

An Overview of Yellowstone Geologic History

Introduction

Yellowstone National Park—the nation's first national park, established in 1872—occupies 2.2 million acres in northwestern Wyoming and southwestern Montana. Located along the continental divide within the Middle Rocky Mountains, Yellowstone is on a high plateau averaging 8,000 feet in elevation. The mountain ranges that encircle Yellowstone vary from 10,000 ft to nearly 14,000 ft, and include the Madison Range to the west; the Gallatin and Beartooth Mountains to the north; the Absaroka Mountains on the eastern border; and the Teton Range, within **Grand Teton National Park**, at the southern end. Yellowstone National Park contains the headwaters of two well known rivers, the Yellowstone River and the Snake River.

The Ecosystem

Yellowstone forms the core of the **Greater Yellowstone Ecosystem (GYE)** which comprises approximately 18 million acres of land encompassing portions of Wyoming, Montana, and Idaho. The GYE includes three national wildlife refuges, five national forests, and two national parks. **This area is the last intact contiguous temperate ecosystem in the world!** Elevation, river systems, mountain topography, wildlife ranges, characteristic flora and fauna, and human-use patterns are unique inside the GYE when compared to the surrounding lands. The GYE still contains nearly all of the living organisms found in pre-Columbian times, though not in the same numbers.

Because of the tremendous biodiversity protected within Yellowstone, the Park was declared an International Biosphere Reserve in 1976 and a World Heritage Site in 1978. While wolves and grizzly bears are spectacular examples of the importance of protecting park resources, it is Yellowstone's thermal features that led to its initial protection.

Biodiversity—from moose to microbes—has been shaped and formed by the Park's underlying geology. Processes of mountain uplift, glaciation, and physical weathering have shaped the



Map of the Greater Yellowstone Ecosystem.

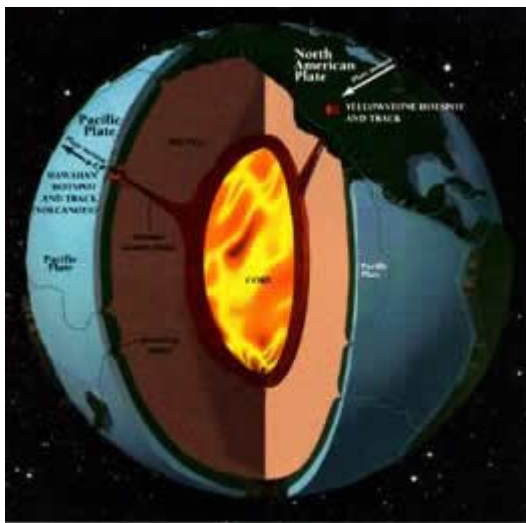
(Lighter colored borders indicate the approximate ecosystem boundary)

landscape, and have influenced both mountain and forest geography. In recent geologic time, violent volcanic activity has most prevalently shaped Yellowstone's topography.

The unique ecosystem, biodiversity and geologic features are intimately related to the geologic history of Yellowstone National Park. Glaciation, tectonic activity and, most importantly, volcanic eruptions, have shaped and influence the landscape and life within the park for millions of years.

What is the source of the heat that derives the Yellowstone thermal and volcanic activity?

Geologists theorize that a [hotspot](#) in the upper mantle of the earth's crust is responsible. Similar hot spot activity resulted in the formation of the Hawaiian Island Chain.



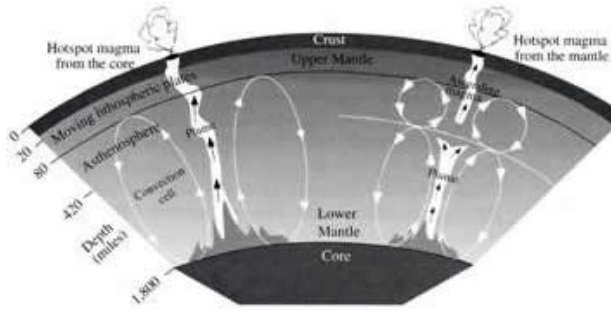
Interpreting the Landscape: Recent and Ongoing Geology of Grand Teton and Yellowstone National Parks by John M. Good and Ken L. Pierce, 1996, Grand Teton Natural History Association

Hotspots

On the left (*top*), the pie shaped slice through the Earth shows an interpretation of the Yellowstone and Hawaii plumes and hotspots. The plates of plate tectonics consist of the crust bound to the solid uppermost mantle. (Plates shown here at 5 times their actual thickness.) The plates glide upon the next lower, more squishy part of the mantle called the asthenosphere which is hotter and more plastic. Mantle plumes are shown originating at the core-mantle boundary and rising to the base of the plates. At spreading centers, new crust from more fluid, mantle (asthenosphere), is created.



