might bend the fork; but the boiled potato is so soft that the fork would easily break it apart. Remember that the brilliant colors of the Canyon are due to hydrothermal alteration. The hot water also weakened the rhyolite layers, much like boiling the potato softened it. The Yellowstone River thus had a relatively easy time cutting through the weak layers downstream from the falls. At the Lower Falls, however, the rock is dull gray, indicating that the rhyolite has not been altered by hot water. The Yellowstone River is therefore having trouble cutting through these harder rocks, and so remains high and must take the big plunge over the falls.

Deposition of Layers

About 600,000 years ago volcanic eruptions occurred in what is now the central part of Yellowstone National Park. So much material came out that it emptied a large part of the magma chamber that lies 3 to 4 miles beneath the Earth's surface. The roof of the Yellowstone Plateau collapsed into the void, forming a deep hole, the ***Yellowstone Caldera***. Later eruptions, from 600,000 to about 70,000 years ago, periodically coated the bottom of the caldera with a sequence of lava flows. Most of the rocks you see today in the Grand Canyon of the Yellowstone are rhyolite layers at the top of this sequence. During winters, 5 to 10 feet of snow accumulates over the higher parts of Yellowstone National Park. Virtually all of that snow melts by August. But imagine what would happen if Earth's average temperature were about 20° F colder - not all of the snow would melt during the summer. Snow would accumulate year after year, developing an ice-cap similar to those today over Antarctica, Greenland, and part of Iceland. It is estimated that ice sheets covering the Yellowstone Plateau during recent ice ages were about 3,000 feet thick, completely burying the top of peaks as high as Mt. Washburn (elevation 10,243 feet). Each time the Earth warmed up, remaining ice dammed the Yellowstone River in the Canyon area. Layers of sediment were deposited in glacial lakes that formed behind the ice dams. Lake sediments can be seen today on top of the Canyon lava flows - on the South Rim Trail between the Upper and Lower Falls; just east of Chittenden Bridge on the road to Artist Point; and on the north face at Red Rock Point.

Carving the Canyon

Did ice or water carve the Grand Canyon of the Yellowstone? When glacial ice carves a valley, it makes a characteristic "U-shape," like many of the broad valleys of Grand Teton, Glacier, and North Cascades national parks. But water carves a "V-shaped" valley, with sides sloping at the same angle from top to bottom. The "V-shape" of the Canyon thus shows that the Yellowstone River was the primary carving agent. However, ice did contribute in an indirect way. At times, ice damming the Canyon broke suddenly, releasing huge torrents of water that scoured the walls.

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Mammoth Hot Springs— Are They Drying Up?

Visitors who have seen Mammoth Hot Springs more than once often ask "Are the Mammoth Hot Springs drying up?" They have asked this question since the late 1890s, when visitors began making their second and third trips to Yellowstone. Today, returning visitors often ask the same question. They remember the active, colorful springs shown in their photos and postcards. They usually don't remember the expanses of bare sinter, which are as common here as in the geyser basins. So they often conclude that the springs are drying up—and they want to know why.

The simple answer is *No, they are not drying up.* These terraces change constantly—sometimes overnight—but the overall activity of the entire area and the volume of water discharge remain relatively constant.

The explanation is in terraces

The terraces are formed from the interaction of hot water, limestone (calcium carbonate), and heat. In the surrounding mountains, rain and snow percolate down through the ground. The water is heated by volcanic heat sources below the surface. As the hot water rises, it dissolves limestone rock beneath the Mammoth area. The limestone was deposited under a sea approximately 500–300 million years ago, during the Paleozoic Era.

When the mineral-rich water reaches the surface, it cools and its pressure decreases, gases are released, and the calcium carbonate is deposited as travertine. Travertine builds up rapidly here at Mammoth and causes the features to change quickly and constantly. Some vents will clog completely, new vents may form, and old vents may reopen. Sometimes the water is concentrated in a few springs while at other times it may spread across many outlets.

In every case, water follows the path of least resistance, which could be above ground or underground. Scientists estimate that, at any given time, about 10 percent of the water in the Mammoth Hot Springs system is on the surface; the other 90 percent is underground.

