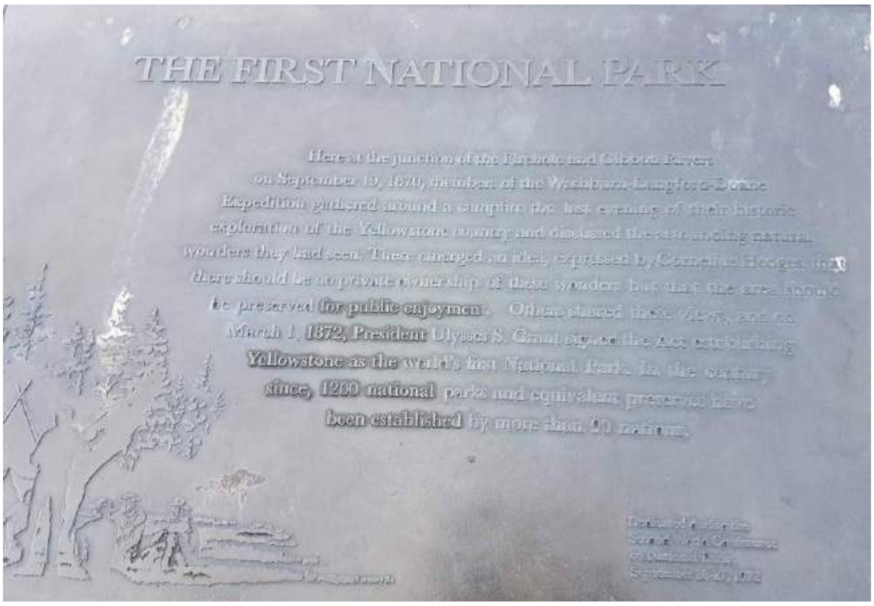
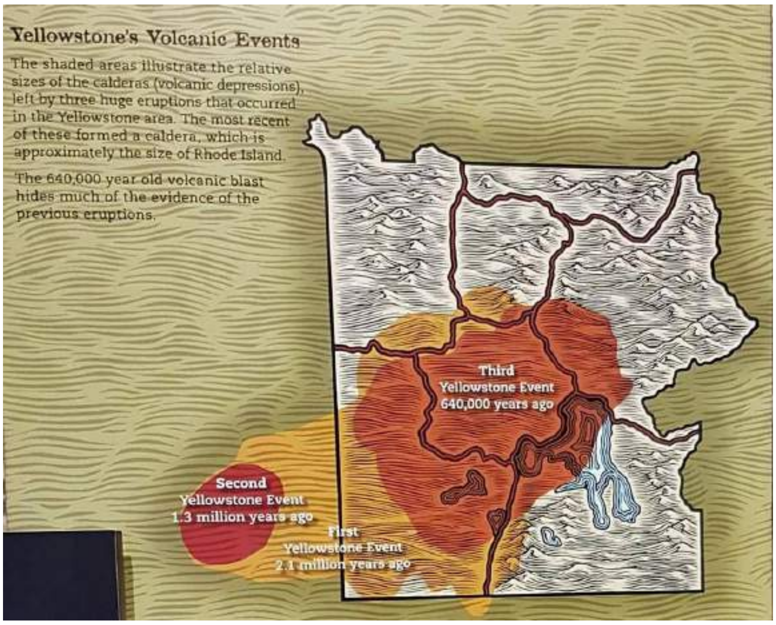
Yellowstone National Park: A guide to geothermal features.

On March 1st, 1872 by President Ullysses S. Grant, the Yellowstone Park Act was signed into law; the world's first national park was established. It has been designated a U.S Biosphere Reserve, a World Heritage Site. Its boundaries protect over 10,000 geysers, hot springs, mud pots and steam vents – the Earths largest array of geothermal features. The Yellowstone Caldera is a volcanic caldera and supervolcano, roughly between 34 and 45 miles.



