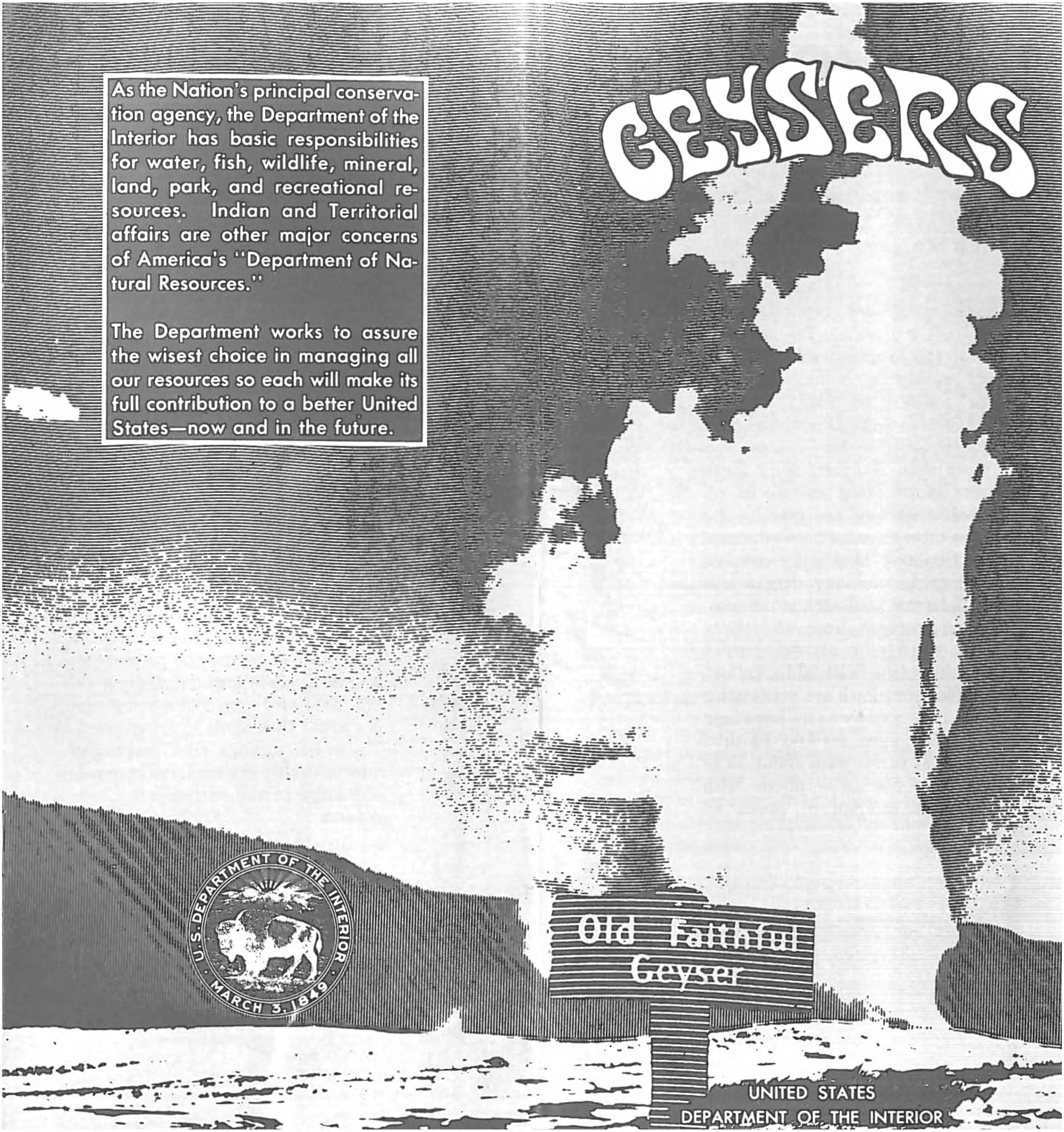
GEYSERS

As the Nation's principal conservation agency, the Department of the Interior has basic responsibilities for water, fish, wildlife, mineral, land, park, and recreational resources. Indian and Territorial affairs are other major concerns of America's "Department of Natural Resources."

The Department works to assure the wisest choice in managing all our resources so each will make its full contribution to a better United States—now and in the future.



UNITED STATES
DEPARTMENT OF THE INTERIOR

GEYSERS

What is a geyser?

