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CHAPTER ONE

About Geysers

WHAT IS A GEYSER?

The standard definition of "geyser" in general worldwide use reads like this:

> *A geyser is a hot spring characterized by intermittent discharge of water ejected turbulently and accomplished by a vapor phase.*

It sounds simple enough, but it really is not. The definition includes several "gray areas" that can be interpreted in different ways—how hot is hot; how high must the turbulence be; are there limits as to how long or short the intermittency needs to be? Such questions will probably never be answered to everyone's satisfaction, but there are two similar varieties of hot spring that definitely do not qualify as geyser. *Intermittent springs* undergo periodic overflows but never actually erupt. *Perpetual spouters* (called *pulsating springs* in some parts of the world) may have spectacular eruptions, but their action never stops. In all three of these cases, however, the cause of the eruption is the same—namely, water boiling into steam at some depth below the ground.

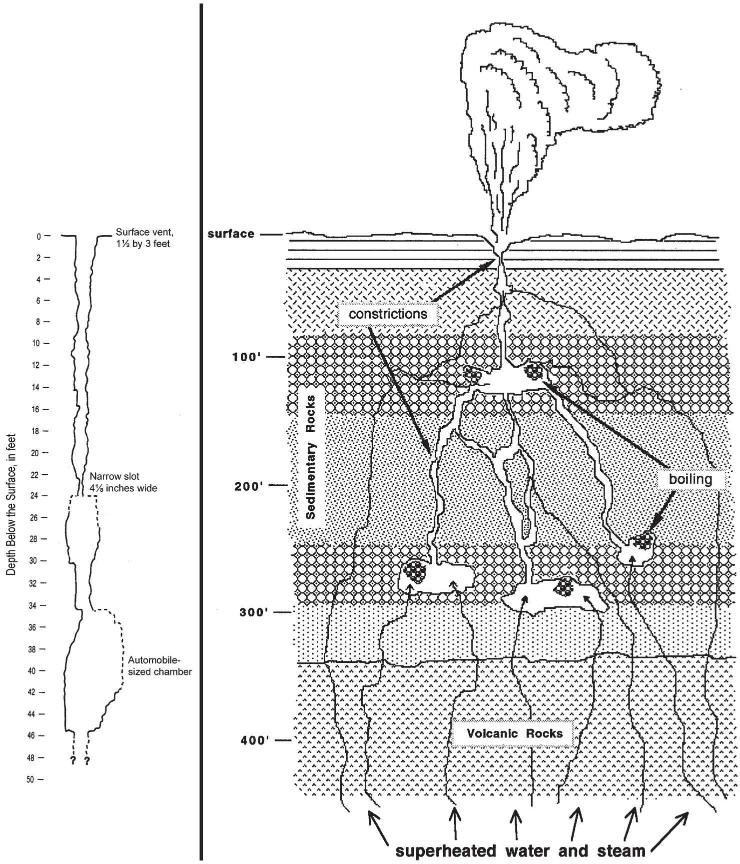
WHAT MAKES A GEYSER WORK?

Three things are necessary for a geyser to exist: an abundant supply of water, a potent heat source, and a special underground plumbing system.

The water and heat factors are fairly common. Hot springs are found in virtually all of the world's volcanic regions. The plumbing system is the critical aspect. Its shape determines whether a spring will be quiet or will erupt. It must be constructed of minerals strong enough to withstand tremendous pressure, and it must include a permeable volume so as to hold the huge amounts of water ejected during an eruption.

Nobody really knows what a plumbing system looks like—it is, after all, belowground and filled with hot water and steam. Considerable research drilling has been done in some of the world's geyser areas, and none has yet found any large, open water storage caverns. This fact led to the conclusion that a geyser's main water reservoir is a complex system of small spaces, cracks, and channels in the porous rocks that surround the plumbing system.

In 1992 and 1993 an experimental probe used at Old Faithful Geyser expanded on this idea and resulted in further changes in our understanding of what a plumbing system looks like. Equipped with pressure and temperature sensors and a miniature video camera, the probe was lowered into Old Faithful's vent shortly after an eruption had ended. The result is shown on the left side of Figure 1.1 (p. 3). At a depth of only 22 feet, there was a narrow slot barely 4 inches wide. Just below that was a wider area that had a waterfall of relatively cool, 176°F (80°C), water pouring into it. Then, at about 35 feet, the probe entered a chamber "the size of a large automobile." As Old Faithful refilled, the temperature of the rising water was 244°F (117°C), fully 45°F (25°C) hotter than the normal surface boiling point at that altitude. The researchers reported that the action resembled a seething "liquid tornado" of unbelievable violence. Years ago, in New Zealand, people were able to scramble down into an inactive hot spring. There they found a chamber with smooth walls punctured by numerous small openings. Once upon a time it must have been the scene of wild boiling like that wit-



(left) *A video probe lowered into Old Faithful Geyser showed its uppermost 50 feet to be little more than an irregular tube partially filled with violently boiling water. All geysers probably have similar plumbing systems.* (right) *Although nobody really knows what a geyser's deeper plumbing system looks like, research indicates that it is probably similar to this illustration.*

nessed inside Old Faithful, and its existence supports the notion that Old Faithful's inferno is normal rather than unique.

