GOSA

THE GOSA TRANSACTIONS

The Journal of the Geyser Observation and Study Association

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A large blue bubble bursting at **Great Fountain Geyser** on August 5, 2008, at 1148. Photo by Bruce Jensen.

Back cover photographs, top to bottom:
Terra Cotta "C" and "A" by Dick Powell
Daisy and Splendid Geysers by Andrew Hafner
Fan Geyser by Lori Hoppe
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An eruption from Black Diamond Pool on May 17, 2009, at Biscuit Basin in Yellowstone National Park. Photographer unknown, permission granted by the photographer for public use through the National Park Service. More photos of this eruption appear on page 56.

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An Explanation of GOSA Measurement and Language Conventions

To assure consistency and the understandability of the articles published in *The GOSA Transactions,* a number of standards have been adopted. It should be noted that these are only the editorially preferred usage. Individual authors may use other measurement values as they wish.

Distance and Height Measurements

This publication's goal is for readers to understand the article information without being bogged down or confused by unfamiliar measurement units. Therefore, GOSA publications prefer using the English measurement system for measuring distances and heights; that is, units of feet, yards and miles, rather than the metric system. Although some feel we should adopt the metric system, the fact is that the majority of our readers, as well as most Americans, do not readily understand metric units. However, please note that articles using the metric system are published as is, using metric measurement units.

Time Measurements and Time Measurement Abbreviations

Units of time are straightforward in nearly all cases. In general discussions, where specific data is not involved, time units are spelled in full ("hours" or "minutes", for example). Within specific data, however, the use of abbreviations is preferred. The units are as follows: d = days; h = hours; m = minutes; s = seconds. To avoid confusion, punctuation-type abbreviations are not used, and longer time units, such as "years" and "months", are always spelled in full.

Other Abbreviations

A number of additional, geyser-observation-standard abbreviations are used within some articles, most consistently within data tables and in text directly associated with specific geyser data. These abbreviations include the following:

I or i = interval; IBE = interval between eruptions; D or d = duration; ie = observed in eruption; and the tilde (~) may be used to note approximate time value. When these terms are used in isolated incidents within an article, they may be spelled out.

Past Tense and Present Tense

Almost without exception, a discussion about geyser activity is based on past observations; therefore, articles have been written in past tense.

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Terra Cotta Complex

Mike Keller

Abstract

Starting in 1989, the author began observing and documenting the behavior of the geysers within the Terra Cotta Complex. During this time a total of 6 independent geysers and a total of 13 overall erupting vents were observed. The following article will discuss the observations made by the author over the past 20 years and provide a quick historical summary of the activity of the geysers in this area.

The Terra Cotta Complex lies on the edge of the Firehole River, approximately 160 feet downstream on the west bank of the river from the footbridge. Within this complex are no fewer than six separate geysers plus an additional seven erupting vents and two more overflowing springs. Another 190 feet to the west from today's Terra Cotta Geyser is Terra Cotta Spring, so named due to its color.

Historical Overview:

Geyser activity from today's Terra Cotta Geyser was not common in the early days of Yellowstone, with no mention of any geyser activity in this area taking place from 1888 until the 1940s. Following further dormancies in the late 1940s and most of the 1950s, Terra Cotta reactivated in 1957, and has remained active in most years since then.

The first reference comes from Walter Weed in July of 1885 and is given to today's Terra Cotta Spring, a small, reddish-colored feature in the grassy area to the north of today's footbridge crossing the Firehole River below Castle Geyser:

> Spring 12-Temp 186 quiet boiling spring of brick red colored water no overflow[1]

In 1886, the following change is made in Weed's formal notebook:

> Spring 12-not the small one, is called Terra Cotta Spring[2]

This entry was written in different colored ink, possibly by Weed himself, to identify this feature as Terra Cotta Spring. This same feature was also called "Brick Spring" in early reports. There is no mention or reference to the geysers that are known as today's Terra Cotta Geysers. In the nearby area were another two features called the "Dishpan" and the "Washtub."

From 1886 until the Hague atlas of 1904, there is no further mention of Terra Cotta Spring or today's Terra Cotta Geysers. In the 1904 Atlas, the name "Brick Spring" was placed on Terra Cotta Spring, and the name Terra Cotta Spring was placed on today's Terra Cotta Geysers. As a result, everyone from George Marler to the *Haynes Guides to Yellowstone* to Scott Bryan has called the erupting features Terra Cotta Geyser(s).

I have been unable to find any reports on thermal activity in the Terra Cotta area from the turn of the century until 1926. The first account for the 20^{th} century I found comes from Ansel Hall:

> TERRA COTTA SPRING is a peculiarly colored spring near the south bank of the river about 250 feet from the bridge.[3]

This account is from an extensive document discussing the placement of interpretive signs for the nature trails in the Upper Geyser Basin. Within it, almost every eruptive feature in the geyser basins that were active in the mid 1920s is given a sign and some sort of description of its activity. Curiously absent is any reference to what are today's Terra Cotta Geysers. Based upon this, and later documentation from George Marler, I believe these geysers were not active for an extensive period of time in the early to mid 1900s.

The next account of Terra Cotta I can find comes from the 1937 index card collection for the Upper Geyser Basin. In it, Phillip Fix notes the following:

> TERRA COTTA SPRING-Steaming a little all summer, no water overflowed or thrown as far as I know. I saw it on the average every other morning while conducting the Geyser Walk party.[4]

Following the 1959 earthquake, an extensive survey was conducted in the geyser basins. Germerad and Watson submitted the following reports in late October of 1959[5]:

> Terra Cotta 'C'-spring-beady geyserite deposits-temperature 170 °F-slight discharge-crater shaped like a figure 8-depth 4 feet
>
> Terra Cotta 'D'-geyser-beady sinter-temperature 201 °F-circular shaped crater-depth 1' 4"-Plays as high as 7' on some bursts. Two vents here, both playing
>
> Terra Cotta 'E'-fumarole-beady and spiny sinter-no temperature given-Doesn't play at present date although it obviously has been a geyser
>
> Terra Cotta 'F'-geyser-beady sinter-temperature 199 °F-crater triangular shaped-depth 3' 2"-Plays 9' high on some bursts.

Unfortunately, I have been unable to find any records for vents A, B, or any additional ones that were surveyed.

George Marler offered the following in his Inventory of Thermal Features in 1972[6]:

> 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 from 6 to 8 feet. The earthquake initiated an eruption cycle. Beginning with 1960 no activity was observed until the 1968 season. If connections exist with other springs they are unknown.

However, when reviewing Marler's annual thermal reports in the Yellowstone Nature Notes[7], Marler lists Terra Cotta Geyser as active in every year from 1960 through 1968. From 1969 through 1971, there is no record of activity from the area, but it is once again noted as active in 1972 by Sam Martinez[8]. In his 1973 "Hot Spring Activity in the Geyser Basins of the Firehole River[9]," Rick Hutchinson lists Terra Cotta Geyser as active. It is believed that Terra Cotta has been active every year since 1971, but there was one additional brief period of dormancy reported by Jerry Carlson in 1978[10], which is also noted by Sam Martinez in his annual report[11]:

> July-about 1 ½ hour intervals, height 6-8 feet August-no eruptions

In 1984, Dan Ng noted the following[12] in his monthly observations of the area:

> Terra Cotta-approximately 4 to 5 minutes between overflow with one to two minutes of overflow. Pool fills, bubbles up, then overflows. Drains to adjacent dry spring vent to the east, then the pool drains about 1 to 1 ½ inches

Further confusion regarding Terra Cotta's activity can be found in each edition of T. Scott Bryan's *The Geysers of Yellowstone*. In the 1979 and 1991 volumes[13], he states:

> Terra Cotta Spring is a geyser, but it is usually dormant. Few eruptive phases were noted until after the 1959 earthquake. Its longest known active period is the present one, as it has been erupting during every year since 1970. The eruptions recur about every 2 hours and last 5 to 10 minutes. Water is sprayed to 10 feet in height from two closely spaced vents.

In the third edition, published in 1995, Bryan's information on Terra Cotta is dramatically changed[14]:

> TERRA COTTA GEYSERS is the name for what is really a number of separate hot springs, all of which have been known as geysers since 1878. In practice, they have come to be called Terra Cotta 'A', 'B', 'C', 'D', and 'E' – awkward, especially since the original Terra Cotta Spring is a small brick-red spring about 100 feet to the northwest. In fact, two of these geysers have officially approved names: "Terra Cotta 'B'" is Dishpan Spring, and "Terra Cotta 'C' and 'D'" together are Washtub Spring. Since the use of "Terra Cotta" for these geysers has become common in recent years, the name is now being applied to the entire cluster.

Unnamed vent "A" is by far the most active. Spouting from several openings, the major part of the play reaches 5 to 10 feet high at a slight angle from the vertical. Intervals are usually around 2 hours, and durations are a few minutes.

Dishpan Spring (vent "B") is considerably less active than "A," but its strongly angled eruptions can reach fully 20 feet high and are strong enough to play into the river. The durations are again a few minutes long.

Washtub Spring (vent "C") erupts from a small square pool. The eruptions are uncommon and last only a few seconds while reaching 15 feet high. Vent "D" is the rarest of all, with only a few eruptions being seen each season. Its bursting play can hit 20 feet through most of a duration of 5 minutes.

Lastly, unnamed vent "E" is a small geyser, hardly visible from the boardwalk but quite frequent in its actions."

Further changes about Terra Cotta's activity can be found in the 2008 edition[15] (changes noted in bold and italics):

TERRA COTTA GEYSERS is the collective name for a number of separate hot springs, all of which are geysers. In practice, they have come to be called Terra Cotta 'A', 'B', 'C', 'D', and 'E' – awkward since it is now known that the original Terra Cotta Spring of 1878 is a small brick-red spring about ***200*** feet ***farther downriver***. In fact, two of these geysers have official names of their own.

Most often, Terra Cotta "A" is the most active. Spouting from several openings, the major part of the play reaches 5 to 10 feet high at a slight angle from the vertical. Intervals are usually around 2 hours, and durations are a few minutes.

Dishpan Spring (***Terra Cotta*** "B") is ***much less active than "A,"*** but its strongly angled eruptions can reach ***12 feet high. The durations typically are only a few seconds long.***

Terra Cotta "C" bears the name Washtub Spring. It and Terra Cotta "D" usually erupt simultaneously. Washtub plays from a small square pool whose sinter has a slight pinkish cast. Uncommon in most years, the eruptions last as long as 5 minutes and can reach 20 feet high at an angle so as to reach the river. The play by "D" is much smaller.

Lastly, Terra Cotta "E" is a small geyser, hardly visible from the boardwalk but quite frequent in its action.

While some of what is reported by Bryan is consistent with what I have observed in the past 20 years, I have never seen any feature in this group erupt at an angle strong enough to reach the Firehole River. The closest erupting vent to the river is "A," being 30 feet away. The vents Bryan reports this activity from are closer to 40 feet from the Firehole River.

Modern Day Eruptive Activity:

The author began watching the Terra Cotta Complex in the fall of 1989. The majority of the information that follows comes from the period of August 1989 through October 1994, with additional extended periods of observation taking place from March 1997 through November 2008.

While it is not easy to see all of the erupting features in the group, I found the best vantage point to be from the boardwalk just to the left of Scalloped Spring. From this location, it is easy to identify vents "A," "B," "C," "D," "E," and "F," and if there is little to no steam obstructing your view when "A" is in eruption, you can usually see the smaller vents around "A" in eruption with the naked eye. From the footbridge over the Firehole River it is easy to spot the larger geysers when they are in eruption, but the smaller vents are all but invisible.

Terra Cotta Complex Overview

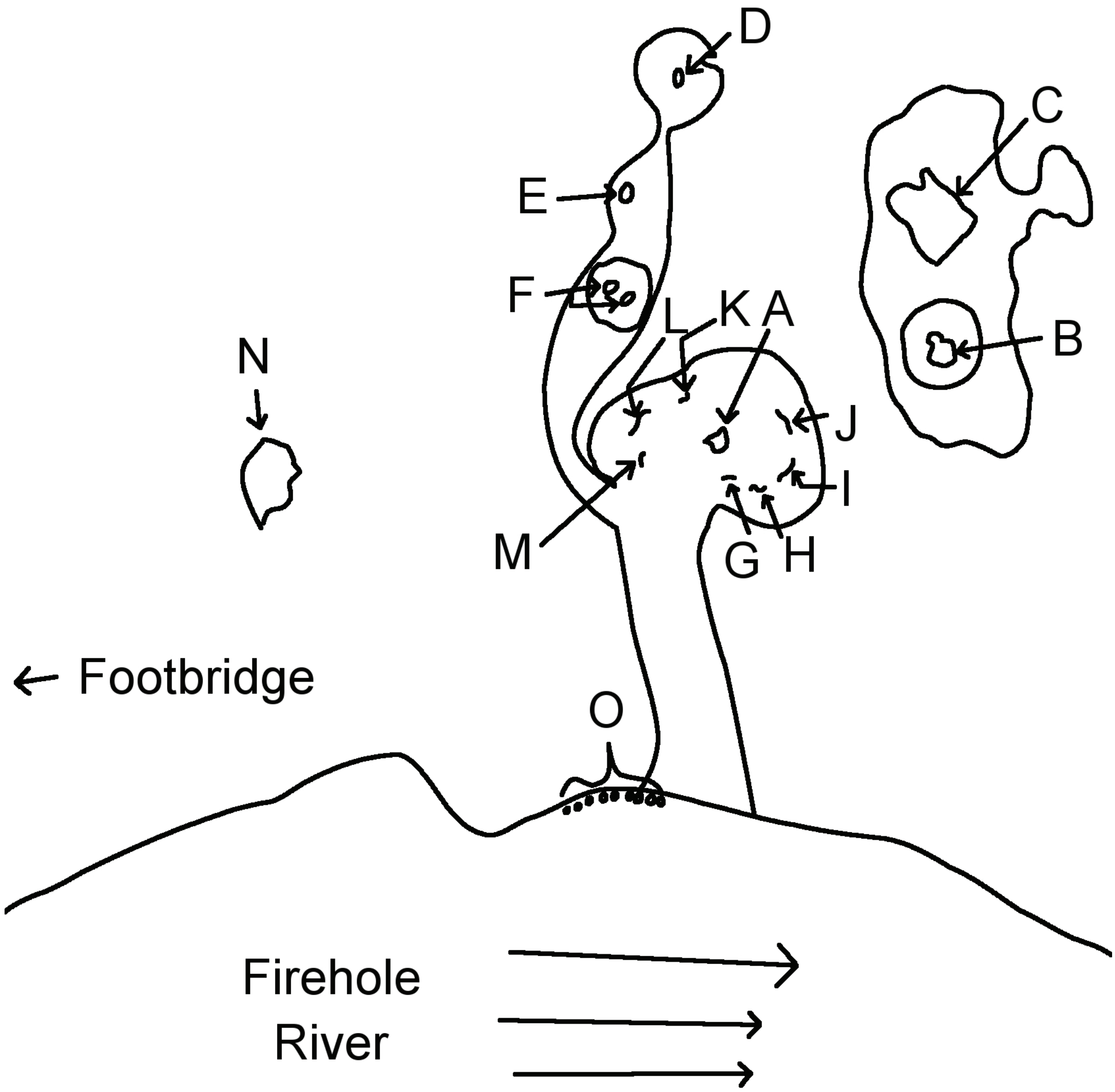
Vent	Interval	Duration	Height in feet	Comments
A	45 min to 5 hours	7 to 10 min	8 to 15	Typically the largest vent seen
B	3.5 to 8 hours	14 to 40 min	1 to 10	Eruptions of "B" will delay activity in "A"
C	11 to 75 min	5 to 20 sec	12 to 25	Cyclic-can be dormant for long periods
D	Seen only twice	> 2 min	3 to 5	Seen only twice by the author
E	5 to 90 min	seconds	1 to 3	Independent of "A"
	45 min to 5 hours	3 to 6 min	1 to 6	When erupting with "A"
F	4 to 10 min	seconds	inches	Independent of "A" during long intervals of "A"
	45 min to 5 hours	2 to 5 min	1 to 2	When erupting with "A"
G	45 min to 5 hours	5 to 8 min	inches	Erupts only with "A"
H	45 min to 5 hours	5 to 8 min	inches	Erupts only with "A"
I	45 min to 5 hours	5 to 8 min	inches	Erupts only with "A"
J	45 min to 5 hours	3 to 8 min	inches	Erupts only with "A"
K	45 min to 5 hours	3 to 8 min	inches	Erupts only with "A"
L	45 min to 5 hours	3 to 8 min	inches	Erupts only with "A"
M	45 min to 5 hours	3 to 8 min	inches	Erupts only with "A"
N	Overflowing Pool			Never observed to erupt
O	Vent in river			Never observed to erupt

Vent-by-Vent Description of Activity:

Terra Cotta Spring- Terra Cotta Spring can be found 190 feet downstream of the Terra Cotta Geysers, about 20 feet from the Firehole River. Walter Weed's description of Terra Cotta Spring from the mid 1880s would still apply today. The water is of brick-red color, the temperature when measured in the 1990s was consistently in the low 180 °F range, and the pool was always observed to be at or just below overflow. I have never observed it to be in any different state than that which I just described.

Terra Cotta Spring. Photo by Mike Keller.

THE TERRA COTTA COMPLEX
SKETCH MAP, NOT TO SCALE
FALL 2009
BY MIKE KELLER

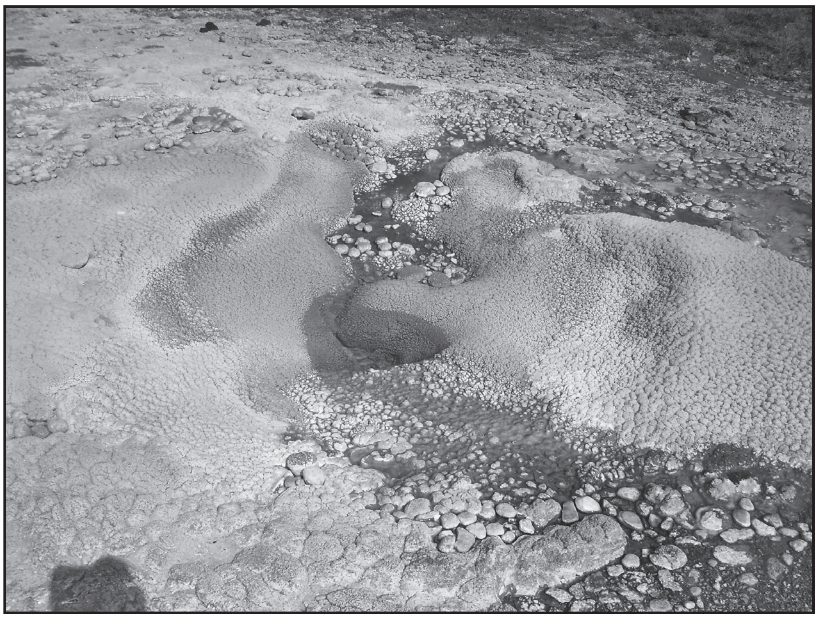


The Terra Cotta Geyser Complex:

Before discussing each vent, letter by letter, I want to start by saying the letter designations given below are mine. Over the years, just as with the placement of the name Terra Cotta, the letter designations have changed, usually depending upon what is active and reported by other observers. When I first started watching this area in 1989, I assumed that I was following the same letters as those before me; however, as I have done more research I have found this not to be true. My apologies to those in the future who have to muddle through my designations in trying to understand which vent is which.

A-Since I have been watching this area, this feature has been the most commonly seen vent in the Terra Cotta Complex. Over the past 20 years its activity has not shown any great degree of change. This geyser sits within a lightly rose-colored triangular sinter basin with a heavily beaded runoff channel that runs to the Firehole River. Along the northern and eastern side of its basin are raised mounds a few inches high that contain smaller vents which erupt with "A".

"A" and nearby "B" are closely related, with eruptions of either geyser affecting the water level and activity of its neighbor. When nearby "B" is not active, "A" will take anywhere from 60 to 150 minutes to fill and start overflowing. The length of time between the start of overflow and an eruption normally lasts 30 to 45 minutes. Every few minutes during the time "A" is in overflow, there will be brief period of bubbling and a rise in the pool level. It is during one of these episodes that "A" will begin erupting. When the eruption begins, this vent will quickly begin jetting in all directions, reaching from 5 to 12 feet, with occasional droplets reaching as high as 15 feet. The eruptions of "A" are very similar to Anemone Geyser on Geyser Hill. A few minutes into the eruption of "A," a number of smaller vents ("E" through "M") will join in. The eruption lasts from 6 ½ to 10 minutes, with 7 ½ being about average. In the 1990s, around 30 percent of the time, about 20 seconds after "A" would quit, it would restart and have a second burst that would last about 40 seconds. While still continuing in the 2000s, these second bursts are much less frequent. On two different occa-



Top left photo: The basin of Terra Cotta A. Photo by Mike Keller. Bottom left photo: Terra Cotta A in eruption, May 2006. Photo by Pat Snyder.

sions I have even witnessed a third burst. Following the eruption, the vent completely drains.

Imminent activity in "B" has been observed to extensively delay the start of "A," and on the few occasions when "B" would start before "A," I have seen "A" drop below overflow. While most intervals of "A" are in the 1 ½ to 3-hour range, I have measured intervals as long as 5 hours when "B" erupts while "A" is in overflow. Where "B" will delay "A" when "B" is ready to erupt, the opposite usually happens following an eruption from "B." It is not uncommon for "A" to start erupting before reaching overflow, with intervals as short as 45 minutes being observed.

B-This feature is what I suspect to be the "Dishpan" from the 1880s. Its basin is brown colored, lined with beaded sinter, and contains a smallish ledge about a foot below the surface giving it a dishpan appearance. I also suspect my "B" is the Terra Cotta "D" of Germeraad, Higgins and Watson in 1959.

"B" intervals can vary depending upon the time of year. In the spring, when the nearby grassy areas are wet from snow and runoff, there is usually a steady flow of cold water into this feature. As a result, intervals are usually in the 6 to 8 hour range. Later in the summer when the grassy area dries out, the intervals of "B" shorten to 3 ½ to 5 hours.

This vent erupts in a series, steadily gaining in size and volume of water, until the series ends. The first eruptions will only reach from a few inches to 3 feet. Later eruptions in the series can reach as many as 10 feet, with 5 to 8 feet being most common. There is normally a pause of a few to as many as 45 seconds between eruptions, and the entire eruptive series normally lasts from 14 to 40 minutes, with 25 to 30 minutes being the average.

As noted previously, "A" and "B" are very closely related. While the interval of "A" is clearly affected by pending activity in "B," it does not appear this is the same for "B" relative to "A". The majority of eruptions that I have observed from "B" have come after a long interval in "A," starting within 15 minutes of the completion of an eruption from "A." On a few occasions, I have seen "B" start while "A" has been in overflow. When this happens, "A" will drain

Top photo: Terra Cotta B in eruption. Photo by Janet White, SnowMoon Photography. Bottom photo: Terra Cotta B (front), C (behind B) and D (upper left). Photo by Mike Keller.

Terra Cotta C (back) in a rare eruption, Terra Cotta A (front) is also erupting. Photo by Dick Powell.

while “B” erupts. I have never observed “A” and “B” to erupt at the same time.

C-This vent is the largest geyser I have ever witnessed erupting in the Terra Cotta Complex. Unfortunately, it is cyclic in nature and prone to long periods (months to years) for dormancy. It is my belief that this feature is the “Washtub” from the late 1880s and is Germeraad, Higgins and Watson’s “Terra Cotta C” of 1959. The crater is about 4 feet deep and is lined with a scalloped border of geyserite. When “C” is not active, it is full and bubbling steadily over the vent. When “C” is active, the water in the vent is a usually a few feet below overflow with its basin empty. Another good indication that “C” is active is the gravel around its basin. When active the eruptions create a large, circular berm around the vent.

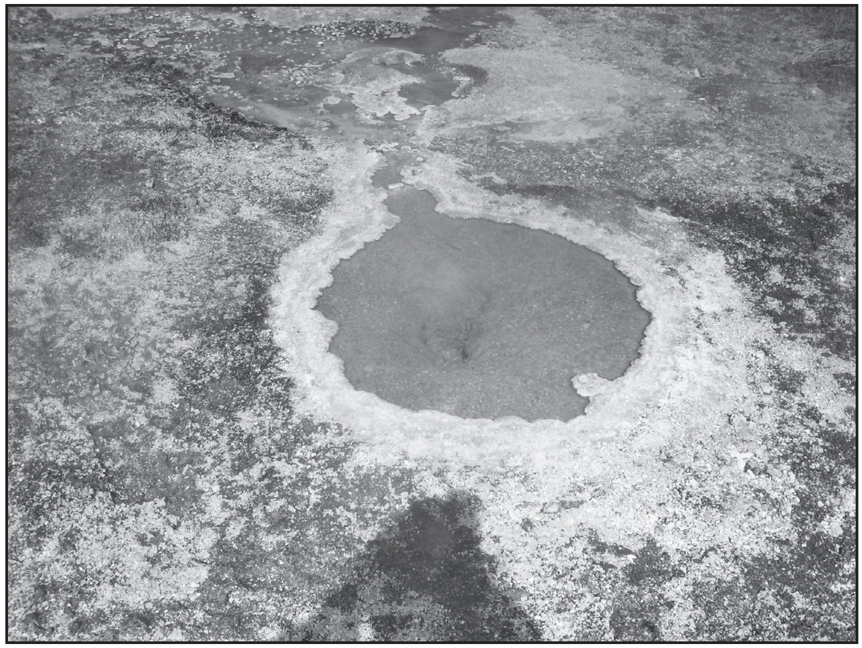
I first saw “C” erupt in the summer of 1990. I have also seen it active in 1991, 1993, 1997, 1999, 2000, 2002, and most recently in 2006. Its activity has been fairly consistent every time I have seen it erupting. The start of the eruption is marked by a quick and sudden surge of water quickly filling its basin. This is followed by a series of quick jets angled to the southwest reaching from 12 to 25 feet. The eruptions last from 5 to 20 seconds and are followed by a rapid draining of the basin. Intervals between eruptions when active are erratic, but are normally in the 15-30 minute range, although I have seen them as long as 75 minutes at times. This vent is more likely to be active in the summer months (June, July, and August). I have never seen it active in the months of November through April, and only once in the months of May (1997), September (1999), or October (1999).

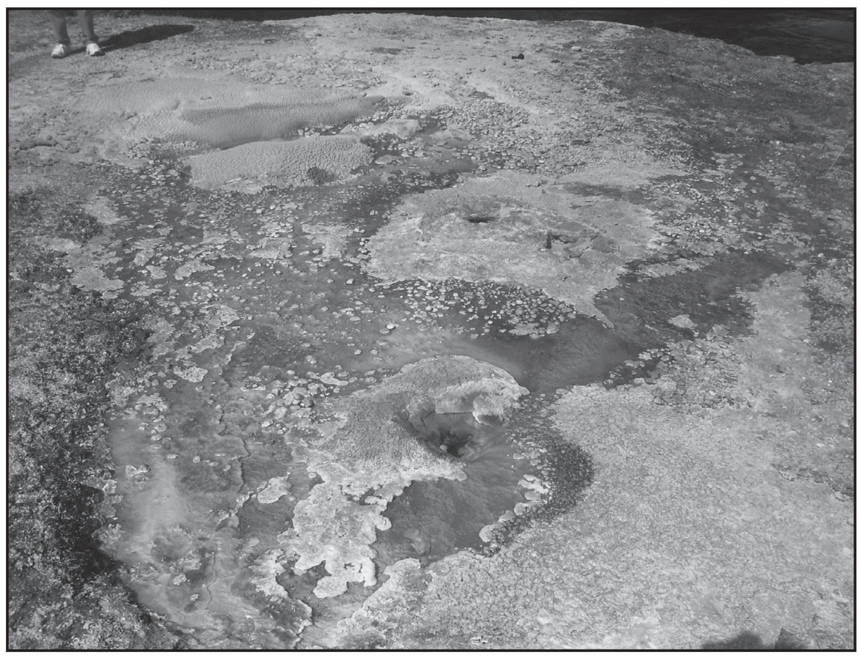
D-During the roughly 20-year period I watched the Terra Cotta Complex, I witnessed only two eruptions from “D,” both taking place in 1992. It was in eruption each time I saw it, lasting just a couple of minutes, and reaching about 2 feet. Markers placed on the feature that year indicated a few other eruptions, but I do not believe it has been active since 1992.

E-This vent is a small beaded geyserite cone 13 feet to the southwest of “A,” The activity and description is identical to that of Germeraad, Higgins and Watson’s “Terra Cotta E” in 1959. Unlike Mr. W’s observation, however, this vent has been active every year I have watched the Terra Cottas. Like many other vents in the area, this geyser erupts with “A,” but it is also independent of “A” and can erupt on its own.

Following an eruption of "A," there will be no activity from "E" for 40 to 90 minutes. Then, every 5 to 20 minutes, "E" will begin to have a series of steam phase-type eruptions where it will suddenly puff heavily for a few seconds. When "A" fills and starts to overflow, the eruptions from "E" will become a mix of steam and spray reaching a couple of feet. Following the start of "A," there will be a pause of a couple of minutes before "E" begins. The first eruption of "E" after "A" starts has normally been the largest of the eruptions I have seen from it, reaching as high as 6 feet in the first moments of play. Once "E" begins, it will continue to erupt a mix of spray and steam for the remainder of the eruption of "A" before falling quiet for another 40 to 90 minutes.

F-Between "E" and "A" is a geyserite mound with 2 vents. This feature is what I have called Terra Cotta "F." While it can erupt independently of other features in the area, most of the time it plays with "A," normally starting a few minutes into its eruption. When it erupts, the play reaches from a few inches to about two feet from both vents, and lasts from two to five minutes, stopping prior to conclusion of eruptive activity in "A." On occasion, when "A" is having a long interval, I have seen "F" have minor eruptions every few minutes to a few inches while "A" is in overflow.





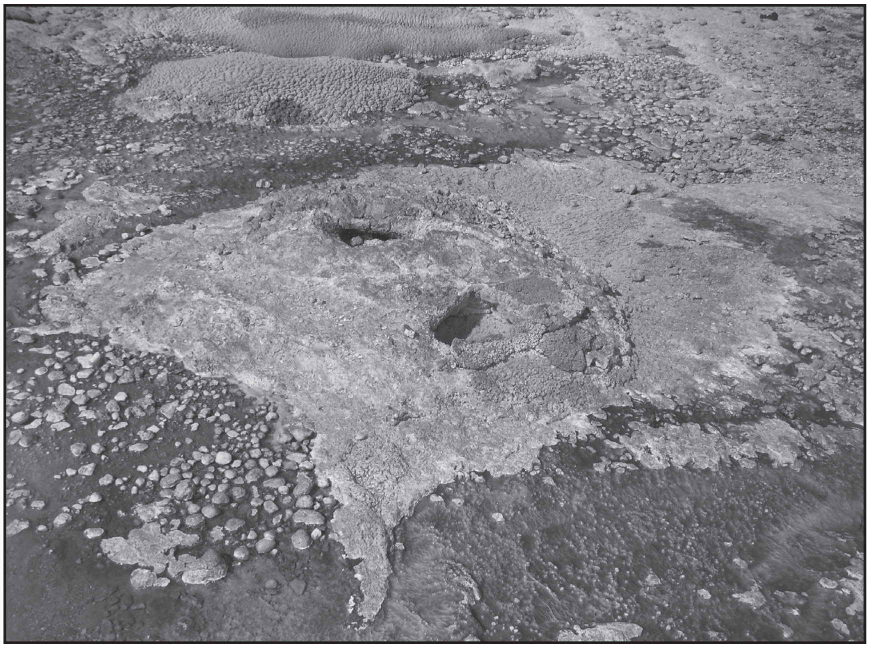
Top photo: Terra Cotta D. Bottom photo:, vents from left, Terra Cotta E, F and A. Both photos by Mike Keller.

G, H, I, & J-These small geysers lie within the pink sintered basin of "A" and consist of a series of cracks in a slight mound just to the west of "A." I have observed them erupt only with "A," playing a few inches high.

K, L, & M-Directly opposite vents "G" through "J" within the basin of "A" is another white-colored sinter mound with 3 openings. As with the aforementioned vents, these three also play during eruptions of "A." They normally start a minute or two after the other geysers begin, and reach a few inches.

N-In the grassy area 20 feet to the south of Terra Cotta "A" lies Terra Cotta "N." This spring has no hard sinter and has always been much cooler than the rest of the vents in the area, with temperatures normally measured around 140° Fahrenheit. I have never seen this feature erupt, or exhibit any changes during eruptive activity in any of the nearby vents, but given its close proximity to the complex, I have included it in this report.

O-Along the river bank where runoff from vent "A" joins the Firehole River, there are a series of seeping springs. Their temperature has always been warmer than the river itself, usually around 12 0° F or so, and on very cold days in the winter a slight amount of steam can be seen coming from them. I have never seen any of these seeps do any-



Top photo: Terra Cotta F. Bottom photo:, Terra Cotta N. Both photos by Mike Keller.

thing but lightly overflow, and I cannot say with any certainty that they are connected or associated with the geysers above.

Endnotes:

[1] Weed, Walter. 1885. Formal notebook box 52, vol 17, 3893-N, p. 75 via Lee Whittlesey, verbal communication, 1992.

[2] Weed box 47, vol 13, July 1886 p. 45 via Lee Whittlesey, verbal communication, 1992.

[3] Hall, Ansel. 1926. A Report of Permanent Educational Improvement at Upper Basin, Yellowstone National Park, Wyoming Made During the Season of 1926. p. 63. Box K-10, YNP Archives.

[4] Index Card File, YNP Archives.

[5] Germeraad, William L., Higgins, and Barry N. Watson, Yellowstone National Park Hydro-Thermal Observation Form – 1959, YNP Archives, pp. 218-221.

[6] Marler, George. 1973. *Inventory of Thermal Features of the Firehole River Geyser Basins and other selected areas of Yellowstone National Park*. National Technical Information Service, Publication No. PB-221289. p. 256.

[7] Marler, George. *Yellowstone Nature Notes*. YNP Archives.

[8] Martinez, Sam. 1972. Report of Geyser Activity in the Upper Geyser Basin, Including the Midway and Lower Geyser Basins for 1972.

[9] Hutchinson, Roderick. 1973. Hot Spring Activity in the Geyser Basins of the Firehole River for the 1973 Season. YNP Archives. p. 3.

[10] Carlson, Jerry. 1978. July and August Report for Castle and Orange Group. YNP Archives.

[11] Martinez, Sam. 1978. Report of Hot Spring and Geyser Activity During the Field Trip of August 20 through September 3, 1978. YNP Archives.

[12] Ng, Dan. 1984. Castle – Orange Spring Report. YNP Archives.

[13] Bryan, T. Scott. 1991. *The Geysers of Yellowstone*, Second edition. Boulder, Colo.: University Press of Colorado. p. 34.

[14] Bryan, T. Scott. 1995, 2001. *The Geysers of Yellowstone*. Third edition. Boulder, Colo.: University Press of Colorado. pp. 59-60.

[15] Bryan, T. Scott. 2008. *The Geysers of Yellowstone*. Fourth edition. Boulder, Colo.: University Press of Colorado. pp. 63-64.

West Triplet and Rift Geysers, Grand Group, Upper Geyser Basin, 2003-2008

Vicki Whitledge, Ryan Frank and James Hollman

Abstract

West Triplet and Rift Geysers in the Grand Group, Upper Geyser Basin, have been electronically monitored for a number of years. The eruptions times, from 2003 through 2008, derived from the electronic data, are analyzed. Basic descriptive statistics on these data and a quantitative description of the relationship between West Triplet and Rift geysers are given.

Introduction

West Triplet and Rift Geysers are important members of the Grand Geyser Group. The possible influence of West Triplet and Rift eruptions on the intervals of Grand Geyser has been noted and investigated; however, the relationship remains unclear. (Bryan 1989, 1993, 2008; Strasser 1989, 2000; Whitledge 2005, 2006, 2008) The eruptions of West Triplet and Rift have been observed to be related. In particular, Rift Geyser erupted only after West Triplet had been active, except when Rift was coming out of a dormant period. (Koenig 1995) In this article, we examine the quantitative details of the relationship between West Triplet and Rift Geysers using electronic data that has been gathered from 2003 through most of 2008. We will also briefly comment on the behavior of Grand Geyser during the periods of this study.

Methods

The eruptions analyzed in this article occurred over nearly a six-year period from 1/1/2003 through 11/6/2008. The end of the study period was determined by the latest data available in February 2009 from the GOSA website. (GOSA 2009) Ralph Taylor, in his capacity as National Park Service thermal volunteer, used data loggers to collect the data and a computer to extract eruption times and durations. (Taylor 2000) The data was then analyzed to determine periods during which both West Triplet and Rift data were recorded. Conditions are harsh in the Upper Geyser Basin, and equipment malfunction occasionally led to the loss of data. In many instances of equipment failure, only one of the two geysers had lost data. Since the intent of this study is to examine the relationship between West Triplet and Rift, data from one geyser was excluded if corresponding data from the other were missing. This resulted in 884 eruptions of West Triplet being excluded due to lack of Rift data and 273 eruptions of Rift being excluded due to lack of West Triplet data. Over the nearly six years of the study, slightly more than a year of data were not analyzed due to equipment failure.

Data for West Triplet and Rift Geysers have data logger delay errors. An explanation of data logger errors can be found in Whitledge 2008. In addition, some extremely short eruptions of West Triplet may not have been detected. Typically, West Triplet begins its eruptions before it has reached overflow. In order to remain out of view, the data logger for West Triplet was located under the boardwalk some distance from West Triplet's crater. If West Triplet had an extremely short eruption (duration < 2 minutes), it is possible that it did not reach overflow and the eruption was not detected.

In the instances that one of the authors (Whitledge) observed very short eruptions, West Triplet had a more ordinary eruption within two hours, so these extremely short duration eruptions may have been "eruption attempts" rather than eruptions. The observed sample size on this behavior was very small, so it may require further investigation.

Data for Rift Geyser contained temperature spikes that were indicative of steam in the system rather than an eruption. (Taylor 2006) These events occurred under specific, easily identifiable circumstances and were excluded from the eruption data. Eight periods of continuous data for both West Triplet and Rift were identified and are given in Table 1. Only the eruptions occurring in these periods were analyzed for this study. The analysis was conducted

West Triplet Geyser erupting before Grand Geyser on Sept. 9, 2009. Photo by Pat Snyder.

Year(s)	Start	End	Length, Days	WT Count	Rift Count
2003a	1/1/2003 0:00:00	1/23/2003 5:36:24	22.2	83	35
2003b	2/1/2003 19:57:59	4/10/2003 1:57:59	67.3	226	103
03-04	5/2/2003 21:18:46	9/15/2004 11:36:20	501.6	1885	768
04-05	9/19/2004 21:56:00	4/2/2005 12:49:31	194.6	722	325
2005	6/28/2005 2:37:00	12/9/2005 16:02:00	164.6	640	320
05-06	12/9/2005 23:44:00	2/16/2006 7:17:00	68.3	257	127
06-08	6/13/2006 0:27:00	1/15/2008 3:59:00	581.1	2591	1249
2008	5/27/2008 23:34:00	11/6/2008 9:24:00	162.4	584	257
		Total	1762.1	6988	3184

Table 1: Periods of Study

on each of these periods separately. The periods of continuous data vary greatly in length; however, splitting geyser data based on any time period is arbitrary, so no attempt was made to standardize the length of each unit of analysis.

For the analysis, basic descriptive statistics and graphs were generated for each period and each geyser on both the intervals and durations. After this, the West Triplet eruptions were sorted into two categories: those that were not followed by Rift and those that were followed by Rift. The time between the start of the eruption of West Triplet Geyser and the start of the eruption of Rift Geyser that followed it was also computed. Basic descriptive statistics were computed on each of these data sets.

Intervals-WT	2003a	2003b	03-04	04-05	2005	05-06	06-08	2008
Count	83	226	1885	722	640	257	2591	584
Minimum	2:06	2:12	0:38	1:54	1:35	0:52	1:14	0:53
5th Percentile	2:33	2:45	2:24	2:27	2:18	2:26	1:56	2:35
1st Quartile	3:27	4:44	3:10	4:45	4:54	4:43	3:59	3:55
Median	6:48	7:34	6:26	6:34	6:06	5:54	5:13	6:42
3rd Quartile	8:36	9:09	8:40	8:00	7:45	7:43	6:57	8:53
95th Percentile	11:24	11:12	11:22	11:05	9:32	9:52	8:54	11:29
Maximum	12:39	19:30	18:48	27:41	13:35	12:39	14:06	13:49
90% Range	8:51	8:27	8:58	8:38	7:14	7:26	6:58	8:54
IQR	5:09	4:25	5:30	3:14	2:51	3:00	2:58	4:57
Range	10:33	17:18	18:10	25:47	12:00	11:47	12:52	12:56
Mean	6:25	7:10	6:23	6:28	6:11	6:07	5:23	6:40
Standard Dev	2:54	2:53	3:04	2:38	2:12	2:12	2:09	2:54
Coef of Var	45.14%	40.22%	48.09%	40.93%	35.71%	36.11%	40.09%	43.59%

Table 2: Intervals of West Triplet Geyser, times in hours: minutes

Intervals-Rift	2003a	2003b	03-04	04-05	2005	05-06	06-08	2008
Count	35	103	768	325	320	127	1249	257
Minimum	9:50	3:05	4:20	1:50	1:09	1:29	1:20	1:38
5th Percentile	10:38	10:50	10:04	9:05	7:04	7:59	5:18	9:18
1st Quartile	11:35	11:45	13:04	12:58	9:58	10:04	8:53	13:10
Median	15:35	15:05	15:19	14:15	13:00	13:03	11:00	15:40
3rd Quartile	18:45	17:50	18:02	15:48	14:42	14:16	13:34	17:16
95th Percentile	23:05	23:57	22:04	20:54	16:34	17:19	16:38	20:44
Maximum	24:55	40:55	64:58	30:55	22:11	23:31	23:29	26:38
90% Range	12:26	13:06	12:00	11:49	9:29	9:19	11:20	11:26
IQR	7:10	6:35	4:57	2:49	4:44	4:11	4:41	4:06
Range	15:05	37:50	60:38	29:05	21:02	22:02	22:09	25:00
Mean	15:35	15:37	15:40	14:23	12:22	12:20	11:10	15:13
Standard Dev	4:06	5:06	4:27	3:44	3:26	3:24	3:31	3:44
Coef of Var	26.37%	32.67%	28.38%	25.96%	27.77%	27.61%	31.51%	24.60%

Table 3: Intervals of Rift, times in hours: minutes

Durations-WT	2003a	2003b	03-04	04-05	2005	05-06	06-08	2008
Count	83	226	1885	722	640	257	2591	584
Minimum	0:18	0:00	0:02	0:14	0:06	0:05	0:01	0:03
5th Percentile	0:24	0:27	0:14	0:25	0:22	0:18	0:18	0:26
1st Quartile	0:27	0:33	0:26	0:30	0:31	0:30	0:27	0:32
Median	0:33	0:39	0:32	0:35	0:37	0:35	0:34	0:36
3rd Quartile	0:54	0:57	0:48	0:50	0:52	0:49	0:51	0:54
95th Percentile	1:00	1:06	1:00	0:58	0:59	0:55	0:59	1:04
Maximum	1:09	1:12	1:12	1:09	1:10	1:05	1:12	1:14
90% Range	0:36	0:39	0:46	0:32	0:37	0:37	0:41	0:38
IQR	0:27	0:24	0:22	0:20	0:21	0:19	0:24	0:22
Range	0:51	1:12	1:10	0:55	1:04	1:00	1:11	1:11
Mean	0:39	0:43	0:35	0:39	0:40	0:38	0:37	0:41
Standard Dev	0:13	0:14	0:14	0:11	0:12	0:12	0:13	0:13
Coef of Var	34.18%	32.80%	39.62%	28.78%	30.63%	32.30%	35.79%	32.11%

Table 4: Durations of West Triplet, times in hours: minutes

Results and Discussion

Basic statistics for West Triplet Intervals, Rift Intervals, West Triplet Durations, and Rift Durations are given in Tables 2-5 for each continuous data set. Boxplots of the intervals of West Triplet and Rift are given in Figures 1 and 2. In all the figures in this paper, outliers were not plotted if their inclusion would adversely affect the display of the main body of the data. The exclusion of outliers from graphs is noted in each case. All outliers were included in the analysis and computation of statistics. Outliers were not plotted in Figures 1 and 2.

As has been known for some time, intervals of West Triplet and Rift tend to be highly variable during any given time period. However, both West Triplet and Rift followed a fairly consistent form of behavior over the entire study period. In 2003a, 2003b, 03-04, 04-05, and 2008, both West Triplet and Rift had longer intervals as displayed across multiple statistics, than in 2005, 05-06, and 06-08. In West Triplet's case, the shorter intervals in 2005, 05-06, and 06-08 were also accompanied by a drop in variability as measured by the 90% range and IQR. Interestingly, histograms of West Triplet intervals had two general forms, one bimodal and the other unimodal. Figure 3 shows a representative graph of the bimodal behavior. This type of behavior was observed in 2003a, 2003b, 03-04, 04-05, and 2008, the same periods that showed the longer intervals. The first peak was generally between 2 to 3 hours, although in 2003b it shifted to 3 to 4 hours. The second peak was generally between 7 to 8 hours, although in 04-05 and 2008 it was between 6 to 7 hours. In 2003a and 03-04, the first peak was much higher than the second, but in the remaining three periods it was lower, as in Figure 3. Figure 4 shows a representative graph of the unimodal form. This behavior was observed in 2005, 05-06, and 06-08. For this behavior, the peak was always from 5 to 6 hours. Histograms of Rift intervals, using two-hour bin-

Durations-Rift	2003a	2003b	03-04	04-05	2005	05-06	06-08	2008
Count	35	103	768	325	320	127	1249	257
Minimum	0:30	0:05	0:02	0:01	0:01	0:04	0:01	0:01
5th Percentile	0:38	0:30	0:38	0:33	0:21	0:26	0:14	0:26
1st Quartile	0:50	0:50	0:52	0:48	0:44	0:40	0:27	0:51
Median	1:00	1:05	1:21	1:07	1:05	0:54	0:42	1:09
3rd Quartile	1:30	1:25	1:44	1:27	1:31	1:20	1:10	1:28
95th Percentile	2:00	2:14	3:12	2:04	2:25	1:57	1:56	1:55
Maximum	2:05	3:20	6:04	2:57	5:55	3:36	3:02	2:43
90% Range	1:21	1:43	2:34	1:31	2:03	1:30	1:42	1:28
IQR	0:40	0:35	0:51	0:39	0:47	0:40	0:43	0:37
Range	1:35	3:15	6:02	2:56	5:54	3:32	3:01	2:42
Mean	1:09	1:09	1:28	1:10	1:13	1:02	0:50	1:09
Standard Dev	0:24	0:33	0:48	0:29	0:44	0:32	0:32	0:28
Coef of Var	35.40%	47.94%	55.26%	42.30%	60.35%	51.03%	63.30%	41.01%

Table 5: Durations of Rift, times in hours: minutes

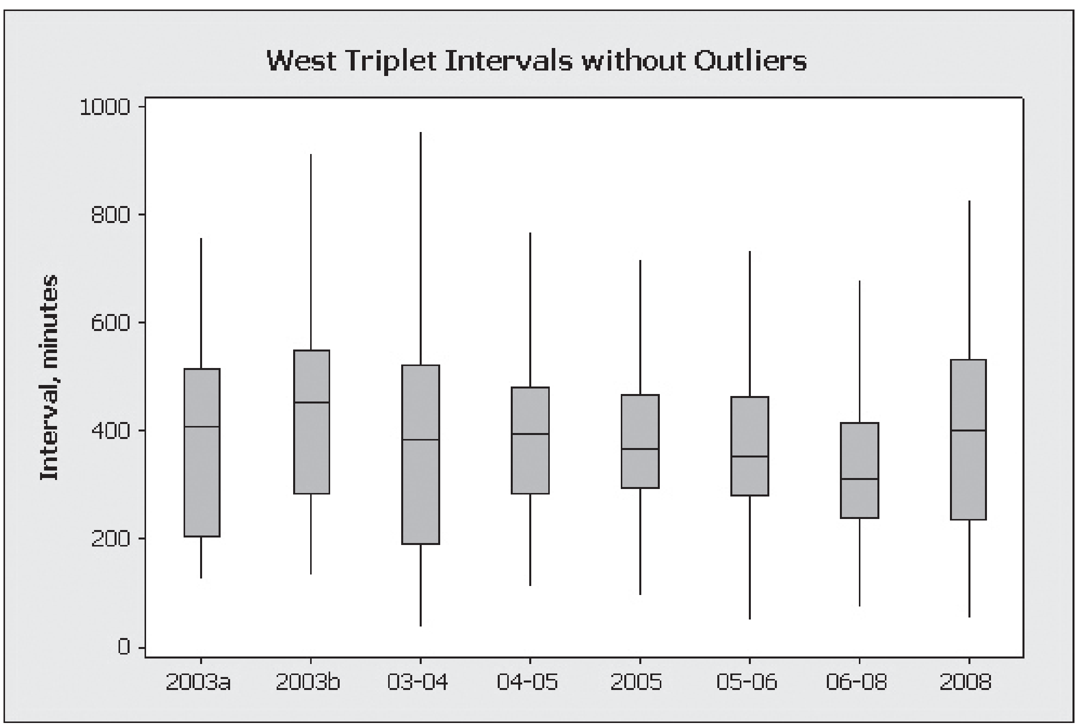


Figure 1: *Boxplots of West Triplet Intervals. Outliers are not displayed.*

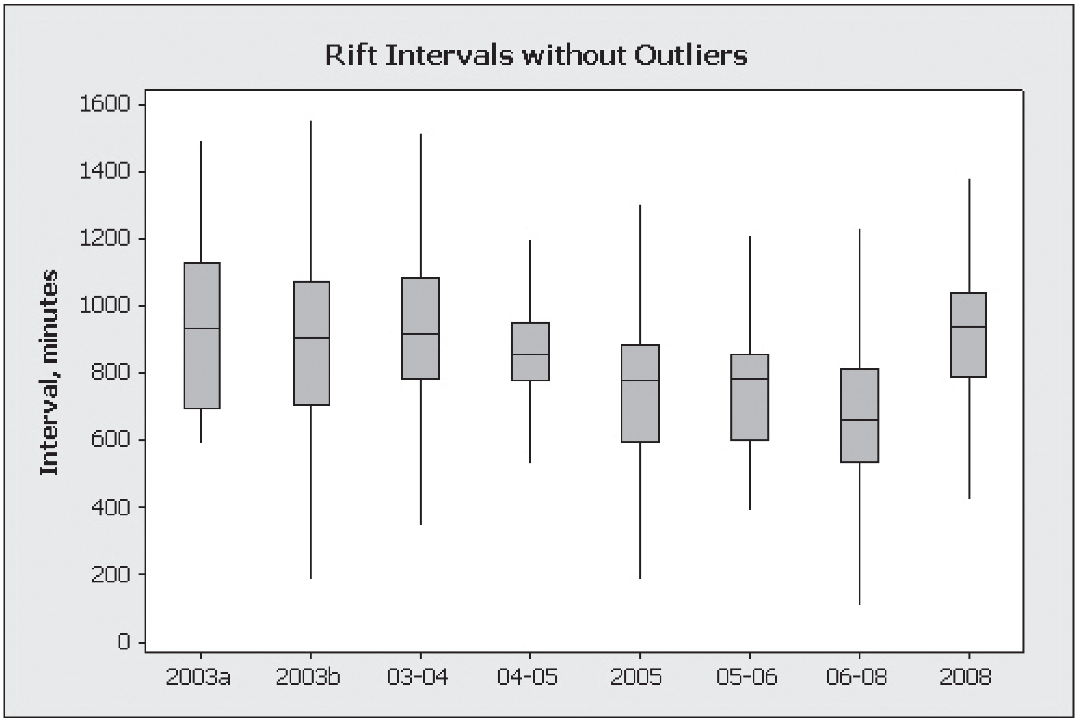


Figure 2: *Boxplots of Rift Intervals. Outliers are not displayed.*

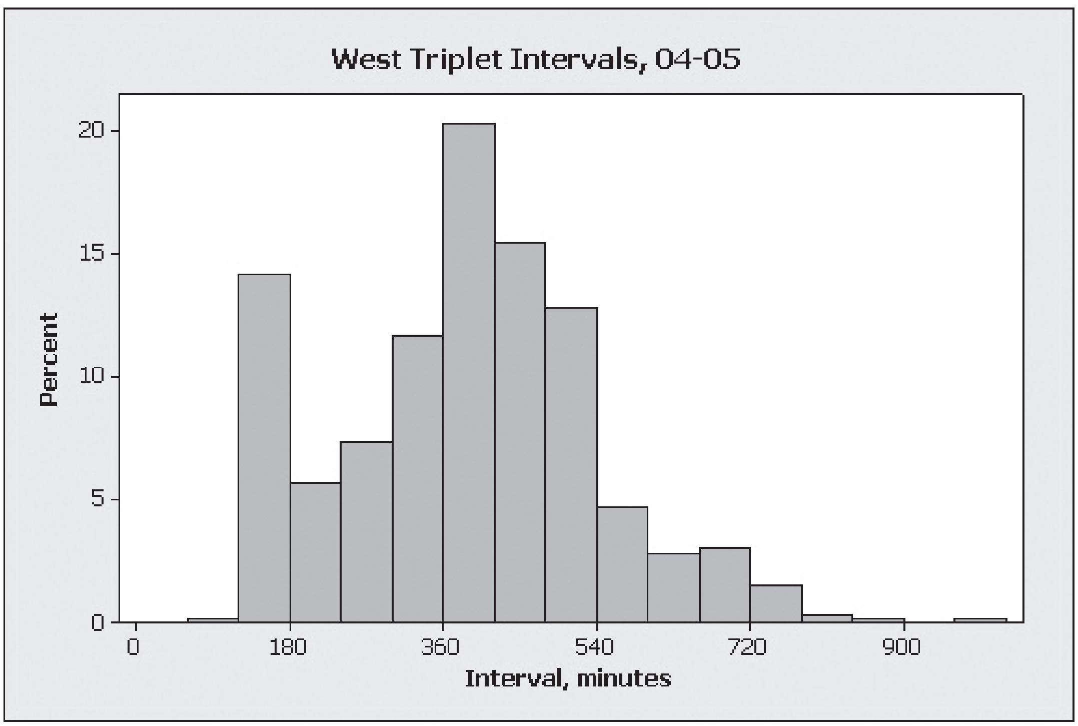


Figure 3: *Histogram of West Triplet Intervals for 04-05. Some outliers are not displayed.*

ning, showed little consistency over the eight study periods. Sometimes the graphs appeared bimodal, sometimes unimodal, but the peaks were not consistent from period to period and could range from 8 to 10 hours to up to 16 to 18 hours. Additionally, Rift showed no consistent changes in variability.

Durations of West Triplet eruptions showed little variation during the study period. Median durations ranged from 32 minutes to 39 minutes. There appears to be little difference in the durations between periods of longer West Triplet intervals and those of shorter intervals. Durations of

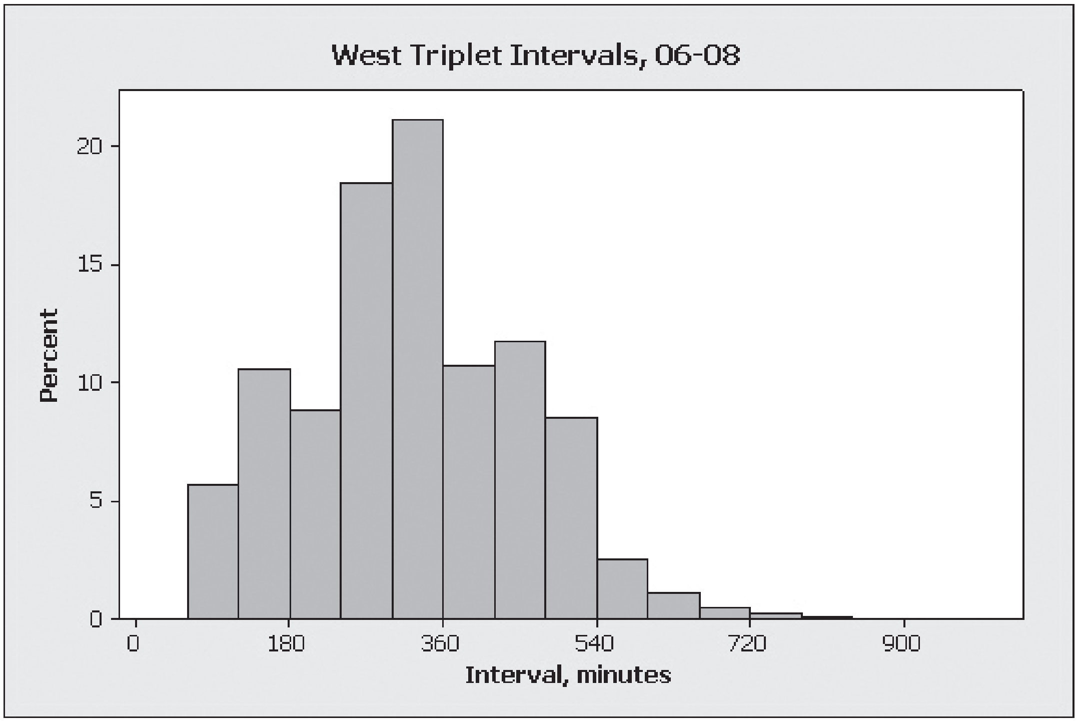


Figure 4: Histogram of West Triplet Intervals for 06-08.

Rift showed more variation across the study periods than did durations for West Triplet. Median durations ranged from 42 minutes to 81 minutes. Again, there was no easy correlation with the median of the intervals.

With the exception of an eruption after dormancy, Rift erupts only after activity of West Triplet; however, not every eruption of West Triplet leads to an eruption of Rift. When Rift erupts after West Triplet, the *subsequent* interval for West Triplet will be long, and the next eruption of West Triplet is not likely to be followed by Rift. If West Triplet is not followed by Rift, then the subsequent interval may be rather short, often around three hours. After the initial analysis, West Triplet eruptions were split into two categories based on whether the eruption was followed by an eruption of Rift or not. Tables 6-9 display the statistics for West Triplet intervals and durations for this classification. While there is variation between the study units for the intervals and durations, of much more interest is the comparison between West Triplet when it was followed by Rift and West Triplet when it was not followed by Rift. This is because both the intervals and durations of West Triplet varied depending on whether West Triplet was followed by Rift. Figures 5 and 6 show boxplots of the data compiled from the entire study period. From Figure 5, it can be seen that the intervals of West Triplet when Rift did not follow were longer than the intervals of West Triplet when Rift did follow. This occurred because when West Triplet was not followed by Rift, it was more likely that the previous eruption of West Triplet *was* followed by Rift. This led to a longer subsequent interval. The intervals were shorter when West Triplet was followed by Rift because it was more likely that the previous eruption of West Triplet was not followed by Rift allowing a shorter subsequent interval. The durations of West Triplet show an even greater difference when sorted by whether Rift followed West Triplet. The median duration of West Triplet eruptions that were not followed by Rift varied little over the study periods of 28 to 33 minutes. The median durations of West Triplet eruptions that were followed by Rift ranged from 49 to 57 minutes. One interpretation of this data would be that West Triplet needs to erupt long enough for Rift to erupt.

Basic statistics on the time between the start of an eruption of West Triplet and the start of an eruption of Rift are given in Table 10. These times were very consistent across the study period. The

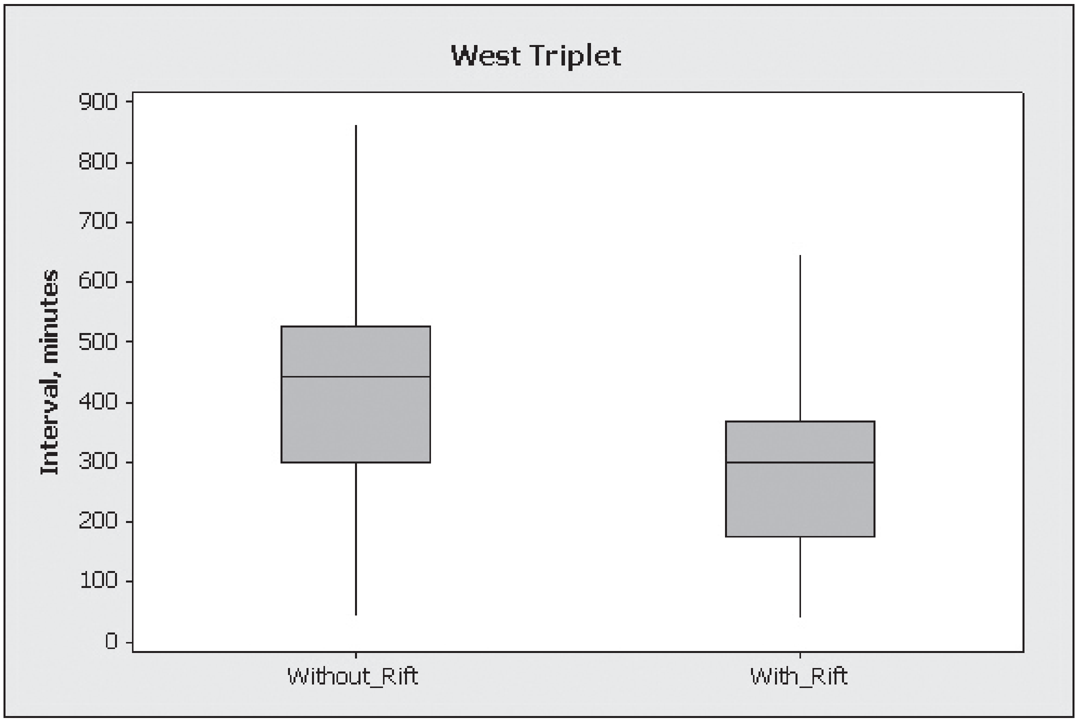


Figure 5: *Boxplot of West Triplet Intervals sorted by whether a Rift Eruption followed. Outliers are not displayed.*

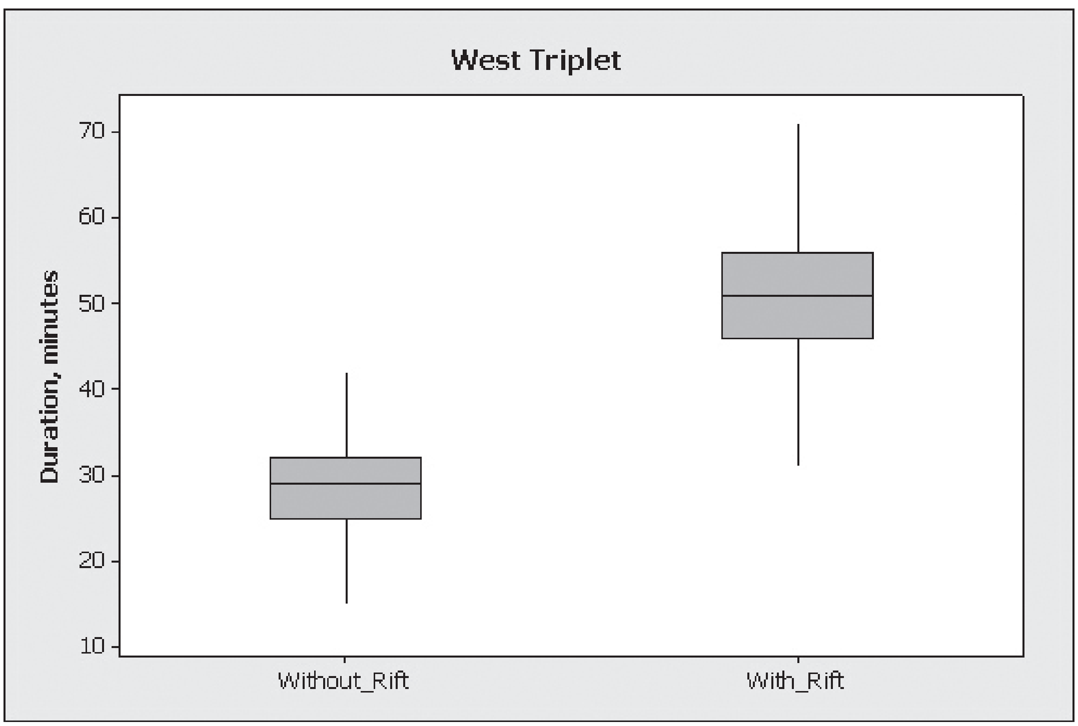


Figure 6: *Boxplot of West Triplet Durations sorted by whether a Rift Eruption followed. Outliers are not displayed.*

Intervals-WT With Rift	2003a	2003b	03-04	04-05	2005	05-06	06-08	2008
Count	35	103	768	325	320	127	1249	257
Minimum	2:06	2:12	0:38	1:54	1:35	1:46	1:14	1:47
5th Percentile	2:15	2:39	2:20	2:17	2:07	2:10	1:49	2:30
1st Quartile	2:46	3:13	2:50	3:01	3:30	4:22	2:49	3:05
Median	3:54	5:39	4:20	5:53	5:43	5:42	4:51	5:34
3rd Quartile	7:07	7:33	6:30	6:32	6:10	6:06	5:27	6:43
95th Percentile	9:07	10:19	8:28	8:00	8:25	8:13	7:14	9:17
Maximum	11:48	19:30	15:58	16:14	10:22	9:52	10:08	12:30
90% Range	6:52	7:40	6:08	5:43	6:18	6:02	5:25	6:46
IQR	4:21	4:19	3:40	3:31	2:39	1:44	2:38	3:38
Range	9:42	17:18	15:20	14:20	8:47	8:06	8:54	10:43
Mean	4:58	5:45	4:49	5:12	5:11	5:16	4:26	5:11
Standard Dev	2:37	2:48	2:22	2:03	1:51	1:42	1:41	2:10
Coef of Variation	52.83%	48.87%	49.06%	39.31%	35.89%	32.49%	37.96%	41.98%

Table 6: West Triplet Intervals when eruptions were followed by Rift, times in hours: minutes

data logger delay errors are important when comparing the time between West Triplet and Rift. West Triplet's data logger delay ranged between 3 to 7 minutes with a mode of 4 minutes, and Rift had a data logger delay of 0 to 2 minutes with a mode of 1 minute. (Whitledge 2008) This means that the times between West Triplet and Rift, as extracted from the electronic data, were likely 3 minutes short but could range from 1 to 7 minutes short. The median time between the start of West Triplet and the subsequent Rift ranged from 31 to 36 minutes. Interestingly, these median times were just slightly longer than the median durations of the West Triplet eruptions that were not followed by Rift. It is possible that there was a critical time in the eruption of West Triplet when Rift had to begin erupting for West Triplet to continue erupting. If Rift did not start to erupt, then West Triplet would stop erupting. This is an alternate explanation for the relationship between the durations of West Triplet and the presence or absence of a Rift eruption.