A geyser is a special kind of hot spring that from time to time spurts water above ground. It differs from most hot springs in having periodic eruptions separated by intervals without flow of water. The temperature of the erupting water is generally nearly at boiling for pure water (212°F or 100°C at sea level). Some geysers erupt less than a foot high, and a few geysers erupt to more than 150 feet. Some small geysers erupt every minute or so, but other geysers are inactive for months or even years between eruptions. Contrary to popular opinion, most geysers are very irregular in their behavior, and each is different in some respects from all others. Among the major geysers, only a few such as Old Faithful in Yellowstone National Park are predictable enough to satisfy an impatient tourist. But even for Old Faithful the interval varies from about 30 to 90 minutes between eruptions, with an average interval of about 65 minutes.

Why do geysers erupt?

Water from rain and snow can seep thousands of feet underground, and in some volcanic areas it is then heated from contact with deeply buried hot rocks. Temperatures of this water can attain 400°F (204°C) or higher—much above the temperature of boiling water at the surface. Such "superheating" is possible because of the high underground water pressures. When the water becomes heated, it expands and rises toward the surface.

Near the surface where pressures become sufficiently low, some of the water boils to steam producing hot springs. In most hot springs, the steam and the heat energy of hot water are lost by steady, quiet escape to the surface. A few springs, however, deliver so much energy to the surface that it cannot all be lost by steady escape. From time to time, steam bubbles become too abundant to escape quietly through the water; instead the steam *lifts* the water, sweeping it upward and out of the vent. As this occurs the pressure at deeper levels is lowered, boiling action increases and a chain reaction is started that leads to an eruption. These hot springs that erupt and intermittently deliver large amounts of energy to the surface are called geysers.

Where do geysers occur?

Hot springs with temperatures near boiling are rather common in many of the "hot spots" of the world, especially in the "circle of fire" of active or recently active volcanoes around the Pacific Ocean. However, geysers are not common even in these areas, and only a few of the boiling springs are true geysers. The word geyser comes from the Icelandic *geysir*, which means to gush or rage; Great Geysir (gayzeer) is a famous geyser in southern Iceland. A large proportion of the known geysers of the world are in Yellowstone National Park (Figure 1). Other major geysers occur in New Zealand, Chile, and the Kamchatka Peninsula on the Pacific side of the Soviet Union. Small