This is quite unlike the standard model of a plumbing system, which has the water rather quietly flowing upward into a single main tube. Still, this revised model probably applies to all geysers. It makes the water supply network more complex but changes nothing about how geysers actually operate. The character and eruptive performance of every geyser are determined by the geyser's plumbing system, and, as in all of nature, no two are alike.

The probe into Old Faithful was never lowered deeper than 46 feet, therefore only into the very top of the plumbing system, but when combined with other data, enough information is available for us to reconstruct the plumbing system of a geyser. An example is shown in Figure 1.1 (right). It consists mainly of tubes extending into the ground, containing many sharp bends and constrictions along their lengths. Connected to the tubes are small open spaces and, especially, layers of water-storing sand and gravel of high porosity. Most of this plumbing is fairly close to the surface, and even the largest geysers extend to a depth of only a few hundred feet. Finally, much of the plumbing system is coated with a water- and pressure-tight lining of *siliceous sinter,* or *geyserite.* This mineral is also deposited outside the geyser and in and about the quiet hot springs. Of course, the geyserite is not magically deposited by the water. Its source is quartz (or silica) in the volcanic rocks underlying the geyser basin.

The water that erupts from a geyser arrives there only after a long, arduous journey. Water first falls in Yellowstone as rain and snow, then percolates through the ground to as much as 8,000 feet below the surface and back again. The round-trip takes at least several hundred years. This is something that can be determined with reasonable accuracy by studying the *tritium* (sometimes called "heavy-heavy hydrogen") content of the geyser water. Tritium is radioactively unstable and decays with age. Young water contains considerable amounts of tritium, while old water contains little or none. It is nearly absent in most Yellowstone waters; in fact, it is believed that the water erupting from Old Faithful today fell as precipitation at least 500 years ago—around the time Columbus was exploring the West Indies—and some geochemical evidence indicates that 1,100 years is more likely.

At depth, the percolating surface water is heated where it contacts a high-temperature brine, which in turn circulates as deep as 15,000 feet where it is heated by the enclosing volcanic rocks. Once heated, it dissolves some of the quartz from the rocks. All this takes place at very high temperatures—over 500°F (200°C) in many cases, and 459°F (237°C) was reached in a research drill hole only 1,087 feet deep. This silica will not be deposited by the water until it has approached the surface and cooled to a considerable extent.

Now an interesting and important phenomenon occurs. Although it was the mineral quartz that was dissolved out of the rocks, the deposit of geyserite is a form of opal (never of gem quality). The mechanisms involved in this process are complex, involving temperature, pressure, acidity or alkalinity of the water, and *time.*

HOW A GEYSER ERUPTS

The hot water, circulating up from great depth, flows into the geyser's plumbing system. Because this water is many degrees above the boiling point, some of it turns to steam instead of forming liquid pools. Meanwhile, additional cooler water is flowing into the geyser from the porous rocks nearer the surface. The two waters mix as the plumbing system fills.

The steam bubbles formed at depth rise and meet the cooler water. At first, they condense there, but as they do they gradually heat the water. Eventually, these steam bubbles rising from deep within the plumbing system manage to heat the water nearer the surface until it also reaches the boiling point. Now the geyser begins to work like a pressure cooker. The water within the plumbing system is hotter than boiling but is "stable" because of the pressure exerted by the water lying above it. (Remember that the boiling point of a liquid is dependent on the pressure. The boiling point of pure water is 212°F [100°C] at sea level. In Yellowstone, the elevation is about 7,500 feet [2,250 meters], the pressure is lower, and the boiling point of water at the surface is only around 198°F [93°C].)

