The landscape of Yellowstone National Park is the result of many geological processes. Here, glacial erratics (foreground), ground moraines (midground), and Cutoff Mountain (background) appear near Junction Butte.

Geology

The landscape of the Greater Yellowstone Ecosystem is the result of 150 million years of geological processes. Here, Earth's crust has been compressed, pulled apart, glaciated, eroded, and subjected to volcanism. This geologic activity formed the mountains, canyons, plateaus, and hydrothermal features that define the natural wonder that is Yellowstone.

While these mountains and canyons may appear to change very little during our lifetime, they are still highly dynamic and variable. Some of Earth's most active volcanic, hydrothermal (water and 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, as well as other wonders such as the Grand Canyon of the Yellowstone River.

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 shapes the planet's surface.

Earth is frequently depicted as a ball with a central core surrounded by concentric layers that culminate in the crust or outer shell. The distance from Earth's surface to its center or core is approximately 4,000 miles. The core of the earth is divided into two parts. The mostly iron and nickel inner core (about 750 miles in diameter) is extremely hot but solid due to immense pressure. The iron and nickel outer core (1,400 miles thick) is hot and molten. The mantle (1,800 miles thick) is a dense, hot, semi-solid layer of rock. Above the mantle is the relatively thin crust, three to 48 miles thick, forming the continents and ocean floors.

In the key principles of Plate Tectonics, Earth's crust and upper mantle (lithosphere) is divided into

Yellowstone's Geologic Significance

Yellowstone continues today as a natural geologic laboratory of active Earth processes.

- One of the most geologically dynamic areas on Earth due to a 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 approximately 500 geysers—the most undisturbed hydrothermal features left in the world.
- The largest concentration of active geysers in the world—more than half of the world's total.
- Mammoth Hot Springs is one of the world's largest active travertine terraces.
- Site of many petrified trees formed by a series of andesitic volcanic eruptions 45 to 50 million years ago.

many plates, which are in constant motion. Where plate edges meet, they may slide past one another, pull apart, or collide. When plates collide, one plate is commonly driven beneath another (subduction). Subduction is possible because continental plates are made of less dense rocks (granites, which have a similar rock composition to the rhyolites and tuffs from the Yellowstone volcano) and, thus, "ride" higher than the basaltic oceanic plates. At divergent plate boundaries, such as mid-ocean ridges, the upwelling of magma pushes plates apart from each other.

Many theories have been proposed to explain crustal plate movement. Scientific evidence shows 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 convective upwellings of hotter, semi-molten rock we call mantle plumes.

At a Glance

Although a cataclysmic eruption of the Yellowstone volcano is unlikely in the foreseeable future, real-time monitoring of seismic activity, volcanic gas concentrations, geothermal activity, and ground deformation helps ensure public safety. Yellowstone's seismograph stations, monitored by the University of Utah for the Yellowstone Volcano Observatory, detect several hundreds to thousands of earthquakes in the park each year. Scientists continue to improve our capacity to monitor the Yellowstone volcano through the deployment of new technology.

In the early 2000s, scientists implemented very precise Global Positioning Systems (GPS), capable of accurately measuring vertical and horizontal groundmotions to within a centimeter (0.4 in), and satellite radar imagery of ground movements called InSAR. These measurements indicated that parts of the Yellowstone caldera were rising at an unprecedented rate of up to seven centimeters (2.75 in) per year (2006) while an area near the northern caldera boundary started to subside. The largest vertical movement was recorded at the White Lake GPS station, inside the caldera's eastern rim, where the total uplift from 2004 to 2010 was about 27 centimeters (10.6 in). The caldera began to subside during the first half of 2010, entered into a renewed period of uplift from 2014 to 2015, and has since returned to subsidence. Episodes of uplift and subsidence have been correlated with changes in the frequency of earthquakes in the park.

On March 30, 2014, an earthquake of magnitude 4.8 occurred four miles north-northeast of Norris Geyser Basin. The M4.8 earthquake was felt in Yellowstone; Gardiner and West Yellowstone, Montana; and throughout the region. This was the largest earthquake in Yellowstone since the early 1980s. Analysis of the M4.8 earthquake indicates a tectonic origin (mostly strike-slip motion), but it was also involved with unusual ground uplift of 7 centimeters (2.75 in) at Norris Geyser Basin that lasted 6 months.

More Information

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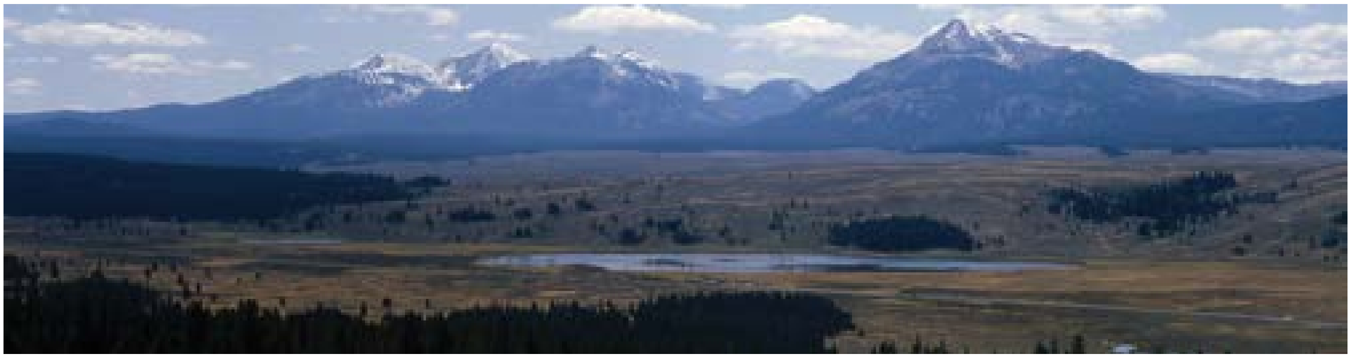


Between 542 and 66 million years ago—long before the supervolcanic eruptions became part of Yellowstone's geologic story—the area was covered by inland seas.

Geologic History of Yellowstone

Most of Earth's history (from the formation of the earth 4.6 billion years ago to approximately 541 million years ago) is known as the Precambrian time. Rocks of this age are found in northern Yellowstone and in the hearts of the nearby Teton, Beartooth, Wind River, and Gros Ventre mountain ranges. During the Precambrian and the subsequent Paleozoic and Mesozoic eras (541 to 66 million years ago), the western United States was covered at times by oceans, sand dunes, tidal flats, and vast plains. From the end of the Mesozoic through the early Cenozoic, mountain-building processes formed the Rocky Mountains.

During the Cenozoic era (approximately the past 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. This period of volcanism is not related to the present Yellowstone volcano.

Approximately 30 million years ago, vast expanses of today's West began stretching apart along an east–west axis. This ongoing stretching process increased about 17 million years ago and created the modern basin and range topography (north–south mountain ranges with long north–south valleys) that characterizes much of the West, including the Yellowstone area.

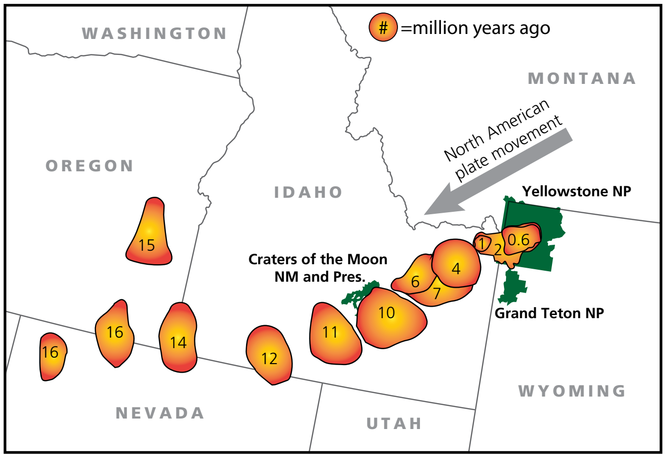
About 16.5 million years ago, an intense period of volcanism initiated near the borders of present-day Nevada, Oregon, and Idaho. Subsequent volcanic eruptions can be traced across southern Idaho towards Yellowstone. This 500-mile trail of more than 100 calderas was created as the North American Plate moved in a southwestern direction over a shallow body of magma. About 2.1 million years ago, the movement of the North American plate brought the Yellowstone area closer to the shallow magma body. This volcanism remains a driving force in Yellowstone today.

