

Index of Yellowstone Thermal Features--Marler Inventory

PART I

12/4/72

Upper Basin

Location^{1/}

Biscuit Basin

Avoca Spring (geyser)	B 4-840E, 530S
"Baby Daisy" Geyser	C 6-580E, 825S
"Biscuit Basin" Geyser	C 6-495E, 725S
"Black Opal" Pool	B 5-825E, 615S
Black Pearl Geyser	B 5-230E, 395S
Cauliflower Geyser	C 6-640E, 190S
East Mustard Spring	B 5-145E, 305S
"Island" Geyser (spouter ?)	C 5-640E, 50S
Jewel Geyser	B 5-135E, 695S
Mirror Pool	C 6-670E, 350S
"North" Geyser	B 5-305E, 75S
"Rusty" Geyser	B 6-330E, 805S
Sapphire Pool	B 5-365E, 650S
Shell Geyser	B 5- 40E, 715S
Silver Globe Spring	B 4-825E, 560S
"Wall" Pool	B 5-750E, 570S
"West" Geyser (see Avoca Spring)	B 4-835E, 390S
West Mustard Spring (see East Mustard Spring)	B 5- 90E, 300S

Cascade Group

Artemisia Geyser	E 7-145E, 100S
Atomizer Geyser	E 6-985E, 155S
Calthos Spring	D 6-865E, 610S
Gem Pool	D 7- 15E, 670S
"Hillside" Geyser	D 6-420E, 325S
"North Pulcher" Spring (see Pulcher)	D 6-700E, 245S
"Pulcher" Spring	D 6-720E, 275S
"Seismic" Geyser	D 6-500E, 420S
Sprite Spring	D 7- 30E, 620S

Morning Glory Group

East Sentinel Geyser	F 8-245E, 60S
Fan Geyser	F 8-635E, 525S
Morning Glory Pool	F 8-450E, 275S
Mortar Geyser (see Fan Geyser)	F 8-670E, 570S
Spiteful Geyser	F 8-655E, 475S
West Sentinel Geyser	F 8- 70E, 195S

Chain Lake Group

Bottomless Pit	F 8-695E, 970S
"Culvert" Geyser	G 8-795E, 45S
"Link" Geyser	F 8-680E, 880S
North Chain Lake Geyser	F 8-595E, 860S
"Square" Spring	G 8-760E, 75S

^{1/}Coordinates of U.S.G.S. detailed maps of thermal areas, scale 1/2,400.

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The attached descriptions of hot springs and geysers have been prepared by Dr. George D. Marler for the U.S. Geological Survey, based on many years as a naturalist and geyser specialist with the National Park Service. All comments are based on Marler's personal observations, except where noted.

Names in quotes ("Cucumber" Springs) are of relatively recent origin and have not been formally approved.

Location coordinates (example for "Cucumber": J5-750E,700S) are precise locations on detailed U.S.G.S. maps that have been made of Yellowstone's principal thermal areas. Each map has a grid system of designated blocks, 1000ft x 1000ft. "Cucumber" is located in block J5 of the Upper Basin Map, and is 750 feet east and 700 feet south of the northwest (J5-labelled) corner of the block.

Upper Basin--ContinuedLocation

Grotto Group

"Grotto Fountain" Geyser

G 8-955E, 220S

Grotto Geyser

G 8-910E, 465S

Indicator Spring

G 8-935E, 310S

Riverside Geyser

F 9-140E, 845S

Rocket Geyser

G 8-910E, 445S

Spa Geyser

G 8-875E, 220S

Giant Group

Bijou Geyser

G 9-260E, 820S

Catfish Geyser

G 9-240E, 830S

Giant Geyser

G 9-225E, 885S

Mastiff Geyser

G 9-255E, 865S

Oblong Geyser

H 9-310E, 350S

Purple Pools -

North

G 9-510E, 955S

East

G 9-565E, 1000S

South Purple Pool

H 9-560E, 65S

Unnamed geysers

H 9-580E, 80S

H 9-575E, 195S

Daisy Group

"Bank" Geyser

H 8-500E, 95S

Bonita Pool

H 8-335E, 30S

Brilliant Pool

H 8-215E, 80S

Comet Geyser

H 8-210E, 50S

Daisy Geyser

H 8-280E, 55S

"Daisy's" Thief

H 8-180E, 80S

Punch Bowl

H 7-115E, 330S

"Pyramid" Geyser

G 7-675E, 765S

"Radiator" Geyser

H 8-380E, 55S

Splendid Geyser

H 8-150E, 50S

Round Spring Group

"North Round" Spring

H 8-825E, 475S

"Pear" Spring

H 8-690E, 540S

Round Spring

H 8-865E, 585S

"West Round" Spring

H 8-600E, 560S

Grand Group

Beauty Pool

H 9-700E, 710S

Belgian Pool

I10-235E, 560S

Bulger Geyser

I10-175E, 560S

Calida Pool

I 9-630E, 270S

Castle Geyser

J10-290E, 430S

Chimney Cone

I10-210E, 945S

Chromatic Pool (see Beauty Pool)

H 9-555E, 640S

Churn Spring

I10-185E, 710S

"Crack" Geyser

H 9-865E, 750S

Upper Basin--ContinuedLocation

Grand Group--continued

Crested Pool	J10-275E, 285S
"East Economic" Geyser	H 9-945E, 900S
East Triplet Geyser	I10-175E, 420S
Economic Geyser	H 9-925E, 925S
Grand Geyser	I10-150E, 350S
Liberty Pool	I10-555E, 945S
Lime Kiln	I 9-335E, 470S
"Milk Cauldron"	I 9-555E, 270S
Old Tardy Geyser	I10-270E, 585S
Orange Spring	J 9-320E, 70S
Oval Spring	I10-320E, 630S
"Penta" Geyser	I10-335E, 675S
Rift Geyser	I10-225E, 460S
Sawmill Geyser	I10-250E, 760S
Scalloped Spring	I10-110E, 835S
"South Scalloped" Spring	I10-140E, 900S
Spanker Geyser	I 9-630E, 675S
Spasmodic Geyser	I10-380E, 665S
"Spatter" Geyser	J10-540E, 60S
Sprinkler Geyser	J10-475E, 115S
Tardy Geyser	I10-290E, 805S
Teakettle Geyser	J10- 80E, 865S
Terra Cotta Geyser	I 9-950E, 945S
Tortoise Shell Spring	J10-255E, 400S
Turban Geyser	I10-150E, 310S
Vent Geyser	I10-140E, 305S
Wave Spring	H 9-920E, 830S
West Triplet Geyser	I10-140E, 440S
Witches Cauldron	I 9-500E, 480S
Unnamed geysers	I10-150E, 400S
	J 9-485E, 85S
	J 9-480E, 60S
	J 9-720E, 500S
	J 9-755E, 530S

Unnamed springs

PART II

Geyser Hill Group

Anemone Geyser	J12-240E, 755S
Arrowhead Spring	J11-765E, 515S
"Aurum" Geyser	J12-115E, 100S
Beach Spring	J12- 70E, 80S
Beehive Geyser	J11-985E, 815S
Beehive's Indicator	J11-995E, 810S
"Bench" Geyser	J12-120E, 640S
Big Cub Geyser	J11-695E, 300S
"Bronze" Spring	J12-390E, 805S
Cascade Geyser	J12-240E, 880S
"Depression" Geyser	J11-815E, 675S
"Dome" Geyser	J12-555E, 475S
Doublet Pool	J12- 60E, 190S

Upper Basin--ContinuedLocation

Geyser Hill Group--continued

Dragon Spring	J12- 50E, 570S
Ear Spring	J11-890E, 125S
Giantess Geyser	J12-240E, 485S
Goggles Spring	J11-775E, 255S
"Heart" Spring	J11-825E, 385S
Infant Geyser	J12-400E, 415S
Lion Geyser	J11-730E, 290S
Lioness Geyser	J11-690E, 350S
Little Cub	J11-705E, 330S
"Little Squirt"	J12-325E, 800S
North Goggle	J11-790E, 235S
"Plume" Geyser	J12-145E, 775S
Pump Geyser	J12-110E, 385S
"Rock" Pool	J12-565E, 635S
"Roof" Geyser	J11-960E, 550S
Scissors Springs	J11-895E, 715S
"Silver" Spring (see Bronze Spring)	J12-340E, 825S
Sponge Geyser	J12- 25E, 420S
"Sulphide" Spring	J12-480E, 755S
"Surge" Geyser	J12-170E, 690S
Teakettle Spring	J12-195E, 420S
Topaz Spring	J12-145E, 385S
Vault Geyser	J12-245E, 420S

Myriad Group

"Abuse" Spring	L10-670E, 250S
"Little Brother" Geyser	K10-200E, 600S
"Myriad" Geyser	L10-500E, 190S
"Round" Geyser	L10-640E, 255S
Three Sisters Springs	K10-190E, 660S
Trail Geyser	L10-285E, 85S
West Trail Geyser (see Trail Geyser)	L10-240E, 60S
White Geyser	L10-830E, 220S

Black Sand Basin

Black Sand Pool	I 6-290E, 120S
Cliff Geyser	J 5-720E, 945S
"Cucumber" Spring	J 5-750E, 700S
Emerald Pool	K 5-400E, 400S
Green Spring	K 5-690E, 160S
Handkerchief Pool	J 5-535E, 930S
"Opalescent" Spring	J 5-900E, 630S
Rainbow Pool	J 5-520E, 880S
Spouter Geyser	J 5-890E, 780S
Sunset Lake	J 5-540E, 740S
Whistle Geyser	J 6- 95E, 940S
Unnamed geyser	K 5-770E, 0S

Upper Basin--ContinuedLocation

Miscellaneous

Cyclops Spring

F 7-810E, 550S

Solitary Geyser

H12-165E, 630S

"Pipeline" Group

K-15, L-15, K-14

~~"LONE STAR" GEYSER~~Midway-Rabbit Creek Basin

Midway

Catfish Geyser

F 5-395E, 615S

"Circle" Pool

E 5-120E, 810S

Excelsior Geyser

C 3-120E, 820S

Flood Geyser

E 5-135E, 920S

Grand Prismatic Spring

D 2-700E, 350S

Indigo Spring

D 3-430E, 235S

Opal Pool

C 2-560E, 760S

Turquoise Spring

C 2-825E, 765S

"West Flood" Geyser

E 4-905E, 950S

Rabbit Creek

Egeria Spring

H 4-110E, 90S

"Grizzly" Pool

H 5-280E, 790S

River Spouter

G 4-285E, 115S

"Three Vent" Spring

H 4-650E, 150S

"Till" Geyser

H 4-490E, 590S

"Tire" Pool

G 4-260E, 960S

"Turbid" Spring

H 4-790E, 165S

Lower Geyser Basin

Great Fountain Group

Great Fountain Geyser

J 7-305E, 900S

Surprise Pool

K 7-210E, 200S

White Creek

"A-1" Geyser

K 7-370E, 440S

"A-2" Geyser

K 7-395E, 465S

"Botryoidal" Spring

K 7-395E, 465S

"Broken Egg" Spring

K 6-525E, 425S

Buffalo Pool

L 8-230E, 450S

Diamond Spring

K 7-740E, 880S

Firehole Pool

K 6-810E, 400S

Five Sisters Springs

L 8- 60E, 375S

"Lemon" Spring

K 6- 75E, 225S

"Octopus" Spring

K 7-900E, 810S

"Pine" Spring

L 7-985E, 395S

"Ravine" Spring

L 7-915E, 70S

"Spindle" Geyser

L 8-275E, 460S

"Verdant" Spring

K 7-535E, 715S

Lower Geyser Basin--ContinuedLocation

White Dome Group	
"Cave" Spring	J 6-815E, 25S
"Crack" Geyser	J 6-790E, 40S
"Gemini" Geyser	J 6-780E, 25S
"Pebble" Geyser	J 6-785E, 55S
White Dome Geyser	I 6-575E, 900S
 Pink Cone Group	
Bead Geyser	H 8-535E, 435S
"Labial" Geyser	H 8-530E, 295S
Narcissus Geyser	H 8- 70E, 75S
Pink Cone Geyser	H 8-280E, 585S
"Pink" Geyser	H 8-235E, 370S
"Shelf" Spring	H 8-505E, 440S
The Tank	H 8-950E, 740S
 Black Warrior Group	
"Dart" Spring	G 9-880E, 625S
Firehole Lake	H11-350E, 50S
"Firehole" Pool	H11-470E, 45S
"Flame" Spring	H11-490E, 75S
Hot Lake	H10-200E, 150S
Steady Geyser	H10-780E, 60S
Zomar Spring	H10-360E, 840S
 Fountain Group	
Celestine Pool	F 5-545E, 140S
"Clep's Well"	E 4-910E, 585S
Clepsydra Geyser	E 4-935E, 600S
"Fissure Springs"	NE 4-755E, 565S
Fountain Geyser	E 5-110E, 570S
Fountain Paint Pot	E 5-640E, 770S
Gore Springs	NE 4-850E, 710S
Jelly Geyser	E 4-990E, 665S
Jet Geyser	E 5-160E, 685S
Leather Pool	E 5-725E, 560S
Morning Geyser	E 5-125E, 470S
"New" Bellefontaine Geyser	E 5-795E, 505S
"Old" Bellefontaine Geyser	E 4-805E, 845S
"Red Spouter"	E 5-660E, 625S
Silex Spring	E 5-740E, 930S
Spasm Geyser	E 5-015E, 625S
"Sub" Geyser	E 4-935E, 340S
Unnamed Geyser (see "New" Bellefontaine)	E 4-760E, 395S

Lower Geyser Basin--ContinuedLocation

Kaleidoscope Group

"Blowout" Spring	D 3- 780E, 385S
"Deep Blue" Geyser	D 3- 900E, 360S
"Drain" Geyser	D 3- 810E, 375S
"Honeycomb" Geyser	D 3-1000E, 430S
"Honey's Vent"	D 4- 40E, 445S
Kaleidoscope Geyser	D 3- 820E, 415S
"Old" Surprise Spring	D 3- 930E, 40S

Sprinkler Group

"Angle" Geyser	D 4- 245E, 455S
"Earthquake" Geyser	D 4- 535E, 275S
"Ferric" Geyser	D 4- 350E, 305S
Gentian Pool	D 4- 720E, 300S
"Sprinkler" Geyser	D 4- 400E, 480S
Unnamed Geyser (see "Angle")	D 4- 240E, 440S
Unnamed Geyser (see "Earthquake")	D 4- 530E, 265S

Thud Group

Cliff Spring	C 5- 510E, 150S
Fungoid Spring	C 5- 275E, 475S
Gourd Spring	C 5- 745E, 305S
Jug Spring	C 5- 620E, 220S
Kidney Spring	B 5- 355E, 965S
Lone Spring	* B 6- 520E, 915S (?)
Oak Leaf Spring	C 5- 395E, 155S
Round Spring	C 5- 150E, 320S
Stirrup Spring	C 5- 515E, 380S
Thud Spring	C 5- 415E, 490S

River Group

"Armored" Spring
"Azure" Spring
"Baby Bathtub" Spring
Bath Spring
Cavern Spring
Cone Spring
Crown Spring
"Diadem" Spring
Fortress Geyser
Grotto Spring
Horn Spring
"Leaf" Pool
Mound Geyser
Ojo Caliente
Perch Spring
Skeleton Pool

Lower Geyser Basin--Continued

Location

PART III

Miscellaneous

Boulder Spring, N. end of Fairy Meadows

"Morning Mist" Geyser , Nez Perce Creek

"Porcupine Hill" Geyser , Porcupine Hill

Snort Geyser, Camp Group

IMPERIAL AND SPRAY GEYSERS - IMPERIAL GROUP

Madison Junction

Terrace Springs

Shoshone Geyser Basin

HEART LAKE Hot Springs

Avoca Spring *Geysir?*

B4-890E, 530S

*Went geysir
64-835E, 530S*
BISCUIT BASIN

?
location OK?

Avoca Spring apparently was named by a member of the Hague Expedition (G.S. Ninth Ann. - 1887-1888, p. 654). It is located on the west side of Biscuit Basin. In elevation it rises above all springs on the west side of the river. The crater consists largely of a rift about 8 feet in length and 2 to 3 inches in width. On the south end of the rift there is a small crater about 3 feet in diameter and 3 feet deep.

There is no record of which I am aware that Avoca ever displayed geyser potential until after the 1959 earthquake. All previous known activity was steady boiling, particularly from the highest vent in the rift. When first observed on the day following the big temblor the crater was empty, also that of the spring on the south end. Sometime during the first week following the earthquake Avoca turned into a steam vent. At about one minute intervals there would be a momentary roar of escaping steam. In mid October water began rising in the south crater. The rise of water apparently in part smothered the steam, as mostly water droplets would be ejected at the time of the former steam periods. By December the steam was very largely displaced by water.

Eruptions at about one minute intervals continued through the next few years following 1959. Water would be jetted for a few seconds to heights varying between about 3 and 10 feet. By 1966 it was evident Avoca had two types of eruptions. The minor one occurred about every 2 to 3 minutes, when a major one would ensue. Following major activity there would be an interval of 13 to 15 minutes before minor activity again occurred. The duration of an eruption was about 20 seconds. Minor activity jetted the water 3 to 6 feet in height; major activity, 12 to 15 feet. Since 1966 the character of the eruptions has remained essentially unchanged. The south crater is still only partially filled.

During the night of the earthquake a large spring about 100 ^{140?} feet north of Avoca had a voluminous eruption, as was evidenced by the amount of wash about the crater. New drainage channels extended away from the spring. During the first 10 days following the temblor there were additional

eruptions, but I was not fortunate in observing one. Due to this spring being the most western one in Biscuit Basin, it was called "West Geyser." Since the initial activity no further eruptions are believed to have occurred.

Except the small spring on the south end of Avoca it has no apparent underground connections with any other spring.

"Baby Daisy Geyser"

C6-580E, 825S

BISCUIT BASIN

During the 1952 season a plot of ground of about half an acre in extent suddenly became hot enough to result in 8 different springs taking on geyser proclivities. This occurred sometime between July 11 and 13. Previous to this I had never observed any geyser activity in this particular group of springs. Most had been quite inauspicious in appearance. These springs are located in the southeastern end of Biscuit Basin, on the east side of the Firehole River. The geyser farthest to the south was called Baby Daisy. The largest, which was near the center of the group, was named Biscuit Basin Geyser. Other springs in the group which showed eruptive activity played to heights varying from about 3 to 8 feet.

Baby Daisy was so named because its eruptions, on a smaller scale, bear a marked resemblance to those of Daisy Geyser. The water from both geysers plays steadily and at a similar angle. Baby Daisy's water was ejected in an easterly direction. The duration of an eruption was from about 2 to $2\frac{1}{2}$ minutes. The estimated height was about 30 feet. Many eruption intervals were determined. They ranged between about 90 and 120 minutes. The waters of an eruption showered a small grove of Lodge Pole Pines about 30 feet distant. This resulted in the death of the trees, which indicated that any earlier cycle of eruptive activity had not occurred for many score years.

Located on the same sinter mound and to the west of Baby Daisy Geyser, there is a large spring which is about 6 feet in diameter. During all eruptions of Baby Daisy this spring erupted in concert. It was a splashing-type eruption, very much like those of Vault Geyser. This unnamed geyser seemed to be the only one in the newly activated group on which Baby Daisy's eruptions had any observed effect.

Eruptive activity persisted in the new hot ground until the end of the season. From 1953 until after the 1959 earthquake no further activity of Baby Daisy was observed. The earthquake initiated a new eruption cycle. Again checked eruptions lasted from about 2 to $2\frac{1}{2}$ minutes; the height the same as during 1952. However, there was greater frequency of eruptions, the intervals ranging between about 60 and 96 minutes. Activity continued for the rest of the year. At the beginning of the 1960 season Baby Daisy was dormant, and is believed to have remained so to date (1970).

"Biscuit Basin Geyser"

C6-495E, 725S ✓

BISCUIT BASIN

In the group of springs which entered an eruption cycle sometime between July 11 and 13, 1952, Biscuit Basin Geyser is very much the largest geyser. It is located about 140 feet northwest of Baby Daisy, or 375 feet southwest of Mirror Pool. It has a crater which is about 5 by 7 feet. The crater extends downward for an undetermined distance without showing any evident constriction from the size of the surface opening. The water while rising in the vent following an eruption was in a constant state of ebullition. When the rising water reached the rim of the crater it remained at a near constant level until the initiation of an eruption. It is a superheated spring. The temperature on all occasions when taken in 1952 was 204°F. During the dormant period the temperature has ranged between 201° and 202°F.

All eruptions observed in 1952 began with a sudden rise of water level and overflow. After momentary surging the eruption started explosively. During the first minute of play a great volume of water was discharged. The diameter of the column appeared to be between 10 and 12 feet. There were two sections to the water column. The first rose about 40 feet. Then near its apex a column of much smaller dimensions shot up an additional 30 or 40 feet. The eruption was spectacular and impressive. The duration was about 1½ minutes.

It was difficult to get an interval on the new geyser. During some days it was known to have erupted 2 to 3 times during daylight hours. Some days no eruption was observed. This no doubt was due to the fact that the geyser was not always in view.

The early eruptions of Biscuit Basin Geyser discharged large quantities of solid matter. Some of the discharged sinter blocks were as much as 4 by 12 inches. Some were hurled fully 100 feet from the crater. In addition to large blocks the water of an eruption was highly charged with rocks ranging down to comminuted particles of sinter, giving the water column a turbid appearance. The water stayed murky for the rest of the 1952 season.

The water of an eruption flows down a mild declivity into the Firehole River, about 240 feet distant. Due to the great volume of water discharged during an eruption the weathered sinter, where drainage channels were formed, all washed into the river, forming deltas. The newly formed channels, plus the great amount of fragmental sinter washed into the Firehole, suggested that the 1952 eruptions might well have been the first.

Following the 1952 season the new geyser was dormant. The earthquake failed to stimulate an eruption. It is believed that no eruption has occurred since 1952. No evidence of subsurface connections with any other spring was noted. However, the fact that so many springs showed a sudden increase in temperature, then decline, is suggestive of subterranean connections with each other.

✓27

"Black Opal Pool"

B5-825E, 615S ✓

BISCUIT BASIN

The large crater of Black Opal was formed in sinter-cemented sandstone. It was during the 1931 season when I first observed this spring. The evidence then seemed unmistakable that it must have had its origin as a result of a steam explosion. Large blocks of sandstone were strewn about the crater. The sandstone consisted of small rhyolite pebbles and obsidian sand. It appeared to have originated as glacial wash.

Reference to a Ranger Naturalist Manual gives a possible clue to when the explosion occurred.

"As the visitor ascends the slope between the run-off channels of Sapphire Pool he observes on his right a huge cavity in the sinter with fractured walls that bear witness of the power of the subterranean explosion that opened it up in the spring of 1925" (Phillips, 1927, p. 137).

That the explosion which created Black Opal's crater was of considerable magnitude was made evident to me in 1931 (then unaware of the above reference) by the fact that small chunks of sandstone were found not less than a 1000 feet north of the crater. Much the greater part of the sandstone was strewn in a northerly direction. Since my first observation weathering has brought about the disintegration of practically all of the smaller pieces.

During the winter of 1931-32 a ranger, Frank Childs, reported that blocks of sandstone were torn from Black Opal's crater. The following season I could see no evidence that the diameter of the crater had been enlarged. It is believed that Childs might have seen, or been aware of one of the infrequent eruptions that have been known to occur.

During the 1947 season Black Opal was known to have erupted two times. The eruptions, as described to me, indicated they began as a sudden bulge of the water, giving it a convex appearance. After the momentary bulge the water exploded to

a height of 20 to 30 feet. There was evidence of heavy wash about the crater, but I could not discover that any new solid matter had been disgorged. During the 1948 season there was evidence an eruption had occurred.

In the late 1950s prior to the earthquake Black Opal was characterized by dark opalescent coloration. During the period in 1959 which preceded the earthquake a continuous thumping sound could be heard. The sounds did not seem to originate at any great depth. Rising convection seemed to indicate that water was being jetted into the crater.

One of the most important effects the earthquake had on Black Opal was to destroy its lovely color. The water was very murky at first and did not clear for the remainder of the year. The water level dropped about 10 inches. By 1960 water was again at the overflow level. On the day following the earthquake it was observed that a large break had occurred on the south shoulder. There had been considerable slumping in the direction of the pool, which slumping slowly progressed all of the 1960 and 1961 seasons. 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 1960 season the crack had completely filled with sediment.

Since the earthquake there has been no evidence of any eruptive activity. Since the beginning of the 1960 season there has been steady overflow. No known underground connections with any other spring exist.

Black Pearl Geyser

B5-220E, 395S

BISCUIT BASIN

Black Pearl is a shallow spring from 4 to 5 feet in diameter. There is a small vent in the central portion. The basin is lined with dark beady sinter, hence the name.

Activity in this small geyser is cyclic. During 1959, prior to the earthquake it was dormant. Due to the earthquake the water dropped about 12 inches in the crater. For the rest of the year it was a constant spouter. Until 1968 near steady jetting characterized this spring; the jets attaining a height of about 4 feet. It apparently is connected underground with a small geyser about 12 feet to the east. It and Black Pearl have been dormant since the 1967 season, both becoming dormant at about the same time.

Cauliflower Geyser

C6-640E, 190S

Biscuit Basin

Cauliflower was named in allusion to the cauliflower-like masses of sinter which surround the crater. These masses also have a biscuit-like appearance, which in part is responsible for the name Biscuit Basin.

Like Mirror Pool, Cauliflower has shown no noticeable change in pattern during the period I have observed it. It is a true geyser. However, the eruptions are very minor in character. The intervals I have checked have varied between about 50 and 90 minutes, the average being between 60 and 70 minutes. Previous to an eruption the water stands about 6 inches below the rim of the crater. An eruption is initiated by a sudden rise in water level and resultant overflow, which is accompanied by boiling. The boiling constitutes the eruption. It lasts from about $1\frac{1}{2}$ to 3 minutes.

The 1959 earthquake had no noticeable effect on Cauliflower's function, however, for about 3 days the water was murky. I have observed no evidence that it might have underground connections with nearby Mirror Pool, or any other spring.

cent. show / A small geyser about 60 feet west of Cauliflower began erupting following the earthquake. No previous activity had been observed. The eruptions occur about every 5 minutes. They last for less than a minute, the height being between 4 and 5 feet. Since 1959 the eruptions have persisted.

30

East Mustard Spring

B5-145E, 305S ✓

West Mustard Spring

B5-90E, 300S ✓

BISCUIT BASIN

Both East and West Mustard Springs are small, being from 4 to 5 feet in diameter. They bear a close resemblance to each other. About 5 feet below the crater rims a small vent punctures the sinter. The name "Mustard" resulted from the fact that both springs were lined with algae, mustard-like in color. ? F. W. L.?

The earthquake brought about similar changes in both springs. Formerly the water had stood at the upper rims of the craters. East Mustard had a temperature of 157°F; West Mustard 163°F. The earthquake dropped the water level about 30 inches; both were in a constant state of ebullition. The temperature had increased to 200°F in both springs. Later the water emptied from both craters with water jetting into their bowls.

Since the big jarrings of 1959 both Mustard Springs have remained in essentially the same state. During the 1961 season the boiling became somewhat more violent in West Mustard, which condition has persisted. No doubt both springs are connected underground.

*which vent
on map?*

About 100 feet south of Mustard Springs, a fumarole developed following the big tremor. By 1960 it had excavated a small crater and had evolved into a geyser. By April it was having eruptions about once an hour, an eruption lasting about half that time. This type of activity continued through all of 1960. However, by 1961 the eruptions had greatly increased in forcefulness. Instead of being 3 to 4 feet in height they were from 10 to 12. During 1961 there was steady enlargement of the crater. By early 1962 the eruptive activity had greatly subsided. By late summer the new geyser was dormant.

"Island Geyser"

C5-640E, 50S

BISCUIT BASIN

This geyser was so named because it is located on a small island in the Firehole River. It is almost directly south of Sapphire Pool, whose drainage enters the river at this point.

Previous to the 1959 earthquake there were several small, murky non-flowing springs on the above island. Following the earthquake eleven of them were observed jetting muddy water from a few inches to near 2 feet in height. A new function had also developed in the channel on the west side of the island. Its jetting water, steam, or both, produced a sound not unlike the engine of a motor boat at slow speed. After 1960 this thumping sound was heard no more.

The activity of the springs on the island persisted until May 1966. Sometime near the middle of this month one of the springs began erupting a large volume of water 5 to 6 feet high. Since the beginning of this eruptive activity Island Geyser has continued without any known pause. It is a steady geyser.

3 pout-?

Jewel Geyser

B5-135E, 695S

BISCUIT BASIN

The Biscuit Basin Group of hot springs was called the "Soda Group" by the Hayden Survey in reference to what they apparently considered its most important geyser. The name "Soda Geyser" was given to this spring at the time of the Survey's first expedition into the Yellowstone country.

"The Soda Geyser was two miles below our camp, on the left bank of the river, and spouted with great regularity every 10 minutes, throwing the water up 10 feet, resembling very much a soda fountain, hence the name" (Peale, p. 186).

As is the case with many hot springs, the first name given was later changed by subsequent visitors, visitors totally unaware of the then existing names. When and by whom the name Soda was changed to Jewel is unknown, at least at the time of the present writing. The name Jewel is in reference to the shiny, beady sinter about the vent.

During the decades I had observed Jewel prior to the 1959 earthquake it adhered to a near set type of function. The interval extremes ranged between about 5 and 8 minutes; the majority of the eruptions being near 6 minutes. During an active phase there were usually 3 separate bursts; sometimes four. The maximum height was near 20 feet.

When Jewel was observed on the day following the 1959 earthquake, like nearby Sapphire, it was erupting muddy water. Also like Sapphire the eruption was a steady ejection of water without pause. As closely as could be determined the continuous activity persisted until about September 1, when it began to show periodicity. The quiet phase would last for about 1 minute, the active phase for about the same duration. The length of the interval gradually increased until by the 18th it was averaging about 6 minutes. The number of separate bursts during an eruption also had increased, being from 4 to 6. This type of function continued for the rest of the year.

During 1960 Jewel was the only geyser in the Sapphire Group whose eruptive activity followed an essentially pre-earthquake

pattern. Despite this, its water never entirely cleared. It was colored by highly comminuted particles which had the appearance of cement. This condition persisted until the 1965 season.

In August 1964 Jewel's eruptions became greatly enfeebled. The activity occurred about every 5 to 8 minutes, but instead of 12 to 15 foot bursts, the water at the time of an eruption would occasionally merely well out. At times there would be but enervated boiling; other times no more than a single jet which would vary between about 6 and 15 feet in height.

Since the 1965 season Jewel has been quite stable in its activity. The intervals have varied between about 6 and 10 minutes. At the time of an eruption there most often are either 2 or 3 bursts. Unless it be with Sapphire it does not seem to have underground connections with any other spring.

An eruption of Jewel lasts about 60 to 90 seconds. The start of activity is indicated by a sudden rise and welling of the water from the vent. Immediately there is an explosive burst, or jet which drops almost as suddenly as it rises. After a few seconds pause the process is repeated; occasionally a third time.

Mirror Pool

C6-670E, 350S

Biscuit Basin

During the years I have been in the geyser basins Mirror Pool has been one of the most fixed and unchanging of the hot springs. Its temperature has remained about 185°F. Following the earthquake the water was murky, but it rapidly cleared. There was no fluctuation in water level or rate of discharge, which amounts to between 30 and 40 gallons per minute.

Mirror has changed its direction of overflow two times during the period I have observed it. This resulted from algae building up in drainage channels. The algal-colored drainage channels are one of its most distinguishing characteristics. I have observed no evidence that it might be connected underground with any other spring.

200? About 100 feet to the west of Mirror new hot ground developed. A spring whose water was about 8 feet below the surface began erupting. It continues to be active. The height of the eruptions does not reach the surface. / when?

"North Geyser"

B5-305E, 75S ✓

BISCUIT BASIN

The stretch of sinter lying to the north of Mustard Springs has many small springs. I have observed geyser activity in three of them. The northernmost spring was given the name North Geyser, not only due to its location, it was also the largest of the erupting springs.

North Geyser has been cyclic during the period I have observed it. Some seasons it would be dormant, others active. In length the active and dormant cycles about balanced each other. It was dormant during 1959. The earthquake did not induce eruptive activity. However, a new cycle of activity began in late 1962, terminating in 1963. I have observed no evidence of eruptions since 1963. During 1964 it overflowed steadily, but did not erupt.

Prior to the earthquake it erupted about every half hour; the height being from 10 to 15 feet. An eruption lasted about 2 minutes.

31

"Rusty Geyser"

B6-330E, 805S 305E, 795S ?
(Creek location)

BISCUIT BASIN

This geyser was named Rusty due to the color of the deposits. Iron oxides have given the sinter a rusty color. It is a small geyser. Two vents puncture the sinter in the iron-colored formation. Prior to the 1959 earthquake its action was cyclic. Some seasons it would be observed erupting, others not. Prior to the earthquake rejuvenation it had been dormant for several seasons.

The eruptions I observed of Rusty prior to the earthquake were characterized by two jets of water; the one slightly higher than the other. Maximum height was between about 8 and 10 feet. Eruptions were frequent. However, time of intervals was not determined. The duration of an eruption was between 2 and 3 minutes.

The rejuvenation of Rusty as a result of the earthquake persisted through the 1964 season when it again became dormant. During the 1968 season rejuvenation again occurred. The eruptions were frequent, occurring every 4 to 5 minutes. The height was between 10 and 12 feet. In the latter part of the season the boiling became almost constant. Eruptions about 3 feet high occurred about every minute. Only one vent erupted. During 1969 the eruptions were higher than in late 1968, occurring about every 1 to 2 minutes. The same frequency of eruptions persisted through 1970. Most of the eruptions (one vent only) were about 3 feet in height. Occasionally one of greater vigor would occur.

Rusty's marked change in eruptive activity in late 1968 might in part have resulted from a drill hole about 30 feet to the west. It has no known underground connections with any other spring. 4-2, drilled September 1967

Across the road and to the west of Rusty, three small springs erupted as a result of the earthquake. To the northwest, and on the southern end of the parking area, new hot ground developed due to the earthquake. Two new fumaroles were soon in evidence. Before the end of 1959 both had become small, steady geysers, jetting water to a height of from 12 to 18 inches. Due to the location of these springs the Old Faithful road crew at the beginning of the 1964 season dumped a truck load of sand on them with the thought of smothering them. The objective failed in its purpose. Both vents continue to squirt water.

- 33

Sapphire Pool

B5-365E, 650S ✓

BISCUIT BASIN

Pre-Earthquake Period

Early parties visiting the geyser basins, scientific parties not excepted, were primarily interested in erupting hot springs. The major part of their attention was devoted to the same. Despite the fact that Sapphire Pool is a true geyser, and one of the most beautiful springs in the park, early references to it are very scanty. So far as the Hayden Survey was concerned "Soda Geyser" was apparently the most interesting spring in Biscuit Basin.

It was not until 1890 that early guide books made any reference to Sapphire.

"The principal attraction of Biscuit Basin is Sapphire Pool, whose highly ornamented margin suggested the basin's rather odd name. Hundreds of small, symmetrical, biscuit-like knobs of olive-green formation surround the spring, which is of a variety known as pulsating or breathing springs, the constant ebb and flow of its waters now rising threateningly and flooding the margins of hard, biscuit-shaped masses, from one to another of which one must pick his way in order to get a good view of the pool itself; now gently and noiselessly receding, presently, the while, a spectacle as curious as it is interesting" (Guptil, 1890, p. 78).

An early description by park personnel is as follows:

"Sapphire Pool is an excellent example of the intermediate stage between a geyser and hot spring, sometimes called 'Geyser springs' by way of compromise. It boils up violently and overflows every two or three minutes but there is no jet and the only movement of the water is the surging caused by the violence of the ebullition. Between periods there is a short interval of calm during which the deep but transparent blue of the water can be observed. The 'biscuit' structure of the sinter is very conspicuous here" (Phillips, 1927, p. 137).

In their discussion of geyser theories Allen and Day refer to Sapphire as an example of true geyser function, affording a suitable explanation as to why hot springs erupt:

"Perhaps as much of geyser action as may be learned from direct observation can be seen in the Sapphire Pool. It has two characteristics peculiarly favorable to study; within its limpid depths the light-colored walls and bottom are clearly visible, and it erupts every 10 to 20 minutes, permitting frequent observations. As remarked under the caption 'temperature-depth curves,' the heat in this geyser appears to enter somewhere from 18 to 24 feet from the surface on the west side. Under proper lighting conditions the observer can see large steam bubbles rising near the wall of the basin, attended by an upward current which brings superheated water to the surface, while the water level gradually rises, resulting in copious overflows, until suddenly the seething mass domes up in a fountain several feet in height, staging a turbulent eruption that floods the surrounding terrace for some minutes. The water level drops again and the cycle is repeated at short intervals. Both hot water and steam evidently come from a reservoir outside the basin through cracks or fissures in the wall; for the possibility that the water of this capacious basin is lifted by boiling that originates within its own depths is obviously inadmissible. That such a gradual rise is due to displacement by steam outside the basin and not to continuous infiltration of ground water follows from the intermittent character of the discharge. The Sapphire is unquestionably a geyser, though the fact that the erupted water takes the form of a dome, somewhat dwarfed by the size of the pool, instead of a slender jet, has prevented its general recognition as such. So far as external observation shows, this spring lacks the long tube common to the geysers discussed in the literature and imitated in the laboratory; hot water seems to be forced from the subterranean chamber directly into the deep surface pool, or the pool may be regarded as a greatly enlarged tube with no basin at the top" (1935, pp. 220-222).

The biscuit-like structure of the deposits about Sapphire's crater, and extending back several feet from the rim, was unquestionably the principal reason for the area being named Biscuit Basin. Not only did the sinter biscuits lend a unique charm, but the pool itself was one of the loveliest in the park. Of the crystalline-clear springs, blue in color, Sapphire was without a peer. As a name, Sapphire was most fitting. Its water during the quiet phase scintillated as beautifully as the Oriental sapphire.

Prior to the 1959 earthquake eruptions of Sapphire occurred with marked regularity. The average interval in 1940 was near 13 minutes.

"Some data were collected on the activity of Sapphire Pool. This consisted of noting the interval and duration of the 'play' for several hours on each of three afternoons in the latter part of August 1940. In all, thirty observations were tabulated. Although the data are too few upon which to base more than tentative conclusions, they do indicate a remarkable regularity on the part of Sapphire Pool. The average interval was found to be 12.8 minutes, with 14.5 minutes as the longest and 10 minutes as the shortest" (Bauer, 1941, p. 30).

During the 1950s on a number of occasions I checked intervals on Sapphire and found the average was near 15 minutes; 13 and 17 minutes being the extremes. About 1 minute previous to an eruption water would start rising from a level about 6 inches below overflow. About the time the water reached overflow the marked convection and roll of the water when visual conditions were propitious, rendered the water beautifully transparent. At this time when observing into the depths on the west side of the pool a long string of bubbles could be seen rising to the surface. With ascension their size seemed to increase, being about the size of toy balloons. Upon reaching the surface they collapsed. During the rise of the bubbles, which was brief, the water would suddenly, due to superheat, start sizzling over the entire crater. Almost immediately heavy boiling over the part of the crater where bubbles had risen would occur. In a matter of seconds the boiling would seem to engulf the entire spring.

During most eruptions the water would surge to a height of 3 to 4 feet. Occasionally the heavy surging would reach a height of about 6 feet, endangering people who were standing on the walk, which was not more than 6 feet from the violently splashing water. During an eruption there was very heavy overflow. Most of the water drained to the east into Wall Pool. The duration of an eruption was about 4 minutes, following which the water ebbed about 6 inches in the crater.

The nearness to which park visitors could get to the pool, and see it under favorable conditions, made it one of the most popular springs in Yellowstone. Hundreds of comments I heard were to the effect that it was one of their most cherished memories. Invariably when the party returned to the park Sapphire was high on the agenda of important things to be seen.

A Major Eruption

In the late evening of June 14, 1955 park concessioner employees reported that they had observed a major eruption of Sapphire. The eruption was described as being over 100 feet in height. I made examination about 10 p.m. on the 14th; also on the following morning. Conditions about the pool showed unmistakably that a powerful eruption had taken place. There is no record that any similar display had ever occurred previously. This unprecedented activity immediately suggested that the eruption had been soap-induced. The suspicion that Sapphire had been soaped resulted from certain knowledge that soap had been used in many other springs; also that a few of them, as Beehive, had been soaped repeatedly. Further, an isolated natural eruption of the character which took place was a most unlikely occurrence. During the 1955 season there was more soaping of geysers by park concessioner employees than during any season I have been in Yellowstone Park. Both small and large geysers were soaped. Any evidence of the use of soap at Sapphire which might have been detected when the first observation was made was completely obliterated by the following morning, the earliest time a careful survey could be made.

1959 Earthquake

The big temblor of August 17, 1959 affected Sapphire Pool most dramatically. It and the group of springs to which it belongs were affected to a greater degree than any other area in the Upper Basin. None of the group's springs escaped alteration in

behavior. New fumaroles and springs developed. There was more evidence of surface fracturing than in other parts of the Upper Basin.

On the morning following the earthquake Sapphire was in a state of violent boiling. Water was surging up about 8 feet. Due to contained sediments it was of a brownish coloration. It soon became evident that all periodicity had ceased. The boiling was constant. It had developed into a steady geyser.

Sometime during the night of August 21, there was a major eruption, comparable in size to the 1955 eruption. By the morning of the 22nd the crater had again filled and was boiling steadily and in the same manner as prior to the night eruption of the 21st. The steady geyser activity continued until September 5. On this date it was evident that a spectacular change had taken place. At approximately two hour intervals Sapphire was having eruptions of titanic proportions. The eruptions would come suddenly and explosively. Following an eruption the water would ebb from 4 to 6 feet in the crater. With constant boiling and surging it would steadily rise. Upon reaching the base of the biscuits it would suddenly well, overflowing the crater. Then within 2 or 3 seconds the explosion would lift a huge mass of rocketing jets of water to heights which seemed to vary from 100 to 125 feet. Occasionally there would be a burst fully 150 feet in height.

During the entire period I have checked geyser activity I have never observed one to erupt with such suddenness as did Sapphire. When standing near the crater one could scarcely scamper fast enough to get out of range of the far-reaching arms of scalding water.

The eruptions were spectacular, not only due to their height, but for their lateral extension and the tremendous volume of water discharged during the initial burst. Many of the eruptions would be wider than they were high; the estimated width being near 250 feet. This was due to massive jets which arched away from the central mass of exploding water. Following the initial burst, which by competent hydrologists was estimated to discharge in the neighborhood of 50 tons of water, there would be anywhere from 1 to 5 later bursts, about 5 minutes apart. Had it not been for the magnitude of the initial burst some of the later ones could have been viewed with fuller appreciation because

of their own merit. Between the initial explosion and the second one, a series of deep seated steam explosions resulted in marked jarrings of the formations about Sapphire's crater.

The eruptive activity on near 2 hour intervals continued through September 13. From the 14th through the 28th it lapsed back into steady geyser function. On the morning of the 29th it was again periodically erupting on a major scale. Major activity persisted for the rest of the year. Following the September 29 rejuvenation Sapphire erupted for several days in a manner similar to the earlier pattern. Its eruptions then started coming with greater frequency, the intervals being between about 30 and 90 minutes. Occasionally there would be a near two hour interval. With shortened intervals the eruptions decreased in magnitude. Instead of the crater filling before an eruption, the eruption would occur when the water was anywhere from a foot to 3 feet below the crater rim. The higher the water in the crater, the more forceful and voluminous would be the explosion. Once in a while the crater would fill, resulting in an eruption of great magnitude. This type of activity persisted for the rest of the year.

During the 1959-60 winter period Park Ranger Riley McClelland kept an interested and careful check on Sapphire. McClelland reported that major activity continued until January 15. From then until January 30 there was but one known major eruption. During dormant periods the water was in a state of constant boiling. Between February 1 and April 1 Sapphire had active and dormant periods; the active periods being in excess of the dormant ones.

When I visited Sapphire in April 1960 I observed that much additional erosion about the crater had occurred. The erosion of existing sediments was almost as spectacular as the eruptions. Hundreds of tons of sinter had been washed away from the crater; much of it into the Firehole River. During the 1959 period the fragmental sinter that washed south into the Firehole completely blocked all flow of water in the channel on the west side. In the main channel to the east two large deltas were formed which fanned out to the middle of the river. Spring high water largely removed the dam and deltas.

By 1960 about 100 feet from the crater a wall of sinter about 3 feet high had formed. Large blocks of eroded sinter were strewn about the crater in every direction and in the drainage channels.

The heaviest destruction to the formations was on the west side. Here the explosively erupting water had not only completely destroyed all biscuit cover, but was enlarging the crater by tearing out large blocks of sinter, some of which were about 6 inches in thickness and 4 feet square.

Due to the water still being murky in 1960 only a part of the crater, about 4 feet above the ebb following an eruption, could be observed. This section revealed vertical walls. The former sloping shoulders had been sheared off. There was evidence that internal erosion extended to depth. Occasionally sections of sinter were discharged during an eruption that had no surface counterpart. There also were a few masses of highly cemented obsidian sands expelled, indicating that Sapphire had roots in glacial gravels.

During 1960 Sapphire's eruptions underwent considerable variation. The length of the intervals varied from as short as 5 minutes to over 2 hours. In general, the longer the interval the more powerful the eruption. They varied from 10 feet to approximately 150 feet. All of the eruptions that were in the maximum height range had intervals of over an hour.

About November 5, Sapphire began erupting on consistently short intervals. They varied 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.

Outside of Old Faithful no geyser entertained more people during 1961 than Sapphire. The frequency and spectacular nature of its eruptions, as well as interest in "Yellowstone's new big geyser," all contributed to making it one of the focal points in the geyser basins. However, this was the last season that Sapphire erupted as powerfully and spectacularly as during the first several months following the earthquake.

During 1961 there were no periods of dormancy. However, there were days when the average eruption would be more powerful and

spectacular than on others. On the whole major eruptive power was manifest several times daily. The great majority of the eruption intervals varied between about 10 and 30 minutes. Not always, but usually, a longer interval, especially following feeble play, would result in a more powerful eruption. At times, two or more power displays would come in succession. To be really sure of seeing one of the spectacular performances, it often was necessary to wait through three or more periods of activity.

By 1962 the drainage from Sapphire, which previous to the big temblor had been to the east, had shifted to the south. This resulted from the extensive destruction of the sinter cover on the west side of the crater, lowering the outlet by fully 6 inches. During 1961 and 1962 gouging was in progress in the north wall of the crater, undermining the sinter. Much the greater portion of the biscuit-like structure that was on the periphery of the bowl was destroyed.

During 1962 Sapphire erupted with greater frequency than at any time since the earthquake. This no doubt was one of the major factors in bringing about enervated eruptions. The average eruption interval was 15 minutes; the extremes being from 9 to 30 minutes. Many of the eruptions were characterized by feeble ebullition, in even less degree than the pre-earthquake condition. Occasionally, however, there would be a massive burst of water from 40 to 50 feet in height. The state of the eroded ring of sinter fragments on the west side of Sapphire was indicative that no eruptions much in excess of 50 feet occurred.

By 1963 alterations had occurred in Sapphire of a character that no longer made possible major eruptions. During this season as well as during 1964 there was no observable change in their height and frequency. Eruptions occurred about every 15 to 20 minutes, most of them being about 20 feet in height. During succeeding years there was a gradual decline in the strength of the eruptions. During the 1967 season they occurred about every 30 minutes and were from 4 to 12 feet in height. During 1968 the frequency and height were very much the same as during the pre-earthquake period. Since 1968 there has been no true geyser activity. Boiling is constant. However, there is periodic increase in vigor of boiling.

Of all the thermal springs which became murky following the earthquake (this includes fully 95% of them) Sapphire has been the slowest one in clearing. During the period of major activity

the water showed little evidence of clearing. During the 1964 season it had cleared sufficiently so that the pool had a turquoise hue. It was 1968 before marked clearing became evident. However, even today (1970) the former crystal clearness has not been restored.

Prior to the earthquake Sapphire's crater was nearly round, being about 15 feet in diameter. Due to the great destruction of the sinter on the west side the crater presently is oblong in shape, being about 18 by 30 feet.

The overall effects of the earthquake on Sapphire (at least for the present) were adverse in nature. Not only as a beautiful pool, but as a geyser it is presently less interesting than prior to the earthquake. Whether the energy potential has been dissipated to the extent that eruptive activity no longer can occur, or major changes in the plumbing, due to destruction within the crater are at fault, is a moot question. It is believed that both factors have played a role, particularly the latter one. The present ebullition is suggestive that at some depth a fissure might have formed due to the tremendous explosions during the first two years of major activity. The boiling now reaches the surface in linear pattern rather than seeming to originate at one spot. The surface temperature in October 1970 was 202°F. This is two degrees lower than it was prior to the earthquake, but seemingly still hot enough for periodicity and minor activity. Altered plumbing is believed to be principally at fault.

Unless it is with Jewel Geyser, Sapphire has no known subterranean connections with any spring.

36

Shell Geyser

B5-40E, 715S ✓

BISCUIT BASIN

Confusion exists as to which of two small springs should bear the name of Shell Geyser or Silver Globe Spring. Scanty references are indicative that the spring now known as Shell was in recent park history known as Silver Globe.

"Nearby (near Jewel Geyser) is Silver Globe for whose name two equally appropriate explanations have been offered, the large globular bubbles of gas (CO_2) that are constantly ascending from depths and the globular silver-gray masses of sinter in the crater" (Phillips, 1927, p. 137).

"Large silver-gray masses of sinter" are presently quite applicable to Shell, but not to Silver Globe. Ascending bubbles of gas have been observed in Silver Globe, but not in Shell. The spring now known as Shell, not only has globular masses of sinter in its crater, but the general configuration of the spring is not unlike that of one section of a bivalve.

Intervals I have observed on Shell have ranged between about 90 and 120 minutes. An eruption is initiated by a slow rise of water in the crater. A few minutes following overflow boiling begins. At times the water of an eruption scarcely more than wells from the crater. On some occasions I have seen droplets rocket about 3 feet. The eruption is of scarcely more than a minute's duration. Most of the water of an eruption flows back into the shallow, empty crater. During 1970 some change was in evidence. Whenever observed it was in a state of ebullition. Occasionally the boiling increased in vigor with some overflow.