Comparison with Grand Geyser's Behavior

Basic statistics on Grand Geyser's intervals for the periods of this study are given in Table 11. The intervals are also shown in Figure 7 (outliers are not displayed). Grand's interval varied widely throughout the study period, from a median of 9:56 during 2003a to a median of 7:15 in 2005. From August 2003 to July 2004, Grand's median interval declined steadily from over 10 hours to around 7 hours. This accounts for the large variability seen in Grand's intervals in 03-04 in Figure 7. After this time, Grand's median interval remained short until it increased in 2008. West Triplet and Rift vaguely followed this pattern. They experienced their shortest median intervals in 06-08, and then experienced a lengthening of intervals in 2008. It has been hypothesized that West Triplet and Rift delay Grand; however, both West Triplet and Rift had longer intervals when Grand had longer intervals and shorter intervals when Grand had shorter intervals. These data suggest that, while West Triplet or Rift may have a small effect on individual intervals, there are larger factors that impact the behavior of the group as a whole. West Triplet and Rift cannot be the prima-

Intervals-WT sans Rift	2003a	2003b	03-04	04-05	2005	05-06	06-08	2008
Count	48	123	1117	398	320	130	1342	327
Minimum	2:42	2:21	0:42	2:12	1:45	0:52	1:20	0:53
5th Percentile	2:52	3:07	2:32	2:49	1:45	3:29	2:57	2:45
1st Quartile	5:32	7:28	5:02	5:44	5:44	5:02	4:34	5:21
Median	8:12	8:45	7:56	7:42	7:22	7:22	6:33	8:20
3rd Quartile	9:18	9:57	9:42	8:42	8:21:30	8:27	7:49	9:56
95th Percentile	11:19	11:15	11:54	11:44	10:55	10:32	9:37	12:06
Maximum	12:39	15:15	18:48	27:41	13:35	12:39	14:06	13:49
90% Range	8:27	8:07	9:22	8:54	9:10	7:03	6:40	9:20
IQR	3:46	2:28	4:40	2:58	2:36	3:24	3:15	4:35
Range	9:57	12:54	18:06	25:29	11:50	11:47	12:46	12:56
Mean	7:29	8:21	7:27	7:29	7:10	6:56	6:15	7:50
Standard Dev	2:38	2:22	3:02	2:38	2:04	2:20	2:10	2:53
Coef of Variation	35.28%	28.36%	40.74%	35.20%	28.95%	33.63%	34.76%	36.77%

Table 7: West Triplet Intervals when eruptions were not followed by Rift, times in hours: minutes

Durations-WT With Rift	2003a	2003b	03-04	04-05	2005	05-06	06-08	2008
Count	35	103	768	325	320	127	1249	257
Minimum	0:27	0:30	0:06	0:00	0:12	0:24	0:09	0:11
5th Percentile	0:35	0:36	0:30	0:34	0:37	0:36	0:32	0:35
1st Quartile	0:51	0:54	0:42	0:46	0:48	0:46	0:47	0:51
Median	0:54	0:57	0:51	0:51	0:52	0:49	0:51	0:55
3rd Quartile	0:57	1:00	0:56	0:55	0:55	0:52	0:54	1:00
95th Percentile	1:06	1:09	1:03	1:00	1:02	0:58	1:01	1:08
Maximum	1:09	1:12	1:12	1:09	1:10	1:05	1:12	1:14
90% Range	0:30	0:33	0:33	0:26	0:25	0:22	0:28	0:32
IQR	0:06	0:06	0:14	0:09	0:07	0:06	0:07	0:09
Range	0:42	0:42	1:06	1:09	0:58	0:41	1:03	1:03
Mean	0:52	0:55	0:48	0:49	0:50	0:48	0:49	0:53
Standard Dev	0:09	0:09	0:10	0:08	0:07	0:06	0:08	0:09
Coef of Variation	17.19%	17.27%	21.13%	16.84%	15.21%	13.99%	17.87%	18.31%

Table 8: West Triplet Durations when eruptions were followed by Rift, times in hours: minutes

Rift Geyser erupting on May 25, 2009. Photo by Pat Snyder.

Durations-WT sans Rift	2003a	2003b	03-04	04-05	2005	05-06	06-08	2008
Count	48	123	1117	398	320	130	1342	327
Minimum	0:18	0:00	0:02	0:14	0:06	0:05	0:01	0:03
5th Percentile	0:22	0:24	0:08	0:24	0:18	0:15	0:15	0:24
1st Quartile	0:27	0:30	0:24	0:28	0:28	0:24	0:24	0:30
Median	0:30	0:33	0:28	0:31	0:31	0:30	0:28	0:32
3rd Quartile	0:33	0:36	0:30	0:33	0:33	0:32	0:32	0:34
95th Percentile	0:36	0:47	0:36	0:37	0:36	0:35	0:35	0:40
Maximum	0:51	1:12	1:12	0:46	0:43	0:53	0:49	1:00
90% Range	0:13	0:23	0:28	0:13	0:18	0:19	0:20	0:15
IQR	0:06	0:06	0:06	0:05	0:05	0:08	0:08	0:04
Range	0:33	1:12	1:10	0:32	0:37	0:48	0:48	0:57
Mean	0:29	0:33	0:26	0:30	0:30	0:28	0:27	0:32
Standard Dev	0:05	0:09	0:07	0:04	0:05	0:06	0:06	0:05
Coef of Variation	18.87%	27.73%	28.76%	13.73%	18.04%	24.36%	23.95%	17.56%

Table 9: West Triplet Durations when eruptions were not followed by Rift, times in hours: minutes

Time WT to R	2003a	2003b	03-04	04-05	2005	05-06	06-08	2008
Count	35	103	768	325	320	127	1249	257
Minimum	0:19	0:17	0:13	0:09	0:05	0:20	0:12	0:13
5th Percentile	0:25	0:25	0:23	0:24	0:22	0:25	0:22	0:25
1st Quartile	0:30	0:32	0:27	0:29	0:29	0:32	0:30	0:32
Median	0:34	0:35	0:31	0:32	0:32	0:34	0:34	0:36
3rd Quartile	0:36	0:39	0:35	0:35	0:35	0:37	0:37	0:40
95th Percentile	0:43	0:47	0:40	0:44	0:44	0:44	0:42	0:45
Maximum	0:47	0:51	0:46	0:49	0:51	0:51	0:52	0:52
90% Range	0:23	0:29	0:27	0:35	0:39	0:24	0:30	0:31
IQR	0:06	0:07	0:08	0:06	0:06	0:05	0:07	0:08
Range	0:28	0:34	0:33	0:40	0:46	0:31	0:40	0:39
Mean	0:33	0:35	0:31	0:32	0:32	0:34	0:33	0:35
Standard Dev	0:05	0:06	0:05	0:05	0:06	0:05	0:06	0:06
Coef of Var	17.34%	17.08%	16.83%	18.14%	19.13%	16.13%	18.73%	17.59%

Table 10: Time between the start of a West Triplet eruption and the subsequent start of a Rift eruption

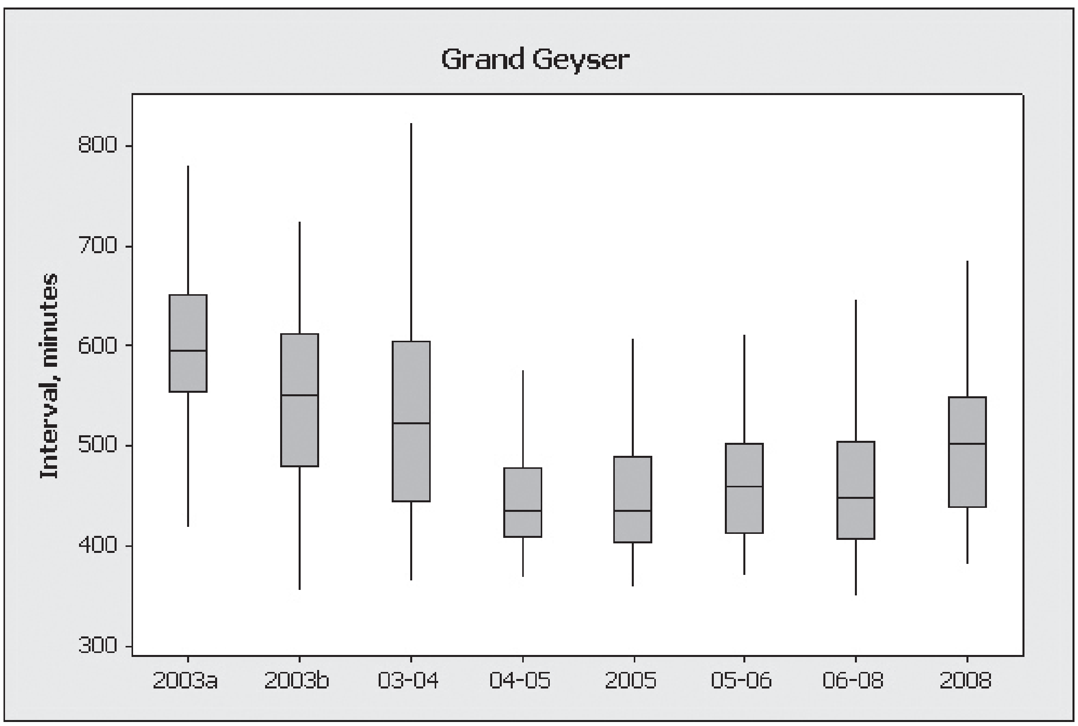


Figure 7: *Boxplot of Grand Intervals. Outliers are not displayed.*

ry cause of long median intervals of Grand since West Triplet and Rift also had longer median intervals at that time. In addition, West Triplet and Rift had shorter intervals when Grand was having shorter intervals.

Conclusions

While West Triplet and Rift Geysers may impact specific intervals of Grand Geyser, there are variables that impact the entire group. This can be seen from the fact that West Triplet, Rift and Grand all showed longer intervals in 2003a,b and 2008, but

Intervals-Grand	2003a	2003b	03-04	04-05	2005	05-06	06-08	2008
Count	53	175	1329	369	517	202	1812	466
Minimum	6:58	5:55	6:04	6:08	6:00	6:11	5:50	6:22
5th Percentile	7:50	6:27	6:33	6:27	6:26	6:26	6:25	6:42
1st Quartile	9:16	8:01	7:26	6:50	6:43	6:53	6:47	7:21
Median	9:56	9:11	8:41	7:16	7:16	7:40	7:28	8:23
3rd Quartile	10:49	10:09	10:03	7:57	8:09	8:20	8:24	9:07
95th Percentile	12:56	11:27	11:30	9:09	9:20	9:54	9:45	10:31
Maximum	13:43	12:05	14:31	11:06	10:38	12:21	12:44	11:26
90% Range	5:05	4:59	4:57	2:42	2:54	3:28	3:20	3:49
IQR	1:33	2:08	2:37	1:07	1:26	1:27	1:37	1:46
Range	6:45	6:10	8:27	4:58	4:38	6:10	6:54	5:04
Mean	10:02	9:05	8:48	7:28	7:30	7:45	7:41	8:20
Standard Dev	1:22	1:28	1:36	0:51	0:57	1:06	1:05	1:10
Coef of Var	13.69%	16.21%	18.20%	11.58%	12.69%	14.21%	14.07%	14.06%

Table 11: Grand Geyser Intervals

all three showed shorter intervals at other times. In addition, our data show that West Triplet and Rift Geysers are more closely related to each other than to Grand Geyser. The median time from the start of West Triplet to the start of Rift was very consistent over the study period.

Future work

The purpose of this study was to be a first basic descriptive of electronic data from related geysers over an extended time period. More detailed analysis could certainly be done to flesh out any relationships.

Acknowledgements

Many people participate in the collection of geyser data by contributing observations to the Old Faithful Visitor Center Logbook. These observations allow us to check the electronic data for accuracy and interpret the data better. Specifically, we would like to thank the following individuals and organizations:

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Grand Geyser second burst (right) with Turban Geyser (center) and Vent Geyser (left) also erupting. Photo by Tara Cross.

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Events at the Daisy Geyser Complex, September 8, 1997

Andrew Hafner

Abstract

On September 8, 1997, the author had the opportunity to observer a sequence of eruptive events in the Daisy Geyser Complex in Yellowstone's Upper Geyser Basin. Following a short introduction to Splendid Geyser's activity in 1996 and 1997, this article briefly describes the types of events that could occur while Splendid was in an active series and describes the events of September 8, 1997 in detail.

Introduction

A) A brief overview of Splendid Geyser's activity in 1996 and 1997

In 1996, Splendid Geyser began showing signs of increased activity after almost a decade of near-dormancy following the active cycles of 1985 and 1986. One eruption was inferred in mid-February, 1996. Beginning in May of that year and continuing through early October, 37 eruptions of Splendid were directly observed or inferred based on washed markers (Koenig and Taylor 1996). Five more eruptions took place between December 21 and December 31, also based on washed markers, and another was inferred, giving a total of 42 to 44 observed or inferred eruptions for 1996 (Stephens in Dunn 1996).

It should be noted that, for all of the isolated eruptions of Splendid recorded between 1987 and 1996, most were post-Daisy, refill-boil initiated eruptions, and were small (in terms of height) by historical standards. Only a few were in series, and the rare series that occurred consisted of an initial and a follow-up eruption, separated by about half an hour.

The following year, 1997, was one of the best ever for Splendid. Instead of the sporadic eruptions of 1996, Splendid had series of eruptions that could last for several days. From mid-April to mid-June, there were 73 known eruptions in 14 series (Stephens August 1997). For much of the rest of the summer, Splendid began having longer active cycles; 290 eruptions in 16 series occurred between the middle of June until late October (Stephens, December 1997). A total of 363 observed eruptions were observed; however, since the Daisy Complex was not under continuous observation during these time periods, this probably does not represent the actual number of eruptions for 1997.

B) A summary of the possible events that could occur during an active phase by Splendid Geyser in 1997

Whenever Splendid Geyser was in an active phase during 1997, it was fairly unpredictable, but it did follow a general pattern. Because of this, and because Daisy Geyser also had eruptions during Splendid's active phases, observers tended to think in terms of "events," or "event intervals." Event intervals could range from 30 minutes to over 2 hours (Bryan, 1997). Public predictions were posted during Splendid's active phases, stating that one geyser or the other (or both) could erupt within 45 minutes of a given time for a prediction window of 90 minutes.

An "event" could consist of any of the following:

1. A solo eruption of Daisy.

2. A solo eruption of Splendid.

3. A concerted, or dual, eruption of the two geysers (Bryan, 1997).

4. Neither, in which case, after a "stall" of several hours during which both geysers seemed imminent but neither erupted, Daisy would finally erupt and resume its normal intervals until the next active phase of Splendid (Cross 2009).

Nearly all of the concerted eruptions in 1997 began with Splendid. With most of these, Splendid would quickly die down and then stop shortly after Daisy began its eruption, and Daisy would take over the full activity. Daisy's eruption would then be stronger than normal, and the duration was increased, too. "Full scale" concerted eruptions occurred much less frequently. These had durations

Figure 1: *A Splendid Geyser solo eruption.*

of up to 8 minutes for Splendid and 6 minutes for Daisy and resulted in much greater eruption heights for both geysers. Finally, in what can probably be described as an aborted concerted eruption or "jam session," Daisy would begin erupting after Splendid had started, but would reach only 20 to 30 feet before quitting. Splendid would then take over the full activity. Bryan (1997) describes this as being an infrequent occurrence during Splendid's active cycles in 1985 and 1986, but it was a fairly common occurrence in 1997 (Cross, 2009).

The Events of September 8, 1997

A solo eruption of Daisy occurred at 0746. Upon finding out that Splendid was in an active phase, I hastened to the Daisy Geyser Complex and arrived there at around 0930. At 1013, Daisy had another solo eruption. This appeared to be about as strong as a normal eruption of Daisy, and the duration was about normal, too. About 30 to 45 minutes after Daisy's eruption had ended, Splendid began having "false starts," in which the water in Splendid's crater would abruptly begin doming and surging to 10-20 feet (or so) for a few seconds, and then die down again.

It should be noted that in 1996 and 1997, Splendid frequently had "false starts" during the early refill after an eruption of Daisy, and in 1997, around the time an eruption of Daisy was expected to take place. Many of Splendid's eruptions began after a series of these "false starts."

At 1135, Splendid once more began to surge heavily. This dropped slightly, and then abruptly built into an eruption with a massive column of water that, in my estimation, reached 60 to 70 feet. The eruption ended after just a few minutes, and is shown in Figure 1.

I then left the complex, to go eat lunch. Another solo eruption by Daisy was observed in progress at 1220 i.e. while I was away. When I returned at around 1230 or shortly thereafter, Splendid was once again having frequent "false starts." This went on for probably an hour or more. The amount of pre-play in Daisy built to a level similar to what is observed when Splendid is not active, when a "normal" eruption of Daisy is expected to take place, with vigorous surging in the main vent and splashing in the two side vents. When combined with Splendid's frequent false starts, it seemed to be very "touch-and-go," as to which geyser would erupt first.

At 1411, the water in Splendid's crater again began to surge heavily. Much like the solo eruption of Splendid at 1135, this dropped slightly, and then abruptly built in height, to about 70 feet. One minute later, at 1412, Daisy began erupting from a lowered water level. A concerted eruption of the two geysers ensued.

The photos in Figure 2 and Figure 3 *(next page)*, respectively, were taken a few minutes after Daisy's eruption had started. By that point, it had become obvious that this was going to be a full-scale concerted eruption of the two geysers. Instead of dropping and eventually quitting, Splendid's height grew to roughly 90 to 100 feet, and its crater was beginning to empty. All that I can remember is that when Splendid changed from a surging eruption to a powerful jet, the water column became narrower, without the wide jetting of the eruption's initial moments, and the increase in height was more rapid. Daisy's eruption, too, was growing stronger.

Figure 2: Daisy Geyser, left; Splendid Geyser, right.

Figure 3: Daisy Geyser, left; Splendid Geyser, right.

The next three photos, Figure 4, Figure 5, and Figure 6, taken from varied locations on the boardwalk, all show the concerted eruption at its peak. By then, Splendid's crater had emptied, and its water discharge was becoming increasingly co-mingled with steam. The eruption began to be accompanied by a roaring sound, somewhat reminiscent of that of Beehive Geyser. The height of Splendid's water column was estimated by Barry Schwarz, another observer who was present at the eruption, to be 110 to 120 feet. It felt as if we were watching Old Faithful erupt from close range. Daisy's height seemed to be "normal."

There is no record of the durations for Splendid and Daisy during this concerted eruption in the electronic versions of the Old Faithful Visitor Center Log Books. I would estimate that Splendid's eruption lasted for more than 5 minutes. Daisy's

Figure 4: *Daisy Geyser, left; Splendid Geyser, right.*

Figure 5: *Daisy Geyser, left; Splendid Geyser, right.*

eruption began to die down, and Splendid followed a short time later. When the concerted eruption had ended, a great amount of water was flowing down the runoff channels leading away from the two geysers. Splendid had an "afterburst" to 20 feet or so, with a thin jet of steam and spray that lasted about a minute, or less. "Afterbursts" were fairly common in 1997 after strong eruptions of Splendid, concerted or not. Comet Geyser's activity had ceased, presumably due to its water level having been drawn down.

Eruptions of Splendid Geyser also have the effect of drawing down Brilliant Pool's water level by several feet. It is only during a series of eruptions by Splendid that Brilliant Pool can have its own eruptive activity. Brilliant's eruptions can be best described as a series of sharp water bursts that are angled away from Splendid (Bryan, 2008). In 1997, I saw Brilliant Pool erupt after some strong eruptions

Figure 6: *Daisy Geyser, left; Splendid Geyser, right.*

Figure 7: *This photo shows a more "typical" concerted eruption by Daisy (right) and Splendid (left) in 1997.*

of Splendid, but I do not recall whether or not any activity took place after the concerted eruption on September 8.

Less than two hours after the end of the concerted activity, Daisy had a solo eruption at 1608, and another at 1759. Splendid erupted at 1944, and Daisy followed later in that same minute for the second concerted eruption of the day. All of the eruption times for the day are shown in Table 1. The events of September 8, 1997, were part of a much longer active series by Splendid Geyser, which began early in the morning of September 7 and continued until mid-afternoon of September 10. The series included at least 15 observed eruptions of Splendid

Table 1.
Events in the Daisy Geyser Complex, September 8, 1997.

Splendid	Daisy
	0746
	1013
1141	
	1220i.e.
1411	1412
	1608
	1759
1944	1944

(there are possibly others, especially at night, which were not observed) and seven observed concerted eruptions of Splendid and Daisy.

(*Author's note:* The descriptions of the events in this article are based almost entirely on personal recollections. I did not keep a personal log book of geyser data in 1997; the eruption times for September 7, 8, 9, and 10, 1997, were taken from the electronic versions of the Old Faithful Visitor Center Logbooks maintained on the GOSA Website.)

Conclusion

The 1997 summer season was a remarkable one for the Daisy Geyser Complex and the rest of the Upper Geyser Basin. It is hoped that this article will provide the basis for someone to write a more in-depth overview of the activity in the complex during that year. The events of September 8, 1997, that are described here were just a few in a much longer sequence of events, and remain among the most thrilling and spectacular hydrothermal displays I have had the opportunity to witness.

Acknowledgements

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Fan and Mortar Geysers: A Summary of the 2000-2005 Active Phase and Details from 2004 and 2005

Tara Cross

Abstract

The active cycle of Fan and Mortar from early 2000 to August 2005 was one of the best on record for the geysers. Fan and Mortar's behavior during this period is summarized, with more detailed observations given for 2004 and 2005.

Section One:
Introduction and Definition of Terms

Introduction

The active cycle of Fan and Mortar Geysers from early 2000 to August 2005 was one of the finest in their history. With relatively consistent preeruptive behavior, Fan and Mortar were easier to see than at any time previously. This article will summarize the active phase and detail observations from 2004 and 2005.

<u>The vents of Fan and Mortar</u>

- The vents of Fan: In order south to north: River, High, Gold, Angle, Main, and East.
- The vents of Mortar: Upper Mortar, Lower Mortar, Bottom Vent, Frying Pan.
- River, High, Gold, and Angle comprise the "minor vents."
- Main Vent, East Vent, and Lower Mortar comprise the "main system." Activity by Main Vent is the best indication of high energy levels in the complex.
- Other vents within the complex are Back Vent, Crack Vent, Beach Springs, Tile Vent, Spiteful Geyser, "Norris Pool," and Backwater Spring. All of these vents are identified on the map published in the *GOSA Transactions*, Volume VII (Figure 1 in Cross 2002).

Definition of terms

Minor cycles have typically been timed from the start of River Vent's minor eruption to the start of the next River Vent.

A *pause* occurs when the minor vents of Fan shut off before Angle begins its minor eruption. If only River comes on and then shuts off, this is referred to as a *River pause*. If River, High, and Gold come on and then all three shut off, this is referred to as a *Gold pause*. If Angle comes on, the cycle is complete and there cannot be a pause. When two pauses occur consecutively without a full minor cycle being completed, this is referred to as a *double pause*. When three pauses occur consecutively without a full minor cycle being completed, this is a *triple pause*, and four consecutive pauses are referred to as a *quadruple pause*.

During 2001-05, River Vent occasionally sputtered on weakly and then shut off within a few minutes. This activity was referred to as a *cough*. Coughs could also include weak activity by the other minor vents. While coughs were not considered to be the same as a pause, they sometimes resulted in a shift of energy to the main system.

The difference between periodic splashing in Bottom Vent and true eruptions of Bottom Vent became hard to distinguish in 2003, and this continued to be the case in 2004-05. Some observers counted individual Bottom Vent eruptions separately, while others noted the total duration of its activity. As in 2001-03, episodes of cyclic splashing were commonly seen in the minutes before River Vent started or during pauses.

Lower Mortar minors were first seen in 1996, and by 2000 they had become a common indicator of stronger cycles at Fan and Mortar. Lower Mortar minors were commonly seen during strong cycles in 2001, 2002, and 2003. They usually occurred when Lower Mortar's periodic splashing built into a sustained eruption and the water level in the vent rose to overflow. Lower Mortar minors became infrequent in September 2003 and ceased to occur in December; none were seen in 2004 or 2005.

Main Vent splashing, pauses, Bottom Vent eruptions, and Lower Mortar minors have been

Fan Geyser in eruption, June 22, 2005.. Photo by Lori Hoppe.

referred to by observers as "events." Cycles that include any of these behaviors are referred to in this article as *event cycles*.

Until 2001, major eruptions of Fan and Mortar typically started from a behavior referred to as *classic lock*, when High, Gold, and sometimes Angle had strong, continuous jetting activity to 3 to 10 feet. In a significant change from previous activity, the most common start type in 2001 was the *Upper Mortar initiated* eruption. For an eruption to be Upper Mortar initiated, the eruption must start from a series of cone-filling surges in Upper Mortar, and the initiating surge must occur when Fan's minor vents are *not* having classic lock behavior. During 2002 and 2003, a little more than half of the observed starts began this way, while the remainder started from a classic lock. In 2004 and 2005, nearly all eruptions started from a classic lock. On three occasions in 2001, eruptions were observed to start during a long Lower Mortar minor. This behavior was not seen during 2002-05.

Section Two: A Summary of the 2000-2005 Active Phase through 2003

After a two-year active phase spanning 1996-98, Fan and Mortar fell dormant for 19 months. Unlike prior dormant periods, which took place every few years on a cyclical basis starting in 1969, a major change occurred in the Fan and Mortar complex during 1998 and 1999. During October and November of 1998, "Norris Pool" transformed from a superheated mudpot to a geyser, excavating the soil and debris from around its vent to reveal an old hot spring crater. Norris Pool had another active phase in 1999, starting in August and ending in November,[1] this time from a vent clear of debris.

When Fan and Mortar resumed activity in early 2000, it commenced one of its finest active phases in known history. The first year of activity was marked by highly erratic intervals, and little is known about the eruptions. There was evidence from wash that

[1] Bryan, T. Scott. 2001. *The Geysers of Yellowstone.* Third Edition. Boulder, CO: University Press of Colorado. p. 119.

Norris Pool was erupting along with Fan and Mortar, but this was not confirmed visually until July 7, 2000. A second eruption was seen in October, and it was also accompanied by Norris Pool, which reached 20 to 30 feet high.

A description of the October 2000 eruption[2] and scattered visitor reports from fall 2000 and winter 2001 suggested that many eruptions of Fan and Mortar were initiated by Upper Mortar surging rather than classic lock, the predominant start type during the 1990s. This shift became clear during the summer of 2001 when 17 out of 21 eruptions seen between June 16 and November 4 were initiated by Upper Mortar surging, while only one was initiated by classic lock. The remaining three eruptions began in a manner that had not been seen previously. On July 11, 2001, an eruption began during a Lower Mortar minor that took place during a pause. This type of start was also seen on August 28 and September 2, 2001.

Other trends in Fan and Mortar's behavior were noted in 2001. No known eruption in 2001 occurred without being preceded by some sort of event and a shift of energy to the main system. Observers looked for splashing in Main Vent as the first indication of this shift. All eruptions were preceded by at least one eruption of Bottom Vent. Often a series of Bottom Vent eruptions would lead to Lower Mortar minors, which were also common prior to eruptions.

Many of the patterns of 2001 remained much the same in 2002. Main Vent splashing remained key to strong cycles, seen prior to all eruptions between June 25 and November 3. Bottom Vent eruptions and Lower Mortar minors continued to be common and occurred during most eruption cycles.

Spring 2002 activity displayed somewhat different characteristics. Some eruptions occurred with no pauses or events, and the time from River on to eruption start was longer. In most years, Fan and Mortar's "spring slowdown" resulted in erratic intervals of 1 to 4 weeks. In 2002 the slowdown was less dramatic, with the longest interval being just under 10 days.

By 2003, significant erosion was evident around the formations of both geysers. Bottom Vent's crater expanded significantly, and it began to leave gold-colored deposits around its vent. An explosive eruption in April 2003 blew apart a portion of Main Vent's cone, leaving a large slab of sinter balanced on a ledge inside the crater. In July, the piece of sinter that had split the vertical portion of Main Vent's column was dislodged, and this column took the appearance of a single fan-shaped stream.

After maintaining regular intervals through the winter of 2002-03, intervals became erratic in the spring, and Fan and Mortar experienced a brief dormancy lasting 43 days from April 26 to June 8. When activity resumed in June, intervals were erratic and events were uncommon. Events became more common in July, but intervals remained at 7 to 10 days.

Event cycles in July, August, and early September resembled those seen during 2002. However, a dramatic change occurred after the September 7 eruption. On September 11, Bottom Vent had a series of 21 eruptions in a single event cycle. This would become the norm in September and October. At the same time, Lower Mortar minors became rare. Though electronic monitors showed that Lower Mortar minors occurred as late as November 2003, they ceased at that time and were not seen in the following years.

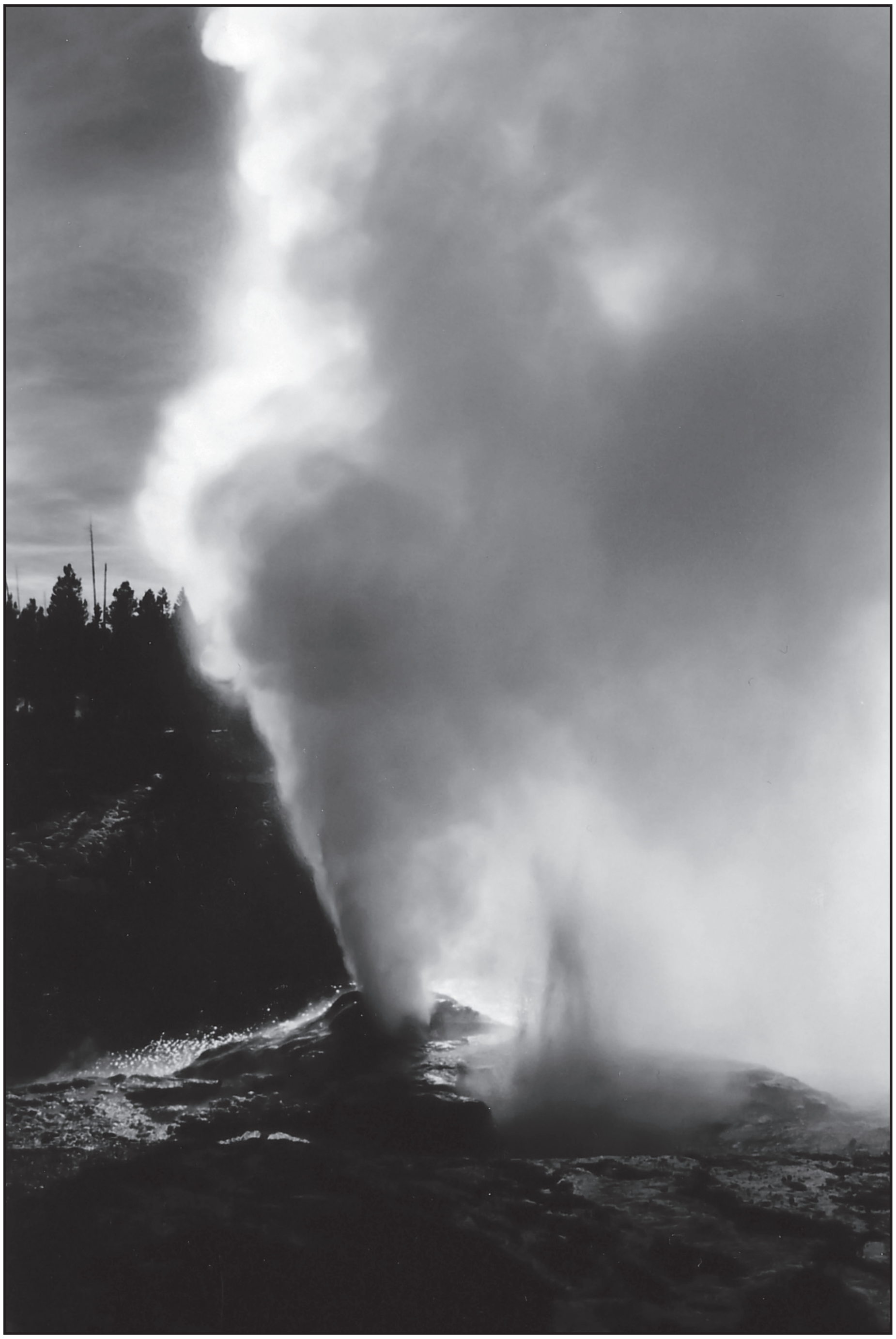
Section Three: Activity in 2004 and 2005

The first interval of 2004 was one of the longest since the 2000 reactivation, just over 35 days. Intervals shortened briefly in February before becoming long and erratic again in March. By late March, observers had noticed some marked changes in the minor behavior of Fan and Mortar from what was seen in 2003. On March 28 it was noted that Crack Vent and Back Vent were completely inactive and their formations were dry. Additionally, Bottom Vent was not having full eruptions. Frying Pan was seen only immediately prior to major eruptions.[3] When regular observations began in late April, this continued to be the case.

Bottom Vent had episodes of periodic splashing but did not produce discrete eruptions, even when Main Vent was splashing. In fact, it appeared that Bottom Vent splashing had replaced the cyclical splashing and "fuzzballs" in Lower Mortar. Though few Lower Mortar minors had been seen in September and October of 2003, observers weren't fully aware that they had ceased to occur until the spring of 2004.

[2] McLean, Matthew. 2001. Personal communication.

[3] Keller, Mike. 2004. Personal communication.



Mortar Geyser erupting November 6, 2004. Photo by Tara Cross.

Intervals remained erratic through April, May, and June. Frying Pan was finally seen during minor cycles in late June, but activity did not stabilize until early July. True Bottom Vent eruptions began to occur with event cycles, with durations ranging from seconds to over 30 minutes. Event cycles also included Main Vent splashing and sometimes pauses as seen in previous years.

Intervals ranged from 3-5½ days during July and early August. Then in mid-August several intervals of less than 3 days occurred. During this time, observers noted unusual activity prior to the eruptions of August 19 and 21. Both eruptions were at short intervals, and in fact the interval between them (1d 15h 56m) was the shortest known interval in over 20 years. Second, both eruptions were preceded by an extraordinarily long period of “classic lock” behavior, 10 and 11 minutes, respectively, as compared with the 1- to 7-minute range seen prior to other eruptions. Finally, both eruptions were triggered by massive surges from Main Vent. The surging before the August 19 eruption was longer and larger than that observed on August 21. It is unknown if this behavior continued beyond these two eruptions; the three following eruptions were not observed, and then a dramatic shift in minor behavior occurred.

This shift began after the eruption on September 1 and was accompanied by lengthened intervals. By September 4, event cycles were being observed at Fan and Mortar every 2 to 4 hours. Although event cycles had occurred this often in the past, more than two or three event cycles on such short intervals had been rare. This behavior persisted throughout the interval until the eruption finally occurred on September 9. Another change was a noticeable lack of water in both Upper and Lower Mortar.

This behavior pattern continued through September and into October, with intervals ranging from 5d5h to 9d3h. In mid-October, the phase of frequent event cycles came to an end, and intervals shortened. Along with this, water returned in Mortar, especially Lower Mortar, which had "fuzzballs" between eruptions of Bottom Vent during event cycles. Fan and Mortar settled into a more regular pattern for the remainder of the year. Between October 28 and December 31, intervals ranged from 2d15h and 6d3h.

Intervals remained remarkably consistent during January, February, and March of 2005, with most falling between 2½ and 5 days and a range of 1d22h to 5d20h. In April and May, Fan and Mortar entered "spring mode" activity. Intervals became more erratic, and no event cycles were observed until mid-May. The longest interval during this time was 16d02h.

Intervals shortened to 3 to 6 days in June, and became even more consistent in July and early August, with a range of 1d22h to 4d09h during that time. Event cycles usually occurred every 4 to 12 hours, with strong events occurring as soon as 1½ days after the previous eruption. In a change from 2004, true Bottom Vent eruptions were seen less frequently, especially during eruption cycles. While eruptions were not as common, Bottom Vent participated in event cycles with light splashing that discharged enough runoff to reach the river. It was perhaps not a coincidence that Lower Mortar's water levels were generally better in 2005 than in 2004.

The only observed eruption during 2004-05 not preceded by some type of event occurred on July 26, 2005. Angle had been splashing during River's off period, and when River and Gold started, water levels were unremarkable. However, approximately 23 minutes after the start of River, High Vent began to erupt steadily to 1 to 2 feet. This activity grew until it was erupting steadily to 3 to 5 feet. It was then joined by Gold and Angle for a "classic lock," and the eruption occurred 7 minutes later, about 35 minutes after the start of River Vent.

Eruption cycles on July 29 and August 2 returned to the more usual behavior, with River pauses and Main Vent splashing. Event cycles became more frequent prior to the eruption on August 5, and two changes occurred in the eruption cycles seen on August 5 and August 8. First, Bottom Vent had full eruptions lasting up to 9 minutes, and second, both were double pause cycles with a second pause that was significantly longer than those seen previously in 2005. These changes may have been coincidental, or they might have signaled that something was changing in Fan and Mortar's system. The eruption on August 8 was the last of 2005.

Fan and Mortar continued to have event cycles throughout August and September, but these quickly declined in strength. After about August 12, River pause cycles became very infrequent. When Main Vent splashing occurred, it was weak and lasted only 5 to 15 minutes.[4] Bottom Vent's activity became gradually weaker.[5] By late August, cycles were getting longer and the minor vents could not maintain water levels.[6] Few observations were made at Fan and Mortar after early September.

The August 8 eruption marked the end of a remarkable 5½-year active phase. Fan and Mortar would remain quiet until June 5, 2007, a dormancy lasting 22 months. The cessation of activity came as a surprise to many because intervals had been very consistent right up to the final eruption, with no signs of slowing down. Also, prior active phases tended to end in the spring months, when Fan and Mortar have been prone to longer intervals. Why activity in 2005 was different from previous patterns will remain a mystery.

4 Robinson, Steve. 2005 Aug. 20. [Geysers] No Fan and Mortar. Report to geyser listserv.
5 Bryan, T. Scott. 2005 Aug. 16. [Geysers] Brief geyser report August 16. Report to geyser listserv.
6 Bryan, T. Scott. 2005 Aug. 27. [Geysers] Geyser report Saturday August 27. Report to geyser listserv.

Mortar Geyser, left, and Fan Geyser, right, erupting on June 22, 2005. Photo by Lori Hoppe.

Trends in 2004-05

Strong cycle events

In 2004, Fan and Mortar continued to have event cycles with one or more pauses. While double pauses were seen, none occurred during eruption cycles. Single River or Gold pauses preceded about half of the eruptions witnessed in 2004. These pauses could last anywhere from 5 to 53 minutes. In the cases when there was no pause, Main Vent splashing would start during the quiet period after the end of the previous cycle and precede the start of the eruption by a range of 57 to 106 minutes. The total range for Main Vent activity prior to eruptions was 47 to 106 minutes in 2004 and 59 and 115 minutes in 2005.

In 2005, Gold pauses were less frequent than in 2004, and there were no observed eruption cycles that included Gold pauses. Double River pauses were most common in eruption cycles, but the range was from 1 to 4 River pauses. Prior to 2005, event cycles were known to have up to three pauses. A quadruple pause cycle, complete with vigorous Main Vent splashing, was seen on May 15, 2005, but it did not culminate in an eruption.[7] Another quadruple pause event cycle occurred on July 29, which resulted in an eruption of Fan and Mortar. Pause lengths in 2005 were generally shorter than those seen in 2004, with most falling between 5 and 12 minutes.

For the first time in the 2000-05 active phase, Fan and Mortar were observed to go into "classic lock" behavior and not follow with a major eruption. This was seen at least 3 times in 2004: on June 4, on July 25, and again in September. It was repeated again on August 5, 2005. This activity was referred to by some as a "false lock." It did not seem to affect Fan and Mortar negatively, but it was a disappointment to observers. Though Fan's vents never fully achieved classic lock on September 6, 2004, East Vent had several visible splashes at the culmination of an event cycle that did not lead to an eruption. Experienced observers had seen this before, but it was and would remain extremely rare.

[7] Bryan, T. Scott. 2005 May 15. [Geysers] Geyser report Sunday May 15. Report to geyser listserv.

Start Types

While classic lock and Upper Mortar-initiated eruptions were about even in 2002 and 2003, only two of the 20 observed eruptions in 2004 were Upper Mortar initiated. No Upper Mortar initiated eruptions were witnessed in 2005. Table 1 shows the trend from Upper Mortar to classic lock start types from 2000 to 2005.

Table 1. Fan and Mortar Start Types, 2000-2005

Year	Classic lock	Upper Mortar	Lower Mortar	Total
2000	1	1	0	2
2001	1	17	3	21
2002	15	17	0	32
2003	9	10	0	19
2004	18	2	0	20
2005	10	0	0	10

In 2004, there was a bimodal trend in the time elapsed between the start of River vent and the start of the major eruption. With only one exception, the time from River to start fell either between 14 and 18 minutes or between 22 and 26 minutes. An unusual eruption on August 21 started 33 minutes after River, following 11 minutes of "classic lock" behavior from the minor vents. In 2005, the time from River to start tended to be longer, ranging from 22 to 35 minutes. In two instances "classic lock" behavior preceded eruptions by 12 minutes; these were the longest known in the 2000-05 active phase.

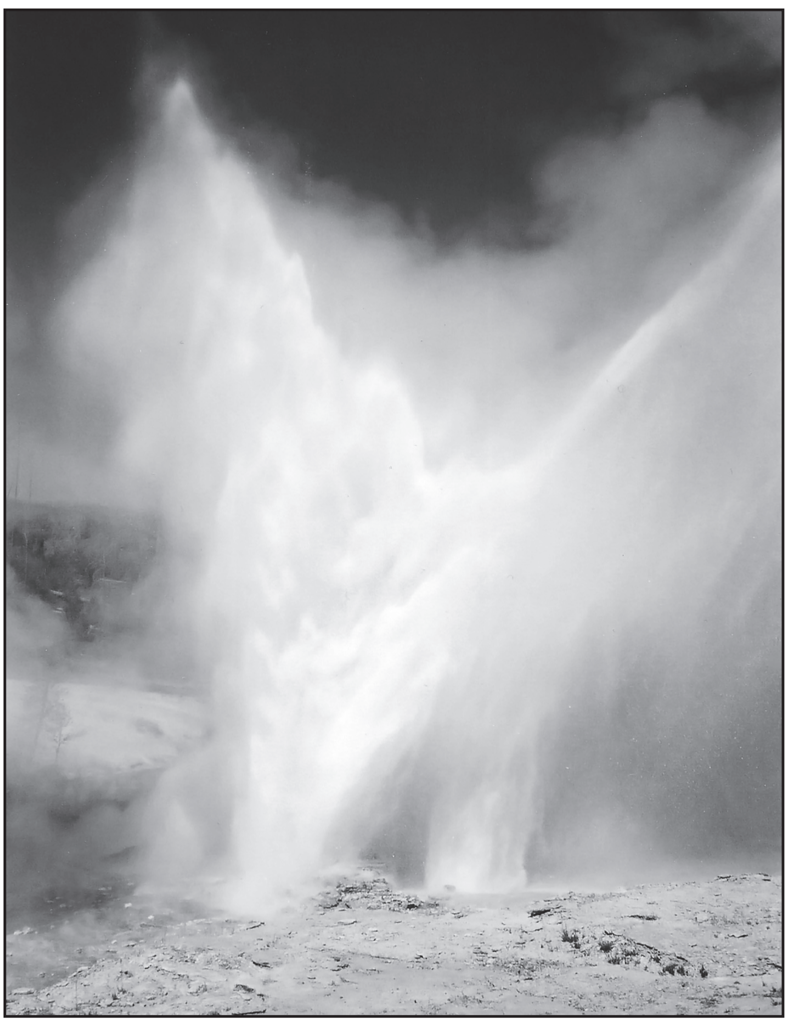
Suggested Reading:

Bryan, T. Scott. *The Geysers of Yellowstone*, fourth edition, University Press of Colorado, 2008.

Cross, Tara. Fan and Mortar Geysers in the Summer of 2001, May 24-November 4. *GOSA Transactions*, 2002, Vol. 7, pp. 56-69.

Cross, Tara. Fan and Mortar Geysers in the Summer of 2002, April 20-November 3. *GOSA Transactions*, 2003, Vol. 8, pp. 96-105.

Cross, Tara. Fan and Mortar Geysers in 2003. *GOSA Transactions*, 2005, Vol. 9, pp. 44-49.



Fan Geyser erupting in 2004. Photo by Kitt Barger.

Table 2: Fan and Mortar Cycles 2004

Date	Time	Pause? (time on-off)	Bottom?	Start Type	River to start	Observer
1/24/2004	1149	River (>13-42)	yes - 10	UM	20m	Mike Keller
3/13/2004	1038	?	yes - at least 2	lock	18m	Michael Lang
3/31/2004	1025	?	yes	lock	>9m	Mike Keller
7/6/2004	1556	at least one River pause	no	lock	23m	Tara Cross
7/11/2004	2239	River (11-30)	yes (d=11m12s)	lock	14m	Andrew Bunning
7/17/2004	1048	Gold (7-37)	yes - 2	lock	18m	Mary Kennedy
7/21/2004	0907	no	yes - 8	lock	16m	Paul Strasser
7/26/2004	1249	no	yes - 3	lock	22m	Paul Strasser
7/29/2004	1618	?	?	lock	?	Paul Strasser
8/2/2004	1158	no	yes - 9	UM	23m	Lynn Stephens
8/5/2004	2136	River (12-5)	no	lock	22m	Andrew Bunning
8/14/2004	1044	no	yes - 8	lock	15m	Lynn Stephens
8/19/2004	1748	?	yes	lock	26m	Lynn Stephens
8/21/2004	0944	River (11-22)	yes - at least 6	lock	33m	Kitt Barger
9/9/2004	1536	Gold (8-53)	yes (d~36m)	lock	15m	Karen Koka
9/24/2004	1042	no	yes - 4	lock	23m	David Leeking
10/3/2004	1329	no	yes - 3	lock	22m	Graham Meech
10/25/2004	1359	no	yes - 6	lock	17m	Tara Cross
11/6/2004	1436	River (5-23)	yes - 2	lock	18m	Tara Cross
11/9/2004	1006	?	yes - at least 1	lock	17m	Karen Low

Table 3: Fan and Mortar Cycles 2005

Date	Time	Pause? (time on-off)	Bottom?	Start Type	River to start	Observer
6/22/2005	0732	River (8-10), River (6-8)	no	lock	22m	Karl Hoppe
6/29/2005	1725	River (10-16), River (9-8), River (10-7)	yes - 3	lock	25m	Tara Cross
7/19/2005	0344	River (9-6), River (10-7)	no	lock	28m	Kitt Barger
7/22/2005	1452	River (6-8), River (8-12)	no	lock	28m	Tara Cross
7/26/2005	1442	no	no	lock	~35m	Suzanne Strasser
7/29/2005	0727	River (7-6), River (9-11), River (7-6), River (8-5)	no	lock	24m	Kitt Barger
8/2/2005	1557	River (13-7)	no	lock	25m	Tara Cross
8/5/2005	2116	River (5-11), River (12-22)	yes - 4	lock	26m	Tara Cross
8/8/2005	0708	River (9-7), River (16-37)	yes - 3	lock	31m	Steve Robinson

Table 4: Fan and Mortar Eruptions 2004 – 2005.

2004	January 24	1149	~35d01h14m
2004	January 30	0538E	~5d17h49m
2004	February 4	0016E	~4d18h38m
2004	February 10	1450E	~6d14h34m
2004	February 14	1414	~3d23h31m
2004	February 16	1753E	~2d03h32m
2004	February 28	2301E	~12d05h08m
2004	March 13	1038	~13d11h37m
2004	March 31	1025	=17d23h47m
2004	April 27	1139E	~27d00h14m
2004	May 20	0541E	~22d18h02m
2004	June 8	1245	~19d07h04m
2004	June 18	0712E	~9d18h27m
2004	June 23	1948	~5d12h36m
2004	July 6	1556	=12d20h08m
2004	July 11	2239	=5d04h45m
2004	July 17	1048	=5d12h09m
2004	July 21	0907	=3d22h19m
2004	July 26	1249	=5d03h42m
2004	July 29	1618	=3d03h29m
2004	August 2	1158	=3d19h40m
2004	August 5	2136	=3d09h38m
2004	August 8	1442	=2d17h06m
2004	August 14	1044	=5d20h02m
2004	August 17	0328E	~2d16h44m
2004	August 19	1748	~2d14h20m
2004	August 21	0944	=1d15h56m
2004	August 26	0053E	~4d15h09m
2004	August 29	0406E	~3d03h13m
2004	September 1	2318E	~3d19h12m
2004	September 9	1536	~7d16h18m
2004	September 17	0032E	~7d08h56m
2004	September 24	1042	~7d10h10m
2004	October 3	1329	=9d02h47m
2004	October 8	1900	=5d05h31m
2004	October 14	0249E	~5d07h49m
2004	October 16	0144E	~1d22h55m
2004	October 25	1359	~9d12h15m
2004	October 28	2119E	~3d07h20m
2004	November 1	1955E	~3d23h36m
2004	November 6	1436	~4d18h41m
2004	November 9	1006	=2d19h39m
2004	November 12	2009E	~3d10h03m
2004	November 18	0219E	~5d06h10m
2004	November 24	0243E	~6d00h24m
2004	November 28	1712E	~4d14h29m
2004	December 4	1848E	~6d01h36m
2004	December 8	0541E	~3d10h53m
2004	December 10	2024E	~2d14h43m
2004	December 13	1800E	~2d21h36m
2004	December 17	0229E	~3d08h29m
2004	December 19	2145E	~2d19h16m
2004	December 23	0648E	~3d09h03m
2004	December 26	0502E	~2d22h14m
2004	December 29	1936E	~3d14h34m
2005	January 4	2341E	~6d04h05m
2005	January 7	2024E	~2d20h43m
2005	January 10	2048E	~3d00h24m
2005	January 15	2009E	~4d23h21m
2005	January 20	1110E	~4d15h01m
2005	January 24	0555E	~3d18h45m
2005	January 26	2220E	~2d16h25m
2005	February 1	1755E	~5d19h35m
2005	February 4	1025	~2d16h20m
2005	February 7	0100E	~2d14h45m
2005	February 10	0830E	~3d07h30m
2005	February 14	1840E	~4d10h10m
2005	February 18	1325E	~3d18h45m
2005	February 22	1900E	~4d05h35m
2005	February 25	0435E	~2d09h35m
2005	February 28	1900E	~3d14h25m
2005	March 2	1555E	~1d20h55m
2005	March 8	0250E	~5d10h55m
2005	March 12	0020E	~3d21h30m
2005	March 15	0905E	~3d08h45m
2005	March 19	1145E	~4d02h40m
2005	March 22	0430E	~2d16h45m
2005	March 25	2020E	~3d15h50m
2005	March 28	1310E	~2d16h50m
2005	April 4	0210E	~6d12h00m
2005	April 7	0445E	~3d02h35m
2005	April 12	1130E	~5d06h45m
2005	April 17	2310E	~5d11h40m
2005	April 28	0635E	~10d07h25m
2005	May 7	0100E	~8d18h25m
2005	May 23	0221E	~16d01h21m
2005	May 28	0153E	~4d23h32m
2005	June 4	0732vr	~7d05h39m
2005	June 10	0541E	~5d22h09m
2005	June 13	0653E	~3d01h12m
2005	June 16	1339	~3d06h46m
2005	June 22	0732	=5d17h53m
2005	June 26	0208E	~3d18h36m
2005	June 29	1725	~3d15h17m
2005	July 3	0241E	~3d09h16m
2005	July 5	0438E	~2d01h57m
2005	July 8	2328E	~3d18h50m
2005	July 13	0218E	~4d02h50m
2005	July 15	0006E	~1d21h48m
2005	July 19	0344	~4d03h38m
2005	July 22	1452	=3d11h08m
2005	July 26	1442	=3d23h50m
2005	July 29	0727	=2d16h45m
2005	August 2	1557	=4d08h30m
2005	August 5	2116	=3d05h19m
2005	August 8	0709	=2d09h53m

Ragged and Jagged Springs at Black Sand Basin: July 2008

Stephen Michael Gryc

Abstract

Ragged Spring and the unofficially named Jagged Spring erupt together. During the summer of 2008, eruptions were frequent with some bursts from Ragged reaching a height of 7 feet while bursts from Jagged occasionally reached 25 feet. This paper describes an eruption sequence typical of those seen on July 4, 5 and 6 and provides a summary of data from 173 eruptions logged during nearly 8 hours of observation.

Location and Description of Craters

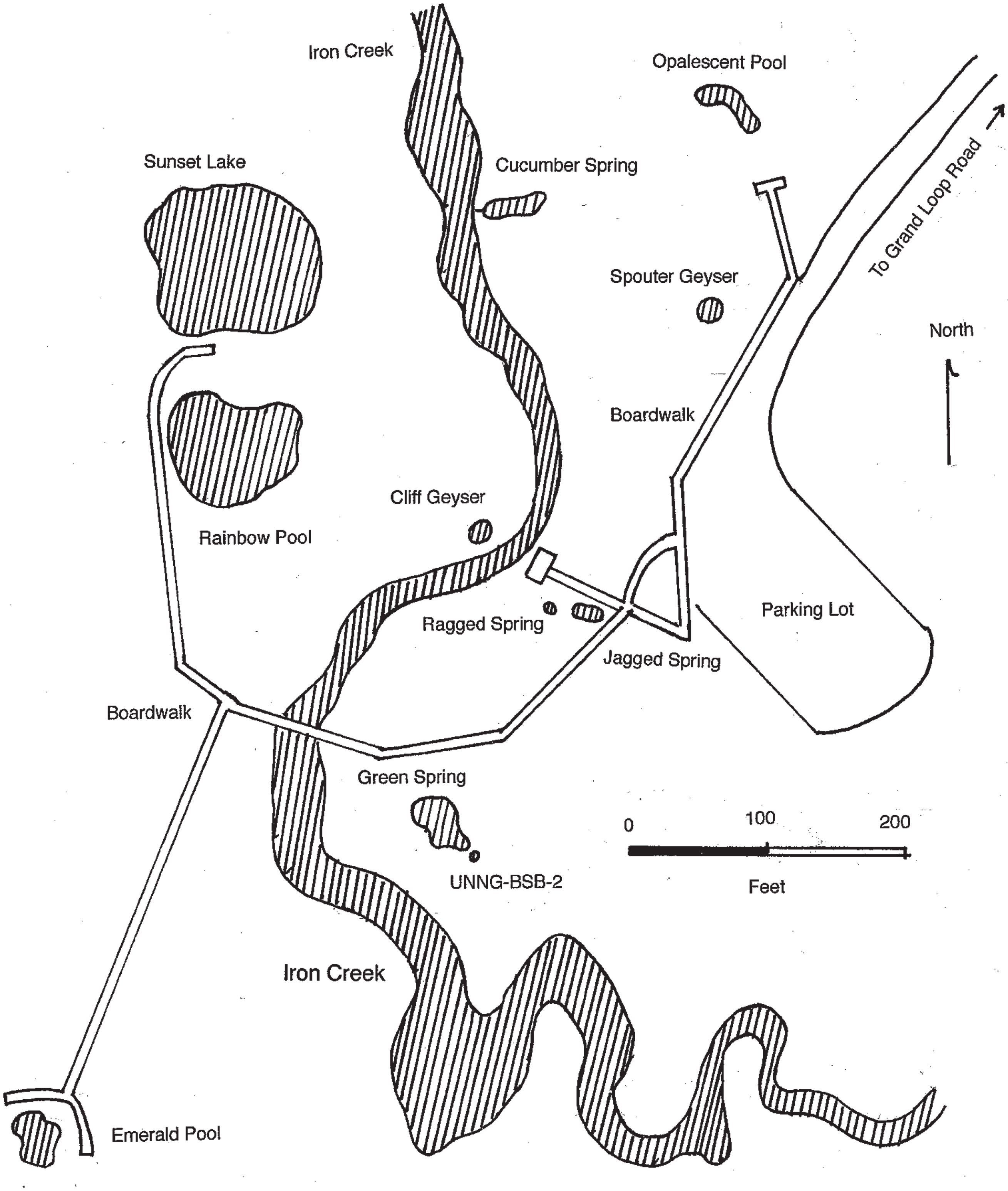
Ragged Spring is a small geyser in the Black Sand Basin of Yellowstone's Upper Geyser Basin. It is located a few yards from the southern bank of Iron Creek and across the stream from Cliff Geyser. *(See map on page 44.)* Ragged's vent is in the center of its round crater which is about 3 feet in diameter and lined with fine geyserite beading of a reddish brown color.

The informally named Jagged Spring lies to the immediate southeast of Ragged Spring. According to Bryan[1] the spring had its origin during the 1930s when the sinter collapsed, exposing the water beneath. Jagged's shape is roughly rectangular with the east and west sides being about 4 feet long and the north and south sides about 6 feet in length. The northern, western, and southern edges of the crater overhang the subterranean pool while the eastern side of the crater slopes down to the edge of the pool where there are three areas of beaded geyserite deposits. Beyond the beading is an area of washed gravel. There is fine geyserite beading around Jagged's western rim that resembles that of Ragged in color and size. Jagged Geyser appears to have been named for the irregular contour of its rim, particularly the southern rim with its protrusions. Orange bacteria dangle like icicles from the protrusions.

Jagged's main vent is the most westerly. There are at least two other nearby vents, one to the main vent's north and one to its south. The main vent always supplies the largest and tallest bursts during an eruption. There appear to be other vents under the western overhang, for an eruption of Jagged always starts with water suddenly bursting out into the pool at an angle from beneath the ledge.

There are three holes in the overhanging southern side of Jagged's rim. The most westerly of these holes lies near the southern vent, and during

Photo 1: Ragged Spring's crater between eruptions. Photo by Stephen Michael Gryc.



Map of BLACK SAND BASIN based on Geologic Map of Upper Geyser Basin (Map I-1371) by Muffler, White, Beeson and Truesdell, USGS, 1982.

Photo 2: Ragged Spring (right) and Jagged Spring (left) in eruption. Ragged with a four-foot burst with Jagged's six-foot burst. Note the blowhole to the left of Jagged's water column. Photo by Stephen Michael Gryc.

an eruption an angled burst from the vent will occasionally send water jetting through this blowhole.

The names of the two geysering springs have been frequently confused. Ragged Spring lies closer to Iron Creek, while the much-larger Jagged Spring (also referred to as Jagged Geyser or Ragged Spring's Annex) is closer to the boardwalk and is the first spring encountered along the boardwalk after entering Black Sand Basin.[2]

Eruption Sequence

During my observations Ragged and Jagged Springs erupted together. Over the past 12 years, I have seen activity in the two geysers increase and greatly intensify. An eruption cycle typical of those seen in July of 2008 is described below in numbered stages.

1. Before an eruption, water rose in both Ragged Spring and Jagged Spring. Just before an eruption the water in Ragged usually covered the bottom of its entire crater though it may not have filled the crater at the beginning of an eruption. The water in Jagged's pool rose enough to be noticed before its eruption.

2. Activity in Jagged would suddenly increase with a burst from its western covered vents that sent a spray of water horizontally into the pool. This increase in activity commenced with a sharp slapping sound, a much higher sound than the low growling that characterized the intervals between eruptions. I regarded this burst as the initiation of an eruption. Jagged's pool continued to rise, eventually covering the flat rock at its center.