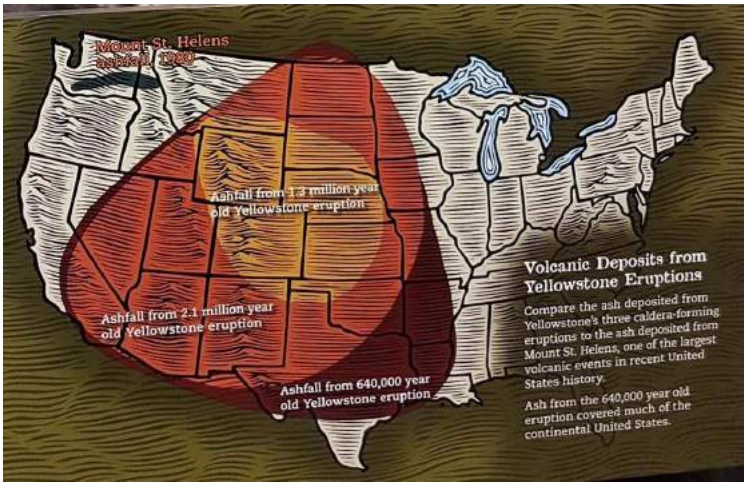
<u>Yellowstone Volcano</u>

The central portion of the park is an immense depression, or caldera, that resulted from a volcanic eruption that occurred 640,000 years ago; ash from this eruption covered much of the continental United States. Since then 80 lava flows have occurred here.

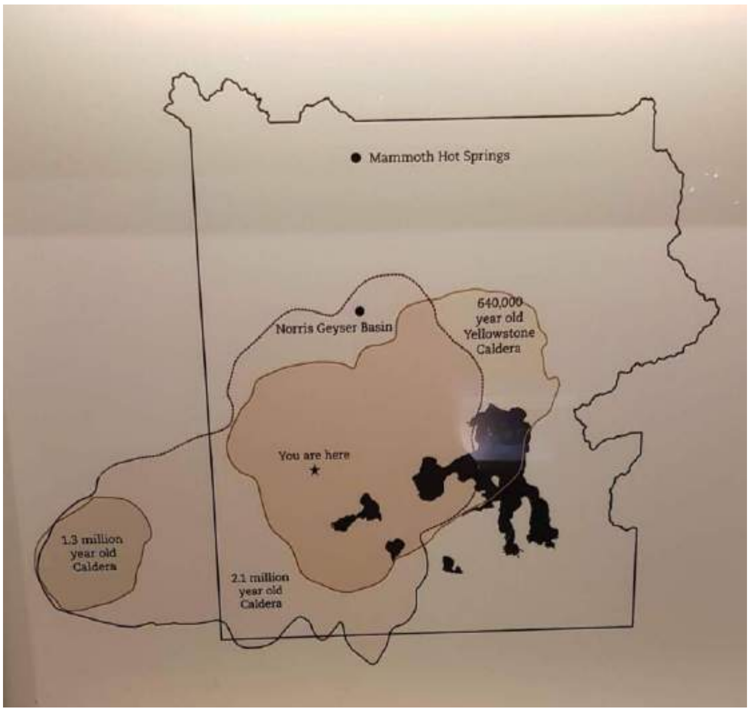


Mapped is the sizes of the calderas from events up to 2.1 million years ago. The most recent caldera is believed to be the size of Rhode Island.

Yellowstone is a hotspot, a place of long lived volcanic activity. The hotspot associated with Yellowstone has been active for at least 16 million years. A shallow body of magma makes the ground beneath the park unusually hot, while the magma origins are still unknown. The magma chamber is believed to be up to some 400 miles deep.



Comparing the ash deposited from the previous three eruptions, in comparison to Mount St Helens ash fall.



The relationship between the location of the calderas, faults, and earthquakes in Yellowstone National Park. These correlations give scientists new insight into the parks living volcano.

Geysers

Yellowstone is home to the world's largest collection of geysers, with 300 active geysers present. This indicates the presence of a very hot, very large, and very active heat source.

Geysers are hot springs that erupt periodically. The geysers of Yellowstone need an active heat source, abundant water, and fractures that are kept open by frequent earthquakes. The blend of these elements is unique to each geyser, which have their own underground story and above ground show.