GEOLOGY

Yellowstone Geologic History

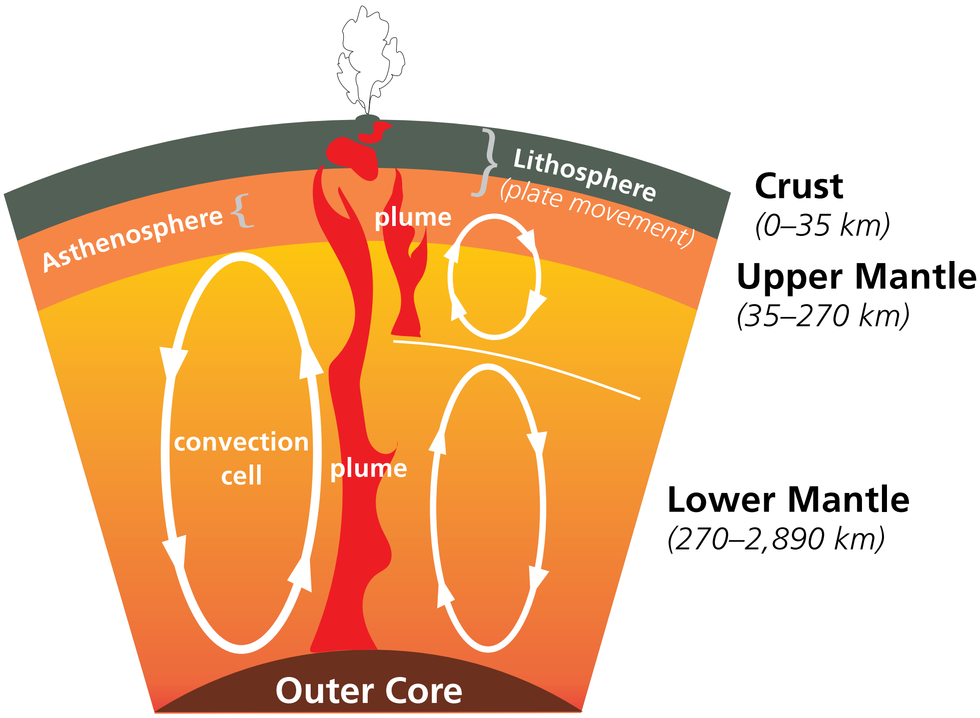
21 to 16 ka	Pinedale Glaciation maximum
160 to 151 ka	Bull Lake Glaciation underway
174 ka	West Thumb eruption
631 ka	3rd Yellowstone super-eruption
1.3 Ma	2nd Yellowstone super-eruption
2.1 Ma	1st Yellowstone super-eruption
16 Ma	Volcanism begins again in present-day Nevada and Idaho
30 Ma to present	"Basin and Range" forces creating Great Basin topography
50 to 40 Ma	Absaroka volcanics
542 to 66 Ma	Area covered by inland seas

Ma = mega annum, or millions of years ago
ka = kilo annum, or one thousand years ago



Ages in millions of years of major calderas formed by the movement of the North American plate over the deep hot spot.

ADAPTED FROM SMITH AND SIEGEL, 2000; AND HUANG ET AL., 2015.



Molten rock, or magma, rises in convection cells like water boiling in a pot. A hot spot may arise from a heated plume originating from the mantle-core boundary (left), or one originating from higher up in the mantle (right). The magma reservoirs of the Yellowstone hot spot originate at a much shallower depth than the mantle plume.

FREQUENTLY ASKED QUESTIONS:

Is Yellowstone a volcano?

Yes. Within the past two million years, some volcanic eruptions have occurred in the Yellowstone area—two of them super-eruptions.

What is the caldera shown on the park map?

The Yellowstone Caldera was created by a massive volcanic eruption approximately 631,000 years ago. Later lava flows filled in much of the caldera, which now measures 30 x 45 miles. Its rim can best be seen from the Washburn Hot Springs overlook, south of Dunraven Pass. Gibbon Falls, Lewis Falls, Lake Butte, and the Flat Mountain arm of Yellowstone Lake are part of the rim.

When did the Yellowstone volcano last erupt?

Approximately 174,000 years ago, creating what is now the West Thumb of Yellowstone Lake. The last of the 60–80 post-caldera lava flows were about 70,000 years ago.

Is Yellowstone's volcano still active?

Yes. The park's many hydrothermal features attest to the heat still beneath this area. Earthquakes—700 to 3,000 per year—also reveal activity below ground. The University of Utah Seismograph Station tracks this activity closely at http://quake.utah.edu.

What is Yellowstone National Park doing to stop or prevent an eruption?

Nothing can be done to prevent an eruption. The temperatures, pressures, physical characteristics of partially molten rock, and immensity of the magma chamber are beyond human ability to impact—much less control.

What is a supervolcanic eruption?

An eruption is supervolcanic when it ejects more than 240 cubic miles of magma. Two of Yellowstone's three major eruptions met this criteria.

Will the Yellowstone volcano erupt soon?

Another caldera-forming eruption is theoretically possible, but it is very unlikely in the next thousand or even 10,000 years. Scientists have also found no indication of an imminent smaller eruption of lava in more than 30 years of monitoring.

How do scientists know the Yellowstone volcano won't erupt?

Scientists from the Yellowstone Volcano Observatory watch an array of monitors in place throughout the region. These monitors would detect sudden or strong earthquake activity, ground shifts, and volcanic gases that would indicate increasing activity. No such evidence exists at this time.

In addition, Yellowstone Volcano Observatory scientists collaborate with scientists from all over the world to study the hazards of the Yellowstone volcano. To view current data about earthquakes, ground movement, and stream flow, visit volcanoes.usgs.gov/yvo/.

If Old Faithful Geyser quits, is that a sign the volcano is about to erupt?

All geysers are highly dynamic, including Old Faithful. We expect Old Faithful to change in response to the ongoing geologic processes associated with mineral deposition and earthquakes. Thus, a change in Old Faithful Geyser will not necessarily indicate a change in volcanic activity.

Magma, Hot Spots, and the Yellowstone Volcano

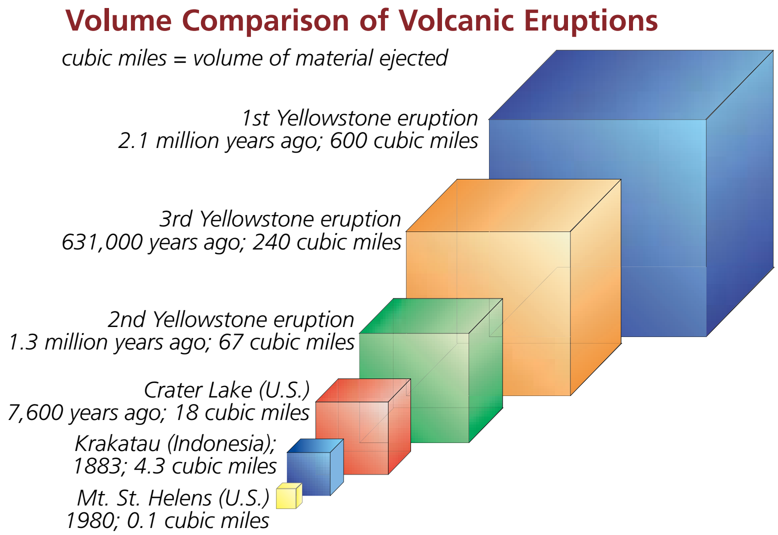
Magma (molten rock from below Earth's crust) is close to the surface in the greater Yellowstone area. This shallow body of magma is caused by heat convection in the mantle. Plumes of magma rise through the mantle, melting rocks in the crust and creating magma reservoirs of partially molten, partially solid rock. Mantle plumes transport heat from deep in the mantle to the crust and create what we call "hot spot" volcanism. Hot spots leave a trail of volcanic activity as tectonic plates drift over them. As the North American Plate drifted southwestward over the past 16.5 million years, the hot spot that now resides under the greater Yellowstone area left a swath of volcanic deposits across Idaho's Snake River Plain.

Heat from the mantle plume has melted rocks in the crust and created two stacked magma chambers of partially molten, partially solid rock near Yellowstone's surface. Heat and increased pressure from the shallowest magma chamber caused an area of the crust above it to expand and rise. Stress on the overlying crust resulted in increased earthquake activity along newly formed faults. Eventually, these faults reached the magma reservoir, and magma oozed through the cracks. Escaping magma released pressure within the chamber, which also allowed volcanic gasses to escape and expand explosively in a massive volcanic eruption. The eruption spewed copious volcanic ash and gas into the atmosphere and produced fast, super-hot debris flows (pyroclastic flows) over the existing landscape. As the underground magma chamber emptied, the ground above it collapsed and created the first of Yellowstone's three calderas.

This eruption 2.1 million years ago—among the largest volcanic eruptions known to humans—coated about 6,000 square miles with ash, as far away as Missouri. The total volcanic material ejected is estimated to have been 6,000 times the volume of material ejected during the 1980 eruption of Mt. St. Helens, in Washington.

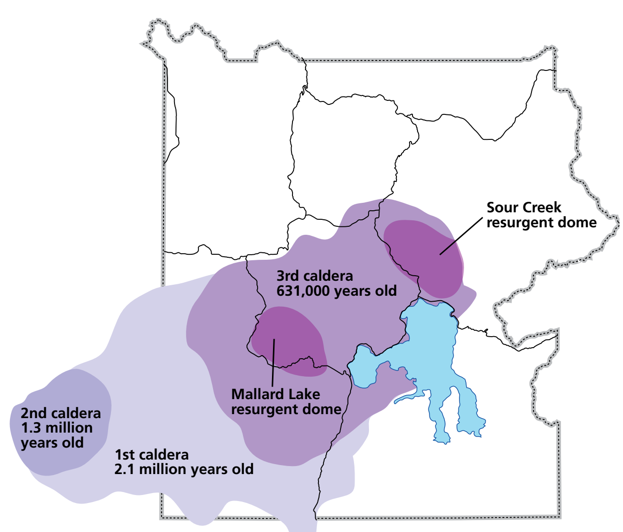
A second significant, though smaller, volcanic eruption occurred within the western edge of the first caldera approximately 1.3 million years ago. The third and most recent massive volcanic eruption 631,000 years ago created the present 30-by-45-mile-wide Yellowstone Caldera. Since then, 80 smaller eruptions have occurred. Approximately 174,000 years ago, one of these created what is now the West Thumb of Yellowstone Lake. During and after these explosive eruptions, huge flows of viscous rhyolitic lava partially filled the caldera floor and surrounding terrain. The youngest of these lava flows is the 70,000-year-old Pitchstone rhyolite flow in the southwest corner of Yellowstone.