Following the earthquake Shell shared in the general increase in temperature which characterized most of the springs in Biscuit Basin. Its temperature rose from 200° to 204°F . For the first few weeks it was active most of the time. Its water was murky. By 1960 its pattern of activity was about the same as before the earthquake. It has no known subsurface connections with any other springs.

✓ 37

Silver Globe Spring

B4-825E, 560S ^{595?} ✓ *check location*
well 111.44

BISCUIT BASIN

As to what names were originally given to Silver Globe and Shell Geyser there is some uncertainty. It is believed that the following description is applicable to Silver Globe. "Silver Globe derives its name from the constant rising to its surface of large, silvery globules of gas or steam, which of course, immediately disappear on reaching the air" (Guptil, 1890, p.80).

Silver Globe is a small spring, about 3 feet in diameter and 4 feet deep. Prior to the 1959 earthquake whenever I observed it the water stood at the top of the crater. There was steady overflow, estimated at about 3 gallons per minute. Whenever taken the temperature was 182°f. Due to the earthquake Silver Globe erupted. Its crater stayed empty for the remainder of the year. It was not until 1961 that a few inches of water appeared in the bottom of the crater. The rise of water was very slow, during all of 1962 it was down about 3 feet. It was not until the 1970 season that the crater was full. However, there was no overflow.

Since the 1967 season a small geyser a few feet east of Silver Globe, and under the same ledge, has been erupting. Checked eruptions have varied between 18 and 22 minutes. The eruption is very brief, lasting about 10 seconds. A small jet is shot out at an angle of about 45 degrees to a height of from 10 to 12 feet. There seem to be underground connections between Silver Globe and the new geyser.

A tract of ground stretching south of Silver Globe and almost to the river, showed a marked rise in temperature following the earthquake. Most of the trees between Silver Globe and the river were killed. Over an area of not less than an acre many previously inactive, empty pot holes showed marked effects from the temblor. Their craters filled with boiling water. Some had erupted. Over the years the craters of several of these old pot holes had partially filled with disintegrated sinter. Some of the reopenings happened explosively. In two springs nearest to Silver Globe tree roots stretched across newly formed craters, in which there was steady boiling. By 1965 about all of the earthquake induced activity over the acre of ground referred to had subsided.

"Wall Pool" -

B5-750E, 570S ✓

BISCUIT BASIN

This spring was given the name Wall in view of the wall-like escarpment which forms the southwestern side of the crater. The wall is about 4 feet in height. Unlike Black Opal, from which it is separated by a narrow dike of sinter-cemented sands, Wall shows no evidence of having had its origin as a result of a steam explosion. It is believed that the 1959 tremblor might furnish a clue as to how the sinter escarpment was formed. On the southwestern sides of both Black Opal and Wall a large break resulted from the earthquake. The break practically encircled Wall Pool. It was over 150 feet long. There was marked slumping in the sinter in the direction of both springs. It is possible that an earlier earthquake or even the great jarring which would have occurred when the explosion of 1925 created Black Opal, could have been responsible for a break in the sinter, and the consequent 4 feet or more of slumping. This could have produced the present escarpment. That this point of view might have some merit is indicated by the fact that the northeastern side of the crater is not raised, but is on the gentle sloping level of sinter which no doubt was deposited by Sapphire Pool, as was the sinter forming the wall.

Prior to the big tremblor of 1959 I was not sure that Wall Pool had a source of water of its own. About every 15 minutes a flood of water from erupting Sapphire poured into it. The pool was no more than tepid and is known to have been used for bathing. The day following the earthquake the water level was down about 10 inches, the same as in Black Opal. On the northern end of Wall several small springs were in evidence. Their activity has persisted. There is a slight overflow which runs into Black Opal.

The great erosion resulting from major eruptions of Sapphire had by 1961 largely obliterated the evidence of the break next to Wall Pool. Most of the break had been filled by washed sinter fragments. During recent years conditions relating to the pool have become quite stable.

Samples

Artemisia Geyser

E7-145E, 100S

CASCADE GROUP OF UPPER BASIN

Artemisia has one of the largest craters of any thermal spring in Yellowstone. It is nearly circular and is about 50 feet in diameter. The unusual sinter deposits which gird the crater on the south and southwest represent the nicest natural ornamentation in the park. In intricacy of pattern it is comparable to the finest crystal structure. From the margin, to a distance of 30 feet from the crater, there are scores of small collecting basins, from a few inches to about a foot in depth. Each is rimmed with a fretwork of sinter which is of delicate design. All have a metallic luster.

There seems to be no information in the Yellowstone Park Library as to when Artemisia was named, or by whom. All that is known about the naming is that it was prior to 1890. It is believed by many that the name is due to the fact that the metallic-like sinter has a coloration which supposedly resembles that of the Big Sage, Artemisia tridentata.

It is somewhat surprising that the Hayden Survey and other expeditions of the 1870s make no reference to the then unnamed Artemisia. Perhaps during this period, as during all subsequent time, its location placed it in a position where access was difficult. It was not known to be a geyser until 1886. A reference to Artemisia in the 1920s states:

"About twenty-five feet below the road level is a really notable geyser that suffers unjustified neglect on account of its inconspicuousness and inaccessibility from the highway" (Phillips, 1927, p. 137).

Geysers were the forte of all early expeditions, but Artemisia apparently was overlooked. The fact that but a single eruption during daytime is generally characteristic, plus its sequestered position, is no doubt in part the reason for no early reference to it. It is certainly one of the important geysers in the Upper Basin. Allen and Day (1935, p.252) regarded it as being one of 12 most important geysers in this basin.

The earliest references to Artemisia which I have been able to find were in 1890.

"Some distance down the road is Artemisia Geyser. The basin is very large and surrounded by a beautiful formation of pearly geyserite. The sides of the crater may be seen to a great depth when the wind sways the pillar of steam from its surface of crystal water. This geyser was first seen in eruption in 1896. The eruptions are infrequent but very fine, an immense column of water rising some 75 to 100 feet" (Riley, 1890, p. 110).

"Although for the most part very quiescent, this spring has occasional pulsations in the nature of eruptions, at which times large quantities of water are forced out, fairly flooding the formation between it and the river. These eruptions are, however, extremely irregular, too few of them having been witnessed, in fact, to render the regularity of its periods of activity a matter of record or even of authentic rumor" (Guptil, 1890, p. 78).

Height of Eruptions

The height of the eruptions of Artemisia, as given by Riley, was copied into guide books issued at a later period. In geyser tables published by Olin Wheeler in 1896 the height was given as 100 feet. In giving this height it must have been the massive steam cloud accompanying an eruption from which height was estimated and not the maximum heights of water bursts. Even in the 1920s, following the establishment of the National Park Service, the given height was apparently still overestimated.

"Its crater is one of the largest of the active geysers in Yellowstone and the blue of its depths together with the pearly, green sinter, that in color pattern is quite unlike any other in the Park renders it beautifully attractive. Its eruptions are in the nature of gigantic upheavals of the contents of the crater altho the jets occasionally reach fifty feet or more" (Phillips, 1927, p. 137).

Allen and Day give the height more closely to what has been my observations during the past thirty and more years.

"Previous to 1929 the eruptions of the Artemisia, that it happened to be our fortune to see, were probably never higher than 10 or 12 feet, generally lasting for a few minutes only. What then was our surprise to see on September 29 a stormy outburst, lasting 25 minutes, which threw the water to a height of 15 to 35 feet. Thus in altitude of their eruptions geysers show no more constancy than they do in other respects" (1935, p. 187).

It is my firm belief, based on a knowledge of Artemisia's eruptive pattern, that the eruptions alluded to as, "probably never higher than 10 or 12 feet," were but parts of eruptions they witnessed and not the eruptions in their entirety. The duration given makes this allegation quite certain. Artemisia will sometimes be in an eruption when, for not less than 10 minutes, the bursts will be scarcely more than 10 to 15 feet.

The first eruption of Artemisia I observed from start to finish was in July 1938. The duration was 22 minutes. I conservatively estimated the highest jets as being between 20 and 25 feet.

Frequency of Eruptions

Due to a lack of sustained observations the frequency of Artemisia's eruptions over almost its entire history have been based on mere estimates. Guptil's statement in 1890 that "too few of them having been witnessed, in fact, to render the regularity of its periods of activity a matter of record or even authentic rumor" was too long the state of the information relative to Artemisia. Charles Phillips, an astute observer of the hot springs, states: "Its interval is unknown and it is evidently irregular but the writer's observations would lead him to put it between one and three days" (1927, p. 133). Since 1930 practically all of the Haynes Guides have given Artemisia's period as between 20 and 30 hours. The data for these figures were derived from chance observations, which were made of daytime eruptions, only.

The 1970 season was the first time in the history of Artemisia that its true eruption pattern became a matter of record. From June 1 through October a special effort was made to check day and night eruptions. Night eruptions were determined by use of markers; also the slow recovery from the effects of an eruption greatly facilitates in estimating when an eruption occurred. This is true for both day and nighttime activity. Not all possible eruption intervals during the five month period covered by the table are included, as I was out of the basin Saturdays and most of Sundays.

During a five month period in 1970 a total of 155 eruption intervals were determined for Artemisia Geyser. They are listed in the following table.

June - 33 Eruption Intervals

Average	Maximum	Minimum
11 hrs. 54 min.	15 hrs. 3 min.	9 hrs. 28 min.

July - 37 Eruption Intervals

Average	Maximum	Minimum
11 hrs. 18 min.	15 hrs. 6 min.	9 hrs. 5 min.

August - 35 Eruption Intervals

Average	Maximum	Minimum
11 hrs. 42 min.	13 hrs. 18 min.	9 hrs. 12 min.

September - 23 Eruption Intervals

Average	Maximum	Minimum
11 hrs. 36 min.	13 hrs. 18 min.	9 hrs. 30 min.

October - 27 Eruption Intervals

Average	Maximum	Minimum
11 hrs. 18 min.	13 hrs. 17 min.	9 hrs. 28 min.

Season's Average	Season's Maximum	Season's Minimum
11 hrs. 30 min.	15 hrs. 6 min.	9 hrs. 5 min.

An Eruption

Due to the fact that Artemisia erupts with a fair degree of regularity I was able to see many eruptions in their initial stages, which otherwise would have been quite difficult, if not impossible. For the great majority of the eruptions the variation from average time was not more than an hour.

Despite many hours of observing during Artemisia's quiet phase, I could discover nothing which might be classed as an indicator. Following the refilling of the crater, subsequent to an eruption, there is steady overflow, with no discernible change in volume of discharge. At first I thought perhaps an evolution of small bubbles might furnish a clue. However, the bubbles start soon after the crater begins to refill and continue until the eruption. The first certain sign of an eruption is a sudden rise in water level. (The same situation exists with Morning Geyser). The lift does not appear to be more than an inch, but this is sufficient to produce a heavy flood in the direction of the river.

Anywhere from about 30 to 45 seconds following the abrupt rise in water level, boiling starts in the crater. The effervescent state of the boiling is indicative of above boiling temperatures. Prior to an eruption the temperature is about 85°C. During the effervescing the temperature I obtained was 95°C.

Following the sudden rise in water level it is from 2 to 4 minutes before the boiling water begins to surge. For the first 2 or 3 minutes the surging is from 10 to 15 feet in height. It is usually about 6 minutes after the start of heavy overflow before major bursts occur. When they do the water rises from the crater in mass, from which jets rocket 20 to 25 feet. Occasional jets might reach a height of near 35 feet. After a short period of major bursts, surging 10 to 15 feet high will recur. The minor activity usually lasts for several minutes, sometimes about 10, before there is another period of major activity. Major activity will occur at least 3 times, sometimes more, during an eruption. The duration of an eruption is a factor in determining the amount of major surging.

The duration of an eruption can be quite variable. The great majority last from about 21 to 24 minutes. The minimum duration checked during 1970 was 13 minutes; the maximum 36.5 minutes. This was the only known eruption to go 30 minutes or over. The eruption terminates quite abruptly. At times there will be

major activity within a minute of cessation of play. When action ceases the water ebbs quite rapidly in the crater, dropping anywhere from 22 to 24 inches below overflow level. Following the drop in water level it is between 4 and 5 hours before overflow begins. The rise of the water is at a remarkably steady rate. The degree of rise in the crater is a very good indicator of the elapsed time since an eruption.

Artemisia's claim for fame as a geyser is not due to the height to which it ejects its water. It is its overall massiveness and heavy deluge of discharged water that impresses the beholder. If the atmosphere is cold or humid there is a tremendous steam cloud.

"Quite inferior in power to anything like this, [Giantess] Artemisia, nevertheless, gives splendid exhibitions, rarely seen by the general public. Its reservoir is even larger than that of the Giantess, 50 feet in diameter and 45 feet deep in the deepest place yet reached by the plummet. Details in the structure of its heavy sinter border are very curious. It is characterized by voluminous eruptions accompanied by a comparatively high discharge. No one who has seen this geyser in action at its best, the sudden uprushes of its dome-like fountains, girdled by swirling currents of superheated water, darting like tongues in every direction, will fail to concede the Artemisia high rank as a geyser" (Allen and Day, 1935, p. 264).

Artemisia was one of a very few springs which did not show murkiness the morning following the earthquake. For a period of at least three weeks it was known to be erupting on shorter intervals. One 6 hour interval was checked. In the hustle of checking all thermal springs along the Firehole, Artemisia was not given the measure of attention it deserved. Within about 6 weeks following the earthquake it apparently was back on its pre-quake pattern.

Artemisia has no known connections with any other spring. However, it is believed that some of the empty craters resting on the hillside above might have been drained when Artemisia came into being. Nearby Atomizer seems to erupt quite independently of whether Artemisia's crater is full or empty.

Atomizer Geyser

E6-985E, 155S

CASCADE GROUP OF UPPER BASIN

As with a number of the hot springs, a certain amount of confusion exists relative to the proper name for the geyser which I am treating as Atomizer. For many years this geyser was called "Restless". The Hayden map of 1878 of the Upper Geyser Basin shows, unmistakably, that the Hayden party named the geyser now known as Artemisia, Restless. The Hague party of the 1880s were apparently the first to designate Hayden's Restless as Artemisia. Then, or later, the name Restless was given to Atomizer. By whom is unknown. The later name is quite descriptive of its main eruption.

Allen and Day's studies of the hot springs were primarily not concerned with their functions. However, a rather detailed observation was made by them of Atomizer, which they called "Restless".

"This little geyser has built up a small cone near the Artemisia in the Upper Basin. The straight narrow orifice is enlarged at the top to a small saucer-like depression with a break on one side that serves as an outlet. As observed October 3, 1929, the water mounted slowly till the basin overflowed; steam bubbles rose, the water palpitated and the discharge continued for about 10 minutes, when the level suddenly dropped 5 or 6 inches. At 10 a.m. the water was overflowing strongly for the third time, palpitating as before. Wavy striations indicated currents in the pool. After 15 minutes there was another drop of 6 or 7 inches. at 11:18 there was again an overflow followed by a drop, and so the cycles continued till 2 p.m. when an eruption occurred reaching a height of 15 feet and lasting for one minute, followed by a drop in the water level of perhaps 2 feet. At each overflow a palpitating or splashing occurred which seemed to be merely an incipient eruption" (Allen and Day, 1935, p. 179).

For a number of years I was aware that Atomizer had more than one type of eruption; one lasting for a minute or less,

another lasting for nearer half an hour. During 1958, and in later seasons, I spent many hours in the vicinity of Atomizer to try to determine if there were any relation between the minor and major eruptions; also the frequency with which the eruptions occurred. Due to a complete lack of sustained observations it was believed by naturalists who had been stationed at Old Faithful for a considerable time that days and possibly weeks would pass between eruptions.

The 1958, and later, observations revealed that Atomizer erupts one or more times daily. Following a steam-phase eruption it is several hours before its depleted water system is sufficiently replenished so that water will again flow from its crater. This flow is brief before an ebb takes place, but from then until the eruption the flow occurs about every twenty to thirty minutes. The overflow evidently produces steam condensation at depth, resulting in the sudden ebb. The ebb is anywhere from about six inches to two or more feet. After several overflow and ebb periods one of the overflow periods results in an eruption. The eruption takes place within a minute or less of the beginning of the overflow. This eruption seems to be a precursor to several succeeding ones of similar character whose intervals are about an hour and a half. The steam-phase seems to be the climax of an eruption cycle. The nature of the buildup to the final eruption seems to have no counterpart in any other geyser.

The eruptions which occur during the buildup of pressure are a minute or less in duration; the height of most is between 10 and 12 feet. Occasionally one will double this height. These eruptions end very abruptly. When the steam-phase eruption ensues the water is at once projected to a height of 20 to 25 feet. After less than a minute of steady water ejection steam begins to manifest itself. The proportion of steam to water steadily increases as the eruption progresses; also the height, the maximum being about 35 feet. The average length of an eruption is 33 minutes. Due to the orifice being but about four inches in diameter the ejected water and steam have the appearance of a giant atomizer. The name Atomizer is quite apropos.

The steam-phase eruptions so completely exhaust the geyser's resources that considerable time is required for pressure to build up for a new eruption cycle. The intervals between the steam-phase eruptions have not as yet been determined.

About three feet northeast of Atomizer crater is a cone of similar size and configuration. Its orifice has apparently been nearly choked off by internal deposition of sinter. The only response this cone shows to minor eruptions of Atomizer is seepage at the base of the cone during overflow periods and minor eruptions of Atomizer. At the time of steam-phase eruptions the northeast cone discharges steam under some pressure. At no time have I seen any water ejected.

Atomizer and the nearby cone are certainly connected underground. No other connections are known to exist. During 1970 I tried to determine if any sympathy existed between Atomizer and Artemisia. I observed eruptions of Atomizer when the crater of Artemisia was full and overflowing, also when the crater was nearly empty following an eruption. However, I have not observed simultaneous eruptions. At present there seems to be no evidence of subsurface connections.

Calthos Spring

D6-865E, 610S ✓

CASCADE GROUP OF UPPER BASIN

The very large mound of Calthos, which rises steeply from the west, is indicative this spring has seen much better days when the thermal activity far exceeded any that has occurred during the historic period. It is believed that the decline in thermal energy was due to the evolution of Gem Pool, which apparently is a much younger spring.

It seems likely that during some earlier period Calthos might have displayed occasional, if not frequent geyser activity. During the night of the earthquake it erupted muddy water which was indicated by succeeding eruptions which occurred during the first few weeks of the post-earthquake period. The eruptions were of short duration, lasting from one to two minutes. The height was about 15 feet. During this period of eruptive activity, the first known since the park's discovery, the water was down several inches in Gem Pool.

By 1960 both Calthos and Gem appeared very enervated. The water was below overflow in both craters. This condition persisted during the succeeding three years. During this period to the west, and across the Firehole, at least eleven springs which prior to the earthquake were inactive, were displaying periodic eruptive activity. In elevation these springs are much below the levels of Calthos and Gem. It was surmised that the new geyser activity might possibly account for the great loss of energy in Calthos and Gem.

Whatever the cause of loss of thermal energy in Calthos and Gem, by 1964 it seemed to be restored. During all of the observed period for this year first Calthos would overflow then Gem. The shifting back and forth of the thermal energy occurred about every 24 to 72 hours. In no other springs connected subterraneously have I observed such rapid shift of energy, or alternation of flow. Since 1964 I have observed no further overflow of Calthos Spring.

Gem Pool

U7-45E, 610S

CASCADE GROUP OF UPPER BASIN

Gem Pool has been a steadily overflowing spring during most of the years I have observed it. In October 1951 I tried an experiment of checking its overflow to determine if by chance it might have underground connections with Calthos Spring, which bore evidence of having had better days. For some time I had thought connections possible. The dam had to be constructed nearly a foot high to check the rising water in Gem. After about a 6 inch rise the level seemed to become somewhat stabilized. At about this time it was evident that water was rising in Calthos. It continued to rise until overflow ensued. With the rise Gem began to ebb. It ebbed about 4 to 6 inches below the water level when the experiment was begun. Sometime during the night Gem's check was washed out and both springs were in the same state as prior to the damming. To my satisfaction I had proven that the two springs had sub-surface connections.

Gem continued steady overflow until the time of the 1959 earthquake, at which time I had another indication of sub-surface connections with Calthos. The morning following the earthquake the water in Gem had ebbed about 6 inches below overflow. The water was murky. Muddy water was erupting from Calthos. For the remainder of 1959 the water stayed below overflow in Gem. It remained in this state during all of 1960. Only two times during 1961 was it observed to overflow and then for short periods. No further overflow was observed until the 1964 season.

During 1964 an unusual sympathetic response existed between Gem and Calthos. An exchange of function, or shift of the thermal energy, between these springs took place with remarkable frequency. It occurred about every 24 to 72 hours. First one spring would overflow then the other. During the non-flow periods the water would drop about 6 to 8 inches in the respective craters. This condition lasted during all of 1964. Since that year the overflow has been steady from Gem.

Apart from Calthos, Gem is not known to be connected underground with any other spring.

"Hillside Geyser

D6-420E, 325S

CASCADE GROUP OF UPPER BASIN

Hillside Geyser is located about 150 feet northwest of Seismic Geyser on the edge of a steep sinter embankment of Firehole River, hence the name. The embankment rises about 30 feet above the river. The geyser consists of two small craters, which are between 4 and 5 feet in diameter. The craters are separated by a narrow constriction of sinter. Only the northernmost vent displays geyser activity.

I was not aware of a geyser being situated at the site of Hillside until the 1948 season. Previously I had visited this spring many times. On at least 3 occasions when temperatures were taken they were 202°F. The 1943 eruptions resulted in close observations. The eruptions occurred about every 2 hours; lasting about 4 minutes; the estimated height 25 feet.

In seasons following 1948 I did not observe any eruptions of the character of the above described ones until after the 1959 earthquake. However, during the intervening period I noted that Hillside had frequent minor eruptions when the water surged up about 3 feet.

The earthquake greatly altered the nature of the eruptive activity of Hillside. It shifted from minor to major eruptions, with a marked increase in discharge. The eruptions were of much greater frequency than in 1948, occurring about every 15 to 20 minutes; lasting for about 4 minutes. Some of the eruptions were not less than 30 feet in height. When viewed from the west side of the river the eruptions were impressive. Hillside has created a beautiful embankment of algal-colored sinter. The erupting water cascading down the embankment afforded a lovely and unique spectacle.

During all of 1960 major eruptions persisted, but with diminishing frequency. Early in 1961 some major activity was noted but by mid-season all eruptions were minor in character. Minor activity persisted during 1962 and until early 1964, but before the latter part of that season only boiling was observed, which decreased in vigor. There was also some ebbing. Since 1964 there has been a steady cooling off and ebbing. At the end of the 1970 season the water was down about 4 feet; the temperature was 188°F.

The evolution of Seismic Geyser without doubt is responsible for Hillside's dormancy and low water level. Being connected sub-surface with Seismic affords little doubt but that it also is connected with Pulcher.

"Pulcher Spring"

D6-720E, 275S

CASCADE GROUP OF UPPER BASIN

This spring was given the name Pulcher, the Latin for beautiful, due to the striking beauty it possessed previous to the 1959 earthquake. It is located at the northwestern base of the large mound of Calthos. Pulcher is oblong in shape, being about 10 by 20 feet. At the upper edge of the spring, where the water must have stood for many score years, a scalloped, almost tooth-like projection of sinter, has been built about the rim of the crater. Previous to the earthquake the water was of a deep indigo-blue color. The small, condensing steam bubbles at the surface indicated superheat. The temperature range I obtained as the result of numerous readings was between 201° and 204°F.

(North Pulcher)

On the north edge of Pulcher another large spring is situated. It is about 20 feet in diameter. It is separated from Pulcher by a wall of sinter from 3 to 4 feet in width. Despite the closeness of these springs there were marked differences in their temperatures. The temperature of the north spring prior to the earthquake was in the 150 degree range, resulting in its crater being lined with algae. Its water level stood from 4 to 5 feet lower than that of Pulcher.

The craters of both Pulcher and the north spring represent craters within a crater. These springs are surrounded by a large wall of sinter which rises about 3 feet above the level of present craters. The sinter wall is covered with Lodge Pole Pines. That this higher embankment, for a very long period, was the upper level of present springs, then being one, was indicated by the 1959 earthquake.

The earthquake affected Pulcher and the north spring in a surprising and very marked way. Water rose almost to the top of the old crater wall. It would perhaps have risen higher were it not for a heavy discharge over the embankment to the north. Both springs had become one with two vents. I had the opportunity, briefly, of seeing these springs restored to a state which must have characterized them for many hundreds of years.

The high water level and overflow were maintained until about October 1, 1959, when ebbing began. The ebbing was slow. At

the end of 1960 the water was still 5 or 6 inches above the pre-earthquake level. By 1962 Pulcher appeared restored to its pre-earthquake condition. This state proved to be short lived. When the new fumarole below Pulcher suddenly gave rise to a new geyser, Seismic, in 1963, the water began to ebb in the upper-level springs. By the end of 1963 the water had ebbed nearly 20 inches in Pulcher. Since this ebbing began it has been slow but continuous. At the end of 1970 the water was about 10 feet below the rims of Pulcher and the north spring. It would seem that a near coup de grace to these springs might have been brought about by the newly evolved Seismic.

Sunglass

. Seismic Geyser

D6-500E, 420S

CASCADE GROUP OF UPPER BASIN

Among the thousands of thermal springs in Yellowstone Park Seismic is one of the most recent in origin. It is not a quiescent or dormant spring rejuvenated. It is one that had its genesis as a result of the earthquake on August 17, 1959.

In the period immediately following the earthquake I observed that two long rifts had formed in an embankment of old sinter which borders on the Firehole River. The rifts were parallel to the river. They were about 200 feet west of the big mound of Calthos Spring, or 150 feet southeast of Hillside Geyser. The break nearest the river, half way up the steep embankment, was the most extensive, being about 60 feet long. The upper one, which was on the shoulder of the embankment and about 30 feet from the edge of the steep declivity to the river, was about 30 feet in length. Steam was issuing from near the central portion of both breaks. The width of the upper break where steam was evolving was about $\frac{3}{8}$ of an inch. The temperature of both the upper and lower fumaroles was 202°F. The upper break traversed an area of densely growing Lodge Pole Pines, which were about 50 years in age. One of the first, if not the first wagon road into the Upper Basin crossed directly over the site of the upper break.

During the remainder of 1959 both fumaroles continued unabated in the discharge of steam. When I first visited this site in early 1960, not only was a heavy discharge of steam still in evidence, the pines over an area of not less than 1500 square feet were dead. The needles had turned brown. It was apparent that in addition to the heat which was evolving from the fumaroles, new hot ground had developed; ground too hot to be tolerated by a vegetative cover. During the 1960 season I observed 26 additional sites in the Firehole Geyser Basins where trees had been killed by the sudden development of hot ground. Some of these dead tree patches were much more extensive than the one between Calthos and Hillside.

During all of 1960 steam evolution from both fumaroles seemed to increase in intensity. The break farthest from the river showed the most pronounced development. At the point of steam egress the break was now about an inch wide. By October it had a temperature of 204°F. Depressed ground about this fumarole was suggestive of alterations in underground structure due to

possible leaching. There seemed to be an excellent chance that a new spring would develop, possibly a geyser. .

During all of 1961 and 1962 both fumaroles persisted in vigor of steam discharge. It was comparable to that which they had shown during 1960. During 1961 and 1962 I made frequent inspections of these steam vents. During both years I was expecting that at any moment water would start discharging from the upper fumarole.

When I first visited the site of the fumaroles in the early spring of 1963 a surprising and remarkable change had taken place. Sometime during the previous winter an explosion had occurred at the site of the upper fumarole. Where steam previously had been hissing through a rift there now was a large crater. Numerous large blocks of sinter were strewn about in heterogeneous array bearing evidence that the crater had formed explosively. The trees which had formerly been over the site of the crater were now scattered and prostrate. Most of the disrupted trees were on the south and west sides. The crater varied in depth from about 5 to 7 feet. It was elongated, being about 9 x 16 feet. Surprisingly, the long axis was at a right angle to the original break as well as to the river.

During all of 1963 water jets about 3 feet in height played into the crater every few seconds. The jets shot in at an angle of about 45° from the end of the crater nearest to the river. The water drained away immediately following the jetting. No water stood in the crater.

Further change in the apparent evolution of a new geyser was noted during 1964. The action became more forceful than in 1963, but less frequent. Some of the jets angled out to almost the length of the crater, the distance being not less than 12 feet. Also, water began to stand in the bottom of the crater. By the end of the season the water stood between 3 and 4 feet below the rim. The fumarole on the steep embankment below the new geyser waned in forcefulness as increased energy was manifest in the new geyser. Presently steam evolution has practically ceased from the lower rift.

The winter of 1964-65 brought about marked changes in the new geyser. Sometime prior to April 1965 a new explosion had occurred near the river end of the crater. An apparent sudden release of pent up energy had not only greatly enlarged the earlier orifice, it had torn out obstructions so that the water now, in much greater volume, erupted vertically instead of at an angle.

Before the 1965 season had advanced very far it was evident that Yellowstone had a new geyser of no mean proportions. Due to the nature of its origin I named it Seismic. During the 1965 and 1966 seasons there was little change in the nature of its activity. Massive bursts of water rocketed from the crater about every one to three minutes. Most of the bursts were from about 6 to 20 feet in height. However, occasionally the water would shoot up to a height of near 50 feet. Some judged it to be higher.

During the 1967-69 period the pattern of Seismic's eruptive activity underwent progressive changes. The length of the quiet phase slowly increased to about 40 to 50 minutes. The active phase would last between about 15 and 20 minutes, during which 30 or more separate bursts would occur. The crater was still slowly being enlarged on its margins.

On several occasions during 1970 two and more hours at a time were spent at Seismic with a view of determining the nature of its eruptive pattern which seemed to have altered somewhat from the pattern of the three previous seasons. At first I found it a bit difficult to distinguish between the active and quiet phases. This in large measure was due to the fact that during an active phase there would be not less than three separate periods of activity. The second period of activity was always the longest, on one occasion lasting for 19 minutes. The duration of an eruption was variable; the extremes being 19 and 31 minutes. An unfailing sign of the termination of an eruption was a drop in water level in the crater. During the quiet periods of an active phase the water in the crater would stand about 4 inches below the rim. With the termination of an eruption the water would drop about 14 inches. The quiet and active phases were about equal in duration, each varying from about 20 to 30 minutes. The heights of the 1970 eruptions were very much the same as those observed during the 1967-69 period. I estimated maximum height to be about 40 feet, which was less than the estimated 50 foot bursts during the 1965-66 period. Like Morning Geyser, many of the highest bursts came near the termination of an eruption.

Underground Connections

Seismic is apparently connected subterraneously with at least four other springs, also the nearby fumarole on the river embankment. The greatly increased discharge of Seismic which began sometime during the 1964-65 winter had what must have been an almost immediate effect upon the water levels of

Hillside Geyser and two large springs on a high sinter bench or embankment about 250 feet to the northeast of Seismic. As the 1965 season progressed the water level in the above springs continued to ebb. By 1970 Hillside's level was down about 4 feet and its temperature had lowered from 202°F in 1963 to 187°F. During this period the water level in the big bench springs had dropped between 10 and 11 feet. Seismic's underground connection with Hillside is not at all surprising. The break in the sinter which was Seismic's precursor extended in the direction of Hillside.

The fact that Seismic seems to have quite certain underground connections with other springs, and one of them a geyser, does not augur well for future, unbroken performances. If the same situation obtains with Seismic and related springs as does in other groups connected subterraneously, the chances are more than even that at some future date Seismic will become dormant due to the focus of thermal energy having shifted to one or more of the springs with which its roots seem to entwine. Its perch on the high sinter embankment might be an adverse factor. However, Hillside Geyser is situated even nearer the edge of the embankment.

Seismic, An Example of Geyser Development

Many theories have been advanced to explain the origin of hot springs. When I first began a tour of duty in the Upper Geyser Basin of Yellowstone Park in 1931 the generally accepted explanation of hot-spring origin was that all springs had their genesis as a fumarole, which later developed into a mud pot. With further disintegration of rock cover there would eventually be an extrusion of ground water. Whether the newly developed spring would possess geyser potential was dependent upon the nature of the plumbing.

The above view was not of local origin.

"It was Bunson's view, as well as Hague's, that larger and deeper springs must eventually develop from smaller ones under the disintegrating influences of steam and hot water that penetrate and widen original seams in the rock" (Allen and Day, 1935, p. 169).

Walter H. Weed, geologist for the Hague investigations in Yellowstone Park, saw in mud springs the precursors of geysers (1889-1890, p. 302).

Allen and Day as a result of their investigations of a number of important thermal areas state:

"From a study of the Katmai fumaroles and from the general association of fumaroles with hot springs of the most active type, the idea suggested itself to one of the writers that the crucial condition for the genesis of each spring or steam vent might be merely the amount of ground water available in any given spot. When it was discovered that the temperature of natural steam vents in hot-spring areas was in places much above the boiling point of water, the conviction was reached that hot springs were circulating ground water of surface origin heated and augmented by steam originally in a superheated state, rising from an underlying magma through deep cracks in the earth's crust" (1935, p. 32).

Earthquakes and Hot Springs

Very few investigators who have advanced theories as to the nature of hot-spring development make any allusions to earthquakes as being agents or causes. It has long been recognized that fumaroles and hot springs develop on the flanks of active volcanoes, and often in the surrounding area, but that they might in some cases owe their genesis to tectonic earthquakes is not of frequent discussion. At least one exception to the above was A. C. Peale, mineralogist of the Hayden expedition.

"The effect of earthquakes upon thermal springs is a proof of their intimate connection with volcanic action. In the first place, as we have already intimated, the existence of fissures and cracks in the earth's surface, by whatever means they have been formed, are efficient agents in causing hot springs by allowing meteoric waters to penetrate to great depths, and affording them afterwards free access to the surface. Earthquakes, as all know, occupy the very first place in the production of fractures of far-reaching extent" (1883, p. 363).

There is little question but that fracturing of the rhyolite cover in sections of Yellowstone Park resulted in the initial development of hot springs. That the fractures were earthquake caused is made highly probable by the park's known seismic history. That a long fracture traverses the Upper Geyser Basin is made evident by the general rectilinear arrangement of the hot springs. When viewing the basin from the Madison Plateau

when the atmosphere is cool or humid, the general alignment, from southeast to northwest, stretching from Lone Star geyser to Biscuit Basin, is one of the most striking characteristics.

The big ice incursion of the Pleistocene completely destroyed all earlier hydrothermal manifestations. Early post-glacial hot-spring development apparently resulted from the hot effluents of smothered and buried hot springs again finding their way through glacial deposits to the surface. In general the new development took place in proximity to what must have been the original fissure alignment.

The evidence seems quite compelling that early post-glacial springs were of lower temperature than that which has characterized present springs during the past several hundred years. This inference is made from the nature of the early accumulations of siliceous sinter. During this period there were few if any boiling springs. None of the sinter of the early period is characterized by cones or mounds - products of boiling water. The deposits, which are extensive and which consist of most of the sinter in the Upper, Midway and Lower Basins today, are in thick sheets, horizontally placed. None of the early springs is known to exist at present. At or near what were their original positions in the Firehole Geyser Basins are no doubt now the sites of most of the boiling springs and geysers which in many instances have made deep incisions into the old sinter shield. During the period of horizontal deposition, which must have been long, as judged by the thickness of the deposits, there apparently were few, if any, major seismic disturbances. Otherwise it is doubtful if the accumulation of horizontal deposits in their present thickness could have occurred.

Park's Earthquake History

Since the discovery of Yellowstone Park earthquakes of sufficient intensity to be recognized have occurred one or more times yearly. There are frequent reports of rattling dishes, swinging lamps and creaking buildings. The earliest report of an earthquake in the Yellowstone Country was by the first scientific expedition to the area.

"While we were encamped on the northeast side of the lake, near Steamboat Point, on the night of the 20th of July (1871), we experienced several severe shocks of an earthquake, and these were felt by two other parties, fifteen or twenty-five miles distant, on different sides of the lake. We were informed by mountain men that these earthquake

shocks are not uncommon, and at some seasons of the year very severe, and this fact is given by the Indians as the reason why they seldom or never visit that portion of the country. I have no doubt that if this part of the country should ever be settled and careful observations made, it will be found that earthquake shocks are of very common occurrence" (Hayden, 1872, p. 82).

The above tremors were also referred to by a second scientific expedition which was encamped on the southeast arm of Yellowstone Lake.

"We experienced last night the singular sensation of an earthquake. There were two shocks, the first one being quite severe accompanied by a rumbling and rushing sound" (Barlow, 1872, pp. 38-39).

On the following day additional shocks were felt.

Recent seismic records indicate that over the park minor tremors are of almost daily occurrence. The park is apparently situated in a zone of crustal weakness.

"Of particular interest is the belt of earthquakes that follows the Rocky Mountain zone of overthrust faults in Montana and then shifts westward to Utah to follow the Wasatch Mountain front southward into Arizona" (Fischer, 1960, p. 25).

Seismic records indicate that on an average of about once in 10 years a strong earthquake is registered in the states adjoining Yellowstone, particularly Montana. The last strong earthquake along the Hebgen Lake fault system, previous to August 17, 1959, was November 23, 1947. Neither the 1947 earthquake, nor any previous historical one was of sufficient intensity to produce attributable hydrothermal changes. The effects of the 1959 earthquake, which was of an intensity of 7.1 in the Richter scale, made it abundantly clear that earlier earthquakes of equal and perhaps greater magnitude had brought about changes in the Firehole Geyser Basins (Marler, 1960, pp. 61-66).

Prior to the 1959 earthquake it had been observed that many breaks or rifts were in evidence in the old sinter shield. Several groups of springs had their alignment on what looked like old breaks. However, it was not until after the events of August 17, 1959 that the causes of these old rifts were

susceptible to valid interpretation. The 1959 earthquake not only greatly altered the functional behavior of numerous hot springs, but it resulted in many rifts forming in the old sinter. This was especially true in the Lower Basin. Criss-crossing cracks and breaks traversed the whole area around Firehole and Black Warrior Lakes. Measurements indicated that were these breaks in a straight line, it would measure 9,072 feet in length. Along new rifts in the sinter in both the Upper and Lower Basins new fumaroles were generated. This was particularly true in the Sapphire, Fountain, Pithole, Kaleidoscope and Sprinkler Groups. Some of these fumaroles have evolved into new springs and geysers. Of these, Seismic, whose development has already been treated, is the most outstanding example.

Resting on the old sinter sheet in the Upper Basin are the cones and mounds of many present-day geysers. Their character and rate of growth seem indicative that most, if not all, had their origins during a relatively short period. They are suggestive that water effluents suddenly became much hotter. That this new surge in thermal energy came about as a result of a major earthquake seems highly probable, especially in view of the fact that numerous grouped springs are not only in alignment, but they are connected subterraneously. This indicates they had their genesis along a common rift.

A list of some present day boiling springs and geysers possessing mounds or cones and whose vents puncture the old sinter shield are as follows: Pink Cone, White Dome, Great Fountain, Jewel, Mortar, Riverside, Rocket, Grotto, Bijou, Catfish, Giant, Comet, Punch Bowl, Castle, Tortoise Shell, Bulger, Old Faithful, Beehive, Lion, Little Cub, Lioness, Big Cub, Teakettle, Sponge and Lone Star. In addition to the above there are numerous geysers without mounds whose eruptive activity is incising into the old sinter as is the case with many of those listed above. Among these might be mentioned Giantess, Fan, Artemisia, Excelsior and Morning. Groups of springs that are in alignment and apparently issuing from an earthquake rift, include the Daisy Group; the following springs being involved: Splendid, Brilliant, Comet, Daisy and Bonita. Beyond Bonita there are three unnamed vents: Grotto and Giant Groups. Both these groups are connected subterraneously. Named springs in these groups that apparently were formed along a common break include Spa, Rocket, Grotto, Grotto Fountain, South Grotto Fountain, Catfish Bijou, Mastiff, Giant, Turtle and Purple Pools. There are additional unnamed springs along this break. It is quite apparent that six springs in the Chain Lake Group have evolved along a common break in an older sinter. The same is true of several springs in the Three Sisters Group. Many

additional groups could be cited. The majority of the major springs in both the upper and Lower Basins are known to have underground connections with other springs, suggesting fissure connections (Karler, 1951, pp 329-342).

One of the most interesting examples of a geyser evolving from an earthquake rift is Old Faithful. Extending across Old Faithful's mound from east to west is a pronounced break in the sinter. The part of the fissure through which Old Faithful issues is but 4 inches in width. Radio-carbon dating of tree sections entombed in the mound indicates that the earthquake which split it open, permitting the birth of Old Faithful, occurred from 500 to 700 years ago.

Craters Formed by Steam Explosions

There is objective evidence that many present-day geysers evolved along earthquake-caused fissures which permitted the ascension of hydrothermal effluents. The craters of these geysers in the early stages of development were no doubt enlarged due to disintegration resulting from ascending hot water and steam. Evidence is equally compelling that the craters of many geysers and hot springs resulted from steam explosions, of which Seismic Geyser is a classic example.

Seismic Geyser is not the only site where a steam explosion occurred as a result of the 1959 earthquake. In 1963, about 100 feet west of Kaleidoscope Geyser a steam explosion scattered scores of sinter blocks about a newly created crater. It is about 10 feet in diameter and from 4 to 5 feet in depth. Water nearly fills the new crater, but to date there has been no discharge. On the south side of White Creek, directly south of Great Fountain Geyser, steam explosions scattered great quantities of sinter about two existing dry craters. The one crater was noticeably enlarged. It is believed these explosions occurred at the time of the earthquake or very soon thereafter.

During the 1963 season a steam explosion opened up a small crater at the southern base of the sinter mound on which the cone of Sponge Geyser is located. Since the initial explosion there has been occasional activity in the new vent. The eruptions are from 10 to 15 feet in height.

A steam explosion in historic times is responsible for the large crater of Black Opal Spring in Biscuit Basin. In 1931, the year I began working for the Park Service, I observed that large blocks of sinter-cemented sandstone were strewn about Black Opal's

crater. The sandstone consisted of small rhyolite pebbles and obsidian sand. It appeared to be glacial outwash which might have smothered some earlier spring.

That the explosion which created Black Opal's crater was of considerable magnitude was made evident by the fact that chunks of sandstone were found not less than a thousand feet north of the crater. Much the greater part of the sandstone was strewn in a northerly direction. During the winter of 1932-33 Frank Childs, a Park Ranger, reported an explosion of Black Opal which tore out new sandstone blocks. This explosion was of much less magnitude than the earlier one.

Since my first observations in 1931 of the great array of sandstone blocks lying to the north of Black Opal, weathering has brought about the disintegration of all of the smaller ones. This has suggested to me that even the early explosion might have occurred since the creation of Yellowstone as a national park.

The known craters which have been formed by steam explosions furnish a most credible explanation as to how the craters of many of Yellowstone's large, deep springs had their genesis. All of the springs listed have deep craters and in many cases sheer walls. Included are Giantess Geyser, Vault Geyser, Crested Pool, Sunset Lake, Emerald Pool, Green Spring, Oblong Geyser, South Purple Pool, Bottomless Pit, including the rest of the Chain Lake Springs, Link Geyser, Morning Glory Pool, Mirror Pool, Cauliflower Geyser, Artemisia Geyser, Sapphire Pool, Great Fountain Geyser, Firehole Pool, Surprise Pool, Fountain Geyser, Gentian Pool, East and West Flood Geysers, Indigo Spring, Grand Prismatic Spring, Turquoise Pool and Excelsior Geyser. Many large unnamed craters as well as a number of smaller springs might well be added to the list.

The absence of rock fragments about these craters is easily explained. The disrupted rock, with few or no exceptions, was derived from the overlying beds of silicious sinter. This rock is a hydrous silicate and disintegrates very rapidly when exposed to weathering. During the 1957 and 1958 seasons unusually powerful eruptions of Link Geyser tore out a score or more of large blocks of silicious sinter from its crater. Due to rapid weathering these blocks had practically disappeared 10 years later.

That the crater of Excelsior, the most powerful geyser and copiously flowing spring in Yellowstone Park, was due to a steam explosion there would seem to be little question. The crater walls on three sides away from the river rise almost

vertically about 12 feet above the water level of the spring. These walls, which partially encircle Excelsior, consist of laminated sinter which apparently was deposited by Grand Prismatic over a period of many centuries. That the sinter deposits of Prismatic rise unchanged in character to near the top of Excelsior's crater is revealing that Excelsior is of comparatively recent origin.

Not only is the physical evidence highly suggestive that a powerful steam explosion was responsible for the creation of Excelsior's crater, but its eruptive activity in the 1880s is known to have further enlarged it. Colonel Philetus W. Norris, then Superintendent of Yellowstone Park, made the following comments on the effects of an eruption of Excelsior which occurred in 1878:

"Crossing the river above the geyser and hitching my horse, with bewildering astonishment I beheld the outlet at least tripled in size, and a furious torrent of hot water escaping from the pool, which was shrouded in steam, greatly hiding its spasmodic foamings. The pool was considerably enlarged, its immediate borders swept entirely clear of all movable rock, enough of which had been hurled or forced back to form a ridge from knee to breast high at a distance of from 20 to 50 feet from the ragged edge of the yawning chasm" (1881 Annual Report, p. 60).

Excelsior was not known to erupt again until 1881. Much eruptive activity was observed during this season. In reference to the power of the eruptions and the discharge of rocks Norris states:

"During much of the summer the eruptions were simply incredible, elevating to heights of 100 to 300 feet sufficient water to render the rapid Firehole River nearly 100 yards wide, a foaming torrent of steaming hot water, and hurling rocks from 1 to 100 pounds weight, like those of an exploded mine, over surrounding acres" (1881 Annual Report, p. 61).

Concerning the creation or enlargement of hot spring craters by steam explosions Dr. Peale commented:

"In some cases the hot springs may become clogged or stopped up, and when the pent up steam bursts out earthquake shocks may be caused. The shocks we experienced at Steamboat Point, on Yellowstone Lake, in 1871 were probably due to inadequacy of the steam vents" (12th Annual Report, 1873, p. 364).

Sprite Spring

D7-30E 620S

check location

CASCADE GROUP OF UPPER BASIN

Sprite has been characterized by periodic overflow. The periods between overflow and ebb apparently are long and have never been determined. One of the most interesting observations I have made relative to this spring was the careening of a small sedan and its landing upside down in the middle of the spring. The top was immersed in about one foot of water. Four boys emerged from the sedan apparently none the worse for the experience. This occurred in 1949.

Prior to the 1959 earthquake there was no overflow from Sprite. Its temperature was 163°F. The day following the earthquake found its previously clear water very muddy and overflowing. Its temperature had risen to 181°F. The water stayed murky for the rest of the year.

From early 1960 until 1963 the water in Sprite was below the overflow level. During most of the succeeding years the periods of overflow have exceeded the periods of ebb in length. I have observed no evidence of underground connections between sprite and nearby Gem and Calthos.

East Sentinel Geyser

F8-245E, 60S ✓

MORNING GLORY GROUP OF UPPER BASIN

The two Sentinel Geysers were named at an early date by Colonel Barlow:

"Here on either side of the river are two lively geysers, called the Sentinels. The one on the left (east) is in constant agitation, its waters revolving horizontally with great violence, and occasionally spouting upward to a height of 20 feet. Enormous masses of steam are ejected. The crater in this geyser is 3 feet by 10. The opposite Sentinel is not so constantly active and is smaller" (Barlow, 1871, p. 25).

It early was considered that the two Sentinels, on opposite sides of the river, stood as guards to entry into the Upper Basin.

I did not observe an eruption of East Sentinel until January 1952. Previously, naturalists who were stationed at Morning Glory infrequently reported eruptions. Following the January eruption I am aware of no further major activity until the time of the 1959 earthquake. The only additional major eruption known was on October 9, 1967.

Sentinel's crater is on the river edge. An old sinter embankment at the eastern edge of Sentinel's deposits has been deeply incised by erupting waters from Sentinel. The major part of this erosion would antedate the historic period. It is indicative that during an earlier period Sentinel was much more active than in recent decades. One possible reason for this lessened activity suggested itself to me during the 1952 January observations. The Firehole River at that time was the lowest I had ever observed it. Water which previously had been pouring into a vent on the east side of the crater had stopped. It is believed that the absence of the continuous intake of cold water resulted in major eruptive activity which more than once was known to have occurred in January of the above year. The cold water came from a small and apparently recently formed channel on the east side of the river.

Except during high water when the crater is flooded by water from the Firehole River, East Sentinel is continuously boiling and splashing, and with greater vigor than its companion across the river.

At the time of the January eruption I observed in 1952 I did not see it in the beginning stages. After I arrived on the scene it continued to erupt from one to two minutes. The height impressed me as being between 20 and 30 feet. It has no known underground connections with any other spring.

Samples

Fan Geyser ✓
F8-635E, 525S

Mortar Geyser ✓
F8-670E, 570S

MORNING GLORY GROUP OF UPPER BASIN

Fan and Mortar are being treated as a single unit in view of the pronounced sympathy existing between them. All major eruptions, of either geyser, that I have observed have been in concert.

Craters of Fan and Mortar

Like so many of the geysers, the craters of Fan and Mortar rest in much older deposits, into which both the river and eruptive activity of these geysers have produced a heavy erosion. The deep fluting in the old, opalized sinter deposits, particularly in the vicinity of Fan, is indicative of a history of marked eruptive activity. Not all of the old sinter can be observed due to an asphalt road having been built over the north section of it.

While the walls of both geysers definitely entwine at depth, resulting in their pronounced sympathetic action, their surface structures are very different in character. Mortar has built a large cone, the southern edge of which rises from the river. From the river side the cone is 8 to 9 feet high. At the apex of the cone is a vent about 18 inches in diameter, while at the northern base is the mortar proper. It is a large mortar-shaped bowl from 4 to 5 feet in diameter. Its vent is about the same size as the upper one. Hayden, thinking he was describing Fan, inadvertently described Mortar.

"There are two craters, the streams from which cross each other. These two craters have orifices of about 2 feet in diameter each. ... The crater of the geyser is composed of pink geyserite, which rises from the river in a series of rounded masses which are beaded with silica" (1873, p. 193).