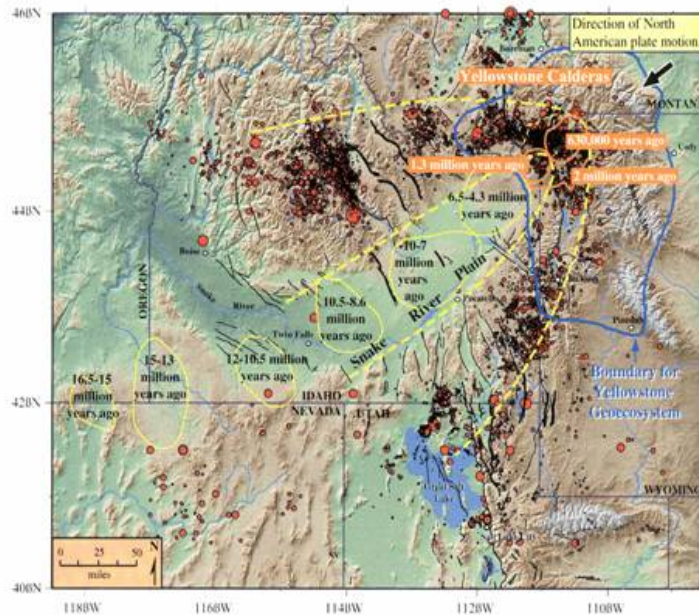
At plate boundaries (diagram left), slabs of cold lithosphere are subducted and sink deep into the mantle. Black dots represent hotspots. Arrows show the apparent movement of the hotspots as plates drift over them. Most hotspots are beneath oceans; however the Yellowstone hotspot is under a continent.



Windows into the Earth: the geologic story of Yellowstone and Grand Teton National Parks by Robert B. Smith and Lee J. Siegel, 2000 Oxford University Press.

The diagram (left) depicts molten rock, or magma, rising in convection cells like water boiling in a pot. The left side shows traditional view of hot spots as a plume of magma rising from the Earth's core. The right side shows the new theory that Yellowstone hotspot originated at a much shallower depth.

At present the North American tectonic plate is moving about 1.8 inches centimeters per year in a southwesterly direction. The slow steady progression of the plate across the magma plume has left its mark on the landscape; as evidenced by the flat-lying basalt volcanic flows across the Snake River Plain of southern Idaho. The plume works much like a blowtorch underneath a sheet of metal, causing melting and bubbling of the metal at the surface. Volcanic activity between the Idaho cities of Twin Falls and Idaho Falls has occurred for millions of years. [Craters of the Moon National Monument](#) is a recent example of this pattern, with Yellowstone National Park acting as the current location of activity.



Path of the Yellowstone hotspot . Yellow and orange show volcanic centers where the hotspot produced one or more caldera eruptions—essentially “ancient Yellowstone” —during the time periods indicated. As North America drifted southwest over the hotspot, the volcanism progressed northeast, Nevada and southwest Oregon 16.5 million years ago and reaching Yellowstone National Park 2 million years ago. A bow -wave or parabola-shaped zone of mountains (browns and tans) and earthquakes (red dots) surrounds the low elevations (greens) of the seismically Snake River Plain. The greater Yellowstone “geocosystem” is outlined in blue. Faults are black lines. Reproduced with author permission from *Windows into the Earth: the geologic story of Yellowstone and Grand Teton National Parks* by Robert B. Smith and Lee J. Siegel, 2000 Oxford University Press.

Yellowstone Volcanic History

Volcanic activity in Yellowstone is, in part, a fairly recent phenomenon, geologically. Over the last 2 million years, three gigantic caldera eruptions have left their mark on the landscape and have influenced the Yellowstone ecosystem.

Calderas are large basin-shaped volcanic depressions that are the remnants of explosive volcanic activity.