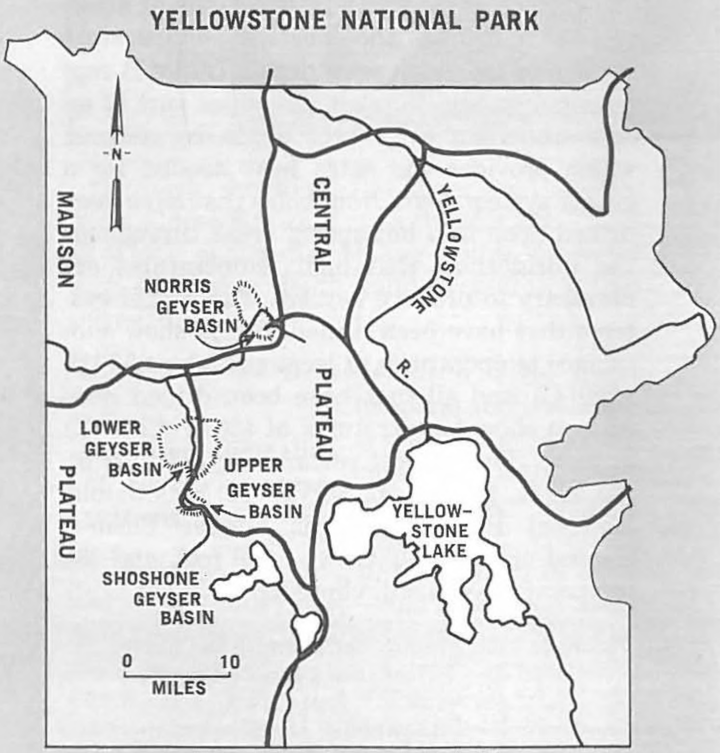


Figure 1

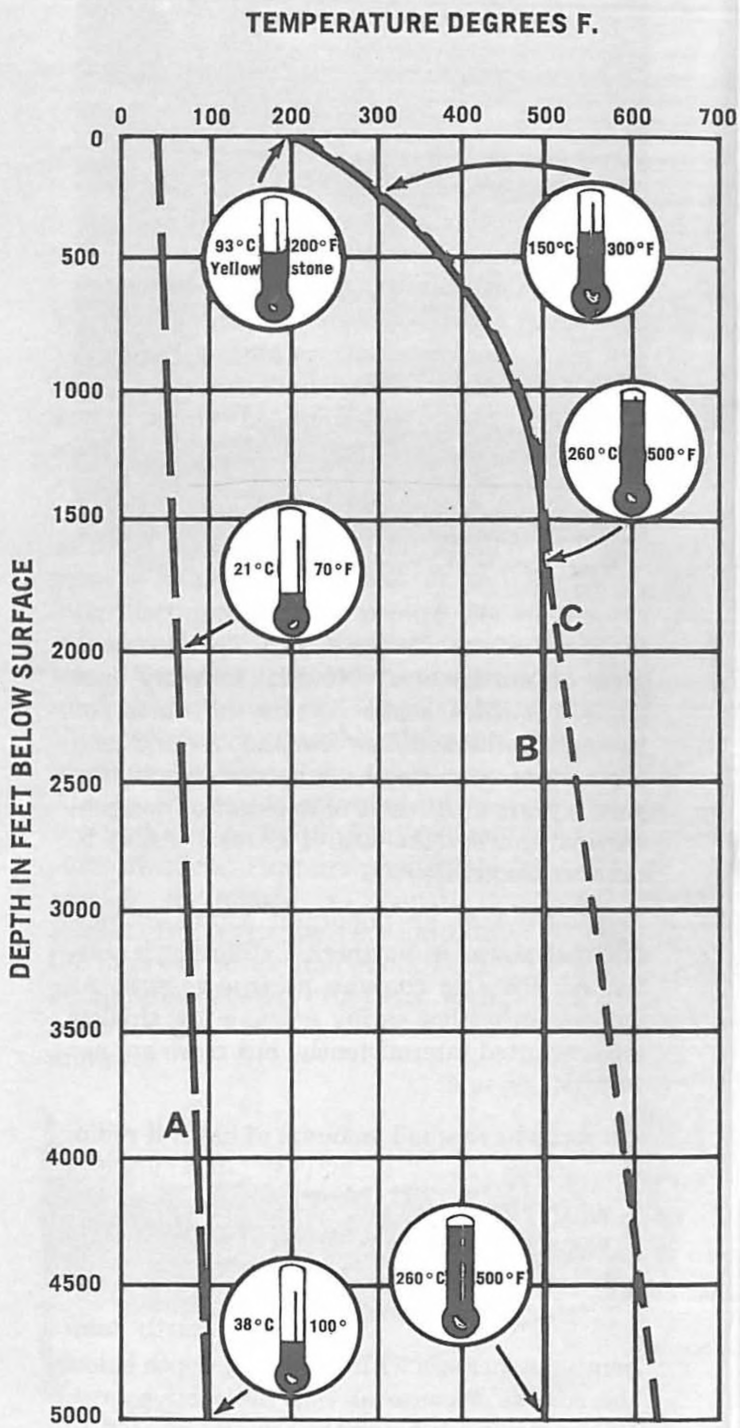
Great Geysir, the "original" geyser of Iceland.

geysers are also known in other countries and in several of our western states. The Beowawe area of northcentral Nevada formerly had many beautiful small geysers, but most of these and others in New Zealand, Iceland, and some other countries have become inactive in recent years as a result of exploration for geothermal power (the use of natural steam to produce electricity).

The Geysers, an important source of geothermal power in northern California, is misnamed; the area contains no true geysers. As in some other hot spring areas, a few shallow wells erupted intermittently, but these are not natural geysers.

What causes volcanoes and hot springs?

All rocks have small amounts of natural radioactivity that produce heat at very low but steady rates. Data from deep mines and oil wells all over the world show that earth temperatures increase with increasing depth below the surface because of this radioactive heat. Volcanoes and hot springs are also related to



this natural heat from radioactivity. Some hot spring systems have little if any extra heat other than this "normal" heat of the earth. The extra heat needed for a geyser system comes from magma (molten rock) that forms at great depths—probably at depths greater than 20 miles (or about 32 kilometers). In some places, magma moves upward to the surface to produce volcanic eruptions; in others, however, magma stops short of the surface forming "hot spots" that may be small or very large. Where conditions are favorable, water that falls as rain or snow circulates underground close to these "hot spots" through interconnected channelways and is heated sufficiently to support geyser action.

