GEYSERS

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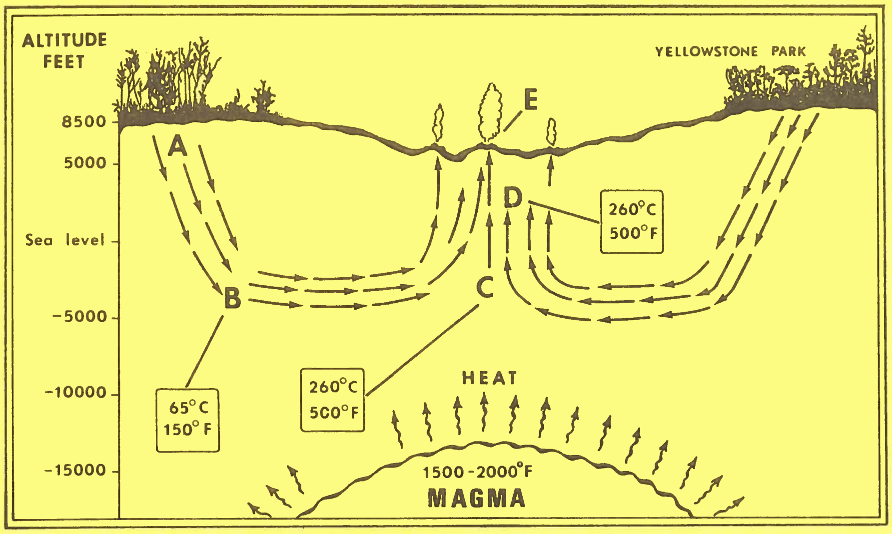
When Old Faithful's eruption is over, everyone leaves. The show is over. There is no more to see.

The show may be over, but the action is not. The actual workings of the geyser -- the plumbing, we could say -- is underground where no one can see it.

Actually, a geyser is in continuous activity. Underground, Old Faithful is already fueling up for its next show. It has to recover the two elements necessary for its eruptions: water and heat energy.

Suppose there were a big slit in the earth and we could see a cross-section view of the underground plumbing of the geyser. What would we see?

We would see that the vent opening at the surface is the top of a rather large, vertical tube that leads down through narrower and narrower roots that are the feeding channels for the system; they draw the water in. Deep in the earth we would see the heat source, the magma (molten rock). (See Figure 1). In areas where geysers occur, the magma is much closer to the surface



From: "Geysers", a U.S. Geological Survey pamphlet, 1971.

Figure 1. This is a model of a geyser basin's high-temperature circulation system. The water temperature increases from A to B to C. No one really knows the depth of the magma; -15,000 is an arbitrary figure.

than usual. It is its unusual closeness to the surface that provides the superheating needed for geysers.

If we were to pour water on the surface at the top of the system, we would see some of it soak into the earth, getting closer and closer to the heat source until it became quite hot, causing it to rise and eventually be drawn into the geyser's tube system.

The basic principles at work here are these: cooler water is heavier and therefore moves down; while warmer water is lighter and moves up. The cooler water, which originates from rain and snow falling on the surface, actually pushes the warmer water back up or aside, out of its way. This is a continuous process. Not only does the temperature increase as the depth below the surface increases, but the pressure also increases.

Water expands as it heats, so the hot water that is rising is actually seeking lower pressures, so that it can have room to expand, boil, and escape as steam. A geyser, or hot spring, provides this escape.

Essentially, a geyser is a kind of hot spring that erupts. The difference has to do with the construction of the tube system, and the amount of water and heat.

If we measured the temperature of the water rising in the ground we would probably discover that it was superheated, that is, above boiling point temperature for its depth. (The lower you go below sea level, the higher is the temperature required to make water boil, and vice versa.) But the water cannot boil at depth because of the great pressure on it, so it rises.

As this water enters a geyser tube, its pressure abruptly lowers to match the pressure of the water standing in the tube, and it may turn directly to steam. Then, because the water in the tube is much cooler than the water coming in, the steam condenses, turning back into water. Soon all of the water is heated to boiling. New steam bubbles form because of the boiling action, and they begin to rise up through the water, to escape through the surface vent. As the bubbles rise through the water, the pressure on them lessens, therefore they expand in size. If there is room for all of these larger bubbles to steadily continue rising and escaping at the surface, they will. This is a hot spring, and it will not erupt.

