HOT SPRING ACTIVITY IN THE GEYSER BASINS OF THE FIREHOLE RIVER FOR THE 1960 SEASON

GEORGE D. MARLER

Hot Spring Activity In The Geyser Basins Of The Firehole River For The 1960 Season

George D. Marler *

The hot springs in the geyser basins of the Firehole River continued to show marked effects and alterations due to the Hebgen Lake earthquake of the previous year. In general, the springs which did not return to near pre-quake status within a few days to about 6 weeks following the quake continued during all of 1960 to persist, with modifications, in the changes that had been induced in them.

Many alterations in hot spring activity that resulted from the earthquake were latent in character. Days, weeks and sometimes months passed before these changes became evident. Some of the changes in hydrothermal functioning during 1960 must be ascribed to alterations in ground structure produced by the earthquake. These changes resulted in new foci of expression of the thermal energy. In many places deep-seated fracturing has so altered former avenues of steam egress that there is little or no liklihood that conditions in the geyser basins will ever be the same as before the big tremor. There is a high degree of probability that it will be several years before the hot springs along the Firehole River become what might be called stabilized from the effects of the 1959 earthquake. Some of the many new fumaroles, that had their genesis in the rifts and cracks produced by the jarrings, show evidence of progressive development into hot springs. At three of these sites, water is already being discharged. With the development of new springs many nearby springs are bound to be affected, with the possibility that a few will become dormant, others extinct.

---

* The author would like to acknowledge the observations of all the Naturalists stationed at Old Faithful who kept a daily log of geyser activity. Further credit is given to Park Ranger Riley McClelland for observations made in the Upper Basin during the 1959-60 winter.

Slow Developing Hot Ground

In a number of places in the geyser basins of the Firehole, new cracks in the geyserite were in evidence the morning following the big tremor. As stated, some of these cracks had fumarolic action. It was not until spring of 1960, however, that the extent and character of the new hot ground became evident. Many of the fractures resulting from the quake were deep seated, with no surface expression. However, during winter, gases had reached near enough to the surface so that the ground had become too hot to support a vegetative cover, particularly the Lodgepole Pines. During the 1960 season, these new hot spots were in evidence due to groups of pines that had died during the previous winter. These brown leaved trees contrasted sharply with nearby green needled ones. In late 1960, this new hot ground was plotted and temperatures were taken one foot below the surface, near the roots of dead trees. The temperature range was from 64 to 204 degrees*. Ground temperatures adjacent to the new hot spots ranged between 38 and 44 degrees. On at least two of these tree-covered spots of hot ground, new thermal springs would appear to be evolving. In the Cascade Group, existing springs are now being affected by this new development.

During 1960, geyser activity was observed in the following named hot springs:

UPPER BASIN

Giantess Group

1. Little Squirt Gey.
2. Anemone Geyser
3. Surge Geyser
4. Roof Geyser
5. Beehive Geyser
6. Plume Geyser
7. Depression Geyser
8. Lion Geyser
9. Little Cub Gey.
10. Goggle Spring
11. N. Goggle Spring
12. Beach Spring
13. Aurum Geyser
14. Sponge Geyser
15. Vault Geyser
16. Giantess Geyser
17. Infant Geyser
18. Mound Geyser
19. Solitary Geyser

Myriad Group

Three Sisters:
1. North Vent
2. Middle Vent
3. South Vent
4. Little Brother
5. Bell Spring
6. Round Geyser
7. White Geyser

Black Sand Basin

1. Spouter Geyser
2. Cucumber Spring
3. Cliff Geyser
4. Black Sand Pool

---

* In giving temperatures, the Fahrenheit scale is used.

Daisy Group

1. Daisy Geyser
2. Comet Geyser
3. Radiator Geyser
4. Daisy's Thief
5. Bank Geyser
6. Pyramid Throne
7. Bonita Pool

Old Faithful Group

1. Old Faithful Geyser
2. Chinaman Spring

Lone Star Group

1. Lone Star Geyser

Castle & Sawmill Groups

1. Castle Geyser
2. Tilt Geyser
3. Deleted Teakettle
4. Sawmill Geyser
5. Penta Geyser
6. Spasmodic Geyser
7. Tardy Geyser
8. Bulger Geyser
9. Sprinkler Gey.
10. Churn Geyser
11. Terra Cotta
12. Frog Spring

Grand Group

1. Grand Geyser
2. Turban Geyser
3. Vent Geyser
4. Rift Geyser
5. W. Triplet Gey.
6. Spanker Geyser

Round Spring Group

1. W. Round Spring
2. Round Spring Geyser

Giant Group

1. Bijou Geyser
2. Oblong Geyser

Grotto Group

1. Grotto Geyser
2. Rocket Geyser
3. Spa Geyser
4. Surprise Geyser
5. Grotto #2 Gey.
6. Grotto #3 Gey.
7. Riverside Gey.

Cascade Group

1. Artemisia Geyser
2. Atomizer Geyser
3. Hillside Geyser

Biscuit Basin

1. Cauliflower Gey.
2. Sapphire Pool
3. Jewel Geyser
4. Avoca Spring
5. E. Mustard Sp.
6. W. Mustard Sp.
7. Black Pearl Gey.
8. Shell Geyser
9. Coral Geyser
10. Fumarole Gey.
11. North Geyser

MIDWAY BASIN

1. Catfish Geyser
2. Flood Geyser
3. Tromp Spring

LOWER BASIN

Great Fountain Area

1. Great Fountain
2. Surprise Pool
3. White Dome Gey.
4. Gemini Gey.

Pink Cone Group

1. Pink Cone Geyser
2. Bead Geyser
3. Narcissus Gey.
4. Box Spring

Firehole Lake Area

1. Steady Geyser

Fountain Group

1. Clepsydra Geyser
2. Spasm Geyser
3. Jelly Spring
4. Bellefontaine Gey.
5. Sub Geyser
6. Red Spouter
7. Cone Spring

Hotel Group

1. Kidney Geyser
2. Cliff Spring
3. Stirrup Spring

River Group

1. Bath Spring
2. Mound Geyser

UPPER BASIN

Geyser Hill

During all of 1960, the geyser activity on Geyser Hill followed essentially the same pattern that prevailed during the last three months of 1959.

Anemone Geyser: The changed pattern of play induced by the 1959 earthquake presisted during all of 1960. Instead of the former chain action, which had been initiated by the north vent, the south vent was in an almost constant state of activity. There was a profuse growth of algae in its runoff channel.

Plume Geyser: Until October 1960, Plume's intervals were about twice as long as prior to the quake. It had been determined in September 1959, that this delayed activity resulted from water flowing into Plume's crater. This water came from springs which had their origin the night of the big tremor.

During the first 9 months of 1960, the intervals varied from 2 to 3 hours. About the first of October it began playing with greater regularity and on much shorter intervals. Some of this increase in activity apparently resulted from diminished flow of the new springs lying directly above Plume, however, an additional factor, or factors would seem to be involved.

Since September, most of Plume's eruptions have occurred on intervals of less than an hour. In October, I checked one interval of 33 minutes. This is the shortest one on record. There would seem to be little question but that the earthquake greatly stimulated Plume's activity.

One hundred feet north of Plume, a hitherto dormant spring was initiated into eruptive activity by the quake. It is called Surge Geyser, the name being descriptive of its manner of function. The eruptions continued during all of 1960, lasting for about one minute. They occur about every 5 minutes.

Little Squirt Geyser: The constant "squirting" of this small geyser, which began the night of the quake, continued without any interruption during all of 1960.

The Cascade Geyser, which is situated on the shoulder of the steep embankment of the Firehole, and directly below Little Squirt, was inactive during all of 1960. Its earthquake rejuvenation after 50 years of dormancy would appear to have been but temporary.

Beehive Geyser: During 1960, Beehive played with greater frequency than for several years prior to the 1959 earthquake. One-hundred-three eruptions were recorded. This figure, however, does not cover all of its activity. Night eruptions were not determined. The record of its summer activity is indicative there was at least one unrecorded night eruption for each two daytime ones. On this basis, it can be assumed that the Beehive erupted not less than 140 times during 1960. This would give it an average interval of about 66 hours.

Midway between the Beehive and Arrowhead Spring is a large spring known as Depression Geyser, the name resulting from the depression-like character of the crater. During 1960 it was occasionally observed erupting, but due to the infrequency of the activity no intervals were determined.

The eruptive activity that characterized Arrowhead Spring following the quake, and for the rest of that year, ceased before spring 1960. During all of 1960 there was a slight overflow, a condition that has not characterized it in at least the last 30 years.

Lion Group: The rejuvenation that characterized the Lion Geyser following the quake persisted during 1960. It went into an active phase every second to third day. The Lioness and Big Cub remained dormant, though there were times when they appeared to be on trigger-edge. The craters would fill and boil violently, but with no consequent major activity. Little Cub persisted in its minor and major type functioning.

Goggles Spring, situated at the base of the Lion, overflowed periodically, as it had done prior to the quake. However, a spring about 15 feet to the north, known as North Goggle, was observed on 3 occasions playing to a height of 10 to 12 feet. There is no record of any eruptive activity at this spring prior to August 18, 1959.

Pendant, Beach, Doublet and Pump Springs were very much in a pre-quake status during all of 1960.