3. Violent boiling occurred from Jagged's main vent and occasionally from the blowhole vent as the surface of the pool roiled. There were a series of discrete bursts from the main vent and occasionally from the blowhole vent. There were one to nine bursts in Jagged's eruption, the largest bursts reaching 25 feet above the geyser's rim during the strongest eruptions. Weak eruptions did not include any burst large enough to clear the spring's rim and consisted only of boiling and low splashing. In eruptions where water burst above the rim, the beaded stones at the eastern end of the crater and gravel beyond them were washed. Jagged's pool never overflowed.

Ragged Spring erupted with continuous bursting from one to three feet high, but the force of the eruption and the level of its pool varied constantly. Ragged sometimes overflowed, and the height of its bursts sometimes increased to as much as seven feet.

The relative strengths of the eruptions of Ragged and Jagged were not always matched. Sometimes Ragged would overflow copiously and rise to four or five feet even when Jagged's eruption was weak, or Ragged's eruption would be small while Jagged's eruption was large. During the very largest eruptions, both geysers attained their maximum height.

4. As Ragged's water level dropped into its vent, Jagged calmed quickly. After Ragged's water

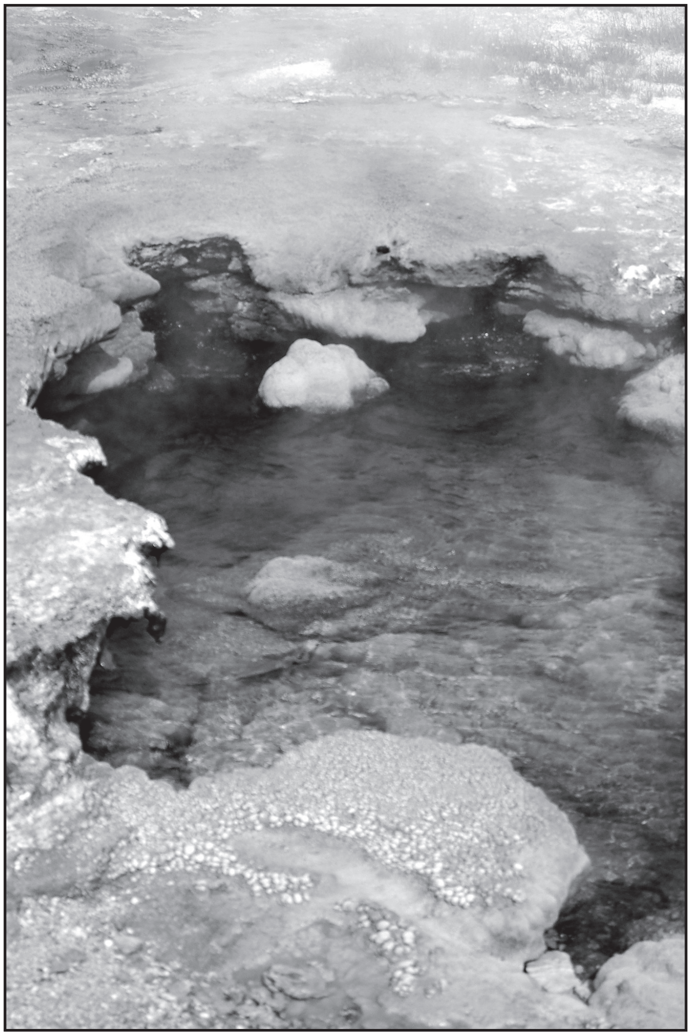


Photo 3: The face in Jagged Spring. Photo by Stephen Michael Gryc.

receded there were no further bursts from Jagged. Jagged's pool dropped proportionally to the size and strength of its eruption with deep drains following the largest eruptions. However, Jagged never drained to the bottom of its crater. The extent of its drain (measured in terms of inches) could be judged by observing the relatively flat but tilted slab of rock in the middle of the crater.

5. Water would gradually rise in Jagged's pool preceding the next eruption or surge. Ragged's crater could fill and drain between eruptions, so a Ragged fill in itself did not indicate the beginning of the next eruption.

When I observed them, Ragged and Jagged were never completely quiet. Ragged occasionally splashed and issued small bursts from its vent between eruptions. The growling sounds from Jagged attracted attention to the geyser when it is not in eruption. I also heard water rhythmically slap the underside of Jagged's western overhanging rim, and there was occasional boiling over Jagged's vents in the interval between eruptions.

Relationship to Cliff Geyser

From my earliest observations of Ragged and Jagged Springs, I suspected that there might be an underground connection between Ragged Spring, Jagged Spring, and Cliff Geyser. When I began my observations in 2008 I tried to note Cliff's activity while logging eruptions of Ragged and Jagged. It didn't appear that the activity of Cliff Geyser bore any relation to the intensity or frequency of the eruption of the other two, so I discontinued the logging of any kind of data from Cliff. It was difficult to keep up with these three frequently eruption geysers and jot down accurate times for all of them. At one point I tried to take a photograph of the three geysers playing together. Triadic eruptions do occur, but I had to wait a long time for one and never got a satisfactory picture of such an event.

Jagged Spring as a Grumpy Old Man

Since the boardwalk through Black Sand Basin begins near Ragged and Jagged Springs, many people see and comment on the geysers. Visitors are often surprised by the violent boiling and large bursts from Jagged (sometimes they even get a little wet), and they are amused by the grumbling sounds that issue from Jagged between eruptions. I found that I was not alone in imagining the likeness of a human face in Jagged's crater with boiling eyes over the main and northern vents and arched eyebrows seen in the rim above. At the appropriate place in the pool there is a nose-shaped rock, and the higher end of the flat rock that sits in the middle of the crater has two small ridges that look like a pair of lips. This old man is grumpy and blustery, to be sure, but he is also wonderfully entertaining.

Eruption Data

On the following pages are logs of my observations of Ragged and Jagged Springs on the days of July 4, 5, and 6 of 2008. The start times were measured from the sharp slapping noise and spray of water that issued from under Jagged's western rim. The end time was recorded when the water level in Ragged's pool receded into its vent and all eruptive activity in Jagged came to an end. Intervals are measured from start to start.

During my observations on July 4, I noticed what could be called false starts. Water levels would rise in both craters and I would hear the slap from the sudden surge in Jagged, but activity in both springs would quickly die down without any true bursting taking place. I decided to log these non-eruptive surges on July 5 and 6. The time of such surges is noted in parentheses with intervals (also in parentheses) measured from the preceding eruption or false start which I designate as a "surge."

Heights measured in feet are noted for Jagged Spring with occasional references to the height of Ragged Spring. Bursts from Ragged Spring typically varied between one and three feet with less frequent bursts as high as seven feet. The height of Jagged's bursts varied widely, and heights were logged as zero when no burst exceeded the rim of its crater. In eruptions with a height of zero there was still bursting from several inches to over a foot above the level of the pool.

Photo 4: A ten-foot burst from Jagged Spring with only weak action from Ragged Spring. Photo by Stephen Michael Gryc.

A perusal of the 173 recorded durations reveals a range of 10 seconds to 109 seconds (1m49s). Three quarters of the durations were between 26 and 46 seconds with the mean duration being between 37 and 38 seconds. The median duration was 37 seconds. The average duration of the larger eruptions (those over ten feet in height) was only slightly longer with a mean duration of about 43 seconds.

Intervals (measured from the start of one eruption to the start of the next) ranged widely from 52 seconds to 484 seconds (8m04s). The mean interval was 166 seconds (2m46s) though 83% of the intervals fell below this mean. The median interval of 149 seconds (2m29s) may be a more meaningful average. The longer intervals generally followed the more massive eruptions, those in which the height was over 10 feet. The single 25-foot eruption for which I have timings was preceded and followed by intervals of 458 seconds (7m38s). The very longest interval of 484 seconds (8m04s) followed a 12-foot eruption.

Occasionally groups of smaller or larger eruptions clustered together. In one half-hour period on July 5, from 08:33 to 09:03 there were no eruptions over 8 feet. During a fifteen-minute period on July 6, between 10:08 and 10:23, there were 4 eruptions of 10 feet or more. In July of 2008 it was easy to see Ragged and Jagged display their full range of activity in one hour with the geysers averaging over 22 eruptions per hour.

Notes

1. Bryan, T. Scott. *The Geysers of Yellowstone,* fourth edition, Boulder, CO: University Press of Colorado, 2008.
2. Bryan, loc. cit.

July 4, 2008

Start Time	**End Time**	**Duration**	**Interval**	**Jagged Height Above Rim In Feet (Comments)**
19:36:55	19:37:30	0:35		0
19:39:10	19:39:45	0:35	2:15	12
19:41:50	19:42:25	0:30	2:40	6
19:44:00	19:44:27	0:27	2:10	0
19:46:00	19:46:29	0:29	2:00	0
19:47:30	19:48:20	0:50	1:30	0
19:49:00	19:49:40	0:40	1:30	3
19:50:47	19:51:25	0:38	1:47	0
19:53:46	19:54:02	0:16	2:59	0
19:55:00	19:55:45	0:45	1:14	15
19:58:40	19:58:50	0:10	3:40	0
19:59:50	20:00:06	0:16	1:10	0
20:00:58	20:01:25	0:27	0:52	12
20:02:26	20:03:08	0:42	1:28	3
20:04:20	20:05:10	0:50	1:54	4
20:06:25	20:07:02	0:37	2:05	0
20:07:50	20:08:22	0:32	1:25	0
20:09:30	20:10:20	0:50	1:40	0
20:11:05	20:11:48	0:43	1:35	20 (observer showered, deep drain)
20:14:30	20:14:52	0:22	3:25	0
20:15:58	20:17:00	1:02	1:28	15
20:18:58	20:19:39	0:41	3:00	0
20:20:24	20:20:55	0:31	1:26	0
20:21:52	20:22:20	0:28	1:28	0
20:23:30	20:24:10	0:40	1:38	1
20:25:40	20:26:27	0:47	2:10	18 (6 bursts over 15 feet; biggest volume and deepest drain observed)
20:29:50	20:30:16	0:26	4:10	0 (very small and weak)
20:31:07	20:31:53	0:46	1:17	0 (very small)
20:32:50	20:33:36	0:46	1:43	0 (explosive 5-foot burst from Ragged)
20:35:32	20:35:58	0:26	2:40	0 (very small)
20:36:26	20:37:12	0:46	0:54	10
20:38:58	20:39:49	0:51	2:32	0
20:40:30	20:41:15	0:45	1:32	0 (weak)
20:42:30	20:42:55	0:25	2:00	0 (weak)
20:43:40	20:44:28	0:48	1:10	5
20:45:50	20:47:39	1:40	2:10	0
20:48:13	20:48:45	0:32	2:23	0

20:51:10	20:51:58	0:48	2:57	20 (5 bursts over 15 feet)
20:55:53	20:56:19	0:26	4:43	0 (very weak)
20:57:15	20:58:10	0:55	1:22	0 (stronger)
20:59:25	21:00:10	0:45	2:10	15 (1 15-foot burst)
21:02:26	21:02:48	0:22	3:01	0 (very weak)
21:03:30	21:04:08	0:38	1:04	inches
21:05:30	21:05:52	0:22	2:00	0 (weak)
21:06:46	21:08:10	1:24	1:16	12 (1 6-foot burst from Ragged; one 12-foot burst from Jagged)

July 5, 2008 (surges now included in parentheses)

Start Time	End Time	Duration	Interval	Jagged Height Above Rim In Feet (Comments)
7:27:08	7:27:50	0:42		6
(7:30:29)			(3:21)	surge
7:31:45	7:32:18	0:33	4:37	5
7:34:25	7:35:22	0:57	2:40	12
7:38:05	7:39:20	1:15	3:40	1
7:40:38	7:41:10	0:32	2:33	0 (weak)
7:42:50	7:43:40	0:50	2:12	0 (weak)
7:44:20	7:44:58	0:38	1:30	9
(7:48:44)			(4:24)	surge
7:49:27	7:49:52	0:25	5:07	inches
7:51:52	7:52:22	0:30	2:25	5
7:53:38	7:54:19	0:41	1:46	12
7:57:24	7:58:01	0:37	3:46	8
(7:59:58)			(2:34)	surge
8:01:15	8:01:54	0:39	1:17	inches
(8:03:16)			(2:01)	surge
8:04:24	8:04:58	0:34	3:09	20 (4 bursts over 15 feet)
8:07:40	8:08:05	0:25	3:16	inches
8:09:42	8:09:58	0:16	2:02	0 (weak)
8:11:41	8:12:15	0:34	1:59	4
8:13:52	8:14:35	0:43	2:11	3
(8:16:30)			(2:38)	surge
8:17:18	8:18:02	0:44	2:26	inches
8:20:02	8:20:39	0:37	2:44	inches
8:24:07	8:24:55	0:48	4:05	12 (3 bursts of 12 feet)
8:27:17	8:27:54	0:37	3:10	inches
8:29:24	8:30:00	0:36	2:07	12 (1 large burst but most bursts around 3 feet)
8:33:19	8:34:07	0:48	3:55	inches
8:36:23	8:37:16	0:53	3:04	6
8:38:52	8:39:38	0:46	2:29	0 (weak)

8:40:35	8:41:17	0:42	1:43	8
(8:43:04)			(2:29)	surge
(8:44:24)			(1:20)	surge
8:45:24	8:46:02	0:38	4:49	2
(8:47:58)			(2:43)	surge
8:49:34	8:50:28	0:54	4:10	2
(8:51:33)			(1:59)	surge
8:52:46	8:53:29	0:43	3:21	inches
8:54:12	8:54:42	0:30	1:26	inches
8:55:42	8:56:26	0:44	1:30	inches
8:57:06	8:57:41	0:35	1:24	inches
8:59:48	9:00:23	0:35	2:42	inches
9:01:28	9:01:55	0:27	1:40	0 (weak)
9:02:59	9:03:31	0:32	1:31	15 (2 15-foot bursts)
9:05:28	9:06:09	0:41	2:29	5
(9:08:36)			(3:08)	surge
9:09:50	9:10:23	0:33	4:22	10 (2 10-foot bursts)
9:12:17	9:12:46	0:29	2:27	inches
(9:14:06)			(1:49)	surge
9:15:18	9:15:53	0:35	3:01	10 (4 bursts over 8 feet)
(9:17:28)			(2:10)	surge
9:20:42	9:21:13	0:31	5:24	0 (weak)
9:22:47	9:23:40	0:53	2:05	4
(9:25:20)			(2:33)	surge
(9:26:41)			(1:21)	surge
9:27:26	9:28:02	0:36	4:39	inches
9:28:56	9:29:28	0:32	1:30	10 (2 10-foot bursts)
(9:31:35)			(2:39)	surge
9:32:45	9:33:25	0:40	3:49	12 (4 large bursts)
(9:35:41)			(2:56)	surge
(9:37:10)			(1:29)	surge
9:38:30	9:38:56	0:26	5:45	0 (very weak)
9:39:57	9:40:44	0:47	1:27	12
9:43:21	9:44:10	0:49	3:24	inches

Break In Data

18:51:30	18:52:05	0:35		1
(18:53:58)			(2:28)	surge
18:55:32	18:56:10	0:38	4:02	0
(18:57:21)			(1:49)	surge
18:59:06	18:59:43	0:37	3:34	0 (weak)
19:00:40	19:01:08	0:28	1:34	4
(19:02:24)			(1:44)	surge
19:03:43	19:04:20	0:37	3:03	8 (only 1 large burst)
(19:05:40)			(1:57)	surge
(19:06:40)			(1:00)	surge
(19:07:50)			(1:10)	surge

(19:09:36)			(1:46)	surge
19:10:59	19:11:34	0:35	7:38	25 (7 bursts over 15 feet)
19:18:37	19:19:05	0:28	7:38	0 (weak)
(19:19:55)			(1:18)	surge
19:21:08	19:21:50	0:42	2:31	0 (weak)
19:24:34	19:25:07	0:33	3:26	0 (weak)
19:25:53	19:26:22	0:29	1:19	0 (weak)
19:27:26	19:27:47	0:21	1:33	0 (weak)
19:28:40	19:29:16	0:36	1:14	1
19:30:12	19:30:48	0:36	1:32	2
19:32:20	19:32:56	0:36	2:08	4
19:35:48	19:36:19	0:31	3:28	0 (weak)
19:37:10	19:37:36	0:26	1:22	1
19:39:45	19:40:27	0:42	2:35	3
19:41:35	19:42:04	0:29	1:50	6 (1 burst of 6 feet)
19:43:44	19:44:28	0:44	2:09	20 (4 bursts of 20 feet)
(19:46:59)			(3:15)	surge
19:49:34	19:50:16	0:42	5:50	inches
19:51:18	19:52:00	0:42	1:44	10
19:54:38	19:55:16	0:38	3:20	4
(19:57:37)			(2:59)	surge
19:58:12	19:58:43	0:31	3:34	6 (lone 6-foot burst, Ragged to 6 feet)
20:00:26	20:00:47	0:21	2:14	1
(20:01:50)			(1:24)	surge
20:03:23	20:03:49	0:26	2:57	3
20:05:07	20:05:30	0:23	1:44	4
20:07:53	20:08:35	0:42	2:46	9
(20:11:26)			(3:33)	surge
20:12:14	20:13:04	0:50	4:21	10
20:15:07	20:15:38	0:31	2:53	inches
(20:17:14)			(2:07)	surge
20:18:20	20:19:01	0:41	3:13	inches
20:20:11	20:20:44	0:33	1:51	2
20:21:36	20:22:13	0:37	1:25	1
20:23:20	20:23:50	0:30	1:44	0 (Jagged weak but 5-foot burst from Ragged)
(20:25:00)			(1:40)	surge
20:26:35	20:27:11	0:36	3:15	20

July 6, 2008

Start Time	End Time	Duration	Interval	Jagged Height Above Rim In Feet (Comments
7:52:40	7:53:12	0:32		6 (blowhole in play)
7:54:31	7:55:12	0:41	1:51	7
(7:56:32)			(2:01)	surge
(7:57:39)			(1:07)	surge
7:59:10	7:59:38	0:28	4:39	0 (weak)
(8:00:39)			(1:29)	surge
8:01:58	8:02:18	0:20	2:48	inches

Break In Data
A rare eruption of Green Spring attracted my attention. I watched the entire eruption of Green Spring and stood by to watch its post-eruption drain and the subsequent refilling of its crater. I noted a 25-foot eruption from Jagged around 9:17.

10:08:12	10:08:51	0:39		15 (6 bursts over 8 feet)
10:11:46	10:12:18	0:32	3:34	12 (2 bursts of 12 feet, blowhole burst)
(10:13:56)			(2:10)	surge
10:15:46	10:16:12	0:26	4:00	inches
10:16:56	10:17:48	0:52	1:10	12 (3 bursts of 12 feet)
(10:19:18)			(2:22)	surge
10:20:38	10:21:01	0:23	3:42	inches
(10:21:43)			(1:05)	surge
10:22:49	10:23:28	0:39	2:11	10 (2 bursts of 10 feet, blowhole burst)
(10:25:40)			(2:51)	surge
10:27:20	10:27:56	0:36	4:31	inches
10:29:00	10:29:34	0:34	1:30	6 (one 6-foot burst)
10:31:00	10:31:36	0:36	2:00	15 (3 bursts over 10 feet, deep drain)
10:34:04	10:34:30	0:26	3:04	6 (2 bursts of 6 feet)
10:36:24	10:36:48	0:24	2:20	1
10:38:25	10:38:51	0:26	2:01	inches
10:40:10	10:40:51	0:41	1:45	5 (blowhole burst)
(10:42:29)			(2:19)	surge
(10:43:15)			(0:46)	surge
(10:43:50)			(0:35)	surge
10:45:54	10:46:40	0:46	5:44	7 (7 feet from Ragged also; blowhole burst)
10:49:40	10:50:19	0:39	3:46	inches
(10:52:30)			(2:50)	surge
10:54:09	10:54:40	0:31	4:29	2

10:57:50	10:58:35	0:45	3:41	20
11:02:21	11:03:00	0:39	4:31	12

Break In Data

15:36:50	15:37:25	0:35		12
(15:42:17)			(5:27)	surge
15:44:54	15:45:18	0:24	8:04	1
15:46:26:	15:46:56	0:30	1:32	12
15:50:43	15:51:36	0:53	4:17	8
(15:53:40)			(2:57)	surge
(15:55:30)			(1:50)	surge
15:56:24	15:57:02	0:38	5:41	inches
15:57:47	15:58:16	0:29	1:23	1
(16:00:22)			(2:35)	surge
16:02:26	16:03:04	0:38	4:39	inches
16:04:08	16:04:52	0:44	1:42	6 (Ragged to 5 feet)
16:06:48	16:07:16	0:28	2:40	1
(16:08:46)			(1:58)	surge
(16:10:19)			(1:33)	surge
16:11:07	16:11:44	0:37	4:19	3
(16:13:00)			(1:53)	surge
16:14:39	16:15:29	0:50	3:32	inches
16:16:16	16:16:50	0:34	1:37	inches
(16:18:03)			(1:47)	surge
16:19:24	16:20:09	0:45	3:08	12
(16:22:32)			(3:08)	surge
16:23:34	16:24:03	0:29	4:10	6 (just one 6-foot burst)
16:25:19	16:26:04	0:45	1:45	0 (very weak)
16:26:33	16:27:19	0:46	1:14	15 (4 bursts over 10 feet)
16:29:40	16:30:21	0:41	3:07	10 (4 bursts over 8 feet)
(16:33:26)			(3:46)	surge
(16:34:53)			(1:27)	surge
16:35:54	16:36:32	0:38	6:14	10 (blowhole burst)
16:38:54	16:39:35	0:41	3:00	1
(16:41:27)			(2:33)	surge
16:42:20	16:42:59	0:39	3:26	12
16:45:09	16:45:54	0:45	2:42	10 (9 bursts, deep drain)
16:49:52	16:50:28	0:36	4:43	1
16:52:24	16:53:16	0:52	2:32	6
16:54:57	16:55:52	0:55	2:33	6 (just one 6-foot burst)
16:58:25	16:59:10	0:45	2:28	1
17:00:43	17:01:24	0:41	2:18	8 (just one 8-foot burst)

Green Spring Erupts: July 6, 2008

Stephen Michael Gryc

Abstract

Green Spring in Black Sand Basin has been known to have infrequent episodes as a geyser. In July of 2008 the author witnessed what may have been the only eruption reported that summer. The characteristics and timing of that single eruption are described.

History

T. Scott Bryan suggests that Green Spring may have been observed in eruption as early as the 1880s when it was noted as “a bulger.” The first true descriptions of geyser activity did not come until 1934 when Green Spring was said to have erupted as high as 20 feet.[1]

George Marler cites August of 1941 as the first eruptions of Green Spring to his knowledge.[2] The eruptions lasted from 4 to 5 minutes and recurred about every 35 minutes. In describing the eruptions, Marler writes, “Large domes of water would rise and then fitfully splash to a height of about 12 feet.”

After 1941 Green Spring saw at least some eruptive activity in 1949, 1950, 1953 and 1957 though most of the time the pool remained quiet and without overflow. Green Spring erupted at the time of the 1959 earthquake but then began a long period of inactivity.[3]

During the past four decades there have been occasional reports of short-lived geyser activity from Green Spring. Rick Hutchinson and Sam Martinez reported activity in 1975 and 1976 respectively. Rocco Paperiello states that at least one large eruption seems to have taken place in May of 1999.[4] According to Bryan, Green Spring, during its rare periods of geyser activity, typically undergoes a series of eruptions, although during 2004-2005 widely spaced eruptions (intervals of hours or days) occurred. Such eruptions were noted earlier in 2008

Photo 1: The eruption of Green Spring was accompanied by much steam, so photographing the event was difficult. The accompanying photograph is the best that I took and shows a burst about four feet high. Photo by Stephen Michael Gryc.

during February and March.[5] As far as I know, the July eruption that I witnessed was the only one reported during the later months of 2008.

Eruption of July 6, 2008

On the morning of July 6, 2008 at about 0745 I arrived in the Black Sand Basin, part of the Upper Geyser Basin, to observe Ragged and Jagged Springs. After witnessing a small concerted eruption of the two geysers, I heard a splash coming from the direction of Green Spring to the southwest of where I was seated on the boardwalk just south of Jagged Spring's crater. *(See map of Black Sand Basin on page 44.)* The splash came at 0803 though I didn't note the timing to the second. A cloud of steam obscured my vision of Green Spring's pool, so I ran down the boardwalk to get a better look at what I supposed was the start of an eruption. I was excited and a bit perplexed because I didn't recall that the usually placid Green Spring was known to have erupted as a geyser.

Green Spring's eruption seemed to occur in slow motion in series of discrete bursts with an interval of 3 to 4 seconds between bursts. There were four to six bursts in each series, each group of bursts being separated by intervals of around 12 to 15 seconds. The doming bursts were from 3 to 8 feet high and were as wide as or a little wider than they were tall. Larger bursts sent waves over the northern edge of Green Spring's sinter-rimmed crater and washed the gravel near the boardwalk. After observing the violent spasms of Jagged Spring, Green Spring's eruption seemed orderly and elegant, and I had time to appreciate the rise and fall of each symmetrical bulge of water.

The eruption lasted eight minutes (0803 to 0811). During the eruption the small spouter to the southeast of Green Spring (Bryan's UNNG-BSB-2) played constantly to a height of a little over one foot.[6] I was surprised to note that I was the only observer in Black Sand Basin at the time of the eruption.

After the final eruptive burst, the level of Green Spring's pool dropped ten to twelve inches over the next twenty-five minutes, reaching low ebb at 0837. With noticeable bubbling over its vent, the pool refilled and reached overflow fifty-eight minutes later at 0935. The bubbling over the vent (located close to the northern edge of the crater and roughly equidistant from the western and eastern edges) continued throughout the day. Even such minor activity as bubbling is exceptional for Green Spring, and it gave hope that more eruptions might be seen. No further eruptions were reported, however.

Notes:

1. Bryan, T. Scott. *The Geysers of Yellowstone*, 4th edition: University Press of Colorado, Boulder, 2008, pp. 157-158.
2. Marler, G. D. *Inventory of Thermal Features of the Firehole River Geyser Basins, and Other Selected Areas of Yellowstone National Park.* National Technical Information Service Publication Number PB-221289, Washington, D.C., 1973, p. 156.
3. Bryan, loc. cit.
4. Paperiello, Rocco. *REPORT: 3 geysers – new activity*, Geyser list e-mail dated May 7, 1999.
5. Bryan, loc. cit.
6. Bryan, ibid.

Photo 2: Geyserite deposits are uncovered at the southeastern end of Green Spring after its pool level drops almost a foot following the eruption. Photo by Stephen Michael Gryc.

Black Diamond Pool Erupts, May 17, 2009

Photos Reprinted with Permission from the National Park Service (photographer unknown), Account Recap by Tara Cross.

This photo sequence shows an eruption of Black Diamond Pool on May 17, 2009, witnessed by Yellowstone Park Geologist Henry Heasler and a group of researchers. Starting in 2006, Black Diamond Pool has had infrequent explosive eruptions lasting less than a minute and throwing water and mud to heights of up to 50 feet. Photos 1 and 2 show two bursts of the May 17 eruption. Photos 3 and 4 show the wave of muddy water that washed into neighboring Black Opal Pool. Photo 5 shows a post-eruptive Black Diamond Pool with a muddy Black Opal Pool in the foreground. Photo 6 shows muddy water flowing into the Firehole River after the eruption. (Photographs provided by the National Park Service; photographer unknown.)

Photo 1.

Photo 2.

Photo 3.

Photo 4.

Photo 5.

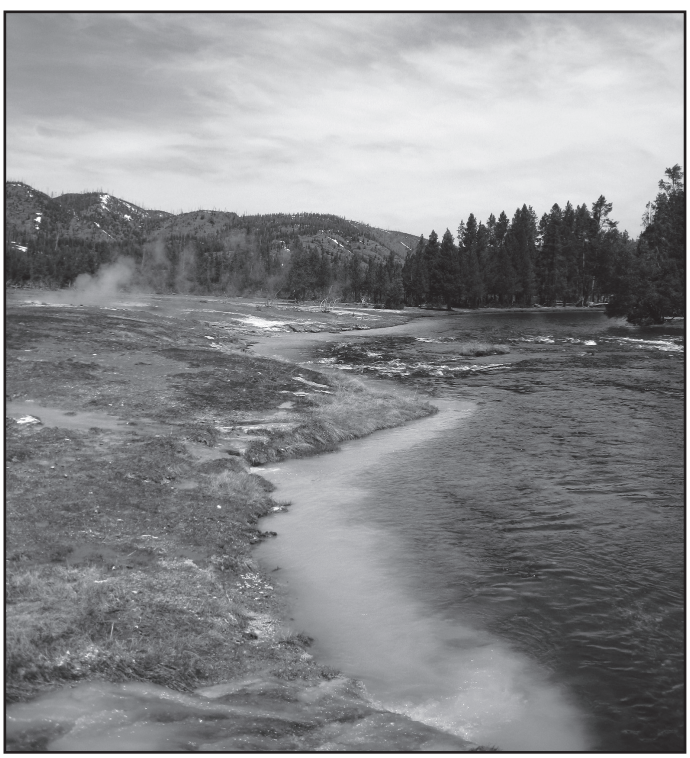


Photo 6.

Additional Information About the 1985 Eruptive Episode of Excelsior Geyser

Lynn Stephens

Abstract

Mary Ann Moss's observations and Mike Keller's personal recollections of the September 1985 activity of Excelsior Geyser were printed in *Transactions X*. This article supplements their personal accounts and observations. Roderick (Rick) A. Hutchinson's report, "Rejuvenation of Excelsior Geyser," prepared on September 18, 1985, is included in this article. The article also includes correspondence between Hutchinson and Daryl Lafferty, a park visitor who first reported the eruptions, and comments from Rocco Paperiello about his observations of some of the 1985 eruptions.[1] Reports of possible activity in 1946 and 1952 are also discussed.

The F. J. Haynes photograph from 1888 showing the force and size of Excelsior Geyser's major eruptions.

HUTCHINSON'S SEPTEMBER 18, 1985, REPORT

Roderick (Rick) A. Hutchinson's report, "Rejuvenation of Excelsior Geyser," prepared on September 18, 1985, is reproduced in this section.

Memorandum
To: All Interested Parties
From: Research Geologist
Subject: Rejuvenation of Excelsior Geyser

> Located in the Midway Geyser Basin, Excelsior Geyser crater has been one of the most powerful and destructive geysers in Yellowstone's recorded history. At irregular and infrequent intervals in 1878 and the 1880s, notably in 1881, 1882, and 1888, it was producing major eruptions. The last confirmed eruptions cited by the late George Marler in his Inventory... (pp. 372-374) and confirmed by Lee Whittlesey in his place names research were in 1890.[2]
>
> An idea of the force of some of the more powerful major eruptions can be had by scanning a number of the witness accounts gathered by Marler (p. 368, 369, 371):
>
>> ...during much of the summer (1881) the eruptions were simply incredible, elevating to heights of 100 to 300 feet...and hurling rocks of from 1 to 100 pounds weight, like those of an exploded mine, over surrounding acres. (Norris, 1881, p. 62)
>>
>> ...On Sunday morning, August 28, 1881, the day General Sheridan left the Upper Basin with his party, this remarkable geyser spouted up a solid body of water from 60 to 75 feet in diameter, to a height closely estimated at 300 feet. This display lasted a number of minutes, and is pronounced by those who witnessed it to be one of the grandest sights ever beheld in Wonderland. (Wylie, 1882, p. 31)

> …Immediately preceding an eruption a violent upheaval occurs, raising the entire volume of water in the crater nearly 50 feet, when instantly one or two and sometimes three, terrific explosions occur, followed closely by the shooting upward of columns of water, and oftentimes masses of the rocky formation, to a height of 200 to 250 feet. Tons of rock in this way have been hurled into the Firehole River, some pieces fully 500 feet from the crater, while specimens may be seen scattered all about the vicinity. At each upheaval sufficient water escapes to raise the Firehole several inches. (Guptil, 1890, p. 50-51.)
>
> …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 clear of all moveable rock, enough of which had been forced back to form a ridge from knee to breast high at a distance from 20 to 50 feet from the ragged edge of the chasm. (Norris, 1881, p. 60)

The best photograph that gives some hint of the force and size of Excelsior's major eruptions was taken by J. Haynes in 1888. (See *Yellowstone, A Century of the Wilderness Idea* by Ann and Myron Sutton, p. 149).[3]

At approximately 1145 or 1150 MDT on Saturday, September 14, 1985, the first confirmed eruptions of Excelsior Geyser in 95 years were observed and reported by a park visitor, Daryl Lafferty of Tempe, Arizona, and a T.W. Services bus driver. The bursts were estimated to be 6 to 15 meters high, of 5 to 10 seconds duration and about 15 seconds apart. Downstream from Excelsior's runoff channels the Firehole River was reported to have turned to a milky yellow color.

Immediately upon receiving these eye-witness accounts, monitoring and photo documentation of the eruptive activity began at 1245 MDT. Listed below is a summary of almost six hours of continuous observation of the geyser on Saturday, September 14, 1985, and a resumption of observations on Sunday, September 15, and Monday, September 16, aided by Jen Hutchinson and Mary Ann Moss.[4]

From the data it is apparent that intervals gradually lengthened and became less regular as Saturday progressed, from around 6 minutes to roughly 10 to 20 minutes at the end of the first observation period. Durations (except for minors) stayed remarkable uniform at approximately 2 minutes, as was recorded for eruptions in 1888 by Captain Harris, then Superintendent of Yellowstone National Park. Maximum height was about 25 meters; average of 39 estimated maximum heights was 4.8 meters on the first day and 6.8 meters from 27 eruptions on the second day. Each eruption consisted of strong surface waves radiating outward to the base of the crater walls and shallow sinter flats to the north and northeast and broad massive surging of boiling muddy water over the central vents. The surging or fountaining was very similar to that which is typical for eruptions of Artemisia, Rainbow Pool, or Sunset Lake, but over a much larger area of usually 10 meters in diameter or greater. Most waves were of an amplitude of 15-25 cm, but wash on the base of the crater walls gave evidence of waves up to 75 cm high spreading across the geyser's pond-like surface. The eruptions reported by the visitors near 1145 on September 14 and the one observed at 1332 on September 15 were of sufficient force to cause waves and/or flood-type discharge to jump across the most westerly runoff channel and briefly inundate about one-third of the width of the asphalt trail leading upslope from the Firehole River footbridge.

The visual changes in and downslope to the river of Excelsior Geyser are dramatic. While in the early morning hours of Saturday, the pool was its usual crystal-clear dark blue color; after rejuvenation the water and all of its effluent was an opaque, turbid, medium-gray color. Only after the magnitude 7.5 Hebgen Lake earthquake of August 17, 1959, has Excelsior ever been observed to be muddy since its eruptions of the 1800's.[5] The copious discharge resulted in rapid clearing in less than a week following the quake (Marler, 1973, p. 377). Extensive wash or removal of cyanobacteria and algae mats, loose weathered sinter, and uprooting or flattening of vegetation is most intense on the steep slopes in and adjacent to the three major runoff channels between the crater and Firehole River. Discharge in quiescent periods between eruptions is estimated to have more than doubled to what has been consistently observed over the last four to six weeks. At their narrowest points the three runoff channels were formerly about 1, 2, and 0.75 meters in width respectively as one moved from east to west. At peak flow during an eruption, the two eastern channels have been observed to expand into one single vigorously erosive sheet of scalding water 28 meters wide; the western channel, in contrast, expands to numerous, more diffuse small gullies or rivulets over a zone of the river bank 31 meters wide. In less than two hours of intermittent eruptive activity, portions of the sinter slopes were scoured clean and eroded to depths of 16 cm below the original soil surface. On Sunday, September 15, during each of the powerful major eruptions a veritable flood of scalding water cascaded over much of the 70-meter-wide slope. In less than a minute, it discharged enough water to turn the Firehole River light gray from bank to bank 400 meters downstream.

One can only speculate as to the cause and extent of Excelsior Geyser's rejuvenation after 95 years. There have been no local seismic swarms in or near the Firehole River Geyser Basins for quite some time, nor any large magnitude regional earthquakes such as the October 28, 1983, magnitude 7.3 Borah Peak, Idaho, event. No visible changes during or before the three days of the geyser's activity have been noted in any of the other numerous thermal features of Midway Geyser basin. Perhaps nearly a century of self-sealing of the near-surface "plumbing system" repaired the geyser's eruption mechanism to the point where circulation and convection was inhibited. Temperatures in the geyser's roots were exceeding the boiling point curve at a critical point, which caused the flashing of steam for an eruption. Almost as abruptly as the rejuvenation of Excelsior Geyser began, it ended only 46 hours later.

What the future holds for what was once the most powerful geyser in the world in the 1880's is unknown and certainly warrants careful monitoring. Eruptive activity may again remain dormant for tens or hundreds of years. Or history may soon repeat itself with the spectacular but dangerous 60-90-meter-high and-wide rock-flinging outbursts of the past. If so, the present boardwalks around the crater could be completely overwhelmed and even destroyed by masses of debris and scalding water, thus obviously endangering park visitors. Even the effects on the ecology of the "blue ribbon" trout stream of the Firehole – if any – are unknown. The only visual difference was intense turbidity at least as far downstream as Ojo Caliente bridge, slightly more than 3 km to the north. Intermittent discharge of massive slugs of hot water from each major eruption followed by significant periods of no discharge were also creating extreme fluctuations in river temperature.

The dynamic nature of Yellowstone's geyser basins continues to renew a sense of awe and excitement for all visitors who are fortunate to experience the beauty and power such as displayed by Excelsior Geyser.

DARYL LAFFERTY'S OBSERVATIONS

On October 1, 1985, Rick Hutchinson wrote the following letter to Daryl Lafferty. Rick included a copy of his Excelsior Report with the letter.

Dear Mr. Lafferty:

I wish to thank you again for taking the time and effort to report your observations on the eruptive activity of Excelsior Geyser. The information you provided was invaluable in answering many of our visitors' questions about the early bursts.

One additional question that I neglected to ask while you were at the Old Faithful Visitor Center: when you first arrived at Midway Geyser Basin, did you notice if the runoff or water in Excelsior Geyser Crater was clear or muddy <u>before</u> the two bursts occurred?

You were a very lucky individual to be able to witness one of nature's rare displays of exceptional power. I hope your future visits to Yellowstone are just as exciting! Again, thanks.

Sincerely,
Roderick A. Hutchinson
Research Geologist

Mr. Lafferty responded on October 9, 1985:

Dear Mr. Hutchinson:

This is in reply to your letter of Oct. 1, 1985, "N3039 (YELL)" regarding the September 14 eruption of Excelsior Geyser.

When I arrived at the Geyser Basin before the eruptions, the runoff from the crater was clear. This was also observed by another (unknown) visitor who I heard remark as we were leaving, "Look how the water has become milky. It was clear when we arrived." The river, which had been clear before, was also now milky out to about one third of its width.

I did not notice the color of the water in the crater; we arrived about ten minutes before the eruption, and the crater was steaming so as to make the interior invisible from the walkway on the north were we passed. We then took a right turn on the walk and went away from the crater, planning to see it on the way back. We were half way around the loop when Excelsior erupted. When we arrived at Excelsior about five minutes later the water in the crater was of course very muddy, and was "boiling" in several areas, though not erupting upward.

I noticed that your memo "Rejuvenation of Excelsior Geyser" stated that the eruptions occurred at "1145 and 1150."[6] It should have read "1145 or 1150." It was not until I returned to my car at 1200 and read the guide book that I realized the significance of what I had seen. At this time I thought back and estimated that the eruptions had occurred 10 or 15 minutes earlier. As you correctly stated, there were two eruptions of 5 to 10 second durations, spaced about 15 seconds apart. These were the only eruptions observed in the half-hour or so we were at the basin that day (from about 1135 to about 1200).

I'm thrilled and astonished at the happenstance that made me a part of this "once-in-a-lifetime" event. As a physicist by training, an engineer by trade, and an amateur scientist by hobby, I can appreciate both the natural engineering responsible, and the beauty that results.

My trip to Yellowstone would have been very memorable anyway, but this made it something extra special that I will never forget. If I can be of any further assistance, please don't hesitate to contact me. I would also appreciate hearing of any further activity connected with Excelsior.

Sincerely,

Daryl Lafferty

ROCCO PAPERIELLO'S OBSERVATIONS OF THE 1985 ERUPTIONS

Rocco Paperiello provided his recollections (of his remembrances) of the 1985 in a personal email communication [2009]:

> As for the 1985 activity Marie [Wolf] and I were there for its last full day of activity and that [reported] 75 feet is by way of Rick Hutchinson. I have photos which will prove that a couple of the later major eruptions hit AT LEAST 125 feet and possibly as high as 150. (There were frequent minor eruptions between the larger ones). The big ones started out as a roiling boil of 10 to 20 feet with a sudden burst aimed toward Grand Prismatic and a second big burst aimed toward the road. (NO third burst like in the 1800 eruptions which hit well over 200 feet. I finally found a descriptive account of the 1888 eruptions and they each had three bursts—one toward Grand prismatic, one toward the road, and the really largest one straight up). Judging the width of the eruption and where the water landed and observing that these two bursts were about as wide as they were high again, I will state that the 75 feet estimation by Rick was VERY low. Of course, he WAS NOT THERE FOR ANY OF THE ERUPTIONS. Only Jennifer who I think left before the really big last eruptions Sunday evening.

REPORTS OF POSSIBLE ACTIVITY IN 1946 AND 1952

T. S. Bryan has used Haynes' photograph of an 1888 eruption of Excelsior in all editions of *The Geysers of Yellowstone*. The initial caption [1979] read "Excelsior Geyser, the only major geyser in the Midway Basin, last erupted during the 1880s when it played as much as 300 feet high." The caption remained the same in the *Revised Edition* [1986] although the text was modified to include information about the 1985 eruptive activity. The *Second Revised Edition* [1991] contained the same caption and information as did the 1986 edition.

The caption in the *Third Edition* [1995] was revised to include (1) note about possible eruption(s) in the 1890s and 1901, and (2) an additional sentence about activity in 1946 and 1985. The new caption read "Excelsior Geyser, the only major geyser in the Midway Basin, last had a full, major eruption in 1890 (maybe 1901), when it played as high as 300 feet. Less activity, some of it up to 75 feet high, was seen in 1946 and 1985." The caption was not changed in 2001 version of the *Third Edition*. The caption in the *Fourth Edition* [2008] also included a reference to activity in 1946.

Bryan does not provide citations or sources for his information that Excelsior was active in 1946. In a personal communication, he indicated that he had been unable to verify his recollection that someone had told him about the 1946 activity, and he would be removing the information about 1946 activity from the next edition of the book.

Whittlesey [1988] generally reviewed geyser activity through 1930 although he also included information about names given to features after that date. He does not mention any eruptive activity of Excelsior in 1946. Whittlesey [1990] included information about the 1985 eruptive activity of Excelsior Geyser in the "Conclusion" section of his article "Monarch of All These Mighty Wonders": Tourists and Yellowstone's Excelsior Geyser, 1881-1890," but does not mention any activity in 1946.

Marler [1973] also does not mention eruptive activity of any type from Excelsior in 1946. Marler did comment: "A seething mass of boiling water in Excelsior's crater is all that has been my privilege to see. The greatest amount of ebullition I have observed was during the 1951 season. At times the water over the main vent would dome up 6 to 8 feet. This promise of eruptive activity never materialized."

Some of Marler's "Annual Reports" of geyser activity were published in *Yellowstone Nature Notes*. Unfortunately, this practice apparently did not start until 1950. Files in the Old Faithful Library contain Marler's annual reports beginning with a 1948 report. None of these reports mention any activity of Excelsior in 1946.

A search of the Yellowstone archives at the Heritage and Research Center by both the author and Rocco Paperiello during the week of March 24-27, 2009, failed to locate a copy of the 1946 annual report. Condon's *Monthly Report of the Naturalist Division* for September 1946 reported that Marler had prepared "A report of the seasonal activities of the geysers…gives the record of 67 geysers which had been observed by him during the present season. This report will be placed in the files." We were unable to locate the file. Edmund B. Rogers' *Superintendent's Monthly Report* for September 1946 also stated a report had been prepared by Marler, but did not include a copy of the report.

In September 1947, Marler prepared a report "Are Yellowstone Geysers Declining in Activity?" He included information about Excelsior's formation and crater, but did not mention any eruptive activity, either minor or major:

> Granting that all of the present geysers have had their origins since the glacial epoch, the Imperial, and particularly the Excelsior, are both very young on this time scale. Both geysers are quite devoid of any cone or mound, both occupy depression-like craters. Like so many of the major geysers, the Excelsior is situated on the flank of a much older feature. The walls of its huge caldron consist of the thin laminated structure of the Grand Prismatic Spring. The symmetrical arrangement of these laminations on all sides of the Excelsior's bowl away from the river, from bottom to rim, furnish certain evidence they were built to their near present height before the Excelsior came into being. Even though a spring or geyser of a different character might have served as an outlet for what is now the Excelsior, this outlet would seem to have been greatly inferior to the present excelsior. It was probably the Excelsior's manner of origin, and certainly the surging waters since it came into being, that are responsible for the excavations it has made into the side of the Grand Prismatic structure. The bowl of the Excelsior is essentially the same size now as when Peale measured it in 1878, preceding its activity of 1881, 1882 and 1888. Thus, prior to these dates, it must have functioned in a manner comparable to its eruptions of the eighties. This observation would lend probability to the speculation that the Excelsior will again undergo another eruptive cycle. Should its foundation be in the rhyolite and not glacial debris, which latter condition seems to be the case, the chances are favorable that when this great source of boiling water, one eighteenth of the entire Park, is finally throttled by mineral accretion within constricted portions of its pipes, a geyser of considerable frequency and magnitude could result.

Marler's "speculation that the Excelsior will again undergo another eruptive cycle" was borne out with Excelsior's activity in October 1985.

Two documents related to questions about activity of Excelsior in 1946 were located during a search of records contained in the Yellowstone archives and library at the Heritage and Research Center in March 2009.

On June 28, 1946, Isabelle F. Story sent a MEMORANDUM for the superintendent, Yellowstone requesting information about a photograph. She wrote:

> Could you give us some information concerning the enclosed photograph? The caption, "Overflow from Excelsior Geyser," indicates that the picture was taken when the Geyser was still active. Yet, since the photograph comes from Western Ways Photo Company, it would seem to be a fairly modern one.
>
> We will appreciate information from you as to whether the picture is a historic one taken at the time Excelsior was active or whether it shows steam and water overflowing from the present pool. We would appreciate return of the photograph with your comments.

On July 3, 1946, Edmund B. Rogers, Yellowstone Superintendent replied:

> "Excelsior Geyser last erupted on July 28, 1890. There is still considerable overflow from the large crater where this geyser was once active and while the attached picture was taken several years ago, the condition is practically the same at the present time."

On October 24, 1952, Mrs. Roy Walter contacted the "National Park Ranger Yellowstone Nat'l. Park" with a question about activity from Excelsior.

> Dear Sir:
>
> We toured the geyser basin the morning of August 23 and saw Excelsior geyser in eruption. I was formerly a Jr. High geography teacher and have much material on the park from teaching days. "Our Country's National Parks" by Melbo states that it hasn't erupted since 1890 when it blew up. I'm very curious to know if the eruption we saw was the first since then, or when it began to erupt again. I would also like to know how often it erupts and for how long.
>
> Thank you very much.
>
> Yours truly,
>
> Mrs. Roy Walter
>
> P.S. Enclosed is a stamped envelope.

On November 4, 1952, Superintendent Edmund B. Rogers responded to Mrs. Walter:

> Dear Mrs. Walter:
>
> We received your letter of October 24 indicating that you visited the geyser basins on august 23 and stating that you saw the Excelsior Geyser in eruption at that time.
>
> After reading your letter we have concluded that at the time of your visit you saw some other geyser in eruption other than Excelsior, and mistook that geyser for Excelsior.
>
> The Excelsior geyser crater is in the Midway geyser basin and is associated with the Grand Prismatic spring, Opal Spring, turquoise Pool and other features in that particular geyser basin. Our records indicate that the last time this geyser was known to erupt with any degree of violence at all was in 1888. Since that date no violent eruption of the Excelsior Geyser has been recorded, either by sight or by physical evidence in the vicinity of the geyser crater. We have been keeping the major geysers under careful observation for years and since our records do not indicate any activity at the Excelsior Geyser this past season we are inclined to believe that the geyser which you saw was another of the large geysers and not the Excelsior.
>
> In the Lower geyser basin there are several large geysers which when they erupt present rather dramatic displays and which you might have mistaken for the Excelsior Geyser. These are the Clepsydra, the Fountain and the morning geysers in the Lower geyser basin near the Fountain Paint pots. An even larger and more spectacular geyser is the Great fountain geyser on the Firehole Lake loop road. Each of these geysers erupted on a number

of occasions this summer, and it is possible that some one of these was in erupton [sic] on August 23 when you were here.

In the Upper Geyser Basin the giant geyser which has been recognized for many years as the largest active geyser in the world played many times this past season, and our records indicate that it was in eruption on August 23. In view of this fact, we suspect that it may have been this geyser which you saw playing. If it were the Giant Geyser there would have been a large crowd of people assembled to witness the eruption of it. The Giant geyser is near the lower end of the Upper Geyser basin and some of the features near it are the Grotto geyser, Oblong geyser and the Daisy geyser group. If can remember the location of the geyser which you saw, I am sure you can identify it from the information which we have accumulated. We appreciate receiving your letter and trust that this will satisfactorily answer your inquiry concerning the Excelsior geyser.

Sincerely yours,
Edmund B. Rogers
Superintendent

It is interesting that Superintendent Rogers indicated the last known eruption "with any degree of violence at all was in 1888." In January 1929 Joseph Joffe, Acting Superintendent, had evaluated Edwin Linton's reports of his observations at Excelsior Geyser and wrote to Mr. Linton: "Thru correspondence with old timers we have come to the conclusion that the last eruption of Excelsior Geyser was in 1890 and not 1888, as was previously believed. We will, in the future, use the date 1890 when referring to the last eruption of this geyser."

On December 7, 1928, J.E. Haynes acknowledged Superintendent Albright's decision to "adopt this [1890 date] in the Government circular and we are doing likewise in our various series of pictures and books that we get out, leaving the date as July 28, 1890, which I think is perfectly justified." The decision was implemented in the 1929 edition of *Haynes Guide*, which modified the caption under the photo of Excelsior on page 48 to read "Ceased to play in 1890" and noted Excelsior's "cessation July 28, 1890, since which time it has remained inactive [p. 49]."

*Haynes Guide*s continued to report the last date of an Excelsior eruption as July 28, 1890, through the 1946 edition. The first edition *Yellowstone Geysers* by Clyde Max Bauer [1937] also reported Excelsior was active in 1890. As previously noted, the Superintendent's office used July 28, 1890, as the last eruption date in a letter dated July 3, 1946, in response to Editor in chief Story's memorandum of June 28.

In 1947 Haynes reverted to reporting 1888 as the date of Excelsior's last activity. The change was made in both the 1947 edition of the *Haynes Guide* and the 1947 edition of *Yellowstone Geysers*. No correspondence or memoranda documenting a decision to make the change was located in the Yellowstone archives or in the Yellowstone museum during the March 2009 search for information about activity of Excelsior Geyser in 1946 or 1947. However, since Superintendent Rogers' office had reverted to using 1888 as the date of Excelsior's last activity, it appears representatives of Yellowstone National Park agreed with the decision.

Mrs. Walter was not satisfied by Rogers' response. She wrote a second letter on November 10, 1952, enclosing a picture of steam clouds, marking one cloud with an "x" to indicate the place from which she thought the eruption had emanated. She wrote:

Dear Mr. Rogers:

I received your reply Saturday to my letter of Oct. 24 in which I inquired about Excelsior Geyser which I thought I saw in eruption between 8 and 9 A.M. on Aug. 23. The information you gave still leaves me puzzled and if I could possibly have been right it would be very interesting to me to find out. Though my husband says "What difference does it make?" I have a different viewpoint because I was formerly a college geog. major, spent 2 summers on college geog. and hist. tours of North America and taught geog. for two years in Junior High.

It may have been Giant Geyser we

saw, though in my memory it seems I read the inscription which said Excelsior. I will describe to you the facts I remember about this geyser. It impressed me a lot. We had stayed at Old Faithful all night. We saw it erupt at about 5:30 AM and then drove north to see some of the Geysers before going on to the Tetons and east to Lusk, Wyoming late Saturday evening. We drove north as far as the junction with the road from the west entrance then turned back. I think we just missed the eruption of the fountain geyser or one of the geysers near it. I can't remember whether we saw the geyser in question before or after we toured the Firehole road. It was on the right side of the road as we drove back south. There was a river or very wide creek between the road and the geyser. We walked across a bridge and up a slope to the geyser which was along the river. Water from the geyser was pouring into the river. The geyser was as described in my book by Melbo who says Excelsior is a big crater. I walked around to the side opposite the river and read the plaque. I remember thinking Excelsior meant higher and I didn't write it down because I thought that after seeing how high that steam went I'd never forget the name. There was a walk right up to the crater with a log across it next to the crater. A man was taking a girl's picture as she leaned on the log. All you could see behind her was white steam. I couldn't see the boiling water because the whole pit was full of steam. There was a board walk laid in a large oval to some other points of interest by this geyser. However, I spent as much time around the erupting geyser and before that in walking to the other end of the parking lot adjacent the geyser to try to get it all in some pictures that the others in our group had completed their walk around the board walk almost before I was ready to start. Since we were in a hurry I didn't walk around so I don't know what else was there.

I don't remember how many people were there, but it doesn't seem to me there were enough to call it a crowd. We hadn't noticed this geyser area as we drove north, or perhaps I should say that since we were in a hurry to reach Lusk that evening we only stopped at places that looked especially interesting or different. However, we spent some time there when we found it erupting as we drove back south.

I am enclosing a picture I took from the other end of the parking lot. My camera bellows sprang a light leak ruining most of my pictures including this one. I am doubtful that it can help in identifying the geyser, but will send it anyway as you can see the end of the bridge by the trees and the people going up to the geyser. The boardwalk extended beyond the right side of the picture. You probably can see enough in this picture to tell if this is Giant Geyser. I think the crater is about where I made the (X) though it could possibly be a little farther left.

I can't remember seeing Giant Geyser unless this is it. Does it have a crater?

You don't need to answer this, though I would like to know if it really was Excelsior that I saw. I thought you may have missed it since it was early in the morning and would like to have this additional information on what I saw to add to your records in case I am right.

Thank you very much.
Yours truly,
Mrs. Roy Walter

Mrs. Roy Walter was correct in describing the feature she believed that she saw erupting as Excelsior rather than Giant. Also, contrary to Rogers' letter, Giant Geyser did not erupt on August 23, 1952.

(According to Marler, 1952 and 1973, Giant erupted on August 21 at 5:45 p.m. and on August 24 at 7:01 a.m.) However, as noted in Superintendent Rogers' reply to Ms. Story in 1946, there is constant overflow from Excelsior Geyser, even when Excelsior is not erupting. As noted by Warren Hamilton, Acting Superintendent, in his reply on November 25, 1952, to Mrs. Walter, large steam clouds from Excelsior Geyser are not an infrequent event.

> Dear Mrs. Walter:
>
> We have received your letter of November 10 accompanied by the picture of the Midway Geyser Basin.
>
> The hydrothermal area which you have photographed showing the people walking up the path is the Midway Geyser basin and Excelsior Geyser crater, Grand Prismatic Spring and other features are found in this basin. The geyser which you viewed and have written about was undoubtedly the Excelsior Geyser crater. This particular geyser has not erupted since 1888 and what you saw on the morning of August 23 was probably the great cloud of steam which arises above this geyser crater.
>
> The geyser when it erupts, if it were to play, would throw water jets into the air some 200 or 300 feet and would shower water in all directions so that people could not stand on the path as you indicated. As indicated in our previous letter to you, occasionally there is a boiling in the center of the cauldron of the Excelsior Geyser, oft times to a height of 12 or more feet. The overflow from this geyser is constant into the Firehole River and that is the runoff which you saw from it on August 23. We are under the impression that you have mistaken the great cloud of steam which forms under ideal atmospheric conditions as an eruption of this geyser.
>
> The area which you visited was the Midway Geyser Basin and the geyser indicated in your picture is the crater of the Excelsior Geyser. Our records and observations which are made daily, summer and winter, have indicated that this geyser has not erupted since 1888.
>
> We trust that this information will clear up the matter for you.
>
> Sincerely yours,
> Warren F. Hamilton
> Acting Superintendent

While Hamilton's statement that observations of Excelsior Geyser "are made daily, summer and winter" may have been a slight exaggeration, Hamilton was correct in noting that a major eruption "would shower water in all directions so that people could not stand on the path as you indicated." Hutchinson [1985] reported that some of the 75 foot high eruptions of Excelsior in 1985 discharged enough water to "cause waves and/or flood-type discharge to jump across the most westerly runoff channel and briefly inundate about one-third of the width of the asphalt trail leading upslope from the Firehole River footbridge." Hutchinson also reported that the 1985 eruptions turned the water in the crater and the Firehole River a gray color. Although Mrs. Walter said she could not see the water in the crater due to the steam, she did not note any discoloration of water in the Firehole River.

Thus, it appears that the inquires in 1946 and 1952 both represented observations of normal overflow from Excelsior rather than eruptive activity.

CONCLUSION

As of early 2009, Excelsior has not had any further exhibitions of eruptive activity similar to those in 1985. The only "activity" reported since 1985 occurred in 1990. "On August 10, [1990], Excelsior was having intermittent, boiling eruptions up to 2 meters high" [*The Geyser Gazer Sput*, vol. 4, no. 4]. However, that activity didn't last very long. "Excelsior's boiling eruptions of mid-August were evidently a very brief episode, persisting only a day or two at most" [*The Geyser Gazer Sput*, vol. 4, no. 5].

A major eruption of Excelsior Geyser would certainly thrill anyone lucky enough to witness it. One can always hope that it rejuvenates during one's visit to the Park. As Mary Ann Moss said, "watch the runoff channel closest in direction to Flood Geyser. If it contains water, then it's time to check Excelsior." Maybe you will be the person lucky enough to witness Excelsior's next eruptive activity.

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ENDNOTES

[1] The Hutchinson report included the same table of observations that was reproduced in the Moss article. Since that table has already been published, it was not included in this article.

[2] Based on his research, Whittlesey [1988] concluded "So great was the interest in Excelsior Geyser that there are many apparently false reports of activity in the literature, notably for 1884, 1886, 1887, and 1893. Eruptions in 1890 are now definite, with 1891 eruptions probably false and 1901 eruptions probable but not definitely proven." Hutchinson's statement that the last eruptions "confirmed by Whittlesey… were in 1890" is consistent with Whittlesey's statement that the 1901 eruptions were "not definitely proven." Marler [1973] indicated that evidence provided by Edwin Linton was "substantial." Marler also refuted comments by Allen and Day's [1935] "That an eruption of Excelsior should actually have been witnessed in the midst of the season and not reported by someone until this late day seems remarkable to say the least."

[3] This Haynes 1888 photograph, used on several penny postcards, has been reproduced in many publications and appears on many internet websites. It is also the photograph used by T.S. Bryan in all editions of *The Geysers of Yellowstone*.

[4] As previously noted, the list of observations was not reproduced here because it was published in the Moss article in *Transactions X*. Observations began at 1251 Saturday, September 14, 1985, and continued through 1016 Monday, September 16, 1985. Observations on September 14, 1985, were apparently made by Jen Hutchinson (Whipple). As noted in her article, Mary Ann Moss did not become aware of the eruptions until the "evening of 14 September, 1985." Mary Ann Moss's observations began at 0800 on September 15 and continued until 2000 when it was "getting too dark to see." Her observations continued on September 16 from 0752 until 1600. As noted in her article, she continued to make occasional observations through October 18, 1985.

[5] Marler [1973] reported: "On the morning following the earthquake, the previously deep-blue colored water of Excelsior had the color of mud. The copious discharge resulted in rapid clearing. By the end of the first week the water was practically back to its original coloration. Murky water was the only apparent effect of the earthquake upon Excelsior. If there were any change in rate of flow it was not obvious. I thought it a bit of a perversity that the earthquake did not stimulate eruptive activity in this geyser, as it did in so many others."

[6] Observations on September 14 began at 1251. It apparently took about an hour for word to get back to R. Hutchinson, for him to talk with Mr. Lafferty, and for him to make arrangements so for someone to go to Midway to begin taking data.

[7] Hutchinson did not include bibliographic entries for citations in his report, so I generated citations for Guptil, Marler [1973], Norris, Sutton, Whittlesey [1988], and Wylie. Hutchinson quoted Guptil, Norris, and Wylie from Marler, so technically these three should be secondary rather than primary citations. The 1973 microfiche copy of Marler's *Inventory* from which my thermofax copy was made did not include Marler's bibliographic citations. The citations for Guptil, Norris, and Wylie were taken from the bibliography included in the reproduction of the *Inventory* that I prepared for GOSA's use. That bibliography was developed from a version provided by Rocco Paperiello from his copy of the *Inventory*, supplemented by additional notations on publisher and place of publication. Citations for Sutton and Whittlesey [*Wonderland Nomenclature*] were written based on copies of the books that are in my personal library.

Wild Phase Activity by Great Fountain Geyser

T. Scott Bryan

Abstract

On relatively infrequent occasions, Great Fountain Geyser undergoes what is referred to as “wild phase” activity, in which it erupts with frequent bursts for total durations longer than two days. The wild phase that started on June 4, 2008, was perhaps the most closely observed of these events from start-to-finish and is described along with an historical perspective.

Introduction

Great Fountain Geyser is regarded as the largest geyser in the Lower Geyser Basin of Yellowstone National Park. Great Fountain is normally a model of consistency. It is the only geyser in the Lower Basin whose eruptions are predicted for the public. Being served by a parking area along Firehole Lake Drive and a short boardwalk spur with benches, it is enjoyed by many people every year.

Normal Activity

Great Fountain’s usual activity consists of eruptions that recur about two times per day. From January 1 to September 9, 2008, excepting the wild phase action in June, the mean electronically-recorded interval between eruptions was 12h 12m; most eruptions began within two hours of the average.

Following an eruption, Great Fountain gradually fills its crater with boiling water. Because the boiling can be impressively vigorous, inexperienced observers often see this and wait for an eruption long before an eruption is actually due to take place. However, this takes place with a water level well below overflow, and overflow must occur prior to an eruption.

In recent years including 2008, overflow began between 75 and 105 minutes prior to the start of an eruption. During overflow, boiling in Great Fountain is intermittent but grows gradually stronger until a strong surge causes the boiling to reach over three feet high. This is referred to as the “one-meter boil”[1] and is regarded as the start of an eruption, even though it can be followed by a “pause” of comparative quiet that lasts several minutes before the start of powerful bursting action characteristic of the full eruption.

Great Fountain’s eruption consists of a series of bursts, usually four or five but sometimes only three or rarely as many as seven.[2] Each burst within the series has a duration of several minutes and is separated from subsequent bursts by another several minutes of quiet. The total duration of an eruption, all bursts considered, ranges between 45 and 75 minutes.

During the first burst, the erupted water usually reaches between 80 and 100 feet high; rare, but anticipated by all observers are “superbursts” that can reach over 200 feet tall. The remaining bursts of Great Fountain’s eruptions are usually smaller than the first burst, and the end of an eruption is considered to be the time when concluding splashes fail to discharge water onto the geyserite platform that surrounds the crater.