A geyser, however, does not allow all the steam bubbles to escape. It delivers so much energy to the surface that it can't all escape at a steady rate. As the heated water continuously enters the bottom of the system, the water in the tube is heated also. As the water heats, more and more of it turns to steam, and more and more bubbles are produced. Eventually, as the steam bubbles form faster and get larger, they plug up the "plumbing". There is no longer room for them all to rise and escape. Instead of passing through the water, they begin lifting the water. The bubbles, still forming and expanding as they rise, work like a plunger forcing the water upward. Some of the water spills out of the vent of the tube in small quick spurts, and then, it erupts explosively. The eruption is on. (See Figure 3.)

The reason for this increased rate of discharge is that, as the water flows out from the top of the geyser tube, the weight of steam that is forming is much less than the weight of the displaced water. The pressure on the water at deeper levels therefore decreases. Much of this deep water was already near its boiling point; with lowering of pressure it starts to boil, more water flashes into steam at progressively deeper and deeper levels, and a chain reaction is started.

Water does continue to come into the geyser system throughout the eruption. Some of it will be expelled during the eruption. The length of an eruption varies widely from one geyser to another. It depends on the amount of water and heat energy available, or in other words, on how long the steam explosions deep in the system can provide the driving force for the expulsion of water and steam. Old Faithful's eruptions last two to five minutes. Spasmodic

Geyser, which erupts daily, has eruptions lasting from 20 minutes to an hour long.

The eruption stops when the geyser exhausts either its supply of water or heat energy.

If the geyser runs out of water first, the main eruption may be followed by a steam phase, allowing it to get rid of its extra heat. In those geysers that exhaust their heat supply first, the excess water is left standing in the tube, with the more slowly forming steam bubbles again able to rise through the water.

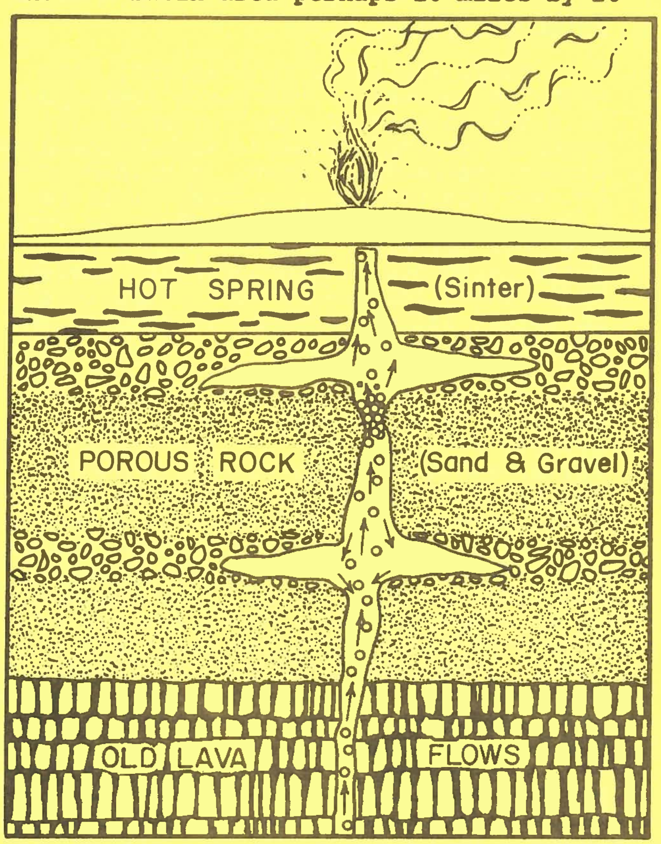
The entire cycle begins over again.

A recovery period is then necessary -- generally much longer in time than the eruption. The time between eruptions for Old Faithful is from 30 to 90 minutes. The recovery consists of two aspects: recovery of water and recovery of heat (energy).

Let's talk about these two elements.

WATER

Most of a geyser's water supply -- 95 to 98 percent -- comes from rain and snow that seeps down into the ground (meteoric water). And since most rain or snow flows into streams and rivers as runoff, actually only a small part of the total precipitation could end up in a geyser or hot spring system. Therefore, a geyser system must draw on water collected over a fairly large area. Figure 1 **shows a basin area perhaps 10 miles by 10** miles, and 3 miles deep, large enough to supply the necessary amount of water, and to contain a number of geysers.