Sponge Geyser: By 1960, the Sponge had largely recovered from the marked ebbing and dormancy that characterized it following the jarrings of August 17, 1959. During 1960, the frequency and manner of its functioning were essentially the same as before the quake, however, the water stood about 4 inches lower in the crater.

Giantess Group: During 1960, there was but one eruption of Giantess Geyser. This was observed by Park Ranger B. Riley McClelland on February 19. McClelland reported that the eruption was "somewhat tame."

The marked activity of Vault Geyser, with which Giantess has subterraneous connectinns, would seem to be a big factor in its infrequent function. If the Giantess is playing less often than at some earlier period, there is a degree of probability it is responsible for its own senility. Being directly connected with a number of other thermal units, under which conditions many springs seem very sensitive to any change in hydrostatic pressure, it is highly probable that the Giantess has built its mound to such a height (thereby increasing hydrostatic pressure), that in recent years the critical temperature for an eruption is seldom reached. Quite apart from this, the great increase in activity of Vault since the quake would in itself divert eruptive potential away from Giantess.

Before the quake, the Vault was in an active phase about two times each week. After the quake, it was dormant for about two months, following

which it began to erupt almost daily, the intervals being from one to two hours. This great increase in function characterized it during all of 1960.

The level of the water in the Teakettle has been several inches below the rim of the crater for several years. Following the quake, it ebbed about 6 feet. It is still from 24 to 30 inches below pre-quake level.

Before the 1959 earthquake, Infant Geyser was never observed to play except in concert with the Giantess. Since the big jarrings, it has developed eruptive activity independent of the Giantess. During 1960, it was active one or more times each day, the water boiling up to a height of from 2 to 3 feet.

Dome Geyser: This geyser is frequently referred to as "Cone Geyser." Dome is its correct name. It has the highest cone, or mound of any spring on Geyser Hill. Since its first recorded activity on November 4, 1959, it was periodically eruptive until May of this year. From then until November 7 it was dormant. The November activity was of comparable scale to that of the previous November.

There is little doubt but that the earthquake is the cause of this spring's rejuvenation as a geyser. At some period antedating the discovery of the geyser basins, it has had a prolonged period, or periods of eruptive activity, of which, the fluted sides of the dome bear mute witness.

In the central area of Geyser Hill, three new springs broke through the sinter the night of the quake, most of the existing springs erupted, some of them persisting to date as geysers. Dragon Spring erupted the night of the quake, prior to which it was a steadily flowing spring. It has never recovered from the effects of the quake. On the morning of August 18, 1959, the water was down about 3 feet. Since that date, there has been slow, but steady ebb and cooling. Roof Geyser persists in its earthquake induced activity, playing about every 5 minutes.

The fumarole which developed at the southwest base of the Giantess, as a result of earthquake fracturing, developed into a steadily spouting spring before the summer of 1960. Geyserite is being excavated slowly in the vicinity of the spouting. Blue Star, Chinaman and East Chinaman Springs, which are situated on the south bank of the Firehole, acroos from Geyser Hill, were in the same state as before August 17, 1959.

Myriad Group

The Myriad, or "Mud Group," in reference to its numerous mud and turbid springs, was greatly stimulated the night of the earthquake. Many of its myriad springs erupted. In a few, eruptions continued for a short period after the quake, but by April 1960, most of the springs, there are a few noted exceptions, had settled down to a pre-quake state.

Three Sisters: These springs are the most noted ones in the group. They were named the Three Crater Springs by the 1878 Hayden Survey. This name was later changed to Three Sisters. The appelation "Springs" appended to the Three Sisters is indicative that when the name was given they were not considered geysers. During at least the last score of years, with one known exception, there has been seasonal activity in the north crater. There are three vents in this crater. The activity has shifted from vent to vent, with not more than one vent being active during a particular season. Prior to the earthquake, all vents had a similar manner of function. The eruptions were characterized by momentary, vigorous boiling, which recurred about every 5 minutes.

The great ebbing that took place in the Three Sisters following the quake, has persisted throughout all of 1960. The type of eruptive activity* that began in October 1959 has also continued with little change. The northernmost vent, however, did not begin present eruptive activity until sometime following January. Little Brother is the most spectacular performer, erupting every 9 to 15 minutes.

The many non-flowing springs south of Three Sisters which erupted the night of the quake were, with the exception of Bell Geyser, not observed playing during 1960. Trail, the most powerful geyser in the area that was stimulated by the earthquake, has not erupted since December 1959. Bell has persisted in its sub-aerial eruptions.

None of the springs lying east of Trail and Bell Geysers were observed to erupt during 1960. The late season activity that built up the cone of the Pink Cistern had subsided sufficiently by spring to result in the partial disintegration of the cone. With the exception of the Three Sisters and Bell Geyser, hot spring activity in the Myriad Group appeared to have subsided somewhat over that which characterized it during 1959 and previously. The great increase in activity of the Three Sisters might offer a partial explanation. The Three Sisters are known to have underground connections with other important springs in the group.

Black Sand Basin

The springs in this area were not as active in 1960 as during the early period following the quake. However, during 1960, there was greater activity than during the 1959 pre-quake period. The water in Cucumber Spring did not entirely clear from the murky state resulting from the quake. The new spouter on the east end of its crater has continued to function without cessation. The water in nearby Black Sand Opal stood at a higher level in the latter part of the 1960 season than had characterized it since the quake.

---

* See page 11, 1959 Report.

Cliff Geyser: The great increase in eruptive activity of Cliff immediately following the earthquake subsided toward the end of 1959. By December, there were not more than 2 or 3 eruptions per week. During the 1960 season, but 2 eruptions were observed, the same as during the 1959 pre-quake period.

Both the Whistle Geyser and Green Spring were inactive during 1960. Since 1957, Whistle has maintained a slight, but steady overflow, a condition which, so far as records are concerned, never previously characterized it. With the rise of the water in the crater during the 1957 winter to overflow stage, the temperature dropped about 50 degrees.

Emerald Pool: The 3 degrees increase in temperature of Emerald Pool at the time of the quake did not persist for more than a few weeks. By 1960, it had dropped from 150 to 142 degrees F., where it stood during most of the season. The slight drop in temperature that has characterized this spring during the past few seasons has changed the former beautiful, emerald green to a darker and less attractive color.

Rainbow Pool: Following the earthquake, and for the rest of 1959, the water in Rainbow stood about 6 inches below overflow stage. Prior to the quake, there had been steady overflow. During 1960, the water had ebbed an additional 6 inches over the 1959 period, however, by October it began to show recovery in level. By the end of the year, the water was only about 4 inches below overflow.

Black Sand Pool: The geyser characteristics which the earthquake imparted to this spring, persisted throughout 1960. The boiling, accompanied by increased overflow, recurred about every 5 minutes. The large spring across the road to the east from Black Sand that was stimulated into eruptive activity by the quake, had no further eruptions. However, during 1960, the water stood about 3 feet higher in the crater than was the case before the quake. Physical evidence about the crater of this spring is highly indicative that at some period much earlier than 1870, there was a considerable amount of major eruptive activity. It could have become dormant as a result of the evolution of Black Sand Pool.

Daisy Group

It is doubtful if the effects of the 1959 earthquake were any more far-reaching in any group of thermal springs than in the Daisy Group. The shift of the energy to the east side of the group showed further intensification during 1960. Right now, it would seem almost necessary for the occurrence of a major quake if the thermal energy ever shifts back to Splendid. The earthquake not only altered the foci of the expression of the energy in this group, it changed previously existing interspring functional relationships, as will be brought out later in this report.

Daisy Geyser: The remarkable increase following the earthquake in the functional activity of Daisy persisted until February 1960. At this time, there was a partial shift of some of Daisy's energy to Bonita Pool. For the remainder of the year, Daisy's intervals were greatly lengthened

and of uncertain time. During all of Daisy's known history, there never was a period when an eruption was as difficult to predict as during 1960. The frequency of eruptive activity seemed directly related to the intensity of Bonita Pool's activity.

From May 5 through October 25, 228 of Daisy's eruption intervals were determined. The average time was 143 minutes; the extremes being 77 and 240 minutes. During the period in August when Bonita's overflow was checked, 58 intervals were determined. The average time was 105 minutes; the extremes being 85 and 128 minutes. During the seven days previous to checking Bonita's overflow, the average time for 19 eruptions checked on Daisy was 141 minutes; the extremes 95 and 210 minutes. Following the removal of the check, Daisy shifted back to pre-dam conditions.

During the summer, in addition to the damming experiment discussed under Bonita Pool, an additional experiment was carried out in the Daisy Group with a view of trying to determine to what extent the earthquake had altered interfunctional relationships between the various springs. In October, on 3 different dates, Daisy's Thief was induced to erupt by lowering its water level a few inches, with a view of determining if an eruption would, as before the quake, render Daisy dormant. The occasional eruptions of the Thief prior to the quake, always occurred at the time an eruption of Daisy was pending. The Thief's eruptions had the effect of shifting the pressure from Daisy, bringing about its temporary dormancy, or causing it to skip an eruption.

The induced activity in Daisy's Thief in October, as previous to the quake, caused gradual subsidence of the water level in Daisy's crater. However, after 1 hour and 40 minutes of activity of the Thief, Daisy erupted! The Thief continued playing and 60 minutes later Daisy again erupted. At the conclusion of this eruption, the Thief also stopped, and the energy shifted back to Daisy with the same conditions prevailing as before the induced activity.

