United States Department of the Interior

NATIONAL PARK SERVICE
PO Box 168
Yellowstone National Park
Wyoming 82190

IN REPLY REFER TO:

YELL 282a
7/06

Dear Student of Geology:

Enclosed is the information you requested on the geology of Yellowstone National Park. We hope you find the information useful in learning about the dynamic and fascinating geology of Yellowstone, the world's first national park.

Please visit our official Website at www.nps.gov/yell for further information and current conditions at the park.

Division of Interpretation
Yellowstone National Park

Geology

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Yellowstone National Park's unique physical landscape has been and is being created by many geological forces. Here, some of the Earth's most active volcanic, hydrothermal (water + heat), and earthquake systems make this national park a priceless treasure. In fact, Yellowstone was established as the world's first national park primarily because of its extraordinary geysers, hot springs, mudpots and steam vents, and other geologic wonders such as the Grand Canyon of the Yellowstone River.

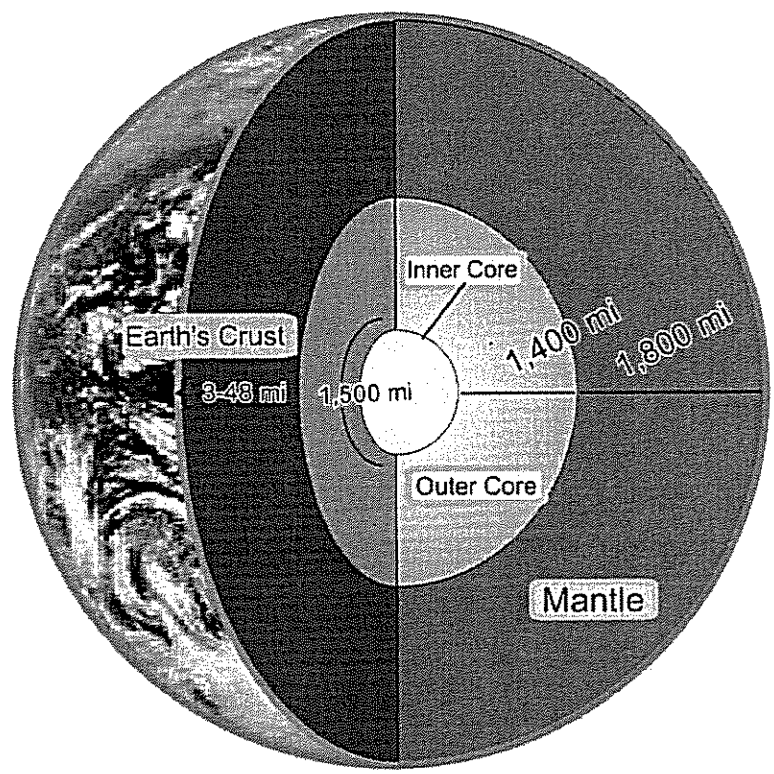
YELLOWSTONE'S GEOLOGIC SIGNIFICANCE

- One of the most geologically dynamic areas on Earth due to shallow source of magma and resulting volcanic activity.
- One of the largest volcanic eruptions known to have occurred in the world, creating one of the largest known calderas.
- More than 10,000 hydrothermal features, including more than 300 geysers.
- The largest concentration of active geysers in the world—approximately half of the world's total.
- Most of the undisturbed geyser basins left in the world (Kamchatka Peninsula has the others; the rest have been modified or destroyed by human development.)
- One of the few places in the world where active travertine terraces are found, at Mammoth Hot Springs.
- Site of many petrified trees resulting from repeated volcanic eruptions over the ages.

What Lies Beneath

Yellowstone's geologic story provides examples of how geologic processes work on a planetary scale. The foundation to understanding this story begins with the structure of the Earth and how this structure gives rise to forces that shape the planet's surface.

The Earth is frequently depicted as a ball with a central core surrounded by concentric layers that culminate in the crust or surface layer *(see at right).* The distance from the Earth's surface to its center or core is approximately 4,000 miles. The core may once have been entirely molten, but, as the planet cooled, the inner core (about 1,500 miles thick) solidified. The outer core (about 1,400 miles thick) remains molten and is surrounded by a 1,800 mile thick mantle of dense, mostly solid rock. Above this layer is the relatively thin crust, three to forty-eight miles thick, on which the continents and ocean floors are found.



The Earth's lithosphere (crust and upper mantle) is divided into many plates, which are in constant motion. Where plate edges meet, one plate may slide past another, one plate may be driven beneath another (subduction), or upwelling volcanic material pushes the plates apart at mid-ocean ridges. Continental plates are made of less dense rocks (granites) than oceanic plates (basalts) and thus, "ride" higher than oceanic plates. Many theories have been proposed to explain crustal plate movement. Currently, most evidence supports the theory that convection currents in the partially molten asthenosphere (the zone of mantle beneath the lithosphere) move the rigid crustal plates above. The volcanism that has so greatly shaped today's Yellowstone is a product of plate movement combined with upwellings of molten rock, as described on the next pages.

3 Ancient Yellowstone

Illustrations on pages 38, 39, 40, and 46 adapted with permission from Windows Into the Earth, *Dr. Robert Smith and Lee J. Siegel, 2000.*

See Chapter 10 for more information about geology in the park's major areas.

This chapter focuses on events and processes of the last 20 million years that have created the park we see today— a tiny fraction of the 4.6 billion years of the planet's existence.