From The Geologic Story of Yellowstone National Park, U.S.G.S. Bull. 1347, by W. Keefer, 1971.

The other 2 to 5% of the water is volcanic water or steam that rises from the magma deep within the earth (magmatic water).

The water in a geyser system is in constant circulation. Some of the water that erupts from a geyser will soak back into the ground and back into the system; some will return by falling back into the vent itself. But most of the expelled water will flow away as runoff. The water expelled from Old Faithful and other geysers in the Upper and Lower Geyser Basins of Yellowstone National Park flows into the Firehole River.

Therefore, the water supply for a geyser system needs to be constantly renewed. Yellowstone's average rainfall of more than 15 inches per year apparently is sufficient to maintain its thermal features.

The plumbing system for a geyser can go very deep. In New Zealand, drilled wells have penetrated 10,000 feet into hydrothermal circulation systems without reaching bottom. Even at these depths, the water is mostly of surface origin. The deep circulation systems in Yellowstone penetrate to at least 5,000 feet, and perhaps more than 10,000 feet.

As you have read, water circulates in these systems because of differences in temperature. Cooler water goes down; hot water comes up. Hot water of a given volume weighs less than cold water; for example, boiling water weighs 4% less than freezing water (near 32°F or 0°C). Water at 400°F (200°C) is 14% lighter, and at 600°F (315°C), it is 28% lighter than at 32°F.

As the water becomes very hot and gets lighter, it flows more easily, just like syrup will when it's hot. Because it becomes a better solvent when hot, it may even dissolve rock. The water may flow laterally for a while (Figure 1, point B to point C) until it is finally driven upward, pushed by the cooler water behind it. It then seeks fissures and cracks in which to flow back to the surface, heating and picking up more water on the way. The fissures and cracks often become the "pipes" of a geyser's "plumbing system". (See Figure 2)

◀◀ Figure 2. This is a drawing of what the underground system of a geyser might look like. You will notice that in addition to the heated water rising from below, water also enters the tube from the sides. This diagram represents the plugged-up phase of an eruption cycle; note the steam bubbles clogging at the constricted point in the tube. Some of the water has been lifted out of the tube and is spurting out of the geyser cone. An eruption will soon follow.

Eventually the water rises to a point (D on Figure 1) where pressure has lessened enough that steam bubbles can form. Tenperature and pressures both decrease as the water moves up from point D. As it rises, the extra heat in the hot water converts some water to steam by boiling. (Boiling temperature in Yellowstone National Park is 199°F (93°C). It is lower that the 212°F required at sea level because of the high elevation of the park.)

Geysers exist because water can be heated to higher temperatures if pressure is high (as in a pressure cooker), but this very hot water must give off its extra heat as steam when the water rises and pressures decrease. Thus this rising water carries its own extra energy required for geyser eruptions.

HEAT

That energy is in the form of heat, the other essential element for a geyser.

As you probably have realized, a geyser region has more than a normal supply of heat. Indeed, a tremendous supply is essential for geysers to occur. Recent measurements by the U. S. Geological Survey show that the total heat is given off from the Upper Geyser Basin in Yellowstone National Park at a rate 800 times normal, that is, compared to what could be expected from any Nebraska wheat field of the same area. Geologic studies indicate that very high heat flows have continued for at least the past 40,000 years.

Where does this heat come from? And why aren't geysers as common as hot springs?

The heat comes from magma -- molten rock -- which is there as a remnant of the earth's creation. It is mostly in the core of the earth, about 1800 miles (2900 km) underground. In a very few places on earth where the magma rises to the surface, it will explode through the crust, forming volcanoes. In other places, however, the magma stops short of the surface, forming "hot spots" that may be small or very large. It is in places like this where most hot springs and all geysers are found.

Most of the world's "hot spots" are in areas of present or former volcanic activity, such as Yellowstone National Park. Geologists can tell by the composition of the rocks blanketing the park area that this definitely was an active volcanic area up to 60,000 to 75,000 years ago. The tremendous heat flow probably has continued since then.

Now -- why are geysers so much rarer than hot springs?

Temperatures generally increase deeper into the earth. This is not entirely due to magma, obviously, because there are really very few areas where magma is close to the surface. All rocks have small amounts of natural radioactivity that produces heat at very low but steady rates (about 1 to 2 degrees per 100 feet of depth in the earth's crust). This radioactive heat is responsible for the fact that earth temperatures increase with increasing depth below the surface. In fact, some hot spring systems have little if any extra heat other than this "normal" heat of the earth.