There are two different types of geysers, cone geysers and fountain geysers. Fountain geysers have large surface basins that fill with water before an eruption and then empty after the geyser erupts. Often water shoots out in various directions during an eruption. Most cone geysers have a constriction in their underground channels, close to the vent. The constriction acts like a nozzle, causing the water to jet in columns. Siliceous sinter forms the cone.

Water seeps deep into the Earth. Meeting hot rock, the water superheats and rises through fissures and weak places in the rock. A tight spot in the fracture system traps the hot water. Pressure and heat build. Confined steam bubbles move so violently that they force water through the constriction. This releases pressure, causing much of the water in the system to flash to steam. Tremendous amounts of steam force the remaining water from the geyser's vent.

Earthquakes help maintain geysers, such as Old Faithful, by keeping the underground system open. Without small, periodic tremors, mineral deposits would build up and possibly seal the subterranean fractures. On the other hand, earthquakes can change a geyser's eruption pattern and frequency or completely destroy the fragile network of underground fractures.

The Upper Geyser Basin is home to over one quarter of the world's geysers, which is within sight of the Old Faithful visitor centre. The Geyser Hill Loop trail passes through the largest concentration of geysers on Earth.

In 1870, the Washburn-Langford-Doane Expedition camped in the Upper Geyser Basin. The explorers observed many of the same geysers and hot springs that we see today. Many of the features' names date from that early expedition: Beehive Geyser for its characteristic cone, Riverside Geyser for its location near the Firehole River, and, of course, Old Faithful for its reliable eruption.

Old Faithful

Location: Upper Geyser Basin

Like other geysers, Old Faithful has a constriction near the top of its system that obstructs the rise of hot water, which are at risk of becoming blocked.

It requires abundant water, as each eruption expels enough water to fill more than 150 bath tubs. The water begins as precipitation, percolating into the Earth. Along the way, water becomes superheated and dissolves minerals from the surrounding rock, as well as mixing with cool water tricking into the system from rain and snow. The water's journey may last a decade or thousands of years.

Yellowstone's active volcano is the heat source that fuels the geyser. A shallow body of magma heats adjacent rock. The rock transfers heat by conduction to the groundwater that has percolated down from surface precipitation. The water may emerge calmly as a scalding pool or erupt in a violent display of frothing water and steam.

Giant Geyser

Location: Upper Geyser Basin

Giant Geyser is one of the largest in the world.

Historic accounts describe Giant's eruptions soaring to heights of 250 to 300 feet. However, recent eruptions have ranged from 200 to 250 feet.

It displays cycles of activity and dormancy. The unpredictability of Giant is due, in part, to interconnections between it and the geysers and hot springs of the nearby Grotto Group.

The large sinter shroud surrounding Giant's vent may be an indication of the geysers great age. The slow accumulation of mineral indicates that it could be thousands of years old.

Castle Geyser

Location: Upper Geyser Basin

The massive cone of Castle Geyser is a sign of old age. The cone has been carbon dated to around 1022 AD and rests upon a much older hot spring. By contrast, Old Faithful's cone may only be a few hundred years old.

Castle Geyser has dramatically changed its surroundings. By altering soil chemistry, the geyser has devoured part of the pine forest and turned it into a thermal desert. Tree skeletons are entombed within the cone.

Grand Geyser

Location: Upper Geyser Basin

The tallest predictable geyser in the world.

Erupts in a series of powerful bursts from its crater or pool.

The Grand Group consists of Grand Geyser, Turban Geyser and Vent Geyser. These three geysers share a subterranean source of hot water. Turban erupts more frequently than the other two. Grand will erupt just before or after Turban erupts. Finally, vent geyser will come to life, jetting water to heights of 75 feet. Though Grand's eruptions last only about 10 minutes, Vent and Turban can continue to erupt for an hour or more.

Grotto Geyser

Location: Upper Geyser Basin

Perhaps the most unusual of Yellowstone's geysers.

Geologists believe that hundreds (or thousands) of years ago, Grotto emerged in a stand of dead or dying trees and, through time, deposited layer upon layer of siliceous sinter (silica) over the stumps and branches.