Figure 2 shows the changes in temperature that are expected with increasing depth below the surface of the earth in two kinds of areas. Curve A shows the *average* temperature change in the earth with depth. Curve B represents a profile through the upper part of an area underlain at greater depth by magma, which provides the extra heat needed for a geyser system. Data from holes that have been drilled deep into hot spring areas throughout the world show that high temperatures are necessary to produce geysers. The geyser systems that have been drilled always show subsurface temperatures at least as high as 300°F (150°C) and all that have been drilled deep enough show temperatures of 400°F (204°C) or more. 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.

Figure 2: Temperature Variations in the Earth.
Curve A—Normal increase in temperature with depth.
Curve B—Temperatures of upflowing water in a large geyser system.
Curve C—Reference Curve; temperatures that water must attain to boil at various depths.

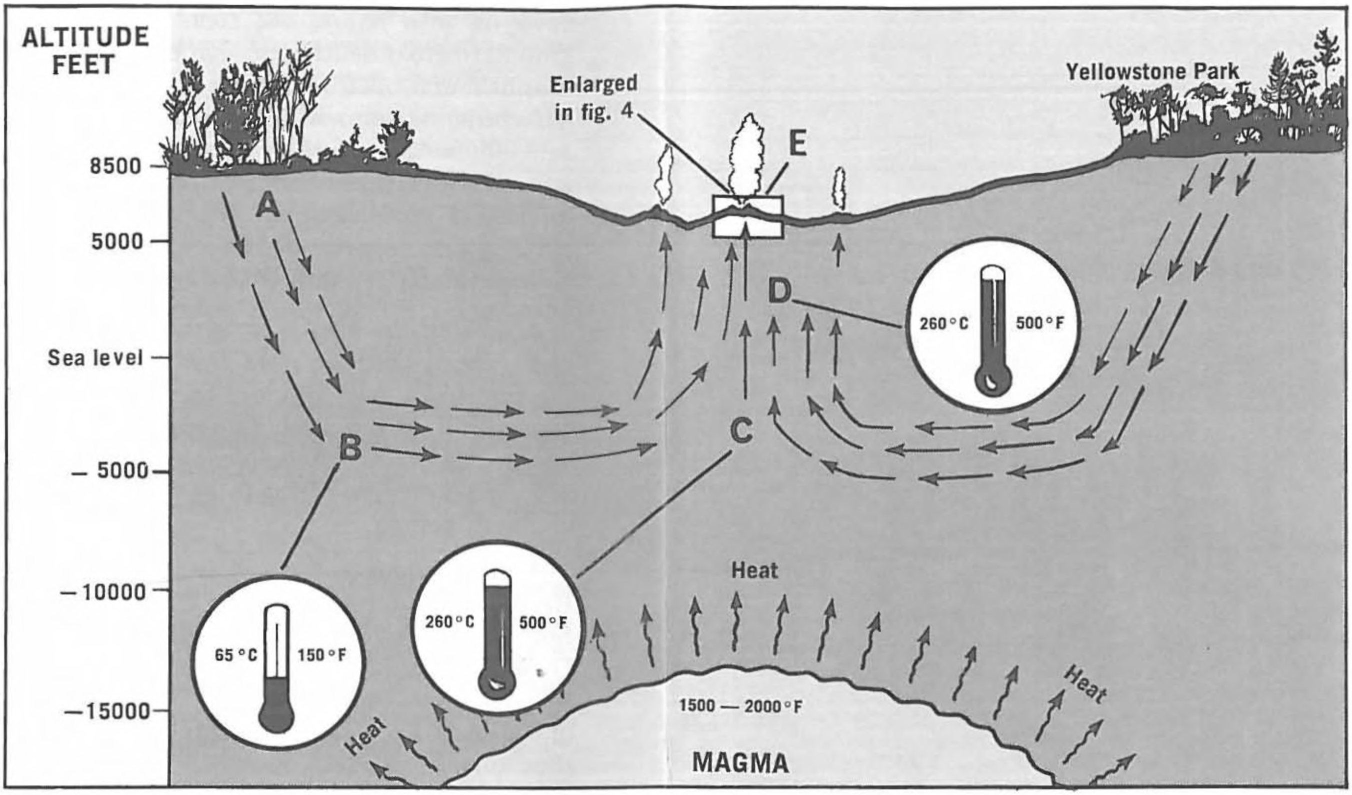


Figure 3: Model of a high-temperature circulation system associated with geysers.