Wild Phase Activity

Wild phase activity in Great Fountain Geyser has been recorded only 15 times from 1967 to 2009 (Table 1, next page). That there are no known reports of wild phase action prior to the 1959 earthquake might be due to a lack of observers that might have documented such events. On the other hand, it is known that the earthquake caused significant changes in Great Fountain’s activity, so the wild phase activity since then could be a result of some physical change in the geyser’s plumbing system at that time.

During a wild phase, Great Fountain’s eruptive action resembles that of the normal activity. Bursts recur every 6 to 15 minutes and last as long as 7

[1] This usage of the metric system measurement, “meter,” was started by former Yellowstone Park Geologist Rick Hutchinson. It stands as the only metric term in common usage among the unofficial geyser gazing community.

[2] The term “burst” has two meanings in reference to geysers. In some cases, such as at Great Fountain Geyser, these two meanings overlap. Here, Great Fountain undergoes a series of bursts, each of which lasts several minutes, *and* each of which itself consists of multiple bursts of water that last just a few seconds apiece.

Table 1
Great Fountain Geyser
Known Record of Wild Phase Activity

Year of Record	Start of Wild Phase	Leading Interval(s)	Wild Phase Duration	Following Interval
visual				
1967	August 21	unknown	2 days	unknown
1970	August 8	unknown	2 days	4 days
1986	September 24	unknown	2.1 days	3.4 days
1994	June 13	6 hours	<3 days	7 days
1996	October 19	6½ hours	>1 day	3-4 days
1997	January 23	unknown	unknown	3-4 days
electronic				
1999	September 25	3h 53m	2 days	4d 06½h
2000	February 12	3h 47m	unknown	5d 15½h
2000	September 21	4h 18m	unknown	5d 04h
2001	November 22	2h 25m and 2h 40m	unknown	6d 06h
2002	December 16	4h 15m and 6h 05m	>1 day	6d 06¾h
2003	October 29	5h 03m	< or =2 days	5d 14h
2006	October 14	unknown	2 days	5 days
2008	June 4	5h 51m	2¼ days	5d 18¾h
2009	October 27	unknown	~2 days	unknown

minutes, and they spray water several tens of feet high. However, instead of the eruption having a duration of about one hour, the action continues unabated for two days or longer.

Once ended, there is a recovery time of about two days before the system refills and resumes overflow, with intermittent overflow then taking place for an additional two days or more before eruptive activity returns to normal.

Once Great Fountain has had its first eruption after a wild phase, it returns to its normal, predictable activity (within days during 2008 but only after several weeks in other cases).

Cause of Wild Phase Activity

As to the cause of Great Fountain's wild phase activity, the answer is quite simple: it is not known.

It has been hypothesized that the trigger for a wild phase is somehow related to the level and/or temperature of groundwater in the surrounding area. In support of this is the fact that 13 of the 15 known wild phase episodes occurred during those parts of the year (August to February) when groundwater levels are expected to be at their lowest. However, the other two wild phase episodes (1994 and 2008) took place in June and, in 2008 at least, that was when the melting of a heavy snowpack was ending and groundwater levels were almost certainly at their highest.

Wild Phase Activity Sequence

Whatever the cause of Great Fountain's wild phases might be, all wild phase episodes appear to follow the same pattern of activity, some of which is summarized on Table 1. This activity sequence is:

1) Great Fountain's "last normal" eruption occurs after a normal interval and gives no indication of the pending wild phase;

2) This eruption may, however, be of an extraordinarily long duration (possibly greater than 4 hours in 2008);

3) The interval from the start of this "last normal" eruption to the start of the wild phase activity is very short, those being recorded all falling within the range of 2½ to 6½ hours;

4) Once started, the wild phase episode continues unabated for 2 to 3 days;

5) Following the end of the wild phase bursting, Great Fountain will not refill to overflow until after another 2 days have passed;

6) Episodic overflow then takes place for still another 2 to 3 days before the first follow-up "normal" eruption is finally triggered;

7) Once this eruption has taken place, Great Fountain resumes its series of normal eruptions. However, it can take anywhere from a few days to several weeks for the pre-eruption overflows to return to the normal 75-105 minute range (which is necessary for continuing eruptions to be accurately predicted).

Table 2 presents a comparison between the wild phase episodes of 1994 and 2008, the only two of these events to have been closely monitored from start to finish.

The Wild Phase of June 2008 – A Narrative

Table 2
Great Fountain Geyser
Comparison of Wild Phase Episodes
June 1994 versus June 2008

Event	June 1994	June 2008
Length of last "normal" interval before wild phase	unknown	11h 12m
Length of short interval immediately before wild phase	~6 hours	5h 51m
Duration of wild phase activity	~2½ days	~2¼ days
Interval, end of wild phase to first post-wild phase overflow	~2 days	1d 21h
Interval, start of wild phase to first post-wild phase eruption	~7 days	5d 18½h
First post recovery interval between "normal" eruptions	unknown	13h 52m

I feel myself fortunate to have experienced much of the Great Fountain wild phase that began on June 4, 2008. My observations and personal recollections follow. Most of the recorded times are based on visual observations and are indicated by the lowercase letter 'v'. These are supported in part by the electronic data log presented as Table 3 (next page). These electronic times were produced by the monitor maintained by Ralph Taylor for the Yellowstone Center for Resources and in the following are noted by a lowercase letter 'e'.

June 3, 2008

- First, it should be noted that Great Fountain may have "tried" to enter a wild phase on June 3, when it was seen in overflow by me at 0605v, an extraordinarily short 2½ hours after the previous eruption (0327e) and fully 10½ hours before the subsequent eruption (1642v).

June 4, 2008

- The "last normal" eruption began at 0354e after an interval of 11h 12m.
- Upon arriving at Great Fountain, I found the geyser to be in eruption at 0612v. At the time, of course, I was not aware of the electronically-recorded start time that was more than two hours earlier.
- At about 0830, other observers arriving at Old Faithful stated that they had just watched Great Fountain in eruption at 0715v, and that the activity continued intermittently until they judged a last burst/end of eruption at 0759v. This immediately "raised a red flag" as these times implied an eruption duration longer than two hours.[3]
- Upon hearing the above report, I returned to Great Fountain. At about 0915v I found it to be nearly full of vigorously boiling water but with a water level a few inches below overflow.
- At 0925v, with virtually no warning, there was a "meter boil" in Great Fountain's pool. This was actually more like a "2½-meter boil" that was sustained for at least 30 seconds before dropping back

[3] As shown on Table 1, in both 2001 and 2002 the wild phase activity was preceded by two, not just one, short intervals; however, the electronic record shows this to have not been the case in 2008.

Table 3
Great Fountain Geyser
Eruption Intervals including Wild Phase, 2008
(all times as electronically recorded)

Date	Time	Interval	Notes
5/24	0845	10h 36m	
	2103	12h 18m	
5/25	0957	12h 54m	
5/26	0033	14h 36m	
	1230	11h 57m	
5/27	0148	13h 18m	
	1215	10h 27m	
5/28	0121	13h 06m	
	1309	11h 48m	
	2336	10h 27m	
5/29	1151	12h 15m	
5/30	0339	15h 48m	
	1645	13h 06m	
5/31	0339	10h 54m	
	1445	11h 06m	
6/01	0233	11h 48m	
	1533	13h 00m	
6/02	0324	11h 51m	
	1521	11h 57m	
6/03	0327	12h 06m	
	[0605]		"False overflow" observed in progress, yet no eruption until >10½ hours later
	1642	13h 15m	Repeated rise to near overflow seen all day
6/04	0354	11h 12m	Start of pre-wild phase eruption; eruption still in progress at 0759 visual time
	~0915		Great Fountain crater full of gently boiling water with no overflow
	0945	5h 51m	Start of wild phase activity (0934 visual time)
6/06	~1450	-----	End wild phase (1450 electronic); wild phase duration approximately 2d 05h
6/08	1158	-----	Start of erratic overflow periods (1158 visual); duration to first eruption 1d 16h 26m
6/10	0424	5d 18h 39m	First post-wild phase eruption
	1817	13h 53m	Eruption followed three extended overflows
6/11	0613	11h 56m	Eruption seemed "normal" (1 meter boil, P=0)
	2222	16h 09m	
6/12	1504	16h 42m	
6/13	0527	14h 23m	
	1813	12h 46m	

Figure 1: A wild phase burst that took place at 1253v on June 6, 2008.

to a gently boiling pool. Except for its exceptional vigor, this had all the earmarks of a normal eruption start.

• At 0934 (visual; 0945 electronic, a time delay due to the amount of time necessary for the erupted water to flow from the geyser to the electronic detector) the wild phase began – with a superburst![4] The water reached at least 180 feet high (visual estimate) and was sharply angled to the northeast so as to reach into the trees on the far side of the paved road.

• The visual times and estimated eruption heights of subsequent bursts were recorded as: 0949 (50 feet), 0959 (50), 1007 (in eruption from the main road as I returned toward Old Faithful to report the observations); then 1041 (30), 1056 (50), 1111 (100), 1125 (80), 1139 (blue bubble but only 40 feet), 1153 (60), 1207 (100+, to paved road), 1221 (70), 1235 (40), 1250 (50).

June 5, 2008

• The wild phase was continuing when Great Fountain was visually observed in eruption at 0609v, 0622v (50), and 0636v (30); and later in the day at 1256v, 1311v, 1325v (50).

June 6, 2008

• The wild phase was still in progress when seen at 0616v in eruption and 0631v (20), at which time I noted the durations as growing shorter.

• Later, at 1026v, the bursting was weak and confined within the crater. At this point, I and others (see acknowledgement) concluded that the wild phase had ended. However, this proved to only be a hiatus, and stronger bursting was soon renewed. The photo (Figure 1) shows a burst that took place at 1253v.

• Although I was not present, other observers determined that the wild phase actually ended shortly before 1450e, on June 6, 2008.

June 7, 2008

• Great Fountain was in "semi-steam phase" at 0620v, billowing steam with the sound of violent boiling and splashing coming from "way deep down in" (as I wrote in my notebook).

• Then, at 1120, I wrote: "Gt Ftn empty, quiet."

June 8, 2008

• At 0620v, 0857v, and 1000v Great Fountain was quiet with no water visible in the crater, but quite abruptly at 1018v water was quietly standing about one foot below overflow with no boiling.

• The water level then fluctuated until the first post-wild phase overflow was observed at 1158v. Frequent overflow episodes then took place throughout the remainder of June 8 and June 9, as seen and recorded by various observers.

[4] It is not known if this is a typical event at the beginning of a wild phase.

June 9, 2008

• Overflow was observed to start at 0626v and at 0926v, and later was reported by other observers as occurring frequently throughout the afternoon.

June 10, 2008

• The first post-wild phase eruption by Great Fountain was electronically recorded at 0427e.

• I observed the crater to be empty at 0900v and with quietly standing water one foot below overflow at 1133v.

• Thereafter, observer Jerald Alderman visually recorded overflow as occurring at 1243 (duration not recorded), 1323 (duration 93 minutes), 1538 (no overflow but vigorous boiling for 20 minutes), 1613 (duration 28 minutes), 1715 (duration 61 minutes ending with an eruption).

• Eruption at 1816v (1817e). This interval between eruptions was 13h 53m.

End of detailed observations.

Conclusion

"Wild phase" activity by Great Fountain Geyser is uncommon, having been recorded just 15 times.[5] While the cause of these episodes is unknown, each appears to follow a set sequence of events. Perhaps the one observational indication of an impending wild phase is a rapid refilling of Great Fountain's crater following a normal eruption, this leading to an abnormally short interval between eruptions.

[5] Only 3 of the 15 observed wild phase episodes took place during the November-March winter season in Yellowstone (see Table 1). However, it is entirely possible that additional, unobserved wintertime wild phases occurred in those years prior to electronic monitoring.

Acknowledgements

Individuals to be thanked are many, but especially include Ralph Taylor for providing the electronic data; both Ralph Taylor and Lynn Stephens for searching the Old Faithful Visitor Center logbooks and early electronic records, and providing this information online to the geysers listserv; Bill Warnock for providing information about the wild phase of 2003; Jerald Alderman for his written report on the June 10 activity; and Jim Scheirer, Jere Bush, Bill Warnock, Barbara Lasseter, Dee Dykes, Vicki Whitledge and Alan Moose, Bill and Carol Beverly, and no doubt others for their verbal reports to me of their visual observations.

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Summary and Analysis of a National Park Service Geyser Activity Report for Summer 1919

Vicki Whitledge

Abstract

Geyser reports from 1900 to 1920 are scarce. (Keller 2002, 27) The advent of Google Books (books.google.com) has made the search for older publications about geysers easier than in the past. A document from 1919 titled "Reports of the Department of the Interior" by Franklin K. Lane was recently found on Google Books. This report is unique for the period in that it contains a table of geyser eruption times from the summer of 1919 and limited descriptions of geyser activity. This article presents the material relating to geysers in the Lane report along with analysis and commentary by the author based on comparisons current observations of geyser activity and information from other historical records.

Introduction:

A document from 1919 titled "Reports of the Department of the Interior" was recently found on Google Books. This report generated by Secretary of the Interior, Franklin K. Lane, contains information about geyser activity in Yellowstone in the summer of 1919, including eruption data from June 20 to September 10. Information about geyser activity during the 1910s is difficult to come by, partially due to the change in administration of the park from the U.S. Army to the newly created National Park Service in 1916 (Keller 2002, 27). This report was not known at the time of Whittlesey's writing of *Wonderland Nomenclature* (unabridged), a very thorough reference on historical geyser activity, nor was it included in other important resources such as Marler (1973), Koenig (1998), and Keller (2002).

Report:

The report contains descriptions of activity and a table of eruption dates and times for Giant, Giantess, Oblong, Grand, Sawmill, Beehive and Castle. The original table from the Lane report is reproduced as Table 1 (see next page).

In regard to the Upper Geyser Basin, Lane writes:

> During the tourist season, except at night when the formations were obscured, a careful record was kept by the ranger force stationed at Upper Geyser Basin of the activities of the principal geysers in that basin. The results of this record indicate a reasonable regularity in playing and but few changes of importance from previous years. This record shows that Grand Geyser, one of the most powerful and beautiful geysers in the basin, played 50 times during the period from June 20 to September 4, inclusive. Old Faithful, the world's most famous geyser, and the object of greatest interest to all Yellowstone Park visitors, played with its usual regularity. The interval between its eruptions this year averaged 75 minutes.
>
> The Daisy plays every 85 to 90 minutes; the Grotto every 3 to 4 hours; and the Riverside every 6 to 7 hours. The Grand goes at times two or three days without playing, but as a rule it plays about three times every 24 hours. These observations were taken by Rangers Watkins and Harrison and by Asst. Chief Ranger Charles J. Smith.

There are three things to note with this passage. First, there were only three individuals credited with taking the observational data, all of whom most certainly had other duties that took precedence over recording geyser activity. Second, it is explicitly noted that activity during the night was not routinely recorded. From these two observations, it is clear that the record of eruptions is incom-

1088 REPORT OF DIRECTOR OF NATIONAL PARK SERVICE.

The geyser record mentioned above follows:

Date.	Giant.	Giantess.	Oblong.	Grand.	Sawmill.	Beehive.	Castle.
June 20		12.00 m.					
21							2.30 p. m.
23				9.00 a. m.			
25				8.25 p. m.	9.00 a. m.		3.10 p. m.
27							4.00 p. m.
30		7.30 a. m.					
July 1	3.15 p. m.						
2						9.00 a. m.	
3				9.45 a. m.			
4			8.50 a. m.	9.00 a. m.			
5		10.00 a. m.		10.40 a. m.			
6		8.00 a. m.		9.00 a. m.			
8				10.30 a. m.			
9				9.25 a. m.			
10				4.15 p. m.			12.15 p. m.
11		6.45 a. m.					
12			9.45 a. m.	9.50 p. m.			
13	2.25 p. m.			9.40 a. m.		8.40 p. m.	
13				8.55 p. m.			
14				7.15 a. m.			8.25 a. m.
14				7.40 p. m.			
15				7.30 a. m.			
15				10.30 p. m.			
16				7.30 a. m.			
17				6.15 p. m.			10.00 a. m.
18				7.30 a. m.			
18				7.30 p. m.			
19				3.20 p. m.			4.15 p. m.
21		2.30 p. m.		12.45 p. m.			
22				5.25 p. m.			
23				3.15 p. m.			
24				1.80 p. m.		2.00 a. m.	
25				8.25 a. m.			
26				2.00 p.m.			1.30 p. m.
27			11.30 a. m.				
28		10.30 a. m.		11.15 a. m.			
29	3.00 p. m.			8.30 a. m.			
31				8.00 a. m.			
Aug. 1							
1							2.00 p. m.
3	9.40 a. m.	8.00 a. m.		7.45 a. m.			
4				5.15 p. m.			5.10 p. m.
7				10.00 a. m.			
7				7.30 p. m.			
8							12.50 p. m.
9				11.45 a. m.			
10		3.00 p. m.					
11				4.00 p. m.			
12				1.10 p. m.			
13		9.15 a. m.		9.30 a. m.			3.55 p. m.
13				7.00 p. m.			
14	7.30 a. m.			7.00 a. m.			8.45 p. m.
14				3.30 p. m.			
16				9.00 a. m.			6.15 p. m.
16				6.50 p. m.			
17				6.30 a. m.			
18		9.40 a. m.	9.15 a. m.	9.00 a. m.			
19							5.00 p. m.
20				3.00 p. m.			3.15 p. m.
22		9.15 p. m.					
24	9.00 p. m.			9.45 p. m.		8.45 p. m.	7.00 p. m.
24						12.15 p. m.	
25				7.10 p. m.			
26			9.20 a. m.				
27	1.45 p. m.	6.00 a. m.					12.15 p. m.
28				12.50 p. m.			
Sept. 2	2.00 p. m.						
4				11.00 p. m.			
10							4.00 p. m.

Table 1: Eruption data as it appeared in the Lane Table.

Giant Geyser		Giantess Geyser		Castle Geyser	
Date and Time	**Interval**	**Date and Time**	**Interval**	**Date and Time**	**Interval**
01/Jul/19 15:15:00		20/Jun/19 00:00:00		21/Jun/19 14:30:00	
13/Jul/19 14:25:00	11:23:10	30/Jun/19 07:30:00	10:07:30	25/Jun/19 15:10:00	04:00:40
29/Jul/19 15:00:00	16:00:35	05/Jul/19 10:00:00	05:02:30	27/Jun/19 16:00:00	02:00:50
03/Aug/19 09:40:00	04:18:40	06/Jul/19 08:00:00	00:22:00	10/Jul/19 12:15:00	12:20:15
14/Aug/19 07:30:00	10:21:50	11/Jul/19 06:45:00	04:22:45	14/Jul/19 08:25:00	03:20:10
24/Aug/19 21:00:00	10:13:30	21/Jul/19 14:30:00	10:07:45	17/Jul/19 10:00:00	03:01:35
27/Aug/19 13:45:00	02:16:45	28/Jul/19 10:30:00	06:20:00	19/Jul/19 16:15:00	02:06:15
02/Sep/19 14:00:00	06:00:15	03/Aug/19 08:00:00	05:21:30	26/Jul/19 13:30:00	06:21:15
		10/Aug/19 15:00:00	07:07:00	01/Aug/19 14:00:00	06:00:30
Mean	**08:23:49**	13/Aug/19 09:15:00	02:18:15	04/Aug/19 17:10:00	03:03:10
Median	**10:13:30**	18/Aug/19 09:40:00	05:00:25	08/Aug/19 12:50:00	03:19:40
		22/Aug/19 21:15:00	04:11:35	13/Aug/19 15:55:00	05:03:05
		27/Aug/19 06:00:00	04:80:45	14/Aug/19 20:45:00	01:04:50
				16/Aug/19 18:15:00	01:21:30
		Mean	**05:16:30**	19/Aug/19 17:00:00	02:22:45
		Median	**05:01:27**	20/Aug/19 15:15:00	00:22:15
				24/Aug/19 19:00:00	04:03:45
				27/Aug/19 12:15:00	02:17:15
				10/Sep/19 16:00:00	14:03:45
				Mean	**04:09:58**
				Median	**03:11:25**

Table 2: Recorded geyser eruption times, 1919. Intervals are in days: hours: minutes.

plete. The third item to note is that the behavior that was observed was felt to be the same as in previous years with only a "few changes of importance." Presumably, such changes of importance would have been mentioned explicitly; otherwise, the behavior should be considered typical of the few years prior to 1919 (at least in the opinions of the observers).

Information for Daisy, Grotto and Riverside for 1919 are not listed in *Wonderland Nomenclature,* but the interval times stated in this report are consistent with the historical behavior that is discussed before and after 1919 (Whittlesey 1988). Grand Geyser will be discussed later when the data in the Lane report is analyzed.

The next comment in the Lane report relates to overall activity, not just the Upper Geyser Basin:

> Consultation with men who have lived in the park for many years developed the general opinion that the geysers and hot springs were less active than usual on account of the extremely dry season due to lack of winter snows, an early spring, and lack of rains during the summer. The paint pots of the park, especially the Mammoth Paint Pots in Lower Geyser Basin, appear to be less active, due undoubtedly to lack of subsurface water. [Author's comment: Mammoth Paint Pots is an old name for the Fountain Paint Pots (Whittlesey 1988, 239).]

This second comment by Lane indicates that, while the observations for 1919 are generally the same as previous seasons, there was perhaps for some features less activity compared with previous years. This comment is worth keeping in mind when the data contained in the Lane report is analyzed, especially for Giant geyser.

The table in the Lane report contains 8 eruptions for Giant, 13 for Giantess, 5 for Oblong, 50 for Grand, 1 for Sawmill, 5 for Beehive, and 19 for Castle (see Table 1). Times were rounded to five minute increments and were stated using a.m. and p.m. designations. Table 2 contains the eruption times for Giant, Giantess, and Castle using 24-hour time, the interval (in days:hours:minutes) between recorded eruptions, and the mean and median intervals.

Giant Geyser: There were 8 eruptions listed in the Lane report for 1919. However, Whittlesey cited seven eruptions "according to George Marler." (Whittlesey 1988, 263). Keller listed the date and time of seven eruptions during this period (Keller 2002, 28). The eruption in the Lane report that is not listed in Keller is the July 29, 3 p.m. eruption. The three shortest intervals for Giant Geyser (Table 2) are striking. The shortest interval between known eruptions is 2 days, 16 hours, and 45 minutes, the second shortest is 4 days, 18 hours, and 40 minutes, and the third is 6 days and 15 minutes. These intervals indicate frequent activity, and in fact, the 1919 interval of 2 days, 16 hours, 45 minutes was shorter than any known interval from 1956 through 2008 (Bryan 2006, 2007a, 2007b; Cross 2008, Dunn 2006, Marler 1973). The only interval from 1956 through 2008 that was similar was a 2 day, 17 hour, 10 minute interval that occurred on April 16, 2006 (Cross 2008, Dunn 2006). The 1919 interval of 4 days, 18 hours, 40 minutes is also remarkable. Intervals this short (post-1955) have been observed only during the 1997-1998 and 2006-2007 periods of activity (Bryan 2006, 2007a, 2007b; Cross 2008, Dunn 2006, Marler 1973). There were no specific comments in the text of the report on Giant's activity. From this and the general commentary in the report, it is reasonable to conclude that such frequent activity was "normal" for Giant during the previous year or two.

It seems likely that some eruptions occurred but were not witnessed or recorded as the earliest eruption recorded was at 7:30 a.m. and the latest at 9:00 p.m. The average interval of the known eruptions is about 9 days, a relatively good level of activity if the recorded eruptions were the only eruptions. The actual average may have been shorter, however, if some of the longer intervals were double or triple intervals. It is possible that the late 1910s saw activity comparable to the late 1990s and the more recent period of activity in the late 2000s.

Giantess Geyser: There were 13 eruptions listed in the Lane report for 1919. As shown in Table 2, the average interval between reported eruptions was between 5 and 6 days and the median was approximately 5 days. Whittlesey lists no data for Giantess but reports that an eruption was observed in 1919 (Whittlesey 1988, 280). Very little information was available on Giantess during this time, but the data for 1919 is consistent with the reported intervals for the early 1910s. The intervals then lengthened in the 1920s (Whittlesey 1988, 280-281). Koenig listed eight known eruptions for Giantess in 1919 (Koenig 1998, 18). With the exception of two eruptions from the Lane report that are discussed below, Koenig listed the eruptions from June 21 through August 3. He did not list the eruptions from August 10 to August 27. In addition, Koenig listed September 16, but with no eruption time recorded.

The first entry in Table 1 is for Giantess: June 20 12:00 m. Koenig listed eruptions in 24-hour time and listed the June 20 eruption as June 20, 12:00 (Koenig 1998, 18). I interpreted the entry as June 20 at midnight rather than noon and, furthermore, the midnight between June 19 and June 20. If this time actually referred to the midnight between June 20 and June 21, then the interval should be a day shorter than stated in Table 2. Another oddity in the data for Giantess is the listing of two separate eruptions of Giantess only 22 hours apart on July 5 and 6. It is likely that the "second" eruption was a continuation of the first. Koenig did not list the July 6 eruption (Koenig 1998, 18).

Castle Geyser: For Castle Geyser, Whittlesey lists activity very similar to that listed in the Lane report: "Park superintendent Horace Albright logged 2 total eruptions of Castle Geyser in June, 5 in July, 10 in August, and one in September, and their times of eruption. The period observed was apparently continuous from June 21 to September 10" (Whittlesey 1988, 102). This is consistent with the data in the Lane report with the exception that the 1919 report lists three eruptions in June (see Table 1). Also included in *Wonderland Nomenclature* for 1919 was a statement that Castle plays every 26 or 27 hours (Whittlesey 1988, 102). Although the shortest interval between recorded eruptions in 1919 was 22 hours and 15 minutes, it is clear that many eruptions occurred but were not recorded for Castle since the mean interval between recorded erup-

Grand Geyser		
Date and Time	**Interval**	**dd:hh:mm**
23/Jun/19 09:00:00		
25/Jun/19 20:25:00	59:25:00	02:11:25
03/Jul/19 09:45:00	181:20:00	07:13:20
04/Jul/19 09:00:00	23:15:00	00:23:15
05/Jul/19 10:40:00	25:40:00	01:01:40
06/Jul/19 09:00:00	22:20:00	00:22:20
08/Jul/19 10:30:00	49:30:00	02:01:30
09/Jul/19 09:25:00	22:55:00	00:22:55
10/Jul/19 16:15:00	30:50:00	01:06:50
12/Jul/19 21:50:00	53:35:00	02:05:35
13/Jul/19 09:40:00	11:50:00	00:11:50
13/Jul/19 20:55:00	11:15:00	00:11:15
14/Jul/19 07:15:00	10:20:00	00:10:20
14/Jul/19 19:40:00	12:25:00	00:12:25
15/Jul/19 07:30:00	11:50:00	00:11:50
15/Jul/19 22:30:00	15:00:00	00:15:00
16/Jul/19 07:30:00	9:00:00	00:09:00
17/Jul/19 18:15:00	34:45:00	01:10:45
18/Jul/19 07:30:00	13:15:00	00:13:15
18/Jul/19 19:30:00	12:00:00	00:12:00
19/Jul/19 15:20:00	19:50:00	00:19:50
21/Jul/19 12:45:00	45:25:00	01:21:25
22/Jul/19 17:25:00	28:40:00	01:04:40
23/Jul/19 15:15:00	21:50:00	00:21:50
24/Jul/19 13:30:00	22:15:00	00:22:15
25/Jul/19 08:25:00	18:55:00	00:18:55
26/Jul/19 14:00:00	29:35:00	01:05:35
28/Jul/19 11:15:00	45:15:00	01:21:15
29/Jul/19 08:30:00	21:15:00	00:21:15
31/Jul/19 08:00:00	47:30:00	01:23:30
03/Aug/19 07:45:00	71:45:00	02:23:45
04/Aug/19 17:15:00	33:30:00	01:09:30
07/Aug/19 10:00:00	64:45:00	02:16:45
07/Aug/19 19:30:00	9:30:00	00:09:30
09/Aug/19 11:45:00	40:15:00	01:16:15
11/Aug/19 16:00:00	52:15:00	02:04:15
12/Aug/19 13:10:00	21:10:00	00:21:10
13/Aug/19 09:30:00	20:20:00	00:20:20
13/Aug/19 19:00:00	9:30:00	00:09:30
14/Aug/19 07:00:00	12:00:00	00:12:00
14/Aug/19 15:30:00	8:30:00	00:08:30
16/Aug/19 09:00:00	41:30:00	01:17:30
16/Aug/19 18:50:00	9:50:00	00:09:50
17/Aug/19 06:30:00	11:40:00	00:11:40
18/Aug/19 09:00:00	26:30:00	01:02:30
20/Aug/19 15:00:00	54:00:00	02:06:00
24/Aug/19 21:45:00	102:45:00	04:06:45
25/Aug/19 19:10:00	21:25:00	00:21:25
28/Aug/19 12:50:00	65:40:00	02:17:40
04/Sep/19 23:00:00	178:10:00	07:10:10

Table 3: Eruptions of Grand Geyser with intervals

tions was more than 4 days (with a median of more than 3 days). A majority of the recorded eruptions were in the afternoon, although the earliest was at 8:25am and the latest was at 8:45 p.m. Little else can be said about the behavior of Castle from this report, since it is likely that a considerable amount of data was not recorded.

Grand Geyser: The eruption times with intervals for Grand are listed in Table 3 with summary statistics of the intervals between *recorded* eruptions is given in Table 4. Recorded eruptions occurred between 6:30 a.m. and 11 p.m., suggesting that overnight eruptions were not recorded. This may account for the wide range of the statistics in Table 4, varying from a minimum of 8 hours 30 minutes to a maximum of 7 days, 13 hours, 20 minutes. That eruptions were not documented is borne out by Lane's commentary that Grand usually had three eruptions a day. Most curiously, it is stated by Lane that "Grand goes at times two or three days without playing."

The data for Grand Geyser were examined more closely in an attempt to determine when eruptions of Grand occurred but were not witnessed versus the times when two to three days passed without an eruption. The observations of geysers in June were too sporadic for any conclusions to be drawn. Grand started to come under close observation only from July 3 on. During July, Grand was observed regularly. With a few exceptions, if Grand was not observed at least once a day, then there were also no other geyser eruptions recorded. This suggests that the observers were not recording

Grand Geyser Statistics	
Minimum	00:08:30
5th percentile	00:09:30
First quartile	00:12:25
Median	00:22:55
Third quartile	01:21:25
95th percentile	03:18:21
Maximum	07:13:20

Table 4: Grand Interval Statistics, 1919. Statistics are in days: hours: minutes.

data that day other than that Grand was not erupting. These gaps in the data where *no* geyser activity was recorded will be considered artifacts of observation in the following commentary. From July 3 to July 9, Grand was typically seen each morning. On July 10, this pattern was broken, and it was seen in the afternoon. From 4:15 p.m. July 10 to 9:50 p.m. July 12, no eruptions of Grand were recorded, while other geyser activity was. It is possible that this was a "true" gap in Grand's eruptive behavior. After this time, from July 13 to July18, Grand was typically observed to erupt twice a day, morning and evening. From July 19 to 24, Grand was typically observed in the afternoon again. Then most eruptions recorded for the rest of July were in the morning, with one afternoon eruption. During July, after the previously noted gap, there are only single days in which Grand was not recorded as erupting.

Frequently, no other geyser activity was recorded on those days, so they were not likely to be instances in which Grand was not erupting. During the first week of August, the observations appear to be more erratic, but it is possible that Grand may have gone a couple of days without erupting. Of special note, on August 3, the records show that Grand erupted at 7:45 a.m, Giantess at 8 a.m., and Giant at 9:40 a.m. A truly remarkable two hours of geyser activity. After this, the records of geyser activity seem consistent from August 7 to August 20. Grand was seen at least once on most days. While there were single days on which Grand was not seen, there were no two-day gaps in the data. After August 20, data collection was too sporadic for any conclusions to be drawn.

The number of observations recorded for Grand relative to the other geysers show that it was a priority for the rangers, but it is still difficult to determine the exact number of times when it may have gone several days without erupting. There is one possible gap in July and possibly two times in early August when records of activity seem sparse. The 2-to-3-day intervals do not appear to have been common however.

Oblong Geyser: There were only 5 eruptions in the Lane report for Oblong. Three occurred in July (on 4, 12, 27) and two in August (on 18, 26). The times were solely between 8:50 a.m. and 11:30 a.m. Whittlesey reports that "records are difficult to find" for large periods of times during this era (Whittlesey 1988, 516). The best that can be said is that it was active.

Beehive Geyser: There were also only 5 eruptions recorded for Beehive. The last two eruptions listed in Table 1 for Beehive, August 24 at 8:45 p.m. and August 24 at 12:15 p.m., are suspect. The eruptions are out of chronological order even though the rest of Table 1 presents the data in order of eruption, and the stated eruptions are only 3.5 hours apart. If the last eruption of Beehive was actually 12:15 ***a.m.*** on August ***25***, then that eruption would be consistent with the formatting that is present in the rest of Table 1. Another possible interpretation would be that the last eruption of Beehive was actually 12:15 p.m. on August ***25***. As it is, it is not possible to ascertain the true eruption time. Whittlesey indicated that no records for Beehive eruptions were found for 1919. While records for the 1910s and 1920s were difficult to come by, many seemed to indicate that Beehive was highly erratic during this time. Records of Beehive often mentioned that Beehive followed eruptions of Giantess (Whittlesey 1988, 42). Most of the eruptions for Beehive listed in Table 1 for 1919 are approximately two days after the start of an eruption by Giantess. This is consistent with the historical commentary.

Sawmill Geyser: There is a single eruption time listed for Sawmill: June 25 at 9 a.m.. Interestingly, this is within the first 5 days of record keeping during the 1919 summer. I seriously doubt that this record is representative of its actual behavior during 1919. Although Whittlesey has no entry for Sawmill for 1919, records from early 1920s indicate that is was "frequent" (Whittlesey 1988, 608).

Other Areas: There were a few mentions of other phenomena in the report, which I will quote without comment.

Norris: "The small geyser at Norris, located across the road in the timber from Black Growler, was seen to play several times during the summer."

West Thumb: "The Fishing Cone at Thumb played frequently to a height of about 40 feet. This is quite an unusual occurrence, and is thought to be due to the fact that the level of the lake is several feet below the usual low-water mark."

"About September 1, 1919, a quiescent paint pot near the south approach road and a few hundred feet east of the Thumb Ranger Station, belched forth a considerable amount of material the color and consistency of whipped cream, which ran down the slope toward the hot spring basin. This paint pot is less active now, but is still puffing out some of its peculiar thick liquid."

Conclusion

Although some of the data recorded in Lane's 1919 geyser report has been published in recent works, much of it has not. Overall, it adds to our knowledge of geyser activity during a time for which detailed records are few.

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The Land of Wonders: Promenade in North America's National Park

by Belgian travel writer Jules Leclercq
Observations of Yellowstone geysers
from a nineteenth-century account of a visit to the Park.
Translated from the French book, *La Terre des Merveilles*, and
annotated by Janet Chapple and Suzanne Cane

Abstract

Jules Joseph Leclercq, Belgian lawyer, world traveler, and president of the Royal Geographical Society of Belgium, visited Yellowstone Park in 1883 and published his lively account three years later. Until the twenty-first century, the only known partial translation of *The Land of Wonders* into English was unpublished and in the hands of Yellowstone Park Historian, Lee H. Whittlesey. For *GOSA Transactions* readers, the translators present a new translation of the six chapters Leclercq devotes to his unique observations of the geyser basins.

Translators' Introduction

La Terre des Merveilles: Promenade au Parc National de l'Amérique du Nord [The Land of Wonders: Promenade in North America's National Park] runs to over 350 pages of text and includes an extensive bibliography and forty engravings, as well as two foldout maps of Leclercq's itineraries through the United States and through the park. It is an engrossing account by a careful observer and must have been warmly welcomed by French-speaking people of the late nineteenth century. Leclercq's observations were made so early on that the wonder and astonishment of seeing geysers erupt was still a great novelty. Walkways and wooden barriers did not yet separate visitors from the hydrothermal features, although by 1883 the hand of man was already evident in the geyser basins, not only in the several buildings and trails that had been constructed, but also in the vandalism that marred many thermal features, as Leclercq discusses in Chapter IX.

Leclercq's style of writing is representative of the travel writing genre of the 19th and early 20th centuries: it falls somewhere between the very detailed and technical approaches found in writings by geologists, biologists, army officers, and so on–men such as Ferdinand V. Hayden, William H. Holmes, Captain William Ludlow, and Arnold Hague–and the many tourist accounts that tell of washing clothes in hot springs, watching geysers spout, and traveling with companions. An educated man with a sound understanding of science, Leclercq mixes scientific information from other sources with his own scientific observations; he makes references to classical literature and comparisons to items with which he knows his readers to be familiar (such as European landmarks), and he relates amusing anecdotes from his own experience. His primary aims are to entertain French-speaking readers and to encourage them to visit the park. Often including what he felt, smelled, and heard, as well as what he saw, Leclercq used his words to give the reader a sense of actually being there–and his word pictures are delightful.

The summer of 1883 was a record season for park visits. The most widely publicized visit was that of the party of President Chester A. Arthur, the first United States president to visit Yellowstone. He and his large entourage arrived at Mammoth Hot Springs after traversing the park from the south, just as Leclercq was setting out from Mammoth for his horseback tour. Arnold Hague and Walter Weed of the U.S. Geological Survey, as well as German geologist G. M. Von Rath, were all in the park that summer. So were the Hatch excursion, celebrating the opening of some park facilities, and the Villard excursion, organized to celebrate the Northern Pacific Railroad's completion of its branch line from Livingston to Cinnabar, Montana, three miles north of the North Entrance. On the station platform in Livingston, Jules Leclercq met Henry Villard, then president of the Northern Pacific. The celebration Villard had organized involved 350 guests–all arriving the same day on three trains and completely disrupting the service of the ordinary trains and setting Leclercq's schedule back a day.

At this remove from Jules Leclercq's Yellowstone visit, it is not easy to learn about the man. We do know that he was born in Brussels in 1848, earned a Doctor of Laws, practiced law, and was a judge. Because he was independently wealthy, he was able to devote a great deal of his time to world travels. He wrote copiously, producing more than fifty publications in a travel writing career that spanned roughly half a century. One of his earliest books, *Voyages dans le Nord de l'Europe* [Travels in Northern Europe], from 1875, includes a visit to Iceland. In *The Land of Wonders* he often compares the thermal features of Yellowstone to those of Iceland.

Leclercq's visit to Yellowstone was part of his second trip to North America; he chronicled adventures not only in Europe and North America, but also in Africa, New Zealand, Asia and South America. By the time he published his book about Yellowstone, Leclercq was president of the Royal Geographical Society of Belgium and a member of the Geographical Society of Paris. He died in his native Brussels in 1928.

In his first six chapters of *The Land of Wonders*, Leclercq provides basic facts about the Yellowstone area and its exploration in the nineteenth century, and he details his journey west from Chicago to Livingston, then south to Mammoth Hot Springs. He devotes a delightful chapter to Mammoth, writing, "I set about to climb up the steps from the heights of which the thermal waters fall. With what childish joy I went on my journey of discovery, running from terrace to terrace, touching the delightful intricate patterns with my finger, dipping my hand in the warm water of the basins and cascades!" (*The Land of Wonders*, page 91.) With two Englishmen he met at the springs, he hired a guide and traveling outfit, and the first day they reached a camping spot on the Gibbon River. The chapters about the geysers follow from this point in the book.

The last six chapters of *The Land of Wonders* tell the story of the Nez Perce attack on the Cowan tourist party in 1877, describe fish and game in the park, and relate details of Leclercq's continuing tour, including Yellowstone Lake, the Mud Volcano (which he calls Giant's Caldron), Sulphur Mountain, the Canyon and Falls, and Mount Washburn.

Leclercq paraphrased or translated directly some passages from his sources.When possible, we have read these sources, and where Leclercq has translated them from English into French, we have used the original text, as indicated in our footnotes. Complete references to all his sources are found in Leclercq's bibliography. In our list of references we include only the ones Leclercq used for his geyser information and others that have been useful during translation. We have tried to retain a nineteenth-century flavor and sensibility in this English version, merely modifying the author's punctuation, and keeping old spellings as long as the meanings are clear (for example *sulphur*, instead of the more modern *sulfur*). In an effort to preserve the context, we have also retained many of Leclercq's long graceful sentences that are full of evocative adjectives and expressive subordinate phrases.

Chapter VII
The First Geysers

The Gibbon Geyser Basin. – The encampment. –
Boiling springs. – Muddy springs. –
Feeling of dread. – Supper. – The campfire. –
A concert in the woods. – A delightful evening. –
Dryness of the atmosphere. – A storm. –
Morning bath. – The geyser basin. –
The Monarch. – The Minute Man. –
The Constant. – The Twins. –
The Emerald Pond. – A mud volcano. –
The Steamboat Vent.

At five-thirty in the evening we reached the end of our first day of march. We had arrived at the Gibbon Geyser Basin,[1] the first group of geysers one encounters coming from the north.

On the banks of the Gibbon River we found a camp of eight A-shaped tents made of sailcloth, anchored with stakes driven into the ground. The largest served as a dining hall; in another, a Chinese man conscientiously carried out the duties of chef; the six others were meant to shelter the station personnel and travelers, on whom exorbitant prices were levied. We took possession of one of them where we found, to our great satisfaction, camp cots and warm wool blankets.

After unsaddling our horses, and while supper was being prepared, we hurried over to the hot springs southwest of the camp. The plumes of white steam we perceived between the trees showed us where they were. According to Hayden's[2] not very poetic but apt comparison, the valley resembles an immense industrial city over which hovers the smoke of factories.

At the end of several minutes' walk, we suddenly found ourselves at the edge of one of those basins that the first trappers who traversed this region likened to the vents of hell. The whole of the basin [Porcelain Basin], with a surface area of about 10 hectares [25 acres] and a depth of 8 to 10 meters, is made up of a combination of boiling hot springs, pools, fumaroles, and solfataras, offering the most bizarre motley of colors and producing I know not what diabolic concert of hisses, sighs like the bellows of a forge, and raucous and hollow-sounding roars. The overheated air is tainted with noxious gases, the ground rumbles and shakes underfoot, as if ready to open up. Except with extreme prudence, one cannot venture onto this treacherous crust from under which one hears the sinister boilings of subterranean waters.

The bottom of the basin, which is white streaked with yellow, is riddled with an infinite number of conduits spewing forth sprays of boiling water or jets of steam, and lined with delicate golden yellow sulphur crystals.

There are also muddy springs of boiling clay; this slate-colored paste constantly heaves and sometimes spurts up several feet high, splattering the nearby area. The Americans designate these mud pots by the picturesque name of paint-pot.

One experiences an inexpressible feeling of horror in the presence of these convulsions of nature, on this ground palpitating like the chest of a sick person, before these somber outlets from where groans seem to escape. Nowhere else, not even in Iceland, had I ever until then felt such an impression of dread. And, despite that, this savage and grim poetry fascinates you. Illuminated by an admirable sunset, the scene had a marvelous, fantastic aspect that I shall never forget.

Upon our return to the camp, night was falling. As we had eaten nothing since eight o'clock in the morning, I will let you wonder whether we did justice to the elk roast we were served in the tent, by the light of a candle stuck in the neck of a bottle. If, in Clarke's opinion, the coffee was not as good as that which we had so often happily savored in Iceland, to compensate, the icy water drawn from the nearby river was excellent.

After this copious repast we fraternized with a caravan of American travelers who had just arrived from the south; among them was an intrepid horsewoman. We made a circle in the open air around a large campfire fed by whole pine trees.

While we were conversing around the merry flames, our friend Alexander sent us distant echoes of Mendelssohn's Wedding March from deep in the woods, played on a perfectly portable little concertina that is the companion of all his travels. It was doubtless the first time that these lonely wilds had resounded with such harmonious chords.

This music in the bosom of the wilderness plunged me into a delicious reverie. No other evening has engraved itself more profoundly on my memory. Never had stars seemed to me to shine with such vivid brilliance: one might have said countless golden lamps dispersed in infinity.

I have always been vividly impressed by the beauty of the nights in these high northern regions of the Rocky Mountains. The brilliance of the stars is due to the great clarity of the air at these elevations; the atmosphere is so dry that all you need do is pass your hand rapidly over a bison pelt to make electric sparks fly. Nights are cold, and in the month of August, frosty nights regularly follow blazingly hot days. But one is less aware of these extremes of temperature than one might believe; the cold does not occur unexpectedly but gradually. Besides, it turns out that one feels the cold but little in camp life, because one does not at all experience the abrupt variations of temperature caused by passing from the atmosphere of an apartment to the outdoor air.

That night we hardly slept at all. For barely an hour I had shared with Clarke the camp cot that served as our common bed, when an appalling thunderclap awoke us with a start. It was a proper storm. The flash of lightning dazzled us even in the tent, whose fabric crackled noisily under the torrents that fell all night. Happily, the tent withstood the downpour; not a drop of water came in.

At six in the morning we were up. A splendid sunshine had succeeded the storm. The temperature was biting, the air extraordinarily sharp and dry.

While breakfast was being prepared, we took a morning dip in the Gibbon River. Fed by the snows of nearby mountains, the water was freezing, so we took only a plunge.

The morning was spent in exploring the active geysers that occupy the plateau southwest of the basin we had already visited. These geysers [in Back Basin] are hardly comparable to those of Iceland nor to those that we would admire later in the

Firehole region; their eruptions are not very sizable, and they generally lack those magnificent basins whose classic structure complements the geysers, but they present phenomena that we would not find elsewhere. The geysers of the Gibbon River differ from their like in Iceland and the Firehole by the disposition of their craters, which generally open at the side of a rock.

American explorers have given these geysers various names. With the appellation of the Monarch they paid their respects to the one that produces the highest column of water. Not having seen it play, we cannot say if it deserves this honor. It is said that it erupts once a day with a spray 30 to 40 meters high, which escapes through three distinct orifices.

Near the Monarch is a little geyser that passes for a model of exactitude and punctuality: regularly, once every sixty seconds, it shoots out a jet of several meters. It is the Minute Man [Minute Geyser]. Although we watched it for a rather long time, it did not deign to disturb itself for us. Probably the Minute Man has periods of slumber during which it forgets to carry out its job.

The Constant [in Porcelain Basin] was nicer: every thirty seconds it offered us the spectacle of a small eruption, at the end of which the basin emptied completely only to refill right afterward.

The Twins, the Triplets, and the Fountain were likewise in perpetual activity.[3]

The Emerald Pond [Emerald Spring] seems to be the crater of a geyser, although it has never been seen to be active.[4] It is an unfathomable chasm, in which the scalloped walls are visible to a great depth through the marvelous transparency of the beryl green water that fills it to the brim. By one of those contrasts so frequent in this enchanted land, next to these crystal clear waters we found a volcano of mud [Bathtub Spring], which, from one quarter hour to the next, throws up a pasty mass three or four meters high.

We were attracted elsewhere by a noise that so closely resembled the booming of a steamship's funnel that it could be mistaken for it: this noise came from the Steamboat Vent [Steamboat Geyser], an enormous hole in the earth, throwing out puffs of superheated steam with a terrifying vehemence. Upon approaching cautiously, we saw that the chimney has two vents. The hissing is so intense that a dozen locomotives together would scarcely produce such a noise.

As Doctor Peale[5] remarked, everything points to this cavern being of recent formation: sulphur and geyserite deposits have not yet had time to accumulate around the vents, but the surrounding ground is covered with a layer of sand that seems to have been thrown out by an eruption; the nearby trees are dead, and some are lying on the ground half buried under the sand.

According to the testimony of Colonel Norris,[6] the Steamboat Vent did not exist in 1875; but since 1878 it has thrown out powerful jets of boiling water.[7] It is obviously a new geyser that has just been born and whose developmental period will no doubt furnish valuable data on the age of the geysers, their patterns of behavior, and the formation of their deposits. A geyser in the different phases of its existence, from its earliest infancy to its decrepit old age, would indeed make a curious story.

Chapter VIII
The Firehole

Elk Park. – Encounter with hunters. –
The Gibbon Paint Pot Basin. –
The Blood Geyser. – New mud springs. –
Chemical phenomenon. – Horses' instinct. –
The Monument Geyser Basin. –
Powerful steam jet. – Beautiful panorama. –
The Gibbon Cañon. – A waterfall. –
The Firehole River. – A log house. –
Travelers' registry. –
The valley of the Firehole. –
Appearance of the geysers at dusk. –
The campsite.

After having devoted several hours to examining these phenomena, we remounted and continued southward. The previous night's storm had transformed the trail into a quagmire, where our horses floundered each worse than the next.

An hour later, Elk Park came into view. Nothing could have been more refreshing than this verdant space enclosed by a magnificent ring of pine-forested mountains. The Gibbon River here winds through the meadows. This is wonderful country for big game lovers, as its lovely pastures are the favorite haunts of the denizens of the Rocky Mountains. Here we came across a camp of hunters; they were traveling in wagons that converted to tents at night. These Nimrods[8] proudly showed us the results of their hunt: they had killed a superb moose and a bull elk.

Near the far end of Elk Park, amid the trees and not far from the entrance to the Gibbon Cañon, lies the Gibbon Paint Pot Basin [Artists' Paintpots]. We approached it along a barely discernible track through the dense undergrowth.

The appearance of this basin is extremely strange. Over an expanse of two or three hectares, the ground is riddled with hundreds of craters spewing out substances half-solid and half-liquid. The Blood Geyser shoots out a column of water so pronouncedly red that the stream flowing from it seems to flow with blood. This coloration is due to the layers of red clay through which the boiling waters pass. Muddy masses of all hues explode on every side, spurt up into the air with peculiar noises and spread out along the edges of the craters, creating with their splatterings the most grotesque and unexpected forms. The mud paste, soft as velvet to the touch, could furnish the palette of a painter with the most vivid colors that exist in nature: crimson red sparkles next to ultramarine blue, and episcopal purple mixes with Sienna yellow or chalk white. The ground surrounding the mud springs has the look of porcelain ready for molding by a potter. The innumerable fumaroles rising from the fissures form a dome of vapor above the basin.

What is the mysterious phenomenon going on in this natural laboratory? Noticing that the water and mud of these mud pots contain much alum, the chemist will reply that what is occurring is a decomposition of the aluminum silicates in the volcanic tuffs as they are subjected to the action of the sulphurous waters.

As we entered the Gibbon Cañon, we took note of a signpost to the right of the road indicating the trail leading along the opposite bank of the Gibbon River to the Monument Geyser Basin. The countless springs of boiling water that spurt out on the banks of this portion of the river are responsible for the hot currents. Crossing the river, our horses knew to avoid them with that marvelous instinct characteristic of both Indian ponies and their Icelandic cousins.

After twenty minutes of arduous climbing up the slopes of Mount Schurz,[9] we reached a basin lying 300 meters above the river and extending over two hectares. Here are clustered a dozen half-extinct geysers whose cones resemble monuments erected by nature's patient handiwork, simulating sometimes a monstrous animal, sometimes a headless man, sometimes an ordinary chimney.

Each of these cones, which vary in height between 2 and 4 meters, possesses an opening at the summit. Some are still emitting steam, but most seem to have earned the right to retire, and their walls, no longer consolidating new deposits of geyserite, are rapidly crumbling. There was a time when streams of boiling water gushed from their vents, but their present appearance indicates that the volcanic activity of this region is diminishing.[10]

This basin encloses all the usual appurtenances of geysers: hot springs, solfataras, and fumaroles. From one fissure a jet of steam escapes with a deafening whistle audible for a considerable distance, like the whistle of a locomotive. The noise alone reveals the presence of the vent, for the hot current is so dry as to be almost invisible. A pine branch, placed before the orifice, dries up, contracts and splinters almost instantaneously.

The existence of this curious basin, lying in an isolated region, has only been known for a short time. Who can say how many unknown marvels this still barely explored land encompasses!

The view over Elk Park embraced from here is most beautiful: the eye follows with pleasure the Gibbon River, tracing its capricious meanders among green meadows framed by the magnificent setting of forests rising in tiers up the mountains.

Returning to the banks of the river, we enter the Gibbon Cañon, a dark defile two leagues long where the river is narrowly hemmed in between high basalt walls deeply furrowed by erosion. This imposing gorge would arouse admiration in the Alps or the Pyrenees, but here the mind is so occupied with the extraordinary geological phenomena bursting upon one at every step, that one views the scenery only abstractedly.

The Cañon has a wild beauty. The high imposing walls lean toward one another; the road often merges with the stream; the blue sky can only be glimpsed as if through a long crack. Nothing is more curious than watching the water ouzel[11] hunt its prey in the clear water of the river, only a few steps from the hot springs gushing forth from its banks.

Near the middle of the gorge, the river forms a romantic cascade [Gibbon Falls]. It shoots over the top of a wall 25 meters high, and its snowy whiteness sets it off clearly against the dark green of the pines dangling from the imposing rocks that dominate the falls.

The Cañon opens onto a beautiful wide valley across whose grassy meadows winds a river fed principally by the countless boiling hot springs one sees welling up along almost its entire length. Hence it was given the characteristic name of Firehole River.[12] At this juncture two arms of the Firehole converge, one coming from the east, the other from the great geyser basin to the south.

After fording one of these streams, as they do in Iceland, we soon found ourselves before a good fire in a log house, the precursor of a comfortable building that will one day be erected here, known as the Firehole National Hotel.[13]

We dined on a delicious leg of elk, then remounted our horses to go camp that very evening some 10 miles away, in the upper Firehole basin.

It was late in the day and we were in a hurry to reach our destination, so we did not tarry to visit the curiosities on the way, which we would explore later. This day we contented ourselves with hailing the geysers in the lower and middle basins from afar.

For two hours we rode along among the countless sulphurous springs that riddle the banks and even the bed of the Firehole. We never tired of admiring the brilliance of the conferva[14] that delight in these hot waters, and the splendid colors of the mineral substances deposited on their edges.

As we advanced, the geysers became more numerous, so numerous that eventually our curiosity was blunted and we became accustomed to the sight, just as did our horses, who displayed not the least fear walking alongside the pools of boiling water all along the trail. In this realm of fire, cold water appears an anomaly: a body of water not emitting steam would seem to be out of place.

As evening drew on, the cooler air noticeably increased the density of the columns of steam rising over the basins. In a charming illusion, the refracted colors of the prism decorated these white clouds, seemingly motionless in the evening calm. One would say that the thousand colors from the edges of the hot springs were reflected in these aerial mists.

Here at last was the famous plain that forms the upper basin of the Firehole. We had crossed almost its whole extent from north to south, greeting along the way the Grotto, the Giant, the Pyramid, the Castle, and other geysers with which we proposed to become better acquainted.

At six o'clock in the evening our campsite appeared before us. It was a group of tents lined up along the right bank of the Firehole, in the vicinity of the Beehive, the Castle and Old Faithful.

Chapter IX
Old Faithful

Characteristics of Old Faithful. –
Appearance of the crater. – Fantastic panorama. –
Vulcan's laboratory. –
An eruption of Old Faithful. –
Vandalism. – A cold night. – A false alarm. –
Appearance of the upper basin of the Firehole. –
Large number of hot springs.

Dismounting from our tired horses, we ran at once to Old Faithful, the most popular of all the geysers of the Firehole valley. It owes its name to the regularity of its eruptions: night and day, no matter what the weather, it goes into action every hour, with such clock-like precision that it could serve as a standard for watches.[15] It is the only geyser that never fails the awaiting camera.

The crater of Old Faithful opens out at the summit of a conical mass of siliceous layers arrayed in terraces. These tiers are pitted with a thousand little pools where warm, limpid waters slumber, overspread with the richest colors: charming mirrors set within the most delicate sculptures. The rock has the granular appearance characteristic of geyserite; in the delicacy and the complexity of its structure, it is reminiscent of coral; from a distance it appears ash-colored, but at close range one finds exquisite shades of pink, orange and saffron standing out from the gray background.

From the height of the crater, the entire valley is revealed. From this point one takes in the full extent of the basin.

The sight of this magical panorama in the slanting rays of the setting sun left us with an imperishable memory. If there are more alluring places in the world, there certainly are none stranger or more fantastic. Lieutenant Doane,[16] who was the first to describe the Firehole valley, has not exaggerated in setting it above all the other wonders found in

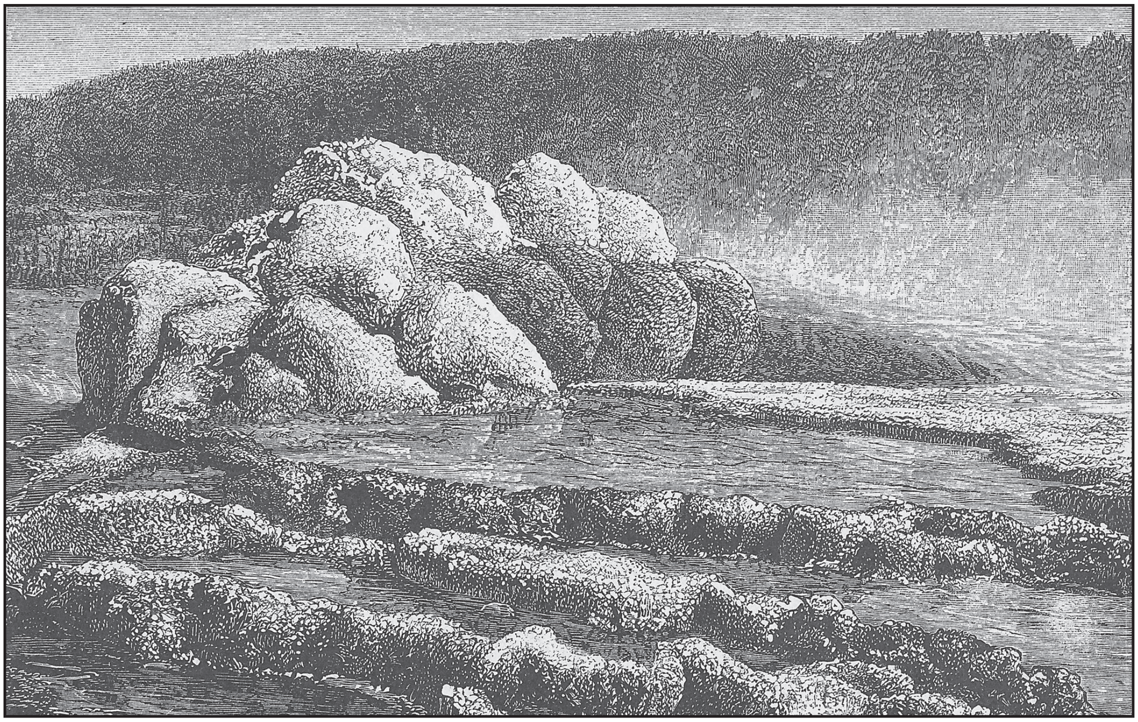

Figure 1. *Crater of Old Faithful.*

America, and one understands that the first explorers must have felt stunned and overwhelmed by the spectacles they witnessed. In this basin, where the earth covers a sea of boiling water,[17] the Ancients would have placed Vulcan's laboratory; Dante would have seen here one of his circles of Hell.

But let each one judge for himself.

All along the Firehole are cratered mounds on whose summits thermal fountains open out. Above all these caldrons, aerial plumes [of steam] stand out like ghosts against the dark green background of fir groves.[18] These vapors impregnate the air with strong sulphurous fumes. Every minute the ground, undermined in a thousand places, is shaken by muffled subterranean detonations resembling the rumbling of a distant storm.

Blended with these sinister noises from time to time is the strange whistling of rockets of boiling water shot into the air; sometimes these are compact spouts of water shooting up in a vertical and ardent jet, sometimes sprays of water opening out like a parasol in the midst of a cloud of foam and iridescent steam, falling back to earth like a rain of diamonds. While dispersing in the air, the sprays of water produce a sad murmur, like the monotonous song of the wind in the forest.

Hundreds of rivulets feed the waters of geysers and thermal springs into the Firehole. The layers of geyserite accumulated on top of each other along the banks of the river form high walls that reach as much as 10 meters in height. The waters rush from the top of these cliffs in steaming cascades, creating a commanding scene.

One would have to have seen with one's own eyes a landscape as extraordinary as this in order to believe that something similar could exist on our planet. If a man were to be suddenly transported to the middle of this valley, he would believe himself in a fantastical world, far removed from our own, or else he would be persuaded that he was the victim of an illusion, so much does reality exceed fiction here, so greatly do the objects which affect the senses appear to belong to the supernatural and improbable.

We had been watching for scarcely a quarter of an hour, when suddenly Old Faithful emitted several menacing hiccoughs, precursory signs of an explosion. We immediately positioned ourselves in the safety of a neighboring knoll to await events.

First the waters rose in the pool with muffled rumblings, then subsided, only to rise again. Only after three or four minutes did the column of water begin to spout up into space: it rose in fitful jets rapidly succeeding each other, and only ceased its continual ascent when it had attained a height of about 50 meters.

At this moment, it seemed a terrifying supernatural phenomenon. The powerful roars of the volcano resounded throughout the valley, and the great rockets of steam and spray shooting much higher than the mass of water seemed to want to surpass the nearby mountains in height.

After reaching its apogee, the column of water gradually subsided. Long after it had sunk underground, there were still explosions of steam; then these last remnants of anger vanished, and we could without danger cast our eyes into the interior of the funnel. Several meters down, the water foamed furiously within the walls of its prison. "*Pretty, Clarke! Pretty, Clarke!*" cried Mr. Alexander, who was in the habit of expressing his admiration in this laconic fashion to his friend Clarke.

The watery eruption had lasted five or six minutes. We noted that a few moments before the phenomenon the temperature of the water inside the crater was 94° centigrade [201°F]; immediately after, it was 77° [170.6°F] in the shallow pools surrounding the crater. At that elevation, the theoretical boiling point is 93° [199°F]. The excess of temperature above the boiling point is doubtless caused by the superheated steam escaping from the bottom of the tube.

Old Faithful was already erupting hourly when discovered in 1870;[19] since then it has never failed to live up to its name. It would be impossible to say how long it has performed on its present schedule. If, as is believed, the activity of the American geysers is generally decreasing, such an observation cannot be applied to this one. This geyser must be quite old, to judge by the size of its cone, which is nearly 4 meters high, 60 meters in diameter at the base and 16 meters at the top.[20]

The crater of Old Faithful, just like that of the Grand Geyser of Iceland, is already covered with hundreds of names carved by visitors on the smooth surface of the rock. In a few hours the inscriptions are covered with a siliceous coating, which preserves the most insignificant names.

The crude hand of vandals does not stop there; it is truly revolting to see them, under the pretext of searching for specimens of geyserite, taking the brutal ax to the fragile and delicate concretions. In building these admirable monuments, in artistically fashioning them, in sculpting and ornamenting them, nature has employed a slowness, a meticulousness, a patience of which men would not be capable, and it takes but one minute for irreverent hands to disfigure the work of thousands of years. There are few craters that have not been damaged by ax and spade, and, if care is not taken, they will gradually crumble to pieces under the attacks of these ruthless destroyers.