Since the last of three caldera-forming eruptions, pressure from the shallow magma body has formed two resurgent domes inside the Yellowstone Caldera. Magma may be as little as 3–8 miles beneath Sour Creek Dome and 8–12 miles beneath Mallard Lake Dome, and both domes inflate and subside as the volume of magma or hydrothermal fluids changes



Volume comparison of global volcanic eruptions.

ADAPTED WITH PERMISSION FROM *WINDOWS INTO THE EARTH* BY ROBERT SMITH AND LEE J. SIEGEL, 2000.



The locations of Yellowstone's three calderas and two resurgent domes.

ADAPTED WITH PERMISSION FROM *WINDOWS INTO THE EARTH* BY ROBERT SMITH AND LEE J. SIEGEL, 2000.

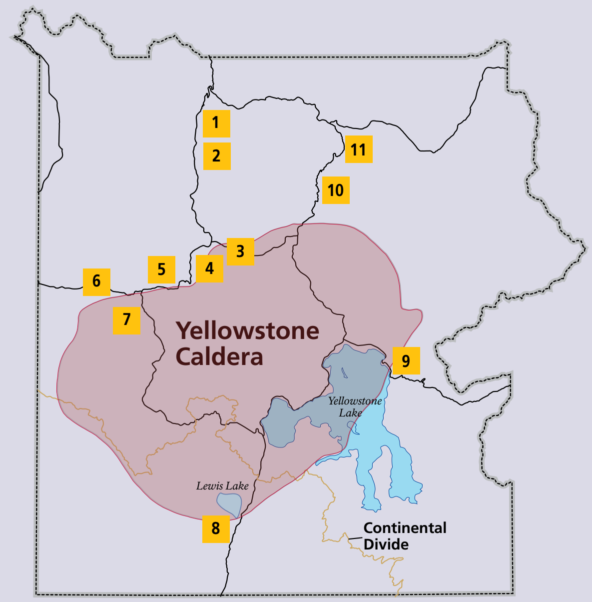
beneath them. The entire caldera floor lifts up or subsides, too, but not as much as the two domes. In the past century, the net inflation has tilted the caldera floor toward the south. As a result, Yellowstone Lake's southern shores have subsided, and trees now stand in water, and the north end of the lake has risen into a sandy beach at Fishing Bridge.

Recent Activity

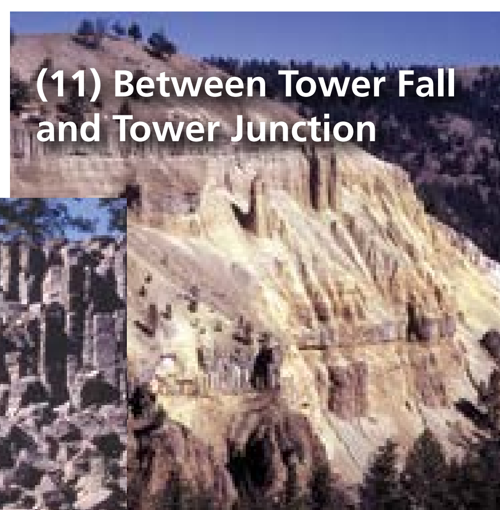
Remarkable ground deformation has been documented along the central axis of the caldera between Old Faithful and White Lake in Pelican Valley in historic time. Surveys began in 1975 measuring vertical motion of benchmarks. By 1985, the surveys documented unprecedented uplift of the entire caldera in excess of a meter (3 ft). Later GPS measurements revealed that the caldera went into an episode of subsidence (sinking) until 2005 when the caldera returned to an episode of extreme uplift. The largest vertical movement was recorded at the White Lake GPS station, inside the caldera's eastern rim, where the total uplift from 2004 to 2010 was about 27 centimeters (10.6 in).

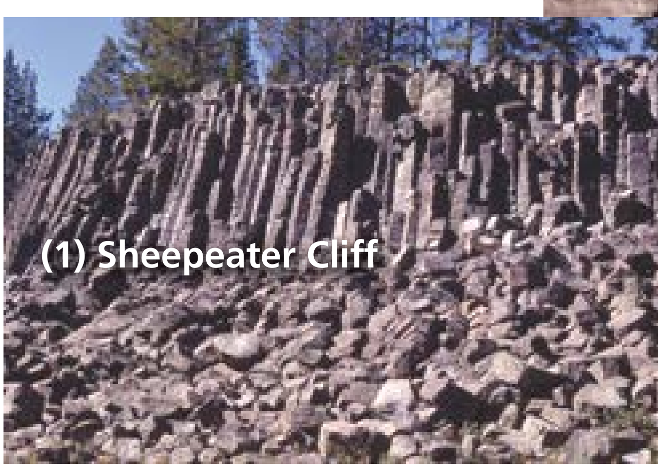
The rate of rise slowed in 2008, and the caldera began to subside again during the first half of 2010. The uplift is believed to be caused by the movement of deep hydrothermal fluids or molten rock into the shallow crustal magma system at a depth of about 10 km (6.2 mi) beneath the surface. A caldera may undergo episodes of uplift and subsidence for thousands of years without erupting. Notably, changes in uplift and subsidence have been correlated with increases of earthquake activity. Lateral discharge of these fluids away from the caldera—and the accompanying earthquakes, subsidence, and uplift—relieve pressure and could

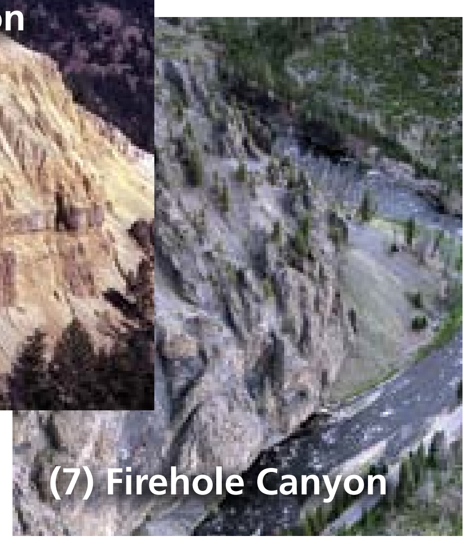
Where to See Volcanic Flows



1. Sheepeater Cliff: columnar basalt
2. Obsidian Cliff: lava
3. Virginia Cascades: ash flow
4. Gibbon Falls: near caldera rim
5. Tuff Cliff: ash flow
6. West Entrance Road, Mt. Haynes, and Mt. Jackson: columnar rhyolite, Lava Creek tuff
7. Firehole Canyon: lava
8. Lewis Falls: near caldera rim
9. Lake Butte: on edge of caldera, overall view of caldera
10. Washburn Hot Springs Overlook: overall view of caldera
11. Between Tower Fall and Tower Junction: columnar basalt


(11) Between Tower Fall and Tower Junction


(1) Sheepeater Cliff


(7) Firehole Canyon

Yellowstone Volcano Observatory

Increased scientific surveillance of Yellowstone has detected significant changes in its vast underground volcanic system. The system is centered on an enormous caldera that is characterized by geologically infrequent but very large volcanic eruptions.

To strengthen the ability of scientists to track and respond to changes in Yellowstone's activity, the Yellowstone Volcano Observatory (YVO) was created here in 2001. YVO is a cooperative partnership among the US Geological Survey, National Park Service, University of Utah, University of Wyoming, University NAVSTAR Consortium, and State Geological Surveys of Wyoming, Montana, and Idaho. The observatory is a long-term, instrument-based monitoring program designed for observing volcanic and seismic activity in the Yellowstone National Park region.

The principal goals of the Yellowstone Volcano Observatory are to

- assess the long-term potential hazards of volcanism, seismicity, and explosive hydrothermal activity in the region;
- provide scientific data that enable reliable and timely warnings of significant seismic or volcanic events and related hazards in the Yellowstone region;
- notify the NPS, local officials, and the public in the event of such warnings;
- improve scientific understanding of tectonic and magmatic processes that influence ongoing seismicity, surface deformation, and hydrothermal activity; and
- effectively communicate the results of these efforts to responsible authorities and to the public.

Current real-time-monitoring data are online at volcanoes.usgs.gov/yvo/monitoring.html.

act as a natural pressure-release valve, balancing magma recharge and keeping Yellowstone safe from volcanic eruptions.

Future Volcanic Activity

Will Yellowstone's volcano erupt again? Over the next thousands to millions of years? Probably. In the next few hundred years? Not likely.

The most likely activity would be lava flows, such as those that occurred after the last major eruption. A lava flow would ooze slowly over months and years, allowing plenty of time for park managers to evaluate the situation and protect people. No scientific evidence indicates such a lava flow will occur soon.

To monitor volcanic and seismic activity in the Yellowstone area, the Yellowstone Volcano Observatory (YVO) was established in 2001. YVO is a partnership of scientists from the US Geological Survey, National Park Service, University of Utah, University of Wyoming, Montana State University, University NAVSTAR Consortium (UNAVCO), and the state Geological Surveys of Wyoming, Montana, and Idaho. YVO scientists monitor the Yellowstone volcano with a real-time and near real-time monitoring network of 40 seismic stations, 16 GPS receivers, and 11 stream-gauging stations. Scientists also collect information on temperature, chemistry, and gas concentrations at selected hydrothermal features and chloride concentrations in major rivers. A monthly activity summary, real-time monitoring of seismicity and water flow, and near real-time monitoring of ground deformation can be found at the Yellowstone Volcanic Observatory website.