Excelsior Geyser

Location: Midway Geyser Basin

Excelsior Geysers rugged crater was created by rare massive geyser eruptions.

In the 1880s Excelsior erupted in bursts 50 to 300 feet high. The thermal violence formed the jagged crater and apparently ruptured the geyser's underground system, causing eruptions to cease after 1890.

On September 14, 1985, Excelsior roared back to life with 47 hours of major eruptions.

It is impossible to predict when this dormant but powerful geyser's next eruption will occur.

Though its eruptions have been erratic, the geyser's outflow is nearly constant, pumping more than 4,000 gallons of boiling water per minute over the crater rim into the Firehole River.

Steamboat Geyser

Location: Norris Geyser Basin

The tallest active geyser in the world, although it is impossible to predict.

Prior to 1904, Waimangu Geyser, in New Zealand, had some taller eruptions capable of reaching 1,600 feet, but, a landslide changed the local water table, and since then, Waimangu has not erupted. Excelsior Geyser in Yellowstone's Midway Geyser Basin likewise was taller, with eruptions reaching 300 feet. However, Excelsior has not erupted since 1985.

Steamboat was dormant from 1911 to 1961.

Sits close to Echinus, a rare acidic geyser.

Porkchop Geyser

Location: Norris Geyser Basin

Was once a hot spring that erupted occasionally. Its eruptions gradually became longer and stronger.

The suspended rocks around the geyser are a result of Porkchop Geyser’s hydrothermal explosion in 1989. Porkchop’s vent failed to relieve a surge in underground pressure. It exploded creating another chapter in the geyser’s dramatic history. Porkchop has behaved as a quiet hot spring, a geyser, a perpetual spouter, and after the explosion, a hot spring again.

Geologists attribute changes like the 1989 explosion to geologic events underground – heat shifts, earthquakes, mineral build up, and pressure changes.

The hydrothermal explosion destroyed the near surface part of the geyser's plumbing system. Pieces of its vent were blown onto the ground, providing a rare opportunity to see the interior of a geyser.

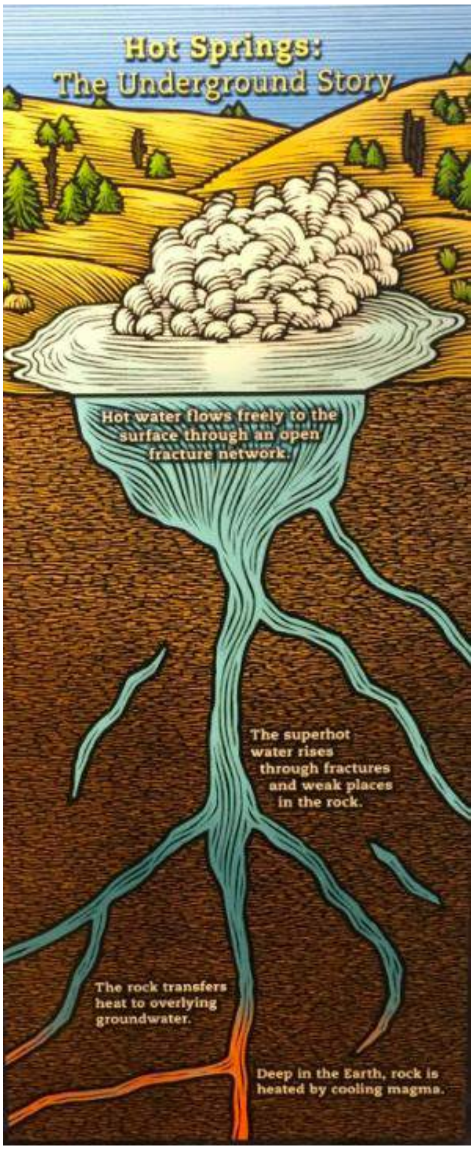
Name	**Geyser Type**	**Height (feet)**	**Duration**	**Amount of water expelled**	**Frequency**
Old Faithful	Cone	90-184	3-10 minutes	3,700-8,400 gallons	45-125 minutes
Giant	Cone	200-300	1-1.5 hours	>1 million gallons	Unpredictable
Castle	Cone	75	20 minutes	n/a	10-12 hours (2 per day)
Grand	Fountain	150-200	9-12 minutes	n/a	2-3 times per day
Grotto	Fountain	10	1-10 hours	n/a	8 hours
Excelsior	Fountain	50-300	1-3.5 minutes	n/a	Unpredictable
Steamboat	Cone	10-300+	3-40 minutes	n/a	1 month-10 years (Unpredictable)