Life in the Water

Thermophiles (heat-loving microorganisms) thrive in the hydrothermal features here, as they do throughout the park. *Archaea* live in the hottest waters (above 165°F/74°C). Sulfur-oxidizing filamentous bacteria live in slightly cooler water. Below 131°F/55°C, cyanobacteria form dense mats containing millions of organisms. These living mats may change color according to changes in the water temperature, flow, and the amount of sunlight available both seasonally and daily. Scientists are studying Mammoth's thermophiles to find out if they affect the travertine deposition rate or the hot springs' activity.

Expect Change

The changes at Mammoth Hot Springs cannot be predicted, but you can be certain that change will occur between now and the next time you visit. If one of your favorite features at Mammoth is dormant today, look for a new feature or more rapid growth of an established one. Check your favorite spring on your next visit. It may very well be back!

At Mammoth Hot Springs, geology is happening before your eyes.

For More Information

www.nps.gov/yell
"Mammoth Area Trail Guide," updated annually, available at Mammoth area trailheads and visitor centers
Yellowstone Resources & Issues, revised annually
Life at High Temperatures, 1994 Thomas D. Brock
Yellowstone: Official National Park Handbook, 2001 David Rains Wallace

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OBSIDIAN CLIFF

Obsidian Cliff, 11 miles south of Mammoth Hot Springs, is at the northern end of Beaver Lake in Yellowstone National Park. The cliff forms the eastern wall of a narrow cut in plateau country. At an elevation of nearly 7,400 feet above sea level, the cliff extends for a half mile, rising from 150 to 200 feet above Obsidian Creek and falling gradually away to the north. The upper half is a vertical face of rock; the lower half is composed of loose and broken rocks forming a talus slope. The cliff is the remainder of a flow of lava that erupted onto the earth's surface and then poured down the plateau.

Obsidian forms when lava cools so quickly that crystals do not have time to form and grow. Because obsidian is usually found as small globes in other rocks, a massive outcrop the size of Obsidian Cliff is quite rare. Obsidian Cliff possibly formed when molten rock (magma) erupted onto the earth's surface and came into contact with the ice of a glacier. This quick cooling of large amounts of magma prevented the growth of crystals. Also, chemical analyses of the obsidian show that there was very little water in the lava. Without water, crystals could not form, thereby resulting in glassy rock. On close observation, one can see the swirling flow in the rock that shows the last movement of the liquid magma before it cooled and hardened.

Found on the southern face of the cliff are a series of columns which commonly occur in rocks of volcanic origin. Columnar jointing, as this formation is called, is another result of the rapid cooling of magma. The liquid rock shrinks inward, cracks, and contracts as it cools to form these four-to-six sided columns.

For centuries, Native Americans made their arrowheads and spear points from obsidian. The rock itself is dark and glassy in appearance (black in this case), and, when broken, fractures into rounded pieces with sharp edges. Arrowheads from as far away as the Midwest have had their origin traced back to Obsidian Cliff in Yellowstone. This indicates that the quality of obsidian found here was great enough for it to spread long distances in its use among various Indian tribes.

Up the Temperature Gradient

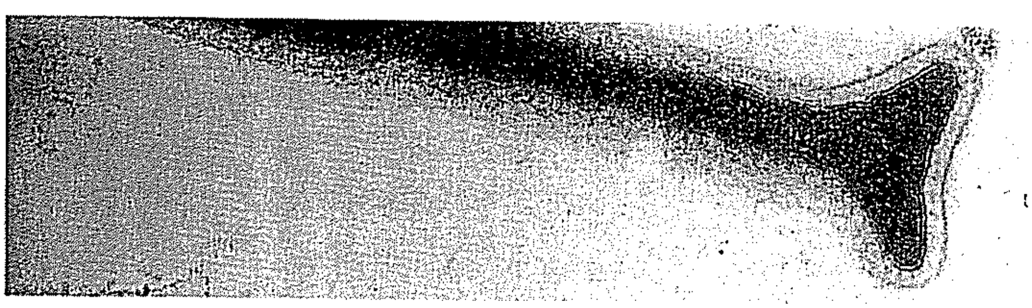
Temperature is one of the most important environmental factors and organisms differ strikingly in their ability to adapt to high temperatures. Biologists recognize three major categories of living organisms, called Eucarya, Archaea, and Bacteria. Higher organisms (plants and animals) are all Eucarya, so called because their cells have true nuclei and undergo cell division by mitosis. We call these organisms with true nuclei **eucaryotic**. Archaea and Bacteria are both much simpler organisms, seldom occurring as multicellular forms, and lacking true nuclei and mitosis. They are called **procaryotic**.