More Information

A field trip guide to the petrology of Quaternary volcanism on the Yellowstone Plateau: https://pubs.er.usgs.gov/publication/sir20175022Q

Caldera Chronicles: https://volcanoes.usgs.gov/volcanoes/yellowstone/article_home.html?vaid=251

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Yellowstone Volcano Observatory: https://volcanoes.usgs.gov/observatories/yvo/index.html

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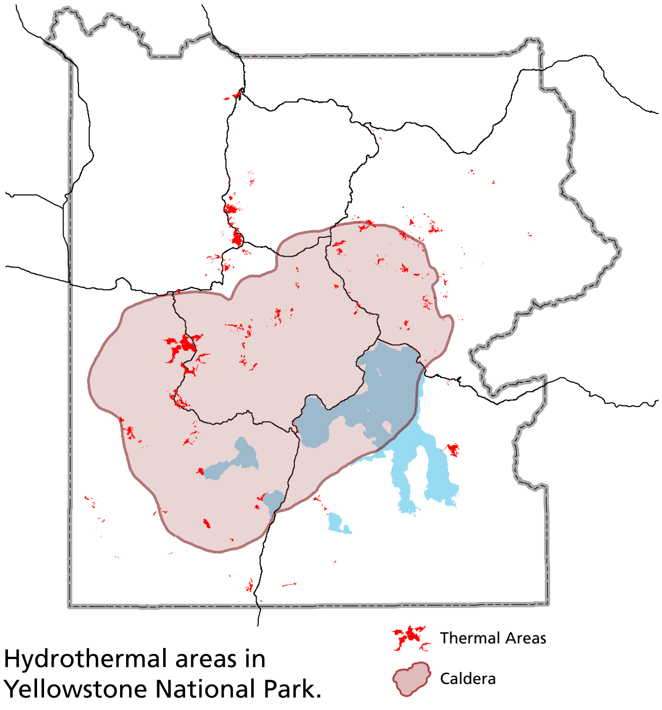
Grand Prismatic Spring is one of more than 10,000 thermal features in Yellowstone. Research on heat-resistant microbes in the park's hydrothermal areas has led to medical, forensic, and commercial uses.

Hydrothermal Systems

Yellowstone was set aside as the world's first national park because of its hydrothermal wonders. The park contains more than 10,000 thermal features, including the world's greatest concentration of geysers as well as hot springs, mudpots, and steam vents. Research on heat-resistant microbes in the park's thermal areas has led to medical, forensic, and commercial uses. Oil, gas, and groundwater development near the park, and drilling in "Known Geothermal Resources Areas" identified by the US Geological Survey in Island Park, Idaho, and Corwin Springs, Montana, could alter the functioning of hydrothermal systems in the park. So in 1994, the National Park Service and State of Montana established a water-rights compact and controlled-groundwater area to protect those areas from development.



Hydrothermal areas in Yellowstone National Park.

Under the Surface

The park's hydrothermal system is the visible expression of the immense Yellowstone volcano; it would not exist without the underlying partially molten magma body that releases tremendous heat. The system also requires water, such as ground water from the mountains surrounding the Yellowstone Plateau. There, snow and rain slowly percolate through layers of permeable rock riddled with cracks. Some of this cold water meets hot 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 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 journey back to the surface following the cracks and weak areas through rhyolitic lava flows. This upward path is the natural "plumbing" system of the park's hydrothermal features.

As hot water travels through this rock, it dissolves some silica in the rhyolite. This silica can precipitate in the cracks, increasing the system's ability to withstand the great pressure needed to produce a geyser.

At the surface, silica precipitates to form siliceous sinter, creating the scalloped edges of hot springs and the seemingly barren landscape of hydrothermal basins. The siliceous sinter deposits, with bulbous or cauliflower-like surfaces, are known as geyserite.

Hydrothermal Activity

The park's hydrothermal areas are dispersed across 3,472 square miles (8,991 km^2) making it challenging to coordinate a systematic monitoring program. Thus, geologists use remote sensing, groundwater

GEOLOGY

flow studies, measurements from individual features, and collaboration with other researchers to gather reproducible data over many years. The variety and duration of monitoring helps to distinguish human influences from natural changes, and define the natural variability of the hydrothermal system. This distinction is essential for Yellowstone to successfully protect the integrity of the system as a whole.

Hydrothermal variability is easiest to see in individual features. On March 15, 2018, Steamboat Geyser began a period of more frequent eruptions after three and a half years of dormancy. The world's tallest active geyser erupted 32 times in 2018, 48 in 2019 and 2020, 20 in 2021, 11 in 2022, 9 in 2023, and 6 in 2024. Eruption intervals ranged from three to 89 days. The Upper Geyser Basin also experienced increased activity around the Geyser Hill area in the fall of 2018. This includes new erupting vents splashing water on the boardwalks, surface fractures, and a rare eruption of Ear Spring on September 15, 2018. The eruption ejected a variety of foreign objects: coins and trash dating back to the 1930s. The Old Faithful eruption typical interval is 102 minutes (+/- 10 minutes) as of January 2025.

These highly visible changes receive public attention, but do not necessarily represent changes in the entire hydrothermal system. New research methods and technology enhance our understanding. Work continues to progress documenting the status of the hydrothermal system by measuring the total amount of thermal water and the total heat output for selected geyser basins. Thermal infrared images taken by aircraft are used to document changes in the hydrothermal areas. Research measuring seismic activity in the Upper Geyser Basin and Norris Geyser Basin used "harmonic tremors" preceding eruptions

FREQUENTLY ASKED QUESTIONS:

Why are geysers in Yellowstone?

Yellowstone's volcanic geology provides the three components necessary for the existence of geysers and other hydrothermal features: heat, water, and a natural "plumbing" system. Magma beneath the surface provides the heat; ample rain and snowfall seep deep underground to supply the water; and underground cracks and fissures form the plumbing. Hot water rises through the plumbing to surface as hydrothermal features.

What exactly is a thermal basin?

A thermal basin is a geographically distinct area containing a "cluster" of hydrothermal features that may include geysers, hot springs, mudpots, and fumaroles. These distinct areas often, but not always, occur in low places because hydrothermal features tend to be concentrated around the margins of lava flows and in areas of faulting.

Where can I see mudpots?

Small mudpot areas occur at West Thumb Geyser Basin, Fountain Paint Pot, and Artists' Paintpots. The largest group of mudpots can be found at Mud Volcano, at the southern end of Hayden Valley.

What is the oldest thermal area in the park, active or inactive?

Terrace Mountain, near Mammoth Hot Springs, is evidence of carbonate hot spring deposits up to 406,000 years old.

What is the most active thermal area in the park?

Norris Geyser Basin is the hottest and most dynamic of Yellowstone's active hydrothermal areas. The highest temperature yet recorded in any Yellowstone hydrothermal area was measured in a scientific drill hole at Norris: 459°F (237°C) just 1,087 feet below the surface. Norris shows evidence of having had hydrothermal activity prior to the last great ice age. The features change often, with frequent disturbances from seismic activity and water fluctuations. Norris is so hot and dynamic primarily because it sits at the intersection of three major faults, two of which intersect with a ring fracture zone from the Yellowstone Caldera eruption of 631,000 years ago.

Is Yellowstone's geothermal energy used to heat park buildings?

Yellowstone National Park's hydrothermal resources cannot be tapped for geothermal energy because such use could destroy geysers and hot springs, as it has done in other parts of the world.

Why can't I bring my dog on geyser basin trails?

Dogs have died diving into hot springs. They also disturb wildlife and are prohibited from all park trails. In the few places pets are permitted, they must be leashed at all times. Ask at a visitor center where you can walk a pet.

Is it really dangerous to walk off the boardwalks in geyser basins?

YES. Geyser basins are constantly changing. Boiling water surges just under the thin crust of most geyser basins, and many people have been severely burned when they have broken through the fragile surface. Some people have died. You may not be able to be detected thin crust above hot waters or acid vapors just by looking.

Why can't I smoke in the geyser basins?

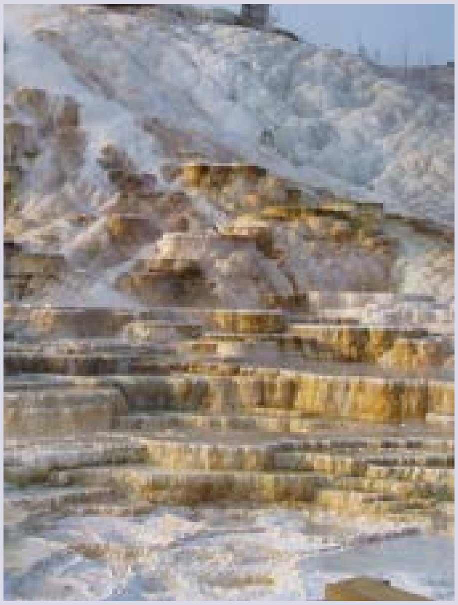
Cigarette butts quickly accumulate where smoking is allowed, and they—like any litter—can clog vents, thus altering or destroying hydrothermal activity.

Hydrothermal Features in Yellowstone

Fumaroles, or steam vents, are the hottest hydrothermal features in the park. The limited amount of water flashes into steam before reaching the surface. At places like Roaring Mountain (above), the result is a loud hissing of steam and gases.