Most of Earth's history (from the beginning to approximately 570 million years ago) is known as the Precambrian era. Rocks of this age are found in northern Yellowstone and in the hearts of the Teton, Beartooth, Wind River, and Gros Ventre ranges. Throughout much of this era, the West was repeatedly flooded by ancient seas. During the Paleozoic and Mesozoic eras (570 to 66 million years ago), this area was covered at times by ocean. At other times it was a land of sand dunes, tidal flats, and vast plains. Near the end of this era, mountain building processes created the Rocky Mountains.

During the Cenozoic era (approximately the last 66 million years of Earth's history), widespread mountain-building, volcanism, faulting, and glaciation sculpted the Yellowstone area. The Absaroka Range along the park's north and east sides was formed by numerous volcanic eruptions about 50 million years ago. Volcanic debris buried trees that are seen today as fossilized remnants along Specimen Ridge in northern Yellowstone. This period of volcanism is not related to the present Yellowstone volcano.

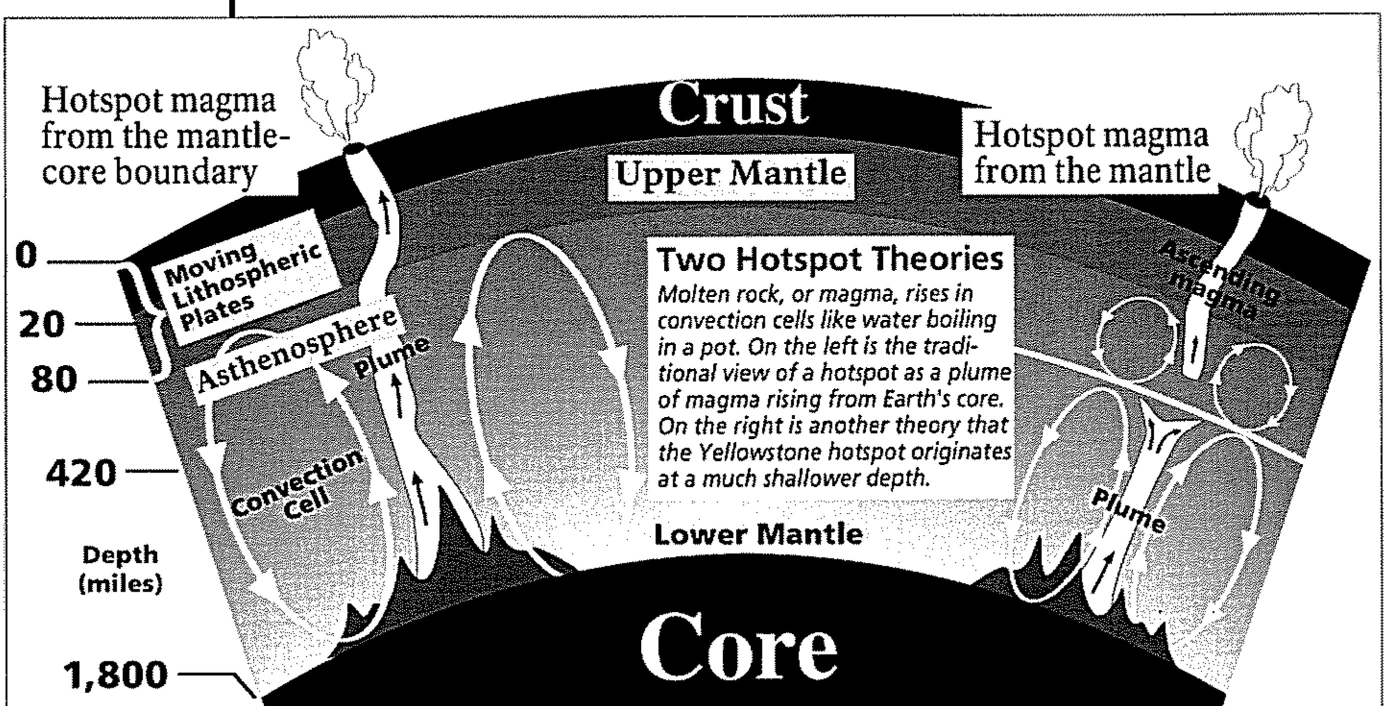
Approximately 30 million years ago, vast expanses of the West began stretching apart along an east-west axis. This stretching process increased about 17 million years ago and continues today, creating the modern basin and range topography (north-south mountain ranges interspersed with long north-south valleys) characterizing much of the Western landscape.

About 16.5 million years ago, a great period of volcanism appeared near the area now marked by the convergence of the Nevada, Oregon, and Idaho state lines. Repeated volcanic eruptions can be traced across southern Idaho into Yellowstone National Park. This volcanism remains a driving force in Yellowstone today.