Stratigraphic units of the Yellowstone Plateau volcanic field

Volcanic Cycle	Precaldera Rhyolite	Caldera-forming ash-flow tuff	Postcaldera rhyolite	Contemporaneous plateau-marginal basalts
Third				Basalts of Snake River Group Osprey Basalt
			Plateau Rhyolite	Madison River Basalt Basalt of Geode Creek Swan Lake Flat Basalt Basalt of Mariposa Lake
		Lava Creek Tuff (0.64 Ma)		
Second	Mount Jackson Rhyolite Lewis Canyon Rhyolite		Undine Falls Basalt Basalt of Warm River Basalt of Shotgun Valley	
			Island Park Rhyolite	Basalt of the Narrows
		Mesa Falls Tuff (1.3 Ma)		
First	Big Bend Ridge Rhyolite			
				Big Bend Ridge Rhyolite
		Huckleberry Ridge Tuff (2.2-2.1 Ma)		
	Rhyolite of Snake River Butte			Junction Butte Basalt

Table Courtesy of USGS; [Volcanic History of Yellowstone Plateau Volcanic Field](#)

Yellowstone's Volcanic Past

The first and largest caldera, which blew up about 2.1 million years ago, was centered in western Yellowstone National Park but extended into Island Park, Idaho (See figure B, next page). The volume of rock produced by this eruption, known as the Huckleberry Ridge, produced approximately 600 cubic miles of rock and ash. In comparison to more recent volcanic activity, this is about 17 times the rock produced during the eruption of Mount Tambora in Indonesia, witnessed in April, 1815 (See figure A., next page). As a result of the tremendous amount of ash projected into the stratosphere during this eruption, mean temperatures dropped from 0.5° to more than 1° F. Farmers in the United States and Europe referred to this year as the “year without a summer.”

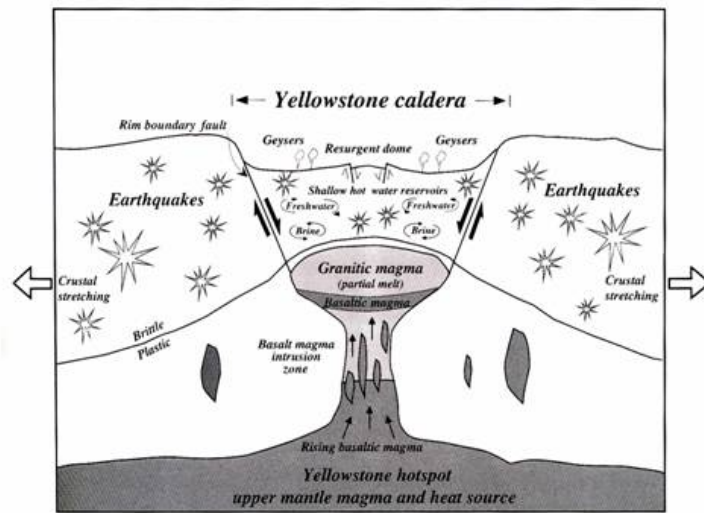
Mount Saint Helens, which erupted in 1980, produced ¼ of a cubic mile of rock, making the Huckleberry Ridge eruption 2,400 times larger!

The second eruption occurred 1.3 million years ago, forming the Island Park Caldera. The smallest of the three eruptions, this caldera overlays the western part of the Huckleberry Ridge eruption (See figure C).

The most recent eruption, Lava Creek, erupted just 630,000 years ago. It also overlays the Huckleberry Ridge, and expands eastward of the original caldera boundary approximately 10 miles. Because of its relatively young age, the Lava Creek lava flows can be readily viewed and studied. Yellowstone Lake, the world's largest alpine lake, occupies a portion of the caldera, Yellowstone II, created during the Lava Creek eruption.

Smaller lava flows dating from 150,000 years ago, 110,000 years ago, and 70,000 years ago have filled in the floor of the Yellowstone II caldera. These smaller flows—composed mostly of rhyolite—have created the topography responsible for Yellowstone's lakes, waterfalls, and stream courses, and have produced the gently rolling terrain characteristic of central Yellowstone.

Tuff is a rock formed as a result of volcanic eruptions and is composed of compacted volcanic fragments; essentially, volcanic ash deposits that have been turned to stone.