On two later occasions, when the Thief erupted, it continued playing through the third eruption of Daisy. All of Daisy's intervals were 60 minutes. Thus, instead of the small unit known as Daisy's Thief acting in that role, as it always had been observed to do prior to August 17, 1959, its activity would now seem to serve as a trigger to bring about an eruption of Daisy.

On October 18, an additional experiment was performed at Daisy. The object was to determine, if possible, what effect the returning water of an eruption into Daisy's crater had upon the duration of the activity.

There is much observational evidence to the effect that both Daisy and Splendid are rather directly connected underground to the same reservoir, yet an eruption of Splendid is not only more powerful than that of Daisy, but discharges several times as much water. I had theorized that the chilled water that flows back into Daisy's crater during its activity resulted in a more enervated eruption than otherwise would be the case. The chilled water acted as a damper to bring about early cessation of play.

With the assistance of seasonal Naturalists Beal and Germeraad, 3 burlap bags of sand, partially full, were placed in two of the drainage channels near Daisy's bowl. This served to check not more than 50% of the return flow. The bags were left in place for two eruptions.

The results of this experiment were very interesting and enlightening. As had been anticipated, the duration of Daisy's eruption was increased. It lasted for 4½ minutes. Prior to, and following the removal of the bags, the duration was 3 minutes. The eruptions were noticeably higher, with a greater evolution of steam. It is quite certain that Daisy's eruptions would be of much greater magnitude and volume of discharge were it not for the heavy return of erupted water. In power, its eruptions might be comparable to those of Splendid.

One result of the experiment not anticipated was the effect the partially checked flow had on Daisy's pre-eruption symptoms. After the pressure built up to a point where an eruption seemed imminent, Daisy stayed in that state from 15 to 20 minutes before playing. The results of this observation lend a high degree of credence to the theory that some geysers bring about their own demise or dormancy by building their mounds to such height that hydrostatic pressure becomes too great for the water in the geyser to reach the critical temperature of an eruption.

Bonita Pool: Even though the evidence was compelling on August 18, 1959, that the big tremor had shifted the thermal energy to Daisy, and to ground farther east, surprisingly, Bonita did not show any immediate increase in activity. As a matter of fact, on the morning of August 18, the water had ebbed several inches. Before the end of 1959, the water had dropped from 104 to 98 degrees.

In February 1960, Bonita became animated. Latent effects of the quake began to manifest themselves. There was a pronounced shift of the energy away from Daisy to Bonita. The temperature rose from 98 to over 200 degrees. Bonita had become a geyser.

When Park Ranger McClelland first observed Bonita's changed state in February, he noted that the eruptions were about 3 feet in height, occurring about every few minutes. There was also a marked and steady overflow between Daisy's eruptive periods. This condition, with occasional waxing and waning in intensity, persisted throughout all of 1960. The only time Bonita would ebb below overflow was for about one-half hour following an eruption of Daisy.

Prior to the February rejuvenation of Bonita, Daisy was erupting about every 60 to 70 minutes, with a fair degree of regularity. Following the shift of the energy to Bonita, Daisy's intervals for the remainder of the year ranged from about 1½ to 4 hours. The length of the intervals seemed to vary with the waxing and waning of Bonita's function.

On the morning of August 24, Bonita's drainage was checked by a sinter dike with a view of determining to what degree the discharge was affecting Daisy's frequency and regularity. It was necessary to build a dike about 6 inches high before hydrostatic pressure stopped convection in Bonita and diverted the flow of the thermal energy to Daisy.

The checking of the flow from Bonita resulted in Daisy playing with marked regularity, making possible the prediction of eruption time with a high degree of accuracy. I had anticipated that the dam would shorten the average time of Daisy to a greater extent than what resulted. The fact that it did not would seem to confirm observations made during other seasons to the effect that units outside the immediate Daisy Group might be connected subterraneously.

The checking of the overflow held the possibility of affecting an exchange of function from Bonita to Daisy, which certainly would have resulted had a comparable situation of relation between Daisy's and Bonita's overflow existed as prior to the earthquake. In other years when overflow from Bonita interfered with Daisy's function, the checking of the flow from Bonita always resulted in a complete shift of the thermal energy back to Daisy. Sometimes years would elapse before Bonita would again overflow. That no exchange of function resulted from the October experiment demonstrates to a high degree the conclusion drawn from surface manifestations, and the experiment at Daisy's Thief, that the quake has greatly altered previous functional relationships that existed between a number of springs in the Daisy Group. The promise of continuing major geyser activity that has characterized the group for perhaps the past few hundred years is not too reassuring. The quake-induced shift of the thermal energy is away from Splendid, the major geyser in the group, and, with the exception of Daisy, in the direction of minor ones. As for Daisy, if Bonita continues in its present role, even the Daisy has seen its heyday.

Both Splendid Geyser and Brilliant Pool were dormant during all of 1960. The Comet played on a pattern similar to that which characterized it before the quake. The new hot ground east of Daisy showed further development during the season. Bank Geyser was active every 40 to 50 seconds. The small geyser at the base of the White Pyramid Throne was not observed erupting.

Castle and Sawmill Groups

Castle Geyser: Between May 5 and October 25, 76 eruption intervals of Castle were determined. The average interval was 9 hours and 30 minutes. The minimum interval was 8 hours and 22 minutes; the maximum, 10 hours and 35 minutes.

Since the earthquake, Castle has played with a high degree of regularity. Its increase in activity, resulting from the quake, persisted during all of 1960. For every 4 eruptions preceding the quake, Castle now plays 6 times. The height, character and duration of the eruptions have remained

essentially the same as before the big tremor. However, since the quake, there is no record of a 4 minute eruption. Such an eruption used to result in a short interval.

Tortoise Shell Spring: This superheated spring continued during all of 1960 in the same manner of function that has ever been its known habit. It is one of very few springs in the Firehole Geyser Basins which to date show no measurable effects from the 1959 earthquake. During 1960, it consistently had the highest temperature of any spring. Its temperature varied between 207 and 208 degrees F.

Crested Pool: Following the earthquake, this spring's temperature dropped from 200 to 155 degrees. Instead of constant overflow, the water dropped 12 inches below the rim of the crater. Crested has not yet recovered from the effects of the big tremor. The water level fluctuates, at times almost reaching a point of overflow. The temperature, however, stays down. In September 1960, it was 7 degrees lower than in September 1959.

Scalloped Springs during 1960 stayed in essentially the same state as characterized them following the quake. There has been steady overflow from South Scalloped. Nearby Deleted Teakettle Spring persisted in the quake induced activity. The new vent on the side of Chimney's cone flowed steadily during the year.

Sawmill Geyser: Eruptions of the Sawmill occurred about every 2 to 3 hours, lasting for about an hour. The Sawmill would seem to be back on a near pre-quake pattern. Nearby Tardy Geyser was in an eruptive state most of the time. Two eruptions of Penta Geyser were observed during the year.

Liberty Pool: Following the earthquake, Liberty had a 40 degree rise in temperature. By September 1960, there was an additional 20 degree rise. No eruptive activity occurred, but the water stayed murky. East Frog Pool, near Liberty, maintained, throughout 1960, the 140 degree rise in temperature that took place following the quake. Sometime during early 1960 another frog pond, designated as West Frog, erupted. During the rest of the year, it overflowed steadily with a temperature range of 195 to 202 degrees. Prior to the quake, both craters of the Frog Pools contained cool water, that was replenished by water seeping into them. In this water there was a profuse growth of moss and other aquatic vegetation. Frogs (Rana pretiosa) were a conspicuous part of the biotic complex.

Spasmodic, Old Tardy and Bulger Geysers erupted on near pre-quake patterns. In Spasmodic, the water stood at a slightly lower level, with the greatest amount of activity occurring in the south vent. The Churn, with infrequent ebbing, overflowed during much of the greater part of the year.

Grand Group

Grand Geyser: The Grand did not share in the general increase in geyser activity following the quake. As a matter of fact, this well named geyser remained dormant for 6 months before demonstrating again that it possessed an eruption potential. Possibly a number of springs that manifested increased thermal energy following the big tremor did so at the expense of Grand.

The first eruption of Grand following the quake induced one, was on February 19, 1960. From then until the end of the year, 28 eruptions were known to have occurred. This would be an average of one eruption every 12 days. The shortest interval was 3 days, the longest 31.

The observed eruptions during 1960 were of essentially the same character as those preceding the quake. They offered no suggestion that Grand's plumbing had been materially affected. The same chain action in other springs took place. The only difference in the eruptive pattern to that of the past few years, was a concluding burst which would come from 15 to 20 minutes following the main series (usually ten). In this, however, Grand was merely reverting back to an earlier pattern. This delayed, and concluding burst, characterized Grand during the late 1930's and in 1940-42.

By June 1960, the surface temperature of Grand was 175 degrees, the same as before the quake. It had completely recovered the 10 degree loss. With surface conditions being essentially the same as before August 18, 1959, the problem as to why it erupted so infrequently was puzzling. All indications were to the effect that increased activity in nearby springs was rendering the Grand largely impotent. By the end of the season, all evidence seemed to point to an unnamed, contiguous spring as being the real culprit. During 1961, it is hoped that it can be determined whether or not this is the case.