Mudpots, such as those near Mud Volcano (above), are acidic features 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 minerals. Various gases escape through the wet clay mud, causing it to bubble. Mudpot consistency and activity vary with the seasons and precipitation.

Cone geysers, such as Riverside in the Upper Geyser Basin (left), erupt in a narrow jet of water. **Fountain geysers**, such as Great Fountain in the Lower Geyser Basin (right), shoot water in various directions, typically from a pool.



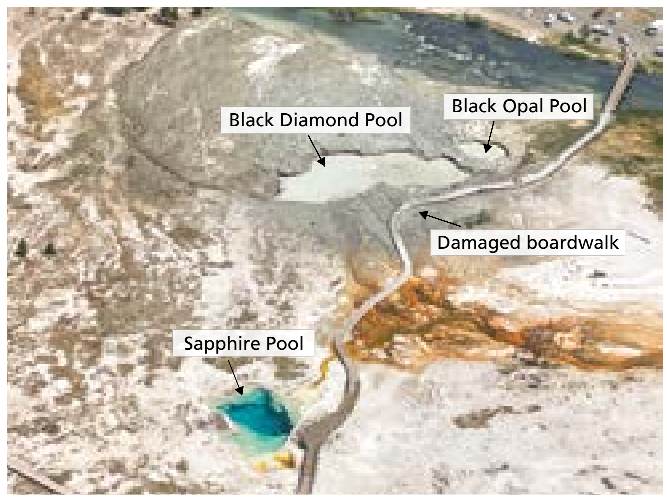
Travertine terraces, found at Mammoth Hot Springs (above), are formed from limestone (calcium carbonate). Water rises through the limestone, carrying high amounts of dissolved carbonate minerals. At the surface, carbon dioxide is released and carbonate minerals like calcite are deposited, forming travertine, the chalky white rock of the terraces. Due to the rapid rate of deposition, these features change constantly and quickly.

Hot springs, such as this one at West Thumb (above), 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 process, called convection, prevents water from reaching the temperature needed to set off an eruption.

How Geysers Erupt

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, similar to water pressure in the ocean. Increased pressure exerted by the enormous weight of the overlying 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. 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.

A section of boardwalk near the hydrothermal explosion at Biscuit Basin was destroyed. Although visitors were present at the time of the event, no injuries were reported.



Black Diamond Pool and Black Opal Pool were affected by the explosion but remain distinct features, although the shape of Black Diamond has changed somewhat.

to create three-dimensional images of geyser reservoirs and plumbing systems. This produced the first three-dimensional seismic images of the Old Faithful and Steamboat plumbing systems.

Hydrothermal Explosions

The rapid transition of water to steam in the subsurface is the phenomenon that drives both geyser eruptions and hydrothermal explosions. This rapid transition happens all the time in established geyser systems, like Old Faithful Geyser or Steamboat Geyser, where well-defined conduit systems allow that steam and hot water to rapidly escape to the surface and result in a geyser eruption.

When the energy released during the liquid to steam transition exceeds the confining force of the subsurface conduit and reservoir system, the pressure due to the expansion of steam bubbles overcomes the strength of the rock, and an explosion occurs. The explosion fragments the surrounding rock and creates jets of steam, water, and pieces of rock that vary from silt-sized particles to large boulders that can be strewn about hundreds of meters from the source vent.

On July 23, 2024, a hydrothermal explosion occurred when waters violently flashed to steam beneath Black Diamond Pool in Biscuit Basin. Multiple explosive jets sent steam and debris hundreds of feet into the air, destroyed the nearby boardwalk and ejected grapefruit-sized rocks tens to hundreds of feet from the source. Some blocks closest to the explosion site are about 3 feet (1 meter) wide and weigh hundreds of pounds. The explosion was largely directed to the northeast toward the Firehole River, and the largest blocks of debris fell in that direction. Geologists are collecting data from the explosion debris to better understand the exact conditions at the time of the event.

Similar, although smaller, hydrothermal explosions took place in 1989 at Porkchop Geyser in Norris Geyser Basin, and on April 15, 2024, from the Porcelain Terrace Area of Norris Geyser Basin. A small hydrothermal explosion occurred from Wall Pool, in Biscuit Basin, in 2009. Significant hydrothermal explosions, probably similar in size to that of July 23, 2024, occurred in the 1880s at Excelsior Geyser, in Midway Geyser Basin.

Hydrothermal explosions typically occur in the park one to a few times per year, but often in the backcountry where they may not be immediately detected.

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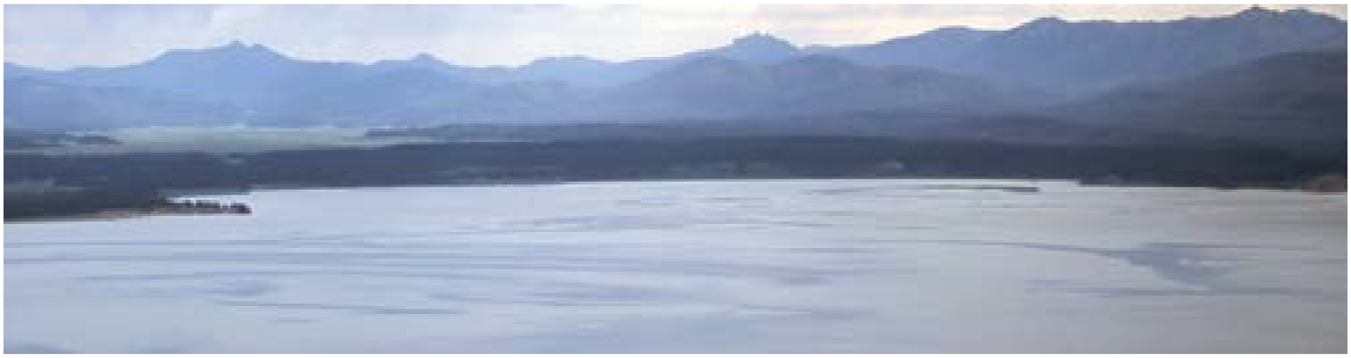

The geology below Yellowstone Lake reflects shaping by lava flows where the lake lies within the caldera and shaping by glacial and other processes in the southern half of the lake that lies outside the caldera.

Yellowstone Lake Geology

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 as they took 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, then suddenly very large, spire-like structures appeared in the photographic field of view. These structures looked similar to hydrothermal structures found in deep ocean areas, such as the Mid-Atlantic Ridge and the Juan de Fuca Ridge. The structures also provided habitat for aquatic species such as fresh-water sponges and algae.

Lake-bottom Surveys

From 1999 to 2007, scientists from the US 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 confirmed the northern half of the lake is inside the 631,000-year-old Yellowstone Caldera and mapped previously unknown features such as large hydrothermal explosion craters, siliceous spires, hundreds of hydrothermal vents, and craters and fissures. The survey also mapped young, previously unmapped faults, landslide deposits, and submerged, older lake shorelines. These features are part of an undulating landscape shaped by 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 processes shaping Yellowstone Lake and

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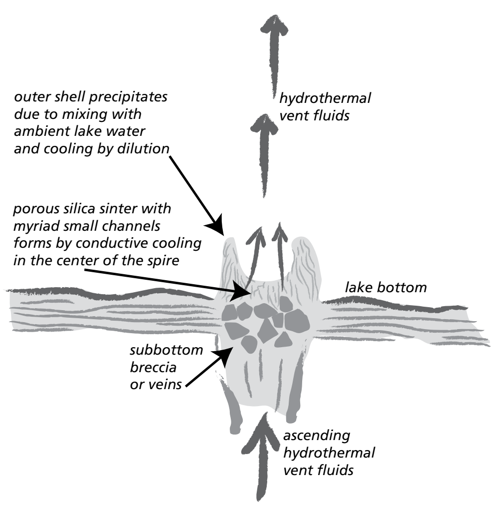
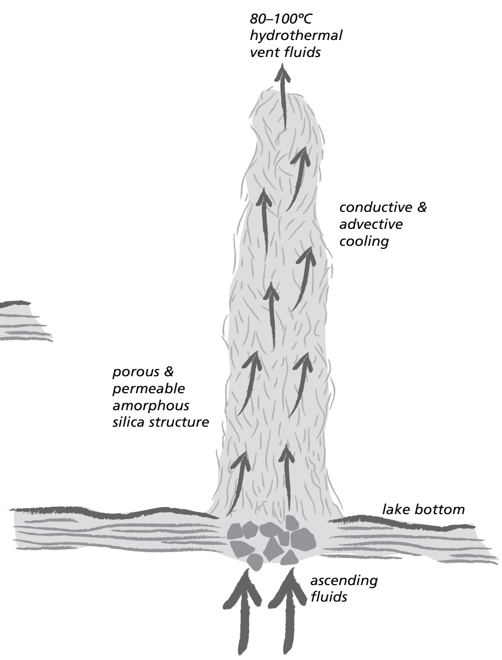
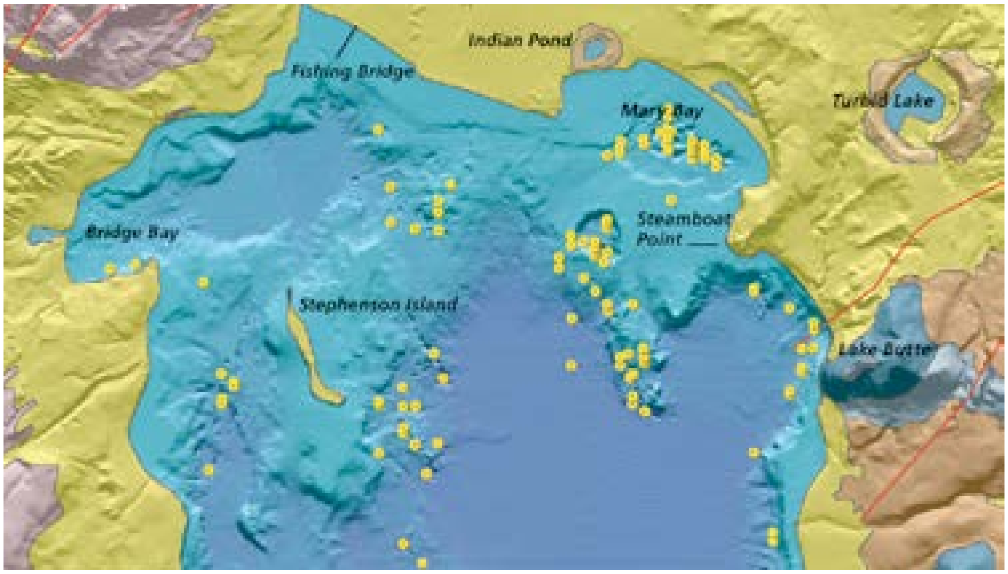