Through much of its upper and middle parts, Curve B is very close to reference Curve C which shows the boiling points of water with increasing depth (and pressure) within the earth.

The deep circulation of water in geyser systems.

Figure 3 shows a model of a deep, high-temperature circulation system. The diagram cuts across a large area that supplies the necessary water—perhaps 10 miles wide, 10 miles long, and 3 miles deep—and includes a number of geysers. (Imagine, for instance, the diagram as applied to the entire Upper Geyser Basin area of Figure 1). The geysers and hot springs are in the visible "skin" but are only a small part of the total system. Near the area where the upwelling water reaches the surface, the hot water transports and deposits silica

Daisy Geyser in Upper Geyser Basin, Yellowstone National Park, erupting about 30° from vertical. This unique geyser is now dormant.

Lone Star Geyser in Upper Geyser Basin of Yellowstone National Park, erupts through a vent in its sinter cone.

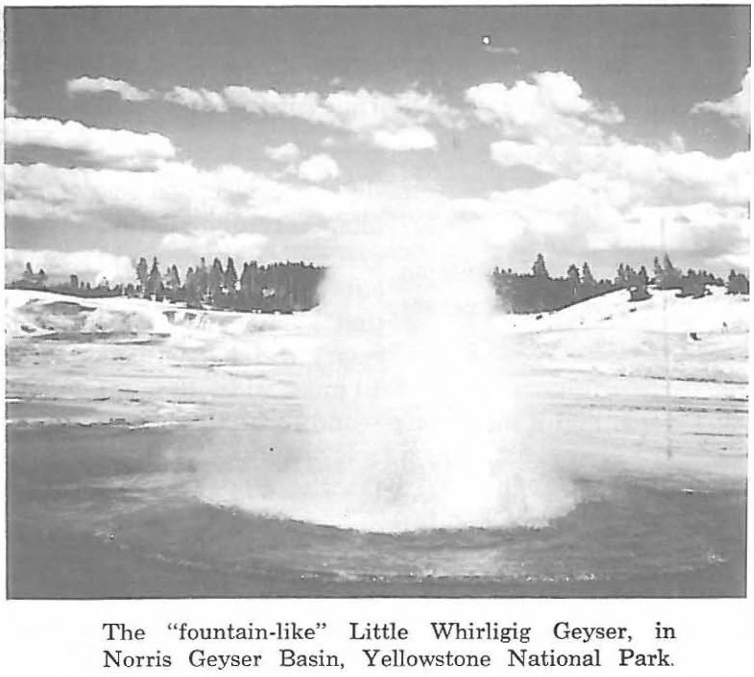
and other minerals, which tend to form a self-sealing cap or "lid" on the system. The hot springs and geysers are fed by water under high pressure that *leaks upward through cracks* in this self-sealed cap. Hard encrustations deposited from hot water can be seen in the geyser basins, and are called *sinter.*

Nearly all of the water of geysers and hot springs originates as rain or snow that falls on the higher ground around the geyser basins such as point A of Figure 3. Most of the water

flows off into rivers, but some seeps underground to great depths through interconnected channels and open cracks in the rocks. Some hot spring systems have been drilled as deep as 8,000 feet. Even at these great depths, the water is mostly of surface origin. Thus, we infer that the water of the geyser-bearing systems circulates to depths of at least 5,000 feet and perhaps more than 10,000 feet.

A magma chamber is shown at the bottom of Figure 3; the heat from this magma drives the system. A small amount of volcanic water or steam may rise from this magma, but research has shown that volcanic water forms less than 5 percent of the total water involved in geyser action.

A tremendous supply of heat is essential. Recent measurements by the U. S. Geological Survey show that the total heat flowing from Upper Geyser Basin is at least 800 times more than the heat flowing from a "normal" area of the same size! Geologic studies also indicate that this tremendous flow of extra heat has continued for at least 40,000 years. This large



The "fountain-like" Little Whirligig Geyser, in Norris Geyser Basin, Yellowstone National Park.

outflow of heat, over many years, is the major reason for believing that a large magma chamber exists below the hot water system.