It is the duty of the American government to halt these devastations, to prevent the criminal profanations of a sanctuary wherein no mortal should enter without a religious feeling of respect. As long as the National Park found itself isolated from populated areas, it had but a small number of visitors; but from now on the railroads will bring legions of the curious here, and a vigilant police force will have to be organized against vandals. Perhaps it would be best to place the Park under the control of the War Department, as Captain Ludlow[21] and General Sheridan[22] recommended. The conservation of this marvelous natural museum would best be entrusted to military posts, which would be established at important points, at Mammoth Springs, Yellowstone Lake and especially the geyser basin.

It was after dark when we went to the tent for supper. The pine campfires burning in the valley illuminated the steam hovering above the geysers with a reddish glow; one might have thought them fantastical Bengal lights.[23] The sky was incredibly clear; the Great Bear and the pole star shone with a wonderful brilliance.

The night was extraordinarily cold. In the tent the thermometer dropped to 0° [32°F]; outside it was freezing. Clarke and I shared our body heat with each other, buried under a mountain of coverings.

At about two in the morning, we were dragged from slumber by frightful rumblings accompanied by earth tremors. It seemed to us that the ground would open up under our tent. The shouts of the camp watchman, "Beehive! Beehive!" told us that it was an eruption of the Beehive, the geyser from which we were separated only by the Firehole flowing between it and us.

When we had recovered from our initial fright, it took us but a moment to emerge from the covers and dash outside, to cross the footbridge thrown across the river, and to rush up to the geyser, at the risk of falling in the darkness into one of the holes of boiling water found in the vicinity.

All this trouble for nothing! The eruption came to an end just as we arrived on the spot. A little sheepish and pretty well chilled, we regained our cot. Alexander was much more sensible: having had no reaction to this untimely eruption, he had not stirred from his warm, snug bed.

The next day was spent diligently exploring the upper basin of the Firehole. It lies in a wide valley, dominated by basaltic hills 500 to 600 meters high, covered with dark pine forests. Here and there meadows stand out like islands of greenery among vast spaces sterilized by invasions of white siliceous deposits. A milky-colored mist, produced by the respiration of the geysers, hovers perpetually over the region like an aerial shroud. The basin stretches over an area of about two square kilometers: its form is that of a triangle with the apex in the north, at the confluence of the Firehole and the Little Firehole. Old Faithful marks the southern extremity.

The area thus bounded is the great wonder of the National Park; it is here that erupt the most powerful geysers known. Nature has grouped them along the Firehole, which runs through the basin in a northwesterly direction. Sometimes their eruptions produce a boiling flood great enough to raise the level of the river suddenly and to increase its temperature noticeably. While one of these watery volcanoes was belching, we observed that a thermometer plunged into the river waters registered 4° centigrade [7°F] above their usual temperature.

The various geysers scattered over the extent of the basin are by no means active at the same time. They gush forth only at more or less regular intervals, and their eruptions vary in length and in energy. Some, constantly at work, explode from hour to hour and even from minute to minute, while others remain quiet for years at a time. This geyser, very active today, will become extinct in the near or distant future, while others will spring up, taking the place of those that have expired. Except for Old Faithful, the appearance of the geysers varies from year to year; thus one cannot furnish data in this regard with absolute precision.

There are more than 1,500 hot springs in the Firehole basin; many of them have been recognized as active geysers, but they have been known for so few years that one may be sure that many springs will be elevated to the rank of geysers when they have been more thoroughly observed.

Chapter X
Beehive and Giantess

Eruption of the Beehive. –
Appearance of the Giantess. –
A marvelously beautiful basin. –
A scalding armchair. – Eruption of the Giantess. –
Appearance of the basin after the explosion. –
Specter and halo. – A boiling shower. –
Decline of the Giantess.

During our stay in this valley, we were fortunate beyond all our hopes. The most powerful geysers, the very ones that erupt only after long intervals, wanted to display their prowess for us.

The Beehive, which had caused a false alarm the first night, was gallant enough to give us a double display. The first took place at ten o'clock the following night, just as I was taking notes in the tent, writing in my lap by the light of a candle; the second occurred at seven the next morning.

What a splendid sight is an eruption of the Beehive! This geyser does not spew forth in a halting, spasmodic way as do most of its fellows, but sends up a sustained, powerful and impetuous jet. A compact column of water a meter wide escapes from its narrow orifice with the exuberance of a waterspout, rising so high in its superb surge that it disdains falling back to earth: the water column partially evaporates in midair and is transformed into a dissipating cloud dispersed into space, carried away by the breeze. Accordingly, the Beehive is the only geyser that one can approach while it is in action, without fear of being scalded. At the height of the eruption, we saw a spectator hold out his hat to the column of water; in less than a second, to the great amusement of the audience, the hat was propelled as high as the towers of Notre Dame and then fell back at the feet of its owner.[24]

The eruptions of the Beehive last about as long as those of Old Faithful. They have so much energy that they cause a violent shaking of the ground around the geyser, accompanied by subterranean cannonades that are particularly frightening at night.

The crater of the Beehive is so modest in appearance that one would hardly think it capable of such fury. It is a cone one meter high in the shape of a beehive, rising abruptly from the ground, without surrounding itself with those tiers of terraced deposits that complete the architecture of most geyser craters. The small quantity of water that falls back to earth during its eruptions is not sufficient to produce these deposits. From afar, the cone appears to be a bench placed there expressly for the comfort of visitors, and one would be tempted to sit there but for the scalding steam constantly escaping from it. Leaning over the edge of the orifice, one looks deep into the interior vent and discerns the waters boiling furiously at the bottom. Several open spouts around the cone allow the steam to escape; one of these faithfully announces explosions of the geyser by its violent whistling.

Nothing is more uncertain than the time of these explosions; they occur with absolutely no regularity. In 1871, Hayden noticed that the phenomenon took place around six o'clock in the morning. In 1881, during one of Colonel Norris's exploratory tours [as superintendent], the geyser spouted the first day at nine forty-five in the evening, the second day at two fifteen in the afternoon, and the third day at eight forty in the evening. We saw it erupt on September 1, 1883, at two o'clock in the morning and at ten o'clock in the evening, and on September 2 at seven fifteen in the morning.

According to these data, it would seem that the Beehive is active daily, but local people have assured us that it had not erupted for several days and that we were especially privileged to be honored by its gallantries.

Heaven favored us once more in allowing us to enjoy the much rarer and infinitely more impressive spectacle of an eruption of the Giantess, one of the most powerful geysers in the Firehole valley. Its dimensions are extraordinary. It is a magnificent basin, completely devoid of those crater-shaped projections surrounding most geysers.[25] Located in the neighborhood of the Beehive, equidistant from the Firehole and the hills dominating the valley on the north, it opens out at the summit of a large mound formed from deposits rising in a gentle slope. At its base, the mound measures 200 meters in diameter. The nearly circular basin is 30 meters in circumference; its edges, made up of thin layers of geyserite, overhang the cavity.

The waters contained in this gigantic bowl are an ideal blue, and as they are as clear as crystal, one can gaze into the depths of the abyss and wonder at the beautiful structure of the inside walls. Beneath the azure water, the innumerable granular formations on these walls look like sapphires.

In Iceland there is no basin of such striking beauty. Its appearance is most animated and changeable: sometimes the steaming waters, completely at rest, display an unbroken surface as transparent as a mirror, and sometimes they are violently agitated by great bubbles that come up to burst at the surface. To provoke these bubblings, one need only toss in a stone. By plunging a sounding line into the chasm, we determined a depth of 24 meters.

At the edge of the basin rises up a rock of geyserite, where I had the unfortunate idea of sitting down. I learned at my expense, jumping up as if propelled by a spring, that in this country the rocks are burning hot. My friend Clarke, witnessing my misadventure, was much amused. He revealed to me clearly that what I had taken for an armchair was in reality the lid of a caldron, and a perfidious jet of steam escaping from it affirmed this only too well.

The local people had assured us that the Grand Geyser would be active in the afternoon that day. We therefore went there after lunch, when, at ten past two, repeated shouts caused us to run as fast as we could go toward the Giantess. In ten minutes we had covered the kilometer that separates the Giantess from the Grand Geyser. The eruption of the Giantess was at its fullest when we arrived at the site.

I shall never forget the magnificence of the great and awesome phenomenon taking place before our eyes. A column of water as wide as the orifice surged spasmodically from the bosom of the formidable caldron. This enormous mass of liquid rose as high as the tallest houses in Paris, bulging at the top like a crystal dome, and fell back with all its weight to the ground, causing it to shake over a considerable radius. In the heart of the main column of water, a passage of thinner jets opened up, and the most powerful of them rose as high as the Barrière de l'Étoile.[26] From where did these jets come? Undoubtedly from secondary vents abutting with the main tube at the point where the explosive force attains its maximum. Dreadful subterranean thunderings mingled with the roaring of this deluge of boiling water as it rose into the sky.

Such an imposing scene would move the most blasé of men and cause the most intrepid to tremble. What, then, are the forces set in motion by man compared with the awesome physical agents that produce these stupefying phenomena?

We noticed that many small geysers in the vicinity of the Giantess participated in the activity of the suzerain, with whom they evidently had connections. It was like a powerful tide lifting this entire subterranean sea, whose numerous spouts boiled and emitted puffs of steam. We had observed an oval crater a few paces from the Giantess at the summit of a dome of geyserite: its waters, which before the eruption were boiling most violently, had completely disappeared when we returned, and the crater was as empty as that of its neighboring drain well.

The Giantess differs from other geysers in the long duration of its eruptions. It only becomes active at intervals of 17 days, but the explosions continue for 12 to 15 hours. It does not play continually like the Beehive, but rather in bursts occurring every half-hour and lasting about 20 minutes.

During the intervals between bursts, we were able to approach the edges of the crater with impunity. This admirable basin, which a short while before was overflowing its rims with water blue as lapis lazuli, was now dry. We could look down into the empty chasm and discern the junction of the vent and the basin at a depth of 8 meters. The subterranean waters remained invisible, but we heard them roaring in the depths of the earth. The inside walls, which had seemed blue under the water, had become whitish and had the granular look of geyserite.

From the bosom of this cauldron thick puffs of steam were constantly escaping. When one of us placed himself between them and the sun, the projection of his shadow onto the vapors created a specter, and the sun's rays were concentrated around the head of this phantom like a sort of sparkling halo, similar to the nimbus of the saints.[27]

The eruptions of the Giantess occur as suddenly as a flash of lightning. I was leaning over the edge of the furnace during the interval between two bursts, when a river of boiling water spurted out without giving me the least warning. I can boast of having executed the longest strides of which legs are capable in this critical circumstance, but I was scalded nonetheless, to the great glee of the onlookers. Thanks be to the broad-brimmed American hat that protected my head from the burning downpour!

Hayden reports that in 1871 the Giantess had two eruptions in the space of twenty-four hours.[28] One must conclude that the bursts were more frequent at that time but of shorter duration. If a dozen years were enough to have decreased the number of eruptions from two per day to fewer than two per month, then perhaps not many more years will pass before the noble geyser decides to retire completely from active life.[29]

Chapter XI
Along the Firehole

Excitement produced by the geysers. –
The Sawmill. – The Grand Geyser. – The Castle. –
The Devil's Well. – The Washtubs. – The Giant. –
The Young Faithful. – The Grotto. –The Fan. –
The Splendid. – A bath in the Firehole. – A storm.

We spent two days in the valley that the Icelanders would call *Reykjadalr* (Steaming Valley). The geyser eruptions kept us in continual activity: sometimes they woke us during the night; sometimes they tore us away from our meals. We ran like madmen, half-awake or with our mouths full, to gaze upon the phenomenon; but often it was abortive, and more than once we returned crest-fallen.

Each one of us wandered about as pleased his curiosity, having no guide other than the map by Ludlow, although it is very detailed and indicates the configuration of the valley and the exact position of the principal springs.[30] Nothing can be more interesting than to roam thus across the fields of geyserite, where here and there emerge craters that take their names either from the fantastical outlines of their cones or from the caprices of their spouting waters.

A path runs along the Firehole, across a plain undermined and riddled with caldrons where the subterranean waters boil. How many times I scoured the area, impatient as a hunter lying in wait, to witness the beginning of an eruptive phenomenon that could at any moment burst forth from under my feet!

At first one feels overcome by I do not know what sense of vague terror. All these bubbling and flowing waters, these steaming fountains, these roaring jets warn you in their singular, other-worldly language that you are in the formidable proximity of the central fire. The crust on which you walk is not always reassuringly solid; sometimes it gives way beneath your footsteps, and the horrible idea of being engulfed crosses your mind. But these perils, which you get used to quickly enough, add to the charm and the mystery of this valley, which seems

Figure 2. Panorama of the valley of the Firehole. 1. Old Faithful. – 2. The Castle. – 3. The Giant. – 4. The Grotto. – 5. The Fan. – 6. The Giantess. – 7. The Beehive. [Translator's note] Giant Geyser is shown steaming between Castle and Grotto in the engraving but is lacking its number.

to possess the secret of what happens in the somber laboratories of the terrestrial core.[31]

With your permission, we will honor with a moment's attention the principal geysers spread out along the Firehole's two banks.

As we leave the Giantess, here, ten minutes away, is a geyser in full play, for it spurts half the time: it is the Sawmill. Its crater, not more than 6 inches wide, opens up at the bottom of a bowl-shaped depression. The eruption presents a most singular game: the column of water rises several meters high, and in falling to earth, it encounters new ascending jets that turn it back in midair, exactly as a [badminton] racket does with a shuttlecock.[32] The basin, ordinarily dry, fills with water at each eruption; the liquid mass is no doubt lifted up by the vapors mounting in the tube, since, just as the burst begins to quit, the water instantaneously re-enters the crater.

A little farther on, the Grand Geyser comes into view. Despite the similarity of the name, it does not at all resemble the Grand Geyser of Iceland. It does not rise from the top of a magnificent dome of geyserite, as does its cousin in the Land of Ice. In fact, its basin attracts so little attention, that one would not find it at all if it were not adjacent to a geyser whose prominent crater is reminiscent of the shape of a turban. Its basin is just a simple depression of a very irregular appearance, not more than a foot deep at its center and lacking raised edges. Large shapeless masses of geyserite frame the mouth of the vent.

We kept watch in vain near the Grand Geyser at the time when we had been assured it would start erupting.[33] It did not deign to give a show. We are told that its eruptions are analogous to those of the Giantess: they are produced suddenly, without any warning.

On the other bank of the Firehole, near the place where a torrent of boiling water rushes down, stands the Castle, the most imposing crater in the entire extent of the basin. Its appearance is reminiscent of an old ruined fortified castle. It crowns a knoll formed of whitish deposits covering about two hectares and rising to almost 12 meters above the river. The 4-meter-high cone is made up of layers of geyserite, accumulated one upon the other.

The silvery gray siliceous deposits are very hard. The geyser's orifice is bordered with orange colored encrustations. Puffs of steam constantly issue from it, and jets of water spurt out from time to time, even in the interval between eruptions.

The Castle launches a column of water from 10 to 15 meters high. There is no doubt that this geyser was formerly the most powerful in the whole valley.[34] Information from travelers about its periods of repose and activity are rather contradictory: according to some, it erupts once in twenty-four hours; according to others, once in forty-eight hours. It is likely that its regime varies according to the time of year. Colonel Norris reported that Castle had an eruption on October 4, 1881, at three o'clock in the afternoon and another on the 6th at nine forty-five in the morning. In 1882 Mr. Haupt[35] witnessed an eruption on August 25 about ten o'clock in the morning. One can therefore conclude that this time period [late morning to mid afternoon] is the most propitious for seeing the phenomenon, but we wasted our time waiting.

At a few paces from the Castle there is a spring called the Devil's Well [Crested Pool]. I would rather call it the Enchanted Goblet, for apart from the temperature of its waters, it has nothing to awaken the idea of hell. Imagine a lovely basin 6 meters in diameter and of unknown depth, perfectly circular and surrounded by a prominent border completely encrusted with an efflorescence that could be taken for pearls. The eye is fascinated by the astonishing transparency of its blue waters, overflowing its edges. Under the crystal liquid, the siliceous encrustations of the walls glitter like precious stones. The sun's rays cast magical prismatic colors, and one's gaze follows these dazzling sights down to the last visible unfathomable depths of the well.

What then is this marvelous spring? An inexplicable mystery! It is very close to the Castle, but during the geyser's active periods, it shows no disturbance. Usually the surface of the pool is as smooth as a mirror, and only at rare intervals does it present a light agitation near the center. To interrupt that state between placidity and anger, no other provocation is needed than to toss in a stone.[36] Then the waters boil violently for a moment and rush over

Figure 3: *Crater of the Grand Geyser. [Translators' note] The crater in Leclercq's engraving looks much more like that of Grand's neighbor Turban Geyser, which contains globular masses resembling Turkish headpieces.*

the edges of the basin, scalding the feet of any impertinent person not quick enough in getting away.

Continuing our promenade along the left bank of the Firehole, we came upon the Washbowls. They comprise a group of small pools 2 or 3 meters in diameter, with solid tubing that connects them to the subterranean regions. Their strongly alkaline waters would please our laundresses: after remaining in the water a few minutes, linen comes out white as snow.[37]

Passing near this natural laundry, I could not resist the temptation to engage in a conscientious laundering. I ran to get everything that needed a soaping and plunged the bundle into the washtub; but at the moment when I was about to take it out, I realized that the things were going down the central vent, drawn in by a mysterious suction, and, before I could retrieve them, the basin emptied out in the way that the convivial cup of Tours wine was emptied down the gullet of Grandgousier, *uno haustu*.[38]

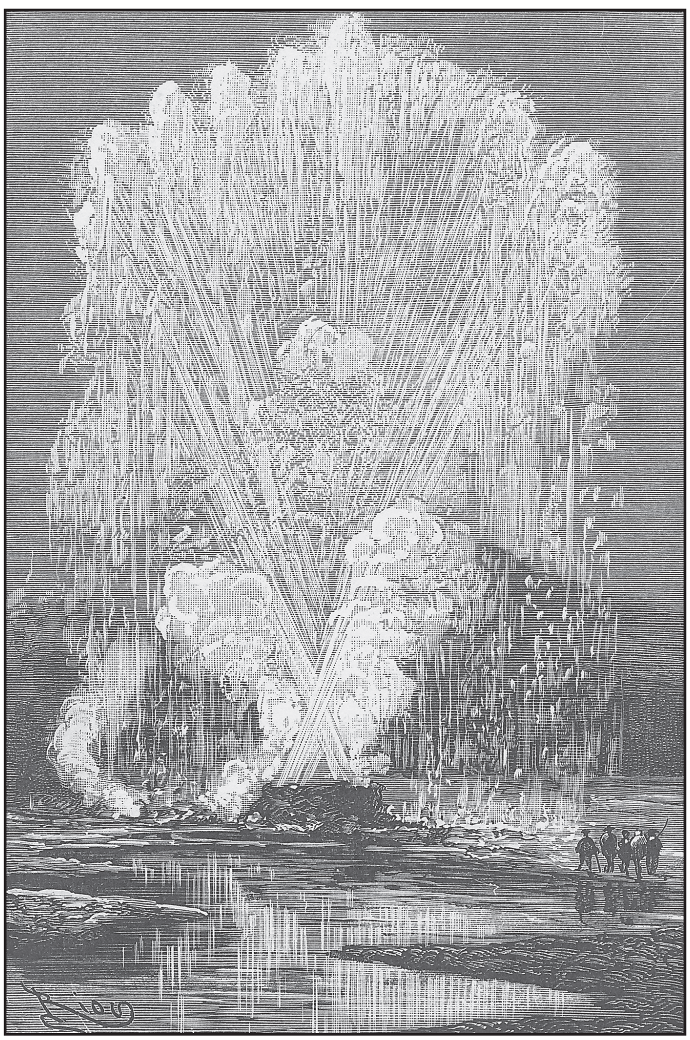

Figure 4. *The Fan.*

Unfortunately, I had no other course of action but to patiently wait for my pilfered things to be restored to me. When I returned two hours later, I found happily that I was dealing with an honest rogue. The linen was washed like new, and it was all there to the last piece. However, beware the Washbowls!

A little farther along, the majestic broken crater of the Giant emerges from the bosom of the plain like a horn whose mouthpiece is turned toward the sky. This 3-meter-high cone is breached from top to bottom on the north side, as if an exceptionally violent eruption had carried away a portion of it. The gap allows one to see the interior walls of the edifice, which display encrustations rather similar to inlaid work: it is a brilliant mosaic, resplendent with saffron yellow, crimson red, and emerald green. Leaning over the edge of the breach, one casts one's eyes down into the chasm, resounding with the noise of the waters boiling in its deep cavities.

An eruption of the Giant is an imposing phenomenon, according to travelers who have had the joy of witnessing it. This geyser projects a column of water 60 meters high and 2 meters in diameter straight into the air. One can appreciate the volume of water produced by an eruption of the Giant if one knows that the Firehole is more than doubled by it, although at this place it has a very rapid current and a width of 30 meters. In the vicinity of the Giant there is a multitude of little springs that throw out water and steam. These springs cease their work only when their powerful neighbor is active. One could call them safety valves that are sometimes insufficient to their task. Among them is a little geyser known by the name of Young Faithful [Bijou]; opening up on the top of a mound of geyserite, it is constantly in a state of great agitation and throws out irregular jets in all directions, which earned it the epithet Stupid Spitter from my friend Clarke.

Within an arrow's range of the Giant is a crater that is by far the most curious of all that emerge in the Firehole basin. It is called the Grotto. Under arches of a fantastic architecture open up caverns that function as lateral openings during the geyser's eruptions. Their interior walls are adorned with granular opalescent concretions that evoke the image of a palace of pearls.

The insane inspiration to enter one of these caverns came to me. It is a good thing that all I did was take a quick glance, because, no sooner was I again outside than the fountain began to erupt.

There is nothing more picturesque than the play of the Grotto's waters. Two quite distinct jets escape from different orifices; the larger one rises to 8 or 9 meters; both scatter into spray at a certain height, intermingling and falling back in a rain of droplets on which a rainbow projects its magical glitter. The phenomenon lasts about half an hour and repeats regularly at six hour intervals.

My admiration had not had time to cool when another geyser 300 meters away on the other side of the river had an outburst in its turn. I dashed over to it, just in time to see the most graceful play of water that I had yet encountered. Its name is the Fan. Imagine a group of several small geysers whose separate vents have a common crater and discharge all at once. The different vents, diverging from the vertical to a greater or lesser degree, radiate toward a single center; as a result the sheet of water spreads out like a fan. This performance surpasses the most ingenious combinations of water in the fountains of Versailles.[39] During the eruption, a small neighboring geyser launched an oblique jet as grotesque as the spray of the Fan is graceful.[40]

Figure 5. *The Comet. [Translators' note] Leclercq mentions seeing Splendid erupt but not Daisy or Comet, yet he presents an illustration that seems to be of a dual eruption of Splendid and Daisy and labels it "The Comet." See Note 41.*

As I was returning to the campsite, the Splendid gave me a show of its eruption from a distance; its emotion calmed at the moment I arrived. This geyser is relatively recent. According to Hayden's account, in 1871 it appeared to be an extinct geyser, giving no other sign of life than a plume of steam. Since 1881 it has entered a new period of activity; rivaling Old Faithful in its regularity and in the height of its jet, the explosion occurs at three hour intervals and lasts five to ten minutes. The name Splendid was given it by Colonel Norris; others call it the Comet or the Pyramid. Each traveler thus names the geysers according to his fancy, and a regrettable confusion results: sometimes several geysers receive the same name from different travelers.[41] In the Firehole basin there are two "Comets," three "Fountains," and I do not know how many "Paint Pots." One should keep to the designations of the *Geological Survey*.

A bath in the Firehole ended the day. By a superb sunset I plunged into the famous river of the Holes of Fire. It is well named, because even its bed is riddled with springs of boiling water,[42] as I learned at my own expense. While I was attending to my ablutions, I noticed more than once abrupt elevations of the water temperature when I encountered hot currents: thus it happened that I passed suddenly from 16° to 45° centigrade [61° to 113° F].

During the night one of those horrifying storms that are almost daily occurrences in this corner of the globe broke out. The wind and rain raged to the point where our tent would inevitably have fallen over had it not been equal to the test of the storm.

[We omit Chapters XII, "Land of Wonders and Land of Ice" and XIII, "Theory of Geysers," which respectively compare Yellowstone to Iceland and give geyser theories developed by several early European and American scientists.]

Chapter XIV
Excelsior

The middle basin. – The Devil's Half-Acre. –
The Excelsior Geyser. –
The largest geyser in the world. –
Formidable eruptive force. –
A lake of boiling water. –
The lower Firehole basin. – Enthusiasm. –
The Mud Caldron. – A post office.

On September 3, we resumed our route north with the aim of visiting the geyser groups known as middle basin and lower basin.

At a distance of 8 or 9 kilometers we reached the middle basin, located halfway between the two others [Midway Geyser Basin is roughly halfway between Upper and Lower geyser basins]. We picketed our horses and explored the portion of this infernal country known by the suggestive name of the Devil's Half-Acre.

Crossing a fragile wooden bridge spanning the river, we climbed the high ramparts of geyserite dominating the left bank of the Firehole, and we soon found ourselves before the enormous gaping crater of the geyser Excelsior.

Peering into the abyss, one cannot avoid an unspeakable terror. We were at the edge of the most powerful eruptive spring not only in America, but probably in the entire world;[43] next to it, the Giant, the Giantess and the Grand geysers are nothing but dwarves!

Formidable in appearance, the orifice of the basin measures more than 75 meters in diameter. Its vertical walls have a layered structure that attests to its recent origin. The edges of the crater are so undermined by eruptions that they overhang the chasm. We only ventured near with much circumspection for fear that the siliceous crust, yielding under our weight, would drag us down into the dreadful caldron. The waters are in a state of violent boiling; one feels the ground tremble underfoot, and one instinctively recoils in dread.[44]

Hot puffs of steam escape from the chasm, and it is only when the breeze disperses them that one can catch sight of the blue expanse rippling like a sea 6 or 7 meters deep.

The crater opens out at the river bank, giving issue to the immense sheet of boiling water that pours over the terraces in an infinity of rivulets filled with fine, silky, bright yellow filaments, which the current agitates in a vibratory motion. This vegetation, formed by sulphurous deposits, is so delicate that it crumbles away between the fingers.

Nothing is more marvelous than the variety of hues assumed by the layers of geyserite: scarlet red, pink, and yellow gold blend against a snow-white background.

At the spot where the waters escape from the basin, we measured a temperature of 80° centigrade [176°F]; it was impossible for us to determine the prevailing temperature in the center of the basin, which must be much higher.

In 1880 the Excelsior revealed itself to be a stupendous geyser. Since no one had seen it play previous to that date, it was thought to be a simple hot spring. Hayden, who visited it in 1871, gave it the name of Caldron without suspecting that it was an eruptive spring.

Colonel Norris, superintendent of the National Park in 1880, reported the first eruption of the Excelsior. He was more than two leagues away when he heard the noise of the explosions. He arrived in the area too late to witness the phenomenon, but he was able to observe its staggering effects: the flood of boiling water had so swollen the Firehole that several bridges located downstream had been swept away and were adrift.

That year, the eruptions were exceptionally violent. They caused earthquakes and covered the whole valley with a haze of dense vapors. This period of activity lasted several months. The phenomenon took place daily. The first times it happened around ten o'clock in the evening, but since it occurred later each day by several minutes, at the end of nine months, it was twelve hours later–at ten o'clock in the morning–that the explosion occurred.

The eruptive force of the Excelsior Geyser is hardly believable. According to the testimony of Colonel Norris, a column of water would spout 100 to 300 feet high and with such a volume of water, that the Firehole, which is almost 100 yards wide at this spot, churned as a mass of steaming water. The geyser would launch into the air and scatter far and wide chunks of rock weighing up to 100 pounds.

On August 28, 1881, General Sheridan witnessed an explosion of the Excelsior:[45] a column of water forming a compact mass 60 to 75 feet in diameter was projected to the prodigious height of 300 feet, and the vapors rose more than 1000 feet into a pure, cloudless azure sky.

One year later, on August 22, 1882, Messrs. Haupt and Eccleston had the good fortune to arrive in front of the Excelsior at the very moment when the geyser was preparing to erupt. Dull subterranean rumbles warned them of the phenomenon, and they prudently kept at a distance. Suddenly, they saw a column of water shoot up with a noise of an underwater explosion, rising to several hundred feet. After some seconds they heard the crash of chunks of rock falling back to earth and saw an enormous cataract of boiling water rush down the sides of the crater and descend into the river. The eruption lasted only a few minutes.

In 1883 the Excelsior seemed to have retreated into a period of repose. According to the testimony of local people, it would only spout every now and again. Quite rare are those who have been able to see the power of this formidable aqueous volcano. Of all the geysers spouting on the banks of the Firehole, there is none whose eruptions have more terrible effects. The rock in the walls of its tube being less compact than that of other geysers, it breaks up under the impact of the explosive force. It is for this reason that the Excelsior has the dangerous habit of belching out pieces of rock: the ground is strewn with them to a radius of more than 200 meters surrounding the crater.

Almost beside the biggest geyser in the world, nature has placed its most gigantic hot spring [Grand Prismatic Spring]. It occupies the summit of a mound formed of siliceous deposits tiered in lamellate terraces on the left bank of the Firehole, as high as 15 meters above the level of the river.

As we were climbing these terraces, walking gingerly between the pools and the cascades of boiling water, we were struck by the extraordinary resonance of our steps: it seemed as if the ground were completely undermined.

What an unexpected scene was revealed when we reached the top of the terraces! We were facing a lake of boiling water extending over not less than half a hectare! Mute with amazement and astonishment, we gazed upon this expanse of steaming sapphire-colored water so surpassingly transparent that the thousand fantastical forms on the festooned walls could be distinguished under the crystal liquid. The aqueous layers take on a more and more intense blue color as the eye penetrates deeper into the abyss. Several meters from the edge one loses sight of the bottom of the basin, and the dark color of the water indicates unfathomable depths that are concealed from view. Toward the center of the basin, the water rises several inches high as it boils; agitated by an undulating motion, it regularly spills over from all sides above the curiously festooned siliceous ring with reddish tones that lightly protrudes around the basin. The suspended mineral matter is constantly being deposited, forming a succession of terraces in an incomparable richness of color.

An immense mist of hot vapors rises continually from the bosom of this marvelous expanse of water. Nary a bird glides above it; no tree grows on its banks. Words fail to describe the country surrounding it, sublime in its desolation and nakedness. And yet I need only close my eyes to see it again, for it is unforgettable.

Continuing on our way, toward noon we reached the lower basin of the Firehole, a large valley two leagues wide, totally riddled with springs of boiling water. Hayden estimated their number at 693 and counted 17 active geysers in addition. The average elevation of the basin is 2205 meters, and wooded hills of 200 to 300 meters overlook it. There we observed phenomena that held no more novelty for us, who had just been contemplating the most beautiful geysers in the world. Bedazzled, intoxicated on marvels, and inured to astonishment and enthusiasm, we had only a distracted and disdainful eye for the springs and geysers grouped in the lower basin.

The Mud Caldron alone was able to reawaken our blasé curiosity. This curious basin [Fountain Paint Pot] contains a sort of white siliceous paste rather reminiscent of plaster in the hands of the molder. The paste, half solid and half liquid, is in extreme agitation; it swells up and splashes in bubbles constantly bursting at its surface, and this bubbling activity produces a thousand bizarre figures: globules, sugar loaves, and rings. Sometimes masses of paste are even projected into the air, but their weight prevents them from rising very high like the light showers of the geysers; they fall heavily back, spattering the edges of the caldron. All around this singular laboratory, the ground resembles porcelain paste.

We supped at the log house next to the lower basin, at the confluence of the two branches of the Firehole. We were pleasantly surprised to find a post office there run by the travelers themselves: always practical, these Americans! I took advantage of it to let my family know that I was in wonderful health deep in the Land of Wonders.

The place from which I dated my letter is the very site where a caravan of travelers was attacked by Indians in 1877. It is one of those stories that trappers of the Far West are fond of telling around a campfire, and it constitutes one of the most moving pages in the history of the explorations of the National Park.[46]

Acknowledgments

It might be in order to write a word about how the translators happened to find and translate *The Land of Wonders*. A few years ago, after purchasing a copy of the 1886 book in France and reading it with pleasure, Janet Chapple translated and considered including some chapters in *Magnificent Playground*, an anthology of early Yellowstone writings she has assembled. To accomplish the translation of the Leclercq chapters, she was ably assisted by Suzanne Cane, who soon became equally enthusiastic about Leclercq's writing, and they later decided to work together on a translation of the entire book. Lee Whittlesey endorsed the project and gave them the material he had acquired from its two previous translators.

Janet Chapple and Suzanne Cane are indebted to Christine MacIntosh, who translated Chapters VII, VIII, IX, and X (and many others) for Lee Whittlesey in the 1970's. Her work has been incorporated into theirs with her gracious permission. Elizabeth A. Watry translated Chapter XIV more recently and also kindly gave permission to consult her version. Additional editorial help came from Elizabeth Jung; Evelyne Rossi served as language consultant; Bruno Giletti contributed geological advice; and librarian Ann Poulos from the Providence Public Library provided valuable reference services.

The Land of Wonders
Notes to Chapters VII-XI and XIV

1 Gibbon Geyser Basin was an alternate name for Norris Geyser Basin at the time of Jules Leclercq's visit.
2 Ferdinand Vandiveer Hayden led fact-finding expeditions through Yellowstone in 1871, 1872, and 1878. He and his scientific colleagues wrote voluminous illustrated reports after each expedition, and he also wrote several articles in a more popular style. Leclercq lists most of Hayden's writings in his bibliography, but he does not indicate which of them he is referring to in the text.
3 Twins, Triplets, and Fountain are geyser names not traceable to any features at Norris Geyser Basin, according to Park Historian, Lee Whittlesey. The other geysers Leclercq mentions here have changed or ceased their eruption patterns.
4 Since Leclercq's visit, Emerald Spring at Norris has occasionally been active as a geyser, with extraordinary activity in 1931. (Bryan: 284)
5 Dr. Albert C. Peale was the geologist with the Hayden expeditions of the 1870s. His 400-page report on the thermal springs of Yellowstone was one of Leclercq's most useful references.
6 Superintendent Philetus W. Norris served as park superintendent from 1877 to 1882. His annual reports have been invaluable resources for park historical researchers, as has the guidebook section of his book, *Calumet of the Coteau*. The honorific "Colonel" stems from his service on the Union side in the Civil War.
7 Steamboat Geyser, the tallest active geyser in the world, has erupted as high as 380 feet but is unpredictable, erupting relatively frequently in the 1960s and 1980s, but before and since then frustrating observers with intervals ranging from four days to fifty years.
8 Nimrod was a Mesopotamian monarch mentioned in the Old Testament book of Genesis; his name has become synonymous with a mighty hunter.
9 Monument Geyser Basin is on the northeastern flank of a now-nameless mountain about 8300 feet high. By Leclercq's time it had been named for Carl Schurz, Secretary of the Interior from 1877 to 1881, because he was very supportive of the National Park. However, in 1885 (soon after Leclercq's visit) the name was shifted by geologist Arnold Hague to the second highest mountain in the park (11,163 feet), one of the Absaroka Range peaks east of Yellowstone Lake. (Whittlesey: *Place Names*: 174, 181; USGS Trail Lake topographic map.
10 Monument Basin is one area in the park where the statement that activity was diminishing, proclaimed by many early observers, has held true for over one hundred years.
11 The water ouzel, now usually called the American dipper, is a small bird known for its cheerful song and for its fascinating habit of bobbing underwater to feed.
12 Many early visitors believed quite logically that the Firehole River was named from the boiling springs within and along it. Rather, the name was transferred before Yellowstone was a park from the Burnt Hole or Fire Hole, a burnt-over section of the Madison River Valley. (Whittlesey, *Place Names*: 105)
13 In these two paragraphs pertaining to the area from Gibbon Falls to Nez Perce Creek, Leclercq seems to blend a mention of the confluence of the Gibbon River and the Firehole River (at Madison Junction) with that of Nez Perce Creek and the Firehole about four-and-one-half miles farther south. Both the Gibbon and the Firehole are fed by "countless boiling hot springs." He probably crossed both Nez Perce Creek and the Firehole near their confluence to dine at the first Firehole Hotel, built on the west bank of the Firehole in 1880.
14 Conferva can be any of various filamentous green algae that form scum in still or stagnant fresh water.

[15] Old Faithful's intervals were never exactly 60 minutes apart, as many people believed, but it was surely the most regular and frequent geyser Leclercq would have seen. Although the eruptions have always been quite dependable, large variations from the average interval have often occurred.
[16] Gustavus Cheney Doane (1840-1892) commanded the military escort that accompanied the 1870 Washburn exploratory expedition and wrote an extensive report. He later returned to Yellowstone several times in a similar capacity and tried unsuccessfully to become superintendent of Yellowstone.
[17] The superheated water below Yellowstone's geyser basins does not exist as an unbroken expanse or "sea of boiling water" but rather occupies the ubiquitous fissures created as the still hot lava gradually cools and contracts.
[18] Yellowstone has no fir trees, and near the Firehole River Leclercq could only have seen lodgepole pines.
[19] Old Faithful Geyser was seen and named by members of the Washburn expedition.
[20] Leclercq's dimensions for Old Faithful apply to the entire structure, not just the cone. The engraving reproduced here will demonstrate to readers familiar with its present crater the destruction caused by vandals in the early years.
[21] Captain William Ludlow (1843-1901) made a survey of the Yellowstone region in 1875 and wrote an official report. (Ludlow: 36-37)
[22] Gen. Philip H. Sheridan (1831-1888), Civil War general and commander during wars with Indian tribes, visited Yellowstone on at least four occasions, wrote detailed reports, and was an important advocate for the protection of the park from commercial development, for the expansion of its boundaries, and for placing it under the control of the U.S. Army.
[23] The Bengal light was a type of flare used in the 18th C. for signaling and illumination.
[24] The towers of Notre Dame Cathedral in Paris are 226 feet high. According to Yellowstone researchers Allen and Day (Marler, page 138), in the 1870s Beehive reached a measured height of 200 feet or more several times. Beehive's eruption has a force that could well carry a hat aloft, but present-day visitors are not allowed to approach it closely enough to test that.
[25] Arnold Hague of the U.S. Geological Survey and other geologists referred to two types of geysers: cone-type geysers (like Beehive), which emit a steady column of water from a narrow vent, and fountain-type geysers (like Giantess), which throw out a series of bursts from a broad pool of water. Leclercq would have been aware of one or more of Hague's annual reports, which began in 1880, but he did not list them in his bibliography.
[26] The Barrière de l'Étoile consisted of two tollgates in the Wall of the Farmers-General around Paris. There taxes were collected on incoming goods. Built in 1787, they were destroyed in 1860.
[27] A number of early park observers have written about this halo effect of the sun and steam. It is an optical effect called a Spectre of Brocken, which occurs when the sun is in position to project someone's shadow onto thick steam or mist.
[28] Hayden, *Fifth Report*: 123.
[29] Giantess erupted on average 2 or 3 times per year around the turn of the 21st century.
[30] Captain William Ludlow included a map of Upper Geyser Basin along with his detailed report of a reconnaissance of the Yellowstone area made in 1875.
[31] Numerous early visitors to Yellowstone's geyser basins felt that they were near hell or the devil; others were reminded of Hades or of factory cities like Pittsburgh.
[32] The game of badminton was first played in Europe in the latter part of the 19th C., after being brought to England from British India.
[33] Guidebooks from the 1880s give Grand Geyser's interval as anywhere from 13 to 31 hours. (Marler: 111)
[34] Before Leclercq's visit, a few writers claimed that Castle Geyser occasionally erupted as high as 250 feet, but Henry Winser's 1883 guide, among others, mentions eruptions "100 feet or more." (Winser: 51)
[35] Herman Haupt, Jr. (1807-1905) published a detailed guidebook to Yellowstone in 1883.
[36] Any disturbance to a superheated pool like Crested Pool (the official name of this feature) will cause it to bubble.
[37] On the left bank and downriver from the Castle-to-Sawmill bridge across the Firehole are a few springs, where many early tourists washed their clothes (and sometimes dishes). These springs are now called the Terra Cotta Springs, but one has historically been called Washtub Spring and another, Dishpan Spring.
[38] Grandgousier (Big Gullet), father of Gargantua in the books about *Gargantua and Pantagruel* by François Rabelais published in the 16th century, was known for his voracious appetite. *Uno haustu*: at one draught.
[39] Versailles is a 17th century palace built near Paris by King Louis XIV of France. Among other things, it is known for its elaborate fountains that produce sculptures of water, created by the differing shapes of the many spouts, which cause the water to spurt up in bubbles, blades, tongues or sprays.
[40] In recent years, when Fan Geyser erupts, so does its neighbor Mortar. At the time of Leclercq's visit, Mortar was not named as a separate geyser. Fan's "small neighboring geyser" is probably Spiteful Geyser, active sporadically throughout Yellowstone's history.
[41] According to Marler, Dr. Hayden in 1878 gave the geyser we now call Daisy the name "Comet" and called the one we call Comet "Spray," both of Hayden's names being quite appropriate to their activity. It is not surprising that early observers were confused about the names of geysers in this group: the name Daisy was not used until at least 1884, while Splendid had been named by 1876; today's Comet is a near-perpetual spouter in the Daisy Geyser Complex. Leclercq's illustration labeled "The Comet" seems to be of a "concerted" or dual eruption of Splendid and Daisy. (Marler: 87-88; Whittlesey: 81, 235)
[42] The naming of the Firehole River is explained in Note 12.
[43] Only one geyser with eruptions more powerful than Excelsior's has ever been recorded, and those occurred after Leclercq wrote his book; on New Zealand's North Island, Waimangu erupted black mud, water and rocks up to 450 meters numerous times between 1900 and 1904.

[44] Throughout this chapter Leclercq frequently paraphrases Henry J. Winser's guidebook, published the year of Leclercq's visit. In his turn, Winser used information from Hayden's Fifth and Twelfth reports, including Peale's report in the former. Leclercq probably also read and used General Sheridan's report of his 1881 visit.

[45] Guidebook writer Edwin J. Stanley tells us that Excelsior was named by Colonel Norris, "but has since been named by others the `Sheridan,' in honor of that distinguished General, who recently visited the Park." (*Rambles in Wonderland:* 201)

[46] Young warriors of the Nez Perce tribe did attack, injure, and temporarily capture members of a tourist party near the confluence of present-day Nez Perce Creek and the Firehole River in 1877. However, "trappers of the Far West" were mostly gone from the area by that time.

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The Activity of Several Backcountry Geysers as Determined Through Automatic Data Logger Studies

Jeff Cross, Carlton Cross and Tara Cross

Abstract

From 1998 through 2009, several geysers in the Shoshone, Heart Lake, Lone Star and Gibbon Geyser Basins were monitored through the use of automatic data loggers. Data obtained via loggers is combined with data from literature sources and visual observations to describe the recent eruptive history of Glade Geyser, Double Geyser, Frill Spring, The Hydra, Buried Geyser, Phoenix Geyser and Avalanche Geyser.

GLADE GEYSER

Glade Geyser's first known eruption occurred on 13 July 1957. On that date, it was photographed in eruption by Avon Leeking (Leeking, 2001). Its activity prior to that date is unknown. Paperiello (1988) and Bryan (2008) have discussed the history of Glade Geyser between the date of its discovery and the present. In the 52 years that have passed since 1957, Glade has often been active. However, eruptions usually have been infrequent. In 1998, we initiated a study of Glade Geyser using automatic data loggers, placed under NPS permit.

We found that the average eruption interval, measured between 1998 and 2009 with automatic data loggers and during 1964, 1984 and 1996 by visual observation, is 24 hours. When Glade's interval was 7 hours or longer, it erupts in series. From 1995 through 2009, these series had total durations of 10 to 20 minutes and consisted of individual eruptions lasting around 2 minutes each. A few minutes of violent boiling and minor jetting separated the individual eruptions. Exceptionally short intervals of 35 minutes to 2.3 hours occurred in 1964 and 1996 through 1998. When Glade's interval was this short, it did not erupt in series. The durations of the single eruptions that occurred were around 2 minutes. The greatest height ever estimated for an eruption of Glade Geyser was 60 feet. The average height reported is 43 feet.

Visual Observations, 1964-2008

In 1964, Glade was seen in eruption by George Sanborn. He made three different reports of his observations. The most polished report was published in *Gems and Minerals* in 1975. The other reports are two personal letters written by Sanborn and sent to George Marler. One of these letters, written on 17 March, 1965, was discovered by Rocco Paperiello in the Yellowstone National Park archives. It is reprinted in Paperiello (1988). The other letter is quoted by Marler in his *Inventory* (1973). This letter refers to a correspondence between Sanborn and Marler in the fall of 1964 that has not yet been found. Each report quotes similar figures for the height, the duration, and the sound made by the geyser. However, Sanborn gives two different intervals for Glade's eruptions, and gives numerous different sizes for Glade's main vent.

Sanborn reports the height of Glade's eruption as 25 to 35 feet. The minimum duration given is 1 minute, and the maximum is 2.5 minutes. Some of this variation might be attributed to the inclusion of the steam phase as a part of the longer durations. Shorter durations could refer to the water phase only. Glade's eruptions in 1964 must have been noisy. In his *Gems and Minerals* article, Sanborn describes Glade's eruption as beginning with a "shrill whistling sound followed by a tremendous 'WHOOSH.'" He notes that Glade was "one of the most beautiful—and noisiest—geysers we had ever seen" and that the sound of the "violent" steam phase was "quite appalling." Similar, though less vivid, descriptions are made in both of Sanborn's letters to Marler. In contrast, all eruptions of Glade that we have seen from 1996 through 2008 were fairly quiet.

Glade's main vent is about the same size today as it was in 1964 when Sanborn made his observations. In his 1965 letter to Marler, Sanborn says that Glade's vent "is approximately a foot in diameter and two feet long" (Sanborn, in Paperiello, 1988). White (1973) states that Glade "erupts nearly vertically from oval vent (1.0 x 1.7 ft) [12 by 20 inches] in

Glade Geyser erupting on August 20, 2008, at 1445. Photo by Carlton Cross.

altered glacial till; small 6" x 10" vent 1½´ to NE, not participating in eruption." Paperiello (1988) gives the size of Glade's main vent in 1986 as 13 by 21 inches and the side vent as 6 by 10 inches. In 2006 Glade's main vent was measured at 10 by 18 inches and the side vent at 6 by 9 inches. The differences in these measurements are slight, and indicate that Glade's vents did not enlarge in the 42 years that separate the earliest measurement from the latest.

If Glade's main vent has remained the same size throughout its known history, why do several prominent references (Paperiello, 1988; Bryan, 2008) suggest that it has been rapidly enlarged since 1964? This error can be attributed to Sanborn. Not only does he confuse the size of the main vent with that of the side vent, but he is also inconsistent in reporting his figures—already wrong—for the size of the main vent. In his *Inventory* letter, Sanborn states that "the orifice of the geyser is extremely small, perhaps eight or nine inches across." In his *Gems and Minerals* article, he states that Glade erupts "from an orifice hardly 6 x 12 inches." Later, in the same article, he quotes White (1973) as saying that the main vent in 1964 was 6 by 9 inches. This doesn't match the figure of 8 by 9 inches actually given by White as the size of Glade's main vent in 1964. Because Sanborn knew the correct size of Glade's vent in 1964 (see above), it seems likely that he gave White incorrect data, and then misquoted White. Sanborn also omits the final section of White's description of Glade, where White gives his own—correct—measurements of Glade's vents (see above). Because Sanborn's *Inventory* letter and his *Gems and Minerals* article are widely circulated, his errors have been perpetuated.

Sanborn also gives conflicting figures for the interval of Glade. In his 1965 letter, Sanborn states that "during an approximate two hour stay… the geyser [Glade] was observed in eruption several times—with an estimated interval of from 10 to 20 minutes." However, in his 1975 *Gems and Minerals* article, Sanborn gives the interval as 35 minutes. In his *Inventory* letter, he says that the 35-minute interval was "astonishingly accurate." This implies that he was very certain of the 35-minute figure, but it does not explain how he could have estimated the interval at 10 to 20 minutes a decade earlier. The 35-minute figure is found in the *Inventory* letter and in the *Gems and Minerals* article. Because these references are widely circulated, the 35-minute interval is quoted in Paperiello (1988) and Bryan (2008). Unfortunately, no other evidence from the period around 1964 is known to exist at this time. It is presently impossible to criticize the 35-minute interval any further.

In 1973, White (1973) reported the following data on Glade: "Present interval about 40 to 60 hrs.; eruption consists of 2 phases of ~2 min. each separated by as little as 10 min. or as much as a few hrs."

In 1974, Sam Martinez (1974) observed a pair of eruptions 8 minutes apart. The first eruption lasted 56 seconds and the second lasted 113 seconds. The maximum height was 50 feet.

In 1984, Bryan (2008) reported cyclic activity. The time required for a full cycle was 18 hours. The eruptive series began with minor eruptions reaching 30 feet high and lasting up to 10 minutes, occurring every 2 to 3 hours. The series concluded with a major eruption that reached 60 feet high and lasted for 20 minutes. This is the sole reference to Glade erupting in series with minor eruptions preceding a major eruption. This reference and White (1973) are the only sources to report eruptions occurring on hours-long intervals within a series. All other references to series report that the eruptions follow each other by a few minutes.

In 1986, Paperiello observed several eruptions of Glade (Paperiello, 1988). The eruption on 30 August 1986 was brief, at "less than 2 to 3 minutes." On 30 August 1986, two eruptions occurred on an interval of less than 7 hours. On 18 October 1986, the interval was over 24 hours. On 28 June 1987, one interval was at least 24 hours.

In 1989, Paperiello observed a single eruption of Glade lasting 1.5 minutes and reaching 35 feet high (Paperiello, 1989). From then until 1995, only sporadic reports were made in *The Geyser Gazer SPUT*, usually referring to the dormant state of Glade during those years.

In September of 1995, Murray observed a series of eruptions from Glade. Five eruptions, coming at intervals of 3 to 7 minutes and lasting 2 minutes each, occurred over a period of 21 minutes (Murray, 1995). Heights were 50 feet for the first two eruptions and 30 feet for the last three eruptions. Glade surged frequently between the individual eruptions.

In July of 1996, Leeking recorded a double interval of 2 x 136 minutes (Leeking, 1996). In August of 1996, we witnessed a pair of eruptions of Glade. The second eruption began 5 minutes after the first one started. The first eruption lasted less than 125 seconds and the second eruption lasted 16 minutes for a total duration of 21 minutes. The height was 33 feet for the first eruption and 23 feet for the second. In September of 1996, Paperiello and Leeking estimated an interval of 8 to 10 hours for Glade (Leeking and Paperiello, 1996). They observed one eruption lasting 2 minutes and reaching 50 feet.

In 1997, Glade became very active. On 08 July 1997, Paperiello saw Glade erupt to 45 feet for a duration of 3 to 4 minutes. The following interval was noted at less than 7 hours. Then, on 02 August 1997, we found Glade erupting every 65 to 68 minutes. The average of 3 closed intervals plus 1 triple interval was 66.9 minutes. The five eruptions seen lasted from 109 to 127 seconds each, and averaged 121 seconds. The height was 46 feet.

On 02 July 1998, Paperiello (1998a) recorded Glade's average interval at 85 minutes. On 08-09 July 1998, we obtained 3 intervals of 78, 95 and 97 minutes, with an average of 90 minutes. Durations at that time were 106 to 137 seconds and the height was 49 feet. A data logger, under NPS permit, was placed on Glade in 1998. It showed that Glade erupted every 75 to 105 minutes, with an average of 90 minutes for 66 intervals obtained. Keller saw Glade erupt in late July-early August and recorded 4 intervals of 68 to 102 minutes (Keller, 1998). Durations were 130 to 159 seconds and heights were 35 feet. Glade was observed again on 07 September 1998, erupting to 45 feet for 2 minutes (Baker, 1998). On 08 September 1998, Glade had an interval of 134 minutes (Murray, 1998). On 02 October 1998, Glade's interval was over 2 hours (Paperiello, 1998b). Paperiello suggested that Glade's interval may lengthen during the autumn season. This hypothesis has not yet been confirmed or refuted.

On 11 July 1999, Keller (1999) reported an interval of "2.5 hours or so," a duration of "just over" 2 minutes and a height of 45 feet. On 05 September 1999, Murray (1999) estimated an interval of more than 6 hours.

On 20 July 2003, Paperiello (2003) observed an eruption that reached 40 feet high and lasted for 15 minutes. In 2003, Murray witnessed a series of eruptions that occurred on intervals of 5, 6, 6 and 16 minutes (Murray, 2003). Glade boiled violently throughout the series. The final eruption concluded with a steam phase, and then Glade boiled at depth for over an hour. On 04 August 2003, Moats (2003) observed an eruption that reached 40 to 50 feet.

On 28 July 2008, we observed a series of Glade eruptions, occurring over a period of 14 minutes. Intervals within the series were 4 and 7 minutes. Durations were > 114 seconds for the first eruption, 143 seconds for the second, and 135 seconds for the third. Heights were 40 feet for the first eruption, 25 feet for the second and 10 to 20 feet for the third.

Logger Studies 1999-2009

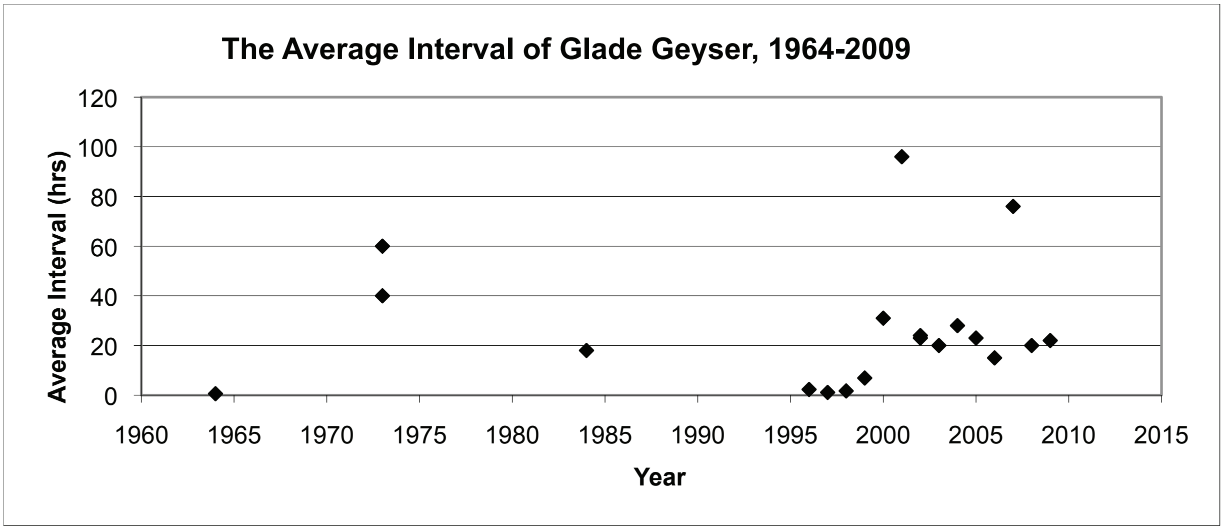
Data logger studies from 1999 through 2009 show that during those years, Glade erupted about once per day, with several exceptions. In 2001, the average interval was 4 days, in 2007 the interval was 3 days, and in 2006 the average interval was 15 hours. This data, together with the visual data from

Table 1: Observations of Glade Geyser, 1964-2009

Year	Average Interval (hours)	Interval Range (hours)	Standard Deviation	n	Duration Range (minutes)	Maximum Height (feet)	Source
1957	First known eruption on 13 July						Leeking (2001)
1964	0.58				1 to 2.5	35	Sanborn (1975)
1973		40 to 60			2	42	White (1973)
1974					0.9 to 1.9	50	Martinez (1974)
1984	18				(minor) 10	30	Bryan (2008)
					(major) 20	60	
1989					1.5	35	Paperiello (1989)
1995					21	50	Murray (1995)
1996	2.3						Leeking (1996)
1996					21	33	Cross, personal observation
1996					2	50	Leeking and Paperiello (1996)
1997					3 to 4	45	Paperiello (1997)
1997	1.1	1.1		6	1.8 to 2.1	46	Cross, personal observation
1998	1.4			3	2		Paperiello (1998a)
1998	1.5	1.3 to 1.6		3	1.8 to 2.3	49	Cross, personal observation
1998	1.5	1.3 to 1.8	0.072	66	2		Logger
1998		1.1 to 1.7		4	2.2 to 2.7	35	Keller (1998)
1998					2	45	Baker (1998)
1998	2.2			1			Murray (1998)
1999					2	45	Keller (1999)
1999	6.9	4.4 to 9.6	0.22	20	15		Logger
2000	31	27 to 38	0.12	8	20		Logger
2001	96	56 to 127	0.25	10	15		Logger
2002	23	20 to 26	0.089	10	20		Logger
2002	24	14 to 33	0.13	44	20		Logger
2003					15	40	Paperiello (2003)
2003	20	17 to 23	0.096	11	15		Logger
2003						50	Moats (2003)
2004	28	25 to 31	0.11	4	20		Logger
2005	23	19 to 27	0.11	23	15		Logger
2006	15	12 to 23	0.12	24	15		Logger
2007	76			1	20		Logger
2008	20	17 to 24	0.1	27	20		Logger
2008					14	40	Cross, personal observation
2009	22	13 to 30	0.185	24	13		Logger
average	24				average	43	

Note: The 1964-2009 average is calculated by taking all the 1998 data as a single value, which is 1.7 hours.

Note: For series eruptions during the 1990s and 2000s, the total series duration is used.



Graph 1.

1964 through 1997, is summarized in Table 1 and is shown graphically in Graph 1. White (1973) provided no average series interval, so the extremes of 40 and 60 hours are shown.

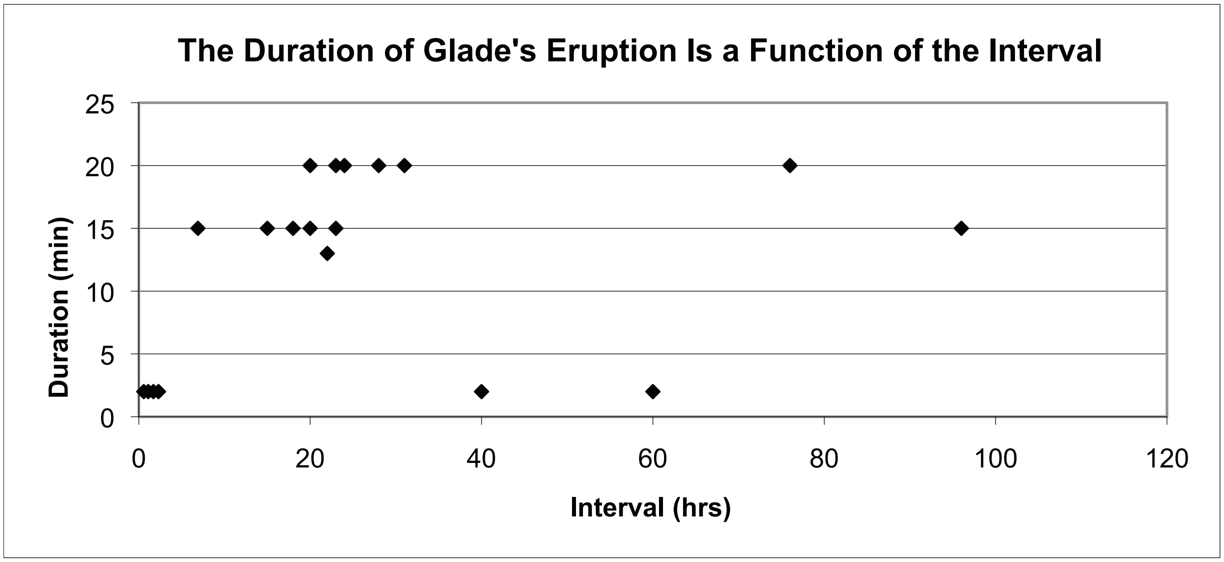
Glade's durations are bimodal. They can be determined accurately only by visual observation. Durations have frequently been reported at either 2 minutes or 10 to 20 minutes. Many of the longer durations are described as a series of individual eruptions (see above), each individual eruption having a duration of around 2 minutes. Total durations can be approximated from the data logger record: 15 to 20 minutes from 1999 through 2008; and 13 minutes in 2009. The logger data obtained during the 13 to 20 minute long-mode durations often shows multiple temperature spikes. It is likely that each spike represents a single eruption that is part of the series. In one observation on 28 July 2008, the temperature record shows three temperature spikes that correlate with the three eruptions that were observed on that day.

The total duration of Glade's eruption is related to its interval. When intervals are long, as has been true for most of Glade's history, the total duration is long and series occur. When intervals are short, the total duration is short and series do not occur. Graph 2 shows that the average duration from 1964 to 2009 was long when the interval was at least 7 hours. At intervals of 2 hours or less, the duration was short. White's 1973 data forms the sole exception to this generalization because White (1973) cites intervals of 40 to 60 hours but cites no total durations longer than 2 minutes. Note, however, that his description of the second eruption sometimes following the first after an interval of 10 minutes is very similar to the series noted in visual observations between 1995 and 2008. The delay of a few hours until the second eruption is unique to his observations. Bryan's (2008) data from 1984 are presented in Graph 2 for the major eruption only. His observation of minor eruptions leading up to a major is unique.

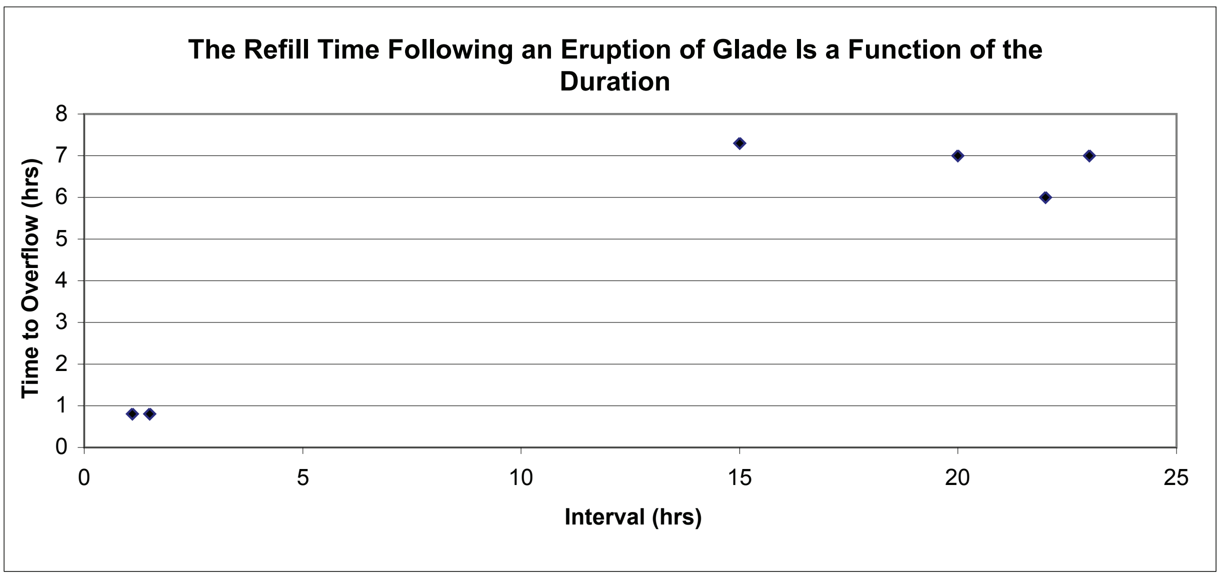
Is it possible that Glade may have minor eruptions prior to a major eruption, like the ones Bryan (2008) saw in 1984? The temperature record from 1998 through 2009 contains no clear evidence of this type of activity. Frequently, the time prior to an eruption of Glade is interrupted by many temperature spikes of short duration. Visual observations, when checked against the data logger temperature record in 1998, showed that Glade's splashing preplay is sufficient to account for these spikes.