His illustration on page 192 (1873) also reveals the error.

Fan is from 40 to 50 feet north northwest of Mortar. Its crater is of the nature of a large fissure or break which ruptures a thick deposit of old, opalized sinter. The break extends in a south southwest direction. From Spiteful Geyser

to the river the break is about 90 feet in length. The part of the break from which Fan erupts is about 35 feet long.

It is believed that the nature and extent of the fissure from which Fan erupts could have occurred by no other agency short of some prehistoric earthquake, high on the Richter scale. On the whole the break is of rather straight alignment. Surprisingly little sinter deposition has resulted from Fan's activity. It is only near the river where much new sinter is in evidence. However, internal deposition might have sealed some of the original break. Part of the break is in sharp relief. It appears that the violent activity of Fan has resulted in erosion that has been in excess of deposition. The main vent from which the major part of the water is discharged during an eruption is completely free of any recent deposit. As a matter of fact the vent is slowly being enlarged by spalls torn away from the older sinter.

Vandalism

Both Fan and Mortar have been the victims of much vandalism. The beaded sinter Hayden referred to on the side of Mortar's cone has completely disappeared. The sound of the pick and the maul during the early period reverberated throughout the basin. There are records of wagon loads of sinter being hacked from the formations. On several occasions I have removed large slabs of sinter from Mortar's lower crater, which had been tossed in by some thoughtless individual. They are not retrievable in the upper. The crater of lower Mortar at one time must have had a pronounced symmetry. The side toward the hillside has been completely broken away.

"Upon our arrival in the basin we found several persons already encamped... The visitors prowled around with shovel and ax, chopping and hacking and prying up great pieces of the most ornamental work they could find; women and men alike joining in the barbarous pastime" (Ludlow, 1875, p. 26).

The vents in Fan are not of a character to permit the easy introduction of rubble. However, great quantities of rocks, including a large hub cap, were disgorged from the upper crater at the time of an eruption I observed. The hub cap came down in the middle of the road, over a hundred feet distant from the vent. In 1933 while examining the fissure I noted that some party or parties many years previously had attempted to block the egress of water. On the river side, and extending for several feet, the break had been

covered with sinter blocks. I had to acquire tools to remove them as they had become cemented. Some fragments still remain, but not over the fissure. It is possible that over the years vandals have made a marked contribution toward the destruction of these geysers.

Early References

Fan Geyser was observed and named in 1870 by the Washburn Party. At the time of this observation Mortar was evidently considered a part of Fan.

"The Fan has an orifice which discharges two radiating jets of water to a height of 60 feet, the falling drops and spray resembling a feather fan. It is very beautiful. Its eruptions are very frequent, lasting usually from 10 to 30 minutes. A vent [Mortar] connected with it, about 40 feet distant, expels dense masses of vapor 50 or 60 feet high, accompanied by loud sharp reports during the time the geyser is in action" (Langford, 1871, p. 123).

Lieutenant Doane also left a description of the 1870 eruption, which in all essential respects, pertains to Mortar rather than to Fan. The duration of the eruption was very different from that given by Langford.

"First the steam would rush from the upper crater, roaring violently, then this would suddenly cease, to be followed by a fan-shaped jet of water rising from the lower crater to a height of over 40 feet, often playing for perhaps two minutes, then this would suddenly stop flowing, and the steam would rush forth again for a time. Occasionally the small crater threw a transverse stream, sometimes alternating with either of the others; and thus they played on for hours, after which they would subside to a gentle bubbling" (1870, p. 31).

In 1872 it was observed by members of an engineering party making a reconnaissance of the Yellowstone River.

"When in full action the display from them is very fine. The waters spread out in the shape of a fan, in consequence of which they have been named the 'Fan Geyser'" (Barlow and Heap, 1872, p. 26).

During the first decade of the park's history considerable confusion existed, not only as to which was Fan and nearby, then unnamed, Mortar, but as to which was Fan and which

Riverside. T. B. Comstock of the Jones expedition greatly added to the confusion of identity and performance then existing. He describes, perhaps part of an eruption he witnessed of Fan, as follows:

"While watching the pulsations of the Grotto, a column of vapor was evolved from a geyser upon the right bank of the Fire Hole River, a few rods below Riverside. This began at 2:43 p.m., almost precisely at the moment when the eruption began in Riverside. Gradually increasing in intensity, it was throwing a large column of water at 2:49 p.m., which continued, but gradually diminishing, until 2:54 p.m., at which time it almost ceased, sputtering occasionally, however, until 2:56 p.m. This record shows the remarkable similarity or sympathy between Fan and Riverside" (1873, p. 252).

That the geyser he mistook for Riverside was Mortar is evident from a later description of what he believed to be Riverside.

"A little below Grotto, across the river, a geyser which is situated near the edge of the stream began to spout at 2:43 p.m. This is known as the Riverside Geyser. A jet of fine spray was suddenly thrown more than thirty feet into the air, which continued quite steadily until 2:47.5 p.m., when it ceased acting for half a minute. At 2:54 p.m. it roared loudly and then became quiet at 2:56 p.m., after which no action occurred. The Riverside has a low irregular mound, with a small chimney scarcely rising near its centre" (1873, p. 252).

Further evidence that Comstock saw an eruption of the then unnamed Mortar and not Riverside is found in the fact that Fan was erupting in concert; also that the descriptions of Fan, then later of Riverside are taken from a single observed eruption.

As late as 1892 it was believed that sympathy existed between Fan and Riverside. "Erupts every 8 hours generally followed by Riverside, its ejected water spreading out in fan shaped jets" (1892, Guptil, p. 59).

There are no data which are suggestive of a sympathetic relationship between Fan and Riverside. However, observation has conclusively shown that a pronounced sympathy exists between Fan and Mortar. I have never observed an eruption of Fan except

there was simultaneous action of Mortar. The absence of signs identifying the hot springs during the first decade or two of the park's history was one of the major causes of confusion relative to identification.

Early Popularity

During the early period of park visitation Fan and Mortar were high on the agenda of geysers to be witnessed. Their spectacular performance quite overshadowed nearby Riverside.

"This [Fan] is one of the prettiest spouters in the region. It has five distinct orifices, and sends up as many jets of water and steam, sometimes reaching an altitude of a hundred feet, the jets ascending and descending in such a manner as to resemble the outlines of a feather fan. It spreads itself three or four times a day, and is greatly admired by all who witness it, some of the spectators growing wild at the gorgeous display" (Stanley, 1877, p. 112).

The Norton party of 1873 was singularly impressed at seeing an eruption. The enthusiasm of some seems unbounded:

"Our party were interestedly inspecting the Giant and a small geyser close by which was continually in eruption, and made as much fuss over its twenty-foot stream as if it felt itself the only spouter in the basin, when just below us, from the opposite bank of the river a vast column of steam burst forth and ascended several hundred feet. On the qui vive for new wonders, we hurried over a slight knoll in that direction, and arrived just in time to witness the Fan Geyser getting up steam for an eruption. When we arrived we could hear a sound as of throwing cordwood into a furnace. This continued several seconds, ceased and was followed by great quantities of steam from the smoke-stack; then the two valves opened, shooting out swift, hissing jets of steam. the next moment there would be an unearthly roar from the double crater, both would fill, and from each aperture a column of water two feet in diameter shoot upwards over eighty feet - one ascending nearly vertical, and the other at an angle of about forty-five degrees, thus forming the 'fan'. The eruption would continue from two to four minutes, then the flow cease for eight or ten seconds, and then the entire movement would be repeated. These repetitions continued twenty or twenty-five minutes and then ceased altogether.....

Its action was watched with intense interest and delight by our party, and when the grand explosion occurred, Dr. Hillhouse Raymond seemed perfectly overcome by the exciting spectacle. Springing from the ground, he leaped into the river, waded water almost waist deep to the other side, and rushing under the sparkling shower, waved his hat and shouted 'Hurrah!' till out of breath. This incident is cited only for the purpose of demonstrating how grandly, delightfully impressive are these most wonderful displays. It is said of Professor Hayden - a man of extremely nervous temperament and with an unbounded enthusiasm for the sciences - that he cannot compose himself in the presence of a geyser in eruption; but losing recollection of the material world for the time, rubs his hands, shouts and dances around the object of his admiration in a paroxysm of gleeful excitement" (1873, pp. 29-30).

Record of Activity

Eruptions of Fan and Mortar occurred with much greater frequency in the 1870s and 1880s than during any later period to date. Early references indicative of length of interval place it at about 8 hours. Stanley (1877) states that it "spreads itself three or four times a day." While Guptil (1892) states that it "erupts every 8 hours." The 8 hour interval was apparently the accepted time, as a geyser table prepared by Olin Wheeler of the years 1894 and 1895 lists both Fan and Mortar as playing every 8 hours (1896, p. 69).

It is believed that prior to the table referred to above both geysers had entered a period of dormancy, or at least one of infrequent activity. Each year, beginning in 1894 and terminating in 1904, Wheeler issued revised guides. In none except the 1896 table, is there a reference to, or a description of either Fan or Mortar. There is no statement indicating these geysers are important ones to be observed. On the other hand, these numerous guides give descriptions of other major geysers and important springs.

The scanty record of Fan and Mortar since the 1890s reveals long periods of dormancy. That major activity, at least of Fan, might have been infrequent in the teens is indicated by the following: "Intervals between eruptions of Fan vary from four to six hours; it plays for two minutes but only six feet high. The Mortar plays thirty feet high for 5 minutes every two hours" (Haynes, 1915, p. 61).

That Fan might have minor as well as major activity is confirmed by observations I made during the 1941 season. No major eruptions were observed, however, at irregular intervals five of the vents would erupt to heights varying between inches and about 8 feet. No eruptions of Mortar were noted in 1941. I have observed this minor activity of Fan but once since the 1941 season - following the 1959 earthquake.

Following the creation of the National Park Service greater attention was paid to the hot springs. During the 1920s Fan and Mortar were regarded as being largely dormant. "At their best these geysers Fan and Mortar are very interesting, but unfortunately they have been seldom seen in eruption the last eight seasons" (Y.N.P. Circulars, 1920, p. 20).

"The Fan and Mortar have developed no action in so many years that they may as well be considered 'dead' and dropped from the list" (Albright, 1922, p. 20).

"Between the road and the river are two small geysers both of which have seen better days. Fan was regarded by the early explorers as a remarkable geyser and they gave it much attention at the expense of the neighboring Riverside. Its Fan shaped eruptions are now infrequent and of much less magnitude. The nearby Mortar was described by the Hayden parties as being sympathetic with Fan but eruptions of the latter are so infrequent that verification is difficult today" (Phillips, 1927, p. 138).

I know of no further references to eruptions of Fan and Mortar until the 1938 season. In May of that year I had my first view of these famous geysers. They were very impressive. This was the only known activity for that season. Five eruptions were known to have occurred during the 1939 season. Night eruptions were undetermined. I was in the immediate vicinity of three of the 1939 eruptions, being at the site of the geysers at the start of one of them. The eruption lasted for more than an hour. The major display occurred during the first 12 minutes. The concerted action of both geysers impressed me to a higher degree than eruptions of other geysers I had witnessed to that date.

I observed no further activity of Fan and Mortar until 1946 when there was but one known eruption. Two eruptions were known to have occurred during the 1949 season. No further activity was observed until the 1956 season, when one eruption took place. One eruption was noted in 1957, then not again until June 21 and 29 during the 1959 season.

From 1959 to 1969 but three eruptions were determined. During 1969 and 1970 both geysers were in what must have been a new cycle of activity on a scale approaching the activity of the 1870s. There is no park record extant which is revealing of so great an amount of activity as occurred during the recent period. However, the prediscoversy record Fan and Mortar have incised into older formations is revealing of a long period of eruptive activity on a scale greater than anything known in historic times. During the 1969 and 1970 seasons night as well as daytime eruptions were determined for all months except May 1969. The following table shows the number of major eruptions per month.

Table I

<u>1969</u>	<u>Number of Eruptions</u>	<u>1970</u>	<u>Number of Eruptions</u>
May	3		3
June	1		2
July	6		7
August	7		7
September	8		8
October	<u>3</u>		<u>4</u>
	28		31

Fan and Mortar were known to be in the active cycle during the 1969-70 winter, but the total number of eruptions was not determined.

The name Mortar for the geyser which early observers called the "vent", "Fan's partner" - even Riverside - was not used until 1883. "Mortar Geyser was so named by Haynes photographer of the presidential party, 1883, because eruptions resembled discharge of ordnance of that name" (Yellowstone Park Library Name File). It would seem that the name "Mortar" was alternately given to both vents of this geyser.

Some of the early descriptions such as that of Hayden in 1878 would lead one to believe that major eruptions of the two Mortar vents might have occurred with a quiescent Fan. It is my opinion, based on observations of numerous eruptions, that this never happened. I believe that the nature and lack of completeness of a number of early references was due to newness and lack of familiarity with the sympathetic relationship existing between the two geysers.

While I know of no major eruption of Mortar of the steam-phase type occurring independently of Fan, there are references to

minor eruptions with Fan not showing major activity. The 1915 Haynes Guide states that Mortar had eruptions every two hours to a height of 30 feet. The eruptions lasted 5 minutes (1915, p. 61). There is no indication in the reference that both vents might have erupted. In Superintendent Albright's report for 1921, he stated: "Mortar observed in action 3 times" (1921, p. 21). In this period Phillips states that "occasionally its main crater, which resembles a huge pharmacist's mortar, fills and throws jets violently in all directions" (1927, p. 138). During August 1932 Mortar was reported as "erupting frequently, playing from a height of 20 to 30 feet. The duration of the play is from 11 to 15 minutes" (1932, Naturalists Reports, p. 25). It was not until 1969 that I observed any action in Mortar's lower crater without concerted action of other vents in the complex. Water splashed up about 20 feet for not more than a minute. During 1969 I also observed a solo from the upper vent. The height was from 20 to 30 feet, lasting for less than a minute. During the recent eruptive cycle of Fan and Mortar there no doubt were other occurrences of minor action of Mortar which were unobserved.

Eruptions

Eruptions of Fan and Mortar, where there is concerted action, are spectacles to be long remembered. It is as if the infernal region had broken loose in full fury. It makes one think of 4th of July rockets all being ignited at once. I have seen nothing which might excell these water blasts except a display of Giant, Mastiff, Catfish and Bijou such as I witnessed on July 18, 1951. When observing Fan and Mortar at their best it is not difficult to visualize why early visitors rubbed their hands and danced about in a paroxysm of gleeful excitement.

Occasionally premonitory signs of eruptions are at a minimum. Usually water starts jetting 6 to 8 feet high in Fan's vents, on the river side. This will continue from 3 or 4 minutes to sometimes about 10 before the eruption starts with marked abruptness. I have observed the start of at least three eruptions when warning signals were completely absent. Mortar's vents appeared as dead as the dodo, with water jetting a few inches to about a foot in some of Fan's vents. Then suddenly, and wholly unexpectedly, water suddenly rose and bulged in Fan's highest vent. This was immediately followed by explosive activity in the whole complex.

Of the vents on the upper section of the fissure, the one where the water was noted to bulge, plays to a height of from about 60 to 80 feet. The vents nearer to the river erupt to lesser

heights. The vent farthest away from the river, and below the main fissure, discharges the greatest volume of water and erupts to the greatest height. At about a 45 degree angle its water arches over the road; the height being not less than 125 feet. The entire road is drenched.

With the sudden explosive action of all of Fan's vents, both Mortar vents simultaneously become animated. The upper one erupts to a height of about 60 feet, with somewhat lesser height from the lower. After a moment or two of steady discharge from the crater a violent steam phase ensues. The steam discharge is not steady but comes spasmodically.

The spectacular part of the eruption lasts anywhere from 10 to sometimes more than 12 minutes; 12 minutes being about average. The roar accompanying the eruption adds to the interest of the spectacle. From then until the end of the eruption, which lasts not less than 90 minutes, the action is intermittent. Ejection of water will suddenly cease, to be followed almost immediately by renewed discharge, the intervals of quiescence increasing. During each renewal of activity the action becomes less forceful. The discharge of one of Fan's vents near the river is principally steam. Mortar's steam vent decreases in forcefulness along with Fan's waning activity.

In the early stages of an eruption it is difficult to determine the exact number of vents which contribute to the so-called "fan". Eruptions I observed the past summer revealed not less than 7 (possibly 9) separate water spouts, with the crack next to the river making an additional one. During eruptions I witnessed in 1938 and 1939 a small steam vent located midway on the high embankment across the river jetted steam in a horizontal direction, which nearly spanned the river. Steam ejection would last for fully two hours. During 1969 and 1970 this vent was inactive. Outside of the main Fan and Mortar complex these geysers have no known underground connections with any other spring.

1959 Earthquake

No eruption of Fan and Mortar resulted from the earthquake. For several weeks following the big jarrings major activity seemed probable due to the greatly increased jetting from some of Fan's vents. No eruption was triggered and the forcefulness of the symptoms gradually declined. During all seasons following 1959 at least one major eruption was known to have occurred except during the 1963 season. The marked activity which characterized the 1969 and 1970 seasons has already been dealt with.

Stargloss

Morning Glory Pool

18-450E, 275S

MORNING GLORY GROUP OF UPPER BASIN

The non-eruptive springs in the park received but little attention from early expeditions to the geyser basins. There is a similar dearth of information in guide books of the early period. Almost the entire emphasis of this period was upon the geysers. During the time Fan and Mortar were being given studious attention and publicity, not a word is said about nearby Morning Glory Pool.

Relative to the naming of Morning Glory, the name file in the Yellowstone Park Library contains the following information: "Mrs. William Brackett on September 5, 1950 stated that her mother, Mrs. E. N. McGowan, was the party who named this pool in 1883." This information was given to David deL. Condon, then Chief Park Naturalist. I know of no reference, either confirming or disproving this statement.

It is believed that starting sometime in the 1880s Morning Glory was becoming a spring of interest to park visitors. Its morning glory-shaped crater, in connection with its sparkling blue water, had a remarkable likeness to the corolla of the flower of that name. It was observed by all parties coming to the geyser basins. For a period of 30 to 40 years the road was less than 3 feet from the crater, which is 23 by 26.6 feet. No one could fail to observe it. "Here too, are Morning Glory, Emerald, and Sunset Pool, each different from the others and all beautiful beyond the power of words to describe" (Wheeler, 1903, p. 48). However, a year later a description was made of this spring.

"Before leaving this unique and wonder-exciting spot, let us stand for a moment on the verge of Morning Glory. It is a symmetrical bell mouthed pool, in form the very perfection of a colossal convolvulus. It is filled to the brim with transparent liquid, which unravels the morning sunlight and paints upon the delicately-chased and snowy walls gorgeous opalescent tints, fairly lurking in mother-of-pearl, but yet incomparable in lavish opulence of color and diversity; so that the radiant effigy blooms with beauty indescribable" (Wheeler, 1904, p. 49).

Morning Glory a Geyser

During the first few years I spent in the geyser basins I regarded Morning Glory as a perfect example of a non-boiling, quiescent spring. On September 18, 1944 it came to me as a surprise that it possessed eruption potential. On this date, in late afternoon, my brother and I were fishing in the Firehole in Biscuit Basin. The day was stormy. While fishing the water suddenly became very roily. Thinking it was due to the storm we pulled our gear and headed for Old Faithful. Upon reaching Morning Glory I suddenly became aware it had erupted. The water was down about 4 feet in the crater; also there was evidence of heavy wash over the surrounding terrain. Bottles, cans, rocks and other debris, even a pair of underwear, were strewn about the crater. It was suggested that the disgorged matter had served as an emetic.

The eruption resulted in my later making close observations of the formations about the crater. Where the water had washed down the embankments to the south and north there was certain evidence of old erosion channels in the sinter, which experience had taught me could have been produced in no other way than by eruptive activity. It was patently discernible that at some much earlier period a considerable amount of geyser action had occurred.

An additional observation I made during the 1940s and 1950s relative to Morning Glory was that at some point in its plumbing, no doubt near the surface, there must be a break leading to the surface in the direction of the hillside. In late May, during seasons when there was rapid melting of snow, Morning Glory would become very murky. After a few days of cloudy water a pronounced odor was in evidence. It smelled very much as if humus or vegetative matter were being cooked. All evidence was to the effect that muddy surface water was finding its way, by sub-surface means, into the pool. That the influx of murky water was not from the river seemed quite certain in view of the fact it was only during those seasons when there was a chinook or rapid melting of snow that the clouded water appeared. Further, the murkiness appeared several days in advance of when it did in the river. Since the 1959 earthquake no early season murkiness has been in evidence.

Early Popularity with Resultant Misuse

By 1900 newspapers and periodicals were loud in their praise of Morning Glory as one of the thermal features all visitors to the park should see. Publicity during the early part of the century seemed to focus on Old Faithful, Handkerchief Pool and Morning Glory as being the outstanding representatives of the hot springs in Yellowstone Park. Interest in Morning Glory has not waned. To the present date (1970) one of the most frequently asked questions relating to the hot springs is, "where is Morning Glory Pool?"

Due to the great amount of publicity Morning Glory has received and this in connection with its ease of accessibility to all visitors, it has not only inspired more people than any other thermal spring in the park (excepting Old Faithful), it also has been the recipient of greater abuse than any other spring. The very heavy visitation, with almost total lack of supervision, has proved to be near ruinous to this spring.

Early photographs made by Park Photographer Frank J. Haynes, reveal a scalloped border of sinter rimming the pool. This was probably completely denuded before the turn of the century.

Before each season is far advanced, on the sides of the bowl is a sight that, depending upon the point of view of the observer, educes either curiosity and morbid interest, or a feeling of revulsion and indignation. It would seem too few are infused with these latter sentiments.

Just how much extraneous matter was thrown into Morning Glory during the first half century of visitation can only be conjectured. Judging by what is known of the abuse of other springs it must have been considerable. There probably were tons of rubble and every other unwanted object the miscreants could get their hands on. Trees, or tree sections were certainly a part of what Morning Glory had to engulf. Many of these tree sections remained on the surface of the pool until they became so infiltrated with the water's hydrous silica they sank to the bottom. When the sun is near the zenith these logs can now be observed firmly cemented to the crater's floor. Being cemented to the bottom is no doubt true of a shocking amount of additional rubble, refuse and trash. During the late 1930s and 1940s I can remember three occasions

when I removed newly introduced logs and stumps which were still floating on the pool. That any water still finds egress into the bowl of Morning Glory is in all probability due to the fact it enters the crater by a side vent or vents.

Since 1950 the temperature of Morning Glory has lowered from 175°F. to a current 161°F. This might not be without significance. The degree to which vandalism might have contributed to the decrease in temperature is of course unknown. The fact remains that with the drop in temperature there has occurred a complete change in appearance of the spring. Instead of the morning-glory blue which characterized it during much the greater part of its known history, the color is now of a brownish, orange tint, due to a temperature which tolerates the growth of algae on the crater's sides. In general appearance this spring has ceased to be the Morning Glory of yesteryear.

Sometime during the 1930s it became a popular pastime for park visitors to toss coins and tax tokens into the thermal springs.

"Many of the Rangers have developed a definite dislike to those shiny tin tokens used by so many states. During the season of 1937 some of the most appealing of the beautiful hot pools and springs were repeatedly marred by showers of the world's least important coin from perhaps equally important people" (Oberhansley, 1938, p. 1).

Because Morning Glory has received many times greater visitation than any other spring, it naturally has been deluged with far more coins. Unfortunately a few irresponsible park concessioner employees have contributed to the coin abuse. It is known, particularly during the 1950s, that some of the bus drivers before reaching Morning Glory informed their passengers that this spring was a "wishing well;" that good luck might result from tossing in some sort of token. During this period the rangers on numerous occasions were asked, "Say, where is the wishing well?"

Following the passing of tax tokens, pennies in steadily increasing numbers were tossed into Morning Glory. The inclined shoulders of the pool to the south and east arrested the descent of thousands of the coins, while untold numbers plunged into deeper recesses. During the pool rehabilitation, which was carried on in Octobers of 1946 through 1950, by means of a large wire-screen basket, which I had made, and

a wire brush attached to a 20 foot pole, I succeeded each autumn in removing the coppery color from the sides of the bowl. In value, the seasonal recovery average amounted to about \$50.00.

Induced Eruption

Following the removal of the coins in October 1950 the idea occurred to me that could Morning Glory be induced to erupt - I knew it possessed that potential - a great quantity of extraneous matter might be disgorged. During earlier cleanup work I had demonstrated to my satisfaction that by reducing hydrostatic pressure in a number of hot springs an eruption could be brought about, with resultant discharge of foreign objects. This was done by using a scoop, and rapidly removing several shovelfulls of water.

My suggestion of trying to bring about an eruption of Morning Glory got a favorable response from the Naturalist Division. The superintendent gave his consent, and with the cooperation of the Naturalist Division work was begun. At first garden hose was used as a means of siphoning the water from the pool. Eleven long hoses were acquired. One end was placed 3 to 4 feet into the pool, the other near the river. The hoses were filled with water from the river. At first the siphoning worked beautifully. After the pool had been lowered about a foot some of the hoses quit operating. Soon all stopped. We concluded that due to formation of steam in the tube the vacuum was destroyed. At the time the operation began the temperature of the pool was 176°F.; with the water down about 12 inches, it was 182°F.

The next operation was a somewhat laborious one. Having no pump that would work in steam laden water, the expedient of bailing the pool was resorted to. Three buckets were attached to ropes and the operation began. We were able to lower the water at a faster rate than by means of the hoses. At the time the operation began the temperature was 184°F.

When the water was lowered about 18 to 20 inches below the crater's rim a sudden rise in water level occurred. With the rise there was a marked rollover of the water in the pool. The temperature had risen to 194°F. An eruption was momentarily expected. After about an hour of agitation, with no eruption, a large box of detergent was added to the pool, but still no eruptive activity in spite of the fact that the

temperature had risen to 200°F. During a long period of waiting there was a decline in temperature. It had dropped to 192°F. Other members of the party had left. I left at 5:40 p.m. for a bite and returned at 6:10. To my surprise and chagrin Morning Glory was in the closing stages of an eruption. It was evident that a large volume of water, accompanied by much trash, had been discharged. Due to oncoming darkness I left the pool until the following morning.

The water in apparently heavy volume was discharged at an uncertain angle to the east. On the west side the formation was comparatively dry with no evidence of discharged material. Appearances indicated that much of the trash lifted by the water column fell back into the crater. Judging by experience gained at other geysers it is believed that for every penny that fell on the formation, ten additional ones still remained in the crater.

Relative to what Morning Glory had disgorged at the time of the eruption, what amazed me most was the quantity of laundry. On the following day I erected a line on which, for photographic purposes, I placed seventy-six handkerchiefs, numerous linen towels - seemingly acquired at accomodation places; bath towels and socks. None of these articles was visible in the crater previous to the eruption. In an effort to sort the disgorged material I was able to identify 112 different kinds of objects, some of which were not without intrinsic value; some too indelicate to mention.

Of the coins strewn about the crater, and recovered, there were \$36.27 in pennies, \$8.10 in nickels, dimes and quarters and tax tokens from 9 different states, 50.3 per cent of which were from the state of Washington.

Two times during the 1950s attempts were made by district rangers to effect an eruption of Morning Glory. Diaphram pumps were used. These efforts were unsuccessful due, it is believed, to the fact that the temperature was 7 to 8 degrees lower than was the case in 1950. I was not in the geyser basin when the pumping was done. In recent years attempts have been made during most seasons to remove pennies and other debris from the inclined shoulders. Nothing is done, however, to stop the seasonal flood of filth irreverent Americans pour into Morning Glory, which happens to be the outstanding example of vandalism in Yellowstone National Park

1959 Earthquake

Morning Glory's pre-earthquake temperature for both 1958 and 1959 was 163°F. On the morning of August 18, 1959 the water was murky and had ebbed about an inch. This was sufficient to stop all overflow; its temperature was 165°F. For the next 10 days the ebbing continued slowly until it was down 6 inches. During September and October the ebb fluctuated between 2 and 6 inches. During the latter part of the year the ebb stayed at a level of near 6 inches.

During all of 1960 the water stayed from 2 to 4 inches below the rim of the crater. Whenever the temperature was taken it was near 168°F. During this season and 1961 there was little evidence of recovery from the effects of the earthquake. In fact in the latter part of 1961 the temperature dropped to 160°F. The upper part of the bowl became coated with yellow algae, dulling the brilliant blue hue.

During 1962 there was slight overflow (little more than seepage) from the crater. The water never reached the river; nor has it done any season since the 1959 drop. For a time I thought Morning Glory was on the way to recovery. Its temperature was 2 to 3 degrees hotter than in 1961. This prevented the growth of the algae in the upper part of the bowl, resulting in a more beautiful pool.

Since 1962 the temperature has ranged between a low of 157°F. and 163°F. At this temperature there has been a steady growth of algae and other primitive plants in the crater. This has resulted in a complete change in coloration. The name Morning Glory is no longer applicable to this spring.

Morning Glory has no known underground connections with any other spring. Following the earthquake, and for the remainder of 1959, water stood about three feet deep and boiling in a previously empty crater directly to the north of Morning Glory. Since 1959 the water has slowly ebbed. Presently the crater is empty. The cause of Morning Glory's loss of thermal energy is unknown.

Spiteful Geyser

F8-655E, 475S

MORNING GLORY GROUP OF UPPER BASIN

Spiteful, a most inappropriate designation, was named by Arnold Hague. It is perched on a sinter embankment 25 feet north of Fan Geyser. Its crater is situated on the same break in the sinter as is that of Fan. Spiteful's crater appears to have been formed by a steam explosion which antedates park history.

During the 1950 cleanup, or hot-spring rehabilitation, Spiteful was induced to erupt to facilitate removal of rocks and other debris from the crater. It was only necessary to lower the water level about a foot to bring about an eruption. The temperature was 200°F when the operation started. The crater stayed empty long enough to remove over a pickup load of rocks, cans, bottles, etc.

Spiteful is apparently cyclic in its activity. The first natural eruption I observed was in July 1964. Other eruptions were known to have occurred during that season. By 1965 it was erupting with considerable regularity, the eruptions occurring about every 15 to 17 minutes. During the 1969-70 seasons the intervals had increased to 20 to 25 minutes. This eruptive activity persisted until late October 1970, when there was evidence to suggest it might be entering a dormant cycle.

Prior to the beginning of frequent eruptive activity in 1965 the water in Spiteful's crater stood at the top of the bowl, whose lowest side is in the direction of Fan. There was light but continuous overflow; also minor ebullition due to high temperature. During the eruptive cycle the crater stayed empty. The only time water was in evidence was during an eruption. With no known exceptions this situation persisted until October 29, 1970 when the crater refilled with consequent overflow. I was unable to stay in the basin long enough to determine if Spiteful had become dormant.

Eruptions of Spiteful are of the splashing type. At the beginning of activity water starts jetting into the bottom of the bowl, which rapidly fills. Splashes are continuous, the height being from about 10 to 12 feet. The duration of an eruption is between 2 and 3 minutes, at the end of which the crater rapidly empties. Most of Spiteful's water flows into the crater of Fan.

Spiteful is a part of the Fan and Mortar Complex.

5

West Sentinel Geyser

F8-70E, 1955 *check map section
1022 11/2/55*

MORNING GLORY GROUP OF UPPER BASIN

During the entire period I have been in the geyser basins West Sentinel has been in a steady state of minor eruptive activity. The water boils to a height varying between one and two feet. For about 3 weeks following the 1959 earthquake there was increased vigor in boiling, which was estimated to be about 3 feet in height. This apparently was due to a slight increase in temperature of from 202° to 203°F. I have observed no evidence to indicate it is connected underground with any other spring.

Bottomless Pit

F8-695E, 970S

CHAIN LAKE GROUP OF UPPER BASIN

Bottomless Pit was named by the Hayden Survey. There is some question as to just which spring in the Chain Lake Group they designated as "Bottomless Pit." It might have been all springs in Chain Lakes, considered as a unit, that was so designated. The southernmost of the chain-lake springs has long been referred to as Bottomless Pit, and so will be treated in the present discussion.

During much the greater part of my observations of Bottomless Pit the water has been of comparatively low temperature, ranging between 138° and 141°F. This low temperature permits a luxuriant growth of dark brown, leather-like algae to line the crater. Occasionally large sheets of the algae will spall from the sides. The dark colored algae make it difficult to see to any depth into the crater, which has vortical walls.

The only time I have been aware of an increase in temperature of Bottomless Pit was during the 1958 season. Following a series of major eruptions of Link it became dormant in early July. This was apparently due to a shift of the thermal energy to Bottomless Pit, whose temperature rose from 141° to 198°F. This temperature increase persisted in Bottomless Pit during the latter part of the 1958 season and throughout all of 1959. No marked drop occurred until the 1962 season.

Following the earthquake I obtained a reading of 200°F in Bottomless Pit. The sides of the crater showed evidence there had been some boiling and surging. For several days the water was very turbid. Later it changed to a turquoise color. Following the 1961 season the temperature dropped again into the 140 degree range, resulting in the crater again becoming lined with brown colored algae, in which state it is now (1970).

Bottomless Pit has subterranean connections with all springs in the Chain Lake Group, unless it be with Culvert Geyser. In 1957 following a series of eruptions of Link the water dropped about 4 feet in the Chain Lake Springs. Following a long series of eruptions of Link in 1958 Bottomless Pit obbed to a measured depth of 8 feet 4 inches.

"Culvert Geyser"

G8-795E, 45S

CHAIN LAKE GROUP OF UPPER BASIN

At the time the road was constructed through the Upper Geyser Basin a spring next to Culvert Geyser, which lay athwart engineer plans as to where the road should be placed, was summarily buried. A spring, later known as Culvert Geyser which was situated at the edge of the road's shoulder, had a rock retaining wall constructed on the road side. When this was done Culvert could not have been in the steady boiling stage which has characterized it for many years. It is believed that the thermal energy of the buried spring shifted to Culvert converting it into a steady geyser. *greater? active spring?*

In 1954 energy from the buried spring began to manifest itself in the nature of an active fumarole on the shoulder of the road next to Culvert. In July of that season the road in the west lane suddenly collapsed forming a large pit, large enough for a car to drop into. Fortunately none did. The cave-in was at once filled. I have seen no further evidence of activity of the buried spring.

During the period I have been in the geyser basins Culvert has functioned as a steady geyser, the water boiling up between 2 and 4 feet in height. As a result of the earthquake its temperature rose from 202°F to 204°F. In 1970 it was 200°F. I have observed no evidence of underground connections with any surface spring. *restated?*

Sample

"Link Geyser"

F8-680E, 880S

CHAIN LAKE GROUP OF UPPER BASIN

Link Geyser lies in a north northwest direction from Chain Lakes, being about 60 feet distant from the middle of the chain. Unlike the separate springs which make up Chain Lakes, and which are connected both above and below ground, Link's only connection with the group is subterraneous. The name Link was suggested to me by Ranger Naturalist Sam Deal during the 1957 season. I had previously observed that certain marked underground connections existed between Link and Chain Lakes. This seemed to make the unnamed geyser another link in the chain.

As is the case with other members of the Chain Lake Group, there is no cone or raised sinter about Link's crater. The crater is ragged edged. It is about 18 feet long. From the southwest to the northeast its width narrows, constricting from about 8 to 5 feet. During much the greater portion of the time the water in the expanded end is in a state of ebullition.

Since 1936 Link has been known to have major as well as minor eruptions. This latter type of activity is the much more frequent state of this geyser and has characterized it for an indefinite period. A sign in the Chain Lake Group during the 1930s stated that there were several geysers in the group, one of which erupted to a height of a few feet. It seems quite certain this latter reference was to Link. When in a state of minor activity eruptions occur about every $3\frac{1}{2}$ to 4 hours. For not less than 2 hours preceding an eruption there is steady boiling and overflow. The eruption is initiated by a sudden rise in water level, accompanied by immediate surging. The surges are from 3 to 4 feet in height. The eruption lasts from about 13 to 15 minutes. The water leaves the crater by two channels. During minor activity the water drops about 2 inches in Bottomless Pit, the southernmost spring in Chain Lakes.

Any marked increase in temperature, or geyser activity of any of the springs in Chain Lakes, results in dormancy of Link. During June and July 1953 the northernmost spring

in Chain Lakes was known to be active two or three times each week. During all of this period Link was dormant. Following a series of major eruptions of Link in 1958 it became dormant for the rest of the season. This dormancy was apparently due to a shift of the focus of thermal energy from it to Bottomless Pit. Prior to the major activity of Link which ended in late June 1958 its temperature was 202°F., Bottomless Pit's 138°F. By June 29 Link's temperature was 193°F., Bottomless Pit's 195°F. From then until the end of the season Link was not only dormant, but no water flowed from its crater.

The earliest reference to major activity of Link was by Ranger Naturalist E. B. Douglass:

"At the opening of the 1936 season most of the area between the Chain Lakes and the road was badly washed, and all superficial debris had been carried away. On the pre-season trip... Park Naturalist Bauer mentioned there was increased activity in the area...

Twice during the early part of the summer the author witnessed eruptions of the new geyser. One occurred shortly after the crowd had dispersed following an eruption of Riverside. The other happened just as the auto caravan was passing the point. On this occasion the water flooded over the two foot bank at the edge of the road in a sheet several inches deep. The gutter was unable to carry all the water, and it rushed out almost to the middle of the road.

In the weeks that followed, tourists frequently brought to the Old Faithful Museum reports of seeing a geyser across the road from Riverside, which apparently had no name. These reports seemed to come about every other day and were usually brought by someone who had been waiting for an eruption of Riverside. We began to wonder if the geyser had a regular forty eight hour interval and if its eruption could be influenced at all by the eruption of Riverside. It was to answer these two questions that an attempt was made to keep a systematic watch of the geyser and record its frequency of eruption.....

The eruption of the geyser was interesting because it came up from the southwestern corner of the pool at an angle, much after the manner of the Daisy Geyser... For the first half minute or more of the eruption, the force is dissipated in emptying the crater and the water was not thrown higher than 5 to 15 feet. During the last of the eruption, the water was thrown to a height estimated at fifty or sixty feet. A complete eruption was witnessed only once, however, and that came as such a surprise and was of such short duration, probably not much over a minute, that no accurate estimate could be made.

The geyser seemed to be closely connected with a nearby hot pool, one of the Chain of Lakes, for during an eruption this pool was drained completely by an aspirating action, and for several minutes after an eruption, water from another pool of the chain drained into this empty pool and out of sight as if down a sewer.

Following the eruption, pieces of white opalite were picked up on the bare area over which the geyser had played. These were very different from the surface geyserite deposits and their presence could only be explained on the basis of their having been thrown out during an eruption. That considerable sub-surface erosion was taking place was evidenced by the very turbid condition of the water which filled the crater after the eruption.....

In view of the size of this new geyser; should it continue to erupt with as much power, it deserves to receive more publicity. The fact that sub-surface erosion is taking place will make future observation of this geyser interesting to determine whether it becomes stabilized or destroys itself" (1937, pp. 17-18)

Major activity of Link persisted throughout at least part of the 1937 season. During this season Ranger Naturalist Fix spent considerable time in the geyser basins. Despite an effort toward that end, he did not succeed in seeing a close up major eruption of Link. He observed it from a distance and stated that the height of the water column seemed to be above the trees. In commenting on the observations of Douglass, Fix wrote:

"Altho it appears geyser activity in the Chain Lakes area is not a new thing, it is believed the first major activity was that reported by R. N. Douglass for the summer of 1936. During that period, it erupted to a height estimated by him as 50 to 60 feet at intervals varying from $\frac{1}{2}$ to 6 days. It was also estimated that the volume of water discharged during an eruption amounted to not less than 1,600 cubic feet" (1937, Geology File p. 18).

During the above period of major activity of Link I was not in the geyser basin.

My first observation that Link had a potential for major eruptions was during the 1954 season. I did not observe an eruption but was aware of its effects in the way of washed sinter about the crater. During the 1955 season 8 major eruptions were known to have occurred, two of which I observed. But 6 eruptions were noted for 1956. However, in 1957 major activity took place on an unprecedented scale; not only for violence of eruptive activity but frequency of play. Large blocks of sinter rimming the inside of the crater were broken away and carried many feet from the bowl. Some of the blocks were estimated to weigh around 300 pounds. The column of discharged water was also in excess of major eruptions noted during previous seasons. It flooded much farther back from the crater and washed away great quantities of disintegrated sinter. I did not observe any of the "white opalite" referred to by Douglass.

The major eruptions I was able to check during June and July seemed to come mostly in series. That is, one eruption was followed by several others at about 3 hour intervals. The longest series was from July 6 to 8. This was the last major activity, except for one eruption known to have occurred in October, for the season. During each successive eruption of the Link the water level in the Chain Lakes would continue to lower. At the conclusion of a series of eruptions the water level in these springs would be down about 4 feet. There was also ebb in the springs between Bottomless Pit and the road. Following the July activity it was 2 days before connecting springs refilled to their usual high levels.

Two eruptions of the Link I was able to observe in their entirety lasted for three minutes; the major part of the eruption lasting not more than a minute. Within 10 seconds after overflow, surging started. Maximum height was reached in from 20 to 30 seconds; estimated height was 75 feet.

During each eruption there were 3 voluminous surges. There was a short steam phase at the end of the eruptions. The angle of the water column was to the west, being 10 to 15 degrees from the vertical.

There was no major eruption of the Link from late October 1957 until April 3, 1958. However, during the winter period the minor eruptions occurred every three to four hours. A major eruption on April 3 was followed during the next few weeks by several additional ones. These eruptions came singly and not in series. Following a major display the activity in a few hours would shift back to the usual minor function. A major eruption at 8:30 a.m. June 7 was followed by a series of eruptions throughout the day, and continuing all of the 8th. I observed several of these big eruptions. They impressed me as equalling in magnitude and discharge the ones I observed in 1957. The eruptions occurred about every two to four hours. The last one in this series was at 7:52 a.m. July 9. This proved to be the last known major eruption until 1968.

During this protracted period of major activity, following each eruption of Link, the water in Chain Lakes would ebb to a new low. Following the eruption on the 9th the water level in Chain Lakes was down eight feet four inches. As in 1957, the springs immediately south of Chain Lakes were down about four inches, indicating subterranean connections with Link and Chain Lakes.

Whether it was pure coincidence or not, I have not been able to ascertain, but the fact remains that the major eruptions I observed of Link during 1954 through 1958, with one exception, came during the early part of the season. By early July dormancy would ensue.

The 1959 earthquake had no observable effect on Link. Minor eruptions continued on the same pattern as previously. From the time of the July 9, 1958 major eruption of Link it is believed no more occurred until September 19, 1968, when two eruptions took place. Since that date there has been no further major activity. I appreciate that several months intervened when no observations were made. However, when Link has a major eruption there are telltale signs about the crater for months afterward. Early checks are made in the spring and throughout the season.

North Chain Lake Geyser

F8-595E, 860S ✓

CHAIN LAKE GROUP OF UPPER BASIN

The water in North Chain Lake usually stands from 2 to 3 feet below the rim of the crater. The eroded sinter on the north side, in the direction of the river, is indicative of occasional, perhaps infrequent eruptive activity.

It was during the 1940s when I first became aware that this North Chain Lake spring possessed geyser potential. I did not observe an eruption during this period, but I noted that at least two occurred. It was not until July 1953 that I saw an eruption. Until late July of that season it erupted 2 or 3 times each week. The eruption was not unlike that of Oblong Geyser. The duration of an eruption was about 2 minutes, during which a large volume of water was discharged. The eruptive activity not only tore out pieces of sinter from the crater, there was also heavy wash of sinter about the crater. During most of the 1953 season the temperature was 195°F, as against 165°F for 1952. Since July of 1953 I am not aware of any further eruptive activity until the night of the earthquake. Since this naturally induced eruption it is believed that North Chain Lake has been dormant. It is very definitely connected underground with other springs in the Chain Lake Group.

"Square Spring"

G8-760E, 870S

CHAIN LAKE GROUP OF UPPER BASIN

Square Spring is nearly square in shape, each side being about 18 feet. It is located about 25 feet southwest of Culvert Geyser. During much the greater part of the time I have observed Square it has been a quiescent spring. However, on a few occasions in the 1950s it was known to have erupted. The night of August 17, 1959 there was an earthquake induced eruption. None of these eruptions was observed. Its temperature following the earthquake was 202°F.

There is evidence that Square Spring is connected underground with other springs in the Chain Lake Group.

5

"Grotto Fountain Geyser" •

G8-955E, 220S ✓

GROTTO GROUP OF UPPER BASIN

What is believed to be the earliest reference to an eruption of Grotto Fountain was of one that occurred during the 1928 season.

"Museum records show that these vents became active geysers on two occasions during the summer of 1928 and at four times during the season of 1931. Apparently remaining inactive during the winter of 1932, these erratic vents burst forth with powerful fury on the evening of May 22, the one closest to the Spa geyser playing to a maximum height of 50 feet and continuing in eruption for seventeen minutes. The eruption of this vent began at 7:08 p.m. and a large volume of water was thrown vertically until 7:25 p.m. when activity ceased suddenly and the surrounding pool began to drain rapidly into the crater. The play was characterized by a steady rush of water and steam, closely resembling the play of Old Faithful, except for a lesser height and smaller volume of water. The roar of the water could be heard for a considerable distance. Filling the surrounding pool to overflowing after four minutes of play, the west vent (nearest the Spa) poured a large stream into the Firehole River for fifteen minutes. At 7:24 or just one minute before the vent suddenly ceased to play, the second vent burst forth and erupted for two minutes to a maximum height of six feet, throwing a large volume of water. At 7:26 this vent also quieted suddenly and water from the pool rushed down the crater.

During the unusual eruption of the drain vents, or at 7:17 p.m. the Grotto began eruption and was followed at intervals by the Rocket which threw water in spurts during the next ten minutes. Within ten minutes after both vents had ceased to play, the surrounding pool had been completely drained and the craters were functioning as usual as flood sewers for the Grotto and Rocket, which were still in eruption when the observation ended" (Skinner, 1932, p. 32).

From 1932 until 1941 Grotto Fountain apparently was dormant. During this period there is no reference to it. From 1937 until 1941 I spent most of the daylight hours each season in the Upper Basin. My first observation of an eruption was in 1941. It came as a great surprise. I had no previous idea that a spring of marked geyser potential was situated in Grotto's north drain channel. During 1941 frequent activity of this geyser occurred. One of the naturalists who was stationed in the basin in 1941 made the following report:

"In the runoff channel below Grotto and Rocket Geysers some 75 feet in distance from them is an inconspicuous 'T' shaped orifice into which flows a great amount of the water running off from these geysers. There is seldom seen any escape of vapor from this vent but to the right or south of this opening about 25 feet is an older orifice or vent from which there is a large quantity of vapor escaping at all times.

That these two orifices are connected is certain for on Friday, August 1st, I was waiting near the Grotto when the vent in the runoff channel started to play as a geyser. Its activity was very striking for in playing from the opening it threw a single column of water into the air similar in shape to that of Old Faithful. It erupted to a height varying from 25 to 75 feet and played almost constantly for 15 minutes. Considerable water was thrown out bringing with it, at the beginning of play, the accumulated sand and debris carried into it by the waters draining from Grotto, Rocket and the immediate roadside. A large quantity of steam was emitted from the opening during the entire play.

During the eruption of this geyser the vent 25 feet to the south was in constant violent eruption to a height of ten feet. At the completion of play the waters of the runoff channel and surrounding basin again ran into the vent from which the eruption occurred while the nearby opening 25 feet to the south continued to be active for a few minutes.

This geyser was observed in eruption on several occasions and the interval has proven to be very irregular so that the time of eruption cannot be

predicted. There is no indication that it is going to play with the possible exception that the opening 25 feet to the south seems to become more active just before eruption" (Replogle, 1942, p.4).

During the 1941 and 1942 seasons one or two eruptions of Grotto Fountain were noted each day. One interesting observation I made in 1941 was that an eruption of Grotto Fountain served as a certain precursor to an eruption of Grotto. The eruption of Grotto would start anywhere from 1 to 5 minutes after the Fountain began. Should one see Grotto Fountain start erupting he can rest assured that in a matter of minutes Grotto and Rocket will begin eruptive activity. While Grotto always follows Grotto Fountain, most of Grotto's eruptions occur independent of Grotto Fountain.

An eruption of Grotto Fountain is not without precedent signs. Previous to an eruption the water will boil in the crater, with periodic overflow. It has never been observed to erupt except when the water in the bowl of Indicator Spring has reached the high water mark. About 20 feet south of Grotto Fountain is another spring, sometimes called South Grotto Fountain, which always starts erupting about one minute ahead of Grotto Fountain. Should the activity last for several minutes previous to Grotto Fountain then Grotto Fountain will not erupt. The activity in its bowl slowly subsides. The south spring will continue to erupt for 10 to 12 minutes before Grotto starts. When Grotto Fountain erupts the south spring erupts in concert with it.

Grotto Fountain attains maximum height within less than a minute following the start of the eruption. Maximum height is maintained during the first 8 to 10 minutes, after which there is slow subsidence of the water column. In the initial stages the water is ejected under considerable pressure. During the concluding stages of an eruption there will be periodic resurges in the strength of the activity. The height of an eruption is between about 40 and 50 feet. Some give a higher figure. The south spring erupts to a height of from 8 to 12 feet.

During the 1941 and 1942 seasons the great majority of the eruptions of Grotto Fountain lasted for about an even 17 minutes. Occasionally one might last for 18, 19 or 20 minutes. Since the first observations in 1941, and to date (1970), the great majority of the eruptions have had a duration in the

range given above. Two seasons have been exceptions. During 1957 many of the eruptions lasted from 40 to as long as 65 minutes. They would persist long after Grotto started. During the 1967 season most eruptions lasted from 13 to 15 minutes.

Following the 1941-42 seasons I was not in the geyser basins until the 1946 season. From then until the eruption cycle of Giant - 1951 to 1955 - Grotto Fountain would erupt with about the same frequency as during 1941 and 1942. From 1952 until the 1955 season it erupted infrequently. However, during 1955 its activity was synchronized very closely with that of Grotto. Following an eruption of Giant, Grotto would always be inactive for a day and a half to two days. Then until Giant's next eruption, Grotto and Grotto Fountain would erupt about every 10 hours. However, at times when an eruption of Grotto Fountain was imminent Spa would start overflowing. This delayed Grotto Fountain for several hours. The overflow from Grotto Fountain served as a very good indicator for the time of its play as well as that of Grotto. At no time during the season was Grotto observed to erupt independently of Grotto Fountain; its activity would commence about one minute following Grotto Fountain's. This close relation between the two geysers did not persist in succeeding years. In 1958 and in the pre-earthquake period of 1959, it was seldom observed erupting. Where activity of precursor springs was involved as a prelude to Grotto, the south spring would trigger most of Grotto's eruptions. This same situation existed following the earthquake.

