EVOLUTION OF SEISMIC GEYSER, Yellowstone National Park

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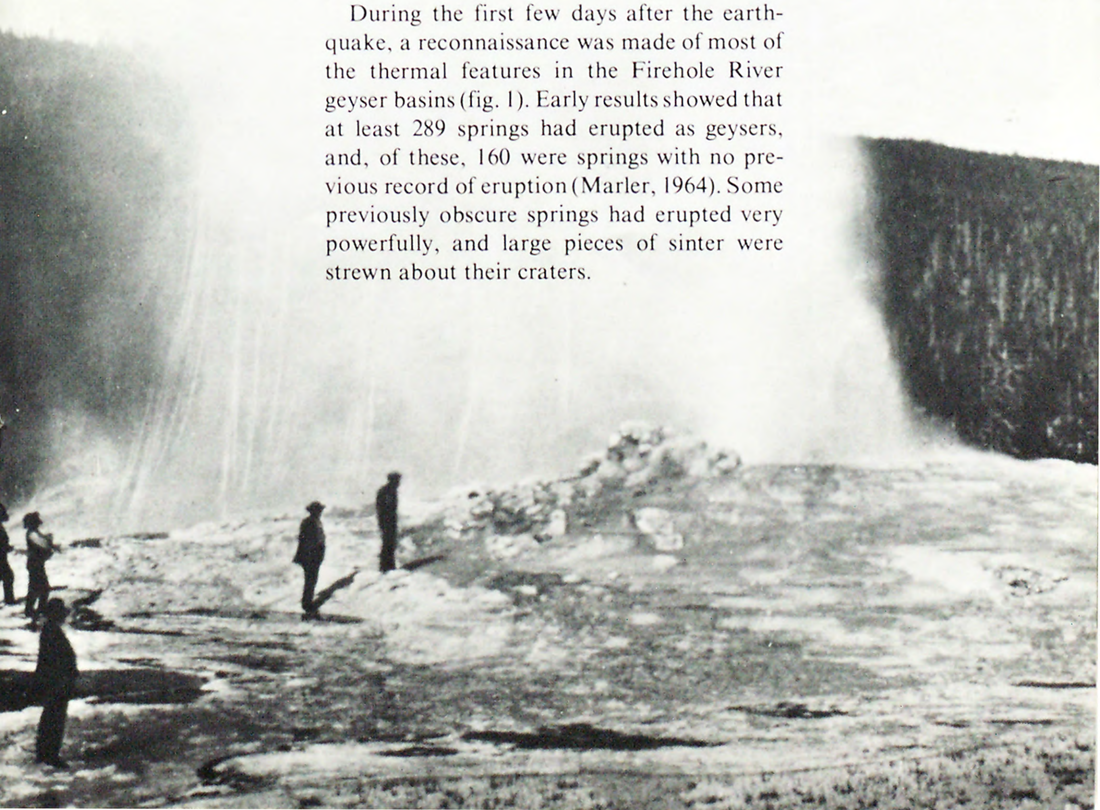
The most significant event that has affected the geyser basins of Yellowstone National Park since its discovery was the Hebgen Lake earthquake, which occurred at 11:37 PM on August 17, 1959, with a Richter magnitude of 7.1. The epicenter of this earthquake was just west of the park, about 48 km northwest of the Upper Geyser Basin. No earthquake of comparable intensity had jarred the geyser basins in historic times. More hydrothermal changes occurred in response to this disturbance than during the previous 90 years of the park's history.

During the first few days after the earthquake, a reconnaissance was made of most of the thermal features in the Firehole River geyser basins (fig. 1). Early results showed that at least 289 springs had erupted as geysers, and, of these, 160 were springs with no previous record of eruption (Marler, 1964). Some previously obscure springs had erupted very powerfully, and large pieces of sinter were strewn about their craters.



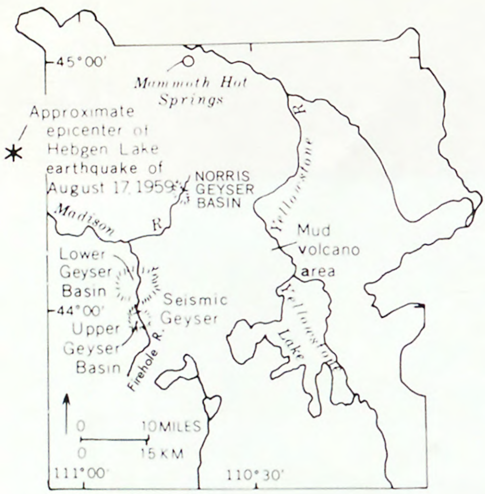


Figure 1.—Map of Yellowstone National Park showing main geyser basins.

During the night of the earthquake, all major geysers erupted that had been recently active, and some that had been dormant for many years were rejuvenated. In 1960, temperature data of all important springs along the Firehole River showed an average increase of about 3°C above their preearthquake temperatures. By 1964, the average temperature had declined slightly below the 1960 level.