The filling and heating process continues until the geyser is full or nearly full of water. A very small geyser may take but a few seconds to fill, whereas some larger geysers take several days. Once the plumbing system is full, the geyser is about ready for an eruption. Often forgotten but of extreme importance is the heating that must occur along with the filling. Only if an adequate store of heat exists within the rocks lining the plumbing system can an eruption last more than a few seconds. (If you want to keep a pot of water boiling on the stove, you have to keep the fire turned on. The hot rocks of the plumbing system serve the same purpose.) Again, each geyser is different from every other. Some get hot enough to erupt before they are full and do so without any preliminary indications of an eruption. Others may be completely full long before they are hot enough and so may overflow quietly for hours or even days before an eruption occurs. But eventually, an eruption will take place.

Because the water of the entire plumbing system has been heated to boiling, the rising steam bubbles no longer collapse near the surface. Instead, as more very hot water enters the geyser at depth, even more and larger steam bubbles form and rise toward the surface. At first, they are able to make it all the way to the top of the plumbing with no problem. But a time will come when there are so many bubbles that they can no longer freely float upward. Somewhere they encounter some sort of constriction in the plumbing. To get by, they must squirt through the narrow spot. This forces some water ahead of them and up and out of the geyser. This initial loss of water reduces the pressure at depth, lowering the boiling temperature of water already hot enough to boil. More water boils, forming more steam. Soon there is a virtual explosion as the steam expands to over 1,500 times its original, liquid volume. The boiling becomes violent, and water is ejected so rapidly that it is thrown into the air. In fact, people standing near very large geysers sometimes hear and feel a thudding, popping sound. Research indicates that this happens because the superheated water is ejected so quickly and then explodes into steam so violently within the water column that the total speed exceeds the sound barrier—the thuds are caused by small sonic booms within the expanding column of steam and water!

The eruption will continue until either the water is used up or the temperature drops below boiling. Once an eruption has ended, the entire process of filling, heating, and boiling will be repeated, leading to another eruption.

THE DIFFERENT KINDS OF GEYSER

All geysers operate in the same fashion, but they come in three varieties. The differences depend on the size and shape of the plumbing system and its constriction, the depth of a pool, the volume of available water, and so on.

Cone-type geysers erupt steady streams of water that jet from small surface openings. The vent is often, but not always, surrounded by a built-up cone of geyserite. Cone-type geysers are rather uncommon, but because the water is squirted under considerable pressure, they tend to have tall, spectacular eruptions such as those of Old Faithful, Daisy, and Riverside geysers.

Fountain-type geysers look a lot different from the cone type because their eruptions rise out of open pools. Steam bubbles rising through the pools cause a series of individual bursts of water, so the action is more a spraying or splashing than a jetting. The fountain-type makes up the vast majority of the world's geysers. Most are small in size, but there are also large examples such as Grand, Great Fountain, and Echinus geysers.

Some observers do not accept *bubble-shower springs* as true geysers but instead list them as a special case of intermittent spring because no vapor phase can be seen rising from deep within the spring's plumbing system. The eruption consists entirely of violent boiling near the surface of an open pool. Some bubble-shower springs, such as Crested Pool, have eruptions as high as several feet, but in most cases the boiling turbulence reaches up only a few inches. This book considers bubble-shower springs to be geysers.

WHY ARE SOME GEYSERS REGULAR, OTHERS IRREGULAR?

The inflow of water into a geyser system is constant, so it would seem that the activity of any geyser should show little variation from one eruption to the next. However, only a few are classed as regular geysers. To be regular, a geyser must either be isolated from other springs or connected only with springs whose overall activity is so constant that they do not affect the geyser. Old Faithful is the most famous example of regularity. Its eruptions can be predicted with nearly 90 percent accuracy. Some other geysers are even more regular, occasionally operating with almost stopwatch-like precision. (Statistically, there are geysers that yield "coefficients of variability" of less than 3 percent.)

But most geysers are irregular. The time interval between successive eruptions is erratic. One time it may be just minutes between the plays, the next several hours. In no way can these geysers be predicted.

The mechanism behind this has been termed *exchange of function*, as first described by G. D. Marler in 1951. What this basically means is that water and energy can be diverted from a geyser to some other hot spring or hot spring group (another geyser is not necessarily involved). This happens because the plumbing systems of most springs and geysers are intertwined with those of others. The activity of any one of those springs must affect all others in the group.

Just what makes exchange of function take place is unknown. Something must act as a valve so as to shunt the water and heat from one direction to another, but whether this is a vapor lock as a result of a buildup of steam bubbles, a fluidic switch operation, a Venturi effect, or something entirely different has never been determined. Most exchanges are small scale in both extent and time and require a knowing eye to detect. Others can be of great significance. Indeed, one group of active springs may suddenly stop functioning altogether while a nearby group of previously insignificant springs becomes animated with an exchange that might last for years. A good example involved Daisy Geyser and nearby Bonita Pool in the Upper Geyser Basin. For years, Daisy was one of the largest and most regular geysers in Yellowstone, while Bonita overflowed only slightly. Suddenly the energy shifted toward Bonita. Daisy was drained of the energy necessary for eruptions as Bonita overflowed heavily and underwent small eruptions. As a result, Daisy erupted just three times in over thirteen years. Then the energy flow shifted back toward Daisy. Now it is predictable again, while Bonita lies quietly below overflow.