During the 1961-62 seasons it was observed that many eruptions of Grotto were not triggered by Grotto Fountain. In 1963 I noted that when short intervals of Grotto occur, an eruption is not preceded by an eruption of Grotto Fountain or the south spring. Neither does the crater of Indicator refill. This would seem to indicate that short intervals of Grotto are but separate phases of the same eruption. By 1969 Grotto Fountain had slowed down considerably. But 3 eruptions are known to have occurred. Six were reported for a 6 month period in 1970. It is possible this geyser might be entering a dormant cycle.

There is very good evidence for believing that Grotto Fountain is cyclic in its eruptive activity. The eroded sinter sheet which partially surrounds the vent furnishes certain proof of either an earlier period of long sustained activity (the present one has scarcely made a new dent in the eroded sinter) or that there have been many recurring periods of activity, perhaps comparable to the present one. That the latter postulation

might be correct is indicated by trees which have grown near the crater. That the activity described in this paper represents a new cycle of activity is shown from the fact that by the end of 1942 several Lodgepole Pines about 50 feet northwest of the geyser were killed and whitened by the frequent wind-blown water they were subjected to. These trees were from 50 to 75 years in age. These trees could not have grown where they were with Grotto Fountain functioning as it has during the past 30 years. Another tree of interest is a stump about 3 feet in height and 24 inches in diameter which grew within a few feet of the crater which Grotto Fountain's erupting waters have excavated. No doubt because it was dead, having been killed during one of Grotto Fountain's eruptive cycles, some early park administration had this tree felled and removed. The tree was not less than 150 years in age. The fact that it grew within a few feet of Grotto Fountain indicates not only cyclic activity, but that some of its dormant periods were long.

Grotto Fountain has been identified by two additional names. At first it was called Surprise Geyser, due to the surprise occasioned by seeing an eruption. Later it was referred to by the uneuphonious title of Grotto Drain Geyser, as the eruption issued from one of the vents into which some of Grotto's water drained. The name Grotto Fountain, by which it has been more generally known, seems more appropriate in view of the fact that in the Lower Basin there is a spring named Surprise, which since the 1959 earthquake has shown occasional geyser activity.

Grotto Geyser

G8-9103,4653

GROTTO GROUP OF UPPER BASIN

This geyser was named by the Washburn Expedition: "The Grotto, so named from the singularly winding apertures penetrating the sinter surrounding it. Externally it presents few indications of its character as a geyser" (Langford 1870, p. 171).

The unique character and form of the sinter which comprises the cone of Grotto have always caught the fancy and interest of the observer. When not in eruption the cone will attract as many visitors as when water is spouting through the arches. Relative to how the cone impressed early visitors the following is of interest: "On the right side of the road as you enter the basin, stands the Grotto Geyser, with the oldest of all the geyser-craters, and of a form that will puzzle the most profound to account for. We all have pet theories and fancies as to how this curious thing was formed, and, in fact, the attempt to unravel the mysteries is a great part of the enjoyment of the visit to the geyser basin. On a low elongated round a few feet in height stands (as you view it from one side) a pillar of geyserite five feet in height, slightly leaning to one side. About this, in a semicircle, is a hollow bank or parapet also of geyserite formation, with openings at both ends like a tunnel, arched over and curved, so that both openings are on the same side of the crater. Near the pillar is a vertical opening of small size. The entire mass is white and snowy. On one side the outer wall of the tunnel is perpendicular; on the other, sloping" (Haupt, 1893, p. 105).

People continue to puzzle and speculate as to just how Grotto came by its unique structure. Its cone, like so many in the geyser basin, rests on an older sinter which is currently being eroded by eruptive activity. Evidence throughout the basin is highly suggestive that a number of geysers might have had their genesis as a result of a major earthquake which fractured an existing sinter cover, permitting a rather sudden evolution of thermal energy. An historic and recent example of this is found in the new Seismic Geyser. There, as at Grotto, a fracture in a spot covered with trees, resulted in the sudden evolution of a new geyser. Grotto's arches and pillar present certain evidence that material apart from normal geyser deposition, served as nuclei for the present grotesque shape of the sinter. It is my firm conviction that if a boring were made in the central pillar silicified wood would be encountered.

During Grotto's quiet phase the curious have ever been wont to investigate the "Grottos". The Washburn Party set a precedent. "Private Williamson, one of our escort, crawled through an aperture and looked into the discharging orifice... When afterwards he saw it belching forth a column of boiling water, he said he felt like one who had narrowly escaped being summarily cooked" (Langford, 1870, p. 171). There is scarcely an early reference to Grotto which does not refer to the inquisitive crawling through the arches. "Some of the party crawled through the openings in the sides of the wall, when it had cooled after an eruption" (Stanley, 1878, p. 113). "In peace it is large, irregular and cavernous, and tourists may crawl about it in inquisitive inspection" (Kenney, 1882, p. 42). Even in recent years, and despite "KEEP OFF" signs, scarcely a season passes but what I have observed descendants of the early visitors similarly inquisitive and curious.

Vandalism

Not only did the cone of Grotto arouse curiosity, but due to specimen hunters, it did not escape the sound of the hammer and chisel. "The markings over a considerable surface are, therefore, exceedingly regular and remarkably fine, resembling a smooth white floor inlaid with glittering pearls. Large slabs of this material, three-fourths of an inch in thickness, can readily be detached without injury, but the geyserite is rather brittle and does not bear transportation well" (Jones, 1873, pp. 251-252).

Not all viewed the detachment of "slabs of material" as being "without injury". "After seeing the injury done to its crater by visitors, the large majority of whom are residents of the Territory, we could not help wishing that the discharge of boiling water were absolutely continuous, so that the depredators might be kept at a respectful distance" (Ludlow, 1875, p. 122).

Apparently the "slabs inlaid with pearls" were largely removed from Grotto before I became acquainted with it. During the period of my observations the major part of the vandalism has resulted from throwing any object at hand into the crater. The Park Service inadvertently placed a wall of limestone on the border of the road abutting Grotto. Most of the hundreds of spalls from this limestone now repose in Grotto and neighboring springs.

Eruptions

All of the early references to Grotto in much the greater measure attempt to describe its oddly shaped cone. References to eruptions

are but incidental. It is very doubtful if there were any sustained observations. Many of those who left written accounts in all probability did not witness the progressive stages of an entire eruption. One writer reported that eruptions lasted for but "ten minutes". He no doubt witnessed the concluding 10 minutes of an eruption. In recent years some Park Service employees have been guilty of similar erroneous conclusions. They report eruptions of geysers as beginning when they first saw them.

The heights for eruptions given in early reports vary from 20 to 60 feet. Those who reported eruption heights as being from 20 to 25 feet were no doubt making a reasonable estimate of Grotto. It is believed that eruptions which were reported to be from 50 to 60 feet in height were of the Rocket. That this in a measure accounts for discrepancies results from the fact that Rocket in the beginning was considered a part of Grotto. The name Rocket is of much later date.

The earliest description of Grotto which represents most closely what must have been its overall pattern of activity since 1870 was based on observations made in the 1920s. "The interval of Grotto and Rocket is extremely erratic but they are in eruption at least twelve hours out of twenty-four in periods of one to three hours at a time" (Phillips, 1927, p.139).

During the 1940s it was my observation that Grotto was in an active phase fully half of the time. However, as to the duration of an eruption, my data were somewhat at variance with those of Phillips. A number of eruptions which I checked lasted for about 8 hours. Many of the quiet phases were equally long. At times a two to three hour interval would be observed.

During an eruption of Grotto, whether long or short, there is continuous splashing through the arches to heights varying between about 8 and 12 feet. The highest splashes are from the southernmost vent. If Rocket has a major eruption during Grotto's active phase there will be a brief pause for the duration of Rocket, whose eruption lasts from 2 to 4 minutes.

When Grotto Fountain acts as a precursor to an eruption of Grotto the initial burst from Grotto is quite spectacular. After about 2 to 3 minutes of pre-play by Grotto Fountain, Grotto will almost explosively initiate an eruption. A voluminous mass of water is suddenly ejected. From the south vent the height is not less than 30 feet. After this grand display it settles down to the 8 to 12 foot splashing.

Giant Affects Grotto

That during the long period Grotto was building its cone there might have been periods of dormancy was not recognized until the 1952 season. During 1952 the behavior patterns of Grotto and Giant presented certain evidence that they are connected subterraneously. It is surprising that the pronounced sympathy existing between them was not recognized in 1951 or at the time of an earlier active cycle of Giant. Evidently too much attention was focused on Giant.

There is little question but that prior to the 1959 earthquake the Grotto Group of springs was the main cause of Giant's cyclic behavior. It seems equally certain that Giant's earlier active cycles must have been attended by a decrease in function of the Grotto Group.

During the early part of the 1952 season I became aware that there was a noticeable decline of activity in the Grotto Group. Following this observation Grotto was given special focus as a possible cause of Giant's increase in activity. It soon became apparent that a pronounced sympathy existed between the two groups. An eruption of Giant acted as a precursor to an eruption of Grotto, whose eruption came about 45 minutes following the start of Giant. Except for a series of 3 or 4 eruptions of about 40 minutes duration, coming as a sequence to an eruption of Giant, Grotto was in large measure dormant during the 1952 season. A few times Grotto erupted when the quiet phase of Giant was about 48 hours old. With but two observed exceptions, this was an unfailing herald of a delayed eruption of Giant. The eruptions of Grotto which occurred during the quiet phase of Giant preceded an eruption of Giant by about 10 hours. On two occasions, the exceptions alluded to above, instead of the eruption of Grotto delaying Giant, they both erupted near simultaneously.

Additional evidence of the pronounced sympathy existing between Grotto and Giant is found in the fact that the eruptions of Grotto which preceded Giant by about 10 hours came only at the time of one of Giant's hot periods; the only time at which Giant will erupt.

During the 1953 and 1954 seasons there was some variation in the relation between Giant and Grotto. Occasionally Grotto would follow the Giant in the same manner as during 1952. However, eruption of Spa, a part of the Grotto Complex, following Giant was the more common pattern. Giant and Spa reduced Grotto to a state of near dormancy during 1953 and 1954. Interfunctional relationship in the Grotto Group seems very complicated.

About July 1, 1955 Giant's intervals began to lengthen, resulting in dormancy a few months later. With the increasing length of Giant's intervals there was a noticeable increase in activity in the Grotto Group. At about 10 hour intervals the Grotto began to have eruptions during Giant's quiet phase, which had now lengthened from 7 to 10 days. Grotto Fountain became reactivated. All eruptions of Grotto were preceded by Grotto Fountain by about 2 minutes.

From 1956 to the time of the earthquake Grotto was in an active phase fully half of the time. However, the duration of the eruptions showed a much wider range than previous to Giant's active cycle. At one time I observed an eruption of Grotto which lasted for but 45 minutes. On another occasion an eruption was checked which lasted in excess of 15 hours. In 1958 in late season most of the intervals increased from about $1\frac{1}{2}$ to 3 hours to near 8 hours. The duration of the quiet phase closely corresponded to the length of the active one. The behavior of the springs in the Grotto Group during this period furnishes additional evidence of the varying, shifting and complicated patterns of activity which characterize a system of hot springs containing many geysers connected subterraneously. In the intertwining Giant and Grotto Groups fourteen of the springs are known to be geysers.

1959 Earthquake

During the pre-earthquake period in 1959, as in 1958, Grotto was active about half of the time. The active and quiet phases were both about 8 hours in length. Immediately following the big tremors the active phase showed considerable increase over the quiet phase. Due to the duration of an eruption, and the limited opportunity for checking, it was difficult to determine how long most of the eruptions lasted. It is certain that the great majority continued for more than 24 hours. One active phase, by means of a recorder, was determined to have lasted for about 45 hours. The quiet phase seemed to vary between 8 and 12 hours. The marked increase of the active over the quiet phase is revealing of the extent of the increase in thermal energy.

During this period of greatly increased activity of Grotto the eruptions did not seem any more forceful; also the discharge seemed to be of about the same rate as before the earthquake. In September of 1959 two days were spent at Grotto in making weir measurements of discharge. Considerable difficulty was experienced in channeling the water through the weir. The figure arrived at was 470 gallons per minute. At this rate

Grotto would discharge 676,800 gallons during an eruption lasting for 24 hours. This would compare with about 242,000 gallons for Old Faithful during an equal period. Apparently Grotto is connected with a copious water supply.

The great increase in thermal energy shown by Grotto during the first few months following the earthquake was less pronounced during 1960. None of the 24 and more hours of protracted play occurred. The duration varied between about 1 and 12 hours. The active phase was still of greater duration than the quiet one. By 1963 the active and quiet phases were again of about equal length.

During the first few years following the earthquake Grotto's indicators were very active, especially Grotto Fountain. It preceded Grotto anywhere from 3 to 8 minutes. Occasionally the small geyser south of Grotto Fountain would act as a precursor. During recent years activity of the indicators has subsided.

Beginning in 1962 and persisting through 1969, it was observed that when a series of one to two hour intervals occur the indicators never fail or function preceding an eruption of Grotto. The only logical conclusion I can draw from this is that short periods of play are but separate parts of a single eruption.

Grotto is known to be connected with the Giant Complex, which consists of not less than eleven units. In its own grouping there are connections with Rocket, Spa, Indicator Spring, Grotto Fountain, South Grotto Fountain and an unnamed spring.

Indicator Spring

G8-935E, 310S

GROTTO GROUP OF UPPER BASIN

The water level in this spring fluctuates with the quiet and active phases of Grotto. At the time an eruption of Grotto approaches Indicator's crater usually will be nearly full. The crater empties during Grotto's active period.

It was observed in 1954 that by the time the water level in the Indicator was within about an inch of the top of the crater an eruption of Grotto was imminent. The rise of the water was gradual, being about 4 inches per hour. Following the 1957 season and to date the Indicator has been less useful in predicting Grotto. The rise of the water level in Indicator before an eruption of Grotto has undergone some change and modification. After the water reaches about maximum rise there will be 2 to 4 periods of ebbing, amounting to about 4 to 6 inches, before Grotto finally erupts. Also, Grotto will erupt at times before the Indicator fills.

During Grotto and Rocket's active phase some of the discharged water which flows down the north channel pours into Indicator's crater.

Naugle

Riverside Geyser

F7- 140E, 8455

GROTTO GROUP OF UPPER BASIN

Early References

There is no record that Riverside was one among the great array of big geysers observed by the Washburn Party at the time of their memorable discovery of the Upper Geyser Basin in 1870. The following year the U. S. Geological and Geographical Survey Party, directed by Dr. F. V. Hayden, observed it erupting and gave it its present name. During 1871 it was also observed by Captains Barlow and Hearn, Topographical Engineers of the U. S. Army. They named it "Well geyser." They conducted their investigations of the hot springs at the same time as the Geological Survey. These two parties, however, worked independently of each other,

To Barlow and Hearn goes the distinction of being the first to leave a description of Riverside. After having described an eruption of Fen Geyser they state:

"One hundred yards farther up the east side of the stream is found a double geyser. A stream from one of the orifices plays to a height of 80 or 90 feet, emitting large volumes of steam. From the formation of the crater it was named 'Well' geyser" (1871, p. 27).

References to Riverside, and to many geysers by early observers, scientific parties not excepted, reveal a great deal of confusion as to identity and performance. Professor T. B. Comstock of the Jones expedition wrote as follows:

"A little below Grotto, across the river, a geyser which is situated near the edge of the stream began to spout at 2:43 p.m. This known as the Riverside Geyser. A jet of fine spray was suddenly thrown more than thirty feet into the air, which continued quite steadily until 2:47.5 p.m, when it ceased acting for half a minute. At 2:51 p.m. it roared loudly and became quiet at 2:56 p.m., after which no action occurred.

The Riverside has a low irregular mound, with a small chimney scarcely rising near its centre " (1875, p.252).

It is reasonably certain that the geyser which Comstock saw and described was Mortar and not Riverside. The description is not applicable to Riverside's mound or its eruptive activity. It does, however, describe both the structure and function of Mortar. Intermittent play during the eruption, with periods of loud roaring, fits Mortar in toto. Riverside is "a little below Grotto, across the river." Both geysers are about equal distance from Grotto and "near the edge of the stream."

Additional evidence that Professor Comstock saw an eruption of the then unnamed Mortar and not Riverside is found in the fact that Fan was erupting in concert. In reference to this Comstock states:

"This (eruption of the Fan) began at 2:43 p.m.. almost precisely at the moment when the eruption began in Riverside.....This record shows a remarkable similarity or sympathy between Fan and Riverside" (1875. p. 252).

The error that Fan and Riverside could be expected to erupt simultaneously was perpetuated by authors of guide books during the 1870's and 1880's. It grew out of Comstock's erroneous identity of Riverside. In commenting on the above observation of Comstock, Dr. Hayden wrote: "The simultaneous action with the Fan was probably only a coincidence, as during the eruption of the latter, seen by myself in 1878, the Riverside was silent" (1878, p. 194). In making this observation Dr. Hayden evidently had in mind the Riverside his party had named in 1871. He was unaware that Comstock was describing an eruption of Mortar, which he assumed was Riverside.

There are no data that are at all suggestive of a sympathetic relationship between Fan and Riverside Geysers. On the other hand, observation has conclusively demonstrated that a pronounced sympathy exists between Fan and Mortar Geysers. I have never observed a major eruption of Fan unaccompanied by simultaneous of Mortar.

During the first decade or two of the park's history there were no signs identifying the locations of named hot springs. This resulted in considerable confusion. Regarding Riverside, not only did Comstock confuse it with Mortar, then unnamed, but H. J. Norton described Fan thinking it to be Riverside.

"The next that will be visited is the Riverside Geyser, several hundred yards from the Grand, and in the very water's edge of the river. Like the Sawmill, it is an almost constant spouter, but does not throw its jet to any great height" (1873, p. 65).

The first specific reference that Riverside was properly located is found in a guide book of 1883 "The Riverside is 450 feet above, or just south of the Fan, just above the bend of the river" (Winser 1883, p. 53).

Description of the Mound

The Geological Survey during its 1879 study of the hot springs went into elaborate detail in describing the mounds or cones of many of the geysers. Its description of Riverside's is, not only brief, but lacking in usual definiteness. "It has a low irregular mound with a chimney in the center. It has two orifices and spouts at intervals that are undetermined" (1878, p. 194). "A low irregular mound with a chimney in the center" is not at all descriptive of Riverside. It better fits nearby Mortar. Both Riverside and Mortar have two orifices, but "a mound with a chimney in the center" can apply only to Mortar. It seems probable that when field notes were being assembled descriptive data became mixed up. Other observers described Mortar thinking it was Riverside. "The crater stands on the summit of a mound that has been built up in six or more terraces, each smaller in area than the former one, thus making a curve with the edges of the terraces rounded off" (Haupt, 1883, p. 105). Guutil's description is quite naive. "The crater is an unpretentious hole in the ground with an occasional puff of steam" (1890, p. 70).

In 1958 I made some detailed observations and measurements of Riverside's mound which are as follows: The mound rises abruptly from the water's edge on an elbow of a meander of the Firehole River. The mass of sinter which constitutes it is situated abreast of an older, badly eroded thermal deposit. It is apparent that Riverside is a successor to an extinct spring of much earlier date.

A partial destruction of the older mound has resulted from the erosive action of the river, whose course is directly squarely against it. The bed of the stream at this point rests on cemented glacial gravel and sinter of much earlier origin than Riverside's. When the situation here is compared with other thermal springs bordering the river in the Upper Basin it becomes evident that the Firehole at present is incising itself into a new bed, a bed, which for the entire length of the basin is in a sinter which antedates all current functional springs.

The general configuration of Riverside's mound, when viewed from the opposite side of the river, is that of a draped, low-backed chair. The section from which the eruption issues (the basal or seat section of the chair) appears cylindrical in form; the rounded appearance results from the long axis being at a right angle to the river. When viewed close up, on the upstream side, the mound looks more like a sofa than a chair.

The mound sits in the water's edge and rises vertically 10 feet 6 inches above the bed of the river. The front over which the pre-eruption overflow drops is covered with beaded geyserite which shows evidence of frequent spalling resulting from the extreme cold of Yellowstone winters. The arc of the seat, or top at the point of overflow, is 19 feet 2 inches. The seat of the chair, which will be designated the platform, is at an approximate 90 degree angle from the front. The platform, the section where the eruption issues, is oblong in shape, the long axis being 16 feet 8 inches, the short 11 feet 6 inches. The main crater is situated near the river side of the platform, being back 33 inches from the edge.

The orifice from which the eruption issues is somewhat ovate in shape. At the surface it is 45x55 inches and at a depth of 28 inches constricts to 20x24 inches. From the constricted portion the crater extends vertically another 52 inches in the form of an antechamber where a vent about 6 inches in diameter is encountered. This vent is not directly under the main orifice, resulting in the erupting water striking a portion of the overlying platform, thereby deflecting the column away from the vertical.

Two additional vents puncture the platform. They are directly in line and to the east of the main crater. The larger vent is 24 inches from the main orifice and is 12x18 inches; the smaller one is 80 inches distant and is 2x2½ inches. Activity in the smaller vent serves as an indicator to an eruption of Riverside. Directly back of the small vent, and on the side of the old crater, there is a small crack from which water issues during the early part of an eruption.

There are two large orifices on the mound, an upper and the lower one from which the eruption issues. The upper crater, situated on the river side at the top of the back of the chair or sofa, is in an oblong mass of sinter which rises 56 inches above the platform. From the upper orifice the sinter, like a raised chair arm, curves backward 17 feet 6 inches where it abuts the earth of the hillside. The downstream side of the mound is sheer and shows weathering.

The upper crater is more nearly circular than the lower; it is also more cavernous, expanding into the shape of a barrel immediately below the orifice which is 34x36 inches. During the quiet phase the water level, except at the time of splashing from the upper vent, is the same in both craters. The observer unfamiliar with Riverside almost invariably expects the eruption to take place from the upper vent. The structure of the raised section of the mound, and the state of the sinter composing it, make it reasonably certain that during an earlier period there was much more activity than during the current period. During post-discovery time erosion has been in ascendancy over deposition on this section of the mound.

The base of the mound, for the first 33 inches, consists of gravel that has been cemented by hydrated silica and so altered by steam as to take on the texture of dense opalized sinter.

Lack of Early Observation

Despite the fact that Riverside has approached regularity to a high degree during all of its known history, and that due to its location and manner of play it is a geyser of signal beauty, it was not given the same critical focus by early observers as were Splendid, Giant, Grand, Beehive and others. Evidence of this is found in the scarcity and nature of Riverside references. Unless it were in a state of eruption most of the early observers passed it by, deigning it scarcely a glance. The following references are in effect: "When quiet, however, there is little about it to attract the attention of the passer along the trail" (Jones, 1875, p. 252). "It is somewhat out of the way, and unless seen in action would not be taken for a geyser of any importance" (Hayden, 1883, p. 194). "There is little about its crater to attract attention" (Riley, 1890, p. 110). It is an inconspicuous object when not in eruption, and one would scarcely suspect it as being a geyser" (Chittenden, 1895, p. 228).

That Riverside was still being largely ignored, even by park officials, as late as 1896 is made evident by a project carried on by Acting Superintendent Captain George S. Anderson. Captain Anderson was interested in trying to determine how regular the geysers were. During the 1894-96 seasons he had records made of the eruptions of geysers where any regularity might be suspected. Relative to this project is the following statement:

"I have the guards keep a table of geyser eruptions. Of course this is not complete, as they take no account of eruptions during the hours of darkness. I have appended it to this report as principally useful in showing that there is very little regularity of period among any of them except Old Faithful" (1896, p. 13).

No tabulations were made of Riverside's eruptions, yet it perhaps more than any big geyser, Old Faithful not excepted, would have approached regularity.

Overflow as Indicator of Activity

Early references to Riverside by those who were endeavoring to portray its manner of activity reveal that no systematic observations were made. Knowledge of it, as of other geysers, came piecemeal; a long time being required to patch together scattered observations. There are

no known records which are indicative that the frequency and duration of its function were systematically observed before 1912. It was 20 years following discovery of the hot springs before any writer in giving information to park visitors of what to expect of Riverside pointed out that overflow from the crater is indicative of pending activity. "An overflow of water is a certain indication of approaching activity, occurring about thirty minutes previous to eruptions and continuing until the outburst" (Guptil, 1890, p. 70).

Other references and known facts about Riverside, however, are highly suggestive that Guptil did not observe the full time of overflow of some particular eruption he described. It seems probable that he came in sight of the crater thirty minutes previous to the eruption and noted the overflow during the period he put in waiting; and then jumped to the conclusion that overflow precedes an eruption by "about thirty minutes." This inference is made probable from many experiences I have had relative to this and similar situations. Neophite rangers report times of eruptions of geysers as being when they first came in sight of the activity and not the precise time when the eruption began. This is especially true of eruptions of relatively long duration, as those of Castle, Great Fountain, Grand, Riverside, etc.

That the time of overflow was still indefinite as late as 1909 is indicated by a guide book reference. "If there is any water running over the top you may expect action in a very little while" (Campbell, 1909, p. 110). In 1901 Olin Wheeler spent considerable time in the Park seeking information for a guide book he was writing. Relative to the overflow of Riverside he states:

"The Riverside is one of the few geysers that has an indicator that tells the time of eruption. I have sat for an hour or more on the geyser's cone and watched the progress of events up to the grand finale" (1901, p. 74).

Wheeler's statement shows indefiniteness as to the length of overflow, as does Campbell's. However, he does indicate a much longer period of overflow than was given by Guptil in 1890. This supports my statement relative to Guptil's observation.

It can be seen from the above references that Riverside was still without sufficient systematic observation, even at this period, so that a clearcut statement could be made of the duration of pre-eruption overflow. That it was variable then as now goes without question, but the range of the duration of overflow was apparently unknown by writers of the period under consideration; if it were there is no statement to that effect. The earliest reference I have been able to find to observations directed toward determining the exact time of overflow are the 1930 observations (Geology File) made by Park Naturalist

H. T. Lystrup. It seems highly probable that observations similar to Lystrup's were made in the 1920's, but no records are extant.

During most seasons, since at least 1930, the time of the beginning of overflow has been one of the objects sought by those who are trying to predict when Riverside might erupt. The duration of the overflow, like other factors is not a constant. However, there are periods ~~lasting~~ lasting for several weeks when there will be but a few minutes variation in duration of overflow from eruption to eruption. It is only since 1930, and then not for all seasons, that data are available for determining duration of overflow. These data are of considerable interest because they indicate there is a marked correlation between the time of overflow and the length of the interval. The table is further revealing of Riverside's seasonal average during its known history.

Year	Average length of overflow hours - minutes		Average length of interval hours - minutes	
1930	1	38	7	23
1931	1	44	7	28
1932	1	58	7	52
1933	2	40	8	58
1934	2	--	9	20
1935	3	--	9	17
1936	1	45	7	25
1937	2	30	8	30
1938	2	18	8	10
1939	2	14	8	8
1940	1	48	7	52
1941	1	48	7	51
1942	1	46	7	26
1943	1	45	7	25
1944	1	45	7	25
1945	1	41	6	59
1946	1	44	7	11
1947	1	46	7	26
1948	1	40	6	59
1949	1	43	6	54
1950	1	42	7	2
1951 (pre quake)	1	38	7	32
1952 (post quake)	1	22	6	28
1953	1	23	6	36
1954	1	45	7	8
1955	1	46	7	12
1956	1	42	7	6
1957	1	18	6	20

(cont)

Year	Average length of overflow hours - minutes		Average length of interval hours - minutes	
1965	1	22	6	21
1966	1	25	6	27
1967	1	21	6	18
1968	1	17	6	17
1969	1	18	6	14

Appended to this table are all earlier references which are indicative of seasonal average time

1882	2 to 3 times each day	1921	7	30
1883	2 to 3 times each day	1922	7	30
1890	about 8 hours	1925	7	45
1909	6 to 7 hours	1926	7	45
1910	About 7 hours	1927	8	--
1912	6 to 7 hours	1928	7	30
1920	7 hours			

Regularity

Available references to Riverside make it reasonably certain that during post-discovery time there has been little variation in its behavior. What variation there has been would seem to have resulted from periodic shifts in the length of the eruption interval. As to the duration of the activity, as well as the height of the eruption, there is essentially no difference today from the eruption observed by Dr. Peale in 1871, which observation resulted in the name Riverside.

Like Old Faithful, Riverside has shown a high degree of regularity during its known history. Unlike Old Faithful, some seasons it shows greater fluctuation in average time. A season during which the average time might be near seven hours might be followed by one when the average shifts an hour over or under this (see table). Usually the shifts to longer or shorter intervals occur somewhat abruptly, then for months there will be but slight variation from the new average. The nearest to a set time of performance I have noted was during the 1949 season. From late May until August 22 the average held at eight hours. It became a habit that season to go to Riverside near three o'clock each afternoon. Following August 22 the average interval for the remainder of the season shifted to seven and one-half hours. The 1948 pattern was very similar to the 1949 one. There is an occasional season, as during 1952, when some difficulty is encountered in predicting eruption time. Instead of the eruptions occurring near

average there will be a daily fluctuation from near minimum to near maximum time.

Just why some seasons all ~~all~~ eruptions occur about every 6 or 7 hours while during others the intervals will be nearer 9 hours is uncertain. No doubt more than one factor is involved in bringing about this periodic waxing and waning in thermal intensity. The 1912 Haynes Guide makes the following comment: "Sometimes eruptions take place as frequently as five and one-half hours for a period of several days, probably on account of the increased water supply" (1912, p. 60).

At present there are no data for determining any relationship between frequency of eruption and water supply for any of the geysers in the Firehole basins. The fact that Riverside's shifts from long to short averages, and vice versa, come suddenly, and at any season of the year, suggest water supply as being an unimportant factor. In winter the replenishment of water supply would seem to be less than in spring or summer, yet there are observational data (Marler 1954, p. 52) to the effect that Riverside might erupt more frequently in winter than in summer. The activity of the Firehole hot springs over the years indicates a remarkably stable year-round water supply.

The correlation that has been discovered between length of pre-eruption build up and length of interval is highly suggestive that during those periods when the average is eight or nine hours the available thermal energy is less than when the average is, say near six hours. If the behavior of numerous other hot springs may be taken as a clue to the vacillating condition in Riverside there is a chance that it might be connected subterraneously with some other hot spring. A periodic shifting to or away from Riverside of some of the thermal energy would logically account for its shifting to longer or shorter periods (Marler, 1951, p. 334). To date no evidence has been discovered that indicates sympathy exists between it and any other thermal unit. This occasional shift in length of interval furnishes an interesting challenge for future study.

Pre-eruption Symptoms

Following an eruption of Riverside progressive changes transpire, leading up to the next eruption. Following activity the visible portion of the well is empty. About two hours later water can be seen in the bottom of the antechamber, which is 80 inches below the platform. The rise of the water in the well is quite steady. To one familiar with the rate of rise (it differs some seasons, varying with the decrease or increase in time of overflow), relative accuracy in predicting the time of overflow is possible. When the well is filled

to the level of the platform the overflow starts, drop at a time, but within a few minutes near maximum rate of flow is reached. From then until the eruption there will be periods of momentary waxing and waning in the flow; also occasional pauses, lasting a few seconds, when the overflow will entirely cease. In general the overflow precedes the eruption anywhere from about one to two hours.

During the period which follows maximum rate of overflow, which comes near the beginning, it is difficult to ascertain how long it has been in progress. However, the observer is not without additional signs. Usually about 40 to 50 minutes preceding the eruption water will splash from the upper crater. This is generally followed, at indefinite periods, by succeeding splashes. There are some eruptions, and some seasons, when the surges from the upper crater do not occur until within about 15 to 20 minutes of the eruption. I have observed a few eruptions when the splashing did not take place until immediately preceding the eruption. For the great majority of eruptions, periods of preliminary surging are characteristic.

During the overflow there are additional indications of pressure build up. From 30 to 40 minutes (longer some seasons than during others) before an eruption before an eruption water will start playing about 10 inches high from the small indicator vent back of the main crater. This play is continuous until the start of the eruption. On rare occasions the vent will not function until the start of Riverside.

This was the case during the winter and spring of 1958. Since the 1959 earthquake this indicator has varied from 3 to 4 minutes to over an hour.

Occasionally, but infrequently, the pre-eruption symptoms fail to trigger an eruption. The eruption which seemed imminent does not materialize. In this respect Riverside shows a characteristic shared by Old Faithful. Delay in eruption time, and over-average length intervals, are always the result. In the case of Riverside the eruption is usually delayed about half an hour; it requiring approximately that time for recovery of lost eruption potential.

An Eruption

Following the sudden surge of water in the overflow crater, and heavy splashing from the upper, the water column, at an angle of about 20 degrees from the vertical, explosively ascends to maximum or near maximum height. If no wind is blowing against the column sheets of falling water span a considerable portion of the river. With proper time of day, and position with reference to the sun, beautiful spectral colors in the falling droplets add to the loveliness of the scene.

The water plays to near maximum height for about five minutes. From then until the end of water ejection, which in total time is about 20

minutes, the water column slowly subsides in height. Following the water phase of the eruption a weak steam phase is in evidence for an additional five to eight minutes.

For the first ten to twelve minutes of the eruption both the large and small vents back of the main orifice are erupting simultaneously with Riverside. The indicator vent ejects mostly steam, a considerable portion of the sound of the eruption being due to this vent. The indicator vent is the first of the three to cease activity. The vent next to the main orifice plays about 3 to 4 feet high and at about the same angle, but directly opposite to Riverside.

Due to the fact that the water of an eruption falls directly into the river no attempt has ever been made to ascertain the volume discharged. Height measurements are also lacking. In 1871, at the time Riverside was named, Dr. Peale estimated that "it plays to a height of 80 or 90 feet." Other observers since that date have made similar estimates; the guesses range between 60 and 100 feet. The majority of observers place the height at approximately 75 feet.

Many of the early descriptions of the eruptions of the important geysers present highly verbose pictures. The vocabulary of the writer would seem to have been dipped deeply into in search of the superlative. Strangely, in the case of Riverside, these wordy portrayals are wanting. The earliest reference that is expressive of esthetic appreciation is by Olin Wheeler.

"The Riverside is a captain. The water is thrown out in crescentic or arched shape, and when at its full power the water arch spans the stream, the entire volume being thrown into the river. Great quantities of beautiful crystal beads fly centrifugally from the arch and a beautiful rainbow is always seen, unless the day is cloudy" (1901, p. 74).

Another appreciative observer:

"Altho the beauty of its setting is somewhat marred by a very prosaic sandpit* in the background Riverside is without doubt the most attractive pictorially of all the geysers in the Park. Its appeal is wholly romantic and the sense of awe and wonder that is so prevalent in the thermal regions here gives place to one of esthetic pleasure" (Phillips, 1927, p. 138).

* Not only were early writers less moved by Riverside than by other geysers, but park officials and road engineers have shared a similar lack of responsiveness. The "prosaic sand-pit" referred to by

When it comes to setting, Riverside is certainly one of the most fortunate among the geysers. Its position on the very edge of the Firehole River, with the column of water arching over the stream, plus the coniferous-forest background, make it a photographers delight. The activity is of sufficient duration to permit shifting of position to whatever angle presents optimum observing and photographic possibilities.

None except one who is immune to manifestations of beauty in Nature can remain unmoved and unappreciative when Riverside, under proper atmospheric conditions, rises into the sunshine. Not only is it a "thing of beauty," it is Yellowstone's only musical geyser, "it plays over the waves."

Effects of 1959 Earthquake

As a result of the 1959 earthquake Riverside's average interval was shortened about one hour. For the first few days following the August 17 incident the intervals were near 5 hours, following which they began to gradually lengthen. By late 1959 the average had increased to 6 hours and 25 minutes. During the 1960 season the average interval was 6 hours and 35 minutes. During the following three seasons the average was about 7 hours and 10 minutes; shortening close to an hour during 1964. Including the 1964 season, and to the end of 1969, the average was near 6 hours and 20 minutes. The 1969 average, 6 hours and 14 minutes, was the shortest seasonal average on record.

Each season for a period of about 5 to 7 days the intervals on Riverside will suddenly shorten from about 30 to 60 minutes. Following this period of increased activity the intervals will as abruptly shift back to the same average as before the shortening occurred.

As closely as could be determined the water in Riverside did not become murky as a result of the earthquake.

Phillips is a large excavation made in the gravel embankment abutting Riverside. The pit is directly back and edging up to the mound. While this unsightly scar still remains, nature is beginning to efface some of its ugliness with grass cover and new Lodgepole Pine.

Rocket Geyser

GB-910E, 445S

GROTTO GROUP OF UPPER BASIN .

It is not known who named Rocket Geyser or when. In the early history of the park it was considered to be a part of Grotto and any reference to Grotto included Rocket. Grotto was named in 1870 by the Washburn Party. As a functional unit the two craters always erupt simultaneously. There is not only this close functional relationship, but a raised bridge of sinter connects the two cones.

In describing Grotto, Hayden refers to Rocket as "Cone No. 2." He states that it "is 19 feet in diameter at the base and 14 feet at the top. It is 4 feet in height, and has a quadrangular orifice measuring 3 by 5 feet, in which the water during quiescence is from 10 to 15 feet below the top. The basin is 16 feet in depth. On the east side there is a slight depression in the rim" (1878, p. 191).

During the years I have observed Rocket and Grotto Geysers I have never seen any independent action on the part of either, except when there is a major eruption of Rocket. The instant water starts gushing from Grotto there is simultaneous action in Rocket. During an eruption of Grotto the activity in Rocket is characterized by steady jetting and splashing, the heights varying between about 4 and 10 feet. Except on infrequent occasions this steady, minor performance seemed to be the nature of its activity previous to the 1959 earthquake. However, once in a while during some eruptions of Grotto, Rocket, for a short period, would perform spectacularly.

"A hundred yards up the road is a pair of geysers so intimately associated that they are always mentioned in the same breath, 'Grotto and Rocket'. . . Ordinarily neither geyser reaches an elevation of more than ten or fifteen feet, but several times a year the Grotto will suddenly cease playing and Rocket sends up a column that may reach a hundred feet for a few minutes. This is perhaps the rarest of all the normal phenomena of the Upper Basin and to see Rocket play is the finishing touch of a thorough acquaintance with the geysers" (Phillips, 1927, p. 139).

Previous to the 1959 earthquake it was on rare occasions that I observed what could be called major activity of Rocket. Since the earthquake I doubt if there is an eruption of Grotto which lasts for an hour or longer, during which there will not be one or more major displays of Rocket. The longer the duration of Grotto the more eruptions of Rocket are likely to occur.

Major activity of Rocket generally occurs after Grotto has been erupting for about 45 minutes. It is initiated by a sudden burst of water equalling the size of the diameter of the crater. Water in great volume is rocketed to heights varying between 30 and 40 feet, one surge following another. There is a very heavy discharge, the hillside being flooded. The eruption lasts for about an even 4 minutes.

The instant Rocket begins its rocketing performance the action in Grotto practically ceases. It remains quiescent until the end of Rocket's major display, it then immediately resumes its splashing-type eruption.

The height of "one hundred feet" as given by Phillips is a much greater height than any eruptions I have observed.

Rocket is connected subterraneously with all springs in the Grotto Complex.

Rocket Geyser

G8-910E, 4458

GROTTO GROUP OF UPPER BASIN

Rocket and Grotto Geyser are essentially a single functioning unit. Sinter not only connects them at the surface, but direct fissure connections at depth result in a pronounced sympathy of action. Both erupt simultaneously and for the same duration. The Rocket never erupts except in conjunction with Grotto.

There are a number of early references which are descriptive of Rocket's crater, but none describes an eruption as being something apart from Grotto. This is due to the fact that the name Rocket is of later application. A single reference will suffice to show that any activity of Rocket was considered to be of Grotto. "Several of the first explorers crawled through the sinuous apertures when all was quiet. It seems as harmless as curious then, but their opinion was changed slightly when they saw it an hour after throwing a column of water six feet in diameter to a height of sixty feet" (Richardson, 1900, p. 157). Rocket alone sends up "a column of water six feet in diameter to a height of sixty feet". Richardson's description is applicable only to a major eruption of Rocket.

Rocket has both minor and major eruptions. The minor ones start instantaneously with Grotto. Like Grotto's, the eruption is characterized by continuous splashing which varies in height between about 5 and 8 feet. I have never observed a major eruption to occur until about 45 minutes after the start of Grotto. During active periods of Grotto, lasting for 8 or more hours, 3 major eruptions of Rocket are the most I have observed. At the time of one of these major eruptions water suddenly grows voluminous and shoots upward. At this instant all splashing ceases from Grotto. The duration of a major eruption is from near two to four minutes. At its termination both geysers resume the splashing activity.

I have observed numerous eruptions of Rocket as above described. I judged the height to be between 30 and 40 feet. During the 1920s Ranger Charles Phillips reported: "Rocket may occasionally reach one hundred feet in height" (Phillips, 1927, p. 139). Phillips was a seasoned and astute observer. In giving 100 feet as the height of the eruption he might well have been passing on accumulated geyser lore. This explanation seems plausible in view of the fact that many seasons have been known to pass without a major eruption being observed. Phillips might never have seen one.

Rocket shared in the same increase in activity as Grotto following the earthquake. Since the earthquake major eruptions of Rocket have been much more common than during previous seasons when I have been in the basin. Its underground connections are the same as Grotto's.

Spa Geyser

G8-875E, 220S

GROTTO GROUP OF UPPER BASIN

By whom or when Spa Geyser was named is unknown. It is the northernmost of the springs which shows a definite response to an eruption of Grotto; also Giant, with which geysers it is connected underground.

At an early date I became aware of a relationship existing between Spa and Grotto. Whenever the latter erupted the crater of Spa would fill and minor eruptions would ensue. The eruption and overflow would not begin until near the termination of Grotto's activity. The boiling and heavy overflow of Spa would last from about 60 to 90 minutes. During early observations the above described relation between Spa and Grotto was unvarying.

During the 1920s observations of park personnel led to the conclusion that Spa and Grotto were connected underground.

"On the left side of the highway (going in the direction of Old Faithful) is the Spa, named after a type of mineral spring in central Europe. This Spa, needless to add, lacks the curative powers of its namesake. It is a semi-geyser and surges up and overflows at irregular intervals. The writer's observations lead to a conclusion that there is some relation between it and Grotto altho the activity of the two is not always simultaneous" (Phillips, 1927, p. 138).

Earlier descriptive references to Spa seem to be completely lacking.

During the eruption cycle of Giant Geyser in the 1950s, Spa, like Grotto, underwent considerable modification in its behavior. During the 1951-1952 seasons, Spa, Grotto and Rocket would always erupt simultaneously about 45 minutes after Giant's activity ceased. Occasionally jets of water would rocket from Spa to heights varying between about 30 and 40 feet. During 1953 the behavior of Spa was on a very different pattern than in 1952, or for any previously

observed season. Instead of playing in concert with Grotto it erupted independently and for much longer periods. During 1952 the overflow from Spa would last about 45 minutes. During 1953 it would persist from 3 to 6 hours. The activity of Spa seemed to be the most important factor in accounting for irregularity of Giant. In 1954 Spa's activity was very pronounced following most of Giant's eruptions. During the typical boiling and heavy overflow, which characterizes most of Spa's eruptive activity, water would frequently be rocketed 20 to 50 feet in the air. No season before or since have I seen as much major activity. Most of the minor eruptions were accompanied by rocketing jets. During 1955 and 1956 Spa would frequently start overflowing about the time an eruption of Grotto Fountain and Grotto was imminent. Whenever this occurred their eruptions would be delayed several hours. Occasional major activity of Spa was observed until the time of the 1959 earthquake.

The morning following the earthquake the water in Spa was murky. However, due to long periods of overflow it soon cleared. Apart from the murky water the earthquake did not seem to have any effect on Spa unless it was to diminish the frequency of major bursts. Since the earthquake the same relationship has existed between it and Grotto as previous to Giant's eruption cycle. Since 1959 some seasons have passed with no major eruptions of Spa having been observed. None has been recorded since the 1967 season.

Minor eruptions of Spa are characterized by boiling, which is continuous for the period of overflow. During the boiling the water surges from about one to three feet in height. When major bursts occur it is only during the boiling period. These bursts come suddenly, rocketing the water, usually, from about 30 to 40 feet in height. Major activity lasts from about one to three minutes, during which several rocketing jets will occur.

7

Bijou Geyser

G9-260E, 825S ✓

GIANT GROUP OF UPPER BASIN

I know of no reference stating when or by whom Bijou was named. For many years it was called Young Faithful Geyser. Who first used this name is somewhat in doubt. However, as a name, it would seem to hold priority over Bijou, as the following indicates:

"This geyser is on the platform with the Giant. I do not know how or where it obtained the name (Young Faithful), but it is so called in Dunraven's Great Divide; (1875) and as this designation is the only one it has had, as far as I can learn, I have retained it. It has a mound of beautifully beaded geyserite, rising 6 feet above the level of the platform, or terrace, and having a circumference of 232 feet at the base. . . . This geyser acts somewhat continuously, with irregular spurts from 10 to 20 feet. It is probable, judging from the deposits about it, that it has periods of action that would place it among the important geysers" (Hayden, 1878, p. 198).

Another early reference is revealing that, at least until the time of the 1959 earthquake, the nature of Bijou's activity remained very much the same over the years.

"Our party was interestedly inspecting the Giant and a small geyser close by, which was continually in eruption, and made as much fuss over its twenty-foot stream, as if it thought it the only spouter in the basin, and the National Park had been reserved on purpose for it to 'ebulish' in" (Norton, 1873, p. 29).

Until the post-earthquake period (with the exception of the 1957 season), Bijou was in an almost constant state of eruptive activity; the water jetting from 5 to 15 feet in height. The only occasions when neither steam nor water was observed issuing from the orifice were following an eruption of Giant. Then all units on the platform appeared as if the last shred of energy had been wrung from them. Following Giant's activity it was 3 to 4 hours before Bijou began its steady jetting.

During Giant's last eruption cycle, which began in September 1950 and continued until late 1955, the pattern of Bijou's activity in relation to Giant underwent change. At the time of Giant's hot periods, previous to early 1952, there would be enfeebled or at times no action of Bijou. However, at the conclusion of a hot period it would go into a violent steam phase which would last for several minutes before jetting was again resumed. After 1951 its relation to Giant was somewhat different than previously. As a preliminary to an eruption of Giant, Bijou would erupt with some vigor, the height being about 30 feet. There was a comingling of water and steam.

With the exception of the 1960 season there has been a gradual decline in the frequency and forcefulness of Bijou's eruptions. During most of the 1970 season it was practically dormant. The following reference is presently not applicable. "He (Giant) is surrounded by a number of noisy retainers, of whom one named Young Faithful is the most vociferous" (Riley, 1890, p. 93).

There is no question but that Bijou is connected underground with the entire Giant Complex.

Catfish Geyser

G9-240E, 830S ✓

GIANT GROUP OF UPPER BASIN

The mound of Catfish is a part of the mound of Bijou, being situated on the western side. The top of the crater is about 3 feet lower than Bijou's. The shallow basin of the crater is about $2\frac{1}{2}$ by 6 feet. There are two orifices in the bottom, separated by a septum of sinter. During an eruption water issues from both vents.

The literature is practically silent on Catfish. As a geyser it seems to have been largely ignored. During the pre-earthquake period I observed that during the quiet phase of Giant, Bijou and Catfish were in a near constant state of activity. The latter erupting to a height varying between about 3 and 5 feet. However, when Giant was in an eruption cycle Catfish would show much greater animation at the time of Giant's hot periods.

Until July 18, 1951 at the conclusion of one of Giant's hot periods Catfish would erupt with considerable vigor; the height being about 15 feet; the eruption lasting several minutes. On July 18, and for the rest of the season, when the subterranean pressure had shifted to the north side of the platform, Giant's eruptions would always be initiated by those of Catfish and Mastiff. At times Catfish would erupt to heights comparable to those of Daisy Geyser. On July 23, 1951 Catfish alone preceded the eruption of Giant. This eruption lasted for 10 minutes. Catfish had turned into a major geyser. Water in a steady stream maintained a height of about 75 feet. The great pressure of the eruption resulted in considerable roaring. The volume of water discharged must have equalled, or exceeded that of an eruption of Old Faithful.

In early January 1952 the subterranean pressure beneath the platform shifted to the south. From then, and for the remainder of Giant's eruption cycle, which ended in late 1955, there was no more major activity of Catfish. However, at the conclusion of an eruption of Giant, Catfish would erupt to a height of about 15 feet.

Since the 1959 earthquake Catfish has been in a near dormant state. It is only on rare occasions that water has been observed to splash above the rim of the crater.

See glass

Giant Geyser

G9-225E, 885S

GIANT GROUP OF UPPER BASIN

Giant's Cone

The earliest description of Giant's cone was by a member of the Washburn Expedition. "The Giant is a rugged deposit presenting in form a miniature model of the Colosseum. It has an opening three feet in Diameter" (Langford, 1870, p. 110). A more detailed description is found in an 1872 report:

"It is 500 yards northwest from Grand Geyser, on the opposite side of the river, near the water's edge. It has a rough cone-like crater, 10 feet in height, measuring 24 by 25 feet at the base. The top is about 8 feet in diameter, the orifice from which the water is projected being about 5 feet in diameter. This cone is situated on a platform of geyserite, which rises 4 feet above the surrounding level and has a circumference of 342 yards" (Hayden, 1872, p. 152).

In his report Hayden further elaborates on the cone:

"This crater is broken down on one side, as though it had been torn away during an eruption of more than ordinary force. On this side one can look into the crater if he can manage to avoid the jets which are being continually spouted from it. The crater is dark-colored, lined with tawny yellow, and rises 10 feet above the platform" (Hayden, 1872, p. 195).

One of the early park visitors in describing Giant's cone stated: "Its crater has been compared to a broken horn, but for my life I could liken it to nothing that I had ever seen, save the stump of a hollow sycamore tree of gigantic proportions, the top of which had been torn off by a storm" (Stanley, 1877, p. 114).