Turban Geyser: The frequency of Turban's eruptions in 1960 was the same as before the quake. However, they were less vigorous and from the moment a pending eruption was manifest the progressive build-up was much slower. When playing in concert with Grand, or in concert with Rift following an eruption of Grand, it would play with the same vigor as was its pre-quake habit. North Rift and West Triplet would erupt in sequence to an eruption of Grand. The Rift was observed to have two eruptions independent of the chain action.

The marked rejuvenation of both Economic and East Economic as a result of the earthquake lasted less than a month. In temperature and general state during 1960, both were comparable to their pre-quake condition. Nearby Wave Spring was about 20 degrees hotter during 1960 than during the period following the quake.

Beauty and Chromatic Pools: An interesting exchange of function characterized these two lovely springs during 1960. Their inter-functional relationship was not altered by the quake, but on June 7, the energy shifted from Beauty to Chromatic. It has been in a state of overflow since with no flow from Beauty.

I have seen the shift occur in as short as a 6 weeks period, but in general from one to two years elapses before it occurs. They alternate in overflow. When Beauty is overflowing, Chromatic is not, and vice versa.

The 9 degree rise in temperature in Calida Spring which resulted from the quake, persisted throughout all of 1960, as well as its murky water. Lime Kiln and Witches Cauldron were both hotter in September 1960 than in September 1959. As a result of the quake, Witches Cauldron has developed geyser characteristics. Action of the steam vent on the bank of the Firehole Between Witches Cauldron and Deleted Teakettle has been more forceful since the quake.

Giant Group

The near constant jetting of Bijou Geyser in 1960 was the most characteristic action of the springs sharing Giant's sinter platform. At no time was the thermal energy strong enough to cause overflow of the small indicator vents. The sloshing in the Giant was forceful enough at times to reach part way to the top of the broken horn. The water in Mastiff seldom splashed above the sinter platform. There was occasional discharge from Turtle's side vent.

It seems highly probably, if not certain, that the earthquake delayed a new cycle of activity of Giant. The increased activity of Grotto following the quake, with which Giant is connected subterraneously, decreased hydrothermal manifestations in Giant and its related springs. The intensification of Grotto's activity has postponed for an indefinite period a new functional cycle of Giant.

During 1960 there was a slight temperature increase in the Giant and the Purple Pools over that which existed in September 1959. The Giant was consistently 2 degrees hotter, with a rise of 5 to 6 degrees in North and East Purple Pools. It remains to be seen whether this augurs for a recovery of Giant.

Oblong Geyser: During the 1959 period following the earthquake, the frequency of eruptive activity in Oblong was more than doubled. During 1960, its functioning had subsided somewhat over the early post-quake period, however, it erupted more frequently than during any season of record prior to the quake. Intervals were determined for 41 eruptions. The average time was 4 hours and 2 minutes; the extremes being 2 hours and 55 minutes, and 5 hours and 23 minutes.

Grotto Group

Grotto Geyser: The great increase in Grotto's activity following the quake was less pronounced during 1960. None of the 24 and more hours of protracted play, such as occurred in late 1959, was observed. The greatest duration checked was 11 hours and 15 minutes. For most eruptions the active phase was of greater duration than the quiet phase.

The springs involved in the chain action relation with Grotto functioned in a comparable manner to that which characterized them in the pre-quake period. Sometimes Surprise Geyser would start the chain action in the group. At other times, the action would be initiated by the unnamed geyser 15 feet south of Surprise. On two different dates, Spa Geyser shifted from minor to major geyser activity. Minor activity, the usual mode of behavior, is characterized by boiling and heavy overflow, lasting from an hour to an hour and a half. During major activity the water will explosively rocket through the water-filled crater to heights varying between 35 and 50 feet.

In the Riverside Geyser parking area, an unnamed geyser (small) that has been dormant for several years began erupting in February. The greatly increased discharge over that which was its habit during earlier eruption cycles necessitated closing part of the parking area. Continuous overflow, with lessened activity, continued throughout the year.

Chain Lakes: Except for the steady spouting of Culvert Geyser, there was no eruptive activity in the Chain Lake springs during 1960. Since the shift of the thermal energy in 1958 from Link to the Bottomless Pit, Link has remained dormant. Bottomless Pit continues to maintain its high temperature increase. Link was the only one of the Chain Lake springs that showed overflow during the year.

Riverside Geyser: As a result of the earthquake, Riverside's average interval was shortened about an hour. During all of 1960 it held near to this shortened average, which in late 1959 was 6 hours and 28 minutes. During the 1960 season, 336 eruption intervals were checked. The average time was 6 hours and 36 minutes; the extremes were 6 hours and 13 minutes and 7 hours and 36 minutes.

Fan and Mortar Geysers: These geysers erupted on October 3. This was the first observed major activity since December 1957. They were not stimulated into eruptive activity by the earthquake. To date, the quake would seem to have had very little effect on them.

Morning Glory: As yet this spring has shown no positive signs of recovery from the effects of the big tremor. Water still stays below overflow, and the temperature since September 1959 has remained fairly constant at about 168 degrees. In May, for a short period, there was promise of renewed overflow. The water stood at the top of the bowl for several days before ebbing about 4 inches. Since May the water has stood 2 to 4 inches below the rim of the crater.

Sentinel Geysers: Except for an eruption of East Sentinel, which apparently occurred at the time of the quake, neither of these geysers has shown any marked effects from the jarrings. In both, the water has been in a constant state of ebullition, ranging between 202 and 204 degrees.

Cascade Group

Artemisia Geyser: Despite the size of its crater, this geyser showed no immediate effects from the quake. Its water on the morning of August 18, 1959, was still clear and its functional behavior seemed undisturbed. During late summer of 1960, there were some data to the effect that Artemisia was playing more frequently than had formerly been its habit, but these observations have not as yet been fully confirmed.

There are several important unnamed springs in the Cascade Group, most of which are on the south bank of the Firehole. As a result of new hot ground there are many dead trees in this area. All of the springs on this side of the river were stimulated in activity by the earthquake. There was no diminution of this activity during 1960.

New Fumaroles: On the north bank of the Firehole, below Gem and Calthos Pool, the earthquake caused two long rifts, parallel to the river, to form in the geyserite embankment. During late 1959, steam began issuing from points along the breaks. During all of 1960, these new fumaroles increased in intensity. The break farthest from the river showed the most pronounced development. In October, it had a temperature of 204 degrees. Depressed ground bore evidence of alterations in structure, due to leaching. It seems highly probable that this fumarole will develop into a new thermal spring, possibly a geyser.

Gem and Calthos Pools: Both of these springs were affected in a marked way by the earthquake. It caused a shift of the thermal energy to Calthos, resulting in its first known eruption.

Ground structure about Gem and Calthos is suggestive that for a long period antedating their discovery, there has been exchange of function between them. Gem is the youngest of the two. The size and nature of the cone of Calthos are indicative that this spring is now in a senile stage. At one time, activity was much more pronounced than has been the case during the Park's post-discovery period.

For several weeks following the quake, there were occasional eruptions of Calthos. During this period, the water stayed below overflow in Gem. By April 1960, both springs were more enervated than in late 1959. Calthos was dormant and there had been additional ebb in both.

Both Gem and Calthos occupy a perched position with relation to the great increase in thermal activity on the nearby south bank of the Firehole. In addition, the above described fumaroles are situated at the base of the giant cone of Calthos. There is a high degree of probability that the earthquake so altered ground structure in this

section of the Cascade Group that both Gem and Calthos were dealt mortal blows. Right now it appears that they will be replaced by new thermal units, a natural process in the evolution of the geyser basins.

Pulcher Spring is at a lower level than Gem and Calthos, but like the latter it is situated directly above the new hot ground. Pulcher was affected in a marked way by the quake. Water rose several feet in its large crater, resulting in overflow. After about the first of October 1959, the water began ebbing and has continued to ebb since that date. At the end of 1960, the water was still a few inches above the pre-quake level.

The earthquake greatly altered the nature of the eruptive activity in Hillside Geyser. The eruptions became more powerful, with an increase in discharge. During 1960, the new activity persisted, but the eruptions were less frequent than in late 1959. Baby Daisy Geyser was stimulated into an eruption cycle by the quake, but before spring of 1960 it had become dormant.

Biscuit Basin

Cauliflower and Mirror: During 1960, both of these springs behaved as they had prior to the big event of 1959. The small geyser in the west drainage channel of Cauliflower, that was playing every 5 minutes in late 1959, was dormant during the current year. The new hot ground on the west side of Mirror shows no evidence of cooling.

Black Opal and Wall Pools:. Following the earthquake, the level of both springs dropped about 10 inches. In the later part of 1959, there was a gradual rise in water level. By spring 1960, both had completely filled. The thumping activity that was so pronounced in Black Opal before the quake was not heard during 1960. This was no doubt due to a big drop in temperature. The narrow septum of cemented gravel which separates Wall Pool from Black Opal was fractured through the middle for its entire length. By the middle of the summer, this crack had become completely filled with sediment.

The north side of the large quake-caused rift in the geyserite on the south side of Black Opal is in a state of continuous slumping. Since this fracture appeared, the slumping has lowered Black Opal's south shoulder by about 12 inches. That portion of this same fracture which partially encircled Wall Pool is now completely filled with sediments deposited during Sapphire's eruptions.