It is likely that the subsurface plumbing of Glade contains two reservoirs. The primary reservoir participates in every eruption, and is exhausted in 2 minutes. The secondary reservoir participates only in eruptions that follow long intervals. After the primary reservoir is exhausted, the secondary reservoir supplies it with hot water so rapidly that it is recharged in only a few minutes and erupts one or more times following the initial eruption.

Glade has been dormant on several occasions. Two dormancies noted by Paperiello (1988) occurred in March, 1985, and September, 1987. Another dormancy, occurring during 1993 and 1994, is cited by Bryan (2008). It is very easy to miss the signs of eruptive activity at Glade. Many reports of dormancy could refer to periods of very long intervals.



Graph 2. Glade's duration is 13 to 20 minutes when the interval is at least 7 hours. When the interval is 2 hours or less, the duration is around 2 minutes.



Graph 3. Glade Geyser requires 6.0 to 7.3 hours to refill following a long-duration eruption. It requires 48 minutes to refill following a short-duration eruption.

Data collected in 1997 from visual observations and in 1998, 2005, 2006, 2008 and 2009 from the data logger record shows that, following a long-duration eruption, Glade requires 6.0 to 7.3 hours to refill. Following a short-duration eruption, Glade requires about 48 minutes to refill. This data is shown in Table 2 and Graph 3.

Table 2. The refill time of Glade Geyser.

Year	Interval (hours)	Refill Time (hours)
1997	1.1	0.8
1998	1.5	0.8
2005	23	7.0
2006	15	7.3
2008	20	7.0
2009	22	6

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FRILL SPRING

Frill Spring is one of the most enigmatic geysers at Shoshone Geyser Basin. That Frill erupts in series was known as early as the 1970s (Bryan, 1979). However, it was not until the late 1990s that Frill's activity pattern was fully discovered through the use of automatic data loggers, placed under NPS permit.

Frill was observed in eruption during 1994, 1996 and 1997. In 1994, Murray (1994) reported a series of eruptions lasting in excess of 5.5 hours. Individual eruptions occurred every 10 to 14 minutes, lasted from 11 to 38 seconds and reached heights of 25 to 30 feet. The shallow pool uphill from Frill (mapped as Paperiello #30/USGS #46 in Paperiello, 1989) stopped overflowing during Frill's eruptive series. Frill drained 5 feet after the series ended. Frill and the shallow pool uphill refilled at the same rate following the end of the series.

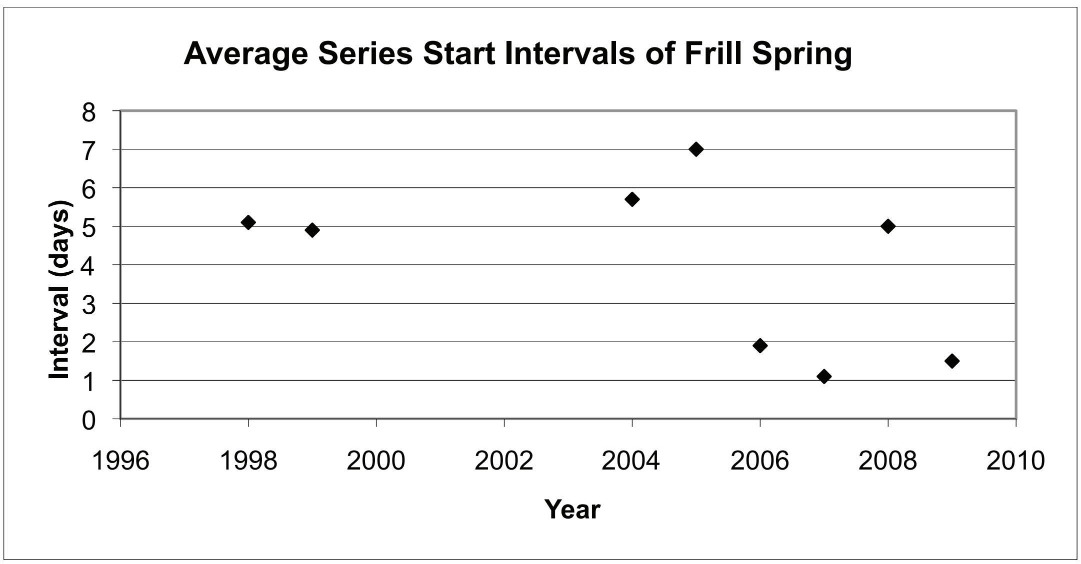
In 1996, Frill was again observed in eruption. Paperiello and Leeking (1996) reported a series of eruptions lasting in excess of 5.8 hours. Individual eruptions occurred every 10 to 15 minutes. Frill boiled violently while the series was in progress. When the series ended, the water drained 4.5 feet.

In 1997, we observed a series of Frill Spring. The series began during a violent thunderstorm. It lasted for a total duration of 2.8 hours, which was much shorter than other known series that occurred during the late 1990s. During the series, 12 individual eruptions reaching up to 23 feet high occurred on intervals of 5.6 to 15 minutes with an average of 11 minutes. Durations ranged from 7 to 21 seconds with an average of 17 seconds. Frill became placid and drained 3 feet following the series.

An automatic data logger, placed under NPS permit, showed that during 1998, 1999, 2004 and 2005, Frill's eruptive series occurred every 3.8 to 7.9 days, with an average of 5.5 days, as shown in Graph 4 and Table 3. Series lasted from 4.8 to 11.1 hours (Graph 5), with an average of 8.1 hours. Each series consisted of 15 to 54 eruptions, and averaged 37 eruptions (Graph 6). Within each series, intervals between individual eruptions tended to lengthen as the series progressed. For individual eruptions within a series, the average interval was 13 to 14 minutes

Table 3. Observations of Frill Spring, 1998-2009.

Year	Average Series Start Interval (days)	Min	Max	n	Average Duration of Series (hours)	Min	Max	n	Average Eruptions per Series	Min	Max	n	Average In-Series Interval (minutes)
1998	5.1	4.2	5.6	3	10.2	8.6	11.1	4	48	45	54	4	13
1999	4.9	4.1	5.5	5	8.9	7.2	10.1	7	40	34	43	7	13
2004	5.7	3.8	7.5	7	6.6	4.8	8.3	8	29	15	39	7	14
2005	7	6.0	7.9	2	7.3	5	8.9	3	31	23	39	3	14
2006	1.9	0.5	4.6	10	1.9	0	4.8	10	5	1	16	11	13
2007	1.1	0.2	2.6	4	1.1	0	3	4	4	1	8	5	16
2008	5	4.3	5.7	2	5	2.3	3.3	3	7	7	8	3	22
2009	1.5	0.3	4.2	12	0	0	0	12	1	1	1	13	



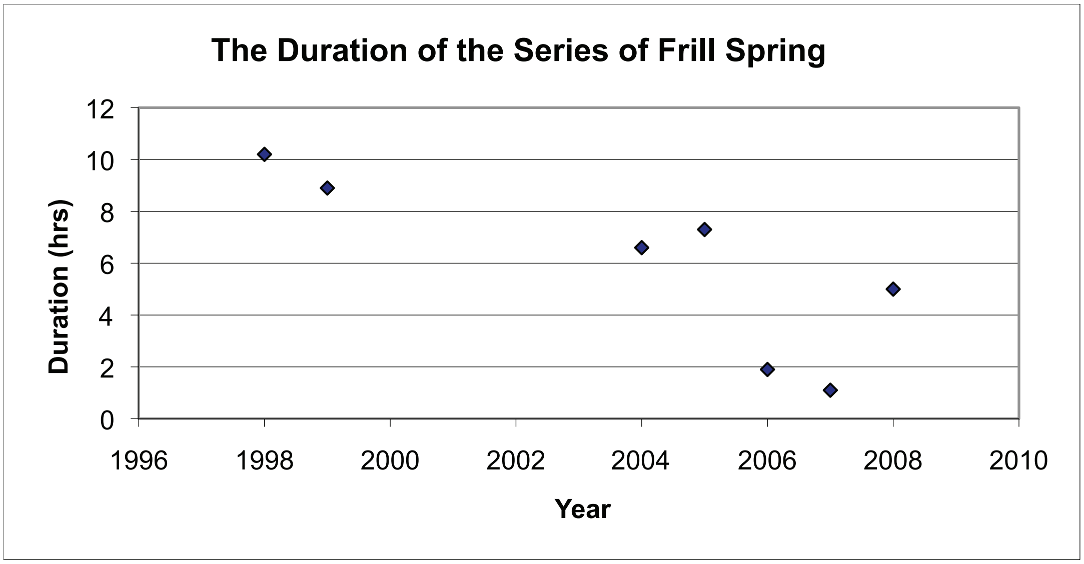
Graph 4.

(Graph 7).

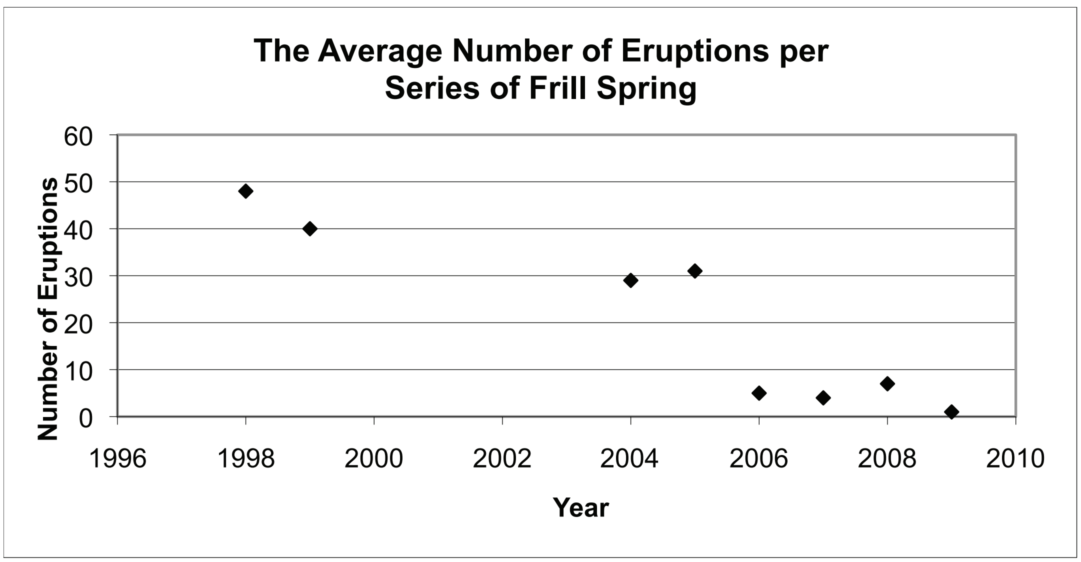
Frill Spring was certainly dormant in 2000. Frill was not monitored during 2001 through 2003. Based on a lack of wash around the crater, Frill was probably dormant during those years. In 2004, renewed activity caused fresh wash and we resumed our monitoring studies.

In 2006 and continuing through 2007 and 2008, the activity changed. Brief series consisting of only a few eruptions became common. At the same time, the interval between series starts shortened considerably. During 2006 and 2007, series occurred every 1.9 and 1.1 days, respectively. In 2008, the interval between series starts increased to 5 days. However, the number of eruptions per series did not increase to its pre-2006 value, and the in-series interval, which had remained very constant with yearly average values of 13 to 16 minutes, increased to 22 minutes (Graph 7). In 2009, Frill was still active, but the activity consisted entirely of single eruptions separated by 0.3 to 4.2 days, with an average of 1.5 days.

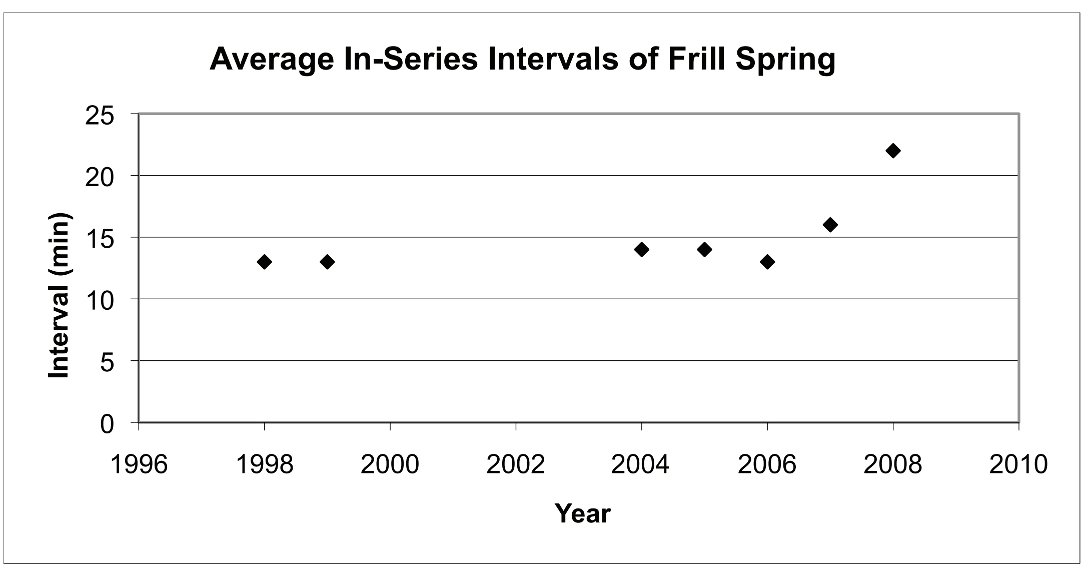
The events leading to an eruptive series of Frill have been infrequently reported. When in between series, Frill overflows every few minutes. All attempts to correlate the strength and frequency of these overflows with imminent eruptive activity have failed. In 2006 and 2007, we were fortunate to witness the start of two series. Each observed



Graph 5.



Graph 6.



Graph 7.

Frill Spring erupting on September 5, 2007. Photo by Carlton Cross.

series began with an extended period of overflow from Frill's pool. Water spilled over the entire pool margin, while bursts rose a foot or two over the vent. These became increasingly violent as the initial eruption approached. A small vent next to Frill's crater sprayed water to 4 feet during the overflow. The overflow lasted for at least 23 minutes in 2006 and at least 18 minutes in 2007. Temperature profiles in the data logger record suggest that the extended overflow lasts from 25 to 35 minutes.

Extended overflow does not always lead to an eruption. In 2008, we witnessed an overflow that lasted for over 11 minutes with increasing agitation of the pool before suddenly failing. The pool became placid and the water slowly drained in the crater. It is unknown how many hours passed before the next eruptive series began. In 2009, we saw a similar period of heavy overflow and bursting that lasted for at least 21 minutes before ending without an eruption. Temperature spikes consistent with extended overflows that do not lead to an eruption are visible in the data logger record.

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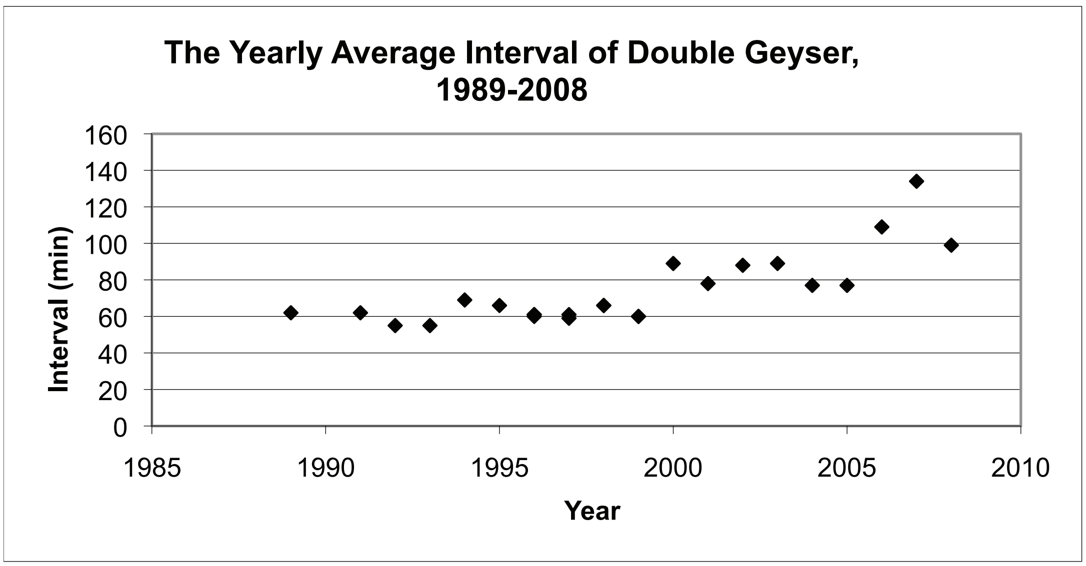
DOUBLE GEYSER

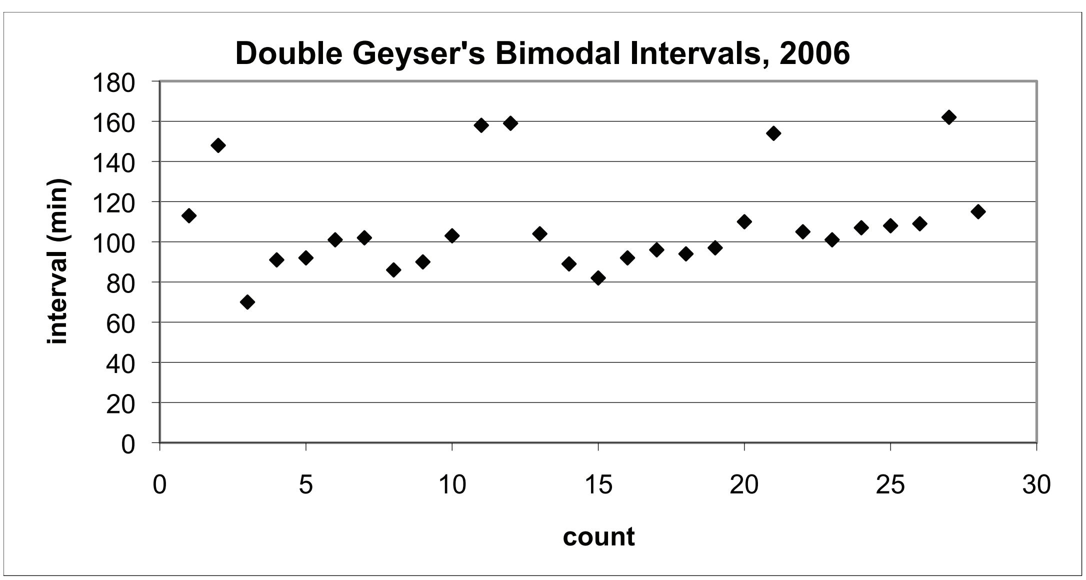
Double Geyser can be one of the most regular geysers in Yellowstone. Because its intervals during the 1990s were very nearly 60 minutes long, Double sometimes exhibited the every-hour-on-the-hour activity often cited in legends about Old Faithful. For example, on 04 August 1996, Double maintained a 61.3-minute average over 7 intervals with a standard deviation only 0.83% of the average. At that time, Double's hour-long intervals were consistent for days at a time. For example, the first observed eruption on 03 August 1996 occurred at 12:05, and the last observed eruption on 05 August 1996 occurred at 15:14. The duration of Double Geyser remained constant at 5 to 7 minutes from 1989 through 2008, and the maximum height was 10 feet.

Double's intervals over the last 20 summers have tended to lengthen from year to year. The first large increase happened in 2000 (Table 4), when the average interval jumped to 89 minutes. Such long intervals had never been seen before. Over the next eight summers, the average interval rose steadily, peaking at 134 minutes in 2007 (Graph 8). In 2003, and increasingly through 2006 and 2007 (Graph 9), Double exhibited bimodal eruption intervals. In 2007, Double also showed completely irregular behavior, at one point failing to erupt at all during a period of over 13 hours. In 2009, Double was probably dormant. No eruptions were seen by any reporting observer for the entire summer. Double is known to have not erupted for a period of 3 hours on 29 July 2009. Though it was overflowing from the vent, the formation was dry.

Little Giant Geyser, which is intimately connected to Double, has also suffered from a loss of energy. Prior to 2005, Little Giant always responded to Double's eruption by splashing a few feet high. This activity was sufficient to keep the formation damp. Between eruptions of Double, a constant stream of bubbles kept the water in Little Giant's pool turbulent. In 2005 it was first noted that Little Giant failed to have minors in concert with Double. Little



Graph 8. Double Geyser's average interval increased over 20 summers prior to Double's 2009 dormancy.



Graph 9. Prior to entering dormancy, Double Geyser began to have bimodal intervals.

Table 4. Observations of Double Geyser, 1989-2009

Year	Interval (minutes)	Min	Max	Standard Deviation	n
1989	62				1
1990					
1991	62	62	63		3
1992	55	52	56	3.2%	4
1993	55	55	55	5.6%	12
1994	69	67	74		8
1995	66	66	67	1.3%	9
1996	60	59	62	3.4%	9
1996	61	60	62	0.8%	7
1996	61	59	62	2.5%	4
1997	59	59	60	0.7%	3
1997	61	60	63	1.5%	4
1998	66	64	68	1.9%	23
1998	66	57	74	5.5%	45
1999	60	58	62	2.4%	5
1999	60	56	70	4.5%	39
2000	89	79	103	7.3%	34
2001	78	72	94	6.8%	35
2002	88	78	93	4.5%	22
2003	89	83	138	10%	32
2004	77	67	125	13%	50
2005	77				2
2006	109	70	162	23%	28
2007	134	77	796	65%	104
2008	99	82	113	7.7%	24
2009	dormant				

Giant lowered its water level an inch or two during eruptions of Double, but the water surface of the small pool was at all times perfectly calm. The small spouting vents on the east rim of the crater fell dormant, while the spouters to the west became more active. The formation around Little Giant dried out. This condition has persisted through 2009.

THE HYDRA

The Hydra is an unusual feature that began erupting as a geyser in 2002. For many years, the central vent, which has the profile of a volcanic cinder cone, had acted as a perpetual spouter. In July of 2002, we saw eruptions from the cone, along with the twelve small vents around it and a small pool a few feet to the north. The central vent shot a thin jet of water to 10 feet, while the pool erupted a rooster-tail jet to 15 feet. The other vents sputtered water a few feet high.

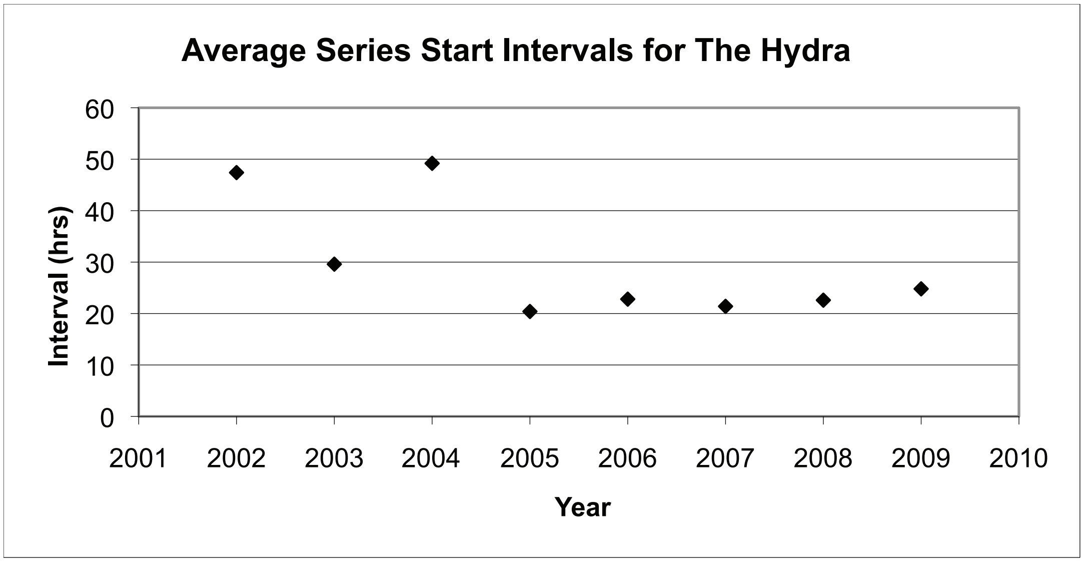
The Hydra erupted in series, with 42 hours passing between the first and second observed series. The first series consisted of three major eruptions and one minor eruption, while the second series consisted of two major eruptions and one minor eruption. Major eruptions were larger and produced considerable overflow, while minor eruptions mainly vented steam.

From 2002 through 2009, a data logger was placed on The Hydra under NPS permit. The data show that eruptive series of The Hydra occurred at highly irregular intervals of 5.9 to 126.8 hours (Table 5, Graph 10). The yearly standard deviation ranged from 49 to 90 percent of the yearly average interval. By contrast, the yearly *average* series start interval remained constant at 20.4 to 24.8 hours during 2005 through 2009. In-series intervals of The Hydra ranged from 47 to 196 minutes. The yearly average ranged from 83 to 110 minutes (Graph 11). The number of eruptions in a series ranged from 1 to 7, and the yearly average ranged from 1.7 to 3.3 (Graph 12).

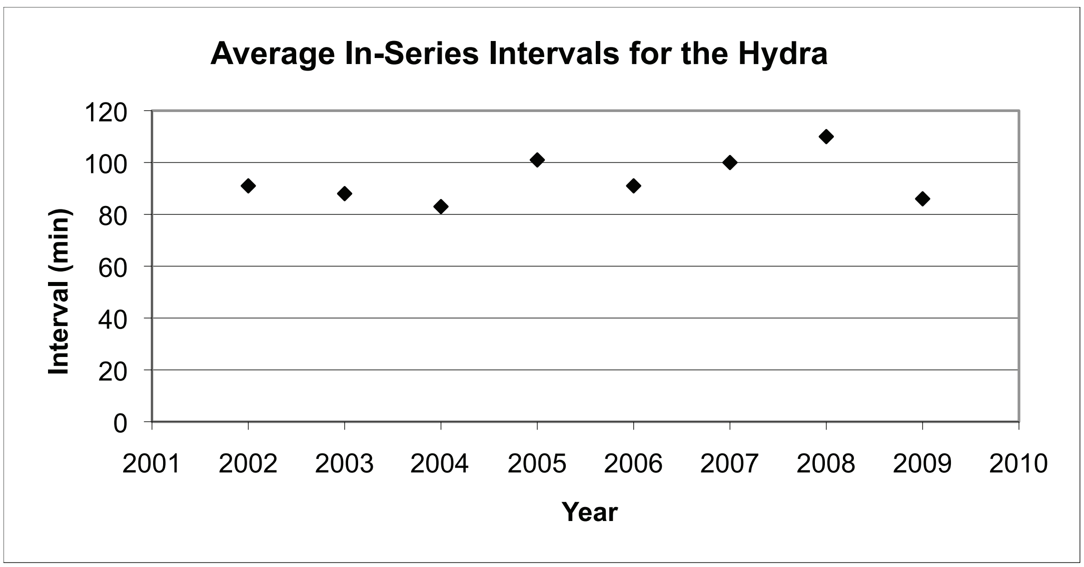
Minor eruptions sometimes interrupted the interval between major eruptions. The interval by which the minor followed the preceding major varied from 12 to 53 minutes in 2009, with an average of 25 minutes and a standard deviation of 39 percent for 23 known intervals. Most minor eruptions followed the preceding major by 15 to 25 minutes.

The occurrence of a minor eruption failed to delay the occurrence of the next major eruption. In 2009, data from 21 intervals between the minor eruption and the subsequent major averaged 60 minutes, with a range of 37 to 100 minutes. The average major interval was 85 minutes in 2009, which is exactly the sum of the interval preceding the minor (25 minutes, see above) and the interval following the minor.

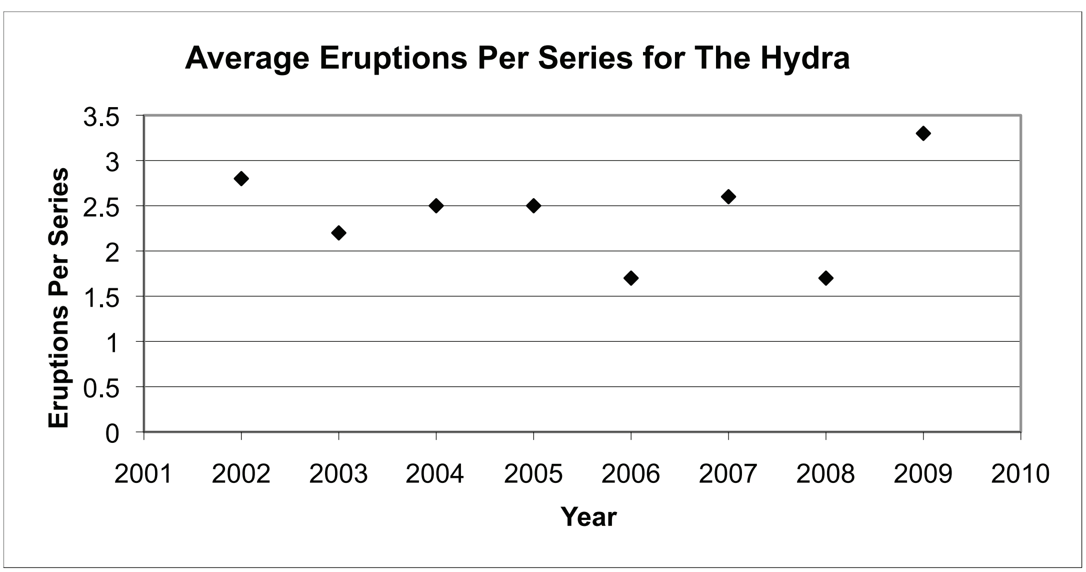
When in between series, the water level rises and falls every few minutes. All attempts to correlate the overflow activity with the onset of an eruptive series have failed. In 2003, it was true that the longer the overflow before a series, the more eruptions the series was likely to have. It was also true that the time to the first overflow following a series was delayed if the series included many eruptions. The Hydra has initiated new series while the system was still drained following the previous series.



Graph 10.



Graph 11.



Graph 12.

The Hydra erupting in September 2009. Photo by Graham Meech.

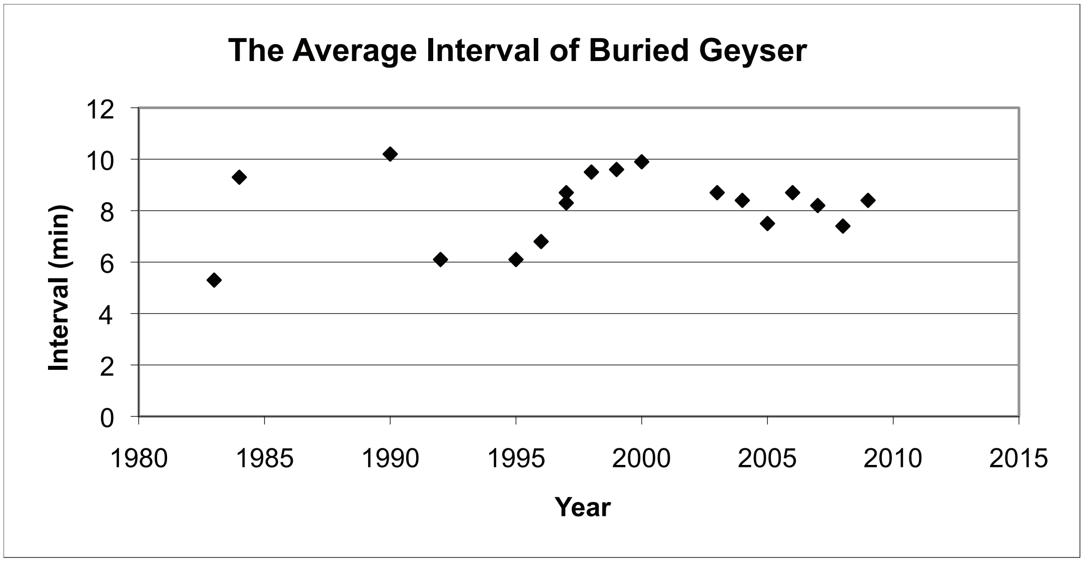
Table 5. Observations of The Hydra, 2002-2009.

Year	Series Start Interval (hours)	Min	Max	Standard Deviation	n	In-Series Interval (minutes)	Min	Max	Standard Deviation	Average Eruptions per Series	Min	Max	n
2002	47.4	22.1	103.9	49%	10	91	56	108	14%	2.8	2	4	20
2003	29.6	8.2	99.6	72%	38	88	56	128	17%	2.2	1	5	47
2004	49.2	20.1	126.8	64%	10	83	56	114	24%	2.5	2	4	16
2005	20.4	7.7	71.6	62%	45	101	56	154	19%	2.5	1	7	69
2006	22.8	9.2	71.4	68%	15	91	75	118	15%	1.7	1	4	20
2007	21.4	5.9	61	90%	9	100	57	145	25%	2.6	1	7	16
2008	22.6	9.3	69.3	84%	18	110	49	196	36%	1.7	1	5	24
2009	24.8	8.3	78.4	67%	20	86	47	153	26%	3.3	1	8	47

BURIED GEYSER

The history and activity of Buried Geyser is discussed in Cross (2008). Buried is often assumed to have major, minor and intermediate eruptions (Bryan, 2008). Modern observations show that, although the power and discharge of the eruptions vary, it is difficult to classify them into major, minor and intermediate sizes. True major eruptions, reaching 35 feet vertically and 45 feet horizontally, certainly occurred in 1983, when the modern Buried Geyser formed (Paperiello and Wolf, 1986). Major eruptions of lesser magnitude may also have occurred in 1999 and 2000. The temperature record at those times shows prominent spikes occurring roughly once an hour. McLean noted in 2000 that Buried was carving new channels in the gravel around the crater (McLean, 2000). At the same time, a sinkhole opened in the runoff channel.

In 1999 and 2000, an automatic data logger was placed on Buried under NPS permit. The temperature record is useful in that a large quantity of data was gathered, and evidence for true major eruptions in 1999 and 2000 was found (Cross, 2008). However, the record is of limited usefulness because not every eruption produced enough overflow to register as a spike on the temperature record. It is therefore possible only to gather data for periods during which



Graph 13.

Table 6. Observations of Buried Geyser, 1983-2009

Year	Average (minutes)	Min (minutes)	Max (minutes)	Count	
1983	5.3	3.6	6.9	21	Paperiello and Wolf (1986)
1984	9.3	7.6	10.1	7	Paperiello and Wolf (1986)
1990	10.2	8.5	12.6	14	Bower (1992)
1992	6.1	4.2	9	22	
1995	6.1	5.3	6.8	6	
1996	6.8	4.9	8.2	8	
1997	8.7	8.1	9.7	5	
1997	8.3	6	11	6	Moats (1997)
1998	9.5	8.3	11.4	5	
1999	9.6			30	
2000	9.9			20	
2003	8.7	6.2	11.3	13	
2004	8.4	6	11	5	
2005	7.5	5.3	9.4	10	
2006	8.7	8	10	5	
2007	8.2	7.6	9.2	8	
2008	7.4	5.9	8.6	7	
2009	8.4	7.8	9.5	8	

it is certain that every eruption produced overflow. The 30 intervals collected in 1999 and the 20 intervals collected in 2000 were interpreted by collecting intervals in batches of 5 and calculating an average for all the intervals collected in this way. Because the onset of overflow from Buried happens early in the eruption if the water level is high, or late in the eruption if the water level is low, it is difficult to correlate any part of the temperature trace with a definite eruption time. Therefore, interval ranges have been given for visual observations only.

The average interval of Buried Geyser has varied from 5.3 to 10.2 minutes from 1983 through 2009 (Table 6, Graph 13). Enough data is available from 1995 through 2009 to show that the change in the interval from one year to the next tended to be gradual.

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PHOENIX GEYSER

Phoenix Geyser began erupting from an old, weathered sinter formation in 1995. The eruptions carved fresh runoff channels into the hillside and killed grass around the crater. Prior to that time, the vent was full of grass and soil (Paperiello and Wolf, 1986). Historically, Phoenix may have been active as the second of two geysers at this site (Allen and Day, 1935), along with the now-extinct Gibbon Hill Geyser, which perished beneath a debris flow in 1989. Rocco Paperiello suggested the name in reference to the geyser having sprung from the ashes of the 1988 forest fires.

In 1996, we and Rocco Paperiello witnessed an eruption of Phoenix Geyser. This eruption lasted 23 minutes and consisted of several surges of activity separated by pauses. A single interval of 2.5 hours was obtained in 1997, and two durations of 7 and 10 minutes were recorded that year. In 1998, a data logger was placed under NPS permit. The temperature record shows that Phoenix erupted every 1.6 to 6.6 hours, with a yearly average ranging from 1.9 hours in 1999 to 5.3 hours in 2002 (Table 7, Graph 14). The duration ranged from 6 to 117 minutes, with a yearly average ranging from 8.5 minutes in 1997 to 87 minutes in 2003 and 2004 (Table 8, Graph 15). Pauses have not interrupted any eruptions seen from 2000 through 2009.

Interestingly, Phoenix is spending more time in eruption each year. In 1997, Phoenix was in eruption 6.7 percent of the time, while in 2003 it was in eruption for 35 percent of the time (Graph 16). The increase was steady from 1997 through 2003. Phoenix has been in eruption for between 24 and 35 percent of the time from 2003 through 2009.

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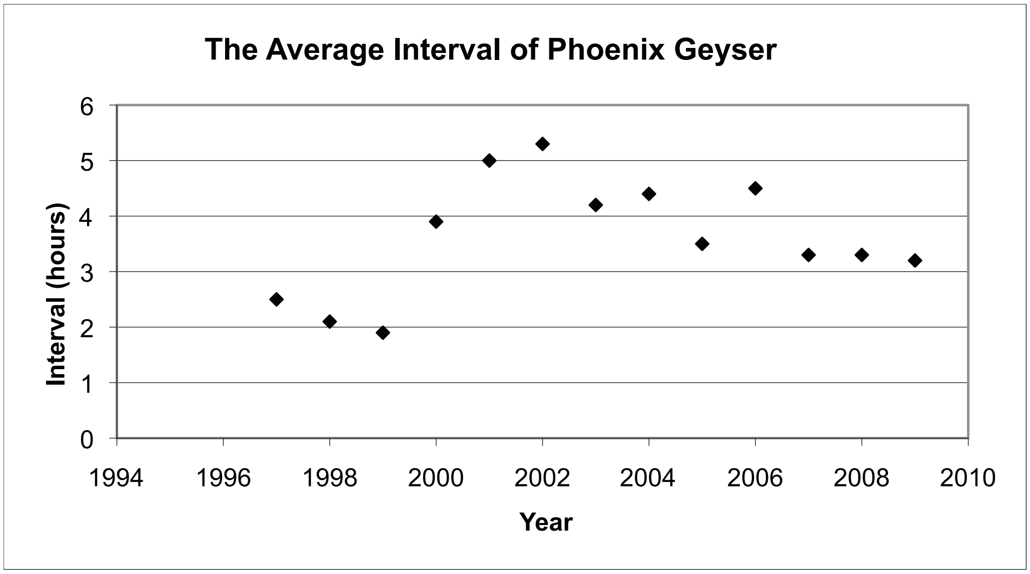
AVALANCHE GEYSER

Visual observations from 1989 through 2009 suggest that Avalanche Geyser erupts at consistent intervals and durations. In 2005 and continuing through 2009, an automatic data logger was placed on Avalanche. The data show considerably more variation that has ever been observed directly. The known range of intervals is 6.5 to 12.7 minutes. Both these extremes are from the logger record. The average interval has varied from 8.6 minutes in 2004 to 10.3 minutes in 1985, with a slight trend toward shorter intervals over the 26 summers from 1984 through 2009 (Table 9, Graph 17). In 1974, the interval was 7.8 minutes (Bryan, 1979), which is about 1.5 minutes shorter than the 1984-2009 average. In 1928 the average interval was 6 minutes (Allen and Day, 1935).

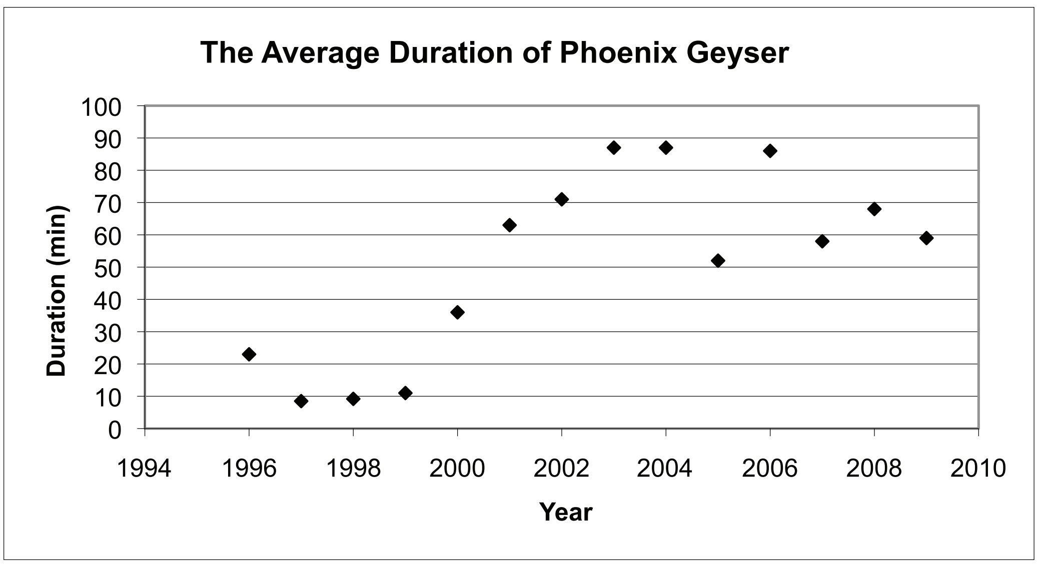
Data on durations are available only through direct observation. Durations have been far less consistent than intervals, with the typical standard deviation being about 3 times larger than the stan-

Table 7. Observations of Phoenix Geyser, Intervals 1997-2009.

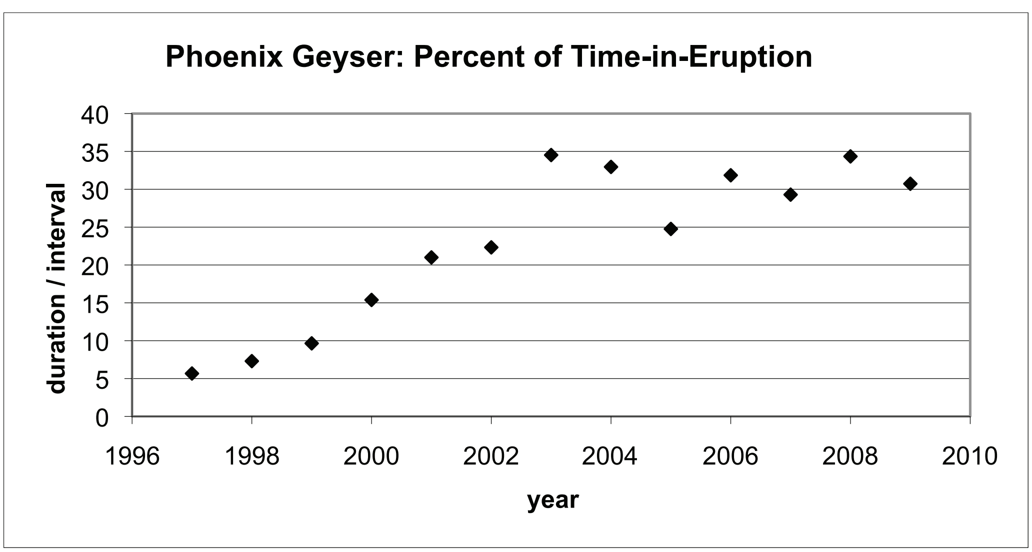
Year	Average (hours)	Min	Max	Standard Deviation	n
1997	2.5				1
1998	2.1	1.7	2.3	0.068	70
1999	1.9	1.6	2.3	0.058	140
2000	3.9	3.6	4.1	0.023	56
2001	5	4.6	5.6	0.04	215
2002	5.3	4.4	6.6	0.072	203
2003	4.2	3.7	4.9	0.077	129
2004	4.4	3.7	4.9	0.063	60
2005	3.5	3	5	0.11	332
2006	4.5	3.9	5.3	0.045	106
2007	3.3	3	3.7	0.06	73
2008	3.3	2.9	4.9	0.1	152
2009	3.2	2.8	4.6	0.079	257



Graph 14.



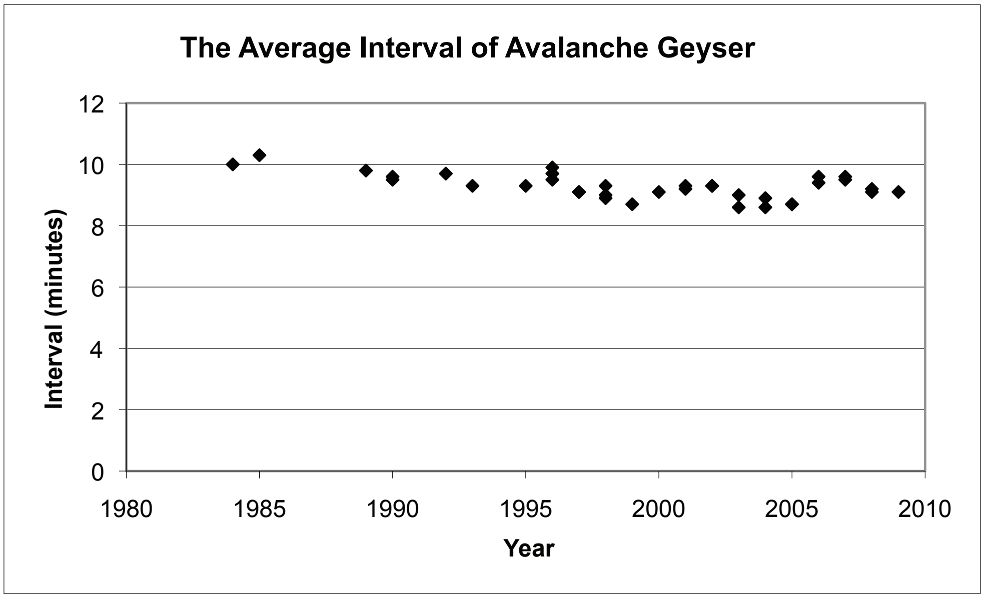
Graph 15.



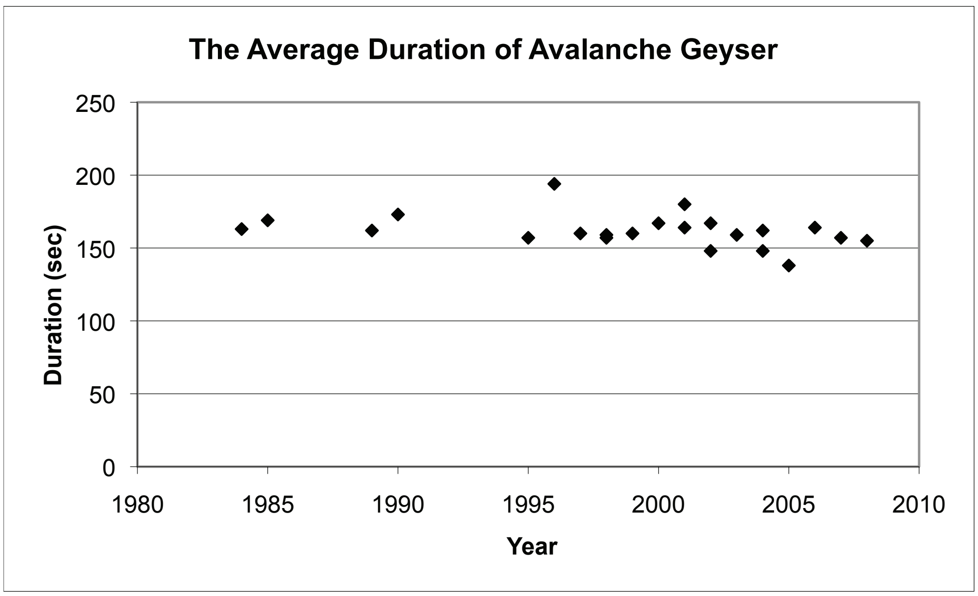
Graph 16.

Table 9. Observations of Avalanche Geyser, Intervals 1928-2009.

Year	Average (minutes)	Min	Max	Standard Deviation	n	Source
1928	6.0					Allen and Day (1935)
1961		8.0	10.0			Frisbee (1961)
1974	7.8	7.1	8.6		10	Bryan (1979)
1984	10.0	9.6	10.7	3.0%	9	data from Milada Vachuda, reported in Paperiello and Wolf (1986)
1985	10.3	8.4	11.2	8.9%	8	data from Milada Vachuda, reported in Paperiello and Wolf (1986)
1989	9.8	9.5	9.9		6	
1990	9.6				9	Bryan (1990)
1990	9.5	9.0	11.0		4	
1990-92	9.7	9.0	11.0		39	Dunn, Dunn and Dunn (1993)
1992	9.7	9.0	10.0	5.0%	10	
1993	9.3	8.0	10.0	9.6%	8	
1995	9.3	8.8	9.7	3.7%	5	
1996	9.9	9.3	10.5	5.1%	4	
1996	9.7	9.5	9.9	2.0%	3	
1996	9.5	8.9	10.4	6.7%	5	
1997	9.1	9.0	9.3	1.6%	6	
1997	9.1	9.0	10.0	3.7%	9	
1998	8.9	8.4	9.3	3.4%	9	
1998	9.0	8.3	9.6	4.4%	7	
1998	9.3	9.0	9.6	3.8%	4	
1999	8.7	8.4	9.0	3.8%	7	
2000	9.1	8.8	9.3	2.1%	5	
2001	9.3	8.9	9.8	3.0%	8	
2001	9.2	8.5	9.6	4.2%	7	
2002	9.3	8.8	10.4	6.3%	7	
2002	9.3	8.3	9.7	3.3%	6	
2003	9.0	8.3	9.5	5.0%	5	
2003	8.6	8.0	9.0	5.8%	9	
2004	8.6	8.3	9.0	3.0%	6	
2004	8.9	8.4	9.8	6.4%	6	
2005	8.7	7.6	10.0	11.6%	4	
2005	8.7	6.5	10.5	6.2%	1836	
2006	9.6	9.0	10.5	4.5%	12	
2006	9.4	8.0	11.6	5.8%	1349	
2007	9.5	9.1	9.8	2.8%	6	
2007	9.6	8.0	12.7	6.9%	1527	
2008	9.2	8.8	9.7	3.6%	14	
2008	9.1	7.3	11.3	6.4%	2364	
2009	9.1	7.5	11.0	5.7%	1772	
Summary						
Min	8.6	6.5	8.6	1.6%		
Max	10.3	9.6	12.7	11.6%		
Average	9.29			4.92%		



Graph 17.



Graph 18.

dard deviation of intervals (Table 10, Graph 18).

The range of average durations obtained between 1984 and 2008 is 138 to 194 seconds. The longest single duration recorded is 253 seconds and the shortest is 120 seconds. Interestingly, the average 1974 duration of 159 seconds is very close to the durations obtained from 1984 through 2008. Whatever happened to change Avalanche's interval between 1974 and 1984 failed to affect the duration.

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Table 10. Observations of Avalanche Geyser, Durations 1974-2008.

Year	Average (seconds)	Min	Max	Standard Deviation	n	Source
1974	159					Bryan (1979)
1984	163	135	186	9%	11	data from Milada Vachuda, reported in Paperiello and Wolf (1986)
1985	169	159	174	4%	4	data from Milada Vachuda, reported in Paperiello and Wolf (1986)
1989	162	131	190		5	
1990	173					Bryan (1990)
1990-92	167	140	188		30	Dunn, Dunn and Dunn (1993)
1995	157	132	193	32%	6	
1996	175	128	253	28%	5	
1996	194	165	203	19%	4	
1996	194	165	240		4	
1997	160	131	177	10%	9	
1998	157	130	170	8%	10	
1998	160	130	210	20%	7	
1998	159	135	185	13%	5	
1999	160	155	175	5%	8	
2000	167	155	185	8%	6	
2001	164	135	190	14%	8	
2001	180	153	211	15%	5	
2002	148	130	160	8%	6	
2002	167	148	188	9%	6	
2003	159	120	210	22%	7	
2004	148	140	155	4%	7	
2004	162	140	189	9%	7	
2005	138				1	
2006	164	135	215	16%	8	
2007	157	135	175	8%	7	
2008	155	135	175	7%	15	
Summary						
Min	138	120	253			
Max	194					
Average	164					

A Model of a Geyser that Erupts in Series

Jeff Cross

Abstract

A model geyser, having two reservoirs and erupting in series with several minor eruptions preceding a single major eruption, is described. Minor eruptions originated in the upper reservoir and major eruptions originated in the lower reservoir. The mechanism by which the series occurs is described. Interactions between the two reservoirs constrained the major eruption to begin during specific parts of the minor eruption cycle.

Introduction

Geysers that erupt in series, such as Lion Geyser and Atomizer Geyser, both in the Upper Geyser Basin, can be fascinating to watch. The height and duration of each eruption, as well as the interval from one eruption to the next, can follow highly variable patterns. For example, the first eruption in an eruptive series of Lion Geyser (Bryan, 2008; Friedman, 1989) is often the tallest and longest. Subsequent eruptions are shorter in length and less powerful. After the final eruption of the series, the geyser is quiet for a long time before the next series begins. At Atomizer Geyser (Bryan, 2008; Stephens, 2005; Leeking, 1993) the small, comparatively brief minor eruptions occur first and the major eruption occurs at the end of the series. For the purpose of this paper, an eruptive series is defined as a sequence of eruptions that follows any kind of repeating pattern of variation in interval, duration or height, or any combination of these.

Geysers that erupt in series do not form a majority of the geysers in Yellowstone. However, they are not uncommon. Of the following 19 large, well-known geysers, eight (42%) erupt in series.

Geyser	**Does it erupt in series?**
Old Faithful	no
Beehive	no
Giantess	yes
Lion	yes
Castle	no
Grand	yes
Giant	no
Daisy	no
Splendid	yes
Riverside	no
Fan and Mortar	yes
Artemisia	no
Great Fountain	yes
Morning	no
Fountain	no
Steamboat	no
Echinus	no
Lone Star	yes
Union	yes

A few of these examples are debatable. Castle Geyser sometimes has minor eruptions prior to its major eruptions. The minor eruptions lack a steam phase and have a shorter duration than the majors. Although Castle has had many modes of activity in the past (Bryan, 2008), its present activity does not reliably include series of eruptions. Artemisia Geyser also has minor eruptions from time to time (Bryan, 2008), but, as with Castle, these do not form a reliable pattern. Some might argue that Splendid Geyser erupts in series. Others might argue that Splendid does not erupt in series, but briefly captures the energy that would have otherwise been discharged through nearby Daisy Geyser. Echinus Geyser erupted in series prior to its current dormancy (Taylor, 2001; Taylor, 2003). However, series were not typical during most of the years when Echinus was active.

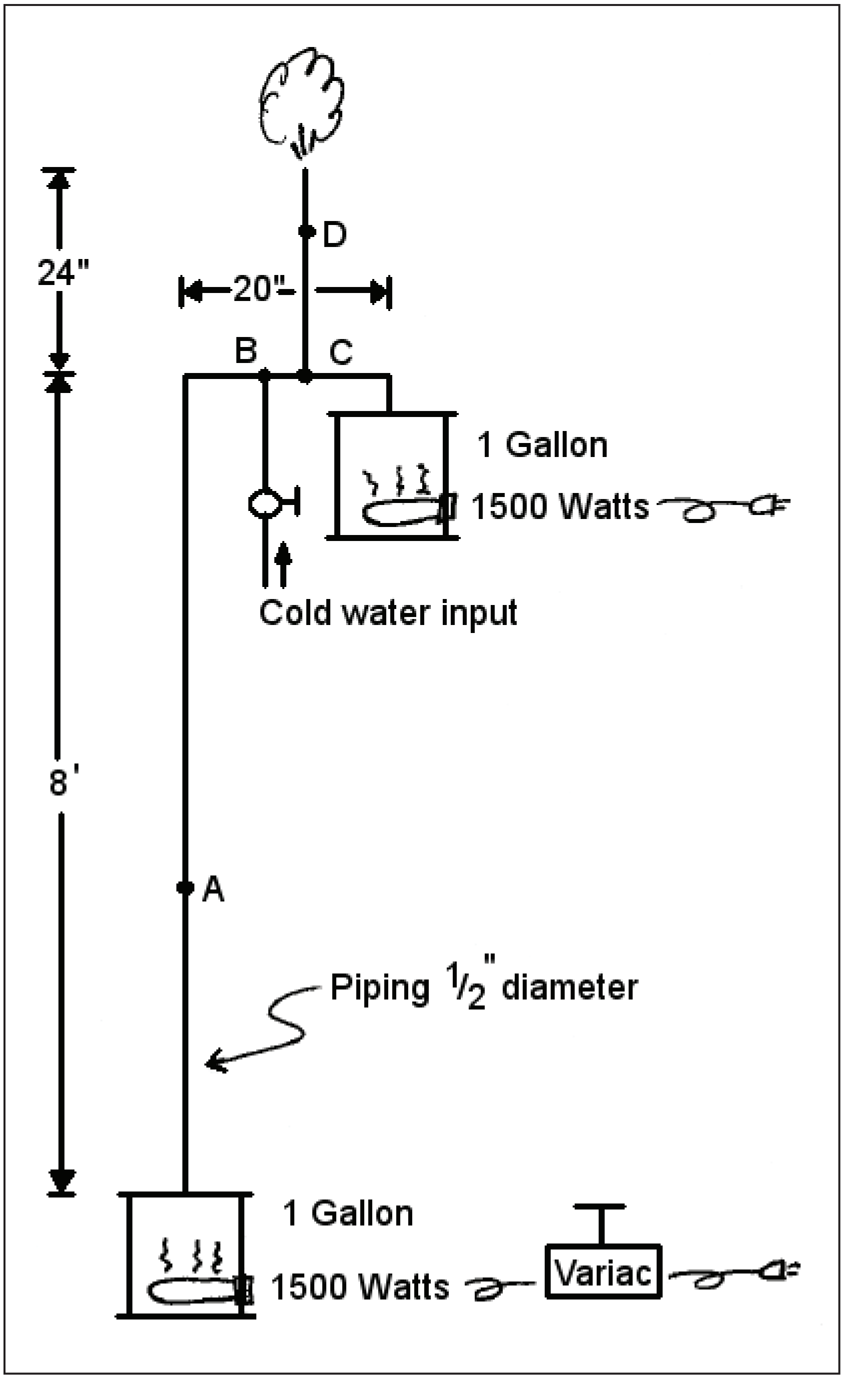


Diagram 1: A drawing of the model geyser apparatus.

Some would consider the eruptions of Grand, Fan and Mortar and Great Fountain to be single eruptions interrupted by brief pauses, and not true series. It possible that one mechanism could cause a geyser like Grand to pause briefly during a single eruption, and a different mechanism could cause a geyser like Lone Star to have long pauses between eruptions. However, it is also possible that the multiple bursts of Grand are thermodynamically and hydrologically similar to the multiple eruptions of Lone Star. That Grand is often classified as having a single eruption interrupted by brief pauses and Lone Star is classified as erupting in series might be due entirely to the opinion of the observer, and therefore without any logical basis.

Note, also, that some geysers that erupt in series have two distinct types of eruptions, as discussed previously at Castle, but the series of other geysers (like Great Fountain) involve smooth changes in height, interval or duration. If the series includes eruptions of two distinct types, the major eruption is distinguished from the minor eruption by its greater height, violent steam phase, or extended duration.

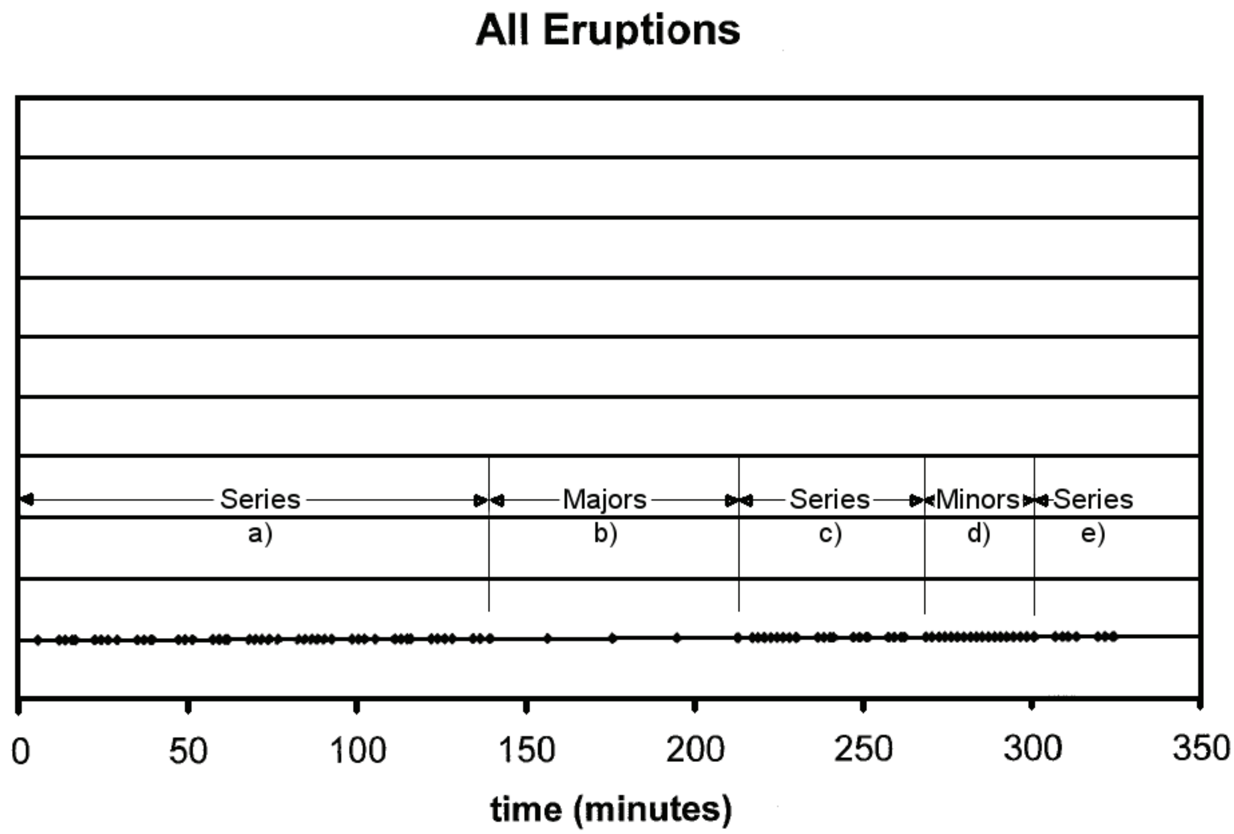
In the following experiment, I demonstrate the operation of a model geyser that erupts in series. The series begins with several minor eruptions and culminates in a major eruption that is distinctly more powerful than the minor. The timing of the major eruption is controlled by the minor eruption cycle. A period of quiet then occurs before the next series begins.