The large break on the west side of Giant's cone has always aroused speculation as to the cause of its occurrence. Most critical observers opine that it must have resulted from an eruption of more than ordinary force. Perhaps the crater

became so nozzleed that it could not further withstand the pressure generated by eruptions. For this to have happened presupposes that the cone at one time must have been a closed, unbroken structure.

It is the author's belief that Giant's cone at one time had somewhat of a resemblance to that of Beehive in symmetry, only on a much larger scale. It would be dynamically impossible for the circular, nearly vertical walls of sinter to have been deposited in the presence of a break such as has characterized it during its known history.

While eruptive activity in all probability, and by degrees, has torn away the west side of the cone, destroying its earlier growth and symmetry, it is believed that other agencies have played a role. Giant is known to have had periods of several years in duration of inactivity. The present one has now extended for 15 years. Decomposition is then in the ascendancy. The solid sinter mass then is weakened and spalls.

During periods of decomposition conditions might have arisen for fractures to have occurred in the cone's hydrated silica. These fractures could have resulted from a major prehistoric earthquake. On the north and east sides of the cone, 5 feet from the top, a circular break is in evidence. Extending at a right angle to this break on the north side there are two vertical ones which reach to the top. One is straight, the other zigzags in the upper part. The upper end of the straight break has broken into the crater for a distance of about 8 inches. Near the top of the cone there are several breaks forming blocks. On the east side, 20 to 24 inches below the first break described, a second circular one occurs, with partial extension to the north side. That there were similar breaks on the west side seems almost certain.

It is possible that ice might have played a role in weakening some of the breaks in the cone. During dormant periods, and perhaps in active cycles as well, when the basin in winter is visited by sub-zero temperatures, which are frequent, ice will form in at least the outer edges of some of the breaks. It might have been ice forming in a break which weakened it sufficiently to make a rupture possible.

That ice might form in a cleft in the geyserite of Giant's cone is not a far-fetched supposition. When cold meets heat in the geyser basins strange things happen. During the winter of 1951-52 when the temperature was sub-zero, on three different occasions I observed a heavy blanket of snow on the sloping, south side of the cone; and this, within a short period of

erutions. To my surprise the snow was frozen where it rested on the sinter.

In January 1952 a large block of sinter at the southern extremity of the base was broken away from the cone by the force of an eruption. I surmised that frost action had made the rupture possible. Examination of former contact sides revealed that most of the break was old. I judged the spalled piece to weigh between 60 and 70 pounds. My first impulse was to leave the sheared fragment at the base of the cone to later show what had occurred. Upon second thought I threw it into the river so as to prevent some fool from tossing it into the crater.

In 1870 when Giant was observed by the Washburn Expedition the break in the side of the cone was not as large as has characterized it during most of subsequent time. Walter Trumbull, a member of the above expedition (Langford, 1870, p. 122) made a sketch of the cone which shows a much smaller break than at present. That the sketch was a fair portrayal of the cone in 1870 is indicated by the following: "In 1851 the break in the cone was not nearly so large, being not more than half its present proportions. This is undoubtedly the result of unusually violent eruptions" (Guptil, 1890, p. 68). That in recent time a major section of the cone has been sheared off from the break of the 1870s and early 1880s is shown by a large smooth break on the south side of the crater. This break covers an area of about 10 square feet.

Since the original break in the cone occurred, with its consequent stoppage of deposition, the interior, particularly on the east and north sides, is slowly decomposing. It has a honey-combed appearance due to numerous pits which have formed in what at one time must have been compact sinter. The north side is in a more advanced stage of decomposition than the east. It will be but a matter of time until the north and east sides crumble away, leaving but a spine of projecting sinter on the south side.

There is an early observation in reference to the decomposed appearance of Giant's crater: "The wall of the chimney is considerably crumbled and decayed, and on one side completely broken through" (Dunraven, 1875, p. 272). The crater's "decayed" appearance at that early date would indicate that the break might have occurred several hundred years ago.

Underground Connections

Resting on the same sinter table or platform with the Giant there are four additional named springs - all geysers. These are Turtle, Mastiff, Catfish and Bijou. The latter three geysers

occupy a position to the north of Giant, while to the south, on the edge of a crumbling platform, rests Turtle, so named due to its top resembling the carapace of that reptile. In addition to the named springs, there are not less than 27 small perforations in the platform. Most of them are between Mastiff and Bijou. Some of these vents, there are 9 in number, which are from 4 to 28 feet in front of the broken section erupt during Giant's hot periods, which later will be discussed.

Due to the pronounced sympathy existing between the above geysers and Giant there is no question but that subterranean connections exist between them. The sympathetic relations will be discussed in a later topic. Giant is also known to have underground connections with the Purple Pools, which are situated to the southeast on the opposite bank of the river. At the conclusion of an eruption of Giant the water drops about 3 feet in the craters of these pools.

The 1952 season made a signal contribution toward revealing some of the causes of Giant's record of great irregularity. It had been known for a number of years that it was connected underground with a number of satellite units, all lying within a radius of about 200 feet. That its subterraneous water tentacles reached far afield, entwining with those of the Grotto Group, and possibly Daisy Group, was never suspected before the 1952 season.

There would seem to be little question but that the Grotto Group has been the principal cause of Giant's record of cyclic behavior. This being true, Giant's earlier eruptive cycles must have been attended with a decrease in function of the Grotto Group.

There are a number of lines of observation which serve to prove that Giant and Grotto have underground connections. It was due to a noticeable decline in activity in the Grotto Group in 1952 that it was given special focus as a possible cause of Giant's greatly increased function. From July 1 when the idea of functional relation between Giant and Grotto first suggested itself to me, and for the rest of the season, there was an unfailing chain-like series of eruptions between the two groups. An eruption of Giant, with no observed exception, was always followed in about 45 minutes by an eruption of Grotto, Rocket and Spa Geysers. Except for a series of either 3 or 4 eruptions of Grotto, of about 40 minutes duration, coming as a sequence to an eruption of Giant, Grotto was in large measure dormant. Occasionally

Grotto would erupt when the quiet phase of Giant was about 48 hours old. This was an unfailing herald of a delayed eruption of Giant, which delay amounted to about 10 hours.

Additional evidence of underground connections between Giant and Grotto resulted from the fact that the eruptions of Grotto which came during Giant's quiet phase, occurred only at the time of one of Giant's hot periods. On two occasions, instead of the eruptions of Grotto delaying Giant, both geysers erupted near simultaneously, with Grotto starting about 3 minutes ahead of Giant.

During 1953 the chain-like activity of 1952 had an altered pattern. Many eruptions of Giant took place without the series or consequent eruptions of Grotto. Grotto showed a higher degree of dormancy. The behavior of Spa, however, was on a very different pattern than during 1952, or for any previous observations. Instead of erupting in concert with Grotto it played independently and for much longer periods. The activity of Spa seemed to be the most important factor in accounting for the irregularity of Giant.

During 1954 Grotto was reduced to near dormancy. Only a few of Giant's eruptions were followed by subsequent activity of Grotto. On the other hand Spa's activity was very pronounced following most of Giant's eruptions. During the typical boiling and heavy overflow of Spa, which characterizes most of its activity, water would frequently be rocketed to a height of from 20 to 50 feet.

One of the interesting observations made in 1955, the year Giant became dormant, was the degree of the shift of the thermal energy from Giant to Grotto. From about July 1 on Grotto began erupting with greater frequency and for longer periods. This was accompanied by steadily decreasing eruptions of Giant.

That Giant and Grotto Groups are connected subterraneously seems amply demonstrated by the data which were obtained during Giant's last eruption cycle - September 1949 through most of 1955.

Early References

During the Washburn Party's memorable day and a half stay in the Upper Geyser Basin it had the good fortune to see eruptions of most of the major geysers, Giant being one. This was a most fortuitous circumstance. The party was singularly impressed with the power of the eruption and gave this geyser the name "Giant." The first written reference to it was by J. P. Langford in

Scribner's Monthly, 1871. "The Giant discharged a vast body of water, and the only time we saw it in eruption, the flow of water, in a column 5 feet in diameter and 140 feet in vertical height, continued uninterruptedly, for nearly three hours" (1871, p. 124).

The year following the Washburn Expedition the U. S. Geological Survey under the leadership of Dr. F. V. Hayden directed some of its summer activities to the geyser basins of the Firehole River. Succeeding observations and studies of the hot springs were made by the Survey in 1872 and more extensively in 1878. In all this time the Hayden Party did not see an eruption of Giant.

One of the earliest descriptions of an eruption was of one observed in 1873. The author leaves little to the imagination. He ran the gamut of the lexicon in painting a glowing picture of its beauty and power, and the awesomeness of its "stupendous" convulsions.

"Then with a terrible rushing and rumbling below, with powerful effort and fearful heavings that caused the very earth to groan, and seemed sufficient to tear the solid walls of the crater into a thousand atoms the Giant came forth in the majesty of his mighty power. A volume of boiling water, the size of the nozzle of the crater, was projected to a great altitude. The action being repeated several times. Then for a moment all was quiet. Thinking it was only a feint, we attempted to approach the orifice and make investigations, when we were met by an immense volume of steaming water, as if from one of Hecate's caldrons, causing another disorderly retreat. It now commenced in earnest, and we witnessed one of the grandest displays of waterworks ever beheld by mortal eyes. The fountains of the great deep seemed to have literally been turned loose again upon our sinful world..... At first it appeared to labor in raising the immense volume, which seemed loath to start on its heavenly tour, but it was with perfect ease that the stupendous column was held in its place, the water breaking into jets and returning in glittering showers to the basin. The steam ascended in dense volumes for thousands of feet, when it was freighted upon the wings of the wind and borne away in the clouds. The fearful rumble and confusion attending it were as the sound of distant artillery, the rushing of many horses to battle, or the roar of a fearful tornado" (Stanley, 1877, pp 114-115).

Another early writer is no less effuse than Stanley in the use of descriptive verbiage.

"Language is almost too circumscribed to describe this phenomenon; yet something must be said of it Accompanied by all the noise and uproar of a cyclone or a tornado, with a tremendous explosion the crater is filled with steam, and a huge column of water nearly eight feet in diameter rises to the towering height of from two hundred and fifty to three hundred feet. This elevation is maintained for some time, when the torrent gradually sinks to two hundred feet and plays steadily for an hour and a half. During the whole period the noise and the roar are almost intolerable and deafening; so boisterous is the tumult of the elements that conversation is impossible, and 'you can hardly hear yourself think'" (Haupt, 1883, p. 103).

Most of the early references to Giant are not quite so enthusiastic as those of Stanley and Haupt. The Giant, however, was a geyser all early visitors eagerly sought to see. The name connoted might and power, the "greatest of the all." Wheeler, in an early guide book, quotes Bishop Cranston's description of Giant as published in the Western Christian Advocate:

"The Giant," as his name indicates, is greatest of them all; but he is not a giant every day in the year. Why? Because there is an active waste-vent in his 'formation.' A fierce column of steam issuing constantly from a minor crater, ... robs him of his mighty energies by day and by night. Built for wonderful performances - his crater structure massive, his endowment ample - when he does respond to the impatient expectancy of those who have traveled far to witness his power, there is no disappointment. His voice is heard afar, and footmen, wheelmen, and vehicles of all kinds hasten to the scene. The voices of all the lesser geysers are lost in his mighty fervidness, as he builds a majestic monument that, should his heated utterances congeal, would stand over 200 feet in the air. He holds straight on for an hour and a half, no matter how the admirers of the 'Daisy' or 'Splendid' or 'Economic' may pant through exhaustion of their pampered faculties. He does not heat his throat, and keep a roaring fire under his ribs, for from seven to sixteen days, only to play a second part to the choir of sizzling geysers on the hillside behind him!" (1904, p. 48).

Record of Activity

Since the discovery and naming of Giant in 1870 there has been discontinuity in its eruptions. It has been cyclic in function. There have been years of frequent to infrequent activity, followed by years of dormancy. During the 1870s there are but three references to anyone having seen Giant erupt - one eruption for each year 1870, 1871, and 1873. It is probable that during this period Giant was in a functional cycle. Scanty visitation during this period would result in scanty records. Following the known eruption of 1873, which is described by E. J. Stanley, Dr. Hayden could find no further reference to an eruption until one that was reported by Superintendent Norris in 1881. From 1881 until 1895 there is no record of a specific eruption. This does not mean that Giant was dormant during all of this period. It merely indicates, that if any sustained observations were made, they were not recorded. That Giant was erupting during some of this period (1881 to 1895) is indicated by the following: "The Giant 'goes off' (in the language of the geyser basins) once in four days irregularly" (Wylie, 1892, p. 41). In reference to its dormant periods is a statement: "This geyser became inactive in the year 1886, but it is probably not extinct" (Riley, 1890, p. 106).

By the middle 1890s Giant was active again. In the years 1895-96 Captain George S. Anderson, army superintendent, endeavored to determine if any geysers in the Upper Basin except Old Faithful showed a degree of regularity. Captain Anderson states: "I have the guards keep a table of geyser eruptions. Of course, this is not complete, as it takes no account of eruptions during darkness. I have appended it to this report as principally useful in showing there is very little regularity of period among any of them except Old Faithful" (1896, p. 13). The fact that "little regularity" in any of the geysers except Old Faithful is indicated is suggestive that the guards in their records were not as meticulous to details as seems desirable. However, the tables they kept seem to be the only available record of geyser activity until after the creation of the National Park Service. During five months of observation in 1895-96 the guards made a record of thirty eruptions of Giant.

During the 1920s I can find references to but 46 eruptions. During the first part of this decade Giant apparently was in an active cycle. In his monthly report for August 1920 Superintendent Albright states: "During this year the Giant is playing on an interval of 7 or 8 days" (1920, p. 18).

This active cycle lasted through at least 1921 and 1922

Much credit must be given to Charles Phillips, who served as a park ranger from 1925 until his untimely death in 1927 for his interest in the hot springs. Ranger Phillips carefully checked Giant from the fall of 1925 until March 1927. During this period he had summer and winter assignments at Old Faithful. In the 13 to 19 months of observation he recorded 7 eruptions. From his data he tried to determine if Giant were erupting with some consistency on three-month intervals. He states:

"In the case of Giant the period usually given is six to fourteen days, yet in the available records the writer can find only a few instances of eruptions occurring so frequently and in no case consecutive eruptions at that interval. During the two years in which he has had the Giant under surveillance the average interval has been 91 days with a maximum of 107 days and a minimum of 52 days.

It is interesting in this connection to note that none of the early expeditions observed as frequent activity as six to fourteen days. The Hayden Surveys of 1871, 1872 and 1873 did not see it at all, neither did the Jones expedition of 1873 or Ludlow expedition of 1875 altho several of these were in its vicinity long enough to see an eruption if they had been as frequent as the interval given above. Dr. Peale of the Hayden Survey in his final report of 1883 states definitely that it is 'rarely seen in action' and that its 'period is evidently a long one'" (1927, p. 139).

That Giant was erupting infrequently during the period Ranger Phillips had it under observation is made further evident by a statement in Superintendent Albright's July 1926 report: "Still the curiosity of the tourist as to when it will erupt" (1926, p. 19).

From 1930 through 1940 there is a record of 82 eruptions of Giant. During this period the geysers were under fairly close observation, with summer records being made of all the major geysers. It is believed that the 82 eruptions account for most of Giant's summer activity during this decade. Some night eruptions probably went unchecked.

At least once during each season in the 1930s Giant erupted. It is believed that the one eruption reported for 1931 was soaped. Following an active cycle of 1929 and 1930, when eruptions occurred about every 4 to 14 days, there was

infrequent activity until 1936 when an active cycle comparable to the 1929-30 period took place. From 1936 through 1939 the average interval was about 10 days.

During the 1940s Giant was less active than during the previous decade. There is a record of but 25 eruptions. It was only during the 1945 season that it erupted with any degree of frequency and regularity. The average interval for this season was 11 days. From 1945 until September 1949 it was dormant. At least no eruptions occurred during the months observers were stationed in the Upper Basin.

The 1948 season was characterized by near dormancy of all connecting units on Giant's platform. I had never observed it appear so dead. Most of the gelatinous silica and algae about the cone of Bijou dried up and peeled off. During the latter part of the 1949 season a marked rejuvenation of Giant, Mastiff, Catfish and Bijou was apparent. Eruptions of Giant on September 4 and 17 seemed heraldic of a new cycle of activity.

During the period I was in the Old Faithful area in 1950 Giant was active seven times. It erupted on the following dates: June 31, August 26, September 6, 15, 22, 29 and October 7. That it was a new cycle of activity was made evident, not only by the number of eruptions during September, but by the degree of activity of Bijou, Catfish and Mastiff, with which it is connected subterraneously.

Unfortunately no 1950-51 winter record was made of Giant. No observer was stationed in the Basin. When I entered on duty May 1, 1951 it was soon evident that Giant was still erupting with about the same frequency as in September 1950.

Giant's 1951 performance was very spectacular. Since the National Park Service began functioning in 1916 records are highly revealing that at no time did Giant erupt with the frequency that it did in 1951. There might well have been and no doubt were earlier cycles of activity of equal character but there are no data to check against. During the seven months I was in the Upper Basin in 1951 Giant erupted 37 times. The average time was 5 days and 17 hours. The maximum interval was 6 days and 17.5 hours; the minimum 2 days and 4.5 hours.

The 1951 record was but a prelude to its 1952 function. During this season, which included winter months, Giant erupted 133 times. This represents day and night eruptions. I kept markers to be certain of night eruptions, however, to one familiar with

Giant a night eruption is, on the following morning, readily apparent; also the probable time of the eruption.

The maximum and minimum length intervals for Giant during 1952 were 6 days and 21 hours and 1 day and 10 hours. The 34 hour interval is the shortest on record. The time of the average interval was 54.4 hours. The increase in activity of Giant in 1952 came suddenly. It occurred about January 17. During 1952 Giant gained the distinction of being the first geyser for which a complete yearly record is extant.

During May to October, 1953 Giant erupted 60 times. The shortest interval was 39 hours and 45 minutes, the longest 93 hours and 30 minutes. The time of the average interval was 60 hours. While the seasonal average was slightly longer than for 1952, the monthly average for June and July is the shortest on record - 52.4 hours. The 14 eruptions which occurred during July were the greatest recorded number of times Giant has played during any one month. However, this record was equalled in July 1954.

In 1954 I had the opportunity of spending but three and one-half months in the geyser basins. Between June 1 and September 24 Giant erupted 45 times. Park Ranger Tom Ela recorded 8 eruptions as occurring during April, which represents 53 known eruptions.

Giant's pattern of activity in 1954 was very much the same as it was the previous season. The number of eruptions was the same for the corresponding months of June, July and August of each year. However, during 1954 Giant reversed the time of day when it chose to display itself. During the 1954 season two-thirds of the eruptions occurred during the daylight hours. During 1953 two-thirds took place at night.

During June 1954 Giant erupted 13 times, the average interval being 54 hours. The average for the 14 July eruptions was a minus 53 hours, with 64 plus hours the average for August and September. The seasonal average was 56 plus hours. The longest interval was 95 hours and 17 minutes, occurring in August; the shortest 43 hours, taking place in June.

My first observation of Giant in 1955 was on May 20. From this date until July 1 eruptions occurred with about the same regularity and frequency as during the three previous seasons. Between June 25 and 29 there was an interval of 109 hours. This was the first time the interval had lengthened sufficiently to suggest that Giant might be moving in the direction of a dormant

cycle. From July 1 and for the remainder of the season, the length of the intervals steadily increased. Seven eruptions occurred during July as against 11 for June. The number decreased to 4 for August. From August 29 to October 25 there were but three additional eruptions. The October 25 eruption was the last recorded one. If any occurred during the ensuing winter they are unknown. All evidence is to the effect that since October 25, 1955 Giant has been dormant.

The present state of inactivity would seem to have been well earned. During the century the geysers have been known there is no record of Giant ever closely comparable to its 1950 to October 1955 performance. During this period 315 eruptions are a matter of record. On the basis of its known performance it is believed at least 150 additional eruptions occurred.

Dates and eruption times of Giant's last cycle of activity, beginning with the 1951 season are tabulated so that the reader will be able to properly evaluate the nature of its impressive performance during this period. A table also shows the number of specific eruptions referred to from 1870 to 1950.

Table I

Specific Eruptions Referred to During the First 80 Year Period

<u>Year</u>	<u>Number of Eruptions</u>	<u>Year</u>	<u>Number of Eruptions</u>
1870	1	1930	2
1871	1	1931	2
1873	1	1932	1
1881	1	1933	4
1882	2	1934	3
1895	23	1935	5
1896	7	1936	9
1919	7	1937	7
1921	15	1938	15
1922	15	1939	10
1926	4	1940	4
1927	5	Total	144

Giant erupted many more times during the 80 year period than the table indicates. If records were made of much of its activity they seem to be lost.

Table II

Record of Giant's Eruptions 1951 Through 1955

May 1951

<u>Date</u>	<u>Time</u>	<u>Interval</u>	<u>Air Temperature</u>
3	8:25 a.m.		
5	1:03 p.m.	2 days 4 $\frac{1}{2}$ hours	
10	4:00 p.m.	5 days 3 hours	
16	1:49 p.m.	5 days 22 $\frac{1}{2}$ hours	
22	7:00 a.m.	5 days 18 hours	
27	10:00 p.m.	5 days 15 hours	

June 1951

2	5:30 p.m.	5 days 19 $\frac{1}{2}$ hours	
8	3:30 a.m.	5 days 8 hours	
13	Midnight	5 days 20 $\frac{1}{2}$ hours	
19	5:30 a.m.	5 days 5 $\frac{1}{2}$ hours	
25	1:30 a.m.	5 days 20 hours	
30	10:27 a.m.	5 days 9 hours	

July 1951

5	11:25 a.m.	5 days 1 hour	
11	5:25 p.m.	6 days 6 $\frac{1}{2}$ hours	
18	8:20 p.m.	6 days 14 hours	
23	11:32 a.m.	5 days 3 $\frac{1}{2}$ hours	
31	4:00 a.m.	7 days 16 $\frac{1}{2}$ hours	

August 1951

6	12:20 p.m.	6 days 8 hours	
13	1:25 a.m.	6 days 13 hours	
18	8:20 p.m.	5 days 19 hours	
24	12:01 p.m.	5 days 16 hours	
31	1:54 p.m.	7 days 2 hours	

September 1951

6	1:45 a.m.	6 days 12 hours	
12	3:29 p.m.	6 days 14 hours	
18	4:00 a.m.	5 days 12 $\frac{1}{2}$ hours	
23	10:10 p.m.	5 days 18 hours	
29	10:05 a.m.	5 days 12 hours	

<u>Date</u>	<u>Time</u>	<u>Interval</u>	<u>Air Temperature</u>
November 1951			
4	6:30 a.m.		8° F.
10	2:00 a.m.	5 days 19½ hours	-9°
16	8:30 a.m.	6 days 6½ hours	-21°
22	5:20 p.m.	6 days 9 hours	20°
28	4:30 a.m.	6 days 11 hours	30°

December			
5	10:00 p.m.	6 days 17½ hours	16°
11	2:33 p.m.	6 days 4½ hours	20°
16	1:05 p.m.	5 days 22½ hours	20°
22	8:34 a.m.	5 days 19½ hours	15°
28	5:30 a.m.	5 days 21 hours	26°

January 1952			
4	2:30 a.m.	6 days 21 hours	-15°
9	8:32	5 days 6 hours	0°
14	12:10 p.m.	5 days 4 hours	15°
17	1:42 p.m.	3 days 1½ hours	10°
21	9:05 a.m.	3 days 21½ hours	5°
25	9:35 a.m.	4 days 1½ hours	21°
27	3:27 p.m.	2 days 6 hours	29°
30	11:28 a.m.	2 days 20 hours	22°

February			
2	3:30 a.m.	2 days 20 hours	23°
4	5:01 p.m.	2 days 13½ hours	26°
7	2:14 p.m.	2 days 21 hours	28°
10	3:13 p.m.	3 days 1 hour	33°
14	4:37 p.m.	4 days 1 hour	18°
18	7:10 a.m.	3 days 14½ hours	-13°
21	2:16 p.m.	3 days 7 hours	11°
24	3:00 a.m.	2 days 13 hours	-32°
27	3:15 p.m.	3 days 0 hours	23°

March			
1	1:00 a.m.	3 days 8 hours	-1°
3	2:55 p.m.	2 days 14 hours	9°
6	7:30 a.m.	2 days 16½ hours	-8°
8	1:46 p.m.	2 days 6 hours	23°
11	12:00 Midnight	3 days 10½ hours	8°

<u>Date</u>	<u>Time</u>	<u>Interval</u>	<u>Air Temperature</u>
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March 1952 cont.

15	2:00 a.m.	3 days 2 hours	-15° F.
19	4:42 p.m.	4 days 14-3/4 hours	18°
22	6:35 p.m.	3 days 2 hours	14°
24	5:32 p.m.	1 day 23 hours	16°
27	8:30 p.m.	3 days 3 hours	22°
31	4:30 a.m.	3 days 8 hours	10°

April

3	6:22 p.m.	3 days 14 hours	26°
6	5:45 a.m.	2 days 11 1/2 hours	19°
10	4:45 a.m.	3 days 23 hours	8°
14	8:44 a.m.	4 days 4 hours	28°
18	2:00 a.m.	3 days 17 1/2 hours	26°
21	5:27 p.m.	3 days 15 1/2 hours	38°
24	9:30 p.m.	3 days 4 hours	32°
27	4:30 a.m.	2 days 6 hours	30°
29	6:30 a.m.	2 days 2 hours	32°

May

1	6:00 a.m.	1 day 23 hours	
3	6:03 a.m.	2 days 0 hours	
6	6:15 a.m.	3 days 0 hours	
7	4:10 p.m.	1 day 10 hours	
10	9:05 a.m.	2 days 17 hours	
12	7:55 a.m.	1 day 23 hours	
14	7:33 p.m.	2 days 11 1/2 hours	
17	4:45 a.m.	2 days 9 hours	
19	5:55 p.m.	2 days 13 hours	
23	10:11 a.m.	3 days 16 hours	
25	6:32 p.m.	2 days 8 hours	
28	11:07 a.m.	2 days 16 1/2 hours	
31	4:55 a.m.	2 days 18 hours	

June

2	2:32 p.m.	2 days 9 1/2 hours	
4	8:41 p.m.	2 days 6 hours	
7	11:30 a.m.	2 days 15 hours	
9	12:30 p.m.	2 days 13 hours	
12	4:34 p.m.	3 days 4 hours	
14	9:45 p.m.	2 days 5 hours	
16	7:46 p.m.	1 day 22 hours	
19	9:33 p.m.	3 days 2 hours	

<u>Date</u>	<u>Time</u>	<u>Interval</u>	<u>Air Temperature</u>
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June 1952 cont.

22	7:20 a.m.	2 days 20 hours	
25	6:50 p.m.	3 days 11 $\frac{1}{2}$ hours	
28	5:45 a.m.	2 days 11 hours	

July

1	4:00 a.m.	2 days 22-3/4 hours	
3	2:22 p.m.	2 days 10 $\frac{1}{2}$ hours	
5	9:05 a.m.	1 day 18-3/4 hours	
7	9:50 p.m.	2 days 12-3/4 hours	
10	8:19 a.m.	2 days 10 $\frac{1}{2}$ hours	
12	6:43 p.m.	2 days 10 $\frac{1}{2}$ hours	
15	11:14 a.m.	2 days 16 $\frac{1}{2}$ hours	
18	1:00 a.m.	2 days 14 hours	
19	12:00 Noon	1 day 11 hours	
22	3:00 a.m.	2 days 3 hours	
24	1:52 p.m.	2 days 11 hours	
26	6:55 p.m.	2 days 5 hours	
29	3:30 a.m.	2 days 8 $\frac{1}{2}$ hours	
31	9:58 a.m.	2 days 6 $\frac{1}{2}$ hours	

August

2	2:25 p.m.	2 days 4 hours	
5	11:53 a.m.	2 days 21 $\frac{1}{2}$ hours	
7	1:55 p.m.	2 days 3 hours	
10	6:45 a.m.	2 days 17 hours	
12	10:10 a.m.	2 days 3 $\frac{1}{2}$ hours	
14	2:49 p.m.	2 days 4 $\frac{1}{2}$ hours	
16	6:57 p.m.	2 days 4 hours	
19	9:25 a.m.	2 days 14 $\frac{1}{2}$ hours	
21	5:45 p.m.	2 days 8 $\frac{1}{2}$ hours	
24	7:01 a.m.	2 days 13-3/4 hours	
26	11:29 a.m.	2 days 5 $\frac{1}{2}$ hours	
29	2:00 a.m.	2 days 14 $\frac{1}{2}$ hours	
31	12:00 Midnight	1 day 22 hours	

September

3	3:00 a.m.	2 days 3 hours	
5	2:42 p.m.	2 days 11-3/4 hours	
8	4:00 a.m.	2 days 13 $\frac{1}{2}$ hours	
10	1:20 p.m.	2 days 9 $\frac{1}{2}$ hours	
13	5:00 a.m.	2 days 15 $\frac{1}{2}$ hours	

<u>Date</u>	<u>Time</u>	<u>Interval</u>	<u>Air Temperature</u>
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September 1952 cont.

15	4:03 p.m.	2 days 11 hours	
17	5:55 p.m.	2 days 2 hours	
20	5:00 a.m.	2 days 11 hours	
22	11:26 a.m.	2 days 5 $\frac{1}{2}$ hours	
24	10:30 p.m.	2 days 11 hours	
26	12:00 Noon	2 days 1 $\frac{1}{2}$ hours	

October

1	4:30 p.m.	2 days 23 hours	
4	5:00 a.m.	2 days 12 $\frac{1}{2}$ hours	
6	2:00 a.m.	1 day 21 hours	
8	10:25 a.m.	2 days 8 $\frac{1}{2}$ hours	
10	3:20 p.m.	2 days 5 hours	
13	9:00 a.m.	2 days 17-3/4 hours	
15	Midnight	2 days 15 hours	
18	12:05 p.m.	2 days 12 hours	
20	10:00 p.m.	2 days 10 hours	
22	Midnight	2 days 2 hours	
25	11:00 a.m.	2 days 11 hours	
28	4:00 a.m.	2 days 17 hours	

November

1	5:05 p.m.	3 days 17 hours	32° F.
4	2:00 a.m.	2 days 9 hours	10°
6	3:00 a.m.	2 days 1 hour	12°
8	12:52 p.m.	2 days 10 hours	28°
11	7:48 a.m.	2 days 19 hours	4°
13	9:40 p.m.	2 days 14 hours	26°
16	7:45 a.m.	2 days 10 hours	16°
19	2:00 a.m.	2 days 17 $\frac{1}{4}$ hours	21°
21	12:22 p.m.	2 days 10 $\frac{1}{2}$ hours	21°
23	2:54 p.m.	2 days 2 $\frac{1}{2}$ hours	18°
26	4:00 a.m.	2 days 13 hours	-32°
28	3:53 p.m.	2 days 12 hours	4°

December

1	3:00 a.m.	2 days 11 hours	-13°
3	10:00 p.m.	2 days 19 hours	15°
6	6:00 a.m.	2 days 8 hours	15°
9	5:15 p.m.	3 days 11-3/4 hours	2°
12	3:53 p.m.	2 days 22 $\frac{1}{2}$ hours	33°

<u>Date</u>	<u>Time</u>	<u>Interval</u>	<u>Air Temperature</u>
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December 1952 cont.

15	4:00 a.m.	2 days 12 hours	9° F.
17	6:00 a.m.	2 days 2 hours	10°
19	12:55 p.m.	2 days 7 hours	33°
21	10:18 a.m.	1 day 21½ hours	28°
23	12:35 p.m.	2 days 2¼ hours	14°
25	6:00 p.m.	2 days 5½ hours	-5°
27	3:32 p.m.	1 day 21½ hours	26°
30	5:30 a.m.	2 days 14 hours	17°

April 1953

30	10:30 a.m.		
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May

3	Midnight	2 days 13½ hours	
6	7:30 p.m.	2 days 19½ hours	
10	4:01 p.m.	3 days 21½ hours	
13	8:00 a.m.	2 days 16 hours	
16	5:00 a.m.	2 days 21 hours	
18	12:15 p.m.	2 days 7¼ hours	
21	5:00 a.m.	2 days 16-¾ hours	
23	1:30 p.m.	2 days 8½ hours	
28	12:10 p.m.	4 days 22-¾ hours	
31	8:50 a.m.	1 day 20 hours	

June

2	7:55 a.m.	1 day 23 hours	
3	Midnight	1 day 16 hours	
6	6:30 a.m.	2 days 6½ hours	
8	11:58 p.m.	2 days 5½ hours	
11	6:26 p.m.	2 days 12½ hours	
13	Midnight	2 days 5½ hours	
16	8:14 a.m.	2 days 4¼ hours	
18	12:56 p.m.	2 days 4½ hours	
21	1:30 p.m.	2 days 12½ hours	
23	3:00 a.m.	2 days 1¼ hours	
24	10:30 p.m.	1 day 19½ hours	
27	12:05 a.m.	2 days 1½ hours	
28	8:00 p.m.	1 day 20 hours	

<u>Date</u>	<u>Time</u>	<u>Interval</u>
July 1953		
1	6:45 a.m.	2 days 10-3/4 hours
3	11:09 a.m.	2 days 4 1/2 hours
6	3:30 a.m.	2 days 15 1/4 hours
8	6:43 a.m.	2 days 3 1/2 hours
9	10:02 p.m.	1 day 15-3/4 hours
12	5:15 a.m.	2 days 7 1/4 hours
14	4:56 p.m.	2 days 11 1/4 hours
16	Midnight	2 days 7 hours
19	1:17 p.m.	2 days 13 1/4 hours
22	2:00 a.m.	2 days 12-3/4 hours
24	4:26 p.m.	2 days 14 1/2 hours
26	8:59 p.m.	2 days 10 1/4 hours
29	6:58 a.m.	2 days 10 hours
31	2:22 p.m.	2 days 7 1/2 hours
August		
2	5:03 p.m.	2 days 2 1/4 hours
5	11:37 a.m.	2 days 18 1/4 hours
8	2:30 a.m.	2 days 17 hours
10	10:19 p.m.	2 days 20 1/4 hours
12	10:00 p.m.	1 day 23-3/4 hours
15	7:59 a.m.	2 days 10 hours
18	10:15 a.m.	3 days 2 1/4 hours
20	2:26 p.m.	2 days 4 1/4 hours
23	8:13 a.m.	2 days 18 hours
27	3:20 a.m.	3 days 19 hours
29	11:33 a.m.	2 days 8 1/4 hours
31	4:27 p.m.	2 days 5 hours
September		
3	9:20 p.m.	3 days 5 hours
6	8:09 p.m.	2 days 22 hours
9	4:05 p.m.	2 days 20 hours
12	8:22 a.m.	2 days 16 1/4 hours
15	6:53 a.m.	2 days 23 hours
18	4:20 a.m.	2 days 19 1/4 hours
21	6:44 p.m.	3 days 14 hours
24	2:00 a.m.	2 days 7 1/4 hours
26	10:20 p.m.	2 days 8 hours
29	2:22 a.m.	2 days 4 hours

<u>Date</u>	<u>Time</u>	<u>Interval</u>
June 1954		
1	6:00 a.m.	
4	7:45 a.m.	3 days 1-3/4 hours
6	7:00 p.m.	2 days 11 1/4 hours
8	3:14 p.m.	1 day 20 1/4 hours
10	4:21 p.m.	2 days 1 1/4 hours
13	6:05 p.m.	3 days 2 1/4 hours
15	5:25 p.m.	1 day 23 1/4 hours
19	Midnight	4 days 6 1/2 hours
21	4:00 a.m.	1 day 4 hours
23	11:35 a.m.	2 days 7 1/2 hours
25	6:40 a.m.	1 day 19 hours
27	5:50 p.m.	2 days 11 1/4 hours
29	5:05 p.m.	1 day 23 1/4 hours
July		
1	5:00 a.m.	1 day 12 hours
3	6:30 a.m.	2 days 1 1/2 hours
6	10:43 a.m.	3 days 4 1/4 hours
8	12:21 p.m.	2 days 13-3/4 hours
10	10:44 a.m.	1 day 10 1/2 hours
12	6:22 p.m.	2 days 7 1/2 hours
15	11:25 a.m.	2 days 17 hours
17	1:10 p.m.	2 days 1 1/2 hours
19	12:15 p.m.	2 days 11 hours
21	3:23 p.m.	2 days 3 hours
23	5:20 p.m.	2 days 2 hours
26	8:15 a.m.	2 days 15 hours
28	4:00 a.m.	1 day 15-3/4 hours
30	6:23 p.m.	2 days 14 1/2 hours
August		
2	4:45 a.m.	2 days 10 1/2 hours
4	6:26 p.m.	2 days 13 1/2 hours
7	1:45 a.m.	2 days 7 1/4 hours
9	3:31 p.m.	2 days 13-3/4 hours
12	4:50 a.m.	2 days 13 1/4 hours
14	6:05 p.m.	2 days 13 1/4 hours
17	2:55 a.m.	2 days 9 hours
19	2:43 p.m.	2 days 11-3/4 hours
23	4:00 a.m.	3 days 14-3/4 hours
25	4:12 p.m.	2 days 12 1/4 hours
27	11:15 p.m.	2 days 7 hours
30	11:09 a.m.	2 days 12 hours

<u>Date</u>	<u>Time</u>	<u>Interval</u>
September 1954		
2	10:58 a.m.	2 days 23-3/4 hours
4	9:09 p.m.	2 days 10 1/4 hours
7	11:20 p.m.	3 days 2 1/4 hours
10	12:19 p.m.	3 days 1 1/4 hours
14	2:00 a.m.	3 days 1 1/4 hours
17	4:00 a.m.	3 days 2 hours
20	5:55 p.m.	3 days 14 hours
May 1955		
28	10:00 a.m.	
30	7:20 a.m.	1 day 21 1/4 hours
June		
1	11:45 a.m.	2 days 4 1/4 hours
4	10:00 a.m.	2 days 22 1/4 hours
6	5:03 p.m.	2 days 7 hours
8	11:40 p.m.	2 days 6 1/2 hours
11	8:40 p.m.	2 days 21 hours
14	10:40 a.m.	2 days 14 hours
16	12:00 Noon	2 days 1 1/4 hours
19	9:30 p.m.	3 days 9 1/4 hours
22	1:06 p.m.	2 days 15 1/4 hours
25	2:00 a.m.	2 days 12-3/4 hours
29	3:19 p.m.	4 days 1 1/4 hours
July		
1	5:00 p.m.	2 days 1-3/4 hours
5	12:00 Noon	3 days 19 hours
8	3:40 p.m.	3 days 3-3/4 hours
14	3:00 p.m.	5 days 23 1/4 hours
17	11:10 a.m.	2 days 20 1/4 hours
22	12:20 p.m.	5 days 1 1/4 hours
27	8:10 a.m.	4 days 19-3/4 hours
August		
9	12:00 midnight	13 days 3-3/4 hours
14	12:35 p.m.	4 days 12 1/2 hours
18	1:30 a.m.	3 days 13 hours
29	4:25 p.m.	11 days 15 hours
September		
12	12:00 Midnight	14 days 7 1/2 hours
October		
1	1:25 p.m.	18 days 13 1/4 hours
25	3:30 p.m.	24 days 2 hours

Preromitory signs of an Eruption

During the greater part of Giant's known history the time of an eruption was largely enigmatic. The following comment is revealing of this uncertainty: "The greater part of the visiting public never see the Giant in action on account of its long irregular intervals which defy prediction" (Allen and Day, 1935, p. 255). However, in the 1920s it had been observed that several small geysers, located on the same platform with Giant will erupt precedent to its activity.

"Giant geyser erupts to a height of two hundred and fifty feet, over a period of an hour, and there is no warning except the increased activity of a number of small geysers and springs in the vicinity of the cone" (Lindsley, 1926, p. 10).

"All the openings about Giant are very active at irregular intervals, especially just preceding an eruption and eject steam and small jets of water with considerable power. The iron pipe bearing the sign steams vigorously on these occasions and water is thrown out of the drilled hole in the sinter in which it is set" (Phillips, 1927, p. 139-140).

For some reason this information about the small geysers did not become common knowledge among later interpretive personnel.

That during all of Giant's active cycles there might have been certain signs of an impending eruption is indicated by the following:

"The 1st thing I observed when it gave signs of action was the geyser nearest it [Mastiff] began to surge at a fearful rate, throwing a great volume of water to an altitude of 20 to 30 feet. It played for a moment and the next one [probably Catfish] went through a similar operation; when, as if ashamed of their insignificant failure to rise in the world, or in honor of the grand chief of the realm who was about to appear, they all retired from the scene and became quiescent" (Stanley, 1877, p. 116).

It was not recognized until May 1951 that during an eruptive cycle Giant has frequently recurring periods when both the temperature and the water suddenly rise in its crater. At the time of this change several small vents on the platform in front of the broken section of the cone erupt to heights varying between inches and about 8 feet. Marked changes also occur in the larger units on the platform. I designated the time of this change as a hot period. It is only at the time of one of these hot periods that Giant erupts.

Careful observation revealed that Mastiff showed the same changes in temperature and water level, which occurred synchronously with Giant's. From close observation I discovered that hot periods took place at about hourly intervals, their range being from about 50 to 80 minutes. The hot periods would last from 4 to 10 minutes, 5 minutes being about average.

Not only was there from 1 to 3 degrees rise in temperature of both Giant and Mastiff during a hot period, there was also a marked change in the behavior of most of the units in the group. The first indication that a hot period was starting was an overflow of water from a side vent on the cone of Turtle Geyser. Almost immediately water would start rising in the craters of both Giant and Mastiff. It was with the rise in water that the increase in temperature took place. The water in both Giant and Mastiff boiled more vigorously at this time. Simultaneously with the sudden change in Giant and Mastiff, the activity of Catfish and Bijou ceased.

Within about one minute following the start of a hot period two or more small vents in front and to the southwest of Giant would begin jetting water. Should Turtle erupt, it did so only at the time of one of the hot periods, and this infrequently, it played to a height of about 20 feet. The termination of a hot period, unless Giant erupted, came with cessation of play from the small vents and a sudden surge in activity in both Catfish and Bijou. Bijou would go into a violent steam phase. This surge of activity was accompanied by a simultaneous drop in water level in Giant and Mastiff and all the small vents. For a minute or two following the drop of water in Giant its agitation would greatly increase, with the water sloshing high enough to go over the ten foot wall. Heavy sloshing also preceded eruptions. These hot periods gave me an impression as if a giant sponge at depth were suddenly being squeezed.

During a hot period the relation between Giant and other springs occupying the same platform proved to be quite complex and variable. Starting on July 18, 1951 and continuing for all observed eruptions except one, for the rest of that year an eruption of Giant would always be initiated by eruptions of Mastiff and Catfish as well as the small geysers. Some of the eruptions of Mastiff were of a major character, the height being in excess of 100 feet and lasting from 5 to 15 minutes. As a general rule the activity of Mastiff would cease as soon as Giant started. However, on a number of occasions I observed Mastiff in major activity for fully 5 minutes after Giant reared its mighty plume. During the remarkable displays of Mastiff, Catfish would erupt to a height comparable to that of Daisy and Riverside. On July 23 Catfish alone, of the big three, preceded Giant. During this eruption of Catfish, which lasted for 10 minutes, it discharged a volume of water equal to, if not in excess of that of Old Faithful. The height was not less than 75 feet.

During Giant's last eruption cycle an interesting phenomenon existed with relation to a shifting back and forth of the focus of the thermal energy beneath the platform. When Catfish and Mastiff were performing so spectacularly during 1951 the major part of the pressure was definitely on the north side of the platform. This was made evident, not only by their eruptive potential, but two small vents in front and to the southwest of Giant were dormant. They had previously been erupting at the time of hot periods. In early January 1952 the pressure shifted to the south, resulting in near cessation of anything approaching major activity of Catfish and Mastiff; also the vents 28 feet southwest of the broken section became reactivated, erupting at the time of the hot periods. When Giant was near average time, as long as these vents were active an eruption of Giant was a distinct possibility. Its increasing vigor of splashing with each hot period was highly suggestive that an eruption was imminent.

When the pressure was on the north side of the platform, as in 1951 I considered Giant to be on what I termed the Mastiff function. With the pressure to the south it was designated as regular function. During the regular function, which persisted for the remainder of Giant's eruptive cycle, there was no more major activity of Catfish. However, in 1953 Mastiff had 3 known major eruptions. It is closer to Giant than Catfish,

being 18 feet as against 22 for Catfish. After 1951 Eijou and Catfish would have minor eruptions for a brief period at the beginning of Giant's eruptions.

The January 1952 shifting from fastiff to regular function of Giant resulted in a marked increase in the frequency of its eruptions. The time of the average interval during 1951 was 137.3 hours. During 1952 it was 54.4 hours. This shortened average persisted until 1955.

An Eruption of Giant

As earlier stated, an eruption of Giant occurs only near the termination of a hot period. When on regular function, which would seem to have characterized most of its known history, the splashing and surging in the crater become very pronounced. Massive jets of water arch over both the southern and eastern rims, more particularly the southern. While this violent surging is ensuing water will start surging 10 to 20 feet vertically. In a matter of a few seconds the surging water suddenly blasts skyward. For a minute or two there are rapidly succeeding explosions at depth, during which each impulse lifts the massive column of water higher. Maximum height is attained during the first moment or two of play. The column then slowly subsides from about 30 to 50 feet below maximum. Following this, about 30 to 40 minutes will ensue with little observable change in the character of the eruption. From then until the termination the strength of the activity slowly wanes. There is a short, minor steam phase at the end, after which all units on the platform have the appearance of being fully spent. Following an eruption it is about 20 to 24 hours before sloshing in the crater and renewal of the hot periods begin. The duration of the eruption varies between about 90 and 115 minutes.

In the initial stages of an eruption of Giant the water column is very massive and impressive. The towering column would appear to be 20 or more feet in diameter. It is truly a giant geyser! The huge size is due to two factors - ascending and descending water. Photographs objectively show its massive dimensions. After the ejection of water becomes less forceful the diameter of the water column shrinks to about 5 to 7 feet; more closely approximating the size of the crater.

The height given for an eruption of Giant by different writers has varied over a rather wide range. At the time the Washburn Party observed it Langford estimated it at about 140 feet while Lieutenant Doane placed the height of this eruption at 300 feet. In 1883, Herman Haupt in his guide book lists the height as between 250 and 300 feet. However, most of the early guide books are more conservative, giving a figure of about 200 feet. When I began serving in the Old Faithful area in 1931 it was axiomatic that Giant erupted to a height of 250 feet. All the literature of that period so stated. It was 1938 before I observed an eruption in its initial stages. During 1938 and 1939 it was my good fortune to see three eruptions from the beginning. None of these eruptions even closely approximated 250 feet. They impressed me as being somewhere between 150 and 180 feet.

On July 18, 1951 while I was observing Giant during a hot period, Mastiff began surging heavily. Almost immediately it and Catfish exploded into powerful eruptions. This lasted for fully 10 minutes. A great volume of water was discharged. The Giant appeared enervated. I wondered if the powerful display of Mastiff and Catfish would take the pressure off Giant, preventing an eruption. While I was mentally querying at this wholly unexpected change, the Giant suddenly began vertical surges which in a few seconds resulted in a spectacular display, which the adjective "giant" alone would describe. Had triangulation been made I am sure the top of the water column would have been found well over 200 feet.

While on the Mastiff function the Giant continued to erupt more powerfully than previously. When it returned to regular function in January 1952, the maximum height was, as previous to the Mastiff function, between about 150 and 180 feet.

When compared with other geysers the volume of water Giant discharges during an eruption is tremendous. No other geyser in historic time, unless it was Excelsior, has exceeded it. During the early stages of an eruption literally a flood of water pours into the Firehole River. Until near the termination of an eruption the discharge is continuous and heavy. By use of chips a park engineer and I attempted on two occasions to arrive at a figure as to the volume discharged. We concluded that the amount of water entering

the river from Giant during an eruption was between 750,000 and 1,000,000 gallons.

Enthusiasm at Seeing an Eruption

Early visitors to Yellowstone Park seem to have been much more awed and appreciative of Yellowstone's thermal wonders than motor-conveyed visitors of today. In the main it was a different class of people. In order to reach the geyser basins they travelled by buckboard, wagon or saddle, sleeping and eating on the ground. Yellowstone Park, as an enchanted land, was an end to be attained. In the first decades, unlike today, it was not merely another place along the course of transcontinental ramblings where the already satiated sightseer might be roused from his lethargy long enough to look out the window following the unfeeling announcement, "This is Yellowstone Park."

The first description of wholesale enthusiasm which was engendered by seeing an eruption of Giant was in 1873.

"The wavering to and fro of such a gigantic fountain when the column is at its highest and glistening in the bright sunlight, which adorns it with the glowing colors of many a gorgeous rainbow, affords a spectacle so wonderful and grandly magnificent, so overwhelming to the mind, that the ablest attempt at description gives the reader who has never witnessed such a display but a feeble idea of its glory. Our entire party was perfectly wild with enthusiasm. We could not suppress emotion, but shouted and cheered until we were out of breath, and some fired guns and revolvers in the air, so great was their excitement in the midst of such a display. Every person in the basin - forty-four in number - was soon on the ground, and lawyers, judges, professors, farmers, merchants, miners and philosophers, were all alike filled with enthusiasm by the magnificent spectacle" (Stanley, 1877, p. 116).

"We stood looking with absorbed interest at the Grand Geyser when a shout prolonged and loud, arose from the crowd at the west end of the basin, 'There goes the Giant!' and in an instant there was intense excitement,

some scrambling around for their ponies to hurry to the scene, others rushing down the road with all possible speed, yelling like demons. Others plunged into the river and rushing madly through the swift-flowing water to get a glimpse of this grand fountain" (Haupt, 1883, p. 102).

When the Giant gave a daytime performance, as it did so often during its last eruption cycle, the road would frequently become jammed with cars. The reason a goodly number of these cars had stopped was because other cars had stopped; also, there was the belief that it was Old Faithful that was erupting. So many times that the novelty wore off, when I was standing near Giant enjoying its mighty display, I was approached by a visitor who excitedly inquired, "Is this Old Faithful?" The revelation that it was the Giant, instead of bringing jubilation, caused the countenance of the questioner to fall. In a moment or two would come the question, "Well, where is Old Faithful?" Soon this individual and party would be seen moving through the dwindling crowd in the direction of his car.