Hot springs

A hots spring is produced by the emergence of geothermally heated groundwater and rises to the Earth’s crust. Hot springs are the most common hydrothermal features, especially in Yellowstone where thousands of hot springs dimple the parks landscape. 60% of the worlds geysers and hot springs are inside the national park.

Water, coming mainly from rain and snow melt, sweeps down into the Earth and becomes superheated. Then water begins to rise towards the Earth's surface through cracks and fissures in the rock. The underground fractures systems of hot springs are open, allowing hot water to circulate freely to the surface. All thermal features are at risk due to their complex plumbing systems that take centuries of development.

Bright colours from hydrothermal basins are from trillions of individual microorganisms grouped together that appears a mass of colour.



Grand prismatic spring

- Prismatic is defined as brilliantly coloured
- Approximately 200 feet (61 m) across
- High temperature of 160° F (70 °C)
- Cloaked in steam

The largest hot spring in Yellowstone, the largest in the United States and third largest in the world.
The pools depth, heat and clarity make its water appear blue. This intense blue colouring in the centre of the hot spring is due to sunlight being scattered by fine particles suspended in the water.
Organisms form colourful rings around the pool edges. The yellow, orange and brown colours lining the run off and encircling the spring are caused by thermophiles – heat loving microorganisms. These microbes contain colourful pigments that make energy from sunlight and thrive in harsh conditions.
The hot spring pours almost 500 gallons of hot water each minute into the Firehole river. Minerals dissolved in the hot water are deposited and gradually builds the terraced shoulders of the feature.

Morning Glory Pool

- 5.8 PH – close to milk.

Morning glory pool once resembles a Morning Glory flower, whereby was named in 1883 by wife of Assistant Park Superintendent Charles McGowan when she stated it resembled the flower.

Due to ignorance and vandalism, people tossing coins and debris into the spring has damaged the circulation system and altered its appearance. In turn the loss of colour is a result from the clogging of the vent and therefore lowering the temperature. Brown, orange and yellow algae-like bacteria thrive in the cooler water, gradually turning the vivid aqua blue to a murkier greenish brown. The future of morning glory is uncertain and is becoming “Faded Glory’.

Dragons mouth spring

- Temperature – 170.2 °F
- PH – 5.4 – close to black coffee

This spring has at least 17 different names, Tongues of water and snorts of steam inspired the current name, Dragon's mouth. Located just down from the mud volcano, Dragon's Mouth Spring boils out of a deep cave. Gasses and steam are released deep in the cave, creating pressure bubbles that explode against the roof of the cave.

Due to the high temperature of the water rising in the surface, hydrogen sulphide, carbon dioxide and water vapour gases expand creating pressure explosions. As a result large amounts of steam rise from the mouth of the cave, giving the impression of smoke billowing from the mouth of a dragon. The discharge is quite small in comparison much activity and energy is located within the cave.