Sapphire Pool: Of all the thermal springs that underwent change due to the earthquake, none was more spectacular in the degree and nature of this change than Sapphire. The change from a geyser whose eruptions were scarcely more than 3 feet in height to the titanic eruptions which occasionally characterize Sapphire has no known parallel in the geyser basins of Yellowstone Park.

The change to major eruptive activity was not an immediate sequence to the earthquake. There were immediate and highly significant changes, but it was 19 days following the quake before the tremendous explosive activity began.

Sapphire's voluminous discharge since major activity began has resulted in an erosion to existing sediments that is almost as spectacular as the eruptions. Hundreds of tons of silicious sinter have been washed into the Firehole River. Large blocks of eroded sinter are strewn about the crater and extend in all directions in the drainage channels. During the late 1959 period, the sediments washed into a distributary of the Firehole, completely blocked all flow of water. The large deltas to the north, in the main channel of the stream, fanned out to the middle of the river.

The destruction to surficial geyserite was no greater than that affected within the visible crater, which destruction is assumed extends to depth. Most of the beautiful, biscuit-like structure that circled the crater has been undermined and washed away. This is especially true on the west side. Here the biscuits have all disappeared, or now exist on broken sections of sinter that have dropped as a result of being undermined. Immediately below the glazed biscuit-like structure, the sinter is of softer texture.

Due to the water still being murky, only that part of the crater (about 4 feet) above the ebb following an eruption can be observed. Appearances here reveal that the walls of the crater are more or less vertical, the former sloping shoulders having been sheared off. This erosion of internal deposits extends to depth, as occasionally sections of geyserite are discharged during the eruption that have no near-surface counterpart. There have been a few masses of highly cemented obsidian sands expelled, indicating that Sapphire has its roots in glacial gravels.

Since Sapphire began having major eruptions on September 5, 1959, it has had a few short periods of dormancy. The first was from September 13 to 29. Following resumption of activity on September 29, there was no more dormancy until January 15, 1960. With the exception of one known eruption, it was then dormant until January 30, when a new cycle of activity began. Powerful eruptions during the early part of this cycle began the initial destruction of the biscuits. Between February 1 and April 1, there were frequent active and dormant periods. From April until late in June it was periodically active, when it again became dormant. During dormant cycles, the crater fills and there is steady overflow. Its next active cycle started August 9, and persisted for the remainder of the year.

From eruption cycle to eruption cycle, as well as during many of these cycles, the character of Sapphire's eruptions would undergo considerable variation. The resumption of activity has always been characterized by larger eruptions than in the later stages of the cycle. The length of the intervals has varied from as short as 5 minutes to over 2 hours. In general, the longer the interval the more powerful the eruption. They have varied from 10 feet to approximately 150 feet. All of the eruptions that have been in the maximum height range had intervals of over an hour.

About November 5, Sapphire began erupting on consistently short intervals. They varied from between 10 and 20 minutes. This resulted in an enervated type of activity. With little or no variation, it maintained this habit

of play for the remainder of the year. During this period of enfeebled eruptions - the height varied between 15 and 40 feet - the ejected water, instead of characteristically surging out in all directions from the crater, would explode over the south side of the bowl only. This resulted in ice creeping in from the north side to within a few inches of the crater. During this period the water stood between 4 and 6 feet below the rim of the crater.

If Sapphire's habits to date continue, the crater will again fill and overflow, with resulting dormancy, to be followed by a new eruption cycle. How much longer major activity can continue with what appears to be internal alteration in plumbing, is a moot question.

Mustard Springs: These springs maintained their earthquake changed status during 1960. In both, the water stood about 30 inches below the crater rims and was in constant ebullition.

About 50 feet south of Mustard Springs, a fumarole developed following the big tremor. During the winter it excavated a small crater and evolved into a geyser. By April 1, it was playing about every 30 to 45 minutes, the eruptions lasting for about that time. It maintained this eruptive pattern for the rest of the year. It is called Fumarole Geyser.

Avoca Springs & Silver Globe: On the morning following the quake, the craters of both of these previously flowing springs were empty. A few days later Avoca's north vent turned into an intermittent fumarole. At about one minute intervals there would be a momentary roar of rushing steam. By December, instead of steam, water was ejected. During all of 1960, it persisted in these one minute eruptive intervals. The crater of Silver Globe is still empty.

The tract of hot ground that developed south of Avoca was much more in evidence during 1960. This in part was due to a line of dead trees that extended from near Silver Globe to the Firehole River, a distance of over 600 feet. In this area, a number of old craters that had been partially filled over the years by disintegrated sinter were reopened by the quake. Some of these reopenings resulted from explosions. Water flows from none, but they all have a temperature of about boiling.

Jewel Geyser: For the first 2 weeks following the quake, Jewel erupted murky water without cessation. It started having pauses about September 1, which gradually increased in length until by October it was back pretty much on its former schedule. During 1960 Jewel was the only geyser in the Sapphire Group whose eruptive activity followed an essentially pre-quake pattern. Despite this, its water has never entirely cleared; and like nearby Sapphire, both are discharging highly comminuted sediments which have the appearance of cement.

MIDWAY GEYSER BASIN

The springs along this section of the Firehole were named the Half-Way Group or Egeria Springs by the Hayden Survey. While it is a specific area in the basins along the Firehole, topographically it is a part of the Lower Basin. The section covered by hot springs extends near 1 mile along the river.

In coming from the Upper Basin, one of the most interesting changes since the earthquake to meet the eye upon entering Midway is a row of dead trees to the east of the road. These trees are situated on and near the distal end of a terminal moraine. The straight alignment through the glacial sediments of the new hot ground is highly suggestive that the earthquake partially opened up a pre-glacial thermal fissure that had been smothered by one or more ice incursions. This old fissure was activated sufficiently to permit the near surface ascension of the gases through the gravels, but not to a degree necessary for fumarolic development. That this new hot ground might have resulted from the activation of an underlying, buried fissure has additional evidence in hot springs that have developed in post-glacial time in the gravels on both ends of the new hot ground. The spring on the South end, Mud Spring, is a true geyser. Its water is limpid. The name Mud Spring was apparently derived from the fact that the water of the eruptions when cascading down the side of the glacial embankment has affected a structure which in appearance looks like mud flows.

Most of the springs along the east bank of the Firehole in the upper section of Midway were stimulated into increased activity by the earthquake. In most instances, this increase in thermal energy has persisted. At least one new geyser has developed. The big unnamed spring at the bend of the river ebbed about 15 inches following the quake, but by spring its crater had refilled. Flood, and an unnamed geyser on the opposite bank of the river, were both periodically active during 1960. Following the quake the unnamed geyser, which in function is very similar to Flood, was dormant for the rest of 1959.

None of the conspicuous and better known springs in Midway was affected in a more evident manner than was Turquoise Pool. The effect of the quake was to give the appearance of a plug having been removed from the bottom of the crater, permitting the water to drain out. At the end of 1960, the water in Turquoise was still several feet below the rim of the crater. Should this pool not recover its pre-quake status, it will be a distinct loss as it was one of the loveliest of the turquoise colored springs. It is possible that in time sediments from Grand Prismatic will again reseal the vent. In historic times, Turquoise has had no source of water of its own. It has served as a collecting basin for water from Grand Prismatic.

Except for altered drainage from Grand Prismatic, both it and Excelsior show no evident effects of the quake. However, the water in nearby Indigo Spring still stays about 1 foot below overflow. At the end of 1960, it was in essentially the same state, except that the water had cleared, as it was on the morning of August 18, 1959.

LOWER GEYSER BASIN

Great Fountain and Lower White Creek: With the exception of Firehole Pool, in which there was no observed change, none of the springs in this area escaped alterations due to the earthquake. A few would seem to have returned to pre-quake condition, while others continue to manifest change in state or function.

Surprise Pool: As happened in the case of numerous springs, this famous, superheated unit did not show any immediate change in function following the earthquake. The murky water observed on the morning following the big tremor soon cleared. About mid-October the previously steady flow became periodic. For the first time in its known history, it began having eruptions. The eruptions were minor, but all the attributes of a true geyser were manifest. By the end of the year, the two-foot surges at the time of eruption were in the nature of a kettle boiling over. During all of 1960, this condition more or less persisted. The frequency of the overflow periods was not determined, but they occurred one or more times each day. The boiling and overflow would last about 8-10 minutes, when there would be a near 6 inch ebb.

Most of the springs along Lower White Creek erupted the night of the quake. Geyser activity had been previously observed in 5 of them. All were active during 1960. Only one spring in this area, Diamond, is named. Its eruption the night of the quake was its first and only known one. However, by 1960, it was evident that the quake had altered its character. Like Surprise, its former constant water level now has ebb and flow periods. This might be a prelude to geyser activity.

Great Fountain Geyser: This geyser has one of the loveliest and most symmetrical cones of any geyser in the park. It was named the Architectural Fountain in 1871 by the Hayden Survey, and then renamed the Great Fountain in 1872 by this same party.

Since discovery, Great Fountain would seem to have approximated a close pattern of play. The greatest known variation from its usual seasonal performance occurred the night of the big tremor. Previous to the earthquake, it had approximately 2 eruptions each day (24 hours). Following the quake the eruptive activity was greatly stimulated. During the first few weeks it erupted nearly 4 times each day. By the end of the year, the average time was 7½ hours.