However, geyser systems require extra heat, the "superheat" that comes from magma. The magmatic heat sources for geysers are probably deeper than 20 miles (32 km). This is actually fairly close to the surface, though, when you compare it to the normal depth of the magma in the core -- 1800 miles (2900 km).

To give an indication of the difference between the normal heat of the earth, and the superhot temperatures present in a geyser area, a few comparisons: expected average temperature at a depth of 250 feet would be only 2.5 to 5 degrees higher than the surface temperature. Geyser systems that have been drilled always show subsurface temperatures at least as high as 300°F (150°C), and they increase with more depth. The deepest research hole drilled by the U. S. Geological Survey in Yellowstone National Park -- at Norris Geyser Basin -- showed 465°F (240°C) at 1,088 feet, and the temperature was still climbing.

WHERE DO GEYSERS OCCUR?

Where are these "hot spots"? The main "hot spots" of the earth correspond with the "circle of fire" of active or recently active volcanoes around the margin of the Pacific Ocean. A number of hot springs with temperatures close to boiling occur in these regions, but very few true geysers. The few places on earth where geysers do occur are places where there has been long-ago volcanic activity, and where there is still a lot of hot spring activity.

A large proportion of the known geysers of the world are in Yellowstone National Park (Wyoming). Other major geysers occur in Iceland, New Zealand, Chile, and the Kamchatka Peninsula on the Pacific side of the Soviet Union. Small geysers are also known in other countries. North central Nevada used to claim several beautiful small geysers, but these have become inactive recently, as have some in other countries, as a result of exploration for geothermal power (using natural steam to produce electricity). The Geysers area in northern California is misnamed; there are no real geysers there.

Hot (or warm) springs are much more common; they are found all over the world. In Iceland, geysers are less than

1% of the hot springs. In Yellowstone, geysers number probably less than 10% of the total thermal features.

DIFFERENCES BETWEEN GEYSERS AND CHANGES IN GEYSER BEHAVIOR

Old Faithful Geyser in Yellowstone National Park long ago became the tourists' favorite. It is fairly predictable and erupts fairly often, so it is perfect to satisfy an impatient tourist. Each year, most of the nearly 2 million visitors to the park see Old Faithful erupt.

Contrary to popular opinion, most geysers are very irregular in their behavior, and each is different in some respects from all others. Not even Old Faithful is really regular. The time between its eruptions varies from 33 to 98 minutes, with the average about 65 minutes.

Beehive Geyser, in the Upper Geyser Basin, is more spectacular than Old Faithful, erupting for 5 to 8 minutes to a height up to 219 feet in a graceful, slender column. But fewer people see this, because Beehive erupts only two or more times a week, if it is in an active phase at all. Giantess Geyser is another that erupts infrequently. However, when it does erupt, water shoots 200 feet into the air for 12 to 36 hours!

There are several reasons why geysers differ so much from each other. The differences are mainly due to rate of heat flow, rate and amount of water supply, and shape and size of the tube and feeding channels.

Some geysers have one surge of water at each eruption; some may have several surges, like Grand Geyser (Upper Basin) which erupts in 30 separate surges. This can be explained. During the steam phase of a geyser eruption, the water flowing into the system may nearly balance the pressure of steam and other gases. The pressure of the collecting water generally becomes dominant after a single eruption, but the balance may be close enough to enable a geyser to erupt again in two or more closely spaced stages.

Other differences between geysers may depend on how much erupted water flows back into the geyser tube, thus replacing some of the water lost earlier in an eruption.

Some geysers can have two or more different intensities of eruption, such as Steamboat Geyser in the Norris Geyser Basin, considered the largest and most powerful in the world. Its usual eruptions are 20 to 30 feet high and last only seconds, but occasionally it erupts 380 feet high for a duration of several hours. This is probably because it has some deeper reservoirs almost separate from the rest of the system. These deeper parts may regain enough energy to take part in some eruptions but not all. It's like two geysers with different but interconnected systems, and different eruption schedules, but sharing a common vent.

Subsurface connections to other springs and geysers may also drastically affect the activity and predictability of many geysers. In fact, if one geyser is altered, it is very likely that the activity of other interconnected geysers and hot springs will change also.