The table on the next page shows the upper temperature limits for growth of various types of living organisms. Note that the eucaryotes are unable to adapt to high temperatures, their upper limit being about 60–62°C (140–144°F). The upper temperature limit for plants and animals is even lower, less than 50°C (122°F). It is important to note that only a very few eucaryotes are able to adapt to these upper limits, the majority being restricted to much lower temperatures.

At temperatures above 60–62°C (140–144°F) the only organisms present are procaryotes. The photosynthetic bacteria have upper temperature limits lower than those of nonphotosynthetic bacteria. The upper limit of photosynthetic bacteria, defined by the "V" shown in the photo on page 8, is about 70–73°C (158–163°F). At higher temperatures, only nonphotosynthetic bacteria are able to grow. At the highest temperatures, over 100° C (212°F), the only bacteria found are a few unusually heat-adapted Archaea called *hyperthermophiles*.

Water boils in Yellowstone at about 92°C (198° F). These bacteria are thriving in boiling water!

Group	Upper temperature limits (°C)	Upper temperature limits (°F)
Animals		
Fish	38	100
Insects	45-50	113–122
Ostracods (crustaceans)	49-50	120–122
Plants		
Vascular plants	45	113
Mosses	50	122
Eucaryotic microorganisms		
Protozoa	56	133
Algae	55-60	131–140
Fungi	60-62	140–144
Procaryotes		
Bacteria		
Cyanobacteria (oxygen-producing photosynthetic bacteria)	70-73	158–163
Other photosynthetic bacteria (do not produce oxygen)	70-73	158–163
Heterotrophic bacteria (use organic nutrients)	90	194
Archaea		
Methane-producing bacteria	110	230
Sulfur-dependent bacteria	115	239



This bacterium, shown under the electron microscope, lives well in boiling water.

The Upper Temperature for Life

When microbiological researchers first began to study the Yellowstone hot springs in the 1960s, one of the biggest surprises was the discovery that procaryotes were thriving even in boiling water. These procaryotes were not obvious, such as those of the microbial mats, but rather lived attached to the rock-like walls of the springs or to pebbles, and sometimes their long intertwined filaments accumulated on the bottom of the channels (photo bottom of next page). Even if the source pool looks white and sterile, microscopic study usually reveals large numbers of procaryotes. Such procaryotes are found not only in Yellowstone, but in hot springs all over the world, even where springs are at lower altitudes and water therefore boils at higher temperatures. It is amazing that in addition to living in boiling water, these procaryotes are growing surprisingly rapidly; a population can double in as few as two hours.

The presence of procaryotes in boiling water (100°C) (212°F) makes us wonder if there is an upper temperature for life. Temperatures even hotter than 100°C occur in the thermal vents found at the bottoms of the oceans. Because of the high pressure in the ocean depths, temperatures of over 300°C (572°F) are found. Careful study has shown that at such high temperatures, no living organisms are present, but evidence exists of procaryotes living at temperatures as high as 115°C (239°F). In fact, cultures have been obtained that can be easily grown at this temperature in the laboratory.

It is an interesting fact that 115°C (239°F) is near the temperature at which hospital sterilizers are operated, yet here are procaryotes that actually *prefer* such temperatures!

Procaryotes can grow over the complete range of temperatures in which life is possible, but no one organism can grow over this whole range. The bacteria that cause disease, for which the hospital sterilizer is intended, are completely unable to grow at the high temperatures of hot springs. Likewise, the bacteria living in hot springs are unable to grow at the temperature of the human body.

Thermophiles and Evolution

How is it possible for living organisms to survive at such extremes of temperature? Actually, we are only surprised that life thrives in boiling water because of our anthropocentric orientation. It is true that humans and other animals are very heat-sensitive, but the biological world is much more diverse than we realize from our experience. Life, and especially procaryotic life, is able to adapt to environmental conditions that are deadly to humans.