One of the important changes in the Firehole River geyser basins that resulted from the earthquake was the development of new hot ground. Most of the less conspicuous hot spots did not become evident until the spring of 1960 when they were revealed as linear distributions of dead or dying lodgepole pines generally trending northwest toward Hebgen Lake. Many springs and geysers in the geyser basins are alined on such north-striking trends, reflecting regional tectonic stress patterns.

Some fumaroles related to these new fractures later became the sites of hot springs and geysers. The evolution of one of these fractures into a fumarole and then into a large geyser (Seismic Geyser) has far-reaching significance in understanding the formation of other geysers, geyser tubes, and hot-spring vents.

Among the thousands of thermal springs in Yellowstone Park, Seismic Geyser is one of the few that is totally recent in origin. It is not a quiescent or dormant spring that was reactivated; rather it is one that had its genesis as a direct result of the earthquake on August 17, 1959.

Evolution of Seismic Geyser

Within several days after the earthquake, two new fractures were observed in an embankment of old sinter that borders the Firehole River in Upper Geyser Basin about 550 m south of the Biscuit Basin parking area, and steam was issuing from each break. The fact that steam was escaping under pressure indicates a temperature above 92.9°C, the boiling temperature at this elevation. The upper break traversed an area of densely growing lodgepole pines that were about 50 years old. One of the first wagon roads into the Upper Basin crossed directly over the site of the upper break.

During the remainder of 1959, the discharge of steam pressure continued unabated from both fumaroles (fig. 2). In addition to the heat that was visibly discharging from the fumaroles, dying trees over an area of at least 150 m^2 were evidence that new hot ground had developed with near-surface temperatures too high to be tolerated by the vegetative cover.

By the fall of 1960, the evolution of steam from both fumaroles had increased in intensity. The shorter break farthest from the river showed the most pronounced change. By October, its temperature had risen to 96.1°C, and the ground near this fumarole had subsided somewhat, suggesting some change in underground conditions. The possibilities seemed excellent for a new spring or geyser to develop.

When the site of the fumaroles was first visited in the early spring of 1963, a major change had taken place. Sometime during the previous winter, explosive activity had occurred at the site of the upper fumarole. Where steam previously had been hissing through a narrow rift, there was now a large crater. Numerous large blocks of sinter from 0.3 to 1 m in diameter were strewn about randomly, bearing evidence that the crater had formed explosively (fig. 3). The dead trees that had formerly been in place over the site of the crater were now broken and scattered.

During 1963, water jets about 1 m high played every few seconds into the crater from its west end. The fumarole had thus evolved into a small geyser.

The winter of 1964–65 resulted in new marked changes in the geyser. Sometime prior to April 1965, a new explosion occurred near the west end of the crater. Sudden release of energy had not only greatly enlarged the earlier hole but had also torn out obstructions. The water, now discharged in much greater volume, erupted vertically instead of at an

Figure 2.—Earliest photograph of the fumarole area that later developed into Seismic Geyser (spring, 1960).

Figure 3.—Seismic Geyser after initial eruptions in spring of 1963. Note large blocks of sinter near the vent, with fine debris absent in splashed area.

Figure 4.—Explosive burst just breaking the surface pool of Seismic Geyser with water level below level of discharge (May 30, 1966).

angle. Yellowstone evidently now had a new geyser of no mean proportions, and it became known as Seismic Geyser.

The eruptions increased in vigor in the late winter of 1966 (fig. 4). By this time, the diameter of vigorously washed ground around the geyser was about 21 m, caused by the nearly vertical fall of erupted water. During the years of 1967 through 1969, the pattern of Seismic Geyser's eruptive activity underwent progressive changes. The length of the quiet phase between eruptions slowly increased to about 40 to 50 min. Each eruption was complex with a duration of about 15 to 20 min, during which 30 or more separate bursts occurred. The first burst of each sequence explosively broke the surface of the pool, as shown in figure 5. The crater was still slowly being enlarged on its margins.

In the early part of 1971, a vent (now called Satellite Geyser) developed on the east shoulder of the crater. Satellite's vent, like Seismic's, resulted from one or more explosions. During the season, further enlargement occurred. There was a break of about 0.6 m in the side next to Seismic Geyser, which resulted in the water of both springs being continuous at the surface when levels were high.

When first observed in 1971, the water was boiling vigorously in Satellite's crater, and this was characteristic of its pattern throughout the remainder of the season. But periodically, Satellite erupted with massive bursts to a height of about 3 to 3.7 m and occasionally to 6 m. Its eruptions were synchronized with those of Seismic, with both vents erupting simultaneously.

Figure 5.—Bursting eruption of Seismic Geyser (August 1968).

By the spring of 1972, further changes were evident. During the previous winter, Satellite's vent had enlarged and had become heart shaped. No further change took place in Seismic's crater during the 1971–72 winter, probably because it had ceased eruptive activity. Geyser activity was confined wholly to Satellite's vent, while Seismic had become an intermittently overflowing spring.