Magma & Hotspots

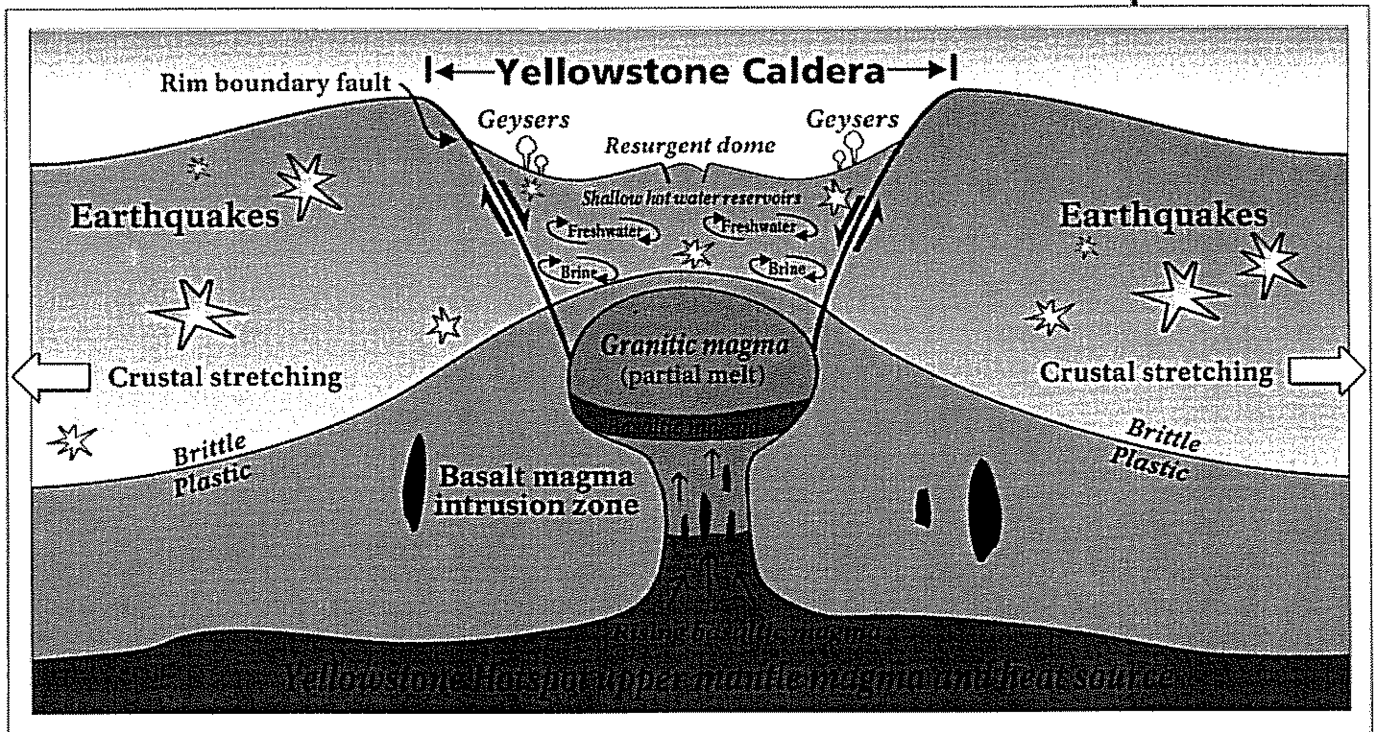
Magma (molten rock from Earth's mantle) rises to within a few miles of the surface in Yellowstone. This heat fuels the Yellowstone volcano and its associated hydrothermal areas. How it rises and whether or not a hotspot is involved remain the subject of much scientific research and discussion. *(See illustration below.)*

Traditional hotspot theory holds that a plume of molten rock rises all the way from Earth's core-mantle boundary to trigger volcanic



Two Hotspot Theories
Molten rock, or magma, rises in convection cells like water boiling in a pot. On the left is the traditional view of a hotspot as a plume of magma rising from Earth's core. On the right is another theory that the Yellowstone hotspot originates at a much shallower depth.

eruptions at the surface. Newer theories relate the rise of molten rock to areas in Earth's crust weakened by stretching and thinning such as that which is ongoing throughout the interior West. Some of these theories also propose a shallower mantle origin for hotspots. Still other theories place Yellowstone's hotspot on the surface as a manifestation of longlived volcanism.