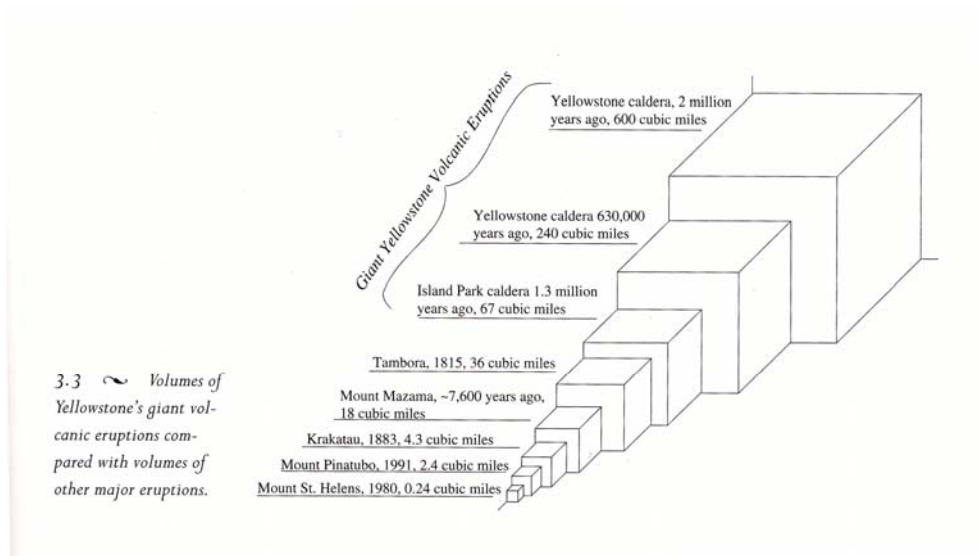


3.7 Volcanism, earthquakes, and geysers interact in the Yellowstone caldera. Heat and magma originate from the Yellowstone hotspot. Magma ascends into the overlying crust, melting surrounding rocks and lifting the ground surface. The molten rock explodes to the surface during eruptions. Then the ground collapses along faults to form a caldera. Pressures in the ground trigger earthquakes in cooler, brittle rock. The magma also heats groundwater from rain and snow to produce geysers and hot springs. (Adapted from Dzurisin, 1990.)

The heat from molten rock under the caldera as little as 3 miles beneath the surface powers Yellowstone's geysers and hot springs.

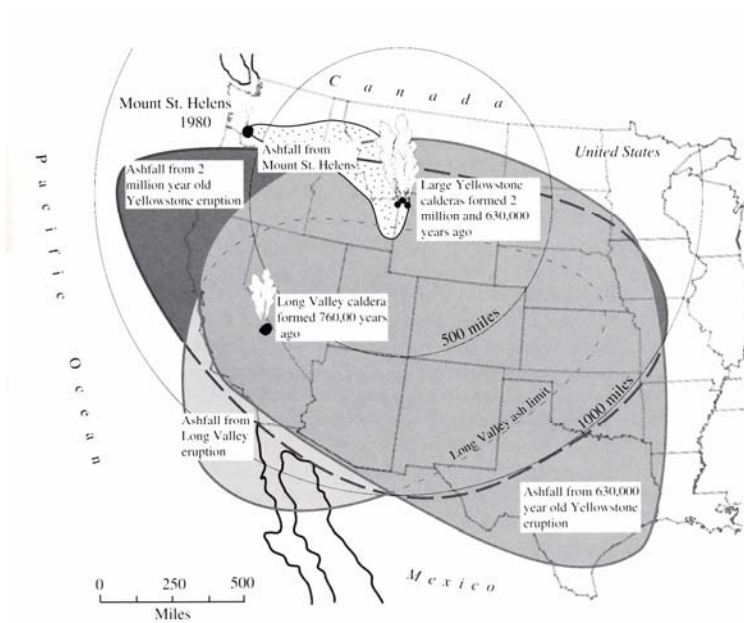
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A.