WHY ARE GEYSERS SO RARE?

There are few places on earth where the three requirements for the existence of geysers are met. The requisite water supply poses no great problem; in fact, a few geysers are able to exist in desert areas, places normally thought of as dry. But the heat source and plumbing systems are tied to one another and are much more restrictive.

Nature's heat source is volcanic activity. The heat is supplied by large bodies of molten or freshly cooling rock at great depth. Given a proper water supply, hot springs are possible in any area of geologically recent volcanism.

Most hot spring areas do not contain geysers, however, because there is a catch. Not just any volcanism will do. The plumbing systems must be pressure-tight, and that requires silica-rich rocks to provide the source of the geyserite that lines the plumbing systems.

The answer is *rhyolite*. Rhyolite is a volcanic rock very rich in silica; it is the chemical equivalent of granite. Rhyolite is rather uncommon, though, and large recent fields of it are found in few places. Yet virtually all geysers are found in such areas. Most of the exceptions to this rule are still associated with recent volcanic activity, although their rocks—dacite, andesite, and basalt—are somewhat less rich in silica. And as seems to be usual in science, there are a few anomalous geyser localities, such as Beowawe, Nevada, where the activity is not associated with recent volcanic action or even directly with volcanic rocks of any type or age.

Not only is Yellowstone a major rhyolite field, but it is of very recent origin. Although the last major volcanic eruption was 600,000 years ago, minor activity continued as recently as 70,000 years ago. Yellowstone could well be the site of further volcanic eruptions. That is another story entirely, but for now the Park is incomparably the largest geyser field in the world.

HOW MANY GEYSERS ARE THERE IN YELLOWSTONE?

This chapter opens with a basic definition of "What is a geyser?" and notes that there are a number of gray areas and transitional kinds of springs. When such features as bubbling intermittent springs, variable perpetual spouters, and random splashers are eliminated from consideration, the number of geysers actually observed to be active in Yellowstone in any given year might approach 500, and research indicates that an absolute minimum of 700 springs have erupted since the national park was established in 1872.

The count of 500 active geysers is an amazing number. The second largest of the world's geyser fields, Dolina Geizerov on Russia's Kamchatka Peninsula, contains no more than 200 geysers. El Tatio, remote in the high Andes Mountains of Chile, ranks third, with 85 active geysers. New Zealand's North Island has 70 geysers, and Iceland has about 30. All other areas contain fewer; taken together, the entire world outside of Yellowstone might total fewer than 500 geysers. (See the Appendix for more about the rest of the world's geyser fields.)

Yellowstone, in other words, contains well over half of all the geysers on Earth. The number of geysers is not stable, however.

They are very dynamic features, affected by a wide range of physical factors and processes. The slightest change in the geological environment may radically alter, improve, or destroy the geysers.

Recent studies of historical literature have shown that much about Yellowstone had been forgotten. Many springs taken to be "new" geysers in recent years are now known to have been active during the 1800s. Nevertheless, the number of active geysers appears to be increasing. In 1992, a geochemist with the U.S. Geological Survey, who had conducted studies in Yellowstone for more than fifty years, stated that in 1955 one could easily count the number of geysers on Geyser Hill on two hands. This book enumerates 51 individual or clustered geysers on Geyser Hill, and at least 45 of them were active during 2007. Authors Allen and Day of the Carnegie Institute of Washington counted 33 geysers at the Norris Geyser Basin in 1926; 83 are enumerated here. Similar situations exist throughout Yellowstone.

All this fits with recent studies that suggest that Yellowstone's geyser basins—all of them and all of the geysers and hot springs within them—operate on a "pulse and pause" basis. If this is correct, then decades-long episodes of vigorous geyser activity are separated by longer time spans when few or even no eruptions occur. These pauses are demonstrated by the growth of trees, such as the silicified remains near Old Faithful Geyser, on the rim of Castle Geyser, within the formation of Grotto Geyser, and even the stand of dead trees behind Grand Geyser. The apparent fact is that there really are more active geysers today than perhaps ever before in recorded history. We do not know why this is so, but clearly right now Yellowstone is within a "pulse," and right now is the "good ol' days" of geyser gazing.