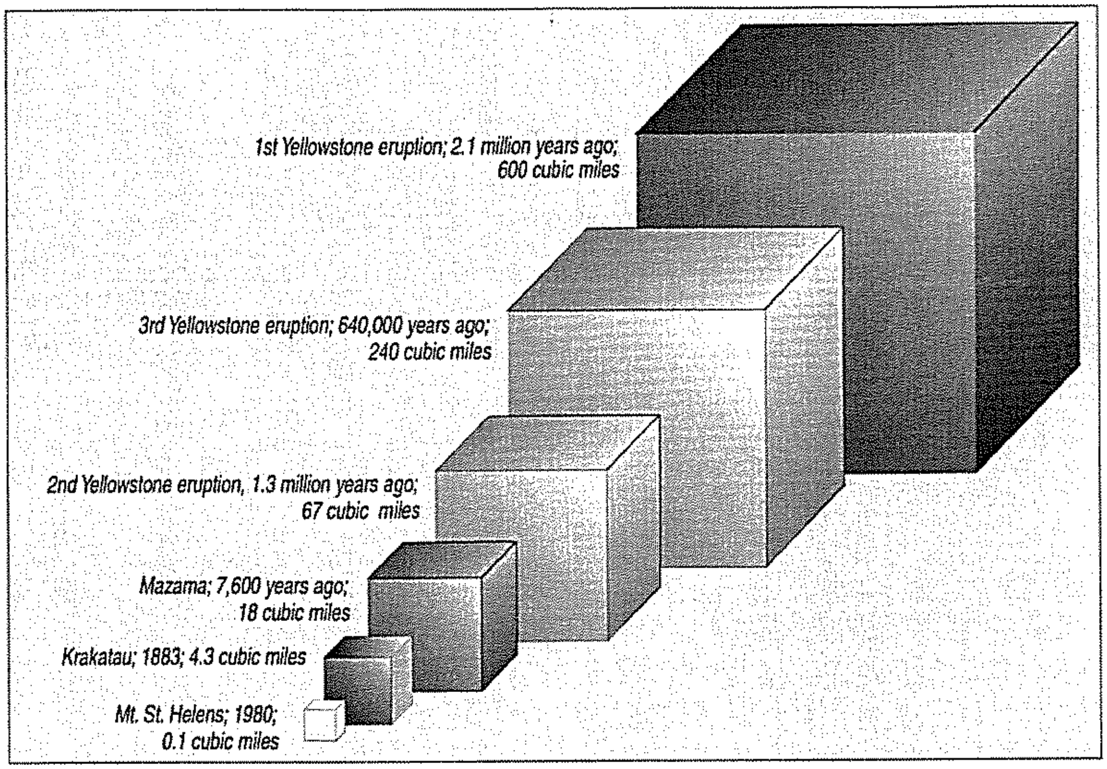


At Yellowstone and some other volcanoes, some scientists theorize that Earth's crust fractures and cracks in a concentric or ring-fracture pattern. At some point these cracks reach the magma "reservoir," release the pressure, and the volcano explodes. The huge amount of material released causes the volcano to collapse into a huge steaming crater—a caldera.

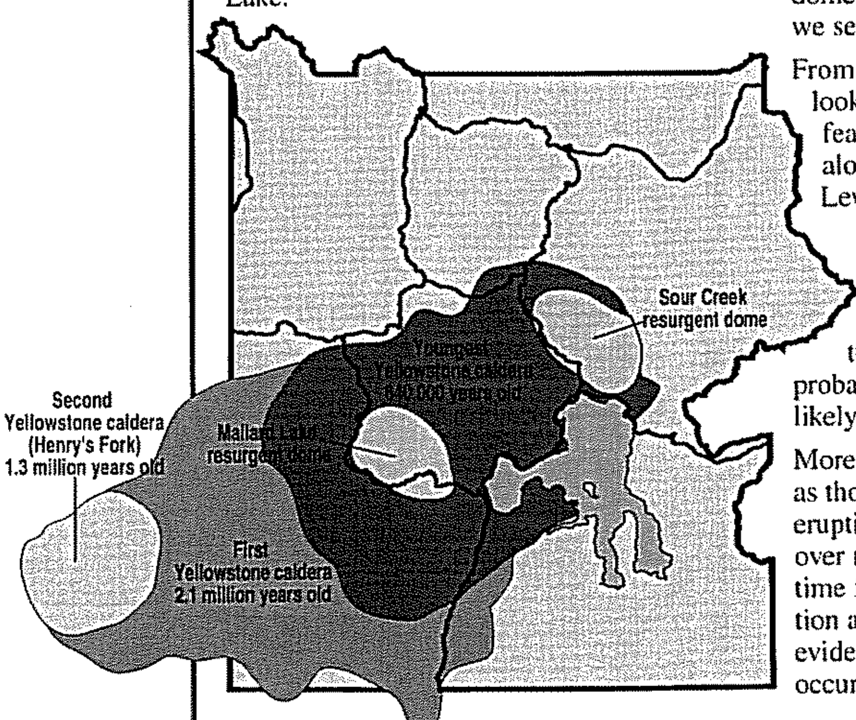
Regardless of its origins and subsurface behavior, the magma chamber feeding Yellowstone's volcano has been close to the surface for some 16.5 million years, erupting repeatedly and leaving a track of 100 gigantic calderas (craters) across 500 miles from the Nevada-Oregon border northeast up Idaho's Snake River Plain and into central Yellowstone. This trail of evidence was created as the North American plate moved in a southwestern direction over the shallow magma. Earth's surface bulges above it, notable in the Yellowstone area where the average elevation is 1,700 feet higher than surrounding regions.

About 2.1 million years ago, the movement of the North American plate brought the Yellowstone area into proximity with the shallow magma. The heat melted rocks in the crust, creating a magma chamber of partially molten, partially solid rock (see below). Upward pressure from the shallow magma chamber cause overlying rocks to break, forming faults and causing earthquakes. Eventually, these faults reached the deep magma chamber. Magma oozed through these cracks, releasing pressure within the chamber and allowing trapped gases to expand rapidly. A massive eruption then occurred, spewing volcanic ash and gas high into the atmosphere and causing fast-moving superhot pyroclastic flows on the ground. As the underground magma chamber emptied, the ground above it sunk, creating a huge crater known as the Huckleberry Ridge Caldera. Smaller lava flows eventually filled in the caldera over tens to hundreds of thousands of years.

The volume of material ejected during this eruption is estimated to have been 2,400 times the size of the 1980 eruption of Mt. St. Helens in Washington *(see illustration next page)*, and ash has been found as far away as Missouri. Approximately 800,000 years later, a second, smaller volcanic eruption occurred on the western edge of the Huckleberry



Ridge Caldera and created the Henry's Fork Caldera. Then 640,000 years ago, the third massive volcanic eruption in central Yellowstone created the Yellowstone Caldera, 30 by 45 miles in size. About 162,000 years ago, a volcanic eruption created a smaller caldera now filled by the West Thumb of Yellowstone Lake.