Water circulates in these systems because of differences in temperature. Hot water of a given volume weighs less than cold water; at 212°F (100°C), it is 4 percent lighter in weight than near its freezing point (32°F or 0°C). Water at 400°F (200°C) is 14 percent lighter and, at 600°F (about 315°C), it is 28 percent lighter than at 32°F. The cold water, because of its extra weight, pushes the hot water onward, and eventually upward and out of the system. Differences in altitude between points A and E of Figure 3 also give a gravitational advantage that provides some extra driving force.

The circulating water has great differences in temperature. It is cool when it seeps underground from rain or melted snow at point A; it then percolates downward many thousands of feet, and is heated only slightly by the time it reaches point B. Its temperature then increases markedly as it flows from B to C; the actual increase depends on *how fast* it is flowing and *how much heat* is rising upward from the magma chamber. If the water is flowing too fast or if the supply of heat is too small, the temperature at point C is less than 300°F (150°C) and the system can not sustain natural geysers at the surface.

The vast differences in the *temperature* of the circulating water are possible because *pressure* increases with depth. Although the water at point C may be heated as high as 500°F, it will not boil because of the tremendous depth and water pressure (see reference curve C of Fig. 2). The hot water rises upward from point C (Fig. 3) because the heat has made it lighter and the cold heavier water moving in from the side is driving it onward. As it rises, the pressure decreases.

The water eventually rises to point D, where pressures have dropped to the point that steam bubbles can start to form. With further rise from D to E, temperatures decrease continuously by boiling as the extra heat in the hot water converts some water to steam (see Curves B and C, Fig. 2). At the surface of the earth at sea level, the temperature must be 212°F (100°C) for water to boil, and at the altitude of Yellowstone National Park (because of lower air pressure at about 7,000 feet altitude) water boils at only 199°F (93°C). 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.*

Having followed the water as it circulates through a large hot spring system and rises toward the surface, let us focus on a single geyser and its mechanics of eruption.

Steam clouds rising over Midway Geyser Basin, Yellowstone National Park.

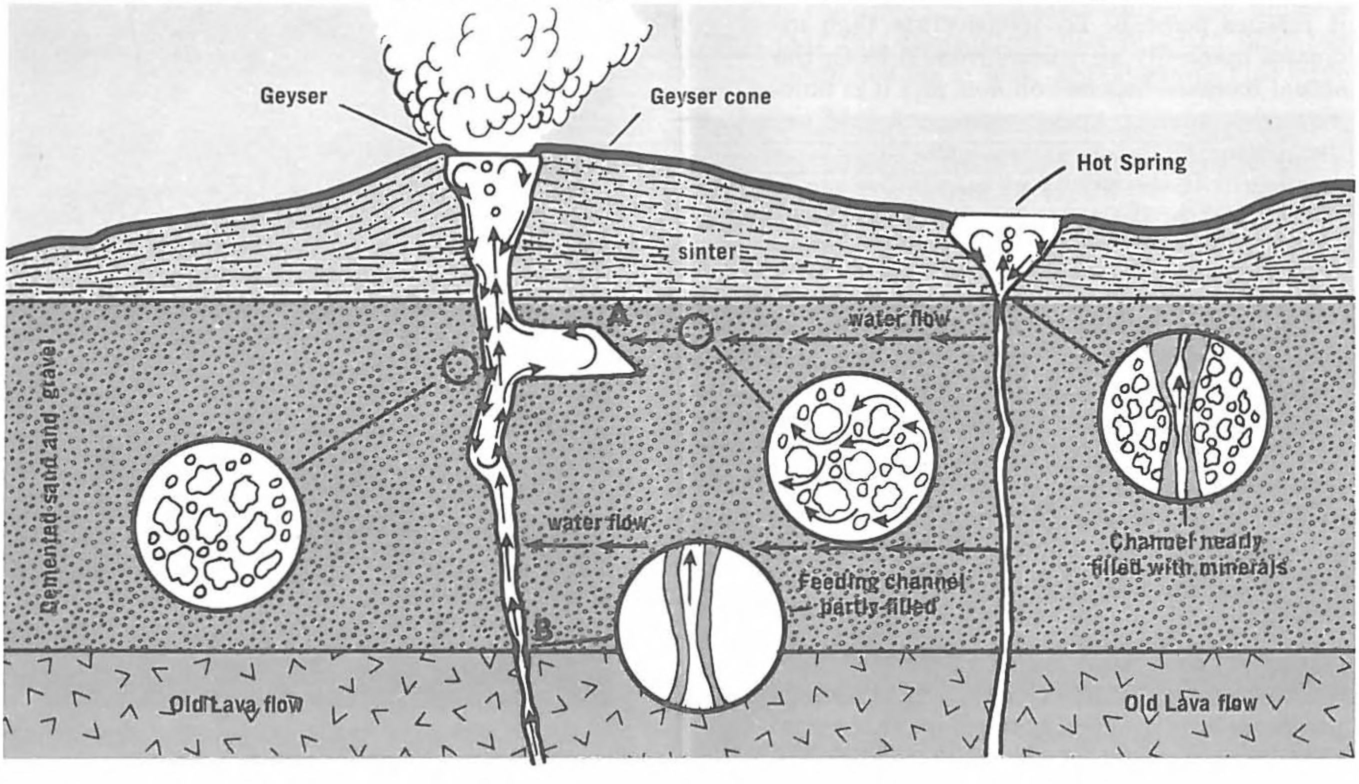
The "plumbing system" of individual geysers.