A photo of a Bridge Bay spire, initial spire growth (center), and a mature spire (right). Illustrations adapted from originals by Yellowstone National Park researcher and US Geological Survey research geologist Lisa Morgan.



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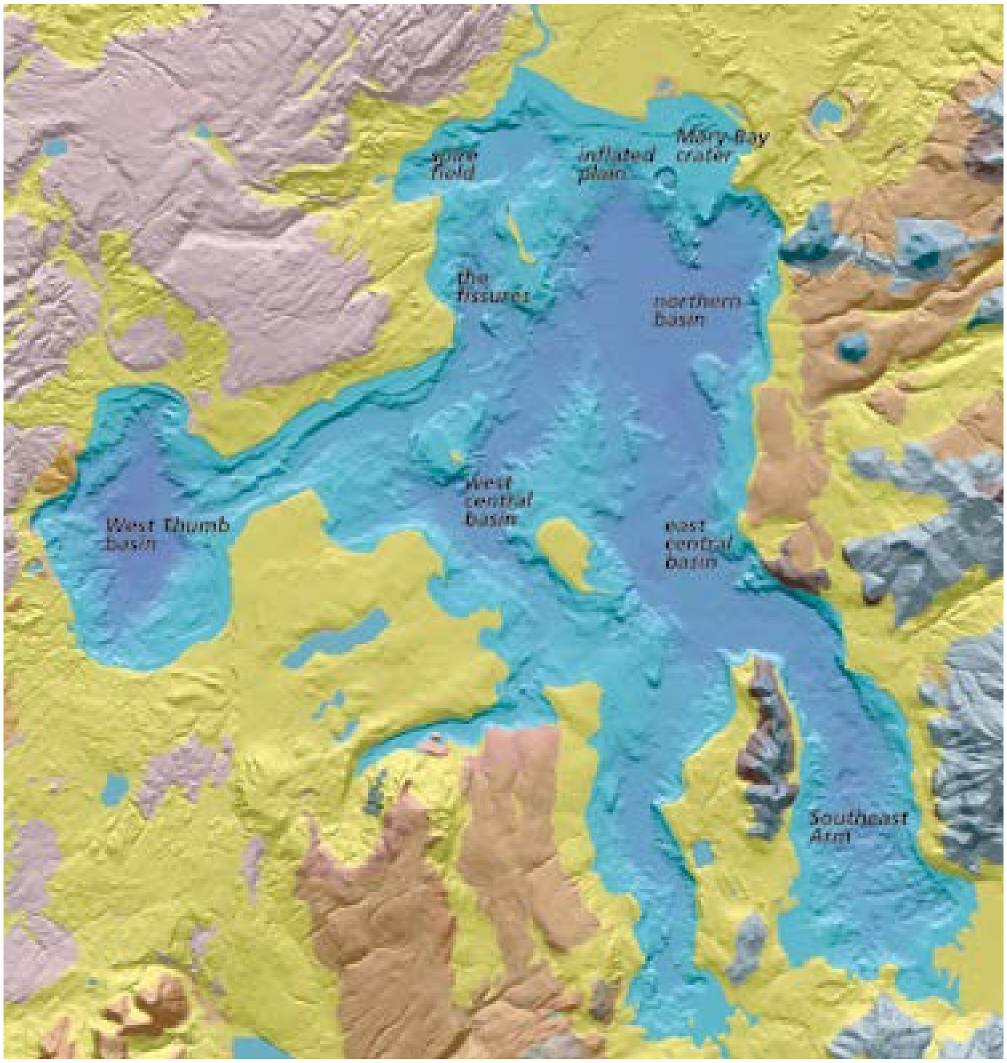

USGS/ LISA MORGAN

Yellowstone Lake has existed since the end of the Pinedale glaciation. The lake drains north from its outlet at Fishing Bridge into the vast Atlantic Ocean drainage via the Yellowstone River. The elevation of the lake's north end does not drop substantially until LeHardys Rapids, which is considered the northern geologic boundary of the lake. The top map shows locations of hydrothermal vents in northern Yellowstone Lake; the map below shows the geologic features of the lake bottom. Both maps resulted from the five-year survey project.

determine geologic influences affecting the present-day aquatic biosphere. For example, hydrothermal explosions formed craters at Mary Bay, Turbid Lake, and Indian Pond. Spires may form similarly 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 pieces of spires and a complete 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.

Tests by the US Geological Survey show that the spire is about 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. The spire's interior shows evidence of thermophilic bacteria. Scientists say this suggests that silica precipitated on bacterial filaments, thus playing an important role in building the spire.

These and other research projects are expanding our understanding of the geological processes 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.

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Anywhere from 700 to 3,000 earthquakes occur each year in the Yellowstone area; most are not felt. The 1959 Hebgen Lake earthquake (7.3 *M*) caused significant damage to park roads, shown here near Gibbon Falls.

Earthquakes

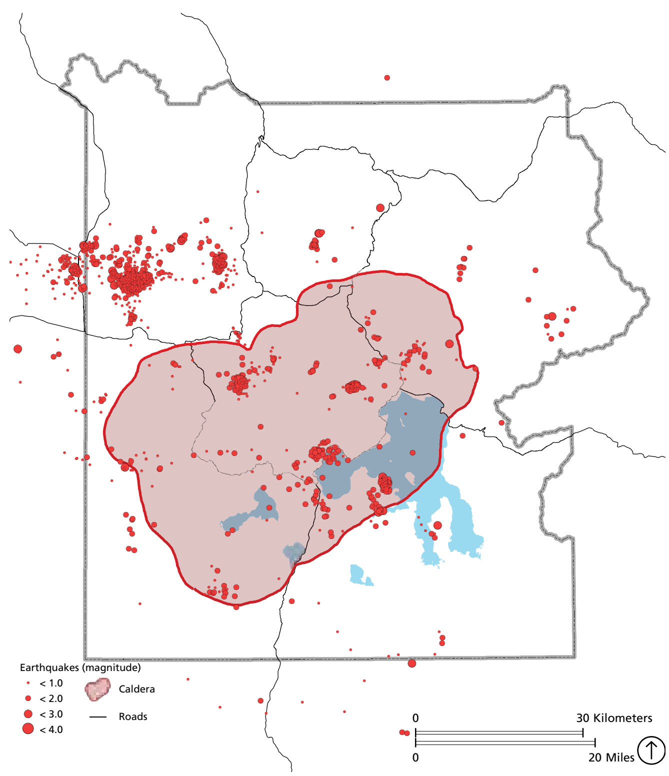
Yellowstone is one of the most seismically active areas in the United States. Approximately 700 to 3,000 earthquakes occur each year in the Yellowstone area; most are not felt. They result from the extensive network of faults associated with the volcano and surrounding tectonic features. Yellowstone earthquakes tend to occur in swarms—close together in time and space. This phenomenon is related to transport of volcanic fluids along the many small fractures in the shallow rocks over the magma, a pattern that has been noted in volcanos around the world.

Earthquakes occur along fractures in the crust where stress from crustal plate movement and volcanic activity build to a significant level. The rock along these faults becomes so strained that eventually it slips or breaks. Energy is then released as shock waves (seismic waves) that reverberate throughout the surrounding rock. 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 of both horizontal and vertical ground motion.

In Yellowstone, earthquakes help to maintain hydrothermal activity by keeping the "plumbing" system open. Without periodic disturbance from 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 (7.3 *M*) and 1983 Borah Peak (6.9 *M*) earthquakes caused measurable changes in Old Faithful Geyser and other hydrothermal features.

Yellowstone commonly experiences "earthquake swarms"—a series of earthquakes over a short period of time in a localized area. The largest swarm occurred in 1985, with more than 3,000 earthquakes recorded during three months on the northwest side of the park. Hundreds of quakes were recorded during swarms in 2009 near Lake Village and 2010 between Old Faithful area and West Yellowstone, MT. Scientists posit these swarms are due to shifting and changing pressures in the Earth's crust that are caused by migration of hydrothermal fluids, a natural occurrence of volcanoes.