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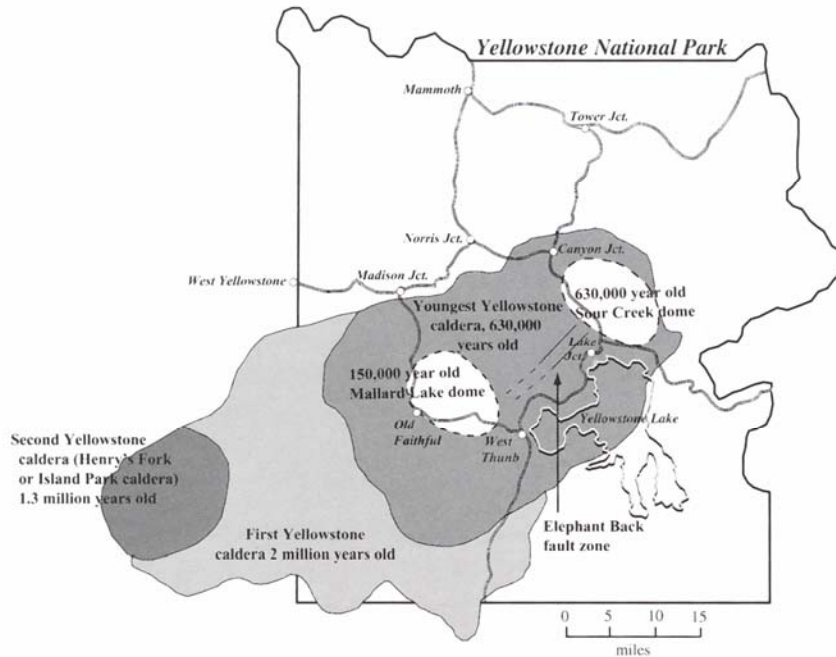
B.



Areas of the United States that once were covered by volcanic ash from Yellowstone's giant eruptions 2 million and 630,000 years ago, compared with the ashfall from 760,000 year-old Long Valley caldera at Mammoth Lakes, California, and the 1980 eruption of Mount St. Helens, Washington. (Adapted from Sarna-Wojcicki, 1991)

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C.



3.1 Yellowstone's main volcanic features include 2-million-, 1.3-million-, and 630,000-year-old calderas as well as the Mallard Lake and Sour Creek resurgent domes, which may be connected by the Elephant Back fault zone.

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Current Eruption Activity at Yellowstone Caldera

Yellowstone contains over 10,000 [thermal features](#), and between 300 and 500 active [geysers](#). Conservatively more than 55% of the world's geysers reside in Yellowstone National Park. The park's thermal features lie in the only essentially-undisturbed geyser basin in the world. Unlike Iceland or New Zealand, few park thermal features have been diverted for human use. Globally, the second largest geyser field is Dolina Geizerov on Russia's Kamchatka Peninsula containing 200 geysers. New Zealand has approximately 40 active geysers, Chile has 38, and Iceland contains around 25.

Yellowstone's thermal features are evidence of a continued heat source not far from the earth's surface; recent volcanism is the furnace that provides the heat for Yellowstone's geyser and hot spring activity. Hot springs, geysers, fumaroles, and mudpots are found in regions of young volcanic activity. Surface water deposited as snow on the Yellowstone Plateau percolates through the cracks and fissures in the earth's surface created by the uplift and explosion of calderas. This cold water comes into contact with the shallow magma chambers beneath the surface, allowing water temperature to quickly super-heat beyond the boiling point. Because of the great pressure exerted from water and rock above, water cannot escape as steam and remains in a liquid state, often at temperatures exceeding 400° F!

The superheated water is less dense than the colder water sinking around it, and convection currents develop. The more buoyant water is carried toward the surface of the thermal feature, following the cracks and fissures in the earth's crust. The hot fluids interact with the surrounding rock as they move through the underground plumbing system.