Yellowstone remains atop the shallow magma. The pressure and movement of the underlying heat, magma, and fluids cause the entire caldera floor to inflate and deflate rapidly (compared to more typical geologic processes). Rising magma has created two large bulges in the Earth called resurgent domes (Sour Creek and Mallard Lake), which we see as large hills.

From the summit of Mt. Washburn, one can look south into much of this vast volcanic feature. The caldera rim is also visible along the park road system at Gibbon Falls, Lewis Falls, and Lake Butte.

Future Volcanic Activity

Will Yellowstone's volcano have another catastrophic eruption? Over the next thousands to millions of years, probably. In the next few hundred years? Not likely.

More likely activity would be lava flows, such as those that occurred after the last major eruption. Such a lava flow would ooze slowly over months and years, allowing plenty of time for park managers to evaluate the situation and protect people. There is no scientific evidence indicating such a lava flow will occur soon.

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Geyser Basin Systems

Geyser Basin Systems

Yellowstone's hydrothermal features would not exist without the underlying magma body that releases tremendous heat. They also depend on sources of water, such as in the mountains surrounding the Yellowstone Plateau. There, snow and rain slowly percolate through layers of porous rock riddled with cracks and fissures. Some of this cold water meets hot saline brine directly heated by the shallow magma body. The water's temperature rises well above the boiling point but the water remains in a liquid state due to the great pressure and weight of the overlying rock and water. The result is superheated water with temperatures exceeding 400°F.

The superheated water is less dense than the colder, heavier water sinking around it. This creates convection currents that allow the lighter, more buoyant, superheated water to begin its slow journey back to the surface following the cracks, fissures, and weak areas through rhyolitic lava flows. As hot water travels through this rock, high temperatures dissolve some silica in the rhyolite.

While in solution underground, some silica coats the walls of the cracks and fissures to form a nearly pressure-tight seal. This locks in the hot water and creates a "plumbing" system that can withstand the great pressure needed to produce a geyser. At the surface, silica precipitates to form either geyserite or sinter, creating the massive geyser cones, the scalloped edges of hot springs, and the seemingly barren landscape of geyser basins.

Geysers are hot springs with constrictions in their plumbing, usually near the surface, that prevent water from circulating freely to the surface where heat would escape. The deepest circulating water can exceed the surface boiling point (199°F/93°C). Surrounding pressure also increases with depth, much as it does with depth in the ocean. Increased pressure exerted by the enormous weight of the overlying rock and water prevents the water from boiling. As the water rises, steam forms. Bubbling upward, steam expands as it nears the top of the water column until the bubbles are too large and numerous to pass freely through the tight spots. At a critical point, the confined bubbles actually lift the water above, causing the geyser to splash or overflow. This decreases pressure on the system, and violent boiling results. Tremendous amounts of steam force water out of the vent, and an eruption begins. Water is expelled faster than it can enter the geyser's plumbing system, and the heat and pressure gradually decrease. The eruption stops when the water reservoir is depleted or when the system cools.

Geyser basin landscapes, as at Norris (above right), owe their light, barren appearance to a rock called sinter. ***Cone geysers,*** *such as Riverside in Upper Geyser Basin (above) erupt in a narrow jet of water, usually from a cone.* ***Fountain geysers,*** *such as Echinus in Norris Geyser Basin (right) shoot water in various directions, typically from a pool.*

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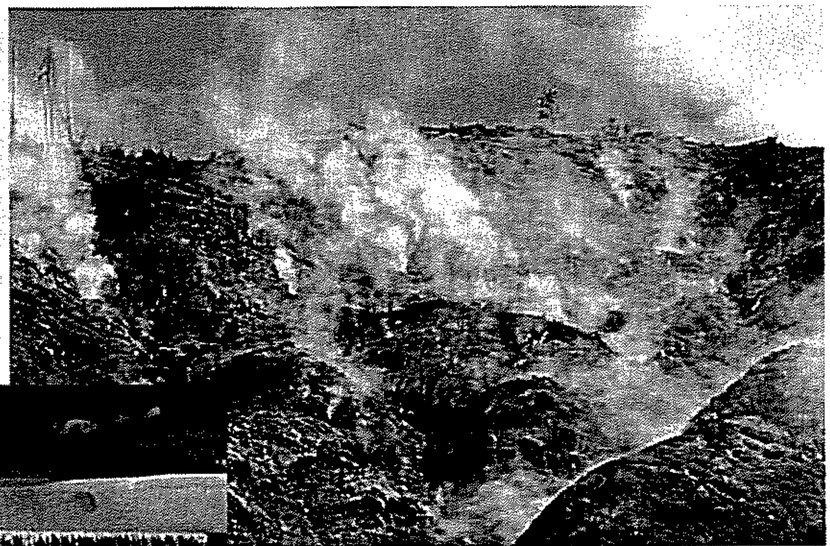
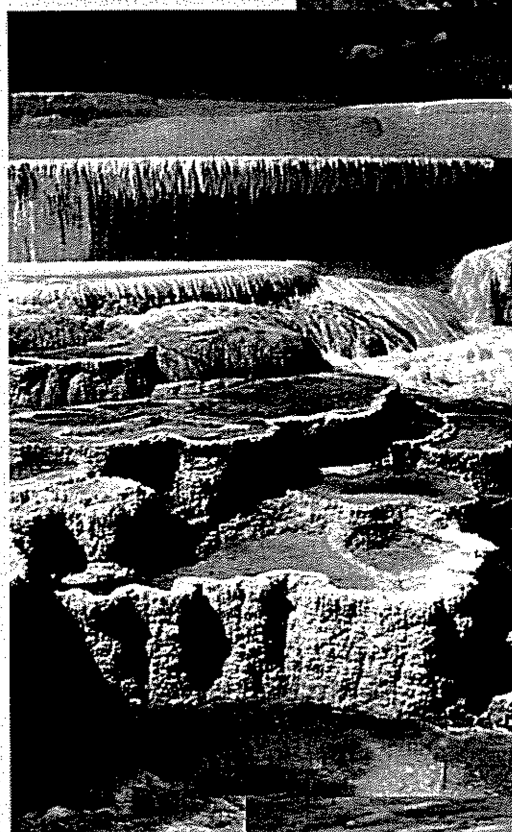
Hydrothermal Features