This happened after the Hegben Lake earthquake just west of Yellowstone National Park in Montana in 1959. Most geysers probably start when new cracks or channels are formed underground by earthquakes. At least one entirely new geyser, Seismic, was created by the 1959 earthquake, and spectacular changes occurred in many other already existing geysers and hot springs. Some geysers became dormant, some hot springs became active geysers, and some small geysers became major ones, such as Sapphire Geyser in the Upper Geyser Basin.

Before the earthquake, Sapphire Geyser erupted to heights of 10-12 feet. The quake disrupted that routine for awhile with violent eruptions shooting 100 feet high. Since then, it has calmed down, seemingly settling back to pre-earthquake characteristics.

Some geysers become so rigorous that they effectively "kill themselves" by enlarging their tubes and underground pools; the system then becomes large enough to dissipate extra energy steadily. It quits erupting and turns into an ordinary hot spring. Many of Yellowstone's hot springs probably were once geysers. Perhaps all geysers eventually evolve into hot springs or become inactive.

Some geysers quit erupting because of deposition of minerals in their feeding channels, therefore letting less water into the system. The extra heat can be lost through circulation, evaporation, and the quiet steady rise of steam bubbles through the water.

Humans also can affect or change geyser activity. Attempts to tap geysers in Nevada and elsewhere for their geothermal energy has caused them to become inactive. Digging or drilling into a geyser system would change its subsurface construction and would surely alter its behavior.

One example of a man-caused change is Minute Geyser in the Norris Geyser Basin. This geyser formerly erupted to heights of nearly 100 feet, but its tube was filled with rocks by careless or curious tourists, and the geyser no longer erupts.

GEYSERS IN YELLOWSTONE

To count all the individual thermal features (hot springs and geysers) in the park would be virtually impossible. Estimates range from 2,500 to 10,000, depending on how many of the really small ones are counted. Geysers probably number about 300 of the total. Geysers are scattered throughout the park, but most of them are concentrated in a few areas called geyser basins. See Figure 3.

The major geyser basins are Norris Geyser Basin (G. B.), Upper G. B. (where Old Faithful is), and Lower G. B. Smaller ones are: Midway G. B., Biscuit B., and Gibbon G. B.(between Upper and Lower); Black Sand G. B. and Monument G. B. (near Norris); Shoshone G. B., West Thumb G. B., and Heart Lake G. B. The other largest thermal area in the park is Mammoth Hot Springs, but there are no geysers there.

If you visit a geyser basin at Yellowstone National Park, you may see a lot of "steam" in the air. This is actually fog, or water droplets condensed from the steam given off by the hot springs and geysers. The amount of fog in the air depends on the temperature and humidity and has nothing to do with how "active" the thermal features are. On cold or very humid days, it can be so foggy above the geyser basins that you can barely see the actual hot springs, whereas on a warm, dry summer day, the air may be completely clear.

As you walk through Upper Geyser Basin (or any of the others), you should observe and obey signs instructing you to

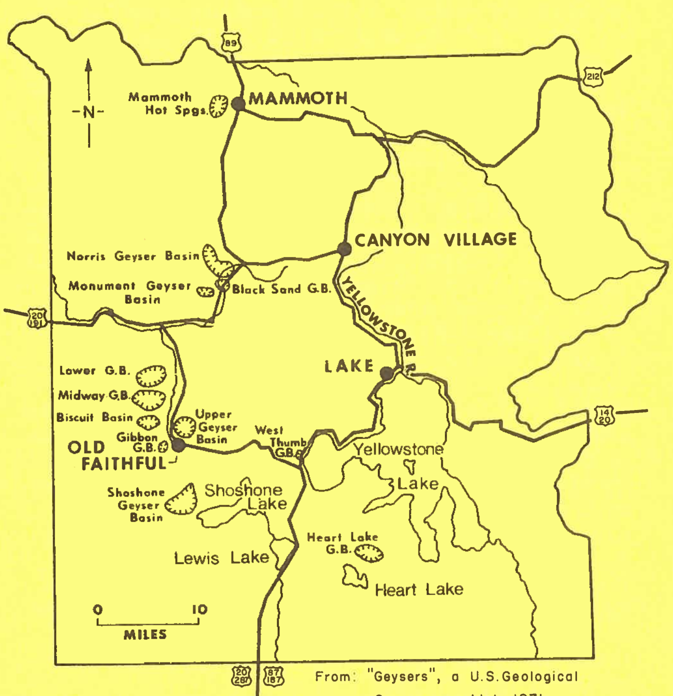


Figure 3. The majority of North America's geysers are found in these eleven geyser basins in Yellowstone National Park. Another major thermal area, although it contains no geysers, is Mammoth Hot Springs.

stay on the boardwalk. This is partly for your own safety. That ground may *look* perfectly safe, but in some places it may be only a crust over a hot pool, or the thin rim of a hot spring, and you could easily break through. Furthermore, those hot springs are *really* hot -- hot enough to severely burn, or even kill you.