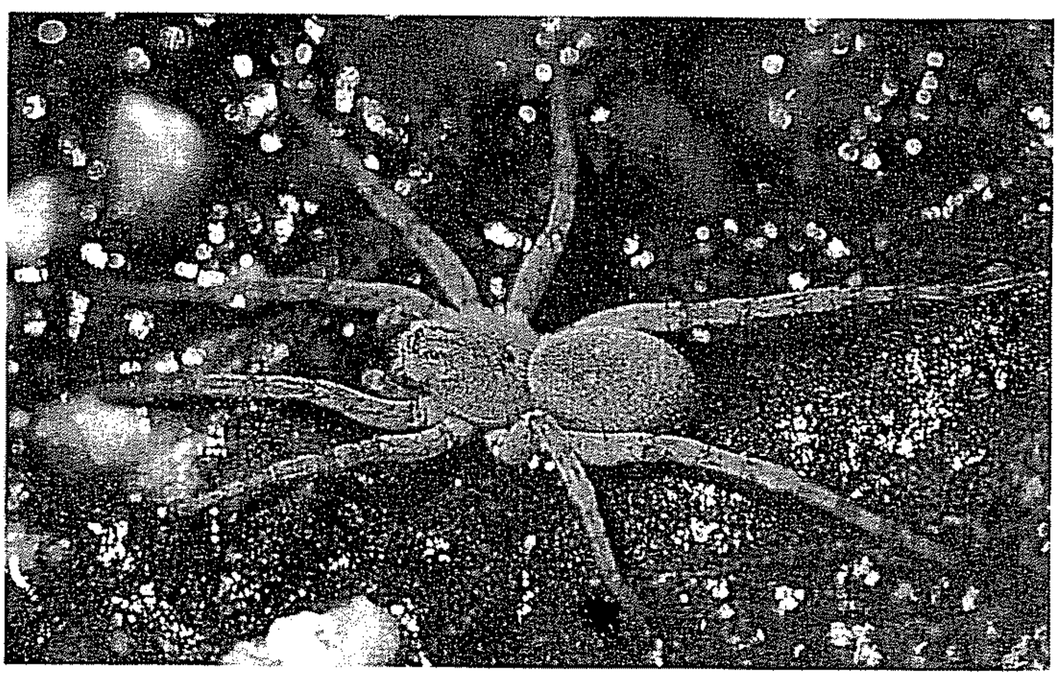
In fact, many scientists believe that life as we know it might first have arisen three billion or so years ago in high-temperature environments, and that the first organisms on earth might therefore have been thermophiles. Such thermophiles would then have continued to exist on earth in the intervening period, finding refuges in the hot springs that continue to dot the earth. In addition, these thermophiles would have been the forerunners of all other life forms, including, eventually, humans.

The Life Cycle of the Ephydrid Fly

The eggs usually hatch within a day and the larvae creep onto the surface of the microbial mat or burrow into it, devouring large amounts of the microbial cells. Within a week the larva is fully grown and it transforms into a pupa. Metamorphosis occurs and in a matter of days the adult fly emerges. The life cycle from adult to adult takes about two weeks. As many as 500 adult flies have been counted in an area of a square yard, and one spring had over 100,000 larvae per square yard!

The maximum temperature at which the adult flies can live is about 43°C (109°F). However, the adults can go partway underwater surrounded by a bubble of air which acts as insulation, so that they can feed in hotter water.

The ephydrid flies are strict vegetarians, but other animals associated with hot springs are carnivores and eat the ephydrids. One common carnivore is the spider. These animals live at the edges of springs, making mad dashes out onto the mat to catch adult ephydrids. As long as the spider keeps moving, it can traverse hotter water than it can otherwise stand.