Intervals between ruptions of the new vent during 1972 ranged from 15 to 37 min; each eruption lasted 21 to 31 min and consisted of either two or three separate periods of spouting. Each eruption was initiated by a rise in water level of about 0.20 m in both craters. At times, Seismic overflowed for a few minutes with no consequent eruption of Satellite. Boiling in Satellite was continuous from eruption to eruption.

By June 1974, all eruptive activity was confined to Satellite, which most commonly surged to heights of about 1 m but had some spurts to 3 m or a little higher. The duration of observed eruptions of Satellite ranged from 31 to 47 min, and the eruption intervals ranged from 49 to 66 min (data from Roderick Hutchinson, Natl. Park Service). At times, between eruptions, both pools were quiet in striking contrast to earlier almost constant activity.

Seismic's vent was probed extensively in 1974, but the maximum accessible depth was 6.6 m, where temperatures ranged from 89.6° C to 95.6° C. Temperatures at the bottom were, in general, slightly below those at 3.7 m, where the observed range was 88.9°C to 99.0° C. Satellite's vent was probed to a maximum depth of 3.7 m, where the temperature range was from 94.3° C to 97.8° C (temperature data from Manuel Nathenson, U.S. Geol. Survey).

Seismic activity around Yellowstone Park

Since the discovery of Yellowstone Park, earthquakes of sufficient intensity to be recognized have occurred rather frequently. (The most recent earthquakes were in the Mammoth Hot Springs area on December 19, 1976, magnitude M_L=4.3 and 4.5, respectively.) After the 1959 earthquake, the National Park Service, in cooperation with the U.S. Geological Survey, installed three seismographs in the park. One was also set up at Hebgen Lake. They commonly record an average of about five shocks daily around the park; on rare occasions, they may record 100 or more in a single day. Most events are so slight that they cannot be felt by man, but occasionally strong earthquakes occur, such as that of August 17, 1959.

Seismic records indicate that, on an average of about once in 10 years, a strong earthquake occurs in the States adjoining Yellowstone National Park, particularly in Montana. The last strong earthquake prior to August 17, 1959, was on November 23, 1947. Neither the 1947 earthquake nor any earlier historical one was sufficiently intense to produce major hydrothermal changes. But some of the evident changes in the hot springs that have occurred over the centuries are probably associated with strong seismic activity. The Hebgen Lake earthquake, far from being the only incident to affect the geyser basins, was no doubt preceded by many earthquakes of equal intensity during the past few thousand years.

Microearthquake monitoring of the park in recent years by the U.S. Geological Survey and by the University of Utah has revealed a pattern of frequent small events that tend to be localized immediately outside of the Yellowstone caldera but rarely occur inside the caldera. (See "Teleseismic Studies Indicate Existence of Deep Magma Chamber Below Yellowstone National Park" by H. M. Iyer, *Earthquake Information Bulletin,* March–April 1974, vol. 6, no. 2.)

The active belt extends eastward from Hebgen Lake to Norris Basin and then eastward for a few kilometers adjacent to the caldera rim. Thus, of the major geyser basins, only Norris is near the most active seismic belt; Shoshone, the major Firehole River geyser basins, and West Thumb are all within the relatively inactive caldera.

Subsurface properties of Yellowstone's geyser basins

The temperature and pressure gradients in the upper few hundred meters of Yellowstone's geyser basins provide the basis for understanding how and why new vents form.

Research holes drilled in Yellowstone National Park show maximum temperatures ranging from 143° to 237.5°C. As drilling progressed, the standing level of water in each hole rose to the ground surface and then attained positive pressures (in capped holes) that ranged up to an equivalent level of 65.5 m above ground. The excess pressure exceeded the hydrostatic pressure by 47 percent in one hole.

These very high pressures near the surface in rocks that are originally very permeable mean that some kind of self-sealing mechanism operates within the geyser reservoir. Such a highly pressurized system has subsurface temperatures that indicate a superheated condition of the fluids.

Seismic response of Yellowstone geysers

Earthquakes, largely localized just outside of the Yellowstone caldera, result in violent shaking of the large, high-temperature convection systems of the geyser basins. New fractures form in the self-sealed shallow parts of these systems where high-temperature water is confined at pressures well above hydrostatic. The new fractures provide new escape channels for fluid in the overpressured system. As old fractures and permeable channels become sealed by precipitation of hydrothermal minerals, new channels are provided by the periodic seismic activity. The seismic response of such a system evidently differs greatly from place to place. Some responses are nearly instantaneous, but others evolve slowly over a period of years.

We believe that Seismic Geyser provides the keys for understanding the origin of other spring and geyser vents. Some other craters are also of recent origin, with jagged ledges of sinter and sediments in the crater walls bearing mute evidence that powerful eruptions were responsible for creating the vents. Other spring and geyser vents are smooth walled, probably because they are old enough for initial irregularities to have been covered by sinter.

References

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