Fumaroles *or steam vents, are the hottest hydrothermal features in the park. They have so little water that it all flashes into steam before reaching the surface. At places like Roaring Mountain (right), the result is a loud hissing of steam and gases.*

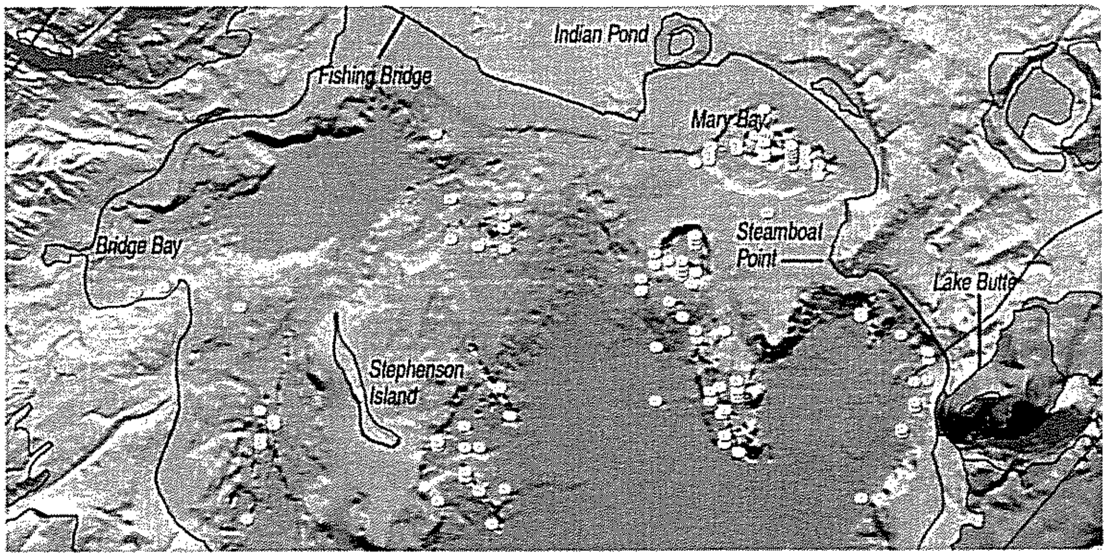




Travertine terraces, *found at Mammoth Hot Springs (right), are formed from limestone (calcium carbonate). Thermal waters rise through the limestone, carrying high amounts of dissolved carbonate. At the surface, carbon dioxide is released and calcium carbonate is deposited as travertine, the chalky white rock of the terraces. Due to the rapid rate of deposition, these features constantly and quickly change.*

Mudpots *such as Fountain Paint Pot (center, right) are acidic hot springs with a limited water supply. Some microorganisms use hydrogen sulfide, which rises from deep within the earth, as an energy source. They help convert the gas to sulfuric acid, which breaks down rock into clay. Various gases escape through the wet clay mud, causing it to bubble. Mudpot consistency and activity vary with the seasons and precipitation.*

Hot Springs *such as this one at West Thumb (right) are the most common hydrothermal features in the park. Their plumbing has no constrictions. Superheated water cools as it reaches the surface, sinks, and is replaced by hotter water from below. This circulation, called convection, prevents water from reaching the temperature needed to set off an eruption.*



Beneath Yellowstone Lake

Until the late 1990s, few details were known about the geology beneath Yellowstone Lake. In 1996, researchers saw anomalies on the floor of Bridge Bay in the results of single-channel depth soundings. They deployed a submersible remotely operated vehicle (ROV), equipped with photographic equipment and sector-scan sonar. Large targets appeared on the sonar image when suddenly very large, spire-like structures appeared in the photographic field of view (photo at right). These structures looked similar to hydrothermal structures found in deep ocean areas, such as the Mid-Atlantic Ridge and the Juan de Fuca Ridge. They also provided habitat for aquatic species such as fresh water sponges and algae.

Hydrothermal vents in northern Yellowstone Lake (above) were mapped as part of a five-year project. Scientists also are studying spires from Bridge Bay (below) that no one knew existed a decade ago. Scientists think they may be very old hydrothermal vents.

Lake-bottom Surveys

From 1999 to 2003, scientists from the U.S. Geological Survey and a private company, Eastern Oceanics, surveyed the bottom of Yellowstone Lake using high-resolution, multi-beam swath sonar imaging, seismic reflection profiling, and a ROV. The survey showed the northern half of the lake to be inside the 640,000-year-old Yellowstone Caldera and mapped previously unknown features such as large hydrothermal explosion craters, siliceous spires, hundreds of hydrothermal vents and craters, active fissures, and domal features containing gas pockets and deformed sediments. Also mapped were young previously unmapped faults, landslide deposits, and submerged older lake shorelines. These features are part of an undulating landscape shaped by old rhyolitic lava flows that filled the caldera.