The Apparatus

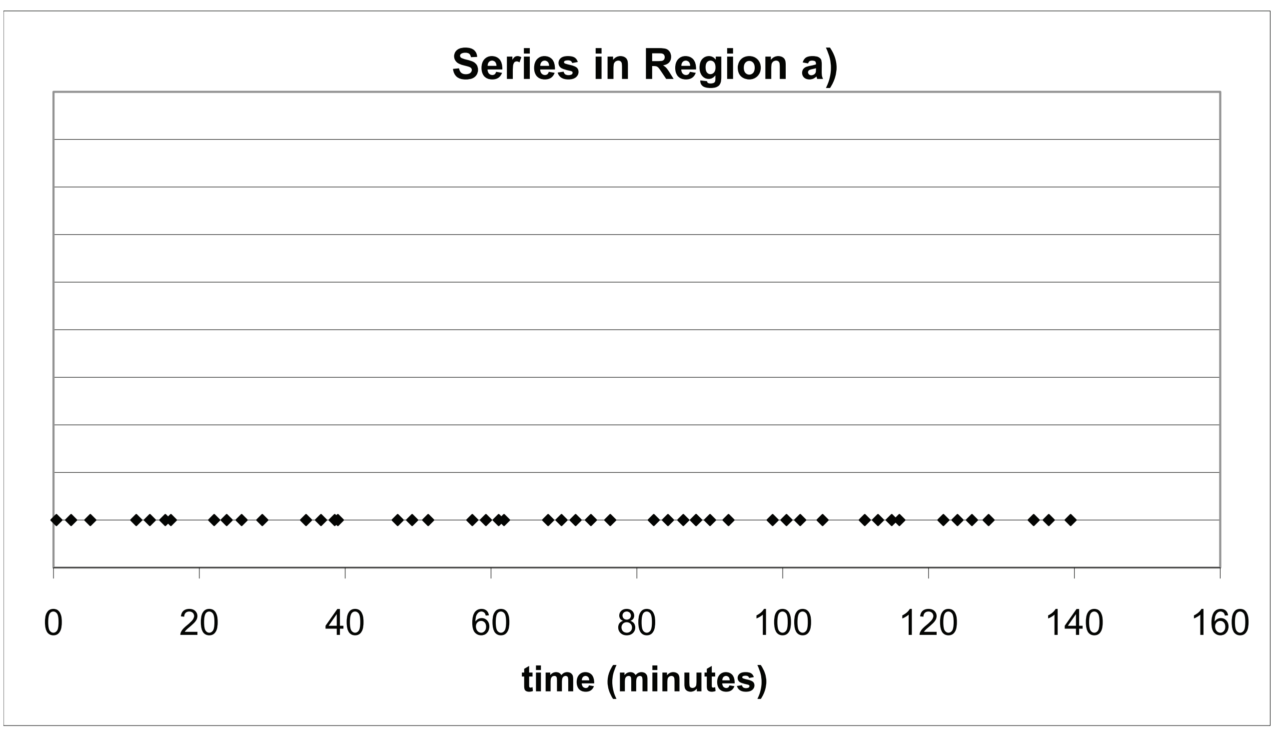
The model geyser (Diagram 1) consists of two reservoirs, both having a volume of 1 gallon. Each reservoir is supplied with 1500 watts of heat via an electric water heater element. The standpipe A from the lower reservoir is 8 feet (2.4 meters) long. It and the short standpipe from the upper reservoir are joined by a horizontal pipe including points B and C, which is 20 inches (0.51 m) long. A 24-inch (0.61 m) long standpipe D rises from the horizontal connecting pipe. Its upper end is open to the air, forming the vent. The entire model is about 10 feet (3.0 meters) tall. A steady supply of cold water is admitted to the connecting pipe at point B. All piping is 0.5 inches (1.3 centimeters) in diameter.

Observations and Analysis

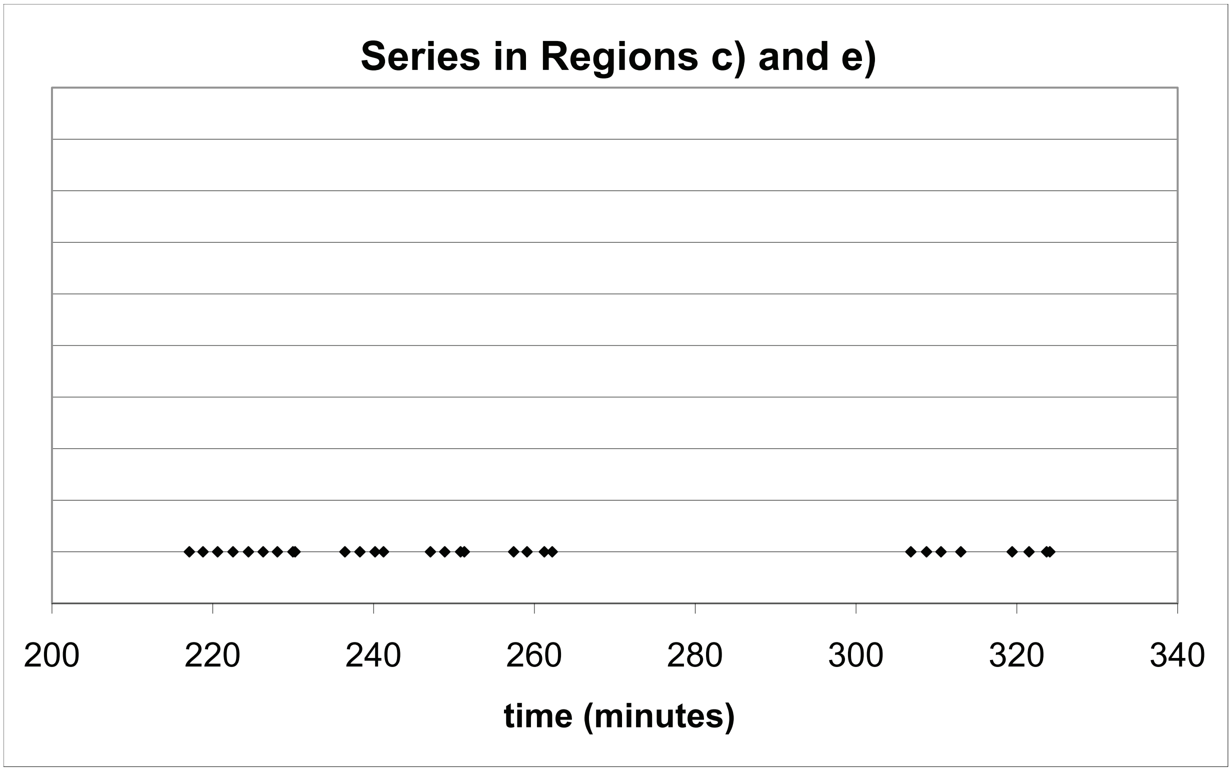
When in operation, the flow rate of cold supply water was adjusted with a valve. The heat supply to the upper reservoir was constant. The heat supplied



Graph 1: *All eruptions of the model geyser are shown. In regions a), c) and e) heat is supplied to both reservoirs. The geyser erupts in series. The series begins with minor eruptions and ends with a single major eruption. In region b), heat is supplied to the lower reservoir only. Single eruptions, identical to the major eruptions in regions a), c) and e) occur. In region d), heat is supplied to the upper reservoir only. Single eruptions, identical to the minor eruptions in regions a), c) and e) occur.*



Graph 2: *Detail of region a), showing eruptions occurring in series. Note the bimodal interval between the last minor and the major eruption.*



Graph 3: *Detail of regions c) and e), showing eruptions occurring in series. Note the bimodal interval between the last minor and the major eruption.*

to the lower reservoir was adjusted with a variac. When a proper supply of cold water and heat was attained, the geyser erupted in series, as described below. All of the eruptions are shown on Graph 1, which can be divided into five different regions a) through e), according to the type of activity that is demonstrated.

Three different experiments were run:

- Heat was supplied to both reservoirs. The geyser erupted in series, shown in regions a), c) and e). Each series consisted of two to eight minor eruptions and concluded with a major eruption. This activity is shown separately in Graphs 2 and 3.
- Heat was supplied to the lower reservoir only. The geyser had single eruptions, shown in region b). These eruptions were in all respects identical to the major eruptions in regions a), c) and e).
- Heat was supplied to the upper reservoir only. The geyser had single eruptions, shown in region d). These eruptions were in all respects identical to the minor eruptions in regions a), c) and e).

From this experiment, it is apparent that the major eruptions came from the lower reservoir, minor eruptions came from the upper reservoir, and series occurred when both reservoirs functioned at the same time.

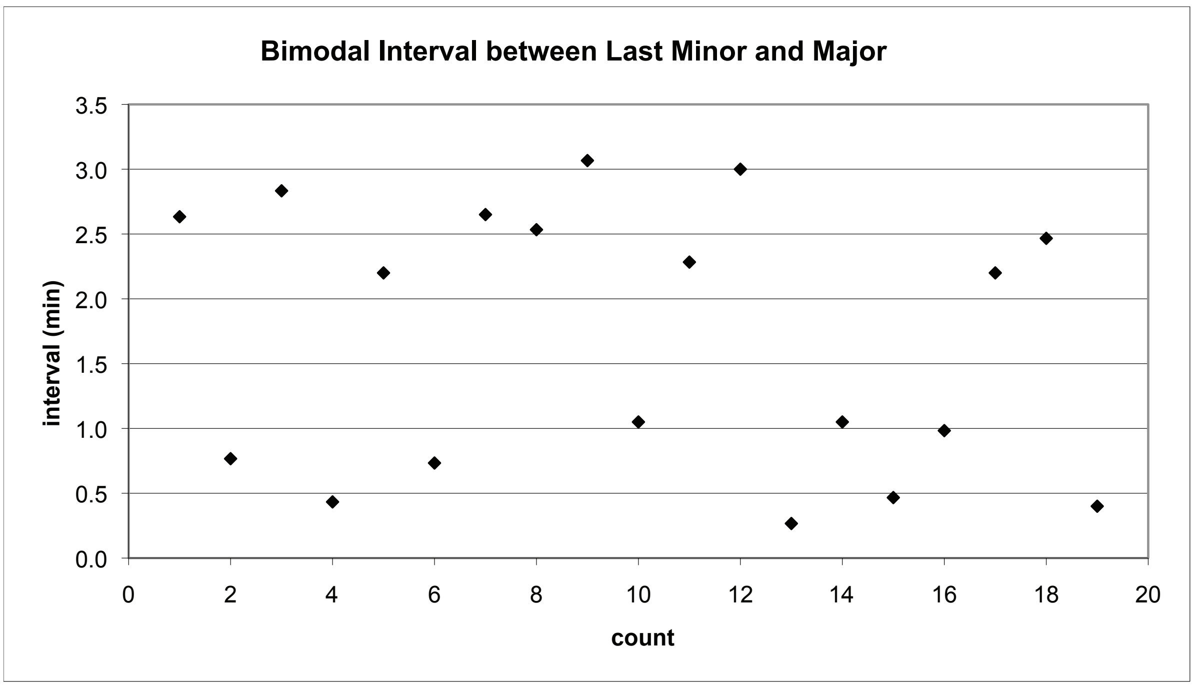
Description of Series

A total of 18 series were recorded. Series began with two to eight minor eruptions, with an average of 3.4 minor eruptions per series. The minor eruptions occurred on intervals of 1.7 to 2.2 minutes, with an average of 1.9 minutes, and lasted for 6 to 30 seconds, with an average of 16 seconds. A single major eruption ended each series. The major eruptions occurred every 10.1 to 16.2 minutes, with an average of 11.9 minutes, and lasted for 11 to 13 seconds, with an average of 12 seconds. The interval preceding the first major eruption in region c) was included with the intervals in region b).

The interval between the last minor and the major that followed it was bimodal. This is apparent on Graphs 2 and 3, where the final eruption either followed the previous minor closely (0.3 to 1.1 minutes), or began after the next minor would have been expected (2.2 to 3.1 minutes). These two possibilities happened with nearly equal probability. The intervals are shown on Graph 4. Note that no

Table 1.

	Range	Average
Number of minor eruptions in series	2 to 8	3.4
Minor eruption interval in series	1.7 to 2.2 minutes	1.9 minutes
Minor eruption duration in series	6 to 30 seconds	16 seconds
Major eruption interval in series	10.1 to 16.2 minutes	11.9 minutes
Major eruption duration in series	11 to 13 seconds	12 seconds
Final interval of series	0.3 to 1.1, or 2.2 to 3.1 minutes	
Time to first overflow after a major eruption	5.5 to 6.1 minutes	5.8 minutes
Time to first minor eruption	5.8 to 6.4 minutes	6.1 minutes
Minor eruption interrval not in series	1.7 to 2.1 minutes	1.9 minutes
Major eruption interval not in series	17.0 to 19.2 minutes	18.2 minutes



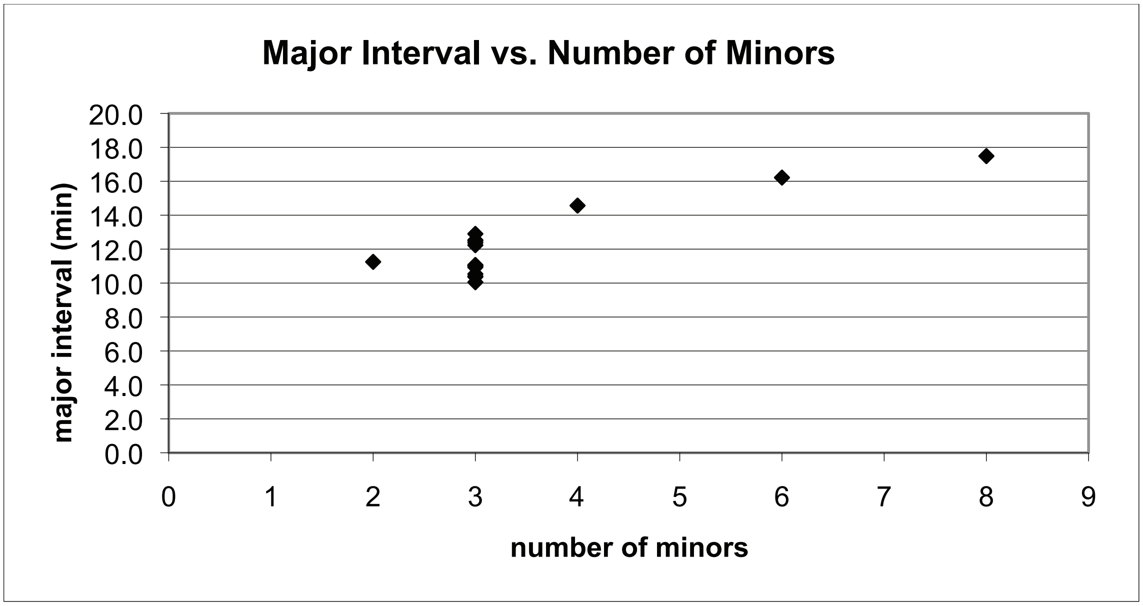
Graph 4: *The interval between the last minor eruption and the major eruption is bimodal.*

intervals fell within the 1.1 to 2.2 minute range. If the final interval was long, it was often punctuated by surging and incontinuous splashing. This activity, which seemed to represent a failed minor eruption, always ended with an abrupt drain after the 2.2 minute mark. The major eruption usually started a few seconds later.

Following the start of each minor eruption, overflow began after 0.8 to 1.9 minutes, with an average of 1.5 minutes. Following the start of each major eruption, overflow began after 5.5 to 6.1 minutes, with an average of 5.8 minutes. The length of time from the start of the major to the start of the first minor was 5.8 to 6.4 minutes, with an average of 6.1 minutes. The number of minor eruptions in a series was a function of the major interval. Longer major intervals included a greater number of minor eruptions, as shown in Graph 5.

Interaction between the Reservoirs

The activity of the lower reservoir had almost no effect on the interval between minor eruptions. Minor eruption intervals occurring as part of a series had a range and average (1.7 to 2.2 minutes, average of 1.9 minutes) nearly identical to that of minor eruption intervals occurring while the heat supply to the lower reservoir was turned off (1.7 to 2.1 minutes, average of 1.9 minutes).



Graph 5: *The number of minor eruptions in a series increases as the major interval increases.*

The activity of the upper reservoir had a substantial effect on the interval of the lower reservoir. When the upper reservoir was heated, the major eruption occurred every 11.9 minutes on average, but when the heat supply to the upper reservoir was turned off, the average increased to 18.2 minutes. Possibly, the recharge water circulated through the upper reservoir, where it was heated, before spilling down standpipe A into the lower reservoir. When the heat to the upper reservoir was turned off, the recharge water was no longer heated in this way, leading to long intervals for the isolated major eruptions occurring in region b) of Graph 1.

Temperature and Pressure Measurements During the Cycle

Thermometers were attached to both the upper and lower reservoirs. Water in the lower reservoir reached a temperature of 221° F (105° C) immediately prior to the major eruption. During the major eruption, the temperature fell to 212° F (100° C). Following a major eruption, the temperature remained constant at 212 °F until the standpipe began to fill with water about 3 minutes after the major ended. Then it slowly rose toward 221° F. Temperatures in the upper reservoir varied from 215 °F (102° C) before minor eruptions to 213° F (101° C) after minor eruptions.

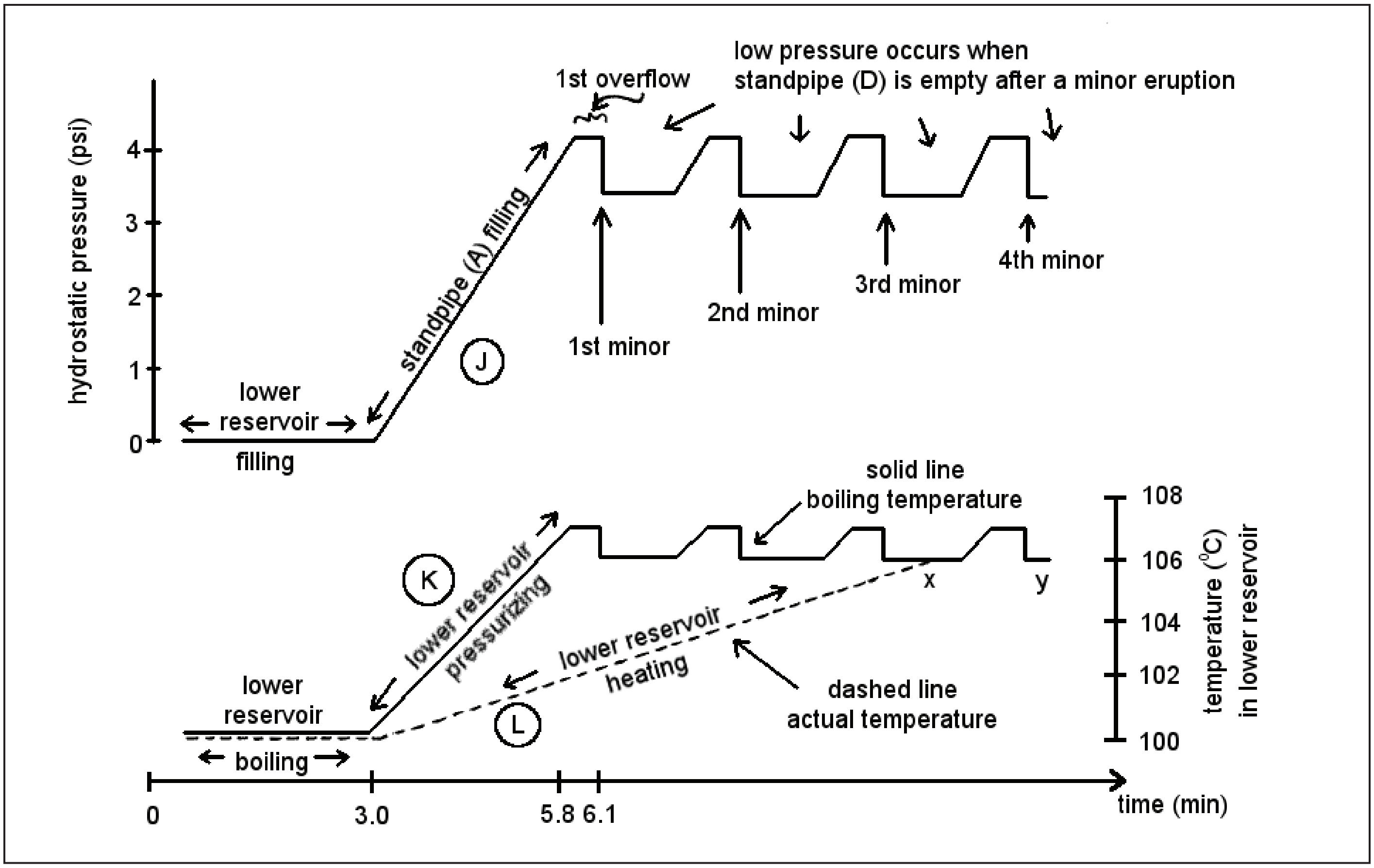
A pressure gauge attached to the lower reservoir showed that hydrostatic gauge pressures of 4 to 5 psi (28 to 34 kPa) were attained prior to the major eruption. This is reasonable, given that the hydrostatic pressure at this depth should be 4.3 psi (30 kPa), as calculated from $P = \rho g h$, with $\rho = 1000\ kg/m^3$, $g = 9.8\ m/s^2$ and $h = 3.0$ m.

All hydrostatic pressure was lost during the major eruption, and the gauge read zero until water began to fill the standpipe about 3 minutes after the major ended. Minor eruptions caused the pressure in the lower reservoir to fall slightly. The magnitude of this pressure change was too small to measure accurately since the pressure gauge was marked in units of 2 psi and the pressure change was much smaller than 2 psi. By calculation, the loss of 24 inches (0.61 m) of hydrostatic head should lower the hydrostatic pressure by 0.8 psi (6 kPa).

A Hypothesis for the Timing of the Major Eruption

As noted above, the major eruption began when the temperature in the lower reservoir reached 221° F (105° C). If the major eruption began under a full 10 feet (3.0 meters) of hydrostatic head, the boiling temperature would have been 225° F (107° C). The water in the lower reservoir should have reached that temperature before the major eruption started. Why should the major eruption have started when water in the lower reservoir was still 4° F (2° C) below the calculated boiling point?

If 24 inches of hydrostatic pressure were suddenly lost, as happened when the standpipe at point



Graph 6: *The hydrostatic pressure (upper graph) controls the boiling temperature in the lower reservoir (lower graph, solid line). The hydrostatic pressure, and thus the boiling temperature, is controlled by the minor eruption cycle. When the actual temperature in the lower reservoir matches the boiling temperature (point X), a major eruption begins. This is most likely to happen in between minor eruption (point X), or at the end of a minor eruption (point Y).*

B was empty after the minor eruption, the boiling point in the lower reservoir would fall to 223 °F (106 °C), which is the boiling point for water under 8 feet of hydrostatic pressure. This lowering of the boiling point in the lower reservoir could trigger the major eruption, if the slight deficiency in the observed reservoir temperature versus the calculated boiling temperature is ignored. This hypothesis is represented in Graph 6.

Three hypothetical lines are shown on Graph 6. They represent the hydrostatic pressure (line J, solid), the boiling point of water that is subjected to that pressure (line K, solid), and the actual temperature in the lower reservoir (line L, dotted). The horizontal axis represents time elapsed since the last major eruption. As described above, the hydrostatic pressure is zero for the first 3 minutes of the interval. During this time, the lower reservoir fills. The hydrostatic pressure is zero. Boiling in the lower reservoir is continuous because the rate at which heat is supplied is sufficient to heat all the cold recharge water to the boiling point. The temperature in the lower reservoir is steady at 100 °C.

At about the 3-minute mark, the lower reservoir is full. Water begins to fill the narrow standpipe, and the hydrostatic pressure increases. Boiling in the lower reservoir is quenched because the boiling temperature rises faster than the actual temperature of the water. When the 5.8-minute mark is reached, the entire apparatus is full of water, and the first overflow occurs. At this time, the pressure has risen to 4.3 psi and the boiling point of water in the lower reservoir has risen to 107 °C.

At the 6.1-minute mark, the first minor eruption occurs. This lowers the hydrostatic pressure to 3.4 psi and lowers the boiling point to 106 °C. Because the temperature in the lower reservoir is several degrees below 106 °C, the major is not triggered by the loss of pressure. However, as time goes by, the temperature of the water in the lower reservoir steadily increases. After the third minor, it is hot enough that it can initiate a major eruption (point X) if the pressure is lowered by a minor eruption.

If the boiling temperature is reached when the pressure falls at the start of a minor eruption, the minor is quenched by relatively cool water that is pushed ahead of the steam bubbles rising from the lower reservoir through standpipe A. The minor eruption cannot occur when the lower reservoir is fully primed because any loss of pressure will trigger the major eruption. However, the major eruption cannot occur because the minor eruption that could empty standpipe D is unable to initiate. The result is a long series of surges and splashes from the quenched minor. When the water level falls after the quenched minor is over, the major eruption ensues immediately (point Y).

It is important to note that the mutually exclusive nature of the major and minor eruptions is probably an artifact. In this model geyser, the rate of heat loss through the walls of standpipe A is so great, and the circulation that transfers heat from the lower reservoir into standpipe A is so poor, that the water in the standpipe never gets very hot. Unless the geyser is in eruption, the water in the standpipe of most models like this one seldom gets hotter than bath temperature. In natural geysers, the situation is probably different. In a natural geyser, the water in the standpipe would almost certainly be very near the boiling point. Under such conditions, the water pushed out at the start of the major eruption would be so hot that the minor would not be quenched. Rather, the minor would quickly build into a major eruption.

Conclusions

This model geyser demonstrates that eruptions can occur in series when fluids from two different reservoirs erupt through the same vent. The timing of the major eruption is probably controlled by pressure variations that occur during the minor cycle. The major eruptions erupt from the lower reservoir, and the minor eruptions erupt from the upper reservoir. The power of the eruption is proportional to the depth at which the source reservoir lies below the vent.

The pattern of eruptions illustrated by this model can be compared to two well-known geysers in Yellowstone: Atomizer and Lone Star. Both geysers begin a series with one or more minor eruptions, and conclude the series with a major eruption. In both examples, the major is distinguished from the minor eruptions by its longer duration, greater height, and the presence of an audible steam phase. The plumbing system of each geyser, by analogy with the model, likely includes a shallow reservoir that produces the minor eruptions on a short interval, and a deep reservoir that produces the major eruptions on a longer interval.

Acknowledgments

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Periodicity of an Underwater Geyser Varying with Tide

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Abstract

The periodicity of an underwater geyser in the Taketomi submarine hot spring in Yaeyama archipelago, Japan, has been investigated for the first time by Furushima et al. (Marine Technology Society Journal, 43(3), 13-22, 2009). After conducting a time-series analysis of the upward velocity using an acoustic current meter, they concluded the time cycle of the geyser responded to the tide. The time cycles of the geyser at high and low tide were 66 s and 41 s, respectively. They also considered the relationship between the temperatures of the heat source and the recharge water, based on the vertical tube theory (Yuhara and Seno, 1969), a physics model of an onshore geyser. Assuming that the heated domain was just below the sea floor, and that the temperature of the heat source (Θ) was over 200 °C, they calculated that a recharge water temperature (θ_0) of 117.96 °C could sustain the observed time cycles at high and low tide. However, the relationship between Θ and θ_0 can vary according to the underground depth of the heated domain (*H*). In this study we obtained a time series of *H* from the averaged integration of upward flux per each eruption, after assuming that the cross-sectional area of the vertical tube had a constant value throughout the vertical direction. Results showed that *H* ranged from 6.6 m to 14.9 m with an average of 9.9 m. With some exceptions, we could regard *H* as a constant value of 10 m, as the tide changed from high to low. Again according to the vertical tube theory, this new *H* of 10 m indicated that at least the Θ must be above the boiling point of the recharge water (Θ>133.82 °C), and to stably sustain the cycles, the conditions of Θ > 200 °C and $\theta_0 \rightarrow \theta_{0s}$=130.57 °C are desirable. These estimations of Θ were consistent with the previous estimations of the "deep underground water temperature" at the Taketomi Submarine Hot Spring, which ranged from 160 to 200 °C as reported by Kaneshima et al. (1983), Kimura et al. (1985) and Oomori (1987).

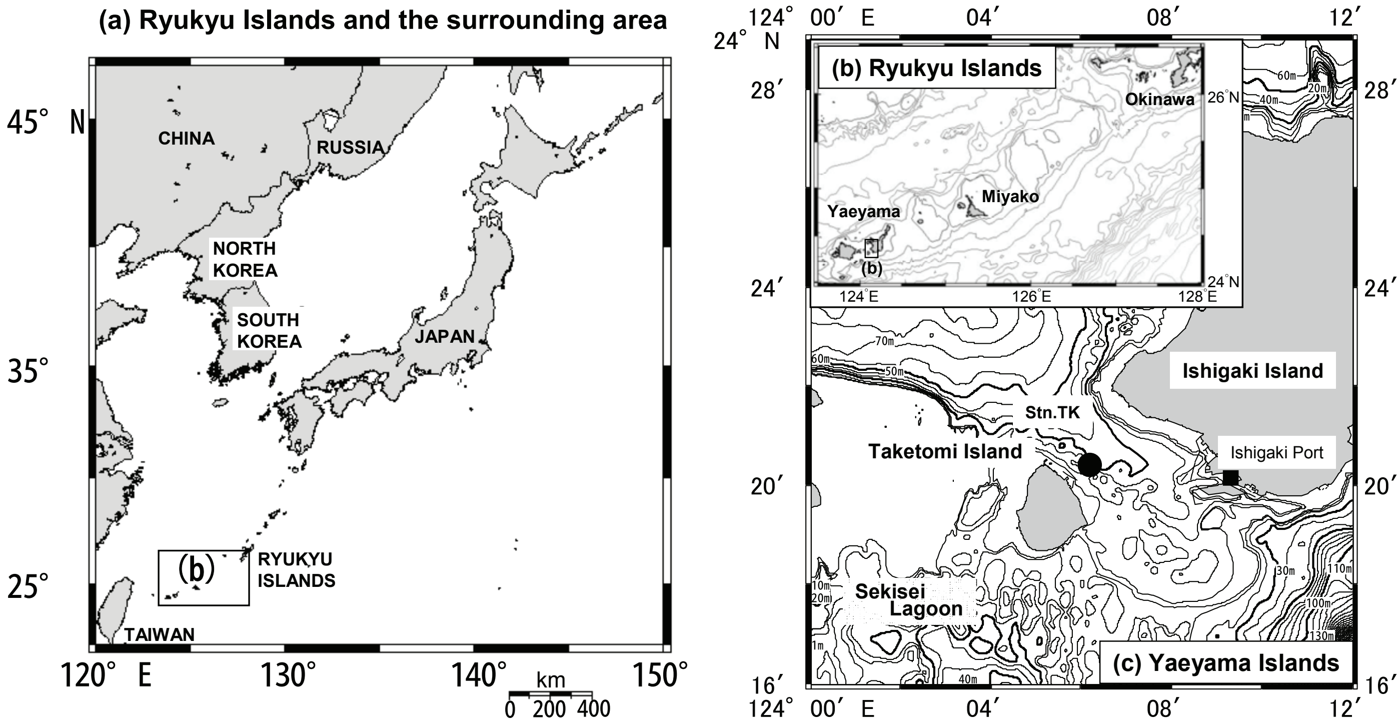


Figure 1. Ryukyu Islands and the surrounding area. **(a)** Taketomi Island and its surrounding ocean area. **(b)** Ryukyu archipelago, Japan. **(c)** Observation point of the Taketome Submarine Hot Spring at Taketomi Island (Stn.TK). (Adopted from Furushima et al. (2009) with alteration).

Introduction

The Taketomi submarine hot spring is a hydrothermal vent off eastern Taketomi Island, Yaeyama Archipelago, Japan (**Figure 1**). It is the only hydrothermal spring in Japan's coral reef region and is famous as a scuba diving spot and tourist attraction. Photosynthetic biota, such as Acroporid coral, etc., inhabit the area surrounding the hot spring (Nakamura et al., 2006). However, chemosynthetic organisms live near the hydrothermal vent and use chemicals such as methane and hydrogen sulfide for energy. Thus, there is a different ecosystem near the Taketomi submarine hot spring. Since coral is flourishing in the shallow water region where methane is blowing off, we expect this spring to have a definite influence on the coral reef ecosystem.

Geographically, the submarine hot spring has the form of a mortar (**Figure 2**). Many small-scale bubble jets, like a curtain of fine bubbles, can be intermittently seen coming from the main hydrothermal vent on the south-southwest slope. The geochemical observations of blowing gas (Kaneshima et al., 1983), hot spring water, and sediment (e.g., Oomori, 1987; Oomori et al., 1991) conducted at the Taketomi submarine hot spring suggest the gas is volcanic. Moreover, Oomori (1987) suggested the Taketomi submarine hot spring originated in hydrothermal activity in the Ryukyu archipelago since many heavy metals are contained in the sediment. Hydrothermal activity of the Taketomi submarine hot spring is similar to the activity of the Okinawa Trough where hydrogen sulfide, methane, heavy metals, etc., are contained in the spouting gas.

As a part of the Taketomi submarine hot spring, there is an unique underwater geyser (**Figure 2**). It intermittently releases a bubble jet. Most of the physical research on geysers has been done on land in hot spring regions (e.g., Yuhara and Seno, 1969; Ingebristen and Rojstaczer, 1993; Nomura et al., 1995; Bryan, 1995) or in the laboratory (e.g., Imura, 1999), but not at the sea bottom. By taking upward velocity data from the underwater geyser, Furushima et al. (2009) investigated for the first time the periodicity of this geyser and found its dependency on the tidal cycle. They also obtained a primary approximation of heat source temperature and recharge water temperature after assuming the underground depth of the heated domain to be just below the sea bottom.

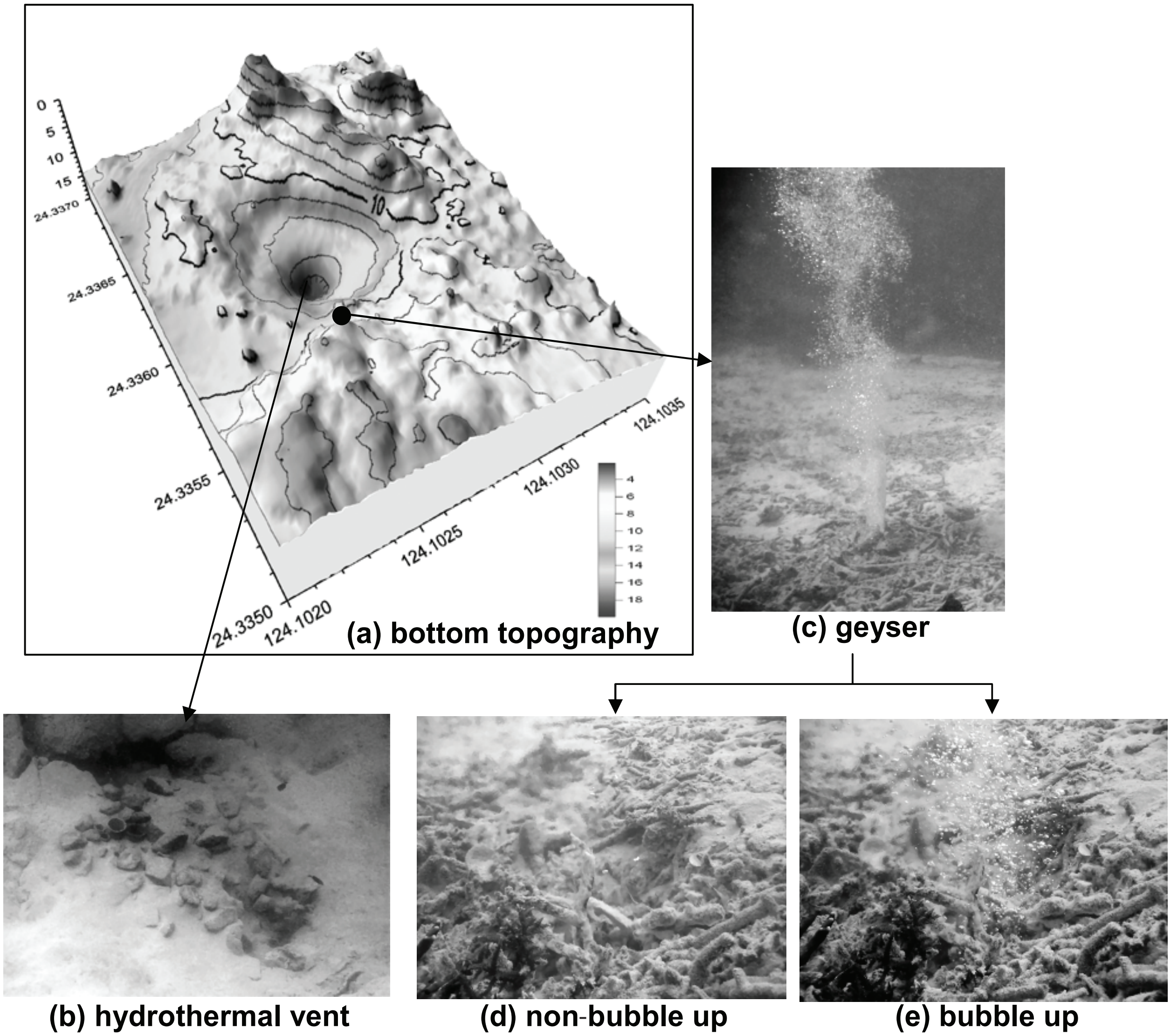


Figure 2. Observation site in Taketomi submarine hot spring. **(a)** Bottom topography map using multibeam echo sounder, **(b)** main hydrothermal vent, **(c)** geyser at a point 35 m south-southwest from the main vent, **(d)** geyser with non-bubble jet eruption and **(e)** with bubble jet eruption. Diameter of geyser blowhole is about 30 cm. (Adopted from Furushima et al. (2009) with minor alteration.)

After reconsideration of the results by Furushima et al. (2009) this paper adds some new results about this geyser's underground depth of the heated domain and thermal condition.

Method

The depth of the main thermal vent (**Figure 2(b)**) and the underwater geyser (**Figure 2(c)**) are 20 m and 10.1 m, respectively. The geyser blows off or vents a bubble jet periodically (**Figure 2(d)** and **2(e)**). Continuous data of the bubble jet's upward velocity (V_u) was obtained once a second from 9:00 on September 28, 2005 to 15:00 on September 29, 2005. These data were obtained using an acoustic current meter (Aquadopp2000, Nortek AS) from a distance of 0.7 m above of the geyser. The Aquadopp2000 has (1) an echo frequency of 2 MHz, (2) an internal sampling rate of 23 Hz, (3) a measurement cell size (thickness of a setting layer) of 0.75 m, and (4) a measurement distance along the beam from 0.35 to 5.00 m. It was installed 1.25 m away from the center of the geyser. The time interval per measurement burst was one second, and the number of pings per burst was 23. Measurement accuracy of the velocity is 0.5 cm/s of the measured value. The Aquadopp2000 can collect data for averaged upward (V_u), northward and eastward velocity for each one- second burst. The details of

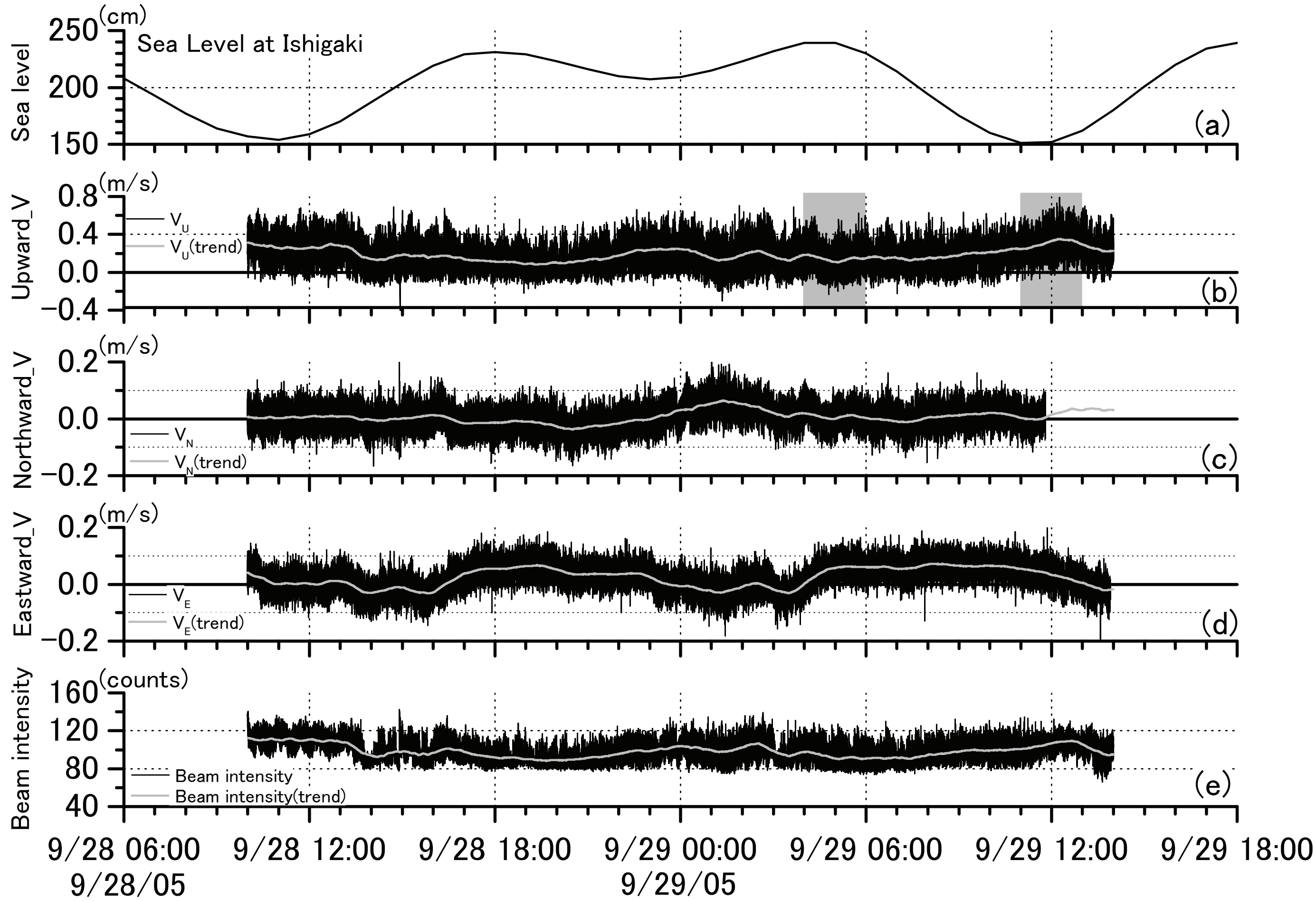


Figure 3. Time series of sea level at Ishigaki Island and data collected by Aquadopp2000. **(a)** sea level at Ishigaki Island recorded as a height above its reference monitored by Japan Meteorological Agency, **(b)** upward velocity (V_u), **(c)** north-south horizontal velocity (V_N), **(d)** east-west horizontal velocity (V_E), **(e)** average beam intensity. V_u in hatching regions are enlarged in **Figure 4-1** and **4-2.** (Adopted from Furushima et al. (2009).)

the velocity measurement are given in the paper by Furushima et al. (2009).

On the basis of the Doppler Effect, the acoustic current meter measures water velocity using acoustic frequency difference between the original and the reflected acoustic pulse due to reflection off backscatters (BS) in the water (e.g., Takasugi, 1998). When we observe the bubble jet from the geyser using the Aquadopp2000, the main contribution to BS seems to be the bubbles of volcanic gas or suspended material from the sea bed. If most of the BS are bubbles, we would need to determine whether V_u of the bubbles is the same as the jet itself. In this paper, however, we assumed that V_u measured by the Aquadopp2000 agrees with the upward velocity of the jet.

Results

Characteristics of the eruption's dominant time cycle

The time series of V_u (**Figure 3(b)**) between high and low tide indicates a more rapidly changing V_u during low tide than during high tide (**Figure 4-1**). In addition, the fluctuating range of V_u during high tide was between 0.6 m/s and -0.2 m/s, while during low tide it was between 0.8 m/s and -0.1 m/s (**Figure 4-1**). In **Figure 4-2** the contrast in the time series of V_u is increased between high and low tide, and the periodicity of V_u at high tide appears to be much longer than at the low tide. To confirm this, power spectrum densities for high and low tide data in **Figure 4-1** were obtained (**Figure 5-1**). Because the dominant time cycle of eruption seems to exist only from 10 s to 180 s, we looked

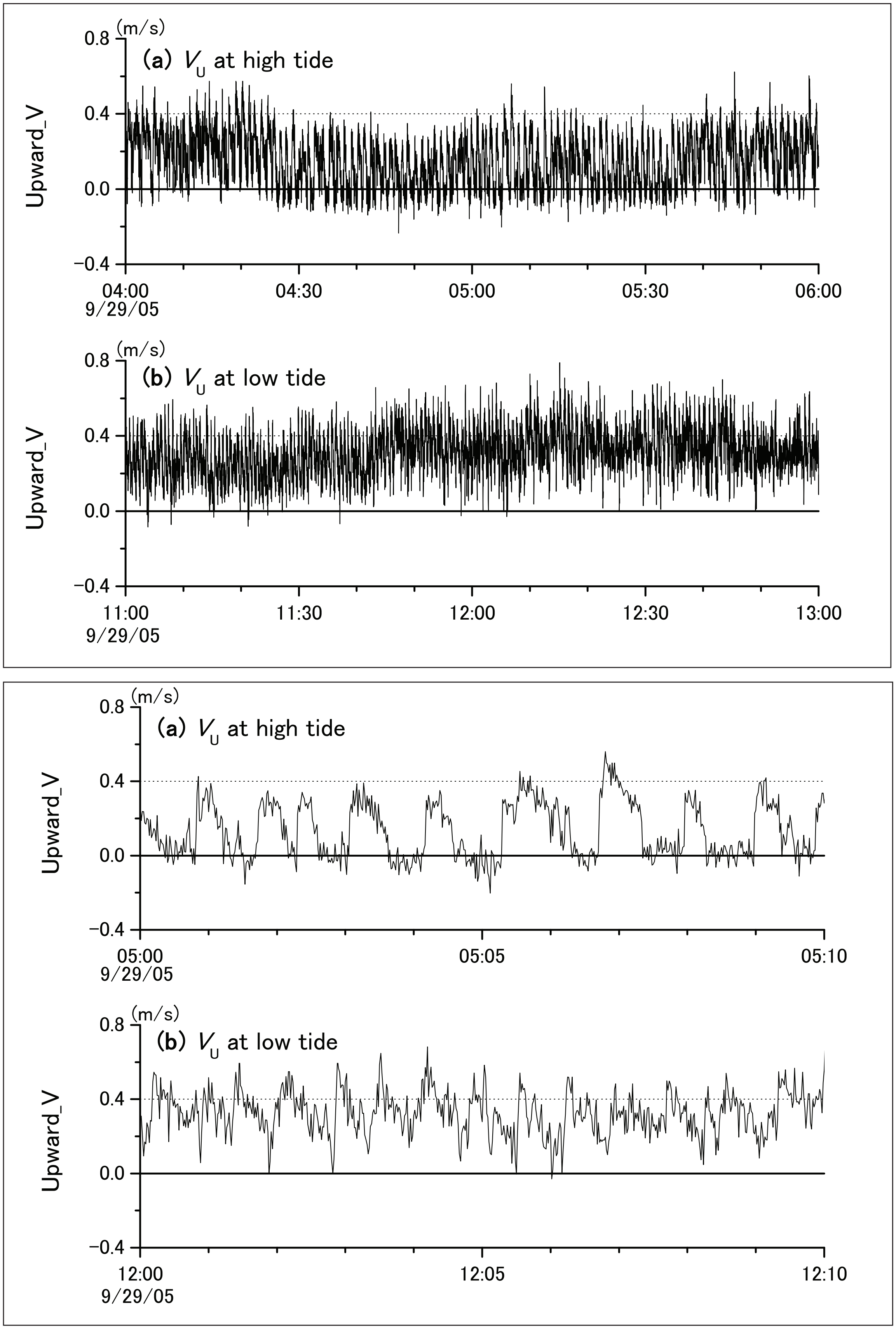


Figure 4.
4-1. (Top Panel) Contrast of time series of V_u between **(a)** high tide (04:00-06:00 on September 29, 2005) and **(b)** low tide (11:00-13:00 on September 29, 2005). (Adopted from Furushima et al. (2009).)
4-2. (Bottom Panel) Contrast of time series of V_u between **(a)** high tide (05:00-05:10 on September 29, 2005) and **(b)** low tide (12:00-12:10 on September 29, 2005). (Adopted from Furushima et al. (2009).)

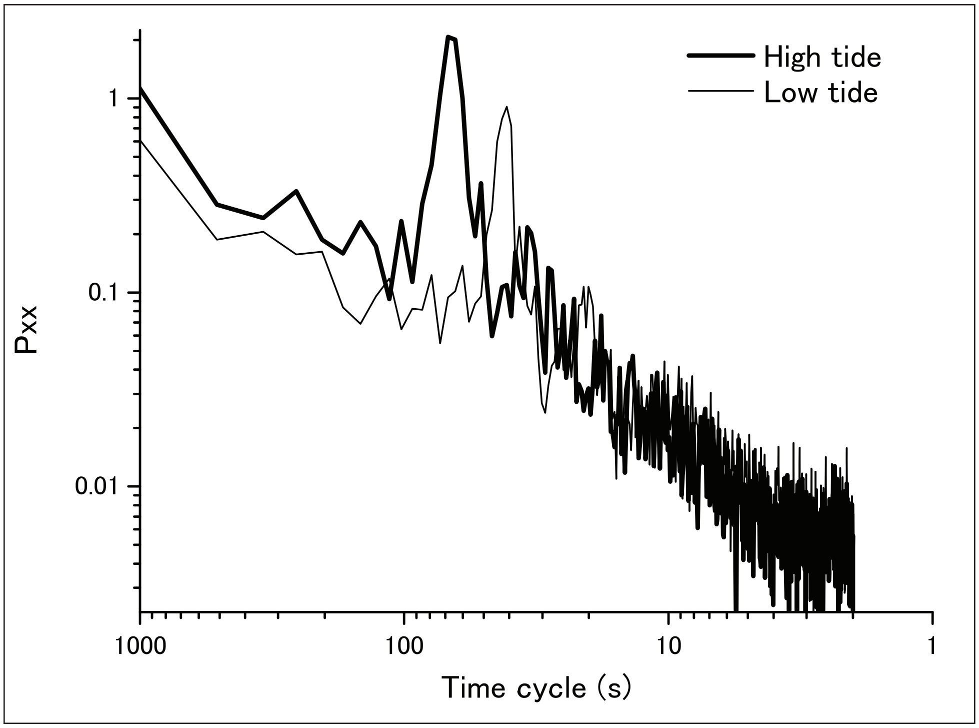
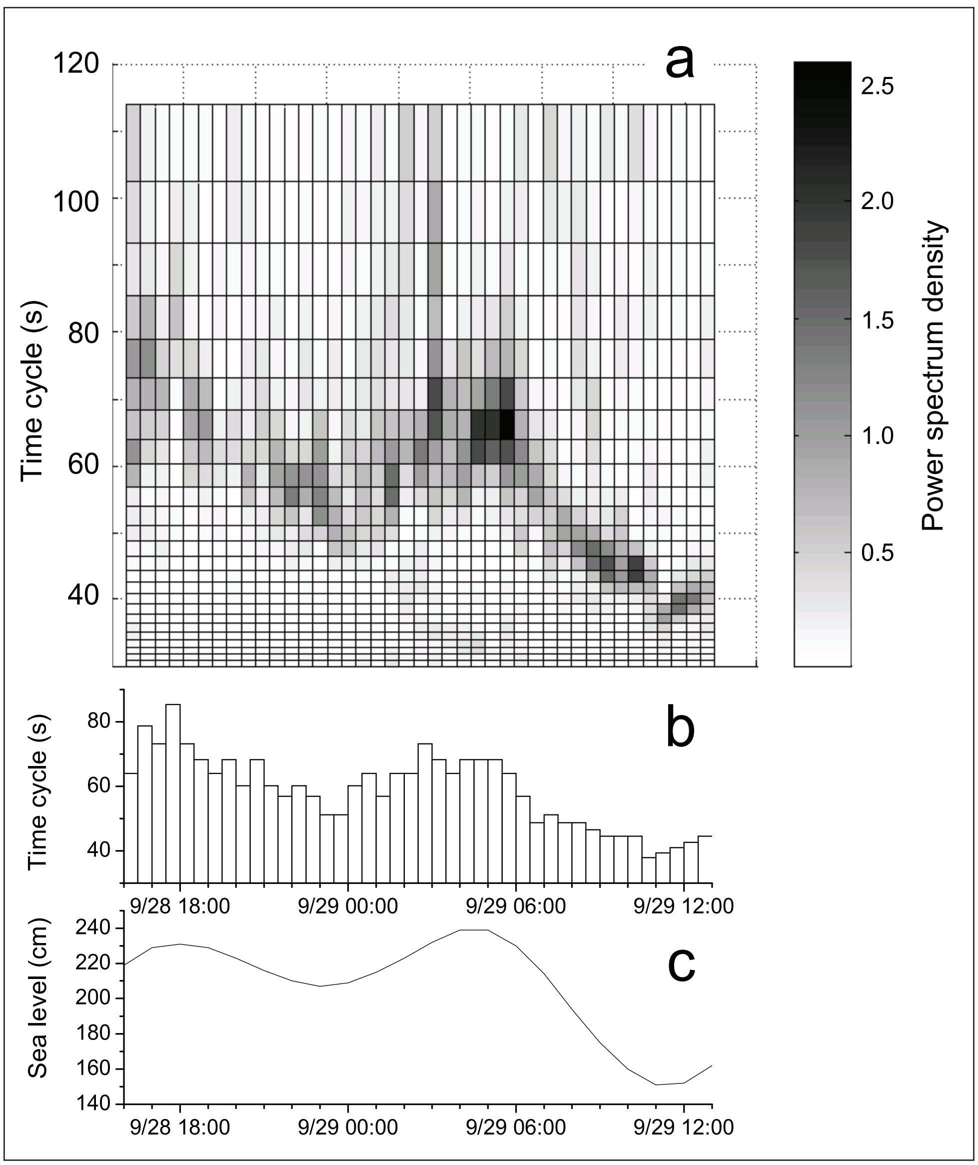


Figure 5.
5-1. Contrast of power spectrum density of V_u between high tide and low tide. Analyzed data are shown in **Figure 4-1**. (Adopted from Furushima et al. (2009).)



5-2. Time series of **(a)** power spectrum density, **(b)** dominant time cycle and **(c)** the sea level at the Ishigaki Island. (Adopted from Furushima et al. (2009) with minor alteration.)

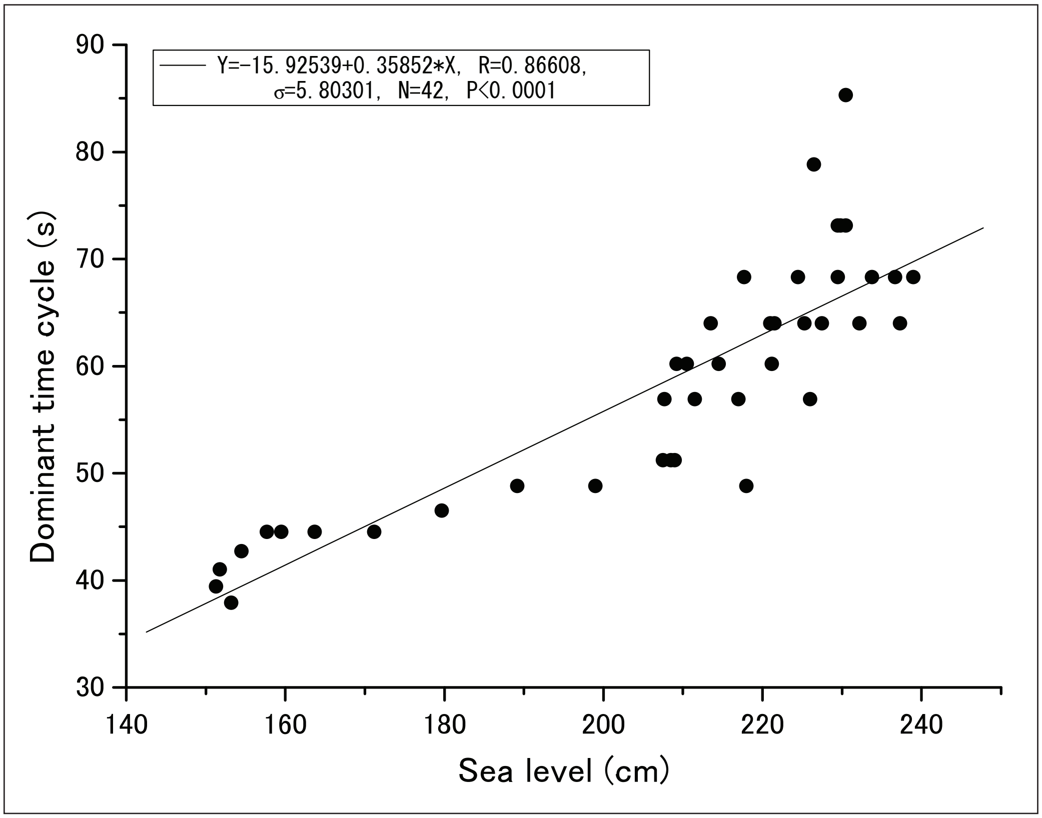


Figure 6. Correlation between the sea level and the time cycle of the eruption. (Adopted from Furushima et al. (2009).)

for the dominant time cycle in this range that had a high power spectrum density. **Figure 5-1** shows that the dominant time cycle at high tide is 66 s (primary) and 34 s (secondary), and at low tide is 41 s (primary) and 20 s (secondary). At high tide the time cycle of eruptions is longer; at low tide the time cycle is shorter.

Encouraged by the result shown in **Figure 5-1**, we examined the trend of the time cycle for the geyser. Data corresponding to 21 hours from 16:00 on September 28 to 13:00 on September 29 were used for analysis. We separated the time series of V_u into every 30-minute blocks. Then, power spectrum densities were computed for each of these 30-min intervals (**Figure 5-2(a)**). In **Figure 5-2(a)** time cycle (Y-axis) ranged from 30 s to 120 s, because this is the range for the dominant time cycle of eruption. **Figure 5-2(b)** shows the dominant (primary) time cycle of the eruption obtained from the spectrum peak after scanning the time series of the power spectrum densities in **Figure 5-2(a)**. **Figure 5-2(c)** is the time series of sea level at nearby Ishigaki Island. As shown in **Figure 5-2(b)**, the longest time cycle of 85 s was observed during the high tide at 17:30-18:00 on September 28, which is a lower high tide than the high tide on September 29. In contrast, the shortest time cycle of 38 s was observed during the low tide at 10:30-11:00 on September 29, which is the lower of the two low tides that occurred during the observation period. For the period of higher high water (4:31, September 29) to the lower low water (11:27, September 29), the time cycle of 68 s during 05:00-05:30 decreased to 38 s during 10:30-11:00. After 12:00, the dominant time cycle increases. **Figure 6** shows the correlation between the sea level and the time cycle of the eruption based upon the results in **Figure 5-2 (b)** and **(c)**. Strong dependency of the time cycle on the sea level implies the sea-level change due to tide controls the time cycle of the geyser.

Upward flux from the geyser

The time series of upward flux, dominant time cycle of eruption, and sea level are shown in **Figure 7**. The upward flux as flow volume per unit area and unit time was obtained by integrating over V_u for every 10 min period. The upward flux tended to increase when the sea level dropped. This tendency can be explained as resulting from the difference of quiescent time of the geyser between high and low tide. If unit upward flux for one blowout is steady, the amount of the upward flux per unit time depends on the number of blowouts per unit time. Thus, the upward flux at low tide is larger than at high tide

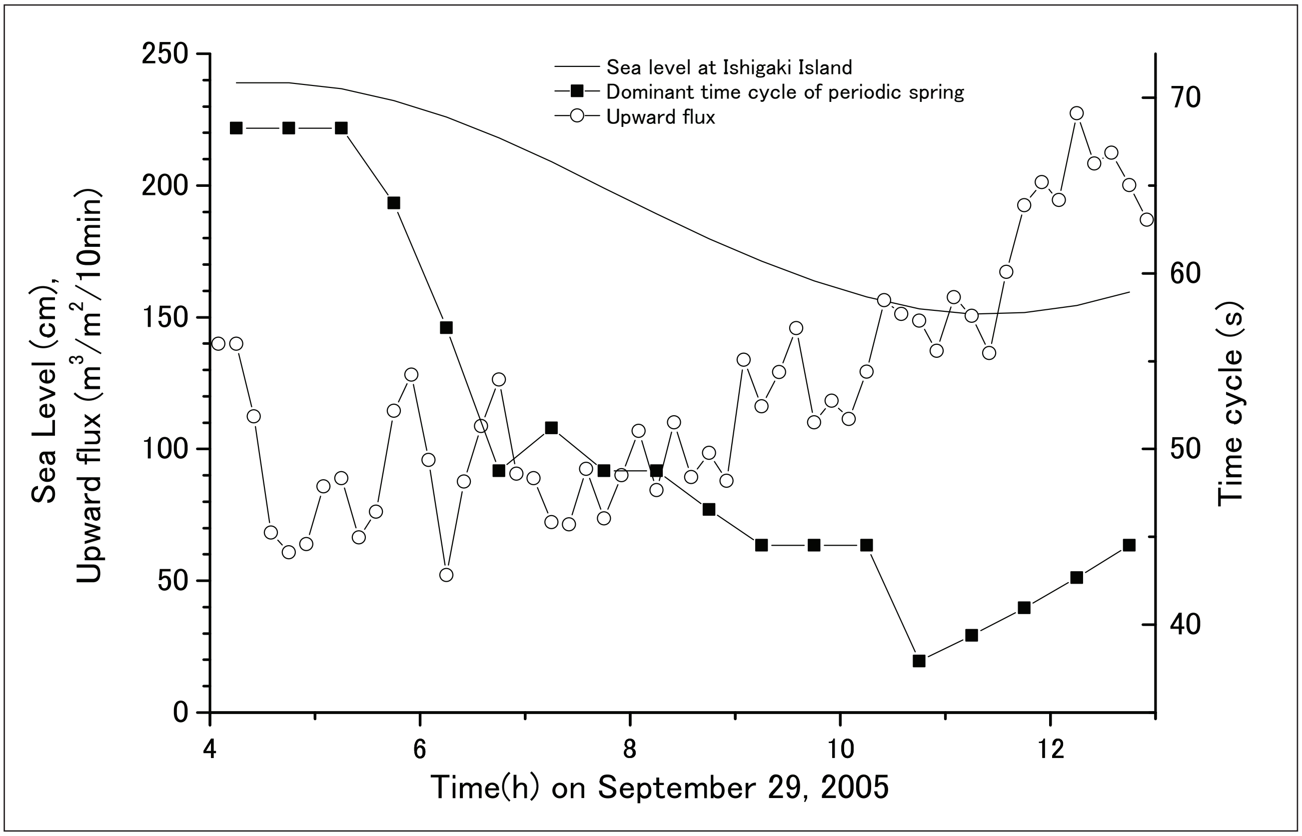


Figure 7. Time series of upward mass flux, dominant time cycle and sea level at the Ishigaki Island from 04:00 on September 29, 2005 through 13:00 on September 29, 2005. Mass flux was obtained by integrating the upward flow velocity for each 10 minute interval. (Adopted from Furushima et al. (2009).)

because the dominant time cycle (quiescent time) of the geyser at low tide is shorter than at high tide (see **Figure 5** and **6**).