Figure 3 shows a large system that supplies hot water to many hot springs and geysers. The local reservoirs or "plumbing systems" of *individual* geysers are in the uppermost shallow parts of the large system, within a few feet to perhaps several hundred feet below the surface. Figure 4 is an enlargement of only a small part of Figure 3, and shows a single geyser and a hot spring that does not have the conditions necessary for eruption.

A geyser reservoir commonly consists of a rather large, nearly vertical tube that is open to the air, but that leads down through narrower and narrower "roots" that are the feeding channels. The only part of a geyser's reservoir that can ordinarily be measured with scientific instruments is directly below the surface vent.

Temperatures deep in the main tubes of geysers are generally too low to trigger eruptions. The triggering mechanism thus occurs either near the tops of the geyser tubes, where the rapidly upflowing water is hot enough to boil, *or* in the deep inaccessible parts of the "plumbing" system where much hotter water is flowing into the geyser reservoir, as at points A or B of Figure 4. Because this inflowing water may have a temperature at or even slightly above the boiling point (Curve C of Figure 2) for its depth (because of extra pressure), some of the inflowing water may flash into steam as the pressure abruptly drops to that of water in the geyser tube. The liquid water near these steam bubbles is heated as the steam condenses; finally, the temperature of boiling for the existing pressure is reached. New steam that enters the tubes can no longer condense in cooler water; these steam bubbles

Figure 4: Model of a geyser tube showing reservoir of pore spaces and narrow feeding channels.



start to rise, and they expand continuously upward as pressures decrease.

At some critical time and place that differ for each geyser, the steam bubbles form and expand so fast that they can no longer flow upward individually *through* the liquid water; instead, the water is swept upward along with the bubbles. The effect of the many expanding bubbles is now like a moving plunger, forcing the water upward through the geyser tube. At first the frothing water overflows quietly or in individual spurts and then, like a giant water gun, it may erupt explosively. The reason for this increased rate of discharge is that, as 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 temperature; 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.

In most geysers, the climax of eruption occurs very soon after the eruption starts, when the supply of water and temperatures are greatest. Especially during this early stage, water is erupted from the open tube much faster than new hot water can flow into the geyser through its narrow feeding cracks and channels. The tubes are large and open *only near the surface*, as in Figure 4. At deeper levels, the cracks and channels are partly filled with minerals deposited from the hot water. The flow of water into each local geyser reservoir is slow, relatively continuous, and under high pressure. This slow continuous feed explains how a geyser gains back the supply of water lost in its previous eruption, and it also explains why a geyser can erupt only intermittently. During an eruption, the local reservoir is partly emptied or "overdrawn," just like a bank account when withdrawals exceed deposits.

Riverside Geyser in Upper Geyser Basin, Yellowstone National Park, is one of the few geysers whose eruptions are somewhat predictable.

The geyser cycle.