Many in Yellowstone Park who have been bitten by the "geyser bug" spare no effort in trying to be on hand when a big and infrequent geyser erupts. That the great majority of visitors so not seem to share the rousing appeal of the geysers often comes as a surprise to these enthusiasts. A number of ranger naturalists have suffered a rude shock when they stepped before the thousands who were awaiting an eruption of Old Faithful, and in a voice bursting with excitement blared out through the loud speaker, "The Giant is playing!" "THE GIANT IS PLAYING!" Instead of the expected pandemonium to get from Old Faithful to Giant the announcement is met with drooping heads, twitching bodies and shuffling feet. Further announcement, and a briefing of the rare opportunity that has exploded in their midst, again bounces off into the ether with as little effect as if it had been addressed to the forest. Careful scrutiny will indicate the casual departure of a few, but in such manner that it might be some press of circumstances, apart from a water spouting Giant, that is motivating them.

On one occasion two fishermen who were artfully placing their flies in the rippling water of the Firehole reached the Giant just as it began one of its grandest exhibitions. Being on the bank of the stream with my kodak I shouted above the noise of the rushing water and hissing steam, "The Giant is playing!" To my knowledge the fishermen never deigned to give Giant so much as a glance. Perhaps by way of courtesy to my exclamation one of them inquired, "Say, what kind of trout are in this river?"

The above portrayal is by no means a blanket indictment. Thousands of appreciative visitors yearly enter Yellowstone's portals. Many people have had a life-long ambition to come to Yellowstone Park; unbounded enthusiasm is expressed for the thermal wonders that are seen. However, in general, it can be said that when some person is observed rushing pell-mell in the direction of an erupting geyser that person, in all probability, is an interested employee, or a tourist who has a knowledge of what is happening. To such people the pronouncement of an eruption of the Giant brings an instantaneous and enthusiastic response. Like the trumpet call to battle, "THE GIANT IS PLAYING" heralds a long awaited spectacle that sets in motion every limb and fiber of the faithful few. Stations and posts are deserted in the mad scramble to seek the shortest route to the coronation. That the Firehole River might lie athwart a straight line approach is of little consequence. One ranger naturalist, later professor of geology at Tufts College, was seen to bolt like a fleeing animal through this water barrier, which, like the Red Sea, "parted" as he plowed through. Like an old time sprinkling wagon, water from his dripping clothes showered the wayside as he fanned on lest he be late for his rendezvous.

Period of Pre-Earthquake Dormancy

During the 1956 season the Giant was observed closely to determine eruption possibility. As during its recent active cycle water continued to slosh in its crater very much as it did during the intervals of its eruptive periods. One of the most noticeable changes was the absence of hot periods and the dormancy of the small vents on the platform. During 1957 there was almost complete cessation of activity of all springs occupying the same sinter platform with Giant. Bijou, which had been quite active in 1956, was almost dormant. Its rich algal growth and deposits of silica gel on the river side dried up, as in 1943. Only occasionally was splashing in the crater of Giant visible from the road. In 1958 there was increased animation in the group. Catfish was dormant. Bijou was in constant activity. Splashing in Giant and Mastiff showed increased vigor. As the season progressed the surging in both grew more forceful and volubrious. The increase in activity seemed suggestive that Giant might be approaching a new eruption cycle. During the pre-earthquake period in 1959 sloshing in Giant became more vigorous than in 1958. Water would occasionally rise 5 or more feet in the crater. I predicted that a new eruption cycle was imminent.

Effects of the 1959 Earthquake

Critical inspection of Giant on August 18, the morning after the earthquake, revealed that no eruption had occurred, which had been the case with so many geysers and hot springs along the Firehole River. There was no evidence of murky water. For more than a week following August 17 there was promise of an eruption. For the first time since 1955 sloshing was heavy enough for the water to go over the east and south sides of the cone, more particularly the south. There was heavy splashing in Mastiff and strong action in Bijou. Catfish remained dormant. During this increased animation the indicator vents were quiescent.

The increased activity in the group gradually waned during the rest of the year. I concluded that the necessary energy to bring about an eruption of Giant was being dissipated by Grotto, and possibly to some extent by Oblong. Both geysers were much more active than during the pre-earthquake period.

From 1959 to the 1970 time of this writing Giant has shown little or no indications of eruption possibilities. During 1960 the sloshing at times reached part way up in the crater; there was near constant jetting of Bijou. However, in succeeding years with occasional periods when the water would splash above the broken rim in Giant, there has been a steady decline in any manifestations of thermal energy.

There has been a rather marked consistency in the temperature of the water in Giant's crater, which is ever in a state of boiling, even when not sloshing. It is, and has so been since discovery, a superheated spring. During Allen and Day's studies extensive temperature readings were taken of "the most important individual springs." In reference to Giant, they state: "The very hottest surface water anywhere in the Yellowstone Park was observed in the crater of the Giant Geyser" (1935, p. 241). Several readings were made of Giant from 1927 to 1929. The highest reading was on December 1, 1927, - 95.5°C. Their lowest reading was 93.2°C., taken in March 1929.

I took numerous temperature readings of Giant during its eruption cycle in the 1950s and since. Its temperature during intervals between eruptions ranged between about 95.5°C. and 95.0°C. During the hot period the temperature would rise to 208°F. or 96.5°C. Despite its long period of quiescence, its September 1970 reading was 202°F. or 95.0°C. Its period of dormancy apparently is not due to lowered temperature but to a lack of sufficient superheated water being diverted to it.

The long period of dormancy of Giant has resulted in considerable decomposition of the sinter composing the platform. Some of the small vents are filled with fragmental sinter. At the time of Giant's eruptions there was marked evidence it was eroding away the platform on the south. The last eruption cycle shortened it from 6 to 8 inches. However, eruptions kept the sinter hard and firm to the west and east.

How much longer Giant might continue in dormancy is quite impossible to predict. Prior to the earthquake some of the dormant periods were from 4 to 5 years in length. However, there are no data on which to make forecasts of any new eruptive cycle. The earthquake might have rendered Giant dormant for all time. It is quite certain, however, that it has weathered major earthquakes prior to the 1959 one.

Daugherty

Mastiff Geyser

G9-255E, 865S

GIANT GROUP OF UPPER BASIN

Mastiff is located on the east side of the Giant's sinter platform. Unlike Giant, Catfish and Bijou, it is coneless. Its crater lies in a NW-SE direction and consists of two large vents, separated by a septum of sinter. In appearance the crater reminds me of the nose of a hippopotamus. It is quite closely related to Giant, 22 feet distant. Of the geysers on the sinter platform Mastiff would seem more closely related to Giant than the others. Its temperature at all times is essentially the same as Giant's, and like Giant's, its water is in a constant state of ebullition.

Little can be said about the functioning of Mastiff prior to Giant's last active cycle. The only reference to an eruption of Mastiff prior to this was an observation in 1873: "The first thing I observed when it [Giant] gave signs of action was the geyser nearest it [Mastiff] began to surge at a fearful rate, throwing a great volume of water to an altitude of 20 to 30 feet" (Stanley, 1877, p. 116). Such action on the part of Mastiff must have been infrequent in succeeding years as all references I have seen to Giant say nothing about Mastiff.

During the eruption cycle of Giant in 1938-39 I was in the Upper Basin and in sight of Giant during much the greater part of those seasons. None of the eruptions of Giant which I observed was preceded by Mastiff. My first observation and knowledge that Mastiff had eruption potential was on May 11, 1951. One of Giant's eruptions was preceded by Mastiff. I estimated the height to be about 30 feet. The eruption lasted about 2 minutes. When Giant started all action in Mastiff ceased.

My next observation of Mastiff was on July 13, 1951. While observing Giant in a critical stage of heat, both Catfish and Mastiff began playing more vigorously than usual. Suddenly Mastiff rocketed skyward to a height comparable to that of Old Faithful. At the same time Catfish, which even in its most violent stages had rarely ever reached 30 feet, fully doubled its height, with a pressure display very much like that of Beehive. The Bijou went into a violent steam phase which equalled Black Geyser at its best. This awesome performance lasted for fully 10 minutes when the Giant suddenly joined in

the hydrotechnic display. Instead of Mastiff bowing out of the picture when Giant shot skyward, for fully 5 minutes it played on equal terms with its Giant companion. Of the two, Mastiff was the more impressive, due to the fact it lifted not one but two huge columns of water into the celestial sphere. The water from the northwest vent played at an angle of about 15 degrees from the vertical, and away from the southeast vent whose water reached for the zenith. This vent erupted to a greater height than the northwest one.

Until early January 1952 Mastiff continued to erupt precedent to Giant. Some of the eruptions were more powerful than others. As the 1951 season advanced there was a decline in the vigor of Mastiff's activity, the height diminishing to about 30 to 50 feet. With this less forceful activity the northwest vent ceased erupting. When Giant shifted to regular function on January 17, 1952 Mastiff was not again observed until the following summer when 3 eruptions, about 30 feet in height, were noted. Since then it has been dormant.

Apart from my own, the only other description of Mastiff during its remarkable display of activity in 1951, was written by a companion naturalist who witnessed the July 13 eruption.

"When Mastiff Geyser began vaulting wave upon wave to heights comparable to those of Old Faithful, but in a manner of Grand's rocket-like eruptions, George began a cycle of activity that led him behind Giant Geyser in order to better observe Mastiff's performance and more accurately estimate its height. Then before Giant began playing he dashed over to the pickup parked on the highway to get his camera.

"Meanwhile I held my position behind Giant Geyser, with the Firehole River in the rear, a heavy deluge of Mastiff's water a foot deep and several rods wide to my right, and then when Giant erupted, a hot river of similar width and greater depth on my left. In front rose the massive Giant, in power and majesty, to greater heights than I had ever witnessed. My position was indeed an interesting one, and momentarily frightening, although not actually dangerous, because the breeze was on my side and the ponderous Giant, at least in this critical stage, played vertically. The horn-like conformation of sinter, forming its cone prevented water from rushing in my direction. The Giant, while momentarily rivaled by the surging Mastiff, was soon in a position of ascendancy. The Giant's

exceptional performance, notwithstanding the exuberant fifteen-minute dissipation of pressure and water from the Mastiff, was a phenomenon that impressed me mightily" (Beal, Yellowstone Nature Notes, 1951, p. 39).

At the time of the 1959 earthquake Mastiff did not respond with an eruption. It is believed no eruption is possible except as a prelude to or in conjunction with Giant. Since the earthquake it, as earlier stated, boils steadily and its temperature, on all occasions when checked, has been essentially the same as Giant's, about 95.0°C. During the past decade it is but rarely that the water surges above the rims of the craters.

Oblong Geyser

H9-310E, 330S

GIANT GROUP OF UPPER BASIN

Oblong was early recognized as one of the important geysers in the Upper Basin. This was due, not only to its great discharge of water during an eruption, but the crater following an eruption reveals some of the most elaborate and colorful sinter structure found in any geyser. The deposits surrounding the crater are but a veneer over the deposits of a hot spring antedating Oblong.

"This handsome basin was thought to be merely a hot boiling spring in 1871, but in 1872, when it received its name, it was suspected to be a geyser, although not seen in action. It has never before been described, although it figured in the report for 1872 (p. 155). It is an oblong pool 50 feet in length by 31 feet wide at the end nearest the river, and 21 feet at the opposite end. At the bottom are two large cavern-like bowls that are of great depth and over which the water appears of a deep greenish-blue tinge. The ridge or platform, separating these two bowls is 7 feet below the surface of the water. The bowl nearest the river end is the largest and deepest. The rim of the geyser is raised from 2 to 6 inches and is elaborately ornamented with large, white, globular masses of geyserite, somewhat like those in the crater of the Turban Geyser, only more numerous and more regular. Outside of these is a layer or rim about 2 inches high, which has an appearance as though it had been cut out by a die, so clearly defined and regular is it. The basin thus described is on the summit of a broad platform (about 250 by 150 feet), which is about 5 feet above the level of the river. The water boils in the center, and when examined on the morning of September 11, 1878, had a temperature of 195°F. at the surface and 196°F. below the surface. The overflow passes off from the center of the south side of the basin, flowing into a series of shallow basins ornamented like the main spring, on a diminutive scale. They are gray and yellow in color. Similar basins are seen on the north

side also, but here instead of receiving the overflow they hold the water that falls during the eruptions. The eruptions are very fine, and resemble in some respects those of the Giantess, although the duration is only a few minutes. The whole mass of water in the basin appears to be tossed into the air in an immense splashing mass, with an immense escape of steam, through which occasional jets are projected to a height of 30 or 40 feet" (Hayden, 1873, pp. 198-199).

A few early guide books make reference to Oblong. In some cases descriptions are word for word copies of observations made by an earlier writer. The earliest known is cited.

"This is a pool of deep green-blue color, on the river bank south of the Giant. It is fifty feet in length, and thirty-one feet wide at the end nearest the river. At the bottom are two large bowls of great depth--the ridge which separates them being seven feet below the surface of the water. The rim of the basin is raised and elaborately ornamented with large white globular masses. The eruptions, occurring about four times daily are not very high, but the whole body of water in the basin is tossed upward in a splashing mass. This geyser has sometimes been called the Comet, but the name given it in 1872 is more appropriate" (Winser, 1883, p. 51).

Following an eruption of Oblong the water level drops between 5 and 6 feet. About 20 minutes after the ebb the steam from bordering collecting basins and within the crater will have cooled sufficiently that the rising vapors no longer obscure the vision. It is then that the colorful and ornamented sinter within the crater can be observed to advantage.

The rise of the water in the crater is gradual. It takes anywhere from about an hour and a half to two and a half hours for the crater to fill. From the time it fills until an eruption there are frequent periods of overflow and periods of ebb. Until an eruption occurs, there is no observable change in their character. This makes an eruption difficult to predict. Following a period of overflow, which lasts about 6 to 8 minutes, the water will ebb 5 to 6 inches. After a period of about 8 to 10 minutes

of ebb the water suddenly rises when the overflow part of the cycle is repeated. Relative to Oblong's periods of overflow and ebbing Allen and Day made the following observations:

"The behavior of a few geysers is worth recording in greater detail. The Oblong Geyser is situated on the bank of the Firehole River in the Upper Basin; a pool of hot water more than 40 feet across when full, heavily lined with silica and surrounded by a roughly circular sinter sheet, 50 yards in its greatest diameter, sloping away more or less gently in all directions. On September 27, 1929, its intermittent behavior was watched continuously for about six hours, during which it displayed a remarkable regularity. For nine minutes the water rose slowly till the pool was full, when it overflowed for about seven and a half minutes, only to repeat the same cycle. The record follows: . . .

Steam bubbles rose in the pool from time to time, more abundantly, as it seemed, while the overflow was greatest, when finally at 3:16 p.m., on the point of maximum discharge, a fountain of water domed up in the pool to a height of nearly 20 feet and there was a tumultuous eruption, the water flooding the surroundings in every direction" (1935, p. 179).

During the period I have been in the Old Faithful area I have noted that seasonal naturalists and rangers when looking down into the basin from Old Faithful will frequently mistake a high rising steam cloud as indicating either Giant or Grand is erupting. This situation regularly obtains during morning hours of a chilly atmosphere which results in high rising steam clouds above Oblong's heavy water discharge. From Old Faithful the above three geysers are in near alignment, particularly Oblong and Grand.

When an eruption occurs it is about 3 to 4 minutes after the start of overflow. At this time, when standing on the north side of the crater, a series of deep detonations can be heard and felt. The eruption begins with gentle boiling, which is soon followed by surging. It takes about one minute for the surging to develop into the full throes of an eruption.

During the main part of an eruption of Oblong the highest surges attain a height of about 20 feet. Due to the size of the crater the surging water is even broader than it is high. This results in voluminous discharge. In the concluding stages the surging becomes less forceful. The eruption lasts from 7 to 8 minutes and terminates quite abruptly. This is followed by rapid ebb. The flood of water which pours from Oblong during an eruption spreads out in all directions. All of the water soon drains into the Firehole River. Due to the crater's resting on the bank of the river extreme difficulty would be encountered in measuring discharge.

Until the 1959 earthquake Oblong's eruption intervals varied between about 3 and 8 hours, the great majority being nearer 8 hours. The earliest known reference to length of interval was by Winsor in 1883, already cited. A later report stated: "Eruptions of Oblong occur about every six hours" (Guptil, 1890, p. 68). In 1893 Superintendent Anderson had the guards record eruption intervals on a number of geysers in the Upper Basin, Oblong being one. Only figures were recorded which represent length of interval in hours: "7 - 7 - 8 - 6 - 3½ - 4 - 9 - 9 - 7½ - 7½ - 4 - 7 - 5½ - 8 - 6 - 8 - 7 - 6 - 5 - 6 - 7 - 6 - 5½ - 5" (Anderson, 1893, pp. 23-24). In the 1920s the frequency of eruptions was about the same as in later decades prior to the earthquake. "Oblong is irregular but plays usually once and sometimes twice a day" (Phillips, 1927, p. 140). During this period it was not under as close a surveillance as in later years.

During the pre-earthquake period that I was in the Upper Basin Oblong erupted with what I considered a fair degree of regularity; the average time being about 7 hours. The great majority of the intervals varied between about 6 and 8 hours. Occasionally there would be longer and shorter intervals. Shorter than a 7 hour average was especially true during the 1954 season. During this season it erupted with what seemed to be a remarkable frequency. The great majority of the intervals ranged between about 4 and 5 hours. On August 30 of that season an interval of 2 hours and 35 minutes was recorded.

1959 Earthquake

During the pre-earthquake period of 1959 eruptions of Oblong occurred about every 6 to 8 hours. This had been the frequency of activity since the 1954 season.

On August 18th, the morning following the earthquake, I noted that Oblong's water was very murky. By the following day it had cleared. The rapid clearing might in part have been due to the increase in eruptive frequency. During the first few days following the big temblor, due to a lack of opportunity to make observations, very few of Oblong's intervals were checked. During this period the shortest determined interval was 2 hours and 14 minutes. During the last week in September 47 eruption intervals were mechanically checked. The minimum interval was 2 hours and 29 minutes; the maximum 5 hours and 24 minutes. The average was 3 hours and 31 minutes. For the remainder of the year it continued to erupt with essentially the same frequency.

The marked increase, more than double, of recurring eruptions was not balanced by any decrease, either in the duration of activity or the volume of discharge. The big increase in the output of thermal energy was actual and real and to the degree that was manifested by the increase in eruptive frequency.

Oblong's activity during the 1960 season had subsided somewhat over what it was in the latter part of 1959. However, during 1960 it erupted more frequently than during any season of record prior to the earthquake. Successive 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. By 1961 eruptions were occurring less frequently. The seasonal average was 5 hours and 50 minutes. The longest interval checked was 8 hours and 3 minutes; the shortest was an even 3 hours.

Following the 1960 season the decline in eruptions of Oblong for the more part was progressive. By the beginning of the 1964 season eruptions were occurring with about the same frequency as during the 1959 pre-earthquake period. However, from mid-July 1964 and for the rest of the season the intervals varied between 4 and 5 hours. The maximum interval checked during that season was 8 hours and 42 minutes; the minimum 3 hours and 50 minutes. By 1966 and through 1967 Oblong stayed pretty much on the 6 to 8 hour pattern. During 1967 the length of the maximum determined interval was 8 hours and 33 minutes; the minimum 5 hours and 30 minutes.

Oblong's activity during the first part of the 1968 season was of about the same character as in 1967. The determined intervals ranged between about 4 and 8 hours. During the latter part of

the season days would pass when no eruption would be observed. During the first two months of the 1969 season daily eruptions of Oblong were noted. In July the length of the intervals began to noticeably increase. The only eruption checked in August was on the 15th. Following this there is no record of further activity until September 8. Markers placed on Oblong indicated that between this date and the end of October there were but two eruptions - on September 23 and 30. During the 1970 season, from May 1 to the end of October, but 5 eruptions were determined.

There is no record of Oblong ever having shown such great irregularity and infrequency of activity as has characterized it the past two years. The sudden and marked decrease of activity, which is without precedent, occurred a few weeks following the heavy discharge of the man-made spring when a piling was put down in the construction of the overpass on the new road. These occurrences might be mere coincidence. However, there is a possibility this is not the case. While Oblong is near a half-mile from the man-made spring it is not out of the realm of possibility, in view of the fractured nature of the Upper Basin, that a break might extend from the overpass area to Oblong. It is believed that radioactive isotope tests might determine whether or not this situation exists. Long observations have unmistakably shown that even a slight loss in thermal energy can bring about dormancy of a geyser.

It is unlikely that Oblong is an isolated unit. It is in almost direct alignment with the subsurface fracture which connects the Giant and Grotto Groups. During Giant's last eruption cycle on two occasions when an eruption of Giant seemed imminent Oblong erupted. On both occasions it was several hours later before Giant erupted.

Purple Pools - North and East

North - G9-510E, 955S ✓

East - G9-565E, 1000S ✓

GIANT GROUP OF UPPER BASIN

North and East Purple Pools are being considered together in view of the fact their temperatures and functions have been essentially the same during the period I have observed them. Their underground connections would seem to be quite open and direct.

These springs were apparently named Purple Pools (by whom unknown) because of the dark appearance of the water, it being of a dark blue or purplish cast. The temperatures of both springs have never shown more than two degrees of variation from each other. Their range has been between 197 and 203 degrees F. Due to a near constant water level, plus the high temperatures, both springs are building shelves about the upper margins of their craters. On rare occasions, and for brief periods, I have observed slight overflow of both springs.

Purple Pools are connected subterraneously with Giant, which is on the opposite bank of the Firehole River. As an eruption of Giant progresses the water levels in these springs ebb. At the end of an eruption the ebb amounts to about three feet. It takes from 24 to 30 hours approximately for them to refill.

The day following the earthquake both pools had ebbed about 18 inches. The water in both was very murky. They continued to be murky for the rest of the year.

South Purple Pool

H9-560E, 65S

GIANT GROUP OF UPPER BASIN

The crater of South Purple Pool is much larger than those of the North and East Pools. It is about 10 by 18 feet. In temperature and general appearance there are marked dissimilarities from the other pools.

About the only thing the three Purple Pools have in common is a drop of about 3 feet in water level following an eruption of Giant. This is the only observed evidence that the south pool might be connected underground with the other two.

There is great variation of temperature in South Purple Pool. The minimum temperature I have obtained was 131°F; the maximum 183°F. During most of the seasons I have checked temperatures of this pool the range has been between about 140 and 165 degrees F. When the temperature is in the 160 range the crater is lined with yellow algae, which gives the pool an emerald hue.

During many seasons there is steady overflow of the south pool, amounting to about 75 gallons per minute. Since the 1959 season the overflow has not been observed to cease. During overflow periods the temperature is generally near 180°F. In September 1970 it was 182°F.

During the 1959 season, prior to the earthquake, there had been steady overflow of this spring. However, following the earthquake the water had dropped about 18 inches in the crater and was very murky. It was 1960 before overflow was resumed.

Unnamed Geyser

H9-580E, 80S

GIANT GROUP OF UPPER BASIN

When entering the Upper Basin on May 1, 1970 I observed a small geyser 30 feet south of South Purple Pool in an eruptive state. This was the first activity of this spring I had observed since the early 1950s, and then for but a short period. As closely as I could determine the 1970 activity was constant. This ^{spring?} steady activity continued until the last week in May. During this period melting snow water from the hillside poured into the crater. This brought about cessation of eruptive activity. When the melt water ceased flowing into the crater geyser activity was again in evidence.

From June 1, and for the rest of the season, this small geyser continued to erupt. However, the steady activity of May was changed to periodic function. The eruptions occurred about ^{4 to 6 times} every 2 to 4 minutes; the duration being about a minute and a half.

The crater of this geyser is round, being about three feet in diameter. The sinter in the direction of South Purple Pool, into which all the water of an eruption pours, shows evidence of earlier, sustained activity. The eruptions are of a splashing type. Most of the splashes vary between about 3 and 10 feet. Occasional bursts will attain a height of not less than 20 feet.

Ranging from about 6 to 20 feet south of the unnamed geyser three new springs developed during the season. Apparently they are on the same fissure as the unnamed geyser. The water in all three springs was murky. Nearby trees were killed by this new development.

unnamed ?
New Geyser

H9-575E, 1955

GIANT GROUP OF UPPER BASIN

When driving north in the Upper Basin on September 1, 1970 I suddenly became aware of a water spout across the river from Oblong Geyser. The eruption was issuing from a point where I was unaware of the existence of a hot spring. It was about 100 feet southwest of South Purple Pool. Examination revealed that it was a new geyser.

The orifice from which the water issued was only about 4 by 5 inches. A few pieces of fragmental sinter were lying near the vent, indicating an explosive beginning. The eruption continued for about 2 minutes after I reached the site.

During September and October I saw several additional eruptions. I caught none of them at the beginning. I was unable to determine the length of an interval or the duration of an eruption.

The eruption of the new geyser quite closely resembles the preliminary eruptions of Atonizer. The jet being of about the same diameter. It also resembles the action of Pink Cone in that the eruption would subside and then increase in vigor. Maximum height of the jets was about 15 feet.

"Bank Geyser"

H8-500E,955

DAISY GROUP OF UPPER BASIN

Prior to the 1959 earthquake Bank erupted about every 45 seconds to a minute. An eruption lasted for about 10 seconds, during which about 5 gallons per minute were discharged. During the eruptions the splashes were to a height of about 18 inches.

The earthquake did not seem to affect the length of Bank's intervals. Its eruptions, however, were more vigorous. From 1962 on the eruptions seemed to grow less forceful. During 1969 there was no evidence of eruptive activity, only steady boiling.

I have observed nothing in Bank's behavior that is suggestive of underground connections with the Daisy Complex.

Two small springs are situated on the shoulder above Bank. Both erupted the night of the earthquake. One continued to erupt for about three weeks. The height of the activity was about one foot. Eruptions were frequent.

Bonita Pool

H8-335E,30S

DAISY GROUP OF UPPER BASIN

Until the ill-advised construction of a road between (and almost over the top) of Daisy and Bonita, the overflow from Bonita was used to predict the time when Daisy would erupt. When the flow reached a certain distance from Bonita it was time for Daisy to respond. Following cessation of Bonita's overflow being used as an indicator it became a little noticed spring until 1937.

My first opportunity for close inspection of Bonita was during the 1937 season. In August of that year the water level in Bonita would rise every few days about a half an inch above the normal high level. This was sufficient to cause a marked overflow from the pool. As long as the water stood at this high level, with the resulting overflow, Daisy would be very irregular and unpredictable. The water would rise to the rim of Daisy's crater where it would stand for hours with no overflow. On August 20th, 1937 Bonita took on geyser proclivities and erupted to a height of about 12 feet. There was no activity in Daisy that day. On the morning of August 21 the water level in Bonita had receded below the rim of the crater and Daisy had resumed its usual schedule, erupting on about a two hour and ten minute interval until last observed on September 6.

The next observation of Daisy was on May 10, 1938. In the deepest part of the bowl surrounding the vent a marked growth of orange colored algae was very indicative of a long period of dormancy. About one sixth of a second foot of water was flowing through a well defined channel from Bonita. That it had been flowing in this manner for possibly months was indicated by a luxuriant growth of algae lining the drainage channel.

The deposition which normally results about geyser and hot spring vents was, so far as Bonita was concerned, being more than counteracted by tourist-induced erosion. It was very apparent that the strand about the bowl of Bonita during previous years had suffered greatly from human erosion and was probably lower by two or more inches as a result of being constantly trodden upon and rolled over by cars. Bonita is situated in what was the Daisy parking area. With this thought in mind I tried damming the overflow channel at the point where it left the pool of Bonita. Following the placement of the check which required but a half-dozen shovelfulls of fragmental

sinter, the water in Daisy began to rise. Within half an hour it erupted. Only one other time during 1933 was the placing of a check in Bonita's overflow necessary.

Following the 1938 season, until the 1959 earthquake, it was only infrequently that Bonita overflowed and stopped Daisy. On all occasions the checking of the overflow brought an immediate response of Daisy. During most of the indicated period it was overflow of either Brilliant Pool or Splendid that accounted for most of Daisy's eccentricities. During the 1950s Bonita's temperature dropped from 140°F. to 104°F. The water never rose to overflow level.

Even though the evidence was compelling on August 18, 1959 that the big tremor had shifted much of the thermal energy from the west side springs to Daisy and to ground farther east, surprisingly, Bonita, which lies between Daisy and the eastern area, did not show any immediate increase in activity. As a matter of fact, on the morning of August 18 the water had ebbed 18 inches below overflow. Before the end of 1959 its temperature dropped from 104°F. to 98°F.

In February 1960 Bonita became animated. Latent effects of the earthquake manifested themselves. There was a pronounced shift of thermal energy away from Daisy to Bonita. Its temperature rose from 98°F. to 200°F., following which it began erupting about every 4 minutes to a height of about 3 feet. After a few weeks the eruptions ceased but steady overflow continued. The only time overflow ceased during 1960 was following an eruption of Daisy. The fact that Daisy would occasionally erupt with Bonita in a state of overflow was without precedent. It was indicative that due to the earthquake Daisy had a source of energy not previously possessed.

On the morning of August 24, 1960 Bonita's drainage channel 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 the dike about 6 inches high about the pool before hydrostatic pressure stopped convection and diverted the flow of thermal energy to Daisy.

The checking of the flow from Bonita resulted in Daisy erupting with marked regularity. The dam about Bonita was left for a week before its removal. With removal steady overflow from Bonita was resumed with a very irregular Daisy. I had hoped that the stopping of flow

from Bonita might result in an exchange of function, which had been the case with all experiments before the earthquake. Apparently the jarrings had altered underground conditions.

During the 1960-61 winter the activity of Bonita increased to a point that resulted in complete dormancy of Daisy. During this season, except for Comet, there was no eruptive activity in any of the other springs in the Daisy Group.

No cessation of overflow of Bonita was observed until the 1967 and 1968 seasons. Particularly during 1967 Bonita would ebb 4 inches to a foot one or more times each day. During the period of ebb which would last from about 30 minutes to an hour, pressure would build up in Daisy to a point where an eruption seemed imminent. Then very suddenly Bonita would refill and resume overflow. No eruption of Daisy resulted from Bonita's ebbs. No ebbing was observed during 1969.

In comparison with Daisy and Splendid Geysers, Bonita Pool is a small, shallow and prosaic spring. To have named it Bonita was a gross infringement in the use of descriptive terms. As an adjective, it is a misnomer. It is rather remarkable that in the changes in the Daisy Group resulting from the earthquake that a small hitherto non-flowing spring would bring about dormancy in two of the park's largest and most important geysers. Yellowstone visitors have sustained a major loss for which the Park Service must bear some responsibility. Be that as it may, it is possible that major energy shifts of a character comparable to this one have occurred before in this group. If this is true, Daisy and Splendid in all probability will have future eruption cycles.

Brilliant Pool

H8-215E,803

DAISY GROUP OF UPPER BASIN

Until the 1950 season Brilliant Pool's pattern of activity seemed very fixed. At the time an eruption of Daisy started, Brilliant's water would begin to ebb. At the conclusion of Daisy's eruption the water in Brilliant would have ebbed 12 to 15 inches. Almost immediately following cessation of Daisy the water in Brilliant would begin to rise. After a lapse of about 25 to 30 minutes the crater would be full with a trickle of overflow. The rhythm of rise and fall was as unerring as Daisy's eruptions.

During the 1950 season, on three different occasions, when Brilliant's crater filled, instead of the trickle of overflow, water poured over the rim on the southern and western sides. When this first occurred, during the following 3 days there was no cessation of overflow, neither was there an eruption of Daisy. As I had done at Bonita, I tried the experiment of placing a small sinter dike along the line of overflow. This not only stopped any further rise in Brilliant but there was an almost immediate rise of water in Daisy and 23 minutes following the placing of the dike, Daisy erupted.

From 1950 until the time of the earthquake there were many times when Brilliant Pool overflowed, stopping either Daisy or Splendid. Sometimes the overflow would cease after 2 or 3 hours. If it continued for more than a day I would place a small sinter dam. Once I let the overflow continue for a week before placing a dike. A few times during 1952 Splendid, instead of Daisy, erupted following the checking of Brilliant's overflow.

Following an eruption of Splendid, the response of Brilliant Pool was very different from what characterized it following Daisy. During an active phase of Splendid when two or more eruptions occurred, Brilliant would drop about 4 feet following Splendid's first eruption, dropping further with each succeeding one. If there were 4 eruptions in Splendid's series Brilliant's crater would empty. Usually about 4 to 5 minutes following Splendid's second or third eruption, Brilliant would erupt. The eruptions lasted from one to two minutes and were characterized by jets which were expelled at a sharp angle to the south. The height of the jets was from 15 to 20 feet.

When I first observed Brilliant Pool the morning following the earthquake the water was down about 4 feet. From then until the end of the year the water was in a state of ebb. Instead of the crater filling as it had formerly done before an eruption of Daisy, it would be a foot below the rim of the crater, ebbing another 3 feet by the end of Daisy's activity. The degree the water would rise in Brilliant was governed by the level of the water in Daisy at the time of an eruption. When the water was down 3 to 4 feet in Brilliant Pool its temperature was 202° to 203°F. Before the earthquake when the crater was full the temperature was 194°F.

During the 1960 season, due to flow from Bonita, the water level remained about 16 inches below the crater rim in Brilliant Pool. The ebb following an eruption of Daisy was not as great as during the latter part of 1959. Conditions during 1961 were about the same as during 1960. As Daisy's level slowly rose so did Brilliant Pool's. The water is still 2 to 4 inches below the rim of the crater.

Brilliant Pool is definitely connected underground with the rest of the Daisy Complex.

- Comet Geyser

H8-210E, 50S

DAISY GROUP OF UPPER BASIN

In 1878 Dr. F. V. Hayden gave the name "Spray" to the present Comet Geyser. There is nothing about this geyser to suggest the name Comet. This name, Comet, was very appropriately given by Dr. Hayden to the present Daisy Geyser. Due to early confusion of names the errors have been perpetuated.

Comet is the only geyser in the group which possesses a cone that is at all imposing, suggesting power as a geyser. This fact led early observers to believe that major eruptions in the group, which they beheld from a distance, were those of "Spray Geyser" (Hayden, 1878, p. 201).

The water stands at the same level in Comet as in Daisy and Splendid during their quiet phases, and the same as in Brilliant Pool. The height of Comet's crater no doubt prevents any periodic overflow which might interfere with the function of related springs. Following an eruption of Daisy there would be but momentary pause in Comet's ebullition. However, following an eruption of Splendid the water level would drop 3 to 4 feet in Comet, with cessation in boiling for about half an hour.

Except following an eruption of Splendid, Comet has shown little change in its behavior pattern since I first observed it. That it was functioning similarly during the 1870s is suggested by the name "Spray". Spray, or water droplets are almost constantly being ejected above the crater rim. It has periods of eruption which occur about every 4 minutes. The water then, in the form of droplets, rises 3 to 4 feet above the cone.

The morning following the earthquake the water was down fully 4 feet in Comet. Before the end of the day water was feebly splashing in the crater. During succeeding seasons, as the water table gradually rose in the group, the action of Comet followed very much the same pattern as had characterized it during pre-earthquake days.

Comet is definitely connected underground with Daisy and Splendid and no doubt with the rest of the Daisy Complex.

Hayden

Daisy Geyser

H8-2802,55S

DAISY GROUP OF UPPER BASIN

Early Uncertainty as to Identity

The first historical reference to Daisy is found in the Hayden Report of 1878. In this report it is listed as Comet Geyser, in allusion to the fancied resemblance to a celestial comet. Dr. Hayden's description of the crater is sufficiently complete in detail to make it certain that the geyser he observed in action and named "Comet" is the geyser now called Daisy:

"no. 7 Comet Geyser - This name is the one originally given to the Grand by Colonel Barlow, and I have transferred it to this, which from all accounts, is a geyser of some importance. It has a large, flat grayish white basin which connects with No. 6 (Brilliant Pool) when it is full. In about the center of this basin are two mounds of yellowish-green-gray beaded geyserite. The largest is on the west side, and is about 18 inches high with a diameter of about 2 feet. The eastern one is only about a foot in height and has two orifices. These two mounds appear to be in constant action. Between them is a pool from which the spouting takes place. Between the eruptions the water in the pool is in ebullition" (Hayden, 1878, p. 201).

To those familiar with the crater of Daisy it will be immediately apparent that Dr. Hayden's description of his "Comet" fits Daisy in toto. Further it will be noted that even then, 1878, it had a reputation of being "a geyser of some importance."

The first time the name Daisy was used, so far as available records are concerned, was in 1887 by Dr. Arnold Hague. In an address to the Institute of Mining Engineers in July of that year he lists the "Daisy" as one of the geysers in the Upper Basin. Whether the name Daisy can be accredited to Dr. Hague, or whether he was using a name already current, will in all probability remain an enigma.

When it is appreciated that during the early period of park history there were no place names for designating the hot springs, it is not surprising that considerable name confusion resulted. That name signs

were not in the Daisy Group as late as 1890 is made evident by a statement in one of the Guides of the period. In trying to locate Splendid for park visitors the following is stated:

"It is located fully 1,000 feet west of the Giant and a short distance south from a prominent mound of geyserite, called from its color the White Pyramid. The entire absence of anything like cone structure, and the numerous crater-like openings in its vicinity, puzzle one at first to locate the geyser proper; however, the extreme western opening, nearest the knoll of timber, is that from which Splendid plays" (Guptil, 1890, p. 71).

The Daisy Group offered a fruitful field for confusing names. Its two important geysers, Splendid and Daisy, plus the crater of the present Comet, which has the external appearance of being a more powerful geyser than the other two, are located very close together. To further complicate matters, during the early period, there was frequent exchange of function between Daisy and Splendid. During Splendid's active cycles Daisy would be dormant, and vice versa; also at times they were observed erupting in concert. At times either Daisy or Splendid would from a distance be observed erupting. Great uncertainty existed as from which orifice the water was issuing. On one occasion Dr. Hayden observed an eruption which in all probability was of Splendid, but he assumed it was of "Spray Geyser", presently called Comet.

Early guide books show the same uncertainty of identification: "There would seem to be some confusion as to the name of this geyser (Splendid), one authority calling it Comet" (Winser, 1883, p. 52); also "Quite unlike other geysers, the Splendid throws its stream at a sharp angle instead of vertically, which fact, when it was first discovered, caused it to be called the Comet" (Guptil, 1890, p. 71). Guptil was describing an eruption of Daisy, not Splendid. Splendid's eruptions are decidedly vertical.

Confusion as to Origin

Not only did confusion exist as to names in the Daisy Group, and which geyser was which, but for over 50 years the story was standard information that Daisy first functioned as a geyser in 1892, the year Splendid was accredited with becoming dormant.

This story was glibly relayed to me when I first entered upon duty in the Old Faithful area.

In 1934 the then Chief Park Naturalist C. Max Bauer, wrote the following text for a sign which was placed at Splendid: "At one time this was the location of one of the most interesting geysers in this Basin, but in 1892 activity ceased from this crifice and a nearby, previously unnoticed opening became the source of the Daisy Geyser which can rightfully be considered as the successor to the Splendid."

Information already presented under the heading Early Uncertainty as to Identity, affords convincing evidence that Daisy displayed itself as a geyser before 1892. All guide books prior to 1892 make reference to Daisy (Comet). A single reference will suffice: "There is a smaller geyser east of it (Splendid), which throws an oblique stream; this and Splendid often act together, which enhances the beauty of the spectacle. I have frequently seen the two joined by a brilliant rainbow" (Wylie, 1882, p. 40).

Early History

By not later than 1900 the name Daisy would seem to have come into general use for what was named "Comet" in 1873 by Dr. Hayden. Of the large geysers that have functioned since the time of the park's inception, early records of Daisy are fewer than for any other major geyser. One reason for this no doubt resulted from the uncertainty and confusion as to identity and performance in the Daisy Group. There is an additional fact that most of the attention of early observers was focused on Splendid due to its being a larger and more powerful geyser. Except for the eruptions observed by Dr. Hayden, September 11, 1873, most references to Daisy are incidental, in which it is reported erupting in concert with Splendid.

The first descriptive reference I have been able to find in which the name Daisy was used is in a 1901 guide. "Not far from these two geysers and across the road are Splendid and Daisy. The Daisy plays many times each day, but throws its fountain-like stream to but moderate heights" (Wheeler, 1901, p. 74).

Haynes Official Guide, 1910, p. 47, states: "Daisy Geyser, located near the White Pyramid and Wylie Upper Basin Camp, plays about every hour to a height of 75 feet."

It was not until after the second decennium of the present century that regular reports on Daisy became a matter of record. Starting with Superintendent Horace M. Albright's reports in 1920, Daisy may be said to have entered its modern period.

Erratic Performance

During Daisy's known history its performance has ranged from great regularity, through great irregularity, to dormancy. During the period I observed it, prior to the 1959 earthquake, it played with a high degree of regularity. For months at a time its eruptions could be predicted with greater accuracy than Old Faithful's. From the 1930s on it was possible for the informed observer to approach Daisy, and without knowing the time of the last eruption, and with an error of not more than 10 minutes, predict the time of the next eruption. From eruption to eruption there was a progressive change at the surface, which like an hourglass, was indicative of the probable time of pending activity. That during the 1920s Daisy erupted with considerable regularity is revealed by Superintendent Albright's monthly reports, as July 1920: "The Daisy plays quite regularly from 60 to 85 minute intervals." July 1921: "Daisy regular at 60 to 70 minute intervals." May 1922: "Daisy is quite regular, average 75 minutes." June 1926: "This beautiful little geyser erupted on a 70 minute average, and is more regular than it has ever been." November 1927: "The Daisy has been active with a regularity rivaling Old Faithful." April 1928: "Daisy playing regularly and on schedule." June 1929: "Daisy has had maximum eruptions with but little variation in its intervals."

Except for Daisy's occasional erratic behavior, which was more pronounced some seasons than others it erupted with a high degree of regularity during most seasons, at least until the rejuvenation of Splendid Geyser in 1951. Each season there were many days when eruptions would occur at a near set time. In reporting on the 1946 activity, I commented as follows:

"During the entire season the Daisy has been more consistent than during any previous season I have observed it. The average interval has been about two hours. The extremes being between 100 and 150 minutes. In general there has not been more than fifteen minutes variation from the two hour average. Only on three occasions was there interference due to activity on the part of any of the connecting vents. During many days the Daisy would not vary more than three or four minutes from its two hour periods. During two different

days it played on a fixed two hour period for the entire day, six eruptions being noted for the one day and seven for the other." (Marler, 1946, Geology File No. 700).

Daisy was not always accomodating in coming through with an eruption. Occasionally it displayed another side of its nature, becoming irregular and unpredictable. The first known reference to irregularity is found in Superintendent Albright's monthly report for October 1926. "The Daisy which was reported dormant for several days in early October by Ranger Martindale, has resumed activity at its customary interval." "Its interval is between one hour and a quarter and one hour and a half and its only irregularity is an occasional vacation for a day or two" (Phillips, 1927, p. 145).

The first reference to the effect that high winds might cause Daisy to become irregular resulted from observations made in 1933. "My observations lead me to believe that strong winds play a strong role in affecting the interval between eruptions. The same would be applicable to all open pool types of geysers such as Daisy and Grand" (Lystrup, 1933, p.25).

With respect to Daisy, all succeeding observers confirmed Lystrup's observation that high winds resulted in longer intervals. However, as to Grand and "all open pool types of geysers", later observations, with the exception of Morning Geyser, made Lystrup's conclusions wholly untenable. The cause of delayed activity of Daisy due to winds will be considered later.

The first recorded observations that irregularity might result from increased activity of nearby springs are found in reports made in 1937 by Park Ranger Naturalists Fix and Marler. "Usually when Bonita has overflowed, Daisy has been very erratic, but there have been times in August when Bonita was perfectly quiet, yet Daisy was very erratic, in fact refusing to erupt for periods of more than 24 hours at a time. At these times Splendid has usually, but not always, been exceptionally active.

"It is apparent at the present time that the heat and water supplies of the Daisy have found escape in erratic fashion thru the Splendis and Bonita, which is responsible for the situation we have observed this summer" (Fix, Geology File, No. 700).

I first began observing the springs in the Daisy Group in August 1937. Quite independent of Fix I reported conditions comparable to those

which he described. Beginning with the 1937 observations, and until the present, I have determined that any increase in activity of any of the springs in the group known to be connected subterraneously with Daisy will distinctly affect its activity. For a discussion of this phase of the problem see American Journal of Science, Volume 249, May 1951, pp. 334-336, Marler.

The determinations of Daisy's extreme sensitivity to energy losses due to any increase in discharge of springs with which it has subterranean connections, made its delay due to winds wholly explicable. Winds of sufficient velocity to produce waves, when blowing over its wide collecting basin when the crater is full and overflowing, accelerate the rate of discharge sufficiently to delay the eruption. It is loss of energy due to increased rate of discharge, and not "surface cooling", as earlier surmised that is responsible for this singular condition. Daisy's winter record of 1951-52 shows that "cooling" (air temperature) has no affect on the length of the interval.

Further and increased erratic function of Daisy resulted from the rejuvenation of Splendid Geyser in July 1951 after a half century of dormancy. Due to Splendid's activity in 1951-1952 there were stretches of from 7 to 14 days when Daisy was dormant. From 1952 to 1959 Splendid erupted infrequently - one to three times during a season. During this period Daisy showed a degree of regularity except on those days when Splendid was active, or Brilliant Pool was overflowing. Occasionally Splendid would overflow for several hours without erupting. During these periods of overflow Daisy was dormant. Beginning with the 1953 season and until the time of the 1959 earthquake, Splendid erupted with a frequency comparable to the 1951-1952 period. This resulted in the same situation for Daisy as in 1951-1952.

Declining Activity

The records of Daisy's activity reveal there was a gradual decline in the frequency of its eruptions from the time of the earliest observations until the time of the earthquake. One of the earliest references to length of interval is in a 1910 guide book. "Daisy plays about every hour to a height of 75 feet" (Haynes Official Guide, 1910, p.57). By 1920 Haynes Guide gives the length of interval as "60 to 90 minutes"; 1926, "80 to 90 minutes". For 127 eruption intervals checked by Lystrup during the 1931 season he gave the average interval as 99 minutes. Observations which I made during the 1938 season show an average time of 125 minutes. With seasonal fluctuations, by 1955 the intervals had increased to 138 minutes. The 1957 average was 144 minutes.

In giving average times only those eruptions which occurred when Daisy was not delayed due to increased activity of underground related springs are considered.

During the 1955 season Daisy was subject to delaying influences that I had not previously observed, and for which the observation to date does not present a plausible clue. During all previous seasons in which I had observed this geyser, its occasional highly irregular activity could satisfactorily be explained by the observable shift of some of the thermal energy to one of the connecting units or to winds. During this season there were a few days when the eruption would be delayed from 2 to 4 hours, with all known connecting springs showing no undue activity or overflow. Daisy would seem to progress to within 5 minutes of its eruption time and stay in that state for as long as 4 hours before finally playing.

The seeming decline of activity of Daisy was no doubt local in character. It is believed it was governed by conditions resident within the complicated plumbing system, of which Daisy is but one external expression. Minor changes in underground conditions, or direction of heat flow, would in all probability affect eruption potential.

An Eruption

Some unknown party back in the late 1880s upon seeing a geyser erupt, and not being aware it was Comet Geyser, no doubt exclaimed, "It's a Daisy!" This resulted in this name being applied and perpetuated. At all events, the adjective "daisy" is well put, in spite of priority rulings.

The eruption starts when the churning water in the bowl reaches a degree of ebullition wherein the large globular masses begin to break apart into incipient jets. These jets rapidly increase in forcefulness. From the time of the initial burst of the eruption it takes about 45 to 60 seconds for the steadily growing column to attain maximum height. Maximum height is maintained about 45 seconds and is characterized by a series of rapid, rocket-like jets, the highest jets being from 70 to 75 feet. The column then begins to descend at a slightly slower rate than it rose. The duration of the eruption varies between about $2\frac{1}{2}$ and $3\frac{1}{2}$ minutes. The water is expelled at an angle, which is about 30 degrees from the vertical, giving it a fancied resemblance to a comet.

Daisy is quite conservative with its water, making any weir measurements of volume discharge impossible. During the entire

period of the eruption, water flows back into the crater from the large, relatively flat collecting basin. Experiment has indicated that were it not for the steadily returning air-chilled water the eruption would last much longer. The action seems to be smothered by this stream of returning water. The flooding of the crater effectively blocks any steam phase. An eruption of nearby Splendid furnishes ample evidence that Daisy discharges but a fraction of the water from the underground sources it shares with Splendid and several other springs.

Whenever Daisy erupts the pronounced sympathy between it and several other springs is made very evident. Daisy's draft of water from those springs progresses steadily as long as the eruption lasts. Due to the size of their craters, the drop in water level is most evident in Brilliant and Bonita Pools and Splendid Geyser. In all the water level is lowered from 10 to 12 inches. The drop in water level in Bonita does not progress as rapidly as in Brilliant and Splendid. These springs refill simultaneously with Daisy.

During the park's early history there were glowing reports of Splendid and Daisy erupting in concert. Since the rejuvenation of Splendid, when there have been two or three eruptions during an active phase, with the initiation of eruptions succeeding the first one, Daisy appeared to be on trigger edge, but no eruptions occurred. On one occasion I observed Daisy erupt about an hour following Splendid. The water was down in all craters and surging violently. This eruption was of greater magnitude than any of the thousands I have seen of the Daisy. The height was in excess of 100 feet and the duration between 4 and 5 minutes.

. . . 1959 Earthquake

The Daisy group of hot springs underwent profound changes as a result of the earthquake. The main part of the thermal energy, which during the earlier part of 1959 had been shifting back and forth between Daisy and Splendid Geysers and Brilliant Pool, shifted to the east in the direction of Daisy. This resulted in the development of a number of new small springs and fumaroles on the east side of the group.

On the morning following the big tremors the water in Daisy and in all springs known to be connected subterraneously, was in a state of ebb comparable to that which follows an eruption of Splendid. The water in the craters of Splendid, Conet, Brilliant Pool and

Daisy was boiling violently. Before the day had progressed far it was evident that in spite of the ebb condition of all springs Daisy was erupting on much shorter intervals. During the first week the average time was 89 minutes, which continued to shorten during the next two weeks.