Beauty and Chromatic Pools

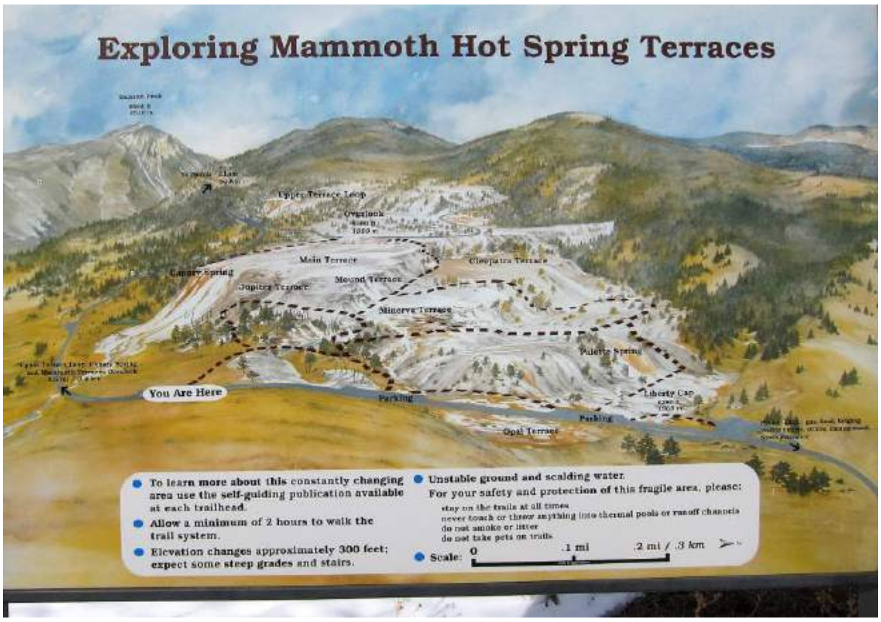
Beauty Pool shares an underground link with Chromatic Pool. When Beauty Pool is full Chromatic Pool water level is much lower; sometimes the reverse may be observed. The factors affecting such exchanges of function are many, this may include phenomena such as earthquakes and continuing mineral accumulations in each feature's underground 'plumbing'. These fluctuations in water level take place over periods ranging from a few weeks to several years. During this shift, the temperatures can change about 10 °F, temperatures ranging from 164 to 175 °F (73 to 79 °C).

The vivid colours of Beauty Pool's basin and runoff channels are created by microscopic lifeforms. These organisms survive and thrive in an environment that would be lethal to us and most other living creatures, these amazingly hot spring environments may sustain a diversity of organisms rivalling that of a terrestrial rainforest.

Sulphur Caldron

One of the most acidic springs in Yellowstone, PH (power of hydrogen) levels are recorded to be between 1-2.4, which is close to levels of battery acid. Sulphur caldron sits on the edge of one of the most active areas of Yellowstone buried volcano, where sulphur rich gasses rise furiously.
Even in the pool of boiling acid life can survive, certain bacteria known as thermoacidophiles can withstand harsh conditions. These bacteria living within the ultra-hot waters, create the colours you see. Temperatures in the Sulphur Caldron at Yellowstone are about 190 °F.

<u>Hot spring terraces</u> – Mammoth



The hot spring terrace that we visited in Yellowstone is 'Mammoth'.
Yellowstone hot springs terraces are among earths most extreme environments, yet life survives and thrives in conditions that would be lethal to humans. Scientists studying hot springs terrace habitats are learning about life's limits on earth.

Water heated deep underground rises to the surface at Mammoth. As it rises the water percolates through buried limestone, dissolving calcium carbonate. Above ground the hot spring water deposits the calcium carbonate building travertine terraces.

- Mammoth hot springs look different from other hydrothermal areas in Yellowstone. The white mounds and stalactite like balconies are products of hot water sculpture in overdrive.
- At times, more than one hundred hot springs have been present at Mammoth, but not one single geyser or mud pot. This is because the underground water is not hot enough to generate the explosive energy needed by them. Many of the hot springs in this area have bubbling water, but this is not an indication of boiling temperatures, rather the bubbles are due to the presence of carbon dioxide gas.
- The water here is cooler than that of many other hydrothermal areas. The rock of the terraces travertine is quickly built causing new forms to emerge every day. Bright colours indicate abundant microbial life.

Through this hot terrace springs life, time fluctuations occur. They may become dormant at any time for days, months or years.

- Within Mammoth hot springs, massive deposits of travertine have been found, most of it covered by soil. This travertine is a rock composed of calcium carbonate. Deep underground, limestone provides the source of the calcium carbonate. Warm carbon dioxide rich waters readily dissolve the limestone and rise to the surface. When the water emerges, carbon dioxide is released which causes the calcium carbonate to deposit as travertine.