The Maple Creek Swarm began on June 12, 2017, and persisted until October. A cluster of more than 2,475 earthquakes was recorded in the area six miles



Approximately 1,950 earthquakes with magnitudes greater than 0.0 occurred in and directly outside of Yellowstone in 2018. Earthquake data provided courtesy of University of Utah Seismograph Stations Network.

north of West Yellowstone, Montana, and on the west side of the park. Earthquake sequences like these are common and account for roughly 50% of the total seismicity in the Yellowstone region

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

On June 16, at 6:48 PM Mountain Daylight Time, the largest earthquake of 2017 occurred. The magnitude 4.4 quake was located about nine miles north-northwest of West Yellowstone, Montana. The earthquake was reported felt in the towns of Gardiner and West Yellowstone, Montana. It was the largest quake since the 4.8 *M* that occurred on March 30, 2014. This earthquake was part of an energetic swarm in the same area.

Beginning in the fall of 2015, the University of Utah, in collaboration with the University of Texas El Paso and Yellowstone National Park began deploying seismic instrumentation around Old Faithful and the Upper Geyser Basin. Repeat deployments have been done in 2016, 2017, and 2018 as well. The goals of this work are to image the subsurface of the geyser basin and in particular, the plumbing system of Old Faithful, as well as to record seismic signals related to hydrothermal activity that can shed light on how these systems work. In total, they have installed around 980 nodal seismometers in and around the Upper Geyser Basin. They have revealed the plumbing system of Old Faithful down to about 80 meters (~260 feet).

Starting in 2018, and continuing into 2019, due to the increased activity of Steamboat Geyser, they started doing similar deployments in the Norris Geyser Basin. These deployments have focused on recording major eruptions of Steamboat Geyser and imaging the subsurface connection between Steamboat Geyser and Cistern Pool (which drains shortly after major eruptions of Steamboat). These data provide an unprecedented look into the Steamboat Geyser (the tallest active geyser in the world) eruption process during this historic run of activity.

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Real-time earthquake data: www.seis.utah.edu

University of Utah Yellowtone Research: www.uusatrg.utah.edu/

Yellowstone Volcano Observatory: volcanoes.usgs.gov/yvo

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Much of Yellowstone was shaped by glaciers. Glacial erratics are scattered across Yellowstone's landscape, as shown here alongside a glacially formed pond in the Lamar Valley.

Glaciers

Glaciers result when, for a period of many years, more snow falls in an area than melts. Once the snow reaches a certain depth, it turns into ice and begins to move under the force of gravity or the pressure of its own weight. During this movement, rocks are picked up and carried in the ice, and these rocks grind and sculpt Earth's surface. Once the glacier eventually melts and recedes, rocks and sediments are released from the ice or transported by meltwater streams, and deposited on the surface. Large U-shaped valleys, ridges of debris (moraines), and out-of-place boulders (erratics) are evidence of a glacier's passage across a landscape.

Yellowstone and much of North America have experienced numerous periods of glaciation during the last 2.6 million years. Succeeding periods of glaciation have destroyed most surface evidence of previous glacial periods, but scientists have found evidence of them in sediment cores taken on land and in the ocean. In Yellowstone, a glacial deposit near Tower Fall dates back 1.3 million years. Evidence of such ancient glaciers is rare.

About 150,000 to 140,000 years ago, glaciers covered the Yellowstone region in an episode known as the Bull Lake glaciation. Evidence exists that this glacial episode extended farther south and west of Yellowstone than the subsequent glaciation, known as the Pinedale, but little surface evidence of it is found to the north and east. This indicates that the Pinedale glaciation covered or eroded surface evidence of Bull Lake glaciation in these areas.

The Yellowstone region's last major glaciation, the Pinedale, is the most thoroughly studied. Its beginning has been hard to pin down because field evidence is missing or inconclusive and dating techniques are inadequate. Ages of the Pinedale maximum vary around the Yellowstone Ice Cap from 20,000 years ago on the east to 18,000 years ago on

MODIFIED BY J. LICCIARDI IN JANUARY 2023 FROM LICCIARDI AND PIERCE (2018)

Light shaded areas bounded by black and red lines indicate the areas covered during the Pinedale and Bull Lake glaciations, respectively. Blue lines are contours in thousands of feet on the reconstructed Pinedale glacier surface. Black dashed lines with double-pointed arrows indicate main ice divides. Yellowstone and Grand Teton National Park boundaries are shown by green outlines.

the north and possibly as young as 16,000–15,000 years ago on the south. Most of the Yellowstone Plateau became ice-free between 15,000–14,000 years ago.

During the Pinedale glaciation, glaciers advanced and retreated from the Beartooth Plateau, altering the present-day northern range. During glacial retreat, meltwater flowed through and covered Hayden Valley, depositing various sediments. Glacial dams also backed up water in the Lamar Valley; when the dams failed, catastrophic floods helped to form the modern landscape around the North Entrance of the park.

During the peak of the Pinedale glaciation, the center of the Yellowstone Plateau was covered by an ice cap that was over 3,500 feet thick. Mount Washburn was completely covered by ice. This ice cap was not part of the continental ice sheet extending south from Canada. A large ice cap formed on the Yellowstone volcanic plateau, in part, because the Yellowstone hot spot caused uplift of this region, and the resulting high elevations allowed large amounts of snow to accumulate.

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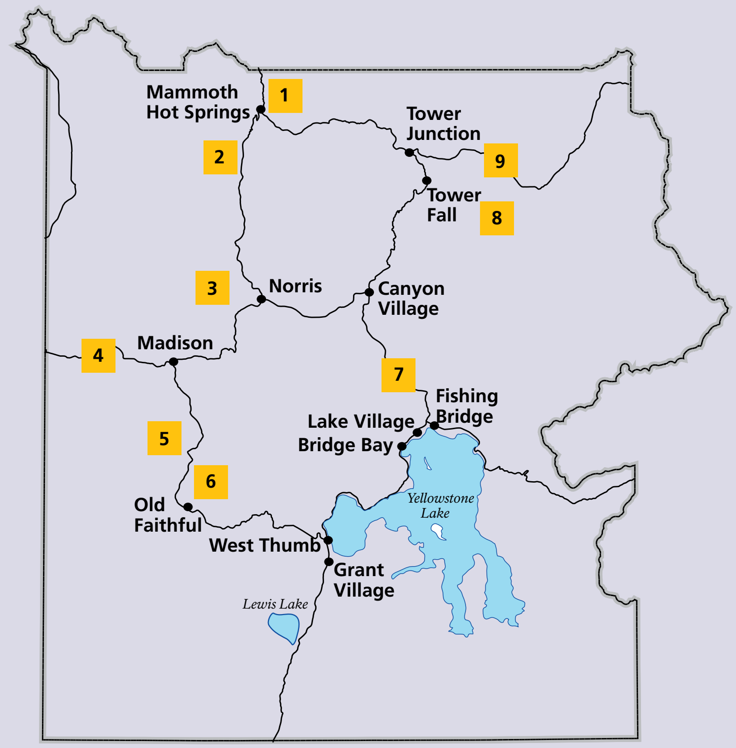
Where to See Evidence of Glaciers



1. Mammoth Hot Springs: Thermal kames (steep-sided mounds of sand and gravel deposited by melting ice sheets) exist in this area. Mount Everts and Bunsen Peak were both overridden by ice. The top of Sepulcher Mountain peeked above the Pinedale ice.
2. Swan Lake Flat: These meadows and wetlands formed after the glaciers retreated. Electric Peak, to the northwest, was also sculpted by glaciers.
3. Norris Geyser Basin: Several high peaks in the Gallatin Mountains stood above the Pinedale ice cap.
4. Madison Valley, west of Seven Mile Bridge: Glacial moraines, glacial outwash, and recent Madison River deposits can be seen.
5. Fountain Flats: The Porcupine Hills and Twin Buttes are thermal kames.
6. Upper Geyser Basin: Volcanic rocks and ice-water contact deposits are present here. Deposits underlying this and other geyser basins in the area store the water necessary for geysers to occur and allow the water to percolate up from depth.
7. Hayden Valley: The valley is floored with glacial lake sediments that formed when Pinedale ice dammed the Yellowstone River and created a lake. The valley also has a variety of large boulders, known as glacial erratics, that were carried here by ice that flowed south from the Beartooth Mountains. The glacial lake sediments contain an abundance of fine grain sizes, including clay, that do not allow water to percolate quickly into the ground. Thus, Hayden Valley is marshy.
8. Tower Fall area: North of Tower Fall, sediments between layers of basalts may show evidence of the oldest known glaciation in Yellowstone. Plus, huge glacial erratics from the last major glaciation rest atop the youngest basalt.
9. Lamar Valley: Huge boulders and ponds between the Lamar and Yellowstone rivers were left by melting glaciers, as were several moraines. Other ponds have formed within post-glacial landslides.

GEOLOGY

Sedimentation and erosion actively shape Yellowstone's landscape. Here, the Lamar River erodes its banks and transports the sediment for deposition elsewhere.

Sedimentation and Erosion

Not all the rocks in Yellowstone are of "recent" volcanic origin. Precambrian igneous and metamorphic rock in the northeastern portion of the park and on Beartooth Plateau are at least 2.7 billion years old. These rocks are very hard and erode slowly.

Sedimentary sandstones and shales, deposited by seas during the Paleozoic and Mesozoic eras (approximately 540 million to 66 million years ago) can be seen in the Gallatin Range and Mount Everts. Sedimentary rocks in Yellowstone tend to erode more easily than the Precambrian rocks.