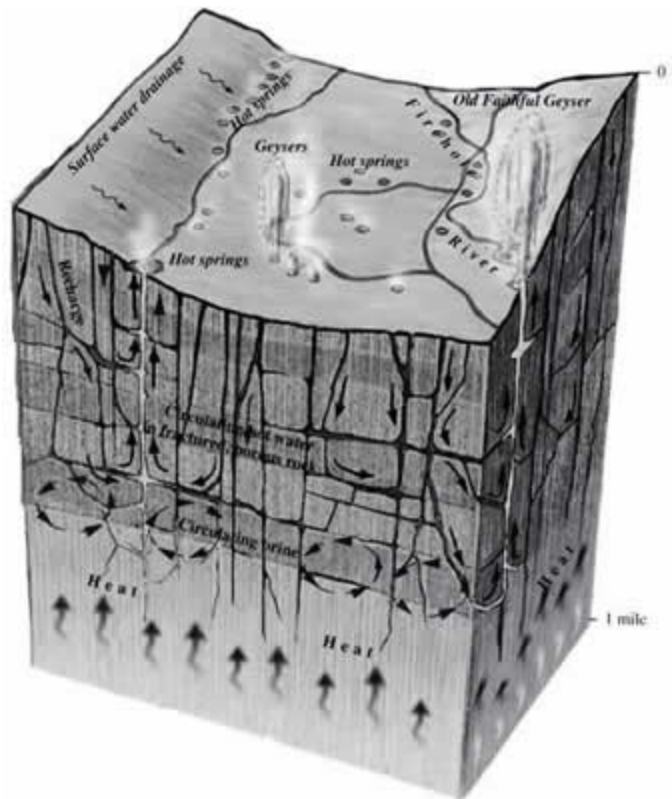


Diagram (ABOVE): Yellowstone geyser system. Heat from cooling magma rises to heat water circulating in the porous rock layer. Heat is transferred to groundwater, recharged by rainfall and snowmelt. Shallow hot water can be trapped and pressurized in small underground reservoirs, released through narrow constrictions, creating geysers. Reproduced with author permission Windows into the Earth. Robert B. Smith and Lee J. Seigel. Oxford University Press. 2000.

Much of the composition of the earth's crust beneath Yellowstone consists of [rhyolite](#) and [basalt](#). Rhyolite is an important component of many of the geysers we see because it contains an abundance of the element silica (Si) or quartz (SiO_2)—the mineral used to make glass. As hot water travels through cracks and fissures in the rhyolite, some of the silica is dissolved in the water and is deposited at the surface in geysers and thermal pools as a rock called *siliceous sinter* or *geyserite*. Siliceous sinter also forms a water-tight and pressure-tight lining as a coating in the plumbing systems of Yellowstone thermal features. The pressure tight seal, readily available water, and a heat source from the shallow magma chamber are all prerequisites for Yellowstone thermal activity.



If the movement of the water through the plumbing system is slow enough that pressure is released gradually as water reaches the surface, a hot spring develops. If there is a constriction along the plumbing system, a [geyser](#) is the more likely outcome. Expanding steam bubbles build up behind the constrictions, squeeze through the narrow areas heating the water above, and force the water to overflow at the surface. The release of water at the surface causes a sudden decline in pressure of the super-heated water below

lowering the boiling temperature of the water and allowing steam to form. Water expands rapidly as steam—to over 1,500 times its original liquid volume—exploding as the geyser erupts. The eruption continues until water is depleted or the temperature drops below boiling. Once the eruption has ended, the entire process of filling, heating, and boiling, begins again.



Old Faithful Geyser erupting, Upper Geyser Basin, Yellowstone National Park.



Yellowstone's Thermal Features

In addition to geysers, Yellowstone is home to many interesting and unique thermal features.

Fumaroles, also called *sofataras* are another type of thermal feature. Fumaroles are hot, and water supply is limited, so most water evaporates before reaching the surface. Steam and gas are released from these features, and hissing is often audible (*Top, right*)



Mudpots occur where hot water is limited and pH of the thermal waters is acidic. Acid waters dissolve the surrounding rock into silica and clay. Not enough water is present to carry away the dissolved rock and it mixes with the water creating this thick muddy bubbling feature.

Mudpots features like these (*middle and bottom*) are found in Lower Geyser Basin and at the Mud Volcano area.



Other Thermal Features:

While most of Yellowstone is underlain by silica-rich rhyolite, the northwest corner of Yellowstone where Mammoth Hot Springs is located has a different underlying geology. Approximately 340 million years ago, sediments rich in calcium carbonate (CaCO_3) were deposited in the vicinity of Yellowstone. Geologists estimate that the waters of Mammoth Hot Springs carry more than 2 tons of dissolved CaCO_3 to the surface at a flow rate of 500 gallons per minute.

Water and CO_2 combine to form a weak carbonic acid. Carbonic acid dissolves the CaCO_3 -rich limestone into solution, precipitating travertine limestone at the surface as temperatures decrease. Travertine deposition is rapid—about 8 inches a year are deposited at Mammoth.

It is thought that thermal waters reach this area of the park in part from a fault that runs from Norris to Mammoth, and from surface waters that follow cracks and fissures and are heated from below. Geysers do not occur at Mammoth for two reasons: travertine is not pressure resistant and could not withstand the force of an eruption; and water temperatures don't reach the boiling point ($\sim 93^\circ\text{C}$ in Yellowstone). Thermal waters at Mammoth can reach up to 75°C ; bubbling that you see is due to gas release, not boiling temperatures.

Mammoth Hot Springs Terraces



Travertine Limestone deposited in Terrace Formations, Mammoth Hot Springs, YNP