The southern half of the lake lies outside the caldera and has been shaped by glacial and other processes. The floor of the Southeast Arm has many glacial features, similar to the glacial terrain seen on land in Jackson Hole, south of the park.

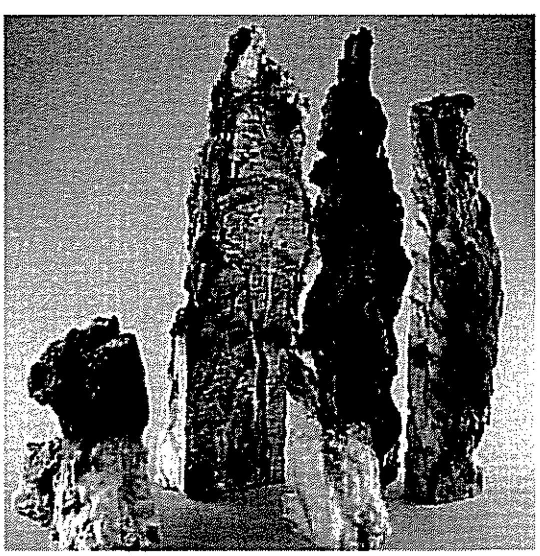
These new surveys give an accurate picture of the geologic forces shaping Yellowstone Lake and determine geologic influences affecting the present-day aquatic biosphere. For example, craters result from hydrothermal explosions caused by water flashing to steam which is often accompanied by failure and fragmentation of overlying caprock. Spires may be formed in a way similar to black smoker chimneys, which are hydrothermal features associated with oceanic plate boundaries.

Spire Analysis

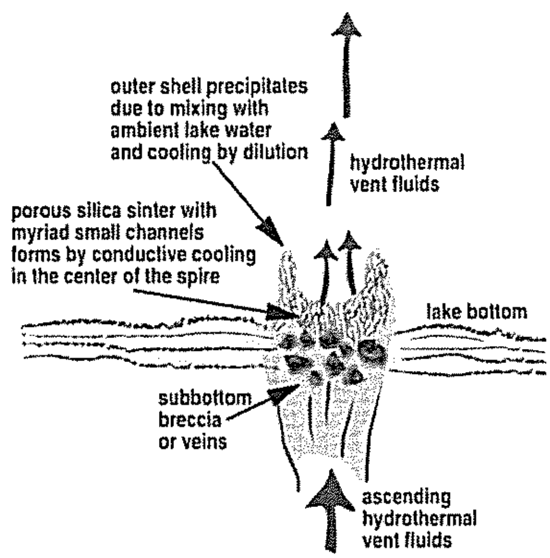
With the cooperation of the National Park Service, scientists from the University of Wisconsin–Milwaukee collected a small spire for study by several teams. They conducted a CAT scan of the spire, which showed structures seeming to be conduits, perhaps for hydrothermal circulation. When they cut open the spire, they confirmed the presence of conduits and also saw a layered structure.

Early tests by the U.S. Geological Survey show that the spire may be more than 11,000 years old, which indicates it was formed after the last glaciers retreated. In addition to silica, the spire contains diatom tests (shells) and silica produced by underwater hydrothermal processes. Ongoing investigations include confirming the spire's age and composition.

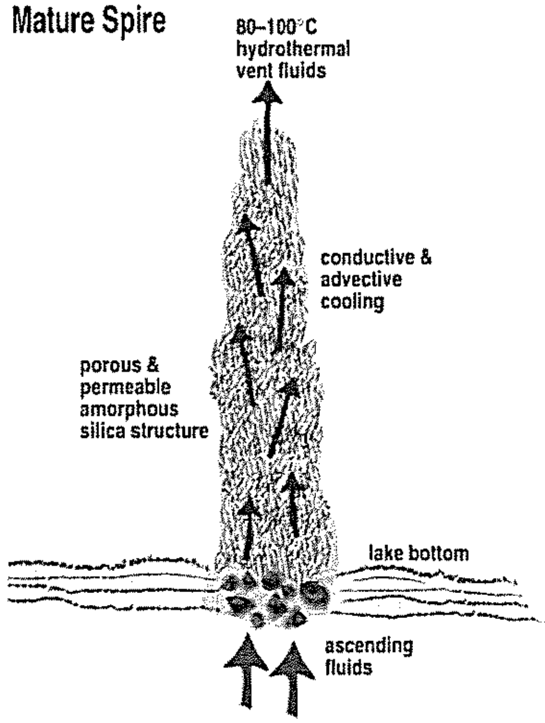
Both research projects have already expanded our understanding of the geological forces at work beneath Yellowstone Lake. Additional study of the spires and other underwater features will continue to contribute to our understanding of the relationship between these features and the aquatic ecosystem.



Initial Spire Growth



Mature Spire



Illustrations on this page adapted from originals by Dr. Lisa A. Morgan, U.S.G.S. Research Geologist

Earthquakes

Earthquakes occur along fault zones in the crust where forces from crustal plate movement build to a significant level. The rock along these faults becomes so stressed that eventually it slips or breaks. Energy is then released as shock waves (seismic waves) that reverberate throughout the surrounding rock.