During the 1960 season, 84 eruption intervals were checked. The average time was 7 hours and 30 minutes; the extremes were 5 hours and 30 minutes and 9 hours and 40 minutes.

The increase in manifestations of thermal energy by the Great Fountain is not of as great a magnitude as the great increase in frequency of eruptive activity would suggest. In 1960, the duration of the average eruption was less than before the quake. There would seem to be a direct relationship between the shortened duration of play and the frequency increase.

The changed situation, as described above, might have come about as a result of slight alterations to underground ramifications of the geyser. Changed pre-eruption symptoms offer further suggestion that this might be true. In addition, new hot ground and a new fumarole with a temperature of 202 degrees have developed on the west edge of Great Fountain's base which, in itself, is evidence of probable disturbances to underground structure.

White Dome Geyser: During the 1960 season, Park Ranger Naturalist Lewis checked 55 eruption intervals of White Dome. The average eruption time was 29 minutes; the extremes 8 and 88 minutes.

For a few days following the quake, White Dome did not erupt. In early September it was having occasional eruptions, which increased in frequency with the advance of the season. Its 1960 activity is suggestive of return, or near return to pre-quake function. However, its variations from mean time in 1960 were less than has been its habit in previous seasons.

Across the road to the east of White Dome there is a tract of decayed sinter. A few small springs are on the edges of this tract. Two of the springs on the west side erupt to a height of near 6 feet several times each day. They are known as Gemini Geyser. On the east edge of the tract, 2 new springs have developed since the quake.

Pink Cone Group

This group is small, but contains several interesting springs, all of which showed alteration following the earthquake.

Pink Cone Geyser: Prior to the earthquake, this geyser was erupting but 2 to 3 times weekly, the eruptions lasting near 2 hours. For several days after the above event, it erupted almost constantly, then the quiet and active phases became about equal. As the season advanced, the intervals became longer, with corresponding increase in length of the active phase.

Excepting Clepsydra, which has become a steady geyser, no geyser is known to have increased in function to the degree Pink Cone has. During all of 1960, it continued to erupt with greatly increased frequency over pre-earthquake habits. Unlike the Great Fountain, whose increase in function is partially balanced by shortened duration, the great increase in thermal energy of Pink Cone is real.

Bead Geyser: Since the earthquake, Bead has undergone marked changes in the frequency and duration of its eruptions. For the first 6 weeks following the quake, the length of its intervals increased from 31 to 60 minutes; the duration of the play increased from 2½ to 11 minutes. The intervals then shortened to near 15 minutes, with the active phase decreasing to 2½ minutes. During the rest of 1959, Bead was manifesting about 2 times the thermal energy it did before the quake. During 1960, the intervals increased from 15-16 minutes to 20-21 minutes, but the duration stayed at 2½ minutes.

Before the earthquake, Bead played with a higher degree of regularity than any geyser of comparable size that has come under my observation. After the quake, despite frequent alteration in frequency and duration, it has continued to erupt with near set time periodicity. Before World War II, the shallow basins about Bead's crater were filled with small masses of spherical, bead-like sinter. They suggested the name Bead. In recent years park visitors have practically denuded the basins of all beads.

The large superheated spring, located about 12 feet west of Bead, showed no further eruptive activity during 1960. The eruptions that were stimulated by the earthquake occurred about every 4 hours, but after a week, it lapsed into its former dormancy. It is named Shelf Spring because the crater is ringed with a shelf of geyserite that extends for several feet out over the pool. Several small geysers are situated just north of Shelf Spring.

The Tank: The large crater known as the Tank is the recipient of Tangled Creek's drainage. It lies about 100 yards east of Pink Cone. The earthquake produced a fracture in the large mound, resulting in slumping of geyserite on the west side. Since the quake, drainage from the Tank pours out the west side. Formerly there was no flow in this direction. At one time the Tank was used for bathing.

Firehole Lake Area

Evidence of the very extensive fracturing that occurred in this area the night of the quake is still very discernible. However, most of the small cracks were largely effaced by wind and precipitation before the end of 1960. In two of the small cracks there is fumarolic action. In time most of the small fractures will disappear, especially those on the slopes. Many of the new relief features will persist. Their size and position will make them apparent for a long period.

The water in Firehole Lake during 1960, had largely cleared from the murkiness caused by the quake, but it had not entirely recovered its former limpid state. This made it difficult to see the ascent of the gas bubbles except on clear, calm days.

The apparent tilting of Firehole Lake's crater resulted from depression of the geyserite on the north side of the lake. To the west and northwest the slumping was very extensive. Here the formation has settled by as much as a foot. The new drainage from the west side of Firehole Lake is well stabilized. The water flows about 100 feet and then disappears in cracks which are numerous in this area.

Steady Geyser: Steady was originally named the Black Warrior. The springs which surround it are known as the Black Warrior Springs. The Firehole Lake area is characterized by having very few geysers, yet the night of the quake, 12 of its springs erupted. During 1960 Steady was the only one of its springs that showed geyser action.

The earthquake fractured Steady's cone in several places. On the east side of the mound, there appeared to be a slight emergence. The quake did not rejuvenate the top vent, or in any observable way affect the steady action of the side vent. During all of 1960, the side vent ejected water in about the same volume as before the quake. Due to the extensive fracturing of the mound any future functioning of the top vent is problematical.

East Black Warrior Spring underwent considerable alteration the night of the quake. Prior it had been a steadily flowing spring, but all discharge ceased. By the end of 1960 the water was still ebbed below the crater rim. The shoulder of this spring was badly fractured by the quake, resulting in a scarp of more than a foot.

There are several small springs about 300 feet west of Black Warrior Lake. Two of these springs are quite unique in the Firehole Geyser Basins in that they precipitate free sulphur. The sulphur crystals are less in evidence since the quake and one of these springs now shows rhythmic ebb and flow periods. Its water is hotter than before the quake. True geyser action might develop.

Fountain Group

Silex Spring: Since the three weeks of steady geyser action following the quake, Silex has been in what seems a pre-quake state. During most of 1960, there was steady flow, with mild boiling. Infrequently it ebbed. Compared with the length of the overflow periods the duration of the ebb was very short, lasting between 2 and 3 hours.

Fountain Paint Pots: These famous mud puffs, like many other thermal units, did not respond immediately to the jarrings they received on the night of August 17, 1959. It was 3 days later before effects began to show. Spectacular changes then took place rapidly. The general level of the blobbing mud rose fully 12 inches. The activity which had been confined wholly to the southern end spread over the entire surface of the crater. In the reactivated north end many new mud puffs appeared. The new development spread beyond the limits of the crater itself. New fumaroles and mud pots developed to the north across the entrance road.

For the remainder of 1959, the general level of the pots stayed high. There was progressive enlargement of two newly developed pots outside the old crater. On the north end, the shifting energy had extended under the flagstone walk where there has been increasing development to date. During the winter, the activity waned in some of the newly developed pots with increased activity in others. By April, one of the new pots had excavated a large crater in the thick mud embankment on the west side and was blobbing pink mud.

The new mud pots to the north, outside the main crater, changed in a relatively short period from mud springs to steam vents. Steam roared from them for the rest of 1959. In January the northern most unit changed into a mud spouter. From then until May, it spouted brick-red mud continuously to a height of about 6 feet. It has been named the Red Spouter.

About the first of May, the level of the ground water in the Paint Pots and surrounding springs dropped several inches rather abruptly. This brought about interesting changes. The steady ejection of Red Spouter ceased, and once more it reverted back to a hissing steam vent. The general activity over the Fountain Paint Pots crater diminished, however, the newly developed pots in the north end continued to blob, but from lower levels. During the summer the new energy under the walk had periods of waxing and waning in intensity, but on the whole, there was progressive development, indicating that were it not for the stony cover a new mud pot in all probability would have appeared at this site.

In recent years, it has been observed that during the summer season, there is a progressive drop in the level of the Fountain Paint Pots, with a corresponding increase in viscosity. The anomalous part of this situation is that, instead of the level rising in the spring with the advance of melting snows, it occurs in late autumn when ground water would be presumed to be at low level. True to pattern, about November 12, the paint pots rose about 6 inches, with a thinning of the mud and a decrease in temperature. With this rise in ground water level, Red Spouter changed from the role of steam vent to a mud volcano, again spouting its brick-red mud. It is presumed this situation will persist until drop of ground water level next spring.

Leather Pool: This large spring, situated on the very edge of the highway, was a steadily overflowing spring until the night of August 17, 1959. The earthquake roiled the water and dropped its level about 4 inches. After additional ebb a series of eruptions took place. From September until about the first of May, the water stayed at about a 6 inch ebb. Then, at the same time the level dropped in the paint pots, it dropped fully a foot in Leather Pool. From this drop until mid-November there was progressive ebb in water level. This situation was reversed in November at the same time the paint pots started to rise. The rise in Leather was noteworthy. It amounted to about 2 feet. This mutual response of the Fountain Paint Pots to Leather Pool suggests a close connection to the same water supply.

Morning, Fountain & Clepsydra Geysers: These geysers are being considered as a unit because of their close interfunctional relation. Both Morning and Fountain were dormant during all of 1960. The greatly stimulated activity following the earthquake was short-lived, especially in the case of the Fountain. The continuous action of Clepsydra would seem to offer a partial explanation for the dormancy of Morning and Fountain, but other factors might well be involved. Observations made during 1960 point to a situation comparable to what happened in the Daisy Group; a shifting of the main focus of the thermal energy to other springs in the group. Like the Daisy situation, the shift was away from major to minor geysers. The shift was from east to west.