Mammoth hot springs is made up of billions of heat loving microorganisms called Thermophiles. (Filamentous and Cyanobacteria).

- Thread like filamentous bacteria link together creating chains that can spread into aprons. They live on hydrogen sulphide gas rising through vents – which is the gas that you can smell here.
- Like flowering plants, colourful Cyanobacteria use light for energy or photosynthesis. If other microorganisms did not consume hydrogen sulphide gas near the vents, these sun loving microbes would be poisoned.

Heated deep underground, water rises through buried limestone then deposits the mineral calcite above ground. The calcite hardens becoming travertine. As hot spring water flows, trees grasses thermophiles and even the boardwalks are entombed.

Jupiter Spring

- Jupiter spring first bubbled up in a landscape of scattered trees and travertine created by older springs. As Jupiter terrace grew, hot mineral water streamed downhill burying the grass and trees growing there.
- By 1872 the trees were engulfed by travertine.
- Jupiter spring flowed abundantly in 1923, colourful pools adorned its terraces.
- By 1998, the spring had been dormant for several years. If it remains inactive, soil will eventually form on Jupiter's crumbling travertine and become home to trees and flowers again.

Minerva Terrace

The delicate travertine formations around Mammoth were created by hot spring water. Heated by Yellowstone’s volcano, water travels through buried limestone then bubbles to the surface to deposit travertine. Named in the late 1800s, Minerva spring sculpted Minerva terrace. The spring sometimes flows abundantly. At other times, it is completely dry.

Mammoth hot springs terrace is constantly changing. New springs flow, or old one’s flow again as others become dry. But for more than a century the general level of activity has remained consistent.

Mudpots:

How are Mud Pots formed?

Mudpots are the result of Yellowstone's volcanic heat and gases rising to the earth's crust combined with water which has been boiled underground. The combination rises upward until it is forced up through cracks in the rhyolite into a depression where further water is added from rain and snow to give mudpots their name. Their formation is dependent entirely on the scarcity of water supplies. The presence of hydrogen sulphide is essential as when mixed with water creates sulphuric acid, corroding rocks forming fine clay and silica particles. Thermopiles are than added until clay is created and their minerals once bubbled create the variety of colours (see table 1) which can be seen at both Fountain Paint Pots, Red Spouter and Mud Volcano in Yellowstone National Park.

Table -1 Colours which minerals produce in mudpots

Mineral	Colour
Iron sulphites	Black
Iron sulphate	Yellow tint
Pure sulphur	Bright Yellow
Iron oxides	Pink and Red

Lower Geyser Basin

Name: Fountain Paint Pot (Mammoth Paint Pots - 1927)
Location: Firehole River Drainage
PH: 2-3
Temperature: 202.8ºF

The thickness of the material at Fountain Paint Pots changes with the seasons; in Spring the appearance is thin, whilst in Autumn it deviates to a thicker consistency from drier conditions. This results in cone-shaped mounds forming as thick bubbles of mud and gas collapse.

Colours: The high proportion of iron oxides determine the red, pink and beige colours of the Fountain Paint Pots.

Figure 1. Fountain Paint Pots

Red Spouter; On August 17th, 1959, a 7.3 magnitude earthquake hit Hebgen Lake in Montana, 25miles NW of Fountain Paint Pot which created the feature. In Spring, Red Spouter is a hot spring but as the season changes to summer it transitions to a mudpots due to the dry conditions creating a scarcity of water. Eventually it transitions to a steam vent once it has completely dried out.

Figure 2. Red Spouter, (Meagher 1960)

Name: Pocket basin mudpots
Location: alongside Firehole River
PH:
Temperature: 188-200ºF
Eruptive status:
Thickness/Colours: Light brown. Due to the sensitivity of the area, it is currently not open to the public because any walkways that would be built would be too unstable due to the fragility of the crater.