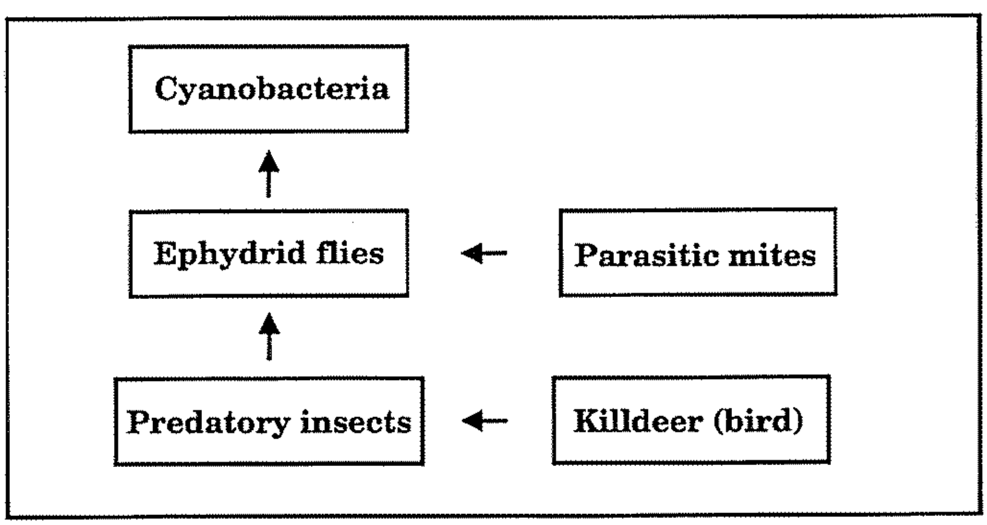
The Hot Spring Food Chain

We have seen that hot springs support a diversity of life, and at the lower temperatures in the run-off channels rather complex feeding relationships have developed. Photosynthetic bacteria, primarily cyanobacteria, are at the beginning of the food chain, capturing light energy and converting it into organic matter.

Ephydrid flies, both larvae and adults, feed on the cyanobacteria. These flies are themselves fed on by other insects, including dolichopodid flies (a vicious predator of the ephydrids), spiders, dragonflies, beetles, and wasps. In addition, the ephydrids are parasitized by red mites, which attach themselves to the bodies of the adult flies, or feed on the pink egg masses. There is also a wasp which parasitizes the pupae of the ephydrids!

These various parasites and predators are themselves fed upon by larger carnivores, of which the most important are killdeers, birds that are often seen stalking their dinners on the geyser basins.

This whole array of organisms constitutes the hot spring food chain, a surprisingly complex, albeit specialized, ecosystem.



Life and Death at Low pH

The numerous acid hot springs of Yellowstone eventually flow into the surrounding rivers and lakes, adding striking amounts of acid to these waters. Even when cool, these acid waters are not felicitous habitats for most plants and animals. Acid rain from burning fossil fuels has caused the acidification of many lakes in the eastern U.S. and acidic lakes and rivers of Yellowstone provide a natural laboratory to study adaptation to acid.

Group	Lower pH limit	Examples
Animals		
Fish	4	Carp
Insects	2	Ephydrid flies
Plants		
Mosses	3	*Sphagnum*
Vascular plants	2.5-3	Heather, Sedges
Eucaryotic microbes		
Algae	1-2	*Euglena mutabilis*
	0	*Cyanidium caldarium*
Fungi	1-2	*Dactylaria gallopava*
Procaryotes	0.8	*Thiobacillus*
		Sulfolobus
Cyanobacteria	4	*Synechococcus*

We can see from the above table that fish do not live in very acid waters; sport fish, such as trout, are even more sensitive to low pH, disappearing when the pH drops below 6. Interestingly, when fish are wiped out by low pH, invertebrate animals often increase greatly in numbers, because they are less sensitive to acidification and no longer have any predators feeding on them.

An alga of acid waters called *Zygogonium* often forms large mats which spread out over the moist acidic basins. This alga provides the base of a food chain in which a few other algae and certain specialized animals thrive. One ephydrid fly, *Ephydra thermophila*, feeds on the acidophilic algae. Interestingly, this fly of very acid environments can also survive on algae from neutral/alkaline springs, but is not found there apparently because it cannot compete with the pink-egg laying *Ephydra bruesi* we discussed earlier. Another smaller ephydrid, *Scatella paludum*, also carries out its life cycle in acid springs. The ephydrid flies of the acid areas are preyed upon by other insects, such as wasps, mites, and tiger beetles. Birds such as killdeer are often seen on the acid alga mats, picking up a dinner of these acidophilic insects. Surprisingly, the birds do not seem to mind the acidic conditions, although they of course can move to less acid waters also. Certain acid lakes in Yellowstone, for instance Nymph Lake, Turbid Lake, and Clear Lake, have quite large populations of Canada geese.

An interesting pair of lakes is North and South Twin Lakes, along the Mammoth/Norris road. North Twin Lake receives most of its water from the very acid run-off from Roaring Mountain, and has a pH of 3.5, whereas South Twin Lake receives its water from nonacid creeks and has a pH of 6. Thus, even though these two lakes are almost touching, they differ strikingly in pH (and also in biological diversity). Obsidian Creek, near Roaring Mountain, also becomes quite acidic during the summer, and this change in pH is reflected in the algae that develop in its waters.

The table also shows that cyanobacteria are rather intolerant of low pH. Thus, although cyanobacteria form the major components of the orange mats we discussed earlier, they are replaced in acid waters by the eucaryotic thermal alga, *Cyanidium caldarium*, which is dark green.