Weathering breaks down earth materials from large sizes to small particles, and happens in place. The freeze/thaw action of ice is one type of weathering common in Yellowstone. Agents of erosion—wind, water, ice, and waves—move weathered materials from one place to another.

When erosion takes place, sedimentation—the deposition of material—also eventually occurs. Through time, sediments are buried by more sediments and the material hardens into rock. This rock is eventually exposed (through erosion, uplift, and/or faulting), and the cycle repeats itself. Sedimentation and erosion are "reshapers" and "refiners" of the landscape—and they also expose Yellowstone's past life as seen in fossils like the petrified trees.

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GEOLOGY

Left: The Beartooth Mountains northeast of Yellowstone are actually an uplifted block of Precambrian rock. Right: Mt. Everts, near Mammoth, exposes sedimentary rock, which erodes easily and often tumbles or slides into Gardner Canyon.

Petrified trees in Yellowstone are the result of volcanic debris flows that occurred about 50 million years ago. This piece of petrified wood shows annual rings.

Fossils

The fossil record of Yellowstone is one of the most diverse in the NPS. Fossils of plants, invertebrates, vertebrates, and trace fossils have been identified from more than 40 stratigraphic units (rock layers of known age and origin) spanning more than 540 million years from the Cambrian to the Quaternary.

Paleontological resources, or fossils, are any remains of past life preserved in geologic context. Yellowstone contains the two main types of fossils: body fossils and trace fossils. Body fossils are the physical remains of an actual organism (shells, bones, teeth, plant leaves, trees, stumps, etc.), while trace fossils (burrows, coprolites, footprints, trackways, etc.) preserve indirect evidence of an organism's activity or behavior. Best known in Yellowstone are the fossil forests of Specimen Ridge, where the remains of hundreds of 50-million-year-old trees stand exposed on a steep hillside, with trunks up to eight feet in diameter and some more than 20 feet tall.

Although the park's paleontologic resources are extensive and scientifically valuable, it is estimated that only 3% of the park's potentially fossil-bearing units have been assessed. Erosion is the key to discovery of nearly all paleontological specimens; however, once exposed, fossils are subjected to physical and chemical forces that can quickly become destructive to them.

Fossils are a non-renewable resource. Road construction, other infrastructure development, and illegal collecting can also impact fossil-bearing units. Due to the fragility of most fossils, it is necessary to inventory and document fossil localities to evaluate existing fossil material and obtain baseline information so that appropriate management decisions can be made about these areas.

Yellowstone fossils have long been studied and have already contributed to important scientific findings. Research in the park by Charles Walcott on trilobites in the late 1800s influenced his theory of the "Cambrian Explosion," a term he used to describe the relatively sudden appearance of complex multi-cellular life possessing "hard parts" such as phosphatic or calcitic exoskeletons.

Sediment cores from the bottom of Yellowstone's lakes contain fossils of pollen deposited during the Late Pleistocene. These pollen records show which plants were present at that time and allow researchers to infer climate conditions. The pollen in sediment layers illustrates the changes in vegetation and climate over time, providing a model of regional reforestation and climate history.

Paleontologists have also devoted much attention to the Eocene fossil plant material in the park, using it to inform regional studies of the paleoclimate and paleoecology of that period. Much could be gained in understanding current global climate change by studying Eocene times, which include an episode of rapid and intense warming when our planet was at its hottest in the past 70 million years.

Paleobotany

More than 150 species of fossil plants (exclusive of fossil pollen specimens) from Yellowstone have been described, including ferns, horsetail rushes, conifers, and deciduous plants such as sycamores, walnuts, oaks, chestnuts, maples, and hickories. Sequoia is abundant, and other species, such as spruce and fir, are also present.

Most petrified wood and other plant fossils come from Eocene deposits about 50 million years old, which occur in many sites in the northern parts of the park. The first fossil plants from Yellowstone were collected by the early Hayden Survey parties. In his

A fossil cone of *Pinus macrolepis*, collected in the Lamar River Valley. This rare fossil cone gives new insight into the plants of the Eocene.

This trilobite, *Tricrepicephalus yellowstonensis*, is about 500 million years old. Every year, new species of trilobites are being discovered all over the world.

The second molar of a brontothere. The tooth is black, set in the gray-white fragment of the jaw bone.

1878 report, William Henry Holmes made the first reference to Yellowstone's fossil "forests."

In 1889, F. H. Knowlton identified 147 species of fossil plants from Yellowstone, 81 of them new to science. He also proposed the theory that the petrified trees on the northwest end of Specimen Ridge were forests petrified in place.

Additional studies and observations informed a modification of Knowlton's original hypothesis. Andesitic volcanic eruptions such as the 1980 eruption of Mount St. Helens showed that trees are uprooted by rapidly flowing volcanic debris flows. The volcanic debris flows not only transported trees to lower elevations, but research shows that approximately 10–15% of the trees were deposited in an upright orientation. Thus, with increased scientific knowledge, our understanding of Yellowstone's fossil forests has changed.

Cretaceous marine and nonmarine sediments are exposed on Mount Everts and other areas in Yellowstone. Similar to Cretaceous rocks throughout the Rocky Mountains, fossil leaves, ferns, clam-like fossils, shark teeth, and several species of vertebrates have been found. In 1994, fossil plants were discovered in Yellowstone during the East Entrance road construction project, which uncovered areas containing fossil sycamore leaves and petrified wood.

Fossil Invertebrates

Fossil invertebrates are abundant in Paleozoic rocks, especially the limestones associated with the Madison Group in the northern and south-central parts of the park. As far back as the first expedition in Yellowstone National Park, invertebrate fossils have been documented. Fossil invertebrates give insight into the paleoenvironment and paleoclimate of an area.

Brachiopods were common during the Paleozoic era (between about 540 and 250 million years ago). They had hard shells and a valve that kept them anchored to the sea floor, and they liked to live in calmer ocean locations. The presence of this fossil in Yellowstone means that the area was home to an inland sea at various times during the Paleozoic.

Long before fish occupied the seas and dinosaurs roamed the land, planet Earth was home to numerous marine invertebrates including trilobites. Trilobites thrived during the Paleozoic era as well. Trilobites were once so abundant, they could be found in nearly every sea and ocean. Today, their fossil distribution helps us understand Earth's history. With more than 20,000 described specimens, trilobites are considered the single most diverse class of extinct organism and can be found in Paleozoic rocks all over the world.

At least 38 national parks have documented trilobites, including Yellowstone National Park. Late 1800s explorer William Henry Holmes recognized large trilobite deposits and gave "Trilobite Point" on Mount Holmes its name. Trilobites reveal fascinating facts about our planet; because of their great diversity, trilobites can offer insights into paleoenvironments, paleoclimate, biostratigraphy, and evolutionary biology associated with the greater Yellowstone area.

Yellowstone fossil invertebrates include corals, bryozoans, brachiopods, trilobites, gastropods, and crinoids. Trace fossils, such as channeling and burrowing of worms, are found in some petrified tree bark.

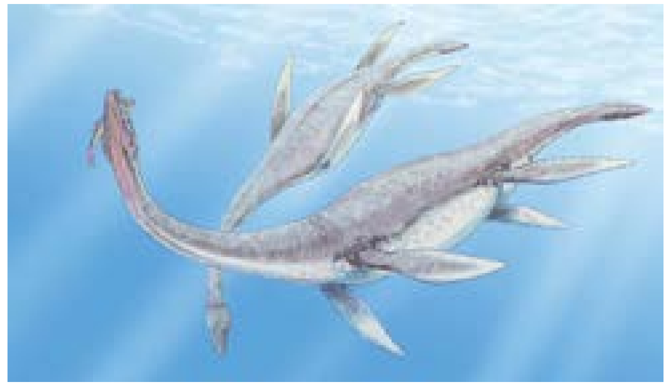
Fossil Vertebrates

Fossil remains of vertebrates are rare, but perhaps only because of insufficient field research. A one-day survey led by paleontologist Jack Horner, of the Museum of the Rockies in Bozeman, Montana, resulted in the discovery of the skeleton of a Cretaceous vertebrate. Other vertebrate fossils found in Yellowstone include

- Fish: Middle Mississippian and Early Permian shark teeth and spines, Early Permian bony fish teeth, cranial plates, and isolated scales; Middle Cretaceous bony fish scales and a hybodont shark spine.
- Horse: possible Pleistocene horse, reported in the 1890s from now-missing fossils.
- Other mammals: Holocene mammals recovered from Lamar Cave; brontothere tooth and mandible found on Mt. Hornaday in 1999.

A partial tooth and jaw segment was found in Early Eocene (49–47 million years ago) volcanic sediments on Mount Hornaday in 1998 by a USGS wildlife biologist. This fossil represents the early brontothere Palaeosyops, a tapir-sized relative to horses, rhinos, and tapirs. These herbivores would evolve to be some of the largest mammals on the planet by the end of Eocene, living in both dense forests and open woodlands, before going extinct 34 million years ago.

Plesiosaurs were large aquatic reptiles that existed from the late Triassic through the Cretaceous Period. These aquatic marine reptiles once dominated the seas, and the largest plesiosaurs were among the biggest predators of all time. The skeleton of what may be a Cretaceous plesiosaur was discovered in Yellowstone National Park nearly two decades ago.


DMITRY BOGDANOV

Potential plesiosaur bone fragments were discovered in 1996.

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GEOLOGY