Because National Parks exist in order to preserve parts of our country in its natural state, every effort has been made to keep them natural -- no small effort, considering the millions that travel through Yellowstone National Park each year. Provisions have been made for the public's safety and convenience, like the boardwalks over the geyser basins, but the purpose has not been to completely *shield* visitors from any dangers that may exist in the natural environment. Consequently, no rails have been put on many of the boardwalks. It is not the National Park Service's responsibility to be sure that visitors to the park are always safe. (If it were, all the bears and buffaloes and moose in the park would be in cages, and every rim of every canyon would be sturdily fenced.) So, your safety, and that of your children, is your responsibility when you visit a National Park.

The other main reason you should stay on boardwalks (and other designated trails in the park) is preservation. Ground formations and deposits made by geysers and hot springs are delicate. Walking on them would destroy their appearance and alter natural processes. So, essentially, the boardwalks are there to protect park visitors from the thermal areas, *and* to protect the thermal areas from the people.

As you walk through any of the geyser basins, you will notice the crusty white deposit blanketing the ground. This is *sinter*, a mineral brought up through the earth by the hot water and deposited by the expelled water as it flows away from geyser vents or hot springs. It is composed mostly of silica (the same as in quartz and ordinary glass), and is sometimes called *geyserite*.

Mammoth Hot Springs, in the northern part of the park, is the only major thermal area where the deposit is not sinter, but *travertine*, which consists almost entirely of calcium carbonate.

The material deposited on the surface indicates the predominant kind of rock through which the hot water flowed during its underground travels. At Mammoth Hot Springs, the water passed through beds of limestone (calcium carbonate); but at the other thermal areas, the main rock type is rhyolite, a rock rich in silica.

Sinter or travertine by itself is white to gray. The bright colors that you see around thermal areas are due to other deposited minerals or to algae.

Algae are miniature plants that thrive where they can be constantly under water, but will not live where it is dry. This is why terraces of inactive hot springs (such as some at Mammoth) and dry areas in geyser basins are white or gray.

In a very general way, in runoff channels from hot springs, one can observe that the hotter the water the lighter are the colors of the algae (cream to yellow), and the cooler the water the darker are the colors (blue and green). The algae can be red, brown, gold, blue, green, yellow, and other shades. It can live at temperatures as high as 190°F.

In some hot springs, the water itself is colored. A delicate blue color probably results from the reflection of light off the pool walls and back through the deep clear water. Other pools are yellow because they contain sulfur, or are green from the combined influence of yellow sulfur and blue water.

Trees and other plants cannot grow on sinter-covered (or travertine-covered) ground. If a new hot spring or geyser develops, the trees and all vegetation close to it will die. They are killed by the excessive water and heat, and because the silica in the water drawn up by the trees clogs their capillaries. The silica hardens in the trunks and effectively "fossilizes" them. You may see some of these dead trees still standing in thermal areas.

How thick is the sinter or travertine coating? The centuries of thermal activities in the park have built up sinter layers to around 10 feet thick. But, in one drill hole at Mammoth, the deposits of travertine were found to extend 250 feet.

The hot springs' and geysers' "plumbing systems" are probably lined with sinter deposits also. This acts as a cement that holds subsurface sands, gravel and soil together, actually reinforcing the strength of the system, at least in its upper parts.

Now that you have a better understanding of how geysers work, you should have a greater appreciation of the thermal features you can see in Yellowstone National Park. Geysers are rare, complex, and beautiful. Let us all continue to value and protect them.

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Castle Geyser (in Upper Geyser Basin). Noted for its resemblance to the ruins of a feudal castle; the dome (of sinter) is one of the largest geyser domes in the park. Steam (foreground) rises from Crested Pool, once known as the Castle Well.