In additon to continuous spouting of Clepsydra and Sub Geysers during 1960, other springs, all unnamed, resting on the same geyserite embankment as the above, were much more active than during any known time previous to the earthquake. Before Morning and Fountain enter a new cycle of activity it seems necessary that the situation be reversed;

that present newly activated units revert back to former functional status. If the subterraneous structure in the group has been altered, former patterns of eruptive activity might never occur again.

Clepsydra in its incessant spouting is dissipating a considerable fraction of the thermal energy that is inherent in the group of springs with which it has underground connections. It is not impossible that should this steady action become periodic, as formerly, both Morning and Fountain might rejuvenate. Bringing about cessation of Clepsydra's steady action could be affected.

During eruptive activity of Clepsydra prior to the earthquake, its west orifice was a steam vent. After a few days of steady action following the quake all 4 orifices turned to roaring steam vents. The great release of steam was impressive and intimidating. A new source of water was found and they all, including the steam vent, turned into water spouters. During 1960, at infrequent periods, the original steam vent would go back into steam-phase activity for a few days, to be followed by much longer periods of water ejection. Most of the discharge from Clepsydra pours down the embankment and into Gore Spring. The addition of this cooled runoff water has lowered Gore's temperature about 20 degrees. This has resulted in less brilliant red algae (gore) than formerly was the case.

Spasm and Jet Geysers: Before the earthquake both of these geysers were responsive to eruptions of Morning and Fountain, particularly the Jet. Following the quake, both erupted with greater frequency. In the case of Spasm, it displayed considerably more power. Toward the end of 1959, action began to wane in both geysers and by spring of 1960, both were dormant. Nearby Twig was also dormant. Jet remained dormant throughout the year, but by late summer, Spasm began to show signs of rejuvenation. In November and December, there were occasional eruptions.

Jelly Geyser: Though Jelly is not far from Spasm Geyser, it is apparently far enough to the west to have escaped the fate that overtook all springs to the east. It would seem to have shared in the westward shift of the energy. During all of 1960 Jelly was very active. While stationed in this area, Park Ranger Naturalist William J. Lewis checked its functional behavior in considerable detail. Two types of eruptions, a major and a minor one, were observed. The minor type is of much more frequent occurrence. Jelly shows a high degree of regularity, erupting about every 12 minutes. The 3 minute duration is also quite fixed.

During the quiet phase of Jelly its temperature is quite constant, at about 193 degrees. Once during the summer, I obtained a higher reading than I have ever recorded in any other spring. It has a shallow crater, and at a depth of 18 inches I got a reading of 209 degrees just as the water of an eruption burst into the bowl.

Bellefontaine Geyser: This geyser is at the south base of the hill below the main Fountain Group. Prior to the quake it was in a dormant state. An unusually forceful eruption the night of the quake made some enlargement of the crater; a new eruption cycle was initiated. During all of

1960, it played on short intervals, the average being about 6 minutes. The eruption is merely a big surge or splash.

In the Pithole Springs to the west of Bellefontaine, a few of the small springs had occasional eruptions. The largest and most important of the geysers in this area has been called Mask by Lewis because its crater reminds him of the "mask worn by the ancient Greeks in their plays." It entered an eruption cycle during the 1958-59 winter. The earthquake in no noticeable way has affected its activity.

Kaleidoscope and Sprinkler Groups

Springs in these groups are numerous and none seemed to escape alteration as a result of the earthquake. They have a generally linear arrangement, in an east-west direction, and are about ½ mile west of the Fountain Group. Many erupted the night of the quake, and some of the previously dormant ones continued eruptive activity throughout 1960. In general, the thermal energy in this area is still more in evidence than it was before the quake.

Gentian Pool: This spring is one of the largest and most beautiful in the park. To many its loveliness has no peer. The earthquake not only caused it to ebb 41 inches, but destroyed the beautiful turquoise-blue coloration. Before the end of 1959, water began rising but it was near spring before overflow was again established. With the filling of the crater, the color gradually came back and by spring, Gentian sparkled with its former loveliness.

The filling and resultant overflow of Gentian revealed an interesting situation. The crater appeared to have been slightly tilted. With overflow from the south end, water was still one inch below the former high water mark on the north end. The overflow from the south end is not only going through the old drainage run off, but is flowing over a new section of the sinter incrustation. Close scrutiny reveals that about 15 feet south of Gentian there is a new depression. This depression extends far enough to the north to depress the south end of Gentian's crater. Should this depression undergo much further development, it will greatly alter Gentian's present state.

The largest, strictly new geyser to develop as a result of the quake, is about 200 feet west of Gentian. It was named Earthquake Geyser. After a week of spectacular performance, activity ceased due to a steam explosion which tore out an opening on the same rift from which Earthquake played. This seemed to close its short life as a geyser. The steam dissipation of the thermal energy still persists. The boiling and surging in the crater is highly suggestive that if the steam vent were blocked, Earthquake would express itself in an eruption.

In the central section of the Sprinkler Group several cracks, running in a north-south direction, resulted from the jarrings. From some, steam is issuing, but as yet no new spring development has taken place.

One of the cracks was along the line of an old fracture, leaving little room for doubt but that some earlier earthquake of similar intensity to the 1959 Hebgen Lake one had shaken this area.

Most of the large springs in this area are near the west end in the Kaleidoscope section. All of these big springs erupted the night of the quake. Some were known to possess geyser potential, but in 4 of these springs, I had never previously observed any geyser activity. Two have eruptions near 50 feet in height. During 1960, there was no diminution of earthquake-induced activity. Only one of the big springs in the Kaleidoscope Group seems to have been affected adversely by the quake. It sits to the north, outside the main group. The water in its large fissure-like crater has dropped about 6 feet below pre-quake level.

Hotel Group

This is a small group - eleven springs in all - and so far as size and general character of the springs are concerned, it is not as attractive as many other groups. The earthquake disturbed all springs. With the exception of Gourd and Round, all springs during 1960 were in essentially the same state as before the quake. Both Gourd and Round show increased energy.

River Group

During 1960, the majority of the springs in this group had largely recovered from the effects of the quake. However, there were a few noted exceptions, mostly unnamed springs. Of the named ones, Grotto, Skeleton and Ojo Caliente persisted in the alterations affected the night of the quake. The water in Skeleton Pool continues to stay from 4 to 6 inches below overflow, while the Grotto, a name given by the Hayden Survey, has developed into a mud volcano. The direction of overflow from Ojo Caliente has been altered.

Pocket Basin: This basin is an essential part of the River Group. The springs being considered in this report are situated on glacial moraines on the east side of the basin, just west of Rush Lake. The only springs that occur here are mud pots. Prior to the earthquake only three of these pots, due to their size, were noteworthy.

This area was visited on the day following the quake and on subsequent dates, the last visit being in October. Up to this time there appeared to be no change in the character of the mud springs. When the area was again visited the following May, the change that had taken place was truly astonishing. Several new groups of mud springs had, as it seemed, almost magically appeared. The original pots, mud volcanoes, were sending their blobs high into the air. The intensity of activity of the central volcano increased until, by mid-summer, surrounding trees and terrain were plastered with mud.

The extensive dying of trees in this area gave additional evidence of the great increase in thermal energy. The trees, which died in winter, due to new hot ground, are along the same general alignment as the mud springs, and extend for a distance of about 700 yards.

The new development in the Pocket Basin mud-pot area closely parallels that described for the Midway Basin. In both instances, the new hot ground has developed on glacial moraines, moraines which owe their positions to pre-glacial hydrothermal springs which were buried during the Pleistocene. That a former thermal fissure lies buried beneath the extensive gravel deposits of Pocket Basin is suggested by the general alignment of the old as well as the new and extended development. The earthquake disturbed the buried fissure to sufficient degree to result in greatly increased ascension of gases through the gravels. One new fumarole has a temperature of 202 degrees. The generally barren nature of sections of Pocket Basin, in places covered with opal-cemented silts, suggests that since the gravels were deposited, there has been a considerable amount of gas leakage through them. All the moraines in the area have murky, non-discharging, acid springs about their bases, which lend additional evidence to the thesis of glacially buried hot ground.

Old Faithful Geyser

During 1960, 4381 of Old Faithful's eruption intervals were determined. This is the greatest number ever checked during a single year, yet the figure represents scarcely more than half of the number of times it played. The average time, 66.3 minutes, indicates that during 1960, it erupted approximately 8000 times. Broken down into months, Old Faithful's performance is as follows:

Month	Checked Intervals	Max. Interval In Minutes	Min. Interval In Minutes	Average
January	607	98	35	66.8
February	607	93	39	66.5
March	437	90	39	65.7
April	228	89	40	65.7
May	470	90	39	65.7
June	314	91	40	66.3
July	367	90	37	66.0
August	358	89	40	67.0
September	291	91	39	67.0
October	189	91	39	66.2
November	264	90	40	66.6
December	249	90	40	66.7
No. of eruptions	4381		Average time	66.3

The eruptions timed during January, February, March, April, November and December were by means of a mechanical recorder. Times of eruptions during other months were done by direct observation. The 98 minute interval during January, is the longest one recorded on Old Faithful to date. There might be some question as to whether it can be officially approved, as the device used to trigger the time of an eruption sometimes failed to function. This was especially true for the November and December eruptions. Minimum intervals and average time would be essentially correct, but it is not impossible that in the 98 minute record an eruption was missed. Whenever there was a southwest wind, the trigger would not function. Greater scientific accuracy could have been had, had the recording device been properly adjusted.