During the first week in September, by means of an automatic recording device, the following data on Daisy were obtained:

Date	Intervals checked	Average	Minimum	Maximum
September 1	7	74.3 min.	69 min.	85 min.
" 3	14	60.9 "	55 "	67 "
" 4	15	61.6 "	45 "	71 "
" 5	30	47.0 "	28 "	61 "
" 6	23	47.8 "	37 "	55 "

For the remainder of the year Daisy continued to erupt on much shorter intervals than prior to August 18. The length of the interval seemed dependent upon how far the water would rise in the crater. A fluctuating condition existed. On some days the eruptions would consistently start when the water was down 12 inches. Other days the ebb would be more or less. Infrequently the crater would fill. At such times the intervals would be about 90 minutes. The degree of ebb determined the length of the interval. The greater the ebb the shorter the interval and vice versa. From October through the rest of the year the average interval was near one hour. It varied between 45 and 90 minutes.

During those periods when the eruption would start with the water down a foot or more the duration of the play was consistently about one minute longer than when the crater was near full. With the shorter intervals and more prolonged activity the force of the eruption was greater.

Following an eruption of Daisy the water would drop in its crater and the craters of Splendid, Brilliant and Comet to about the same degree as was formerly characteristic following the first eruption of an active phase of Splendid. This drop was about 3 to 4 feet.

The remarkable increase in the eruptive activity of Daisy persisted until February 1960. At this time there was a partial shift of some of Daisy's energy to Sonita Pool. For the remainder of the year Daisy's intervals were greatly lengthened and of uncertain time.

During all of my acquaintance with Daisy there never was a period when an eruption was as difficult to predict as during 1960. The frequency of eruptions seemed directly related to Bonita's activity.

From May 5 through October 25, 1960, 228 of Daisy's eruption intervals were determined. The average time was 143 minutes; the extremes being 77 and 240 minutes. In August Bonita's overflow was checked for several days. During this period Daisy's average time was 105 minutes. Following the removal of the check, Daisy shifted back to pre-dam conditions.

In addition to checking the overflow from Bonita an additional experiment was performed at Daisy on October 18. There is certain evidence to the effect that Daisy and Splendid are directly connected underground. Yet, an eruption of Splendid is not only more powerful than one 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. I believed that the returning water acted as a damper to bring about early cessation of play.

With the assistance of Seasonal Naturalists Beal and Germeraad, 3 burlap bags partially full of sand 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 not less than 100 feet in height, 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 per-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 erupting. The results of this experiment which raised Daisy's surface level 3 to 4 inches, lend a high degree of credence to the speculation that some geysers might bring about their own demise or

of 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.

During the 1960-1961 winter the activity in Bonita increased to a point that finally resulted in complete dormancy of Daisy. The increased flow and eruptive activity of Bonita Pool during 1961 was reflected in the water levels of all connecting springs. The water ebbed about 16 inches below overflow in the craters of Daisy, Brilliant Pool, Splendid, Daisy's Thief and two unnamed springs. This lowered water table resulted in increased surface temperature and boiling in all connecting springs, but the energy potential in the group was dissipated to such a degree by Bonita that the water at depth in none of the other units reached the critical temperature of an eruption.

The present situation in the Daisy Group is interesting because of what it reveals in relation to what might exist in other groups of springs. Observations have definitely established the certain existence of interfunctional relationships in many groups. It is being more firmly established from year to year that fewer and fewer springs can be considered as independent and self-sustained units. Thus, as in the Daisy Group, it seems highly probable that currently there might be small geysers and minor springs in other groups which are rendering functionless springs with major eruption potential. There are a few examples besides Daisy and Splendid where this is known to be true. The old adage about the "tail wagging the dog" finds ready application in the Firehole Geyser Basins.

Daisy is known to be connected underground with Bonita and Brilliant Pools, Splendid, Comet, Daisy's Thief and Radiator Geysers; also two unnamed springs.

"Daisy's Thief"

H8-180E,80S

DAISY GROUP OF UPPER BASIN

This small geyser first came to my attention about 1942. While with a crowd waiting for an eruption of Daisy, just as the eruption seemed imminent, a small geyser west of Brilliant Pool began erupting. Previously I had never seen nor heard of this geyser. After a few moments of steady activity it became evident that promise of an eruption of Daisy was subsiding. The boiling not only became less vigorous, but overflow ceased, indicating ebbing water.

Not only was it obvious that Daisy was ebbing, but a corresponding ebb was taking place in Brilliant Pool and Splendid. After the new geyser had erupted between 20 and 25 minutes activity ceased. As closely as I could determine by ebbed conditions of related springs it had drawn from Daisy's water supply an amount equivalent to an eruption of Daisy.

During the period the new geyser was erupting a steady stream was ejected to a height varying between 10 and 15 feet. Following cessation of activity, 122 minutes later Daisy erupted. It continued to erupt regularly without the above described interference for the rest of the season.

In succeeding seasons during the 1940s the new geyser was known to erupt from one to three times each season. Nighttime eruptions no doubt occurred. Its first observed pattern of behavior was typical of that of succeeding eruptions. Its activity always began when an eruption of Daisy was pending, resulting in Daisy's quiescence. Due to this seeming theft from Daisy it was labeled "Daisy's Thief."

On August 9, 1953 an eruption of Daisy's Thief was observed to last for several hours. This was a strange innovation. All previous observed eruptions had lasted for only about 25 minutes. Its cessation of play came after dark so resultant events were not determined.

Daisy's Thief was not observed again until August 2, 1956. It erupted again on August 26 and September 19. On these three dates the Thief erupted for several hours. On the 2nd it was erupting when first observed at 7:45 a.m. and continued until 4:21 p.m. On the 26th it started about 3:30 p.m. and continued into the night. The September eruption lasted for about 4 hours.

During this greatly lengthened period of activity of the Thief a new pattern of activity emerged. There was less forcefulness to the eruptions, the height being from 6 to 10 feet; also, instead of robbing Daisy of eruptive power, the Thief now seemed to serve as a precursor. The eruption of the Thief on the 2nd was terminated by an eruption of Daisy. The eruption on September 19 was terminated by an eruption of Splendid. This was the only known eruption of Splendid during 1955. During the long periods of activity of the Thief it lowered the water level in Bonita, Daisy, Brilliant, Comet and Splendid to a degree comparable to that of an active phase of Splendid.

Had this change in the nature of Daisy's Thief's pattern of behavior occurred following the earthquake it might be readily explicable. I think, however, that it is in some way related to the rejuvenation of Splendid in July 1951. At no time since the new active cycle began in Splendid has the Thief been observed to rob Daisy of an eruption. Strangely, the opposite effect has ensued. Thief's activity stimulates Daisy to erupt.

Following the earthquake Daisy's Thief was not observed to erupt until October 1960. This eruption caused gradual subsidence of the water level in all related springs. After 1 hour and 40 minutes of activity of the Thief, Daisy erupted. The Thief continued erupting and about 50 minutes later Daisy again erupted. With the conclusion of this eruption the Thief also stopped. At the time the activity concluded the water was down about 18 inches in Bonita and from 3 to 4 feet in the other craters. On two later occasions during 1960 when the Thief erupted it continued without ceasing through the third eruption of Daisy. All of Daisy's intervals were approximately 60 minutes. As a result of the 3 eruptions of Daisy, Brilliant Pool's crater emptied.

Since 1960 there is a record of a few additional eruptions of Daisy's Thief. The last known one was in September 1968. At this time Daisy erupted about 2 hours after the Thief started. The two succeeding eruptions of Daisy, until the Thief stopped, were very irregular. One of the intervals was over 3 hours. It was evident there was less energy in the group than during the early 1960s.

The erosion in an older sinter that has been effected by the eruptive activity of Daisy's Thief indicates a probable life span of a few hundred years.

Daisy's Thief is definitely connected underground with the rest of the Daisy Complex.

Punch Bowl

H7-115E, 330S

DAISY GROUP OF UPPER BASIN

During the entire range of my acquaintance with Punch Bowl it has been remarkably staid in nature of performance. Even the 1959 earthquake had no known effect. Unlike the vast majority of thermal springs its water did not become murky. Neither was there any change in its level. Between September 1958 and September 1959 there was a rise of but one degree in temperature. At all times when I have taken the temperature of Punch Bowl there has been a range of from one to three degrees of superheat. The water is in a constant state of feeble ebullition.

Sometime prior to 1919 permission (assumed) was given to use the water of Punch Bowl for culinary purposes. It was piped about a quarter of a mile to the Wiley Camp located north of the Daisy Group. I do not know to what degree the water was lowered in the crater. I was informed that no eruptive activity occurred when the water level was down. Superintendent Albright had Punch Bowl restored to its original state.

I have seen no evidence that Punch Bowl is affected by any other spring.

"Pyramid Geyser"

G7-575E, 765S

DAISY GROUP OF UPPER BASIN

This small geyser is located at the base of White Pyramid Throne. Prior to the earthquake it erupted about every 3 to 4 hours; the height being 6 to 8 feet. Water played from it steadily for a duration of about 12 minutes. Since the earthquake no eruptions have been observed. It has no known underground connections with any other spring.

"Radiator Geyser"

H8-380E, 55S

DAISY GROUP OF UPPER BASIN

Before the 1959 earthquake Radiator Geyser was a small, boiling, non-flowing spring. The water rose to the surface through a fracture in the sinter that might have occurred at the time of a major earthquake prior to 1959.

The boiling water in this spring sounded very much like a boiling radiator. The spring is located in Daisy's old parking area. When driving to check Daisy I would occasionally park so the motor was over this small, crevice spring. Invariably before leaving someone would remark: "Your radiator is boiling," or "It sounds like your radiator is boiling." Hence, Radiator seemed a very appropriate name.

One of the noticeable changes in the Daisy Group following the 1959 earthquake was the development of a number of small fumeroles and springs east of Bonita in Daisy's parking area. Existing springs became more active. Radiator began erupting periodically. Water rose for the entire length of the fracture. It showed a sympathetic response to Daisy by erupting to a height of 9 to 10 feet immediately following an eruption of Daisy. Radiator continued to erupt during the rest of 1959. During 1951 and 1952 it would boil over following an eruption of Splendid. Its behavior before and following the earthquake left little doubt but that it is connected underground with the Daisy Complex.

Splendid Geyser

H8-150E, 50S

DAISY GROUP OF UPPER BASIN

Early History

During the first few years of the Park's history the Splendid, and other springs belonging to the same group, were not given the critical study and observation that were applied to most of the other major geysers in the Upper Basin. This would seem to be due, in part at least, to the fact that the group of which Splendid is a member, was not directly up and down the line of march along the Firehole River. During this period the Splendid was occasionally observed, as was the Daisy, but as these eruptions were seen from a distance, a great deal of confusion arose as to which spring in the group might be erupting.

The earliest reference to an eruption of Splendid was in 1876.

"About a quarter of a mile west of the Giant are situated four large basins, the biggest being about thirty feet in circumference... In the largest basin are two apertures, and by one or both of these the water is constantly heaved up in a great rounded mass, like a huge bubble. The different basins are not in connection with each other. I was fortunate enough to see one of them in a state of great activity, but I was at some distance; and, though I made all possible haste, the eruption, which only lasted a few minutes, had ceased before I arrived at the spot. The volume of water ejected appeared enormous, and I judged the height of the jet to be about 150 feet. I supposed this to be the Grand Geyser, but I see that Professor Hayden locates it at the other side of the river. (Earl of Dintrevan, 1876, pp. 273-274).

The next reference to Splendid was in 1878 by Dr. F. V. Hayden. He had previously made a rather critical study of the physical characteristics of some of the springs in the group, which he had designated the "White Pyramid Group." He observed several eruptions of present Daisy and due to the fact the water was ejected at an angle, he gave it the name "Comet". One day he observed an eruption from a distance which he did not believe was of "Comet"; but from a geyser he had named "Spray" he estimated the eruption "reached a height of at least 100 feet." The geyser Dr. Hayden saw erupting could have been no other than Splendid.

Splendid was named in 1880 by Superintendent P. W. Norris. Before the time of this designation it had become a geyser of much interest to park visitors.

"This geyser, one of the finest in the Basin, has not acted for three years, until the present season (1881). It is located almost due west from Giant, back upon a small hill. Our camp was near it this summer for three weeks, and we had the best opportunity to observe its actions. It is (this season) next to Old Faithful in point of regularity, operating at intervals of about three hours. Sometimes not more than one and one-half hours intervened between its eruption, beginning suddenly and acting about five and sometimes ten minutes. There is a smaller geyser east of it, which throws an oblique stream; this and Splendid often act together, which enhances the beauty of the spectacle... The Splendid is estimated to throw about 200 feet high" (Wylie, 1882, pp.39-40).

Even as late as 1890 there was no fixed idea as to which geyser in the group was Splendid. "The Splendid throws its stream at a sharp angle (Daisy) instead of vertically, which fact, when it was first discovered, caused it to be called the Comet; this designation, however, soon gave way to its present more appropriate appellation" (Gustil, 1890, p. 72).

I believe that the following description portrays quite accurately the nature of Splendid's behavior during the 1880s, and before becoming dormant near 1900.

"Returning to the Splendid I found there had been no display yet and we waited. While waiting I met Mr. W. H. Weed, of the United States Geological Survey, who has spent three seasons in the Park in the employ of the government.

We have been waiting on this geyser ever since eight o'clock this forenoon, expecting all the time to see something fine - if the name of the geyser means anything at all. It was now getting to be about noon and we were getting discouraged, beginning to think that the old adage regarding a 'watched pot' might also apply to a geyser. We had been standing here on the crater of the Splendid for some time, when something about its appearance attracted my friend's attention.

He commenced backing away, saying: 'I believe this thing's going off,' and by the time we were at a safe distance, its column rose fully 150 feet, sfbreading out and throwing up spurts of steam and water, first a little to the right, then to the left, and again straight upward, and as the sun shone brightly upon its splendid display, rainbows encircled it about its crater and in the mist falling around it on all sides, making a scene truly sublime and never to be forgotten" (Dudley, 1886, pp 89-90).

Near the turn of the century the idea became current that Splendid became dormant in 1892. "Near it (Daisy) is the crater of the extinct Splendid Geyser, whose eruptions until 1892 were very powerful" (Haynes Official Guide, 1910, p. 57). Again "The character of its (Daisy's) eruptions are very like the Splendid Geyser which ceased to play about the time the Daisy broke out in 1892" (Haynes Official Guide, 1912, p. 63). A sign placed at Splendid in 1934 stated:

SPLENDID GEYSER CRATER

At one time this was the location of one of the most interesting geysers in this Basin, but in 1892 activity ceased from this orifice and a nearby, previously unnoticed opening became the source of the Daisy Geyser which can rightfully be considered as the successor to the Splendid.

Another sign which was later placed at Splendid by the Park Service stated: "CRATER OF EXTINCT SPLENDID GEYSER"

Further evidence that the belief was firmly implanted that the Splendid was extinct as a geyser is found in the word CRATER on the 1934 sign. The signs at all other geysers in the Basin, except at Economic, merely give the geyser's name, never using the term "crater." The Economic, like the Splendid, had not played for many years. They were thought to be extinct, their craters being the only remaining tangible evidence of their former existence.

That Splendid did not become "extinct" in 1892 is proven by records which Captain George S. Anderson had the guards keep of a number of the larger geysers in the Upper Basin. For Splendid these records were begun in 1891 and were continued in 1893, 1894 and 1895. During the last named season 20 eruptions were recorded (Anderson,

1895, pp. 20-24). Thus, it was much later than 1892 before Splendid became dormant. There is one reference suggesting it might have been active through at least 1900. "Not far from these two geysers, and across the road are the Splendid and Daisy. The former is one of the six or seven finest geysers in the basin, playing to a height of 200 feet, but it is somewhat irregular in its action" (Wheeler, 1901, p. 74). This reference by Wheeler cannot be accepted as certain evidence that Splendid erupted as late as 1900 or 1901 in view of repetitious reports made by a number of guide-book authors of the early period. Season after season they would publish the same information. There is no record as to just when Splendid ceased to erupt.

Rejuvenation

During Splendid's near 50 years of dormancy major geyser activity in the group found expression only through Daisy. During at least some of this period the temperature of Splendid was sufficiently high to render it on trigger edge. That this was true is indicated by the fact that it could be induced to erupt by use of soap. I am aware of three eruptions (it is highly probable there were others) that resulted from soaping. The first was by Allen and Day under ranger supervision.

After observing hot-spring activity in the Upper Basin for a number of years I became aware that in the case of a number of springs there was what seemed to be a periodic shifting back and forth of some of the thermal energy. This led me to believe that it would only be a matter of time before Splendid should have a new cycle of eruptive activity.

"If the past performance of the Splendid and Daisy Geysers, as evidenced by recorded data as well as by their structural details, are useful criteria for predicting future functioning, it would seem reasonable to expect that the Splendid may sometime assume a new role of activity with an infrequent or quiescent Daisy" (Warler, 1951, p. 337).

The prediction of a revitalized Splendid and an infrequent or quiescent Daisy found fulfillment on July 10, 1951. This eruption of Splendid proved to be heraldic of a new cycle of activity.

Premonitory symptoms of the shifting of some of the thermal energy back to the Splendid after Daisy's long command and expression began to manifest themselves several weeks in advance of the July 10 eruption. One or more times each week water would start flowing from Splendid's crater. This overflow would be continuous for

several hours, sometimes days, before the water would again drop below the overflow level. In both the rise and drop of the water not more than an inch difference in level was involved. As long as the overflow from Splendid lasted, the Daisy was dormant.

Frequently during the Splendid's overflow periods incipient eruptions would occur. The water would rocket up ten or more feet, occasionally near 30 feet, suggesting the initial throes of an eruption. Apparently none of these jets was voluminous enough to trigger an eruption, at least until July 10. On this date, at 10:15 a.m., the Splendid again proudly displayed the power and beauty which had engendered such enthusiasm on the part of early viewers. This, and its subsequent activity, demonstrated that in its longevity, the period of dormancy when it was interpreted as being "extinct", was merely one of the recurring rest periods which have characterized its span of years.

From the time of the July 10 eruption until September 4 the Splendid was known to have played 32 times. There were additional night eruptions whose times were not determined. Following September 4 the Daisy became reactivated with a dormant Splendid. In December the energy again shifted back to the Splendid. Between December 24 and April 23, sixty-seven eruptions were determined. For the remainder of the 1952 season the Splendid would go into an active phase about every 3 or 4 days.

From 1953 to near the end of the 1957 season Splendid's eruptive pattern was quite erratic. But 5 known eruptions occurred in 1953, all coming in late summer. During the 1953 to 1958 period considerable evidence accumulated to the effect that during winter and early spring Splendid was more active than during other seasons of the year. Between 1953 and 1957, late May was the earliest I was able to make any observations in the geyser basins. At the time of the May observations there was certain evidence that during the winter, or at least early spring, there had been considerable eruptive activity of Splendid. Observations made during the 1957-58 winter disclosed that Splendid was active during most of the winter with occasional short-period shifts back to Daisy.

Splendid's renewed activity during the 1957-58 winter in all probability was a prelude to another period of activity somewhat comparable to the 1951 and 1952 one. During 1958, twenty-two eruptions are known to have occurred. There was promise of many more, but on a number of days the energy would shift from Daisy to Brilliant Pool or Splendid, or both, then several hours later shift back to Daisy without a consequent eruption of Splendid. In 1959

until the time of the earthquake on August 17, behavior in the Daisy Group was very similar to that of 1958. Eighteen eruptions of Splendid were recorded, as against 15 during the same period in 1958.

Frequency of Eruptions

Following Splendid's rejuvenation it at no time exhibited the frequency or degree of regularity ascribed to it by Wylie in 1881. A report of 1883 states: "It acts usually at intervals of three hours, sometimes more frequently" (Winser, 1883, p. 52). That daily eruptions did not follow this pattern seems quite certain from the nature of its behavior in the 1950s; also other early references. "The most peculiar feature of it is, that its eruptions occur at intervals of three hours, every other day, only, and as it has the reputation of being a frequent 'spouter' persons happening to visit it on quiet days are apt to find their expectations disappointingly blasted" (Guptill, 1890, pp. 71-72).

That daily eruptions "at about three hour intervals" was not the entire story of Splendid's early manner of functioning finds a high degree of evidence in the records kept by the "guards" from 1891 to July 1895. These records clearly prove that the Splendid became active only periodically. That is, one, and sometimes several days would intervene when no eruptions were reported. During those days when activity was indicated, there would be a series of eruptions, the intervals varying from near one to three hours, sometimes longer.

During the 1951 and 1952 period when there was a high degree of activity, Splendid behaved in a similar manner to that described by the "guards" in the 1890s. I observed that it would go into an active phase about two times each week. An active phase would usually last about 3 to 9 hours. During the active phase the number of eruptions would vary from 1 to 4. The number of eruptions seemed dependent on the duration of the initial eruption. If it lasted 8 to 10 minutes this would conclude the active phase. If it lasted only 2 to 3 minutes invariably there would be one or more follow-up eruptions. The intervals would range between about 1 and 3 hours and occasionally near 4 hours. This closely corresponds to the frequency given in early records. It is highly probable that during the 1890s Splendid behaved in a manner very similar to that following its 1951 rejuvenation.

Eruptions of Splendid

The names that have been given to many of the hot springs are adjectives. This is true for springs of both the eruptive and non-eruptive types. An eruption of the Splendid is truly as

splendid a spectacle today as in 1882 when Wylie wrote: "As at the Grand, the beholder, unconscious of the name, exclaims: 'That is Grand.' So at the Splendid, I have frequently heard the expression, 'Well, that is splendid.'" (Wylie, 1882, p. 39).

The preeruption symptoms in the Splendid become manifest, sometimes several hours in advance of the eruption. The first indication that action might be pending is an overflow from the crater. When this condition obtains, the Splendid is said to be "hot." Every few minutes, as Dunraven described it in 1876, "the water is heaved up in a great rounded mass, like a bubble." Immediately preceding an eruption the force motivating these "bubbles" becomes much more pronounced; they grow into ascending masses, some of which are 10 to 15 feet high. During one of these animated bubble episodes, the water suddenly becomes massive and voluminous; the Splendid is starting to erupt. During the first moment there is a tremendous deluge, issuing in growing force as if this were the only instant for its escape from the cavernous imprisonment below. Higher, and still higher, the great pillar of water ascends. Against a blue background this massive pillar looks as if it had been chiseled into the firmament.

Maximum height is attained within the first minute of play. The time this maximum is maintained varies with the duration of the eruption. The play might last anywhere from 2 to 10 minutes, with the water near its zenith for the greater period of the activity. The height of the eruptions is as variable as the duration. Many observers have reported the maximum height to be "200 feet." These are estimates, not based on objective data. Of the numerous times I have seen the Splendid erupt I should say the height varied anywhere from about 100 feet to well over 150 feet. One measurement which was made by triangulation in 1952 showed the height of that particular eruption to be 162 feet.

When there is a series the follow-up eruptions do not discharge the great volume which comes with the initial one, but greater heights in succeeding eruptions are generally attained. As closely as I could determine an eruption lasting from 8 to 10 minutes discharged between 40,000 and 50,000 gallons of water.

1959 Earthquake

Splendid erupted either at the time of the earthquake, or before daybreak the following morning. On the morning of the 13th the water was down 3 to 4 feet in the crater. Over the next few days the level slowly rose, and during the remainder of 1959 it stayed

6 inches to 2 feet below the crater rim. Boiling and surging were constant. At times there would be minor eruptions when the water in mass would shoot up 15 to 20 feet. At times Splendid appeared very hot, but no major eruption occurred. During 1960 the same condition prevailed as in late 1959.

Soon after the earthquake it was very evident that a pronounced shift of thermal energy from the west side of the group to the east had occurred. The springs apparently lie in a deep-seated fissure, traversing an east-west direction. Splendid, which lies on the western end of the fissure, became dormant, while those on the east end showed greatly increased animation.

From 1961 on through succeeding years the water in Splendid has stayed from 2 to 4 inches below overflow level. There has been increased vigor of boiling at times, with an occasional jet shooting up 10 to 20 feet. At no time have I observed conditions suggesting that Splendid might be approaching an eruption.

Since the earthquake but one major eruption of Splendid is known to have occurred. This was during the night of September 19, 1968. In the afternoon of September 19 there were 16 known tremors in the Old Faithful area. The early ones were of sufficient intensity to be heard. The creaking of the District Office was very noticeable. The above is mentioned in view of the fact that several hours later both Splendid and Link, long dormant, had major eruptions. This might have been only coincidence, but the fact that the big tremor of 1959 resulted in delayed eruptions of numerous quiescent springs lends an element of possibility to the view that the eruptions referred to and the earth tremors were related phenomena.

Subterranean Connections

It must have been recognized at an early date that subterranean connections between thermal units in the Daisy Complex existed. The frequent mention of Splendid and Daisy erupting in concert is evidence of the awareness. The marked lowering of the water level in related springs when one, or both geysers erupted was unquestionably observed. There is no available record that any such early observations were made. However, it can be assumed with a high degree of certainty that the existing sympathy was recognized.

The first mention of underground connections in the Daisy Group was in 1927. "This transfer of activity (from Splendid to Daisy) is but one manifestation of the remarkable sympathy existing between all vents in this area. Bonita, the little spring across the road fills

to overflowing before an eruption of Daisy; as the latter plays it drains rapidly, leaving at the end a pool scarcely more than a foot in diameter. Eruptions of Daisy also lower the water level in Splendid and Brilliant while the incessant activity of Comet is reduced for a short period" (Phillips, 1927, p. 145).

Observations made during the 1930s and 1940s showed about the same behavior of springs in the Daisy Complex as was described by Phillips. The occasional eruptions of Daisy's Thief in the 1940s and Splendid's rejuvenation in 1951 further served to emphasize the close bonds of sympathy existing in the group. This sympathy is so pronounced that it is impossible to discuss any of the principal springs without reference to other springs. Every spring is so sensitive to loss of energy, even small, through a shift to a neighboring spring as to require a description of most in order to explain the behavior of any particular one.

When the effects of Splendid's and Daisy's eruptions are considered and compared, it becomes objectively evident that the eruption of a geyser does not necessarily exhaust the supply of ground water to which its underground ramifications lead. The instantaneous response of both Daisy and Splendid to each other's eruptions, also the fact that they have played in concert, demands somewhat direct connections. Yet, Daisy discharges but a small fraction of the water Splendid does. When Splendid is in an active phase, and there is a series of eruptions, each eruption makes an additional draft on the water supply. Underground connections present puzzling and complex problems.

The erratic behavior of springs in the Daisy Complex during the 1952 season was very suggestive that the east-west fissure (possibly earthquake caused) they seem to issue from might extend to the east as far as the Giant Group. During 1952 Giant was very active, erupting about every second or third day. During this season Brilliant Pool overflowed frequently. Whenever the overflow was checked Daisy, but more frequently Splendid, would generally erupt, either shortly before or shortly after an eruption of Giant. If, when Giant erupted, neither Daisy nor Splendid erupted the temperature of the water in Splendid would drop 4 to 6 degrees, with its overflow ceasing. This happened so many times as to practically rule out coincidental occurrence. The late Dr. George Morey of the U.S. Geochemical Division had planned through use of tracers to try to determine if the two groups were connected. His death intervened before he could perform the experiments.

Another facet which might have some bearing on interfunctional relationships existing between Daisy and Giant Groups is the fact

that both Giant and Splendid entered active cycles at essentially the same time. The Giant has had previous short cycles of activity when Splendid did not respond (at least erupt) but the duration of Giant's active cycle in the 1950s; also the number of eruptions, far exceed that for any other known period, indicating a much greater evolution of heat.

The Story Found in the Rocks

The story of Splendid is highly suggestive that eruptions have characterized it only periodically; the cycles of inactivity being of much longer duration than the active ones. This picture finds equal confirmation in the structural conditions found in the Daisy Group as a whole. The nature of the drainage channels leading away from the craters of Daisy and Splendid presents certain evidence that Daisy has been active for much longer periods than has Splendid. Daisy's greatly deepened channels over those of Splendid indicate that in the lifetime of these geysers the bulk of the erupted water has been from Daisy. Neither geyser would appear to be as old as Riverside, Grotto, Giant, Castle, Beehive and several others.

The recent active cycle of Splendid resulted in a marked erosion and general deflation of the relatively flat expanse of weathered sinter lying south of the crater. The amount of the deflation makes it seem unlikely that many eruptive cycles, such as the recent one, could be a part of Splendid's overall picture. Where the water of the eruptions scoured the older sinter, silicified tree sections were in evidence. These tree sections are indicative of a much longer period of dormancy than the one occurring during the first half of the present century. There is also the possibility the trees were interred by a spring not possessing the eruptive potential which has characterized Splendid during its known history. Like Old Faithful, Splendid might be a comparatively new geyser.

Round Spring Group

"North Round Spring"

H8-825E, 475S

ROUND SPRING GROUP OF UPPER BASIN

A state of from about 4 to 8 inches below overflow has characterized North Round during most of my acquaintance with it. At times of infrequent periods of overflow, Round, its bigger neighbor 80 feet to the south, would ebb about 2 inches. Until the 1959 earthquake there was no break in this ebb and flow relationship.

Since the earthquake there has been no observed exchange of function between Round and North Round such as existed previously. During 1967 both springs were in a state of overflow all season. Previously I had never seen this happen. The earthquake resulted in North Round's temperature rising from 151° to 155°F.

North Round is definitely connected underground with Round. It is thought that connections exist with springs in the group to the west.

"Pear Spring"

H8-690E, 540S

ROUND SPRING GROUP OF UPPER BASIN

Pear Spring derived its name from the fact that the crater is shaped like a pear. Prior to the earthquake I had never observed any discharge from this spring. Its temperature whenever taken was near 150°F. The crater was lined with a profuse growth of algae.

Apparently at the time of the earthquake Pear Spring erupted. No follow-up eruptions are known to have occurred. However, there was a marked rise in temperature. When taken in September it was 194°F. By 1961 it had dropped to 163°F. Since the 1964 season algae in increasing amount have been lining the crater.

During the winter of 1960-61 an unnamed spring about 10 feet north of Pear turned into a geyser. During all of 1961 it erupted with marked regularity, the eruptions occurring about every 5 minutes, to a height of about 12 feet. It was named "Pear Geyser".

An apparent energy shift from Round to Pear Spring the night of the earthquake is suggestive of underground connections.

Round Spring

H8-865E, 585S

ROUND SPRING GROUP OF UPPER BASIN

During much the greater portion of time I have observed Round Spring it has been in a state of overflow. Prior to the earthquake during periods of overflow the temperature averaged 175°F. On infrequent occasions the water would ebb about two inches below overflow, at which time North Round Spring would overflow. No rhythm was ever determined for this exchange of function, but it unfailingly occurred.

During the 1956 season there was a change in Round Spring which I had not previously observed. One or more times each day water would ebb about a foot; the ebb lasting for several hours. During the period of ebb two small geysers lying north of Pear Spring would erupt. Previously I had never seen them active. A small geyser near the two new ones would also erupt simultaneously. This latter geyser has been active most seasons during my observations. It was not until the 1969 season that a condition comparable to 1956 was again noted in Round. During the periods of ebb, which was about 6 inches, the new small geysers failed to respond as in 1956. Neither was there overflow from North Round.

As a result of the earthquake Round Spring ebbed about a foot below overflow. The temperature had dropped to 137°F. Apparently the thermal energy had shifted to the springs on the west side of the group. By 1962 Round was again in an overflow condition; the temperature was 167°F. During 1967 both Round and North Round overflowed all season. Previously I had never observed both springs to flow at the same time. The earthquake apparently brought about some changes in relationships existing between the various springs in the group.

The evidence which has accumulated is highly suggestive that Round Spring has underground connections with all springs in this small group.

"West Round Spring"

H8-600E, 560S

ROUND SPRING GROUP OF UPPER BASIN

Prior to the earthquake West Round's crater, like Pear Spring's was lined with dense mats of brown-colored algae which occasionally spalled from the sides. Its temperature during this period was 142°F.

It is probable that the earthquake induced eruptions of West Round and Pear occurred simultaneously. Of the two, West Round erupted more violently. There was a heavy wash which extended back at least 6 to 8 feet from the crater in the loose sinter.

After the initial and only known eruption, West Round cooled faster than Pear Spring. By the middle of September its temperature was 160°F. By 1961 the temperature of both springs was about the same, being in the 150 degree range. The algae presently lining West Round look very much the same as previous to the earthquake.

I believe the evidence is suggestive that West Round is connected underground with other springs in the group.

Beauty Pool

H9-700E, 710S

Chromatic Pool

H9-555E, 640S

GRAND GROUP OF UPPER BASIN

These springs are being treated as one unit in view of the fact that their known function is essentially that of one spring. There is a pronounced sympathetic response existing between them. To treat them separately would be repetitious.

Unless a thermal spring happened to be a geyser little or no treatment was given to it by early writers. There is only one known reference to Beauty and Chromatic, and this in spite of the fact that they (Beauty in particular) rank among the most colorful springs in the geyser basins. In 1927, p. 140, Phillips wrote: "The Terraces are the overflow of Chromatic Pool, the deep blue of whose water in combination with the yellow and red of the algae provides a wide range of colors. Beside it is Beauty Spring, a pool of the Morning Glory type but much larger."

It was during the 1941 season that I first noticed that a pronounced interfunctional relationship existed between Beauty and Chromatic. I became aware that when one of these springs was in a state of overflow the water in the other always stood about an inch below overflow level. It became evident there was a definite exchange of function which seemed to be periodic. During the 1941 and 1942 seasons the shift of the focus of thermal energy occurred about every six weeks. When not overflowing both springs had a temperature of about 164°F. When in a state of overflow the temperature would be about 10 degrees higher.

Following the 1942 season I did not again observe these springs until 1946. From then until the 1959 earthquake there was periodic energy shift. However, the periods of overflow and ebbing were more irregular; also often 3 months to a year would elapse between their occurrence.

At the time of the earthquake Beauty was overflowing and continued to do so for the rest of the year. Its overflow had almost doubled, being about 20 gallons per minute. About the only noticeable effect on Chromatic was additional ebbing.

As closely as could be determined the thermal energy shifted from Beauty to Chromatic on June 7, 1960. From that date to the end of the 1969 season Beauty has remained in a state of ebb with steady overflow from Chromatic, the flow being of essentially the same volume as prior to the earthquake. Possibly the earthquake resulted in changes, altering the nature of their periodic energy shifts.

Belgian Pool 2

110-235E, 560S

GRAND GROUP OF UPPER BASIN

During the entire period of my observations the water has been about a foot below overflow in this pool. The only change in the status quo was following the earthquake which resulted in the water becoming murky; also a drop in temperature of 2°F. It took several years for the water to clear.

Bulger Geyser

110-175E, 560S

GRAND GROUP OF UPPER BASIN

Bulger was named by the Hayden Survey. During its known history it would seem to have erupted on essentially the same pattern and frequency as now. The intervals are between about $3\frac{1}{2}$ and $4\frac{1}{2}$ hours. The heights of the eruptions are from 6 to 8 feet. During the quiet phase water boils constantly, becoming more agitated prior to an eruption. A short period of overflow precedes an eruption.

The earthquake resulted in increased activity for the remainder of 1959. This apparently was due to a 3°F. rise in temperature. The water was murky on the 13th of August but cleared in a few days. Since 1960 Bulger has been on its pre-earthquake pattern.

No evidence of underground connections with other springs has as yet been observed.

Calida Pool

I9-630E, 270S

GRAND GROUP OF UPPER BASIN

The water in Calida was very murky following the earthquake. It was 1961 before it cleared. It did not erupt; however, there was a rise of 9°F in temperature which gradually subsided during the following three years.

Several unnamed springs in the flat northwest of Calida erupted the night of the earthquake.

Castle Geyser

J10-290E, 430S

GRAND GROUP OF UPPER BASIN

Since the official discovery of Castle Geyser in 1870 it has held a place of great interest among the numerous hot springs found along the Firehole River. This, in part, is due to the fact that it possesses the largest and one of the most interesting structures of any geyser in the Park. Dr. F. V. Hayden in 1878 wrote:

"This geyser has the most imposing crater in the Upper Basin and was so named by Langford and Doane in 1870 because of its fancied resemblance to the ruins of a feudal castle; although from most points of view it is more like the ruins of a tower or turret on the end of a platform, suggesting the form of a 'monitor iron-clad vessel'."

Not only was the structure of Castle imposing but the impressive style of play which frequently characterized it contributed to its having a first magnitude rating among Yellowstone's hundreds of geysers. The manner in which it jets the water of an eruption, followed by the great rushing of steam so impressed some observers that in their repertory of geysers they gave it first place. In describing an eruption he witnessed in 1874 the Earl of Dunraven was not lacking in descriptive adjectives and superlatives. In conclusion he wrote: "It is the greatest geyser in the region."

Unlike Riverside's and Old Faithful's, Castle's function since discovery has been marked with periods of dormancy and variations in its patterns of play. If during its early known history there were any approach to regularity it was not recognized by observers before the 1940's. Available records indicate that during the past score of years Castle has not only erupted with greater frequency, but the pattern of its activity makes the eruptions predictable with reasonable accuracy.

In 1878 Dr. Hayden recognized that Castle seemed to have two distinct types of activity:

"The points we have recorded prove that beside the eruptive action, which has a well defined course of procedure, there is a state of constant activity, which is accompanied by spurts which reach 50 feet,

or even 60 feet, as seen by Doane and Langford. They, however, did not see a genuine eruption in which the steam period is the most marked feature.

Additional early references indicate that Castle was viewed as having more than one kind of eruption. Some were characterized as being merely the "frequent jetting of water", while at other times this jetting was followed by a "rushing of steam from the crater". Some of the steam-phase eruptions were viewed as being more powerful than others. In 1883 Henry Winsor wrote:

This geyser usually shoots out a column of water, from 30 to 50 feet in height, several times each day, and throws up smaller jets every few minutes. It occasionally, however, husbands its strength for a grand effort, at which times it forces up a beautiful fountain to an altitude of 100 feet or more, accompanied by a tremendous rush of steam.

There was a period in the 1920's when steam-phase eruptions had become so infrequent that they were viewed as not being the normal mode of Castle's behavior. From the 1890's until about 1920 Yellowstone records are silent on hot-spring activity. Apparently the thermal wonders were not considered by administrative officials as being an essential element of the Park, worthy of reporting. With the administration of Horace M. Albright interest in the hot springs was not only revived, it was resurrected. In his annual report for 1920 Superintendent Albright wrote: "The Castle has been very irregular and disappointing." Three or four eruptions per week were reported during 1921 and 1922. In his 1926 report is the statement, "The Castle only had one active period the past summer season." In 1926 Charles Phillips (a park ranger and devotee of the hot springs) wrote:

Perhaps the most interesting display of geyser activity during January was an exhibit by Castle Geyser of its old time vigor. Castle's normal activity is a steady streaming with jets of water thrown twenty or thirty feet high every minute or two. On this occasion, however, the contents of the tube were erupted 100 feet or more and the steam period that followed quite equaled the Giant in power. The hollow roar was audible for several miles.

In the early winter of 1927 Philips again wrote:

It has been generally regarded that the Castle was formerly much more active than it is at present. Today its normal activity is a steady streaming with jets of water thrown 20 or 30 feet every minute or two. Every four to eight weeks it has an exceptional

eruption during which water is thrown well over a hundred feet for a few minutes followed by a tremendous steam period that lasts a number of hours and whose hollow roar is audible for several miles in winter."

Records through the 1930's suggest that eruptions occurred about once daily; sometimes more frequently. Nighttime eruptions were not determined and Castle was considered as being "very irregular".

Of the activity of Castle characterized by "frequent" and other times "almost continuous jetting of water", records during the 1930's are silent. During the 1940, 1941 and 1942 seasons long periods of sloshing were frequent. In September 1941 I made the following report:

"During the past month there were but three daylight eruptions of the Castle. It has been less active this season than any other that it has been under my observation. Most of the current season it has been in that sloppy or splashing phase that characterizes its inactive periods."

I considered "inactive periods" as those during which no steam phase followed the ejection of water. During the 1941 and 1942 seasons there would be periods of from 7 to 10 days when water would be jetting almost constantly to various heights, usually not more than 10 to 20 feet, occasionally higher. The crater looked not at all unlike a gigantic pot from which water was being constantly sloshed.

Until the 1946 season I considered the steam phase of the Castle an essential element of any activity worthy of being called an eruption. However, during the 1946 season it displayed a distinct type of function I had not previously seen, and to which I can find no reference in the records. In addition to the continuous sloshing or jetting and steam-phase types of activity, a major eruption of short duration, not followed by steam ejection, was observed. The duration of the eruption was about 4 minutes, the display being more powerful than the steam-phase type. During 1949 an eruption of 2 minutes duration was noted. After 1946 there were occasional 4 minute eruptions each season until 1959 but no more 2 minute ones were observed. From the time of the earthquake until 1963 none was observed. Since 1963 a few of both the near 2 and 4 minute eruptions have occurred each season through 1969.

Whether it is an eruption of 2 or 4 minutes duration it occurs at a time when a "normal" or steam-phase eruption is considered imminent. The water is ejected with great force and vigor for the

short period then the eruption abruptly terminates. Without an observed exception to date a steam-phase eruption has occurred about 2 to 4 hours following short play. Whether it is near 2 or 4 hours depends on whether the short duration of activity was near 2 or 4 minutes; the longer the play the greater the lapse of time before the steam-phase eruption.

Beginning with the 1943 season it may be said that Castle entered upon its present pattern of activity. At least the long periods of "continuous jutting" have not occurred and its steam-phase eruptions have been recognized as having a degree of regularity. Between 1943 and the 1959 earthquake the intervals varied between about 12 and 18 hours. Following the 1950 and 1951 seasons (when the intervals averaged a little more than 12 hours) there was a gradual increase in the length of interval until the time of the earthquake. Relative to its activity preceding the earthquake I have reported:

"From May 1, 1959 until the time of the earthquake August 17, 81 steam-phase eruptions were determined for the Castle. The average interval was 15 hours and 53 minutes. The minimum interval was 13 hours; the maximum 18 hours and 28 minutes."

Like most of the geysers along the Firehole it played less frequently during the 1959 pre-earthquake period than during 1958. Castle's 1958 average was 14 hours and 33 minutes.

Following the earthquake it soon became evident that a new source of thermal energy had been made available to the Castle. During August 18 and 19 three daytime steam-phase eruptions were observed. Such activity was entirely without precedent. Eruptions occurring about every 4 hours seemed utterly fantastic. During these two days there was one interval of 3 hours and 55 minutes! In spite of the very short intervals there was no apparent change in the type or forcefulness of the activity. The water phase lasted about 15 minutes, the steam phase continuing for more than double that time.

During the first few days following the earthquake the Castle was manifesting about 4 times as much eruptive energy as in the pre-earthquake period. By September the intervals had increased to approximately 6 hours. The average time continued to increase slowly for the remainder of the season. Between November 3 and 17, 37 eruption intervals were mechanically checked. The shortest interval was 7 hours and 38 minutes; the longest, 10 hours and 23 minutes; the average, 9 hours and 3 minutes.

By 1960 Castle's intervals were ranging between about $8\frac{1}{2}$ and 10 hours. The majority of the eruptions could be predicted within a half hour of their occurrence. It was determined that during equivalent periods of time there were 6 eruptions during 1960 compared with 4 before the earthquake.

Castle's pattern of activity since 1960 has continued with but slight variation. Records denote a small decrease in average time. The average time for 1960 was 9 hours and 30 minutes; for 1969, 8 hours and 38 minutes.

Chimney Cone

110-210E, 945S

GRAND GROUP OF UPPER BASIN

Chimney is a small pipe-like cone on the edge of the Firehole River. There is no open vent at the top, it having been filled by early park vandals or by internal deposition. It is believed that both factors have operated.

Prior to the 1959 earthquake when the days were humid or cold vapors could be seen being gently wafted from the pipe. Following the earthquake steam under pressure was being exhaled. The steam made an audible hissing which could be heard for some distance. No water was discharged from the steam vent. However, there was flow of water from a vent at the base of the pipe. The hissing and flow continued until sometime during the winter of 1961 and 1962. Since that time the cone appears to be in essentially the same state as prior to the earthquake.

Churn Spring

IL0-185E,710S

GRAND GROUP OF UPPER BASIN

This spring was apparently named Churn because of water pulsations in its small vent. Prior to the earthquake I had observed neither overflow nor any boiling action in this spring. The day following the earthquake the water was murky and was "churning" in the vent. There was also light overflow. With gradual clearing this condition persisted for the rest of 1959.

Since 1959 the overflow has been periodic. However, during 1960 there was only occasional ebbing. Since that year overflow has occurred with decreasing frequency. Since 1960 no pulsing has been noted in the vent.

Churn has no known underground connections with other springs.

"Crack Geyser"

H9-865E, 750S

GRAND GROUP OF UPPER BASIN

Following cessation of play of Economic and East Economic geysers on September 21, 1959 a spring 250 feet to the north, located between Wave Spring and Beauty Pool, became eruptive. It played about 6 feet high. Several eruptions occurred each day. The eruptions issued from a fissure in the sinter. This resulted in the new performer being called "Crack Geyser". Activity persisted in it for the remainder of the year. Frequent activity was observed during 1960 and 1961. The temperature drop of all springs in this area in 1962 resulted in Crack becoming dormant, with no further activity to date.

Whether the beginning of eruptions in Crack Geyser was due to a shift of energy from the Economic Geysers is merely conjecture. At least it is suggestive of underground connections.

Crested Pool

J10-275E, 285S

GRAND GROUP OF UPPER BASIN

This large, normally quiescent spring has on two known occasions shown eruptive activity. During April 1952 I observed one eruption. Others occurred during that month. The eruption I observed did not last for more than a minute. Water domed up over the crater then suddenly burst, sending jets up 6 to 8 feet. For but a few seconds there was heavy discharge.

The next and only known eruption since 1952 was on July 5, 1968. At the time of this eruption water boiled up to a height of 2 to 3 feet for a period of about 45 seconds. For the rest of the day there were occasional minor boiling periods.

The 1959 earthquake had a pronounced effect on Crested Pool. Prior to the earthquake its temperature was 200°F., with a 15 gallons per minute discharge. The morning after the big disturbance its water was not only murky, it had also ebbed about 12 inches and the temperature had dropped to 155°F.

During all of 1960 and 1961 the ebb in Crested Pool fluctuated between about 4 and 12 inches, except following an eruption of Castle when an additional ebb of about 4 inches would occur. During the 1962 season there was a slow rise in water level. By October occasional overflow was noted. The temperature had also risen from a low of 150°F. determined during the 1961 season to 170°F. By 1963 it was overflowing steadily. The degree of overflow fluctuated, being heaviest during a 4 to 5 hour period preceding an eruption of Castle. Its temperature was back in the 200°F range. It had apparently recovered from the effects of the 1959 earthquake.

It was during the period of Crested Pool's ebb that for the first time a sympathetic relationship between it and Castle was observed. Prior to an eruption of Castle water would unfailingly rise several inches in Crested Pool then ebb to near 16 inches. When it is full and overflowing the relationship with Castle is not very evident. At the time of the July 5, 1963 eruption of Crested Pool alluded to, Castle's interval was 3 hours over average. It was the longest interval during that season.

"East Economic Geyser"

H9-9453,900S

GRAND GROUP OF UPPER BASIN

There is no record of this spring ever having erupted until the 1959 earthquake. It is located at the base of the hill 20 feet west-east of Economic. On the morning of August 18 I observed, not only Economic erupting, but this previously little noticed spring was also erupting.

Occasionally both geysers were observed erupting in concert, but more frequently alone. Because of the new geyser's close sympathetic response to Economic I dubbed it "East Economic". Like Economic practically all the water of an eruption flowed back into the crater. Its eruptions did not occur as frequently as Economic's. As closely as I could determine the intervals were from 3 to 5 hours. Of the two, East Economic was the more powerful geyser. Its eruptions were not less than 35 feet in height and a voluminous mass of water was ejected. No further eruptions were observed after September 21, 1959.

That the two Economics are connected underground was made evident at the time of eruptions. During the period of activity of either geyser the water would ebb in the crater of the other, the ebb being greater in the crater of Economic.

If East Economic has ever had a previous eruption cycle of comparable magnitude to the earthquake-induced one it must have been a long while ago. This observation is deduced from the fact that the eruptions scalded and killed several nearby Lodgepole Pines which were not less than 75 years old.

Previous to the earthquake, like Economic's, East Economic's crater was filled with dark brown algae. By 1962 its crater again appeared to be in the same state as prior to the earthquake.

East Triplet Geyser

110-175E, 420S . 6

GRAND GROUP OF UPPER BASIN

In spite of the fact that there was a general increase in geyser activity in the Firehole Basins during 1947 it was sometime during that season that East Triplet became dormant. There is no evidence of an eruption since that year. Prior to 1947 I observed frequent geyser activity. The three Triplets would play in concert. During eruptions of East Triplet water frequently played from two vents. The pool-like crater would erupt very much like West Triplet. The second aperture is a small vent on the raised sinter bordering East Triplet. It was observed to erupt either simultaneously with East Triplet or alone. An eruption lasted for several minutes. The water played out at about a 45 degree angle in the direction of Rift to a height of about 20 feet.

At the time of the 1959 earthquake the water became murky and ebbed in the crater between 24 and 30 inches. By 1960 the level existing before the earthquake was again attained.

Following an eruption of Grand the water in East Triplet ebbs from 12 to 15 inches.

Economic Geyser

H9-925E, ⁹²⁵910S

GRAND GROUP OF UPPER BASIN

During the first few decades of park history Economic seemed to be a geyser of considerable interest. This no doubt was due to the fact that eruptions were of frequent occurrence; also that the greater part of the water of an eruption flowed back into the crater - hence the name, Economic.

Most of the early guide books refer to Economic as one of the interesting geysers to be seen in the Upper Basin. "Farther away the Grand and Economic can be seen. The latter geyser is a great favorite with tourists. It throws water to a height of 30 feet only, but it plays every few minutes and is withal such a dainty sort of geyser, that the tourists will stand for a long time and watch it" (Wheeler, 1899, pp.28-29).