Different kinds of seismic waves are released inside the earth during an earthquake. Primary waves ("P-waves") move quickly in the direction of travel, compressing and stretching the rock. Secondary waves ("S-waves") move up, down, and sideways through rock in a rolling motion. Once a seismic wave reaches the surface of the earth, it may be felt. Surface waves affect the ground, which can roll, crack open, or be vertically and/or laterally displaced. Structures are susceptible to earthquake damage because the ground motion is usually horizontal.

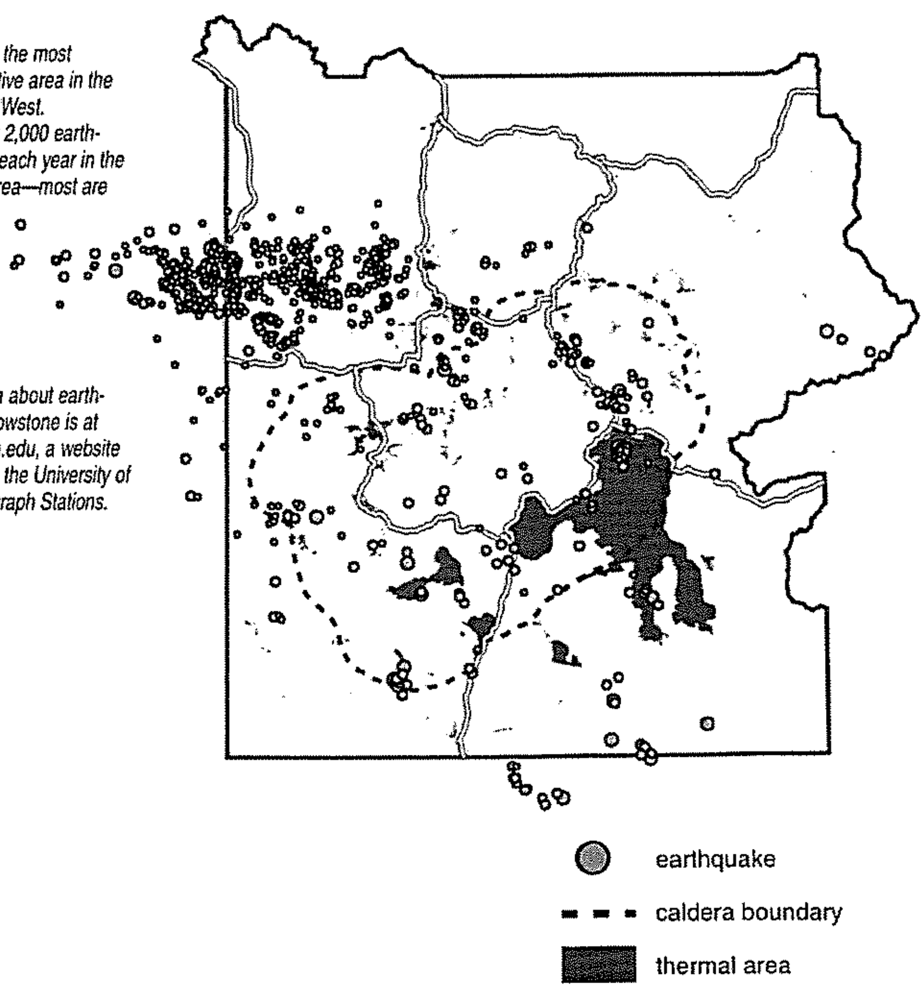
Earthquakes in Yellowstone help to maintain hydrothermal activity by keeping the "plumbing" system open. Without the periodic disturbance of relatively small earthquakes, the small fractures and conduits that supply hot water to geysers and hot springs might be sealed by mineral deposition. Some earthquakes generate changes in Yellowstone's hydrothermal systems. For example, the 1959 Hebgen Lake and 1983 Borah Peak earthquakes caused measurable changes in Old Faithful Geyser and other hydrothermal features.

Earthquakes help us understand the subsurface geology around and beneath Yellowstone. The energy from earthquakes travels through hard and molten rock at different rates. We can "see" the subsurface and make images of the magma chamber and the caldera by "reading" the energy emitted during earthquakes. An extensive geological monitoring system is in place to aid in that interpretation.

1,293 Earthquakes in 2004, Yellowstone Area

Yellowstone is the most seismically active area in the Intermountain West. Approximately 2,000 earthquakes occur each year in the Yellowstone area—most are not felt.

Real-time data about earthquakes in Yellowstone is at www.seis.utah.edu, a website maintained by the University of Utah Seismograph Stations.



Scales of Magnitude

The size of an earthquake is given by its magnitude, which is often referred to as Richter Magnitude. On this scale, the amplitude of shaking goes up by a factor of 10 for each unit on the scale. Thus, at the same distance from the earthquake, the shaking will be 10 times as large during a magnitude 5 earthquake as during a magnitude 4 earthquake. The total amount of energy released by the earthquake, however, goes up by a factor of 32. There are many different ways that magnitude is measured from seismograms, partially because each method only works over a limited range of magnitudes and with different types of seismometers. But, all of the methods are designed to agree well over the range where they overlap.

The methods used in University of Utah earthquake listings include:

ML—local magnitude, the original scale defined by Richter and Gutenberg based on the maximum amplitude of the waves. This is the preferred magnitude, when available.

MC—coda magnitude, based on measurements of the duration of the seismic waves for earthquakes up to about magnitude 5.