Now we can understand the parts of a complete geyser cycle. The eruption is, of course, the spectacular part. As the main eruption ends, some geysers first "run out of water" and then have a steam phase. Other geysers first run out of extra heat (energy), while water is still abundant and stands high in the geyser tubes. In the geysers that first run out of extra heat, steam bubbles form more and more slowly as the eruption decreases in vigor. Finally, a moment is reached when the few steam bubbles again rise slowly *through* the water without sweeping the water up to the ground surface, and the eruption ends. A recovery period is then necessary—generally much longer in time than the eruption. The recovery consists of two aspects: recovery of water, and, in part contemporaneously, recovery of heat (or energy). The recovery of water generally occurs first. This fact is most easily seen in geysers like Riverside in Upper Geyser Basin that, after eruption and quiesence, have a period of preliminary overflow. Water starts to discharge from the vent minutes or even hours before the supply of heat has become great enough to trigger an eruption. In such geysers, the subsurface channels and open spaces of the reservoir fill with water before any appears at the surface. Temperature measurements show that the first water to overflow is generally the coolest. As flow continues, the temperature also increases. Water at low temperature is being flushed out of the reservoir while much hotter water is flowing in. With this loss of relatively cool water and gain of hotter water, the geyser is "reloading," or recovering the energy it needs to erupt again.

Explanation for differences among geysers, and complex eruptions.

The general explanation of a geyser cycle given above may clarify why geysers erupt and why they stop, but it does not help understand why each geyser differs from all others. The eruptions of some geysers are very complex and difficult to understand. For example, Grand Geyser of Upper Geyser Basin in Yellowstone Park has spectacular separate surges. Each new surge starts suddenly about two minutes after the previous surge has ended. Each complete eruption consists of two to more than 30 separate surges. During the steam phase of a geyser eruption, pressure of water draining in from the reservoir margins 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.

Steamboat Geyser in Norris Geyser Basin, Yellowstone National Park, is considered to be the largest and most powerful geyser in the world. The height of this eruption was estimated to be about 300 feet.

Seismic Geyser in Upper Geyser Basin, Yellowstone National Park, erupts through a narrow crack that developed during Montana's Hebgen Lake earthquake of 1959.

Other differences between geysers depend on how much of the erupted water falls outside the cone or pool, and how much flows back into the geyser tube, thus conserving the water supply but requiring more heat for the water to be erupted again. Subsurface connections to other springs and geysers may also drastically affect the activity and predictability of many geysers.

An eruption can be confined essentially to a single central tube with narrow feeding channels, as in Vixen Geyser of Norris Geyser Basin, or the reservoir can extend downward or outward to include other almost separated parts. These deeper parts may regain enough energy to take part in some eruptions but not

Minute Geyser in Norris Geyser Basin, Yellowstone National Park, is no longer active because of debris that accumulated in its main vent.

in others. For this reason, many geysers have two or more different intensities of eruption, as Steamboat Geyser in Norris Geyser Basin has had since 1961.

How geysers are born, and why they die.

Most geysers probably start when new cracks or channels are formed by earthquakes. The 1959 Hebgen Lake earthquake just west of Yellowstone National Park in southern Montana created at least one completely new geyser, Seismic, but spectacular changes also occurred in many other pre-existing ones. Numerous springs not known to have erupted previously became active geysers, and some small geysers became major ones such as Sapphire Geyser in Upper Geyser Basin. Most

changes were almost immediate but others developed over several years.

In Figure 4 the geyser tube and other large nearby open spaces (such as near point A) probably formed by enlargement of a narrow crack, just as Seismic Geyser developed as it increased in vigor, ripping off and ejecting rock fragments that may be seen in the photograph, along with trees killed by the increased activity. The large open spaces thus are *effects* of geyser action, and are not the original causes! Some geysers become so vigorous that they "commit suicide" by forming very large tubes and pools; the extra energy can then be lost by the steady processes displayed by ordinary hot springs. Most of the large hot pools in Yellowstone were probably at one time geysers. Some of these "committed suicide" by vigorous enlargement but others may have become inactive by deposition of minerals in their feeding channels (hot spring of Figure 4). With slower "feed," the smaller extra heat can then be lost by circulation, evaporation, and the quiet rise of steam bubbles through the water.

Probably in time, all geysers change their behavior and eventually become inactive. Very small changes in the channels and patterns of flow can result in major changes in behavior. The western major vent of Minute Geyser in Norris Geyser Basin formerly erupted to heights of nearly 100 feet, but the tube was filled with rocks by careless or curious tourists, and the geyser no longer erupts.

Geysers are rare and beautiful. Let us treasure and preserve these wonderful demonstrations of nature's energy!

From material provided by Donald E. White

U.S. GOVERNMENT PRINTING OFFICE : 1971 O—444-074

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 - Price 25 cents
Stock Number 2401-2029