It is possible that Economic continued to be a "favorite with tourists" until sometime in the 1920's. "The Economic has not been observed in action for a season or more, and may have become extinct" (Haynes Guide, 1926). During the 1930's and 1940's, so far as appearances were concerned, it was extinct. The crater was lined with dark brown algae; the water had a near constant temperature of 144°F.

On May 19, 1957 Park Ranger Jim McKown reported seeing three eruptions of Economic, each about 8 feet high. On June 1, when I first viewed its crater that season, it was full of brown algae. There was no surficial evidence of recent eruptive activity. However, there had been an increase of ten degrees in temperature.

No further eruptions were reported until the morning of August 18, 1959. One of the big surprises on that morning was to see long dormant Economic erupting along with numerous other thermal springs the earthquake had aroused from deep slumber. Most of the eruptions were about 8 feet high. Occasionally one would reach a height of near 30 feet, lasting for less than a minute. Eruptions occurred about every 5 minutes during the first three weeks. The intervals then lengthened to 15 to 20 minutes. After September 21 no further activity was observed. During the period of frequent activity the temperature was 198°F. By 1962 the temperature had dropped back into the 144 degree range. The crater was again filled with dark brown algae, which was its state at the end of the 1969 season.

Economic has certain underground connections with a nearby spring at the base of the hill. There is additional evidence that these subterranean connections extend to Wave Spring to the north and to the Grand Complex to the south. All these springs are in alignment and are located at the base of outcropping rhyolite.

Grand Geyser •

110-150E, 350S

GRAND GROUP OF UPPER BASIN

Among the many geysers in Yellowstone Park that have intrigued and captivated park visitors since 1870, none has surpassed Grand. It is the power and character of its eruptions that are primarily responsible for its popularity. However, another factor, a psychological one, must be considered. To see an eruption of Grand many have patiently waited in hot sun, or chilling wind for hours before reward came. The sudden, explosive rocketing of the mighty jets of an eruption are in such utter contrast to the quietude and unruffled water of the waiting period as to leave the beholder awed; often enthusiastically vociferous in his admiration.

As a geyser Grand made its historic debut on August 5, 1871. The salutation it gave its beholders was so impressive that the adjective "grand" was at once applied. In describing the eruption Dr. Hayden states:

"We camped the evening of August 5th, in the middle of the Upper Geyser Basin. Soon after reaching camp a tremendous rumbling was heard, shaking the ground in every direction, and soon a column of steam burst forth from the crater near the edge of the east side of the river. Following the steam by a succession of impulses, a column of water, apparently six feet in diameter, rose to a height of 200 feet. ... We gave it the name Grand Geyser for its power seemed greater than any other of which we obtained any knowledge in the valley." (Hayden, 1872, p.116)

Many early explorers and visitors to the Upper Geyser Basin left descriptions of impressions gained when seeing an eruption of Grand. Only one will be included in this report. Like others it is indicative of the impact this geyser had on the viewer. In describing an eruption witnessed in 1872 Colonel Barlow of the United States Engineers commented:

"This grand fountain continued to play for several minutes. When dying down, I approached to obtain a closer view of the aperture from whence had issued such a powerful stream. A sudden gush of steam drove me away, following which the water was impelled upward, far above the steam, till it seemed to have lost the

controlling force of gravity, and it would never cease to rise,... We were all lost in the sudden and marvelous spectacle. The enthusiasm of the party was manifest in shouts of delight." (Barlow, 1872, p.27).

Since the above was written Grand has performed before thousands of spectators. Over the years it has lost none of its enchantment. People continue to shout in exultation when it plays. Only the dull and insipid can watch an eruption and not be strongly moved by the beauty and dynamics of the display.

Description of Crater

When passing or viewing the crater of Grand during a quiet phase the uninformd would never suspect it of being a geyser. It has a most unpromising appearance.

The earliest description of Grand's crater is found in Barlow and Heap's report for 1871, in which it is stated:

"The crater of this geyser is very beautiful, though but slightly elevated above the general slope of the plateau; it might be overlooked, should it not happen to play during the visit of an examining party. There are three openings, all of which are connected with the reservoir below. One, a very small aperture, emits puffs of steam similar to the exhaust pipe of a steam engine. The large one, in the center, 6 feet across, boils violently during an explosion, but does not throw water to any great height.

"The third opening is the geyser proper, from which a towering column ascends to the astonishing height of 200 feet. It is 12 by 18 inches in diameter, somewhat narrowed as it descends, and is of great depth, smooth and straight. These cavities are all lined with delicate deposit of rock, beautifully enameled with silica, in appearance as delicate as frost work, but hard and strong, requiring the assistance of a hammer to detach fragments obtained as specimens." (Barlow and Heap, 1872, p.27)

The description by the Hayden party in 1878 is of interest in that it describes the crater in greater detail, and serves very well as a present day description.

"Unless the eruption of this magnificent fountain had been witnessed, one would scarcely take it for one of the most important geysers in the basin; for, unlike Old Faithful, the Grotto, or the Giant, it has no raised cone or crater, nor even a huge cavern-like bowl, as is the case with Giantess or Oblong. It is situated near the base of a hill, and is 52 feet in diameter, and but slightly depressed below the surface, the greatest depth in the central portion being only about one foot. The bottom of the basin is very irregular, and near the mouth of the geyser tube is lined with large cushion-like masses of geyserite, somewhat like those in the crater of the turban. In these masses the crater is 2 by 4 feet. It is situated near the Turban rather than in the center of the basin. There is no marked raised rim to the latter, but there are shallow basins and pools over the surrounding surface, the irregularity of which add to the beauty of the general effect." (Hayden, 1878, p.211)

History

The earliest reference to an interval of Grand is found in the 1871 Hayden report. This interval was 31 hours. During this early period, the frequency of its activity is not at all certain. No systematic observations were carried on. Most of the reports indicate "one or two eruptions each day". An 1873 guide book by Norton states that Grand plays "at least twice in 24 hours". The guide books by Wylie, 1882; Winsor, 1883; Haupt, 1883; and Hyde, 1888; give intervals as ranging between 13 and 31 hours. In 1896 a report states that Grand erupts every 15 to 20 hours (Wheeler, 1896, p.69). The majority of early guide books when discussing the thermal springs contain verbatim information. Plagiarism seemed not to have been particularly frowned upon. It is indicative that little if any field work was performed.

During most of the first two decades of the current century, administrative park personnel largely ignored Yellowstone's thermal wonders. References to hot springs are practically nonexistent. Except for repetitive information in guide books of the period, references to the geysers show a paucity of interest to a marked degree. About the only reference to Grand during this period that is indicative of its eruptive pattern points to extreme irregularity, "playing at intervals varying from one to ten days". (Haynes Guide, 1910, p.70). It is highly probable there was even greater irregularity in determining the nature of eruptive behavior.

Following the creation of the National Park Service in 1916 the earliest known reference to Grand was in 1920. "The Grand seems to have established eleven hours as its interval of eruption" (Albright, 1920, p.27). In 1921 the report states: "Grand is giving fine eruptions two to three times per day" (Albright, 1921, p.22). From 1921 on Grand shows increasing irregularity. "Eruptions vary between sixteen to twenty hours with occasional wide variations" (Phillips, 1927, p.140). The 1920-21 activity indicates a regularity and frequency that was not again approached until the 1950's.

From 1927 on through the 1930's and most of the 1940's there was a general increase in the length of Grand's intervals, with seasonal fluctuations. Between 1930 and 1947 the seasonal average ranged between about 20 and 44 hours; the extreme intervals being 12 and 120 hours. The seasons previous to 1947 during which I had kept data on Grand show an average interval of 38 hours. During the 1947 season it shared in the marked increase in thermal activity that was general throughout the basins. The 1947 average was 12 hours and 5 minutes. The increased activity during 1947 and 1948 was in part due to near dormancy of Rift and Triplets. Following their rejuvenation in 1949 the seasonal average on through 1951 was approximately 20 hours. From 1952 through 1958 there was progressive shortening, from an average of $14\frac{1}{2}$ hours for the 1952 season to 8 hours and 32 minutes for 1958.

During 1958 and the pre-sarthquake period of 1959 Grand erupted with greater frequency and regularity than during any other recorded period. During 1958 I determined 333 eruption intervals. The average was 8 hours and 32 minutes; the extremes were 6 hours and 49 minutes and 12 hours and 40 minutes. Not only did Grand play more frequently than during any other season of record, it set a new record during 1958 by three eruptions being observed during daylight hours of a single day.

There has never been a season in the Grand's history when its eruptive time could be predicted with as high a degree of accuracy as during 1958. The majority of the eruptions did not vary more than one hour, plus or minus, from the average time. This, in connection with its more frequent performance, resulted in many more people seeing it in 1958 than during any previous season.

During 1958, except consequent to an eruption of Grand, West Triplet had infrequent and very short periods of activity.

However, an additional factor entered into the picture in accounting for Grand's show of activity. There was a greatly shortened period of synchronization of Turban and Vent. Where previous to the 1958 season there had been a period of from 6 to 8 hours before Turban and Vent would cease erupting, during 1958 their concerted activity lasted from but 2 to 3 hours. This resulted in a correspondingly earlier recovery and overflow stage for Grand. The shortened period of concerted activity of Turban and Vent has persisted. During recent seasons, including 1969, it has been near 3 hours.

Pre-earthquake Eruptions

The first premonitory signs of an eruption of Grand were the start of ebb in Turban and a slight increase in overflow of Grand. Usually within a matter of 10 to 20 seconds following this evident shifting of pressure from Turban to Grand, a slight pulsing was noted issuing from Grand's vent, sending waves shoreward over the large collecting basin. The pulsing as well as the waves increased in forcefulness, sometimes for several minutes, when suddenly there was doming of water over Grand's orifice, followed by a sudden explosion and rocketing of water. On rare occasions this pulsing would cease, resulting in Turban's activity with no consequent eruption of Grand.

The initial burst of water was quite variable, not only in the manner of its ejection, but also in height and duration. As a general rule the first explosion lasted from 1 to 2 minutes, but at times as long as 12 minutes. If the duration of this phase of the eruption went much beyond 2 minutes, it was characterized by rapidly successive rockets of water, from 50 to 100 feet in height, instead of a more massive and higher burst.

During an active phase Grand had several independent eruptions, most of which lasted scarcely more than a minute. Following each separate explosion the water column dropped with a suddenness that almost equaled its explosive ejection. Much of the falling water rushed back into the crater, but immediately there was doming and another explosion.

The number of separate eruptions during an active phase was quite variable, being anywhere from 6 for a minimum, with 45 eruptions being the most observed to date. As a general rule, the number of eruptions varied between about 8 and 12, with the active phase lasting from 12 to 20 minutes. When 30 or more eruptions occurred during the active phase, the eruptions usually lasted for more than an hour.

Most of the time the second, third, fourth and fifth eruptions were the most massive and played to the greatest height. Instead of a

single stream of water, as characterizes Old Faithful, many independent jets could be seen rocketing through the massive column. Some of these jets occasionally approximated 200 feet in height.

At the conclusion of the last eruption, the crater emptied with much of the water flowing back into the well. During some seasons this concluding burst was followed within seconds by cessation of both Turban and Vent, with all craters emptying. During other seasons, Turban and Vent would continue to erupt for about an hour following Grand before cessation of play and emptying. From 1937 through 1942 it was observed that 15 to 20 minutes after the emptying of the crater there would be a concluding burst from Grand. This delayed eruption was not again observed until the 1960-61 seasons. There has been no known occurrence since.

Much of the above description applies to Grand's current activity. However, since the earthquake some of the sympathetic responses have undergone some modifications which will be treated in the following topic.

Post-Earthquake Behavior

The morning following the earthquake I began a hurried check of the thermal springs. Turban and Vent were observed erupting simultaneously. This, in connection with Grand's empty crater, made it certain that Grand had erupted earlier. Should the eruption have started at the time of the earthquake, 11:37 p.m., as was the case with the majority of the thermal springs, it is highly probable that had its duration been timed it would be the longest on record. It would also have set a record in number of independent bursts. Following this eruption it was dormant for the rest of the year.

Grand's dormancy was no doubt due to a great loss in temperature. Prior to the earthquake the quiet-phase temperature held close to 176°F. After the earthquake it was 165°F. for several weeks. Following the earthquake the crater filled as formerly, with occasional overflow. By October brown algae were beginning to grow in the outer two-thirds of the crater.

The immediate cause of Grand's dormancy can only be conjectured. The following facts offer a probable solution. Temperature readings revealed a drop of about 10°F. in both Grand and Turban. This marked drop suggests a subterraneous shifting of the thermal energy to other springs. That West Triplet and Rift were not the recipients of an energy shift was indicated by the fact that they too were dormant. However, about 200 yards north of Grand long dormant

Economic Geyser, and a nearby spring with no previous record of eruptive activity, began erupting several times each day. This condition persisted until September 21, when eruptions rapidly tapered, soon ceasing altogether. It was during the concluding stages of activity of Economic and the unnamed spring that Turban began having enervated eruptions. By December the temperature of Grand had increased to 173°F. and Turban to 195°F. Both West Triplet and Rift were having infrequent eruptions.

The first eruption of Grand following the earthquake-induced one was on February 19, 1960. From then until the end of the year 28 eruptions were known to have occurred. The average time was about 12 days; the minimum and maximum intervals were 3 days and 31 days. From 1960 on until the 1967 season there was a gradual increase in the number of eruptions: 1961-47; 1962-98; 1963-125; 1964-182; 1965-185; 1966-213.

During 1964 for the first time following the earthquake Grand began erupting with some degree of regularity. The great majority of intervals varied between 15 and 30 hours. By 1966 it was erupting with about the same frequency as that immediately preceding the earthquake, which type of function persisted through 1966 and part of 1967. Since 1967 the average interval has been 11.5 hours.

On June 2, 1969 and for the rest of the season Grand was observed erupting on a different pattern from anything previously recorded since it was first observed by the Hayden Survey in 1871. Instead of the usual 6 to 10 bursts during an active phase that had characterized it since the earthquake, there were only two. The first burst consisted of continuous rocketing for a duration of 10 to 12 minutes, while the succeeding burst appeared normal and typical. As the season progressed the number of bursts increased from 3 to 5. The long, rocketing, first one persisted. Before the earthquake on a number of occasions I observed the initial burst of Grand to last from 8 to 10 minutes, however, the usual series, about 6 to 12 or more eruptions, always followed.

It is believed that as a result of the earthquake the plumbing in the Grand Complex underwent some changes. Quite apart from the dissipation of thermal energy by connecting units, functional behavior of at least Grand, Turban and Vent shows evident modifications. During Grand's overflow periods, which occur during Turban's quiet phase, there is increased discharge. Due to the manner in which the overflow fans from the crater no measurements of discharge have been attempted. However, to one who has observed this overflow for over

a quarter of a century the post-earthquake increase in discharge is quite obvious. Further, the water in Turban during its quiet phase stands 2 to 4 inches higher in the crater than before the earthquake. When Grand erupts in concert with Turban there is no ebb in Turban such as formerly characterized it. The occasional precursor eruptions of Vent were never known to occur before the earthquake. Grand's 1969 change in eruption pattern might result from underground alterations related to the 1959 incident.

Dormant Periods

Not only has Grand shown periods of great irregularity and withal a vacillating behavior, on three known occasions it has become dormant over a period of several months. The earliest reference to dormancy is found in an 1890 guide book by A. B. Guptil: "Eruptions of the Grand are somewhat irregular, usually occurring at intervals from nine to thirty hours. Its inactivity during the latter part of the season of 1888 being attributed to the extraordinary demonstrations of the Excelsior." The duration of this period of dormancy is not known. It might well have extended through a part of the 1888 winter. That the 1888 season dormancy of the Grand resulted from Excelsior's activity can be dismissed as extremely unlikely. The cause, or causes, in all probability resulted from conditions existing wholly within the Grand Complex of thermal springs.

The next known dormancy of the Grand occurred during the 1941-42 winter. One or more additional cessations of activity between 1888 and 1941 might have taken place, but the lack of records and systematic observations for the period make such a supposition wholly conjectural.

My first knowledge that a non-eruptive state might characterize Grand for possibly months came as a distinct surprise in May 1942. Conditions in the bowl of the Grand were at once revealing of a long period of quiescence. The crater, even into the wall, was completely lined with brilliant orange-colored algae, the filaments being an inch long. It would have taken several months of inactivity to produce this condition. So far as could be determined there were no convection currents rising in the well; the odor of the water suggested a stagnant condition.

It was observed that Turban, instead of being periodic, was in a constant state of feeble ebullition, some of its water draining into the crater of Vent, none into Grand. Later observation indicated the Triplets and Rift were also dormant, resulting in the conclusion that Grand's dormancy must result from Turban's peculiar behavior. This condition lasted well into June. I surmised that the constant ebullition of Turban was dissipating energy; that if it would cease an eruptive potential would build up. There seemed to be an even balance between gains and losses in thermal energy. It was noted that water from Turban's steady boiling flowed into Vent but not into Grand. There was no overflow of Vent. This indicated deep circulation. Thus I tried the expedient of putting a generous amount of granulated soap into Vent. To my surprise about 4 hours later Grand erupted. From then on normal functioning was resumed. There has been no recurrence of the above condition.

The only other known dormant period of Grand resulted from the 1959 earthquake. The nature of this dormancy has been treated earlier in this paper.

Grand and the Weather

The climate in Yellowstone Park is quite severe. During a goodly portion of the year, from late October through March, sub-zero readings are of frequent occurrence in the geyser basins. During both summer and winter winds of relatively high intensity will frequently play across the open craters of the hot springs. That such weather would chill the surfaces of large open pools and lower the temperature of the descending currents of convection is patent. It is believed by many that adverse weather, such as the above described, would delay the eruptions of geysers such as Grand which has a surface area of over 2000 square feet. It is hoped the following will be enlightening on this problem:

Not only do the Grand's eruptive periods seem to be uninfluenced by any degree of wind but they also show an equal independence in function with respect to the season. Its eruptions appear to come with as great a frequency when sub-zero conditions prevail as during maximum summer temperatures. The eruption data on the Grand for the 1951 summer when compared with data collected during the following winter should bring out this fact very clearly. From May 25, until September 15, 1951, 136 eruption intervals were determined. The average interval was 20 hours. The minimum interval during this

period was 11 hours, the maximum 39 hours. From November 9, 1951 until April 28, 1952, 208 eruption intervals were determined. The average interval was 14 $\frac{3}{4}$ hours. The maximum during this period was 22 hours, the minimum 8 $\frac{1}{2}$ hours. Some of the shortest intervals during the winter were at the times of sub-zero weather. The coldest temperature recorded at the time of an eruption was -32°F, and the interval was 13 hours, this being nearly 2 hours under the winter average.

Starting on November 22, 1952, a mass of arctic air moved over the geyser basin, and for 10 days the temperature ranged well below zero. The average minimum temperature during these 10 days was 17.4°F. below zero. During this period 12 eruption intervals of the Grand were determined; the average time was 13.3 hours. For the preceding 10 days, from the 12th to the 21st inclusive, 10 eruption intervals were determined, with an average interval of 15.5 hours. The average minimum temperature during this period was 14.6°F. above zero.

Underground Connections

A very complex relationship exists between Grand, Turban and Vent Geysers. A sympathetic response of these geysers to each other was noted by all early scientific observers. Some attributed it to pure coincidence, while others were convinced that a definite interfunctional relationship existed. Even as late as 1935 some research scientists (Allen and Day, 1935, pp.182-183) were of the opinion that no positive evidence existed that the above geysers were connected underground. Their objections are easily refuted.

At least two important factors are responsible for early diversity of opinion on the above subject; first, a lack of sustained observation; second, complex relationships. Due to the short period of time that could be devoted to individual hot springs by all early scientific expeditions, many irregularities, or idiosyncracies in function would in all probability be overlooked, or misinterpreted. Many of the early observations of Grand were made from a distance, without noting attending circumstances in nearby springs. In the case of other eruptions only parts of the complete eruption cycle were noted. There is no evidence that any early sustained observations of active and quiet phase conditions from one eruption to another were ever made. On this subject, Dr. Hayden states: "The Grand is very irregular in its action; but we must remember that the observations are not consecutive over a long time, and until they are carried through a period of months consecutively we cannot predicate anything as to the laws of action it has" (Hayden, 1873, p.215).

An eruption of Grand sets up an unfailing chain reaction in Turban and Vent. Coming upon this chain action in its various stages, and not knowing that Grand had previously erupted could, and would lead to confusion. Due to lack of complete data, conclusions could be and were drawn to the effect that it was only coincidence when all three geysers played in concert. Thus, Hayden was led to state: "I am of the opinion that Grand, Turban and steam vent are independent of each other. Professor Constock, however, thinks there is sympathy to a certain extent " (Hayden, 1872, p.211).

During the period I have observed Grand, which covers portions of 30 years, both winter and summer, I have seen many hundred eruptions in their entirety. I have observed conditions in it and other springs in the complex before and after a Grand eruption for several hundred additional periods of activity. Observations made during quiet-phase conditions would number several thousand. During this protracted period of observation it has been noted that the sympathetic response of Grand, Turban and Vent to each other's eruptions has been unfailing. Further the chain action resulting from an eruption of Grand includes not only Turban and Vent, but also West Triplet and Rift geysers. While evidence of subterranean connections between these geysers is certain there is additional data supporting the conclusion that Grand has underground connections with Economic Geyser and other springs to the north; there is also data suggesting that an underground fissure probably extends from Grand far enough south to include Castle Geyser and Three Sister Springs.

To those who through long observation have become acquainted with Grand, Turban and Vent it has become axiomatic that underground connections exist between them.

Liberty Pool

I10-555E,945S

GRAND GROUP OF UPPER BASIN

During the pre-earthquake period I had observed this spring, it maintained a near constant 133°F. temperature. Its crater was lined with masses of brown algae which would occasionally slough off and, island-like, float to the surface. During the night of the earthquake it erupted. There was evidence of considerable wash about the crater. No further eruptions were noted. However, the temperature had risen from 133°F. to 163°F, which increase was maintained for the rest of the season. The water was very murky.

A year later in September 1960, the temperature had risen to 183°F., but no eruptive activity occurred. The water was still murky. The condition of the water and temperature persisted throughout all of 1961. It was the 1965 season before the water completely cleared and algae began to appear on the sides of the bowl. By 1968 Liberty appeared to have returned to essentially the same state as that preceding the earthquake.

During the night of the earthquake an unnamed pool, I10-60²⁶~~9~~930S, lying 50 feet east of Liberty Pool erupted. What seemed remarkable about the eruption was that prior to its occurrence it and a nearby spring, I10-535E,925S, which later erupted, both contained cold water which 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. All vegetable and animal life was summarily removed from the pools, not only by the eruptions, but by a near 140 F. rise in temperature.

These springs have never returned to their pre-earthquake state. There are still several gallons per minute discharge from I10-60²⁶~~9~~930S.

A spring, J10-735E,65S, designated as "Fissure Spring" lying about 200 feet southeast of the "Frog Pools" erupted violently the night of the earthquake. During the remainder of 1959 there were additional eruptions but I was not fortunate enough to see one. No evidence of eruptive activity has been observed since 1959. Prior to the earthquake it was never known to erupt.

Lime Kiln

I9-335E,470S

GRAND GROUP OF UPPER BASIN

This spring seemed to escape entirely the effects of the 1959 earthquake. During all of its known history it appears to have been a steadily overflowing spring.

"Milk Cauldron"

I9-555E,270S

GRAND GROUP OF UPPER BASIN

A milk colored spring 50 feet west of Calida was named "Milk Cauldron". Following the earthquake the temperature rose from 194°F. to 200°F. A 20 inch drop in the water level resulted in more vigorous boiling.

Old Tardy Geyser

II10-270E, 585S

GRAND GROUP OF UPPER BASIN

This small geyser is very irregular in its eruptive pattern. Some seasons it is dormant; others quite active. During its active cycles the intervals have never been determined. During an eruption which lasts for about 10 to 15 minutes, the water jets up to a height of from 5 to 7 feet.

No earthquake effects were observed. Due to its irregular pattern of behavior it is presumed to have underground connections with other nearby springs. If so, connections are unknown.

Orange Spring ⁷

J9-320E, 70S

GRAND GROUP OF UPPER BASIN

Orange Spring erupted the night of the 1959 earthquake. The crater was empty the following morning. For the remainder of 1959 there was periodic boiling. During 1960 and 1961 there was a gradual rise of water in the crater. By 1962 it was full and overflowing, the orange algal coloration being restored. It has no known connections with other springs.

Oval Spring

I10-320E, 630S

GRAND GROUP OF UPPER BASIN

Prior to the earthquake the water in this large non-flowing spring stood about 4 inches below overflow. Its temperature was fairly constant at about 193°F. During the night of August 17, 1959 there was an earthquake-induced eruption. The water in the crater was murky and in a state of constant ebullition. The temperature had risen to 201°F. However, no further eruptive activity was noted during the remainder of 1959. Since 1960 this spring has been in essentially the same state as that preceding the earthquake.

Oval Spring has no known connections with other springs.

"Penta Geyser" 2

110-355³⁵E, 675S

GRAND GROUP OF UPPER BASIN

Back in the 1920's this geyser was referred to as the "Hand Saw", apparently due to the fact that during an eruption water plays from 5 separate vents. These vents are close to each other and in alignment. I thought Penta a more elegant and descriptive designation.

Penta erupts with great irregularity. Some seasons 2 to 3 eruptions are the most that are observed. At times for a period of a few weeks an eruption will be observed every day, as in May and June 1943. This great irregularity, in part at least, could be due to its underground connections with Sawmill and Spasmodic.

Following the earthquake no immediate effects on Penta were observed. During the quiet phase no water can be seen in the small vents, thus if the water were murky it could not be determined. As with a number of the hot springs, the earthquake effect was delayed in manifesting itself. On October 14 and 15, 1959 there was no known cessation of Penta's activity. It is believed it erupted steadily in excess of 48 hours. During this protracted period of activity there was complete quiescence of both Spasmodic and Sawmill.

An eruption of Penta normally lasts for about 45 minutes. During activity water plays steadily from all vents to varying heights; in the smallest vent, not more than a foot. The large vent plays to a height of from 25 to 30 feet.

Rift Geyser 5

II0-225E, 460S

GRAND GROUP OF UPPER BASIN

Rift has the most inauspicious appearance of any geyser in the Park. Except at the time of an eruption no water is in evidence. To further make it unhot-spring-like in appearance it has no bowl or crater. The structure consists merely of several cracks or rifts in the rhyolite.

During an eruption of Rift water and steam make their appearance from numerous rifts, many of which are not in evidence during the quiet phase. From some of them water of pencil-size proportions plays up but a few inches. In the dominant rift the height is about 3 to 4 feet. During an eruption, which lasts for about 90 minutes, there is a near-steady discharge of water at a rate of about 25 gallons per minute. That activity of the present character has been going on for a relatively long period is made evident by the depth of the drainage channel.

Rift is definitely a member of the Grand Geyser complex. The great majority of its eruptions occur about 40 to 60 minutes following the start of an eruption of Grand. Occasionally it will erupt at about the time an eruption of Grand would seem to be imminent. When this occurs Grand usually erupts on an over-average interval.

During the period of Grand's dormancy following the earthquake Rift was noted erupting but 4 times. Its return to present eruptive frequency has been synchronized with that of Grand's.

Sawmill Geyser
110-250E, 760S

GRAND GROUP OF UPPER BASIN

Early references to Sawmill are very scanty. There is a report in 1895 which states that eruptions occurred every 2 hours (Wheeler, 1896, p.69). During the 1920's there are indications that eruptions followed very much the same pattern until the 1959 earthquake.

During the 1940's and 1950's I had Sawmill under daily surveillance for several months each season except 1943 through 1945, World War II years. Little or no variation was observed in its eruptive pattern. The eruptions occurred about every 2 to 3 hours. The duration of an eruption was essentially the same length as the quiet phase. It was in a state of eruption fully half of the time.

During the quiet phase there is no boiling. Water at a temperature of about 189°F. slowly rises in the crater. The eruption might start when the water reaches the overflow level. At times overflow will precede activity by as much as 30 minutes.

The eruption is characterized by rapidly recurring jets of water. The height of the average jet is about 20 feet. Jets can and do vary between 10 and 35 feet. Sawmill may be classed as a fountain-type geyser.

Following the 1959 earthquake it is believed Sawmill played constantly for a period in excess of 48 hours. Whenever I was in a position to observe, it was erupting. Following this surge of activity it again became periodic, the eruptions occurring about every one to two hours. During the quiet phase the temperature of the water in the bowl had risen from 189°F. to 194°F. This increase in temperature no doubt in part accounted for increased activity.

During 1961 Sawmill seemed to be back on a near pre-earthquake pattern. Eruptions occurred about every 2 to 3 hours. This frequency of activity persisted through 1961 and 1962. During 1963 it was in a state of near dormancy. But few eruptions were observed during that year. Surprisingly 1964 through 1966 witnessed a return to near pre-1963 activity. However, from mid-June 1967 for the remainder of the season Sawmill was dormant. At the beginning of the 1963 season conditions about the crater were indicative that the dormancy of 1967 had persisted through the

following winter. Some rejuvenation occurred in late July 1968. However, it was mid-season in 1969 before any activity was observed. The frequency of the eruptions seemed to increase as the season progressed.

There is evidence that Sawmill has subterraneous connections with at least two additional geysers - Tardy and Penta. There are also indications it is connected with Spasmodic. A sympathetic relationship between Sawmill and Tardy was noted long before the 1959 earthquake. During this period both geysers erupted with about the same frequency. Not infrequently Tardy would erupt in concert with Sawmill. Whenever this occurred, with no observed exceptions, the activity of Tardy would be much more forceful and violent than when erupting alone.

Since the first 3 seasons following the earthquake Tardy's pattern of activity has never been the same. Sometime during the winter of 1962-63 it became almost a steady geyser, erupting fully 95% of the time. During 1963 there is a record of but 2 eruptions of Sawmill. Since that season whenever Tardy shows near steady activity Sawmill is dormant.

It is only since the 1959 earthquake that any sympathy between Sawmill and nearby Penta Geyser has been observed. On October 14 and 15, 1959 Sawmill was dormant. On both days Penta erupted without any observed cessation. Simultaneous eruption of these geysers has never been observed.

Scalloped Spring

110-110E, 835S

GRAND GROUP OF UPPER BASIN

Previous to the 1955 season this spring was in a constant state of overflow. Early in 1955 an orgy of soaping of the hot springs in the Upper Basin occurred, which included Scalloped Spring. Wash about the crater indicated that it had erupted and that considerable water had been discharged. The water was down from 3 to $3\frac{1}{2}$ feet in the crater. The crater has never refilled, but has stayed near the 3 foot level.

As a result of the 1959 earthquake Scalloped Spring became murky; the water level dropped from near 3 to 4 feet; also the temperature rose from 198°F. to 201°F. with steady boiling. The increase in temperature resulted in occasional surging. At times the surges were violent enough to discharge some water from the crater. Since 1963 this type of surging has not been observed.

"South Scalloped Spring" ³

110-140E, 900S

GRAND GROUP OF UPPER BASIN

The scalloped border about this spring is indicative of a near-even water level over a few score years. However, in 1959 prior to the earthquake the water stood about an inch below the edge of the scalloped rim. Following the earthquake the water was murky and the spring discharged about 5 gallons per minute for the rest of the season. The temperature increased from 198°F. to 201°F. Overflow continued through 1963. None has been observed since.

Spanker Geyser •
I9-630E,675S

GRAND GROUP OF UPPER BASIN

During all of its history for which I have any record Spanker has functioned as a steady geyser. Following the 1959 earthquake its water was murky, but before the end of the year it had cleared.

Spasmodic Geyser

110-380E, 665S

GRAND GROUP OF UPPER BASIN

Spasmodic has been described as "a miscellaneous collection of vents around two large craters, which, when the entire assembly is in action does credit to its name" (Phillips, 1927, p.141). There are not less than 13 vents from which water is jetting up from a few inches to a few feet most of the time. At full eruption additional ones spout. While this geyser is constantly boiling and sputtering, at indefinite periods there is a marked increase in the violence of the activity.

Following the earthquake the water was murky for several days but cleared rapidly. There was a drop of about 6 inches in water level with an increase in temperature of 4°F. There was also increase in boiling. During the remainder of 1959 and during 1960 the water stayed ebbed in the craters with most of the activity in the south one. At times this crater would jet water to a height of about 20 feet. Since 1960 Spasmodic has appeared to be in essentially the same state as before the earthquake.

Spasmodic and nearby Penta Geyser appear to be connected underground. Whenever Penta erupts practically all activity ceases in Spasmodic.

"Spatter Geyser"

J10-540E,603

GRAND GROUP OF UPPER BASIN

"Spatter Geyser" is located on the high sinter embankment across the river from Sprinkler Geyser. No water was ever observed in its shallow crater prior to the earthquake. Following the earthquake it erupted frequently with a pattern similar to that of Sprinkler. There is no record of previous activity. It continued periodic activity until near the end of the 1962 season. No eruptions have been observed since 1962.

Sprinkler Geyser "

J10-475E,115S

GRAND GROUP OF UPPER BASIN

Due to the location of this small geyser observation is difficult unless one is in the immediate vicinity. It must have been active as a geyser over a long period in view of the fact it was named by Arnold Hague. I do not know of any dormancy during my period of observation. It erupts several times daily. However, if there is any regularity it has not as yet been determined. The heights of the eruptions are about 10 feet; their duration unknown. It has no known connections with other springs.

Following the 1959 earthquake the water was murky. There was a 4°E. rise in temperature. Both it and a small vent closer to the river became noticeably more active for the first few weeks following the earthquake.

Tardy Geyser

110-290E, 805S

GRAND GROUP OF UPPER BASIN

The only known reference to Tardy's eruptions prior to my own observations was by Park Ranger Phillips (1927, p141). He states that it has a "similar action to Sawmill, but on a smaller scale". It is believed that this type of activity largely characterized Tardy from the time it was named by Dr. Hayden until Phillips' observation.

When I first became acquainted with Tardy, about 1937, the sign in front of it designated it as "Little Sawmill". The name seemed quite appropriate. It did very closely emulate Sawmill's eruptions, but on a smaller scale, as indicated by Phillips.

During the 1940's and 1950's eruptions occurred about every 2 to 3 hours, lasting from about 25 to 30 minutes. Occasionally it would play during an eruption of Sawmill. Its eruptions were then noticeably more violent. When erupting alone the quick successive jets attained a height of from 10 to 12 feet; when in concert with Sawmill they were from 15 to 25 feet in height.

Following the 1959 earthquake little change was noted in eruptive behavior until the 1963 season. During that year, at the expense of Sawmill, Tardy erupted about 95% of the time. During the three succeeding seasons the pre-earthquake relationship between Tardy and Sawmill seemed quite well established. However, since 1966 there have been months when Tardy erupted steadily with quiescence in Sawmill.

Tardy's underground connections with Sawmill have been treated in the discussion of Sawmill.

Teakettle Geyser

¹⁰
J10-3E,865S

GRAND GROUP OF UPPER BASIN

As a result of the 1959 earthquake Teakettle began having eruptions. This was the first time I had ever observed this function. The day following the earthquake I noted 3 eruptions which I estimated to be from 12 to 15 feet in height. The duration was about one minute. It is quite certain I did not see all of the eruptions on that date. Eruptions continued until September 15 after which no more were observed for the rest of 1959. However, there was steady overflow which had not been true prior to the earthquake. During 1960 there were occasional eruptions of the type described for 1959, with overflow except for a short period following an eruption.

No more eruptions of the character described for 1959 and 1960 have been observed. Neither has there been steady overflow. Until 1964 it was observed to occasionally boil about a foot above the rim of the crater at about one-half hour intervals. Since 1964 this kind of function has occurred with diminishing frequency.

Terra Cotta Geyser

19-950E, 945S

GRAND GROUP OF UPPER BASIN

There have been but few seasons during my observations that any eruptive activity has been noted. When in an active cycle it erupts frequently. The geyser consists of two small vents which erupt simultaneously to a height of from 6 to 8 feet. The earthquake initiated an eruption cycle. Beginning with 1960 no activity was observed until the 1968 season. It was dormant during 1969. If connections exist with other springs they are unknown.

Tortoise Shell Spring

J10-255E,400S

GRAND GROUP OF UPPER BASIN

This spring, year after year, has the distinction of usually being the hottest spring in the geyser basins. Its temperature ranges between about 203 and 206°F. That this situation has characterized it over the years is indicated by a 1927 report which states: "Tortoise Shell has the distinction of being the hottest spring in the Park (203°F)." When Giant is in an active cycle its temperature and that of Mastiff are on a par with that of Tortoise Shell.

The water in the crater is in a constant state of ebullition. Periodically there is increase in the degree of boiling. Despite the fact that it is situated at the base of Castle it does not seem to show any sympathetic response to Castle's eruptions. However, the above 1927 report states: "Its ordinary activity is apparently unaffected by Castle; however, its level is lowered about six inches after powerful eruptions of the latter." Just what characterized these powerful eruptions is not at all clear from the report.

Few springs in the geyser basins were so unaffected by the 1959 earthquake as Tortoise Shell. It did not become murky in the slightest degree. There was no apparent alteration in temperature from either the earthquake or Castle's greatly increased activity.

Turban Geyser

110-150E, 310S

GRAND GROUP OF UPPER BASIN

Turban was named by the Hayden Survey. Within its crater there are several globular masses of geyserite. Due to the fancied resemblance of some to the oriental turban that name suggested itself to the Hayden Party (Hayden, 1878, p.212). Some of the masses of sinter in the bottom look not unlike pumpkins. During the 1920's a sign next to the crater bore the designation "Burning Pool".

Turban and nearby Vent and Grand have a complex interfunctional relationship, most of which will be treated during the discussion of Grand.

While early eruptive data on Turban is lacking, its manner of function during the past 40 years, when considered in relation to the form of the raised crater, presents indubitable evidence that the type of activity which has characterized it the past two score years closely parallels its manner of function during the past, perhaps, few hundred years.

Turban's pre-earthquake behavior followed a near set pattern. Following recovery from an eruption of Grand it would play every 15 to 17 minutes, except when the energy would shift to Grand prior to Grand's eruption. The interval would then be from 20 to 25 minutes. Prior to an eruption of Turban the water would rapidly rise from 4 to 6 inches in the crater. If an eruption of Grand were imminent a reverse situation would ensue; Turban's water would ebb from 4 to sometimes as much as 12 inches.

At the time of an eruption of Grand Turban always erupted. Its eruption would at times precede the initial burst of Grand by a matter of seconds; the two eruptions might start simultaneously, or Grand might precede Turban by seconds. The eruptions which occurred during Grand's quiet phase lasted near 4 minutes. They were a splashing type of activity, the maximum height being about 4 to 5 feet. When erupting in concert with Grand the eruptions were much more violent, the water bursting to heights of not less than 8 to 9 feet.

During Grand's active phase, which usually lasted near 17 minutes, there would be no cessation of Turban's violent activity. During

some seasons following Grand's last burst Turban's activity would cease with a rapid and complete drainage of water from the crater; during other seasons Turban would continue to erupt from 30 to 60 minutes before draining. After the crater had been empty for about half an hour it would rapidly fill and another near-hour period of violent activity would ensue. During Turban's recovery period its crater would empty not less than 2 times, sometimes 3 and 4, before it got back on the 15 to 17 minute intervals. When average intervals of Grand were long it would take near 8 hours for Turban to recover. If Grand's average intervals were short Turban's recovery would be correspondingly short.

The morning following the 1959 earthquake Turban and Vent were observed erupting simultaneously, indicating an earlier eruption of Grand. Following this activity Grand and Vent were dormant for the rest of the year. Turban's crater which had emptied August 18, had largely refilled by September 21 and it began to have enervated eruptions at about 17 minute intervals. At times it was observed to overflow without erupting. This was apparently due to a drop in temperature from 197°F. to 187°F.

Following Grand's rejuvenation in February 1960 Turban also became more active. However, its 1960 and 1961 eruptions during Grand's quiet phase were much less vigorous than before the earthquake. By 1967 they were of essentially the same character as before the 1959 disturbance. However, during its quiet phase water stood 2 to 4 inches higher in its crater. Further, little or no ebbing has been observed preceding an eruption of Grand, such as occurred before the earthquake.

The crater of Turban on its east and north sides has been subject to a terrific amount of vandalism, particularly during the first few decades following discovery. Geyserite which formed the sides of beautifully ornamented collecting basins, as shown by early photographs, has all been hacked away by specimen collectors and souvenir hunters. On the sides indicated, no present evidence of these former basins now remains. Chiseled names and dates can be seen in its bowl. Many of the rocks that have been wantonly thrown into the crater are now sealed within a sinter matrix. Many new rocks are added each season.

That the crater of the Turban was victim of early abuse is indicated by an observation made by Captain Ludlow in 1875:

"It is of singular form, highly ornamented, and I experienced almost a pang in becoming conscious of an apprehension that I should meet it again somewhere on exhibition. Some visitor, a little more enterprising than his predecessors, will be sure to detach it and carry it off. Shovel and axe had been busy with the geyser, and large quantities had been removed."
(Ludlow, 1876, p.27).

Vent Geyser "

110-140E, ³⁸⁵259S

GRAND GROUP OF UPPER BASIN

On the northwest corner of Turban's crater there is a small orifice, which in the early descriptions was called the "Steam Vent". Steam was later dropped from the name, and this interesting geyser is now known as Vent. In structure the Vent is not unlike a slit, about a foot long, in the side of Turban's crater.

Much of what has been said relative to Turban's behavior during and after an eruption of Grand is likewise applicable to Vent. Except on rare occasions, Vent erupts only at the time of an eruption of Grand. During and after Grand's activity Vent's action is synchronized with that of Turban. When Turban ceases playing following Grand, Vent ceases activity. Resumption of activity of Turban reactivates Vent. This harmonious performance continues from 3 to sometimes 8 hours or until near the time when Turban refills and enters on its 15 to 17 minute intervals.

Sometimes Vent will start erupting at the time of Grand's first burst. More frequently it is near the time of the second. For the first few moments water plays out at an angle of about 45 degrees to a height of from 30 to 40 feet. Then for the remainder of its activity, which is in concert with Turban's, the height of its steady jet is about 20 feet.

When Grand rejuvenated in 1960 Vent also rejuvenated and with a few exceptions it has continued to have the same close relationship to Grand and Turban as before the earthquake.

The exceptions referred to were first observed during the 1962 season. On April 17 of that year to my great surprise I noted that Vent was erupting without any apparent concerted activity of Turban. Upon visiting the site independent action of Vent proved to be the situation. Such behavior was utterly without known precedent. To make matters more puzzling there had been no recent eruption of Grand. The water in the craters of both Grand and Turban was down about 12 inches. About an hour and a half after this observation, with continuing ebbing in both Grand and Turban, Grand erupted. During the eruption and during the recovery period of Turban and Vent, the manner of their functioning was orthodox in all essential respects.

Following this digression of Vent from its normal behavior it was observed on August 17 and October 19 to again start activity antecedent to Grand. This unusual performance of Vent has been observed only a few times. It occurred on two known dates during 1963, once in 1964 and once in 1967.

The preliminary eruption of Vent has on all known occurrences served as a precursor to an eruption of Grand; the activity precedes Grand anywhere from about 90 to 120 minutes. If this type of pre-Grand play became normal Grand would have a most useful indicator.

Wave Spring

H9-920E, 830S

GRAND GROUP OF UPPER BASIN

During its pre-earthquake history Wave Spring apparently changed little in temperature and manner of performance. Its name was derived from the fact that the pulsing of gas bubbles in the vent sent concentric waves constantly rolling shoreward. There was steady overflow of about 5 gallons per minute.

As a result of the earthquake the wave action greatly increased in strength, resulting in a much heavier discharge. Occasionally this overflow momentarily would further increase in volume. The temperature was 185°F. compared with its former 179°F.

The increased activity persisted until 1962. During that season the wave action and volume of discharge were essentially the same as before the earthquake. The temperature had dropped about ten degrees. Since 1962 its pre-earthquake manner of function has been characteristic.

It has no known connections with other springs. However, its drop in temperature at the same time temperature drops were noted in the Economic Geysers, and other nearby springs is suggestive of subterranean connections.

West Triplet Geyser "

110-140E, 440S

GRAND GROUP OF UPPER BASIN

As the name suggests three geysers would seem to make up the Triplet group. At present but two exist. North Triplet, or the one nearest Grand, had its crater completely filled with sediments which were washed in during eruptive periods of Grand. In the fall of 1947 numerous rocks were removed from near Grand's crater to prevent their being tossed in by unthinking park visitors. The removal of the rocks made possible the washing of the sediments which resulted in the complete effacement of North Triplet. Since the late 1940's only West Triplet of the trio has erupted.

From the late 1930's until the 1947 season eruptions of West Triplet occurred about every 3 hours, which was a greater frequency than during any period since. During the 1950's up until the time of the earthquake there was a gradual decrease in the frequency of the eruptions. During this same period Grand's intervals gradually grew shorter. West Triplet always erupted at the time of one of Grand's eruptions but occasionally it also erupted during Grand's quiet phase. When this happened Grand would have an over-average interval. During the first part of the 1948 season West Triplet was dormant. During this period Grand erupted on shorter intervals. Rejuvenation of West Triplet in July 1948 immediately resulted in longer intervals for Grand.

There has been wide variation not only in lengths of intervals of West Triplet, but also in the duration of its activity. When playing in concert with Grand the duration might be from one minute to about fifteen. When erupting independently of Grand, I have observed the eruption to last from about 60 to 90 minutes.

An eruption is of the pulsing type. Jets shoot up to heights varying between about 3 and 8 feet. There is heavy discharge of water.

Following the 1959 earthquake the water was murky in West Triplet for the remainder of the year. It was dormant during this period. However, occasional overflow was observed. The water would well out quietly without any boiling action. The absence of eruptions was probably due to the fact that its temperature had dropped from 185°F to 182°F.

During 1960 the only time West Triplet was observed erupting was in sequence to an eruption of rejuvenating Grand. However, from that season to date eruptions independent of Grand's have been observed.

Like Rift, West Triplet is a part of the Grand Complex with which it has subterranean connections.

Witches Cauldron

I9-500E,4803

GRAND GROUP OF UPPER BASIN

Apart from being murky following the earthquake no further change was noted in this spring for the remainder of 1959. During 1960 geyser characteristics were in evidence. Every few moments the water would boil to a height of about 2 feet, resulting in marked increase of overflow. This type of function persisted until the 1965 season, during which the boiling greatly subsided. Its 1965 state has characterized it to date.

Unnamed Geysers

J9-435E, 85S

J9-480E, 60S

GRAND GROUP OF UPPER BASIN

Prior to the 1959 earthquake two small unnamed geysers about 8 feet apart were active some seasons and dormant during others. They became more active following the earthquake. During an active cycle the north spring is the more active of the two. It is also the larger. It erupts to a height of about 8 feet; the south 2 to 3 feet. The duration of an eruption is variable. The extremes noted to date are 3 to 8 minutes. Except during the 1969 season, the south spring was seldom seen in eruption. I have observed both springs erupting simultaneously which was their habit during 1968. The usual pattern is for the spring not erupting to ebb while the other is playing, further indicating underground connections. Four seasons since the 1959 earthquake these geysers have been dormant - 1963, 1965, 1966 and 1969.

Unnamed Geyser

110-150E, ⁴⁰⁰~~440~~S

GRAND GROUP OF UPPER BASIN

Some maps show this geyser as one of the Triplets. It is not.

This small geyser lies about 35 feet south of Grand's well. Prior to the 1959 earthquake it would always be observed erupting for undetermined periods during Grand's quiet phase. It would cease erupting at the commencement of Grand's activity. It would never resume activity until after Grand was again in a state of periodic overflow.

Following the 1959 earthquake, and for the rest of the year, this unnamed geyser was never observed erupting. During 1960 it erupted almost constantly. The only time there would be cessation of activity was for a short period following an eruption of Grand. The greatly increased activity was suspected of being, in part at least, responsible for Grand's long intervals. During 1961 the length of the quiescent period began to increase. Today the frequency and nature of its activity are very similar to that which preceded the earthquake.

Two Additional Unnamed Springs

J9-720E, 500S

J9-755E, 530S

GRAND GROUP OF UPPER BASIN

Two additional unnamed springs to the southeast of Orange Spring erupted the night of the earthquake, as was evidenced by wash about the craters. Both craters were empty the following day. They refilled very slowly, it being 1963 before any overflow was observed.

Inkwell Springs

H9-205E, 495S

Upper Geyser Basin

Inkwell Springs are located on the north bank of the Firehole River, approximately 180 feet southwest of Oblong Geyser and 20 feet upstream from the footbridge on the trail which passes Grand and Giant Geysers. I have not been able to find when or by whom the springs were named. The name "Inkwell" was probably made in reference to the dark black mineral and algae colored vents reminiscent of an old-fashioned ink container for quill pens.

Two relatively large black springs and about two dozen white sinter and red algae lined shallow bubblers make up the Inkwell Springs Group. The two black springs are both elongate and are orientated perpendicularly to each other; the easternmost one which lies parallel to the river is $9\frac{1}{2}$ feet long and 5 feet wide while the western spring, separated by about 6 feet, is lined up 90 degrees from the river's bank and has the dimensions of 13 by $4\frac{1}{2}$ feet. Both of these black springs are constant spouters usually throwing the water no more than $\frac{1}{2}$ to 2 feet into the air. As a result there is a splash zone around both of the springs which supports the growth of a thick leathery algae sheath, rich reddish-brown in color, on the margins of the pools.

In line with the west black spring and therefore at right angle to the river is about 10 small bubblers, scattered for a distance of 10 feet and ranging from clear to turbid gray. Most are no more than 4 to 6 inches in diameter. The west black Inkwell Spring is also intersected by a second 18 foot long line of around a dozen small shallow white bubblers at an angle of roughly 35 degrees to the first. Joint control seems the most probable determining factor for the location of these features in the group.

The west group of bubblers (perpendicular to the river) has temperatures which range from 166.5 to 188° F. while the eastern line of bubblers average only 160° F. No visible runoff is present from most of the bubblers but the two black springs and two other additional small springs or seeps produce six short runoff channels which flow directly into the river. An irregularly shaped white sinter buttress has been built up at the water's edge to a height of about 4 feet. The dimensions of the whole Inkwell Springs Group are 28 by 22 feet.