The 66.3 minute average for 1960 is the longest seasonal average since the 1940 season when it was 67.0 minutes. In 1941, the average was 66.3, the same as 1960, Since the 1942 season, and until the time of the earthquake, Old Faithful's average time for the 17 year period ranged between 64.9 for a maximum and 60.6 for a minimum. The 60.6 average was for 1158 eruption intervals determined in 1959 prior to the earthquake. During this period, Old Faithful showed the greatest frequency for any period on record. Following the quake, the average time gradually increased, emerging into the 1960 record.

Old Faithful's 1960 record, since August 17, 1959, makes it seem quite certain that following the earthquake it did not share in the general increase in thermal energy displayed by so many hot springs. A small fraction of its eruption potential was lost. Numerous springs declined in energy following the earthquake. The cause of this decline in most instances is explainable, but not so with Old Faithful. It is not known to have any underground entanglements with other springs. It is thought to be an isolated unit. The cause of its slight loss in thermal energy is not explicable, as yet.

Increased Temperatures Persisting

During the night of the earthquake there was, at least momentarily, a tremendous increase in thermal energy. Scores of quiescent springs, some of which previously had been characterized by low temperatures, erupted. During the days and weeks following the quake, increased thermal energy over the pre-quake period was very much in evidence. During mid-September 1959, temperatures were taken of all springs for which there were pre-quake readings. The temperatures of numerous springs which did not afford comparative data were also taken.

The September 1959 readings showed that a few springs had declined in temperature following the quake, but on the whole there was a significant increase. When pre and post-quake temperatures were compared it was noted that the earthquake had resulted in an average 5.6 degree rise in temperature.

To determine to what extent there might have been gains or losses in temperature from those of September 1959, temperatures were retaken in September 1960. These same temperatures had been taken periodically during the summer, but only the September readings are listed in the table so that comparable seasonal conditions might be had. When these temperatures were averaged they revealed that the 1960 readings were 1.18 degrees hotter than the 1959 average.

The following table shows the 1959 and 1960 temperatures:

		Sept. 1959	Sept. 1960
1.	Morning Glory Pool	169	167
2.	E. Sentinel Geyser	202	200
3.	Spiteful Spring	200	200
4.	Fan Geyser	202	200
5.	Mortar Geyser	200	200
6.	Riverside Geyser	200	200
7.	Link Geyser	163	151
8.	Bottomless Pit	198	193
9.	Square Spring	200	193
10.	Culvert Geyser	202	200
11.	Rocket Geyser	200	202
12.	Grotto Geyser	201	202
13.	Spa Geyser	183	193
14.	Surprise Geyser	198	189
15.	Giant Geyser	203	203
16.	Catfish Geyser	202	201
17.	Mastiff Geyser	205	202
18.	Turtle Geyser	200	196
19.	S. Purple Pool	182	151
20.	E. Purple Pool	196	200
21.	N. Purple Pool	197	200
22.	Chromatic Spring	164	191
23.	Beauty Pool	169	166
24.	Inkwell Spring	201	200
25.	Oblong Geyser	200	200
26.	Bonita Pool	105	193
27.	Daisy Geyser	200	200
28.	Brilliant Pool	203	198
29.	Comet Geyser	202	204
30.	Splendid Geyser	202	202
31.	Daisy's Thief	200	202
32.	Punch Bowl Spring	202	201
33.	Black Sand Pool	200	200
34.	Whistle Geyser	144	181
35.	Spouter Geyser	200	200
36.	Green Spring	179	176
37.	Emerald Spring	150	151
38.	Handkerchief Pool	165	142
39.	Rainbow Pool	163	163
40.	Sunset Lake	190	193
41.	N. Three Sisters	198	185
42.	M. Three Sisters	185	181
43.	S. Three Sisters	185	182
44.	Orange Spring	180	175
45.	Round Spring	142	165
46.	N. Round Spring	165	154
47.	Pear Spring	194	183
48.	W. Round Spring	160	169

		Sept. 1959	Sept. 1960
49.	Castle Geyser	201	202
50.	Tortoise Shell Spring	202	206
51.	Crested Pool	155	148
52.	Sprinkler Geyser	198	198
53.	Chimney Fumarole	200	200
54.	S. Scalloped Spring	202	202
55.	Scalloped Spring	201	202
56.	Deleted Teakettle	199	202
57.	Churn Geyser	161	176
58.	Sawmill Geyser	194	194
59.	Tardy Geyser	196	200
60.	E. Frog Spring	196	197
61.	W. Frog Spring	64	200
62.	Liberty Pool	163	182
63.	Spasmodic Geyser	203	202
64.	Oval Spring	201	191
65.	Old Tardy Geyser	202	200
66.	Belgian Pool	161	154
67.	Bulger Geyser	202	200
68.	W. Triplet Geyser	182	178
69.	Grand Geyser	165	176
70.	Turban Geyser	187	198
71.	Economic Geyser	200	155
72.	Wave Spring	163	184
73.	Calida Pool	192	191
74.	Milk Spring	200	200
75.	Lime Kiln Spring	200	202
76.	Witches Cauldron	200	202
77.	Terra Cotta Spring	197	200
78.	Infant Geyser	201	200
79.	Giantess Geyser	200	202
80.	Vault Geyser	197	197
81.	Teakettle Spring	203	200
82.	Dome Geyser	194	192
83.	Rock Pool	198	201
84.	Pump Geyser	199	200
85.	Sponge Geyser	200	202
86.	Model Geyser	194	201
87.	Dragon Spring	200	177
88.	W. Doublet Spring	193	190
89.	E. Doublet Spring	196	195
90.	Beach Spring	201	202
91.	Aurum Geyser	201	202
92.	Pendant Spring	201	200
93.	Ear Spring	202	202
94.	Goggle Spring	200	200
95.	Lion Geyser	200	204
96.	Big Cub Geyser	203	203

		Sept. 1959	Sept. 1960
97.	Lioness Geyser	201	202
98.	Little Cub Geyser	200	202
99.	Heart Spring	200	197
100.	Arrowhead Spring	200	179
102.	Depression Geyser	188	186
103.	E. Scissor Spring	200	202
104.	Beehive Geyser	203	204
105.	Cascade Geyser	200	191
106.	Plume Geyser	201	201
107.	N. Anemone Geyser	198	198
108.	S. Anemone Geyser	197	200
109.	Blue Star Spring	186	185
110.	Chinaman Spring	201	201
111.	E. Chinaman Spring	198	199
112.	Old Faithful Geyser	200	200
113.	Fumarole Cone	200	200
114.	Artemisia Geyser	181	191
115.	Atomizer Geyser	198	200
116.	Iron Spring	193	180
117.	Gem Pool	194	187
118.	Sprite Spring	181	145
119.	Calthos Spring	195	184
120.	New Fumarole	0	204
121.	Pulcher Spring	201	178
122.	Hillside Geyser	202	202
123.	Cauliflower Geyser	192	188
124.	Mirror Pool	184	184
125.	Black Opal Spring	173	110
126.	Wall Spring	102	102
127.	Sapphire Pool	204	202
128.	Black Pearl Geyser	200	200
129.	W. Mustard Spring	200	199
130.	E. Mustard Spring	200	200
131.	Fumarole (Geyser)	198	200
132.	Avoca Spring	202	202
133.	Shell Geyser	202	199
134.	Silver Globe	180	194
135.	Jewel Geyser	186	180
136.	Excelsior Geyser	199	199
137.	Indigo Spring	201	200
138.	Opal Spring	180	189
139.	Turquoise	132	98
140.	Broken Egg Spring	187	157
141.	Firehole Pool	196	196
142.	Surprise Pool	202	201
143.	Great Fountain Geyser	203	202

		Sept. 1959	Sept. 1960
144.	White Dome Geyser	199	200
145.	Pink Cone Geyser	201	202
146.	Bead Geyser	177	187
147.	Shelf Spring	202	202
148.	Narcissus Geyser	168	182
149.	Zomar Spring	167	163
150.	Black Warrior Spring	177	191
151.	Flame Pool	174	173
152.	Steady Geyser	200	200
153.	Silex Spring	200	198
154.	Celestine Pool	200	194
155.	Fountain Paint Pots	200	200
156.	Jelly Geyser	193	193
157.	Spasm Geyser	200	199
158.	Bellefontaine Geyser	200	200
159.	Fountain Geyser	159	152
160.	Morning Geyser	193	183
161.	Clepsydra	200	200
162.	Sub Geyser	196	196
163.	Jet Geyser	199	194
164.	Thud Geyser	183	183
165.	Thud Spring	189	194
166.	Stirrup Spring	191	190
167.	Gourd Spring	186	186
168.	Jug Spring	161	173
170.	Cliff Spring	196	196
171.	Oak Leaf Spring	196	198
172.	Kidney Spring	199	199
173.	Gentian Pool	168	180