Figure 3, Pocket Basin Mud Pots (Douglass 1970)

Pocket basin is the largest mud pot in Yellowstone and was formed after a hydrothermal explosion occurred on the edge of the crater. Hydrothermal explosions only occur when the water constrained in rocks reaches a certain temperature and disturbs the rocks as it turns to steam. The energy which created pocket basin occurred at around 90m below the surface. A similar reaction can be seen within geysers, although geyser eruptions are not strong enough to disrupt debris. The crater can even be associated with the Pinedale Glaciation 200ka years ago, which was a local event in North America during the Quaternary ice age. In relevance to the creation of Pocket Basin, this would infer the explosion was the result of a lake covering Pocket basin was restricting the release of pressure as the lake was drained.

<u>Hayden Valley</u>
Name; Mud Volcano
Location; 5 miles N of Yellowstone Lake
PH: 1.2 (very acidic)
Temperature: 180-187ºF
Eruptive status: infrequent historic eruptions.
Colours: Black/ dark gray

Figure 4: Mud Volcano, (Davis 2011)

During the Washburn Expedition in 1870; Mud Volcano was discovered and could be seen propelling mud from a cone-shaped deposit and heard from a mile away. Mud volcano sits atop a resurgent dome, which is the result of the caldera floor expanding due to activity in the magma chamber. Today mud volcano remains silent and its cone- shaped deposit was blown away in 1872 after a thermal explosion, although it still bubbles.

In 1978 numerous earthquakes began to occur beneath mud volcano at depths of 1-5km with up to 100 events per hour with the largest with a magnitude 3.1. In continuation mud cauldrons became increasingly active and new ones were created alongside fumeroles. This killed local vegetation due to the increase in soil temperatures. Although the intensity declined by July 1979. Consequently, research implies the seismic intensity recorded in 1978 had expanded the already present fracture systems allowing the flow of fluid to increase. Although it is not accessible to the public, the most active mud pot gumpber is located behind Sour Lake. Like Red Spouter activity of the mudpots at mud volcano are highest in the Spring as water is most abundant in the seasons. However, despite water drying out in the summer, not all of the mudpots turn into steam vents.

Other Mud Pots include:

Figure 5. Rabbit Creek Mud Pot, (Douglass 1967)

Figure 6. Myriad Mud Pot, (Niermann n.d.)

Figure 7. Lewis Mud Pots, (Niermann n.d.)

Figure 8. Boiling Springs Lake Mud Pots, (Niermann n.d.)

The Rabbit Creek Mud Pots (Figure 5) are muddy red in the Lower Springs, and grey at the Tomato soup pools and often have a dried crust atop their crater, although mud is still boiling beneath this (Scott 2011). They are part of the Rabbit Creek group which is located in the Midway Geyser Basin. The Myriad Mud Pots (Figure 6), are located in the Upper Geyser Basin and spread across a smaller area than the Lewis Mud Pots (Figure 7), which are located in the Norris Geyser basin and are much quieter than the Myriad mud pots. Moreover, the Boiling Springs mud pots (Figure 8), are located in the Lassen Volcanic region along the shore of Boiling Springs Lake and like Lewis Mud Pots are also relatively quiet.

Steam Vents:

Fumaroles, otherwise known as steam vents are the result of a hydrothermal features where water has boiled and dried out, turning to steam. Fumaroles have very high temperatures often reaching as high as 138ºC and are the hottest hydrothermal features in the park. One of these is the Black Growler steam vent, in the Norris Geyser Basin where it's location on a hillside adds to its persistence as a steam vent. Its name originates from the black outline of the crater it is positioned on. However, it's location has not remained stationary, in 1928 it moved downslope following a decrease in activity.

Moreover, the Roaring Mountains although not often heard occasionally 'roar' as steam is forced upward through narrow vents. As such, the Roaring Mountains throughout the 1800's could be heard up to four miles away. This is a result of gases escaping through the vents and thus can often be heard before they are seen.

Conclusion

Yellowstone's hydrothermal features provide a glimpse into the distant past when intense volcanism was widespread on the young Earth. The lifeforms found here help scientists understand the type of life that likely arose and diversified billions of years ago on our planet.

Formations that entomb microbes in Yellowstone's geysers and hot springs may offer clues in the search for life on other worlds. Volcanic hot spring systems are believed to have existed on other planets in our solar system, if similar formations are found they may contain evidence that life existed elsewhere in the universe.