The flow rate from the geyser is needed to determine the loads of methane or heavy metal in the effluent. Acroporid coral and like species inhabit the area surrounding the hot spring (Nakamura et al., 2006). Therefore, these results will serve as basic data to assist in our understanding of the influence of the geyser on the photosynthetic activity around the Taketomi submarine hot spring. Furthermore, it can contribute to the understanding of the coral reef ecosystem by comparing the physical environment of the Sekisei lagoon (Furushima et al., 2002; Furushima and Okamoto, 2002) to the Taketomi submarine hot spring.

Discussion

Application of vertical tube theory of the underwater geyser

Here we consider a qualitative mechanism for this underwater geyser using the vertical tube theory (Yuhara and Seno, 1969) (**Figure 8**). This theory does not require the existence of a cavity to explain the periodic behavior of the geyser. The vertical tube theory is well-suited to explain the mechanism of a geyser whose upwelling flux for each eruption is small and the time cycle is short.

According to Yuhara and Seno (1969), the time cycle (t_1) in the vertical tube theory can be written as Eq. (1).

$$t_1 = \frac{M}{c}\ln\frac{(\Theta - \theta_0)}{(\Theta - \theta_1)} \quad (1)$$

Where c is a constant related to specific heat and transfer of seawater, M is the effective volume of the heated domain (A), and Θ and θ are temperatures of the thermal source and the water in the heated domain, respectively. θ_0 and θ_1 are the initial and boiling temperatures of the recharge water, respectively. The natural logarithmic function is ln.

Yuhara and Seno (1969) described the three characteristics of the geyser using Eq.(1): i) large

M of domain A means a longer t_1, ii) high θ_0 means a shorter t_1 with $\theta_0 \rightarrow \theta_1$ producing a continuous discharge instead of a periodic blowout, and iii) high θ_1 means a longer t_1.

In our case, when the tidal level is high, hydrostatic pressure in A is high. This high pressure will cause higher θ_1 due to boiling point elevation. Thus, from the above condition iii), t_1 will be expected to be longer at high tide and shorter at low tide. From the spectrum analysis of our data, t_1 was 66 s at high tide and 41 s at low tide. This result is qualitatively consistent with the above expectation.

Now we consider the relationship between Θ and θ_0, which should satisfy the observed conditions. This relationship is examined after taking into account the boiling point elevation inside the vertical tube, which is dependent on the exterior hydrostatic pressure. If Θ and θ_0 are constants, from Eq. (1) the ratio of t_1 at high tide (t_{1h}) to low tide (t_{1l}) is shown in Eq. (2).

$$\frac{t_{1h}}{t_{1l}} = \frac{A_0 - \ln(\Theta - \theta_{1h})}{A_0 - \ln(\Theta - \theta_{1l})} \tag{2}$$

Where θ_{1h} and θ_{1l} are θ_1 at high and low tide, and $A_0 = \ln(\Theta - \theta_0)$ and we define $k = t_{1h}/t_{1l}$, we can solve Eq. (2) for θ_0 and produce Eq. (3).

$$\theta_0 = \Theta - \exp\left(\frac{k \cdot \ln(\Theta - \theta_{1l}) - \ln(\Theta - \theta_{1h})}{k - 1}\right) \tag{3}$$

When $\Theta \rightarrow \infty$, asymptotic temperature of θ_0 (θ_{0s}) is as shown by Eq. (4) (see **Appendix** for the derivation).

$$\theta_{0s} = \frac{k \cdot \theta_{1l} - \theta_{1h}}{k - 1} \tag{4}$$

After assigning the observed results (k) and the estimated variables (θ_{1h}, θ_{1l}) to Eq. (3) and (4), we can obtain the relationship between Θ and θ_0.

Estimation of underground depth of heated domain

Furushima et al. (2009) estimated θ_{1h} and θ_{1l}, after assuming the location of the geyser was just under the sea bottom, because Kaneshima et al. (1983) reported that the spouting water from the main vent of the Taketomi submarine hot spring mainly consisted of sea water. On the other hand, according to the vertical tube theory, the water located from the top of the heated domain to the sea bottom blows out every eruption (Yuhara and Seno, 1969). Therefore, we can estimate the underground depth of the heated domain from the upward flux of each eruption.

We assume that the cross-sectional area (a) of the vertical tube is uniform throughout the vertical direction (**Figure 8, next page**). The volume from the top of the heated domain to the sea bottom becomes aH, where H is the underground depth of the heated domain. This volume should be equal to an integration of upward rate flow (aV_u) for one eruption time.

$$aH = \int_0^\tau aV_u dt$$

$$H = \int_0^\tau V_u dt \tag{5}$$

Where t and τ are time and eruption time, respectively. t=0 is the beginning of the eruption and t=τ is the end.

Instead of numerically integrating V_u, we use the already calculated upward flux (F [m^3/m^2/10min]) and the dominant time cycle (T [s]) from **Figure 7**. The frequency of eruption per 10 min becomes $600/T$. Thus, the right hand value of Eq. (5) becomes $F/(600/T)$. To be consistent, we shall use F for 30 min (F_{30} [m^3/m^2/30min]) instead of F for every 10 min **in Figure 7**, because T in **Figure 7** represents the value for each 30 min (T_{30} [s]).

$$H = F_{30}T_{30}/1800 \text{ [m]} \tag{6}$$

Figure 9 (next page) shows the time series of H after assigning F_{30} and T to Eq.(6). H varied from 6.6 m to 14.9 m with an average of 9.9 m. Outside of four exceptions at 4:15, 11:45-12:45, we may regard H as a constant value of 10 m.

Relationship among thermal source temperature and recharge water temperature

After assigning observed and estimated values from **Table 1** to variables in Eq. (3) and (4), **Figure 10** indicates the relationship between Θ and θ_0. Note that the air pressure on the sea surface during

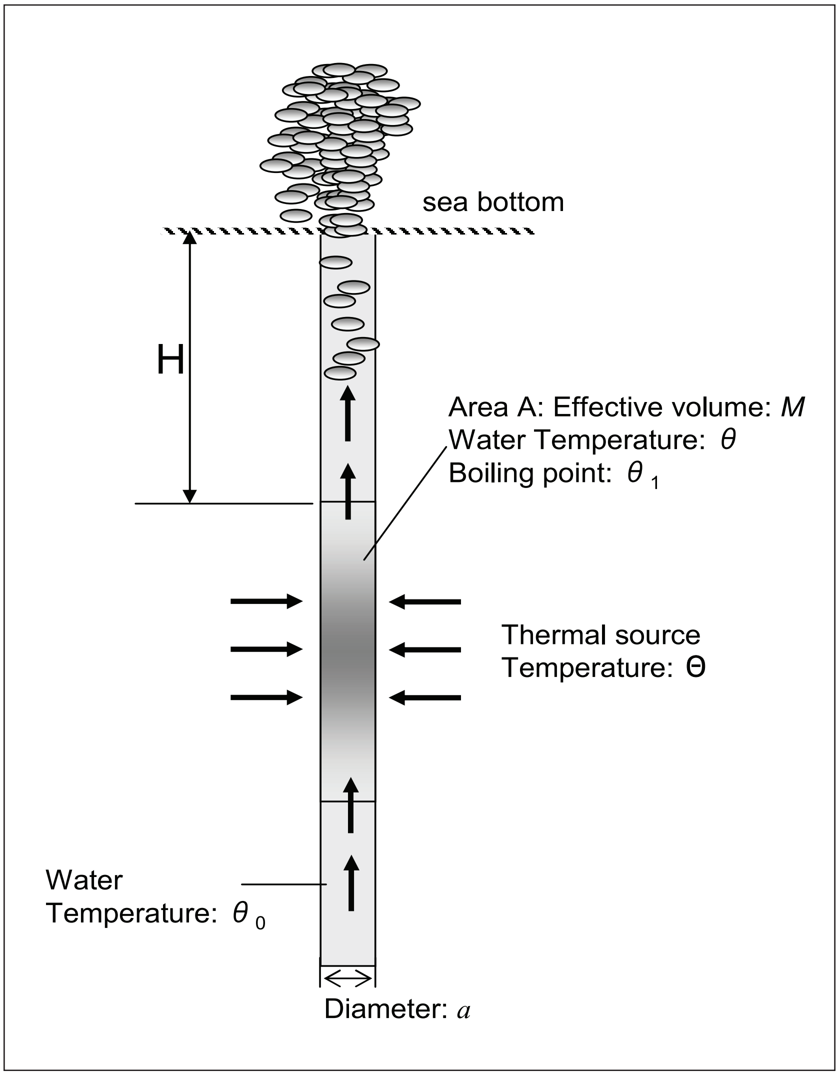


Figure 8. Schematic view of the vertical tube theory. M is effective volume of the heated domain (A), and Θ and θ are temperatures of the thermal source and the seawater in the heated domain, respectively. θ_0 and θ_1 are initial and boiling temperature of the recharge water, respectively. a and H are diameter of the vertical tube and the depth of the heated domain, respectively (adopted from Furushima et al. (2009) with minor alteration).

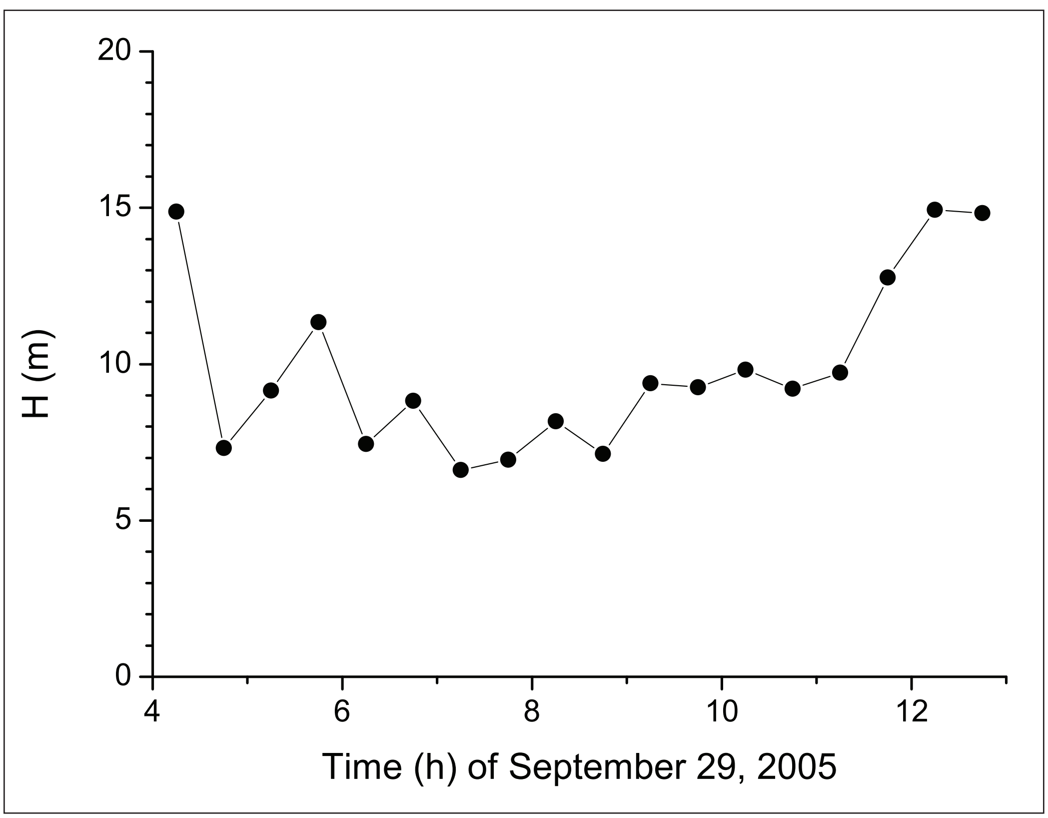


Figure 9. Time series of estimated underground depth of heated domain (H).

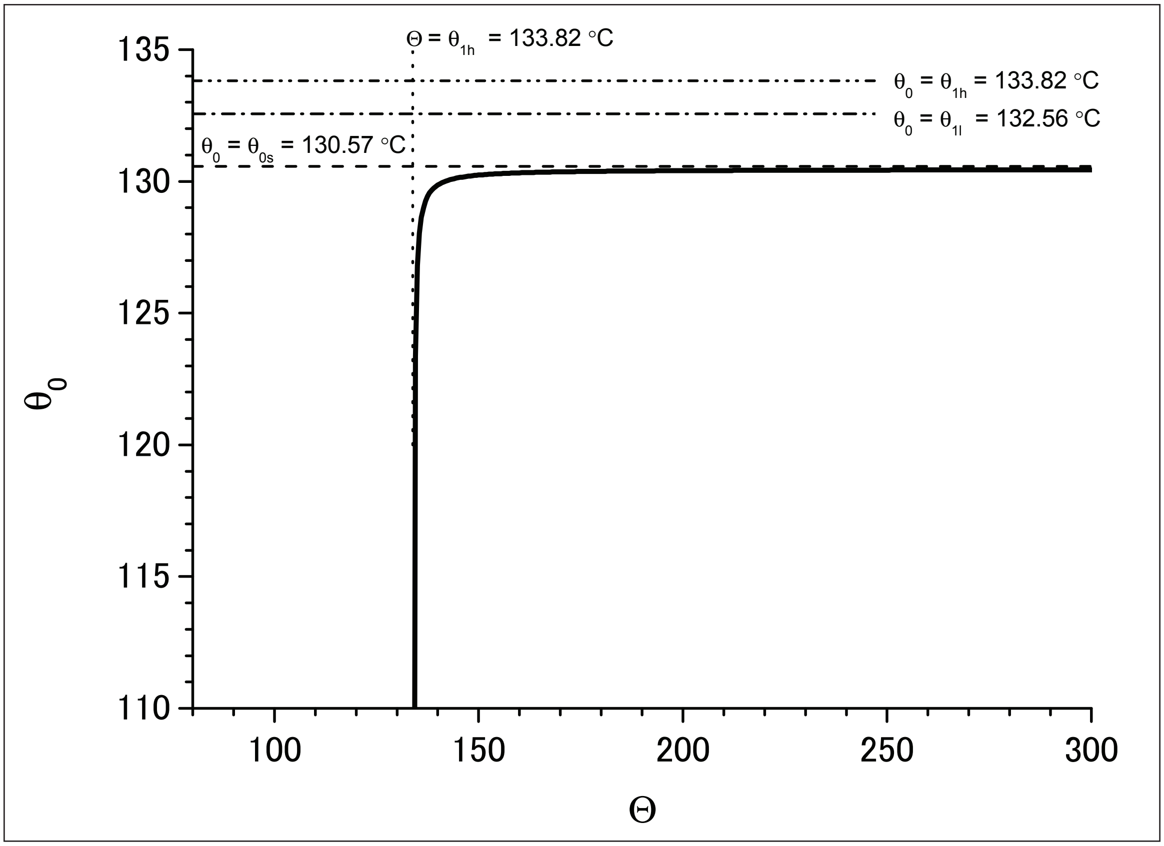


Figure 10. Relationship between thermal source temperature (Θ), recharge water temperature (θ_0) and the underground depth of the heated domain after considering the observed and estimated values in **Table 1**. θ_{0s} is an asymptotic value of θ_0 when Θ becomes infinity.

the field work was from to 1012.0 to 1014.6 hPa and could be regarded as uniform. As a result, to sustain the observed time cycles of the geyser at high and low tide, at least the Θ must meet a requirement of $\Theta > \theta_{1h}$=133.82 °C. And if the Θ was higher than 200 °C and θ_0 was almost the same as an asymptotic temperature of θ_0 (θ_{0s}=130.57 °C), the observed eruption periods at the high and low tide were satisfied.

Note that the recharge water must be preheated to θ_{0s} before it reaches the vertical tube. The θ_{0s} of 130.57 °C is far hotter than the sea water temperature, which ranged from 30.3 to 31.2 °C. If the seawater in the seabed is preheated to θ_{0s} through heat exchange with the thermal source, the observed time cycle can be measured. As shown in **Figure 4-2**, at the high tide the geyser phenomena seemed to obey the vertical tube theory because quiescent time was very clear. However, at the low tide θ_0 may almost equal θ_{1l} because V_u almost always took a positive value, and it implied $\theta_0 \rightarrow \theta_1$(Yuhara and Seno, 1969). These results confirmed θ_0 was almost equal to θ_{0s} (**Figure 10**).

There are some estimated values of "deep underground water" temperatures at the Taketomi submarine hot spring (Oomori et al., 1993). Kaneshima et al. (1983) estimated the temperature at about 200 °C after considering the mixing ratio between the seawater and the deep underground water. Kimura et al. (1985) estimated the temperature at about 200 °C using a silica thermometer that is designed for geothermal areas. Oomori (1987) estimated the temperature at about 160 °C after considering that Mg^{2+} concentration must be zero in original "pure" hydrothermal solutions under high temperature. These reported temperatures ranged from 160 to 200 °C.

On the other hand, our Θ is regarded as the same as the deep underground water temperature. As indicated above, to sustain the observed time cycles, at least the Θ must meet a requirement of Θ > θ_{1h}=133.82 °C, and to stably sustain the cycles, the conditions of Θ > 200 °C and $\theta_0 \rightarrow \theta_{0s}$=130.57 °C are desirable. These requirements for Θ were consistent

Table 1 Applied values to calculate heat source temperature (Θ) and recharge water temperature (θ_0). Boiling point of the recharge water (θ_1), as a function of pressure and salinity, was quoted from *Data book for seawater science and salt production* (The Salt Industry Center of Japan, 2006).

Dominant time cycle(t_1)	**At high tide (t_{1h})**	**66 s**
	At low tide (t_{1l})	**41 s**
	$k = t_{1h}/t_{1l}$	**1.6**
Average Depth	**D**	**10 m**
Underground depth of heated domain	**H**	**10 m**
Sea level difference	**Δ=high tide - low tide**	**1.0 m**
Depth	**At high tide ($D+\Delta/2$)**	**10.5 m**
	At low tide ($D-\Delta/2$)	**9. 5 m**
Air pressure	**P_0**	**10 dbar**
Pressure at heated domain	**At high tide**	**30.5 dbar**
	At low tide	**29.5 dbar**
Salinity of recharge water	**S**	**35**
Boiling point of recharge water inside vertical tube	**At high tide (θ_{1h})**	**133.82 °C**
	At low tide (θ_{1l})	**132.56 °C**

with those reported temperatures, which ranged from 160 to 200 °C.

Unfortunately, we don't have any data that can confirm the origin of the recharge water because we didn't measure the temperature and the chemical quantity of the discharge from the geyser. However, we can introduce an estimation conducted by Kaneshima et al. (1983). They implied that the discharge water at the Taketomi submarine hot spring is mainly composed of the seawater. They estimated that the ratio of the seawater to all discharge water from the main hydrothermal vent (**Figure 2**) was 93%. For these calculations, they assumed that the concentrations of Cl^- and Na^+ in the seawater and the spring water had fixed values. Then they calculated the mix ratio that was accountable for the Cl^- and Na^+ concentrations in the discharge from the main hydrothermal vent.

Summary

Furushima et al. (2009) observed the periodicity of the underwater geyser that spouts intermittently near the Taketomi submarine hot spring in the Yaeyama archipelago using an acoustic current meter and concluded its dominant time cycles at high and low tide were 66 s and 41 s, respectively. This result indicated that the fluctuation of pressure due to tidal elevation affected the eruption period. And, in accordance with the vertical tube theory and assuming the underground depth of the heated domain was just below the sea bottom, they also suggested that the heat source temperature (Θ) was over 200 °C and a recharge water temperature (θ_0) of 117.96 °C could sustain the observed time cycles at high and low tide. However, the relationship between Θ and θ_0 can change by the assumed depth of the heated domain. In this study we obtained the depth of the heated domain from the averaged integration of upward flux per each eruption after assuming the cross-sectional area of the tube had a constant value throughout the vertical direction. Results showed *H* varied from 6.6 m to 14.9 m with an average of 9.9 m. With some exceptions, we could regard *H* as a constant value of 10 m, as the tide changed from high to low. Again, according to the vertical tube theory, this new H of 10 m indicated that at least the Θ must meet a requirement of $\Theta > 133.82$ °C, and to stably sustain the cycles the conditions of $\Theta > 200$ °C and $\theta_0 \rightarrow \theta_{0s}=130.57$ °C are desirable. These estimations of Θ were consistent with the previous estimations of the "deep underground water temperature" at Taketomi Submarine Hot Spring, which ranged from 160 to 200 ˚C reported by Kaneshima et al.(1983), Kimura et al. (1985) and Oomori (1987).

We understand that the application of the vertical tube theory to this underwater geyser should be verified in some way. The most straightforward way is to check whether the actual Θ and θ_0 correspond to our estimations. Although it is difficult to obtain actual values of Θ and θ_0 we intend to accomplish this task in the future. Further comprehensive field experiments to obtain the unknown important parameters (M, c, Θ, θ_0, θ_1 and the pressure inside the tube) will be needed to fully understand the difference in t_1 at high and low tide.

In the future, we expect it will be necessary to carry out research to evaluate the loads of methane, carbon dioxide and heavy metals in the effluent from the geyser. Additionally, we want to carry out ecosystem research in the area surrounding the Taketomi submarine hot spring.

Acknowledgments

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Appendix

When $\Theta \to +\infty$, asymptotic temperature of θ_0 can be obtained from Eq. (2) as follows. Replace the left-hand side by k, the numerator of right-hand side by $f(\Theta)$ and the denominator by $g(\Theta)$. According to L'Hôpital's rule,

$$k = \left.\frac{f(\Theta)}{g(\Theta)}\right|_{\Theta \to +\infty} = \left.\frac{f'(\Theta)}{g'(\Theta)}\right|_{\Theta \to +\infty} \tag{A-1}$$

Assign following derived functions of $f(\Theta)$ and $g(\Theta)$ to Eq. (A-1).

$$f'(\boldsymbol{\Theta}) = \frac{1}{\Theta - \theta_0} - \frac{1}{\Theta - \theta_{1h}} = -\frac{\theta_{1h} - \theta_0}{(\Theta - \theta_0)(\Theta - \theta_{1h})},$$

$$g'(\boldsymbol{\Theta}) = \frac{1}{\Theta - \theta_0} - \frac{1}{\Theta - \theta_{1l}} = -\frac{\theta_{1l} - \theta_0}{(\Theta - \theta_0)(\Theta - \theta_{1l})}.$$

Then, the right-hand side of Eq. (A-1) when $\Theta \to +\infty$ can be written as follows:

$$\left.\frac{f'(\Theta)}{g'(\Theta)}\right|_{\Theta \to +\infty} = \left.\frac{\dfrac{\theta_{1h} - \theta_0}{\Theta - \theta_{1h}}}{\dfrac{\theta_{1l} - \theta_0}{\Theta - \theta_{1l}}}\right|_{\Theta \to +\infty} = \left.\frac{\Theta - \theta_{1l}}{\Theta - \theta_{1h}} \cdot \frac{\theta_{1h} - \theta_0}{\theta_{1l} - \theta_0}\right|_{\Theta \to +\infty} \approx \frac{\theta_{1h} - \theta_0}{\theta_{1l} - \theta_0}.$$

Thus, when $\Theta \to +\infty$, Eq. (A-1) becomes Eq. (A-2).

$$k = \frac{\theta_{1h} - \theta_0}{\theta_{1l} - \theta_0} \tag{A-2}$$

After solving Eq. (A-2) for θ_0, we obtain Eq. (A-3) identical to Eq. (4).

$$\theta_0 = \frac{k \cdot \theta_{1l} - \theta_{1h}}{k - 1} \tag{A-3}$$

The Effect of a Constriction on the Function of a Model Geyser

Jeff Cross and Ron Keam

Abstract

It is sometimes suggested that a geyser can erupt periodically if and only if its plumbing system contains a constriction. In this paper, we examine the effect that the presence and absence of a constriction has on the function of a model geyser. One of us (J.C.) has shown by experiment that a model geyser that lacks a constriction can erupt periodically. We propose an explanation for this observation. We also describe a physical model that explains how a constriction, if present, can help initiate the eruption process in a geyser.

Introduction:

A geyser is a special type of hot spring that accumulates a store of energy and then releases it in an eruption that throws water into the air. Because the eruption is often much shorter than the quiet interval that passes between eruptions, the rate at which energy is lost from the system during the eruption exceeds the average rate at which energy is supplied. For large geysers, the rate of energy release during an eruption can be of the order of hundreds of kilowatts (Rinehart, 1980).

Central to the function of a geyser are two facts: first, the geyser must be able to store heat and water during the quiet period between eruptions; second, the geyser must be able to initiate an eruption so that this energy is rapidly released.

How does the geyser store energy? It is well known that the boiling point of water, which is 212˚ F (100º C) at sea level, is increased by the application of pressure. For example, the hydrostatic pressure 34 feet (10 m) beneath the water surface in a geyser is 14.7 psi (101 kPa) greater than it is at the top of the water column. Under this pressure, the boiling point of water is 249˚ F (121˚ C). Therefore, water 34 feet (10 m) below the water surface in a geyser may attain any temperature up to 249˚ F without boiling (Figure 1). When the geyser erupts, the pressure acting on the water as it moves through the geyser conduit falls from the hydrostatic pressure at depth to the atmospheric pressure at the geyser vent. Since the boiling point falls along with the pressure, the water must cool as it approaches the surface. The energy available to power the eruption through the formation of steam will be equal to the heat lost by the water as it falls from its original temperature to 212˚ F (100˚ C).

How does the geyser's eruption begin? Two mechanisms are possible: either the pressure on a body of water within the geyser must suddenly fall, so that the water finds itself above the boiling point; or the water itself must move closer to the surface, where the boiling point is lower. It is the natural occurrence of

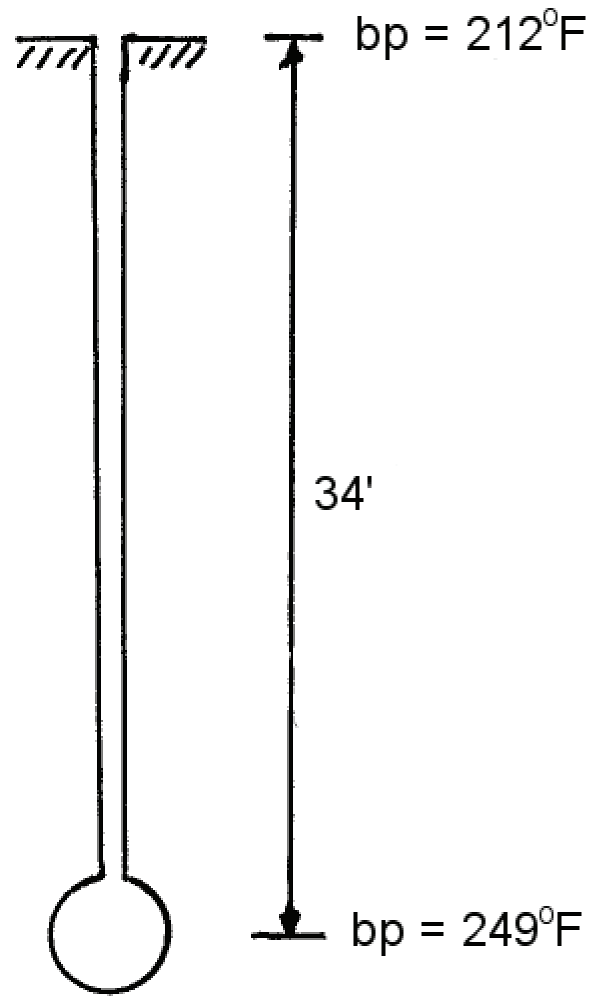

Figure 1. Boiling point of water 34 feet below the water surface.

the first mechanism that is discussed below.

In his 1967 paper on geysers, White suggested that a geyser eruption begins when steam bubbles rising through water in the geyser pipe encounter a narrow spot, or constriction. The bubbles may rise through the constriction, but the descent of an equivalent volume of liquid water can be hindered or prevented by the constriction's narrowness. Such one-way motion thrusts the column of water upward, and out of the geyser. The ejection of a portion of the water in the column causes the pressure to fall. This, in turn, lowers the boiling point, and causes more boiling to occur below the constriction, initiating a self-accelerating effect. Notably, this explanation is constrained by two requirements: first, there must be a constriction; second, the geyser must overflow as the eruption starts.

Observations by Anderson, Anderegg and Lawler (1978) support White's reasoning. Anderson *et al.*, especially, felt that the constriction was important because models lacking a constriction failed to erupt periodically. In models that included a constriction, they observed that eruptions began when, and only when, steam bubbles rose to the base of the constriction. They describe the initiation process as follows: "As bubbles enter the constriction so that the return flow of water is blocked, they lift the entrapped water above them out of the geyser as a mass. As the water above the constriction flows out of the vent, the boiling point at the bottom of the geyser is reduced, and a chain reaction of explosive boiling occurs, producing an eruption of steam and water." Although Anderson *et al.* clearly state that it is the overflow of water from the geyser that triggers the eruption, the analysis presented below shows that pressure reduction could be achieved even without overflow.

A similar process is described by Saptadji (1995), who experimented extensively with model geysers: "An eruption, moreover, is initiated once vigorous bubbling occurs in the chamber. A large vapor bubble rises without collapsing into the channel and it fills almost the whole of the cross section of the channel. The shape of the bubble is very much the

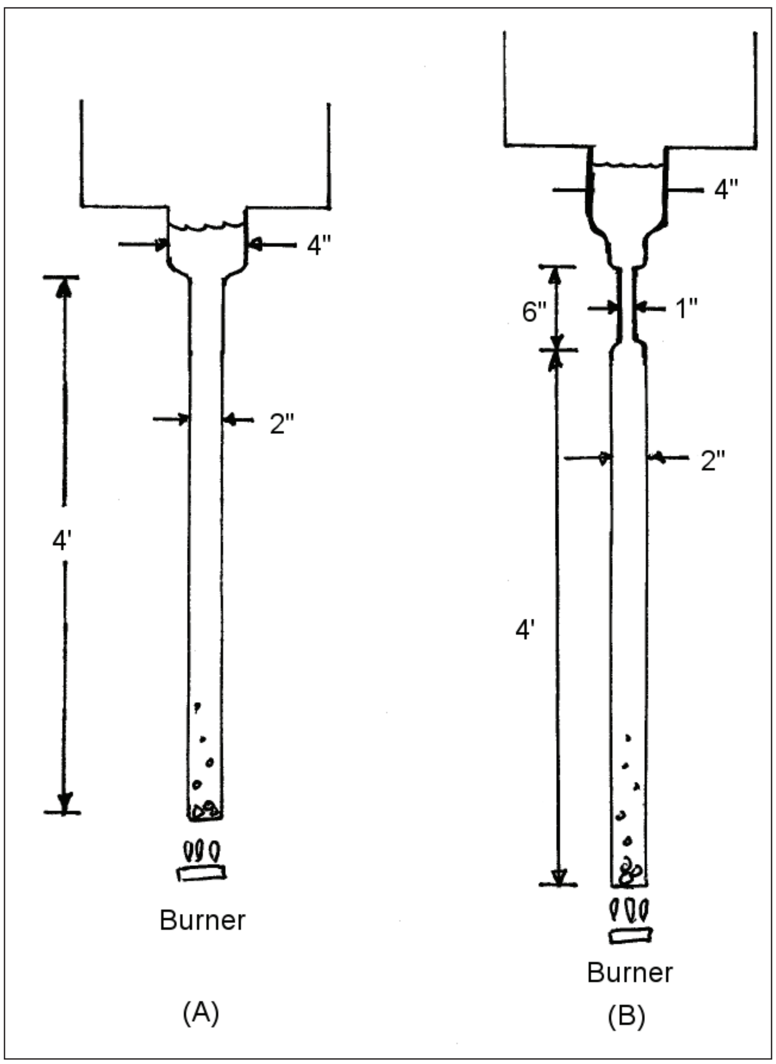

Figure 2. Experimental apparatus:
A) apparatus 1 – constrictionless,
B) apparatus 2 – includes constriction.

	Experiment 1	Experiment 2
Interval	4-48 s	8-17 s
Average	23 s	12 s
Std. Dev.	7 s (30% of avg.)	1.2 s (10% of avg.)
Count	89	143

Table 1: Eruption data for unconstricted (Experiment 1) and constricted (Experiment 2) model geysers.

same as Taylor bubbles (bullet-shaped bubbles)."

Murphy (1965), in contrast to Anderson, Anderegg and Lawler, showed that geyser eruptions can occur in unconstricted vertical tubes. Murphy built several model geysers with tube diameters of 4.22 to 13.5 inches (10.7 to 34.3 cm) and lengths of 2 to 28.3 feet (0.6 to 8.6 m). Geyser eruptions from these systems were most strongly controlled by the length of the tube and by the ratio between tube length and tube diameter.

Clearly, a constriction (or channel) can be an important part of the geyser. However, it is of interest to determine: a) whether the constriction is an essential part of the geyser system, b) how a constriction could affect the eruptive activity of the geyser, and c) whether these mechanisms can be sufficient to allow an eruption to start without any preliminary overflow. These issues are addressed in the following experiments.

EXPERIMENTAL

Experiment #1:

The apparatus consisted of a vertical section of galvanized pipe 2 inches (5.1 cm) in diameter and 4 feet (121 cm) in length (see Figure 2A). The bottom end of the pipe was capped, and the upper end was attached to a short section of 4-inch (10.2 cm) diameter pipe that opened into a catch pan. The model was filled with water so that the water surface lay within the 4-inch section. When heated strongly at the bottom end by the flame of a propane burner, the geyser erupted to 1 foot every 4 to 48 seconds. The average of 89 intervals was 23 seconds and the standard deviation was 7 seconds, which was 30% of that average. Eruptions consisted of a single splash. Water was slowly lost from the system through evaporation. When the water level fell so that it no longer rose into the 4-inch section of pipe, the intermittency ceased.

Experiment #2:

In a second experiment, the model described above was altered by adding a 6-inch (15 cm) long constriction of 1-inch (2.54 cm) pipe between the 2-inch pipe and the 4-inch pipe (see Figure 2B). The model then exhibited far greater regularity. Of 143 intervals, the range was 8 to 17 seconds. The average was 12 seconds and the standard deviation was 1.2 seconds, which was 10% of that average. Eruptions were brief, but were very well defined. Clearly, the model with the constriction was far more regular. When the water level fell so that it no longer rose into the constriction, the periodic activity ceased.

Data for these experiments is shown in Table 1. That the interval was nearly halved in the second experiment could be due to a change in the amount of heat supplied by the burner. It is therefore not necessarily a consequence of the constriction.

Experiment #3:

To further explore the effect of a constriction on the function of a geyser, a simple experiment was performed using air bubbles as a proxy for steam bubbles. A section of flexible rubber tubing was bent into a U-shape and filled with water. A little air was introduced into one side of the U-tube, where it rose as a single bubble that filled the entire cross-section of the tube. At this time, the water stood higher on the side with the air bubble by an amount L, which should be equal to the vertical extent of the bubble (see Figure 3A, next page).

When the tube was pinched above the bubble (as shown by the constriction in Figure 3A), an interesting effect was noted. As the bubble passed through the constriction, the water level rose on the side of the tube containing the bubble. It fell on the side of the U-tube opposite the bubble (see Figure 3B).

After the bubble had finished passing through the constriction, the original water levels were re-

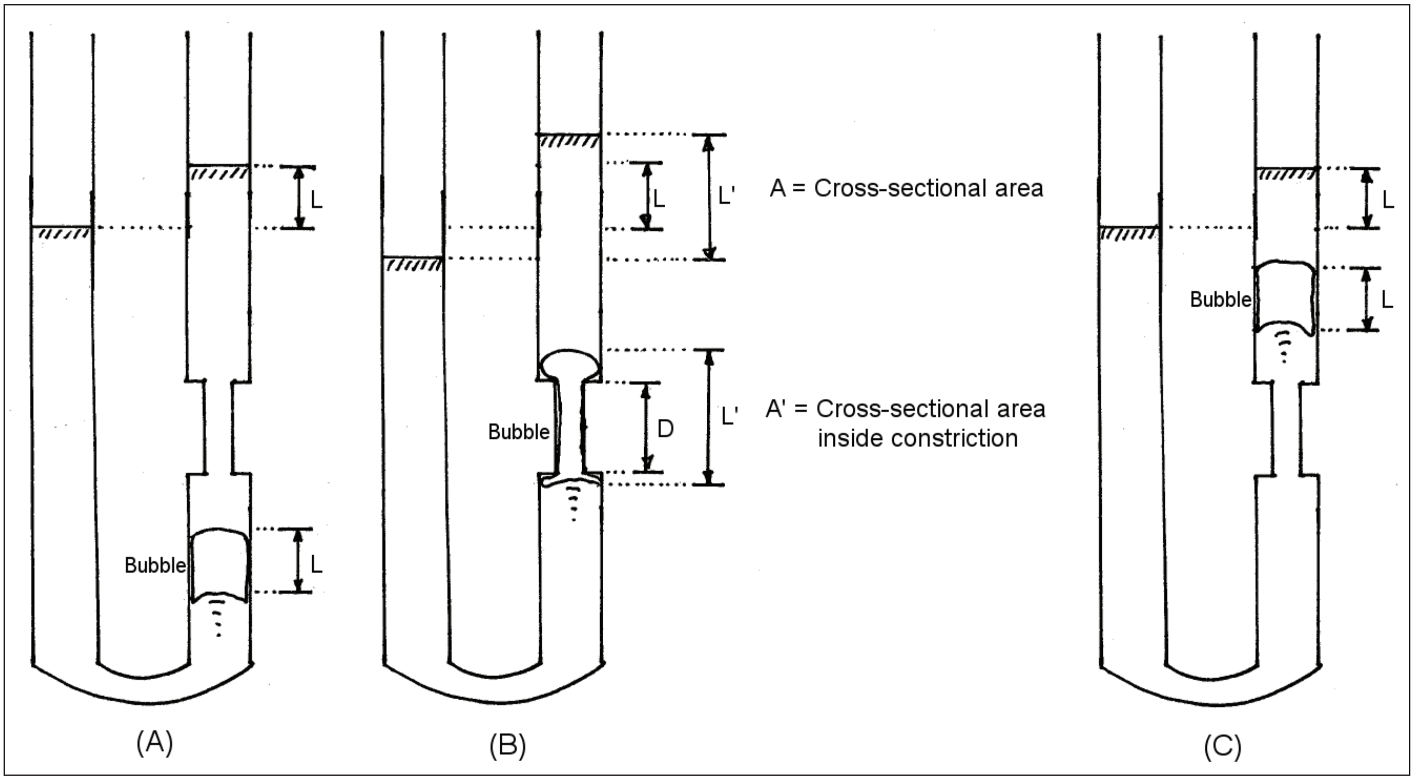

Figure 3. Air bubble rising through constriction in U-shaped water filled tube: A) air bubble rising through the tube below the constriction, B) air bubble passing through constriction, C) air bubble above constriction.

stored (see Figure 3C).

This instantly suggested that when the bubble moved through the constriction, the pressure below the bubble fell. In a natural geyser, the drop in pressure might be sufficient to start the eruption process. This phenomenon is analyzed below.

Analysis:

Experiment #3 can be analyzed from several different perspectives, which vary depending on the geometry of the system and the size of the bubble. The geometries considered below are: 1) a bubble that completely fills the cross-section of a tube rises through a constriction; 2) a bubble that does not completely fill the cross section of a tube rises through a constriction that is narrower than the bubble's initial width; 3) a bubble forms within a narrow pipe that opens into a wide funnel.

Perspective 1:

The change in the pressure that occurs in Experiment #3 while the bubble moves through the constriction is theoretically calculated by considering five distinct stages in the bubble movement:

1) The bubble is rising through the tube below the constriction (Figure 3A).
2) The bubble is entering and partly occupying the constriction.
3) The bubble fully occupies the constriction (Figure 3B).
4) The bottom of the bubble is exiting the constriction.
5) The bubble is rising through the tube above the constriction (Figure 3C).

We idealize the situation by assuming that the constriction throughout its length is of uniform cross-section A′, in contrast to the uniform cross-section A of the unconstricted section. We assume that the volume of the bubble is fixed. Since the density of air is so much less than the density of water, we approximate further by taking the density of the air in the bubble to be zero. We also ignore the tiny volume of water that at all stages is flowing down the U-tube's inner surface as the bubble moves upward.

Stages 1, 3 and 5 are quasistatic situations, so we assume that hydrostatic pressures exist throughout the system while they are in progress. At these times, the hydrostatic pressure within the water throughout the system will increase downward according to the formula $P = \rho gh$, where ρ is the density of water, g is the gravitational acceleration, and h is the accumulated water-depth below the water's upper surface.

Stages 1 and 5 are equivalent and do not depend on the existence of the constriction.

During stage 3, the upper surface of the water in the arm of the U-tube containing the bubble and constriction lies fixed at an elevation L' above the upper surface of the water in the opposite arm. Suppose that A is the cross-sectional surface area of an unconstricted section. The volume of the bubble is $V = AL$ when it is outside of the constriction. The cross-sectional surface area of the constriction is A' and the length of the constriction is D. Since it is being assumed that the bubble does not change in volume when it moves through the constriction,
$V = V_{outside} + V_{inside}$, where $V_{outside}$ is the part of the bubble that lies outside the constriction, and
V_{inside} is the part of the bubble that is inside the constriction. Because $V_{outside} = A(L' - D)$ and $V_{inside} = A'D$ it follows that

$$V = A(L' - D) + (A'D).$$

From this equation in combination with
$V = AL$, we deduce that

$$L' – L = D(1 - A'/A).$$

Equating hydrostatic pressures at the junction of the two arms of the U-tube reveals that during stage 3, the upper surface of the water in the arm with the bubble and constriction has risen by $0.5(L' – L)$, and the upper surface of the water in the other arm has fallen by the same amount. This implies that the pressure at the bottom of the U-tube and indeed at all locations in the unconstricted arm and beneath the bubble in the opposite arm has changed by

$$\Delta P = 0.5\rho g(L - L'),$$

which is negative.

Thus, there is a widespread pressure decrease accompanying the passage of the bubble through the restriction during Experiment #3.

Perspective 2:

In a similar experiment (not performed), one could envision a bubble so small that it fills the cross-section of the geyser pipe only when it occupies part of the constriction (Figure 4A). In this experiment, the vessel is filled with water to a depth of h'. The vessel contains a constriction with a cross-sectional area of A'.

We consider a single bubble rising through the water and passing through the constriction. While the bubble is below the constriction, we may calculate the pressure at the bottom of the vessel by dividing the diagram along a horizontal plane at height k, which passes just above the bubble. The pressure at this point will be $P_1 = \rho g(h' - k)$. The pressure exerted at the bottom of the vessel due to the water contained below plane k will be $P_2 = \rho' gk$, where ρ' is the average density of the fluid, which will be somewhat less than the density of pure water, due to the single entrained bubble. Since the mass of the water is $\rho(kA – v)$ where A is the cross-section of the vessel and v is the volume of the bubble,
ρ' = mass / volume, and the volume of the vessel below the horizontal plane at height k

$$\rho' = \rho(kA – v) / kA$$

and

$$P_2 = \rho g(k – v/A).$$

The total pressure at the bottom of the vessel will be

$$P_i = P_1 + P_2 = \rho g(h'- v/A).$$

We next consider the pressure when the bubble is within the constriction (Figure 4B). If the bubble is wider than the constriction, it must elongate vertically while is passes through. Assuming that the volume of the bubble does not change, the height of the water will still be h'. If the vertical extent of the bubble is L', then the pressure at the bottom of the vessel has become

$$P_f = \rho g(h' – L').$$

The change in the pressure will then be calculated by

$$\Delta P = P_f – P_i = \rho g(v/A - L').$$

Because the volume of the bubble while it is

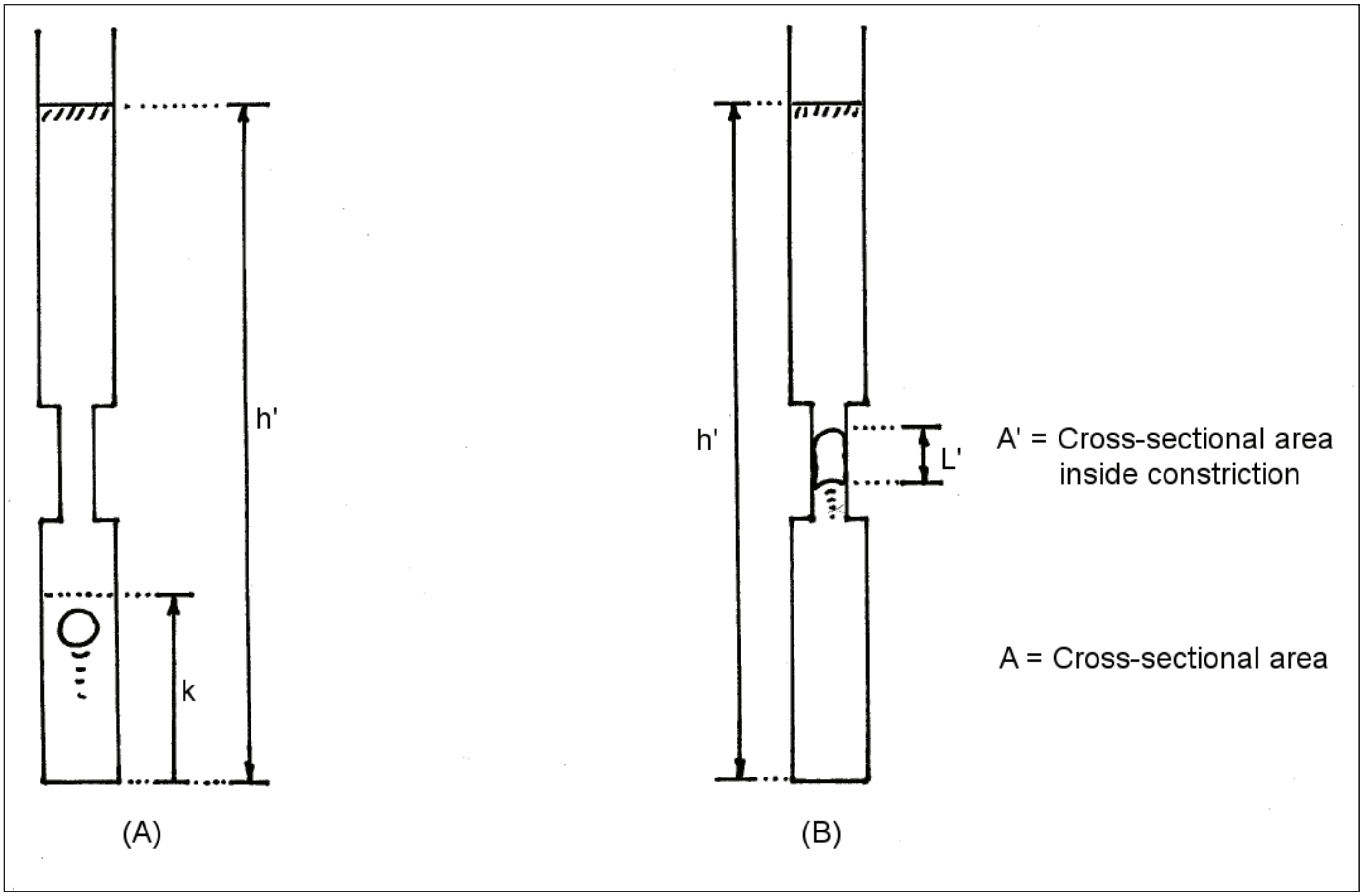

Figure 4. Small air bubble that only fills geyser pipe when in the constriction: A) bubble below constriction, B) bubble within constriction.

within the constriction is $v = A'L'$, this can be rewritten as

$$\Delta P = \rho g L'(A'/A - 1),$$

Since A' will always be less than A, ΔP will always be negative.

Perspective 3:

It is possible that the constriction-less model reported in Experiment #1 erupted periodically because the formation of a bubble in the narrow part of the tube caused an upward displacement of the water in the pool (Figure 5). The upward displacement of the water in the pool must be less than the vertical extent of the bubble. The pressure change would be calculated by the expression

$$\Delta P = P_{final} - P_{initial}.\ P_{initial} = \rho g h$$

and

$$P_{final} = \rho g(h - L' + h'),$$

where L' is the length of the bubble and h' is the height to which the water in the pool is elevated by the formation of the bubble (Figure 5). It follows that

$$\Delta P = \rho g[h' - L'].$$

Because the volume displaced by the bubble ($V_{bubble} = L'A'$) equals the volume of water ($V_{pool} = h'A$) that is injected into the pool when the bubble forms, it is possible to substitute $L' = h'A/A'$. The change in pressure will be

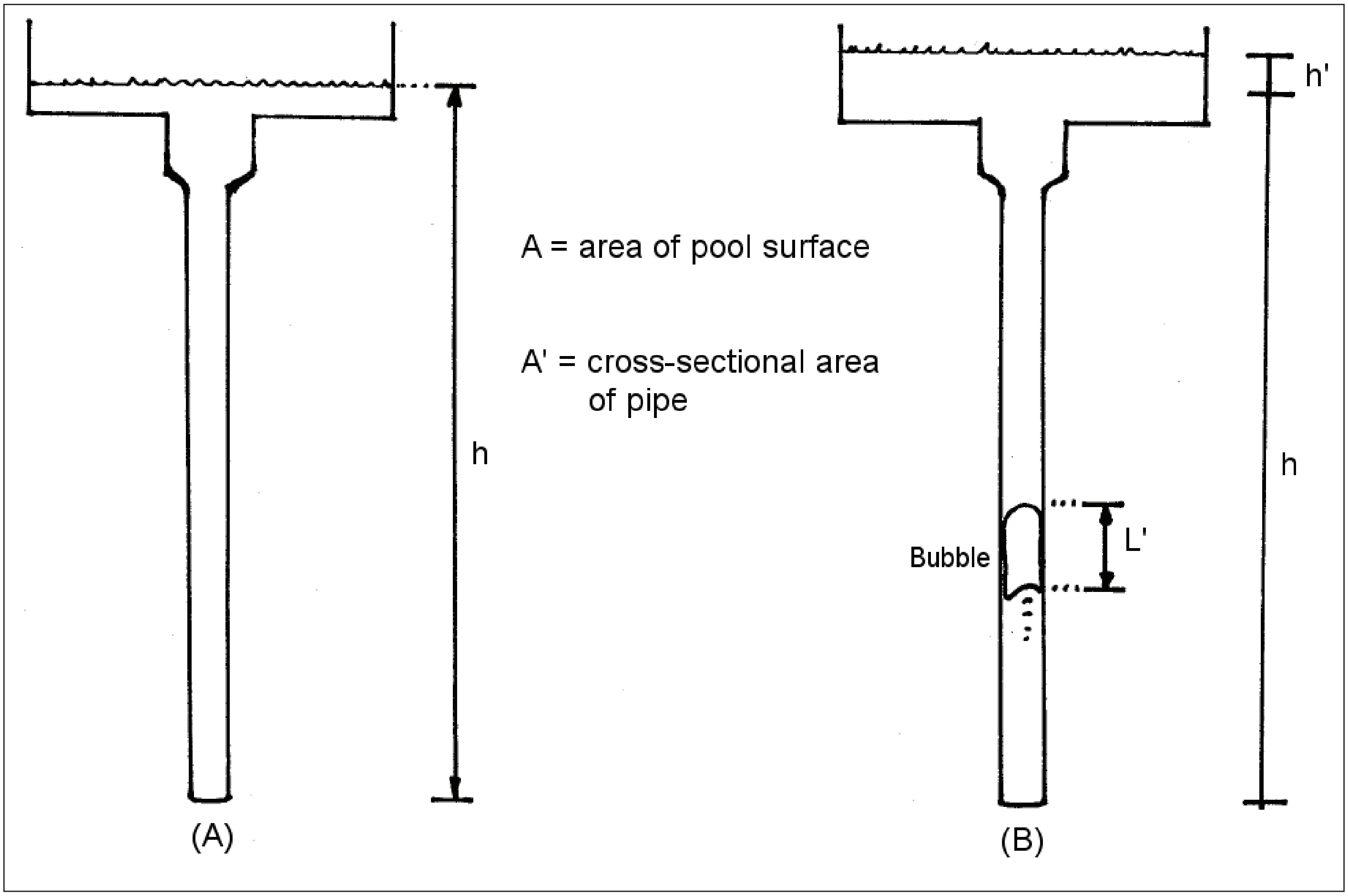

Figure 5. Constriction-less model: A) no bubble, B) upward flowing bubble.

$\Delta P = \rho g h'(1-A/A')$.

Conclusion:

To the extent that air is an acceptable substitute for steam, the mechanisms described above illustrate how the pressure can fall within a model geyser system without requiring that any overflow occur. Although a constriction greatly enhances the periodic nature of a model geyser's eruption, it is sufficient for the geyser pipe to be wider at the water surface and narrower at any point below, and in the constrictionless case that the bubble fills the cross-section at some stage. It is to be emphasized that in our opinion the air bubble proxy can be adequate only with respect to pressure change that may initiate a geyser eruption where the water column within the tube is relatively quiet and can be taken, up to this point, to have possessed an approximately hydrostatic pressure distribution.

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Acknowledgments

The authors thank Brian Davis and Ralph Taylor

Addendum to *The GOSA Transactions* Volume 10, 2008

Correction to "Baby Daisy Geyser Activity in 2003-2004" by Ralph Taylor

In Ralph Taylor's article on Baby Daisy Geyser, Figure 4 was mistakenly replaced with a second copy of Figure 5. The article has been reprinted in its entirety at the end of this volume.

Note regarding "Activity of Excelsior Geyser September 14-16, 1985" by Mary Ann Moss

Rick Hutchinson's report on Excelsior Geyser dated September 18, 1985 was erroneously omitted from Mary Ann Moss's article regarding the 1985 activity of Excelsior Geyser. The Hutchinson report and other correspondence of interest have been included in an article by Lynn Stephens in the current volume.

Addendum to "Narcissus Geyser Eruption Patterns June 27-July 31, 2005" by T. Scott Bryan

for reviewing this paper and David Monteith for his help with the figures.

Articles by Dr. John Rinehart that referenced Narcissus Geyser

Rinehart, John. 1969. "Thermal and seismic activity of Narcissus geyser," EOS, Transactions, American Geophysical Union 50 (4): 348.

------------. 1970. "Heat flow from natural geysers," *Tectonophysics*, v. 10, pp. 11-17.

----------- and Marion S. Rinehart. 1990. "Narcissus Revisited," *GOSA Transactions*, volume II, pp. 127-128.

Behavior patterns of Narcissus Geyser were also referenced in Dr. Rinehart's book, *Geysers and Geothermal Energy*, New York: Springer-Verlag, 1980.

At least some of Dr. Rinehart's personal papers are located in the Special Collections of the Yellowstone National Park Archives at the Heritage and Research Center. These papers may contain an unpublished manuscript describing his observations of and conclusions about behavior patterns exhibited by Narcissus Geyser.

Biographical Information for Dr. John S. Rinehart

John Sargent Rinehart (b. Feb. 8, 1915; d. April 9, 1999) earned his B. S. in education and A. B. in physics, both at Truman State University in Missouri; his M.S. in physics at Caltech; and his Ph.D. in physics at the State University of Iowa.

From September 1940 through Dec. 1941, he taught college physics at Fort Hayes Kansas State College and Wayne State University. In January 1942, he moved to Washington, D.C., where he worked on developing proximity fuzes, for which he received the Presidential Certificate of Merit.

After the war, John joined physicist E.J. Workman and his research group, who at that time were studying proximity fuzes and other terminal ballistic effects on a range south of Albuquerque (in what is now the southern part of the Sandia National Labs/Kirtland AFB facility).

In Jan. 1949, Rinehart moved to the Naval Ordnance Test Station at China Lake, Calif., where he continued his work in terminal ballistics, shaped charges, formation of craters, and finally metal-explosive systems, spalling, fracturing, and ultra high-speed flight. With John Pearson, he published two books: *Behavior of Metals under Impulsive Loads* and *Explosive Working of Metals*.

Later in his career, in the 1950s, Rinehart worked under astronomer Fred Whipple in Cambridge, Mass., studying crater formation and meteorites. In the late 1950s and early 1960s, John taught mining engineering at the Colorado School of Mines and held a Fulbright Fellowship in Egypt. He later joined the U.S. Coast and Geodetic Survey as director of research. The organization later became NOAA, and the research arm was moved to Boulder, Colo., where John conducted studies of geysers.

He retired in 1973 but continued to consult for many years.

Rinehart published over 100 scientific papers on metal-explosive systems and geysers. He also published several books.

Abstract for "'Music, Song, & Laughter': Paradise at Yellowstone's Fountain Hotel 1891-1916" by Lee Whittlesey

The Fountain Hotel, located in the Lower Geyser Basin near its namesake geyser, was a popular stop on the stagecoach tour through Yellowstone National Park from 1881-1916. Historical accounts are described, including bear feedings nearby and geyser viewings at Fountain Paint Pot and the Thud Group. After twenty-six summers of operation, the Fountain Hotel closed when automobiles overtook park transportation in 1916.

Note about names usage:

The geyser referred to as "Underhill Geyser" in Transactions 10 (Gryc, 2008) was previously referred to as "Dragonfly Geyser" in *The Geyser Gazer Sput* (December 2001, vol. 15, no. 6, p. 26). In *The Geysers of Yellowstone* (Fourth Edition, 2008, p. 211), T. Scott Bryan uses the name "YF-305" for the feature. The editors believe the name "Dragonfly Geyser" has received the widest usage.

The geyser referred to as "Oblique Geyser" in Transactions 10 (Cross, 2008) is called "Avalanche Geyser" in this volume (Cross, 2010). "Oblique Geyser" is a historical name from the 1870s Hayden surveys of Yellowstone by A.C. Peale and Walter Weed (Whittlesey, 1988). The name "Avalanche Geyser" has been used since at least the late 1970s (Koenig, 1998). T. Scott Bryan uses "Avalanche Geyser" in *The Geysers of Yellowstone*, First (1979) and Fourth (2008) editions, and "Oblique Geyser" in the Second (1986) and Third (1995) editions.

Baby Daisy Geyser Activity in 2003-2004

Ralph Taylor

Abstract

Baby Daisy Geyser is located in the Old Road Group of the Upper Geyser Basin. It has had only three known periods of activity: 1952, lasting less than one year; 1959, lasting less than one year, and 2003-4, lasting from February 2003 to December 2004. This paper discusses the 2003-4 activity as reported by observers between February and June of 2003 and as recorded electronically from June 2003 to the end of the active cycle in December 2004.

Introduction

The Old Road Group of the Upper Geyser Basin contains numerous hot springs but few geysers. The geysers that exist in this area, located east of the Grand Loop Road and south of Biscuit Basin, have often been active for relatively short periods only. One such geyser is Baby Daisy Geyser. This small geyser has had only three known periods of activity. The most recent active phase, which is the primary topic of this paper, began during the winter of 2002-3 and continued until December of 2004.

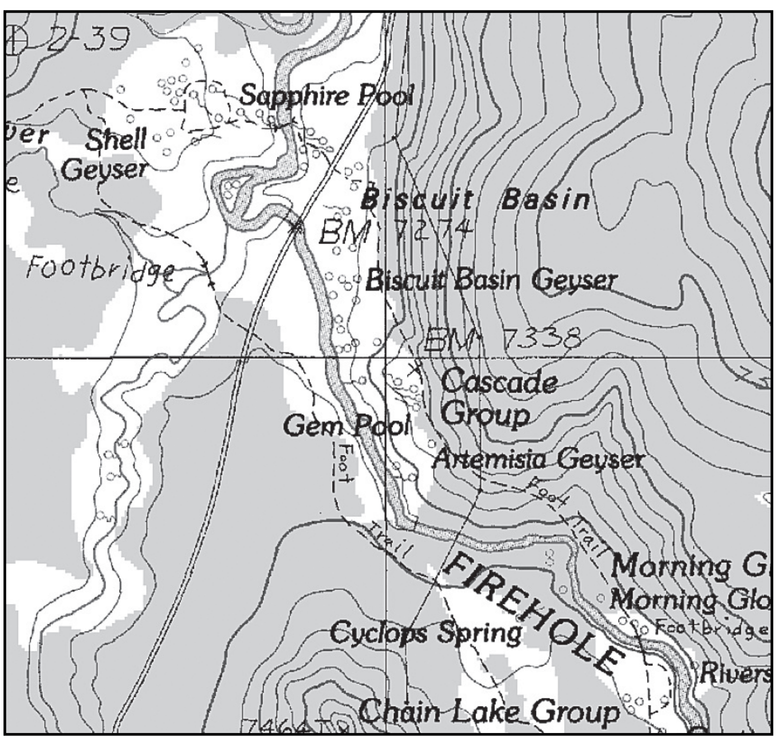

Figure 1. Section of the USGS topographic map showing the Cascade Group and Biscuit Basin. Baby Daisy Geyser is "B" in Biscuit Basin Geyser.

Location

Baby Daisy Geyser is located in a small group of features located between the footpath that follows the old Grand Loop Road and the Firehole River. Figure 1 is a section of the Old Faithful quadrangle topographic map showing the area. Baby Daisy Geyser is located below and to the left of the letter "B" in the "Biscuit Basin Geyser" caption. While it was active it was often seen from passing vehicles, especially those traveling from north to south. Baby Daisy's formation is located within sight of the trail from Morning Glory Pool to Biscuit Basin, but trees and undergrowth made it difficult to spot the low-lying crater when Baby Daisy was not erupting. When Baby Daisy was in an active phase and in eruption, it could easily be seen from the trail, as shown in Figure 2.

Historical Background

George Marler first noted eruptive activity at Baby Daisy in 1952. He wrote:

> 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. [1]

He stated that activity continued for the rest of the 1952 season, but that no activity

[1] Marler, George D. *Inventory of Thermal Features of the Firehole River Geyser Basins and Other Selected Areas of Yellowstone National Park*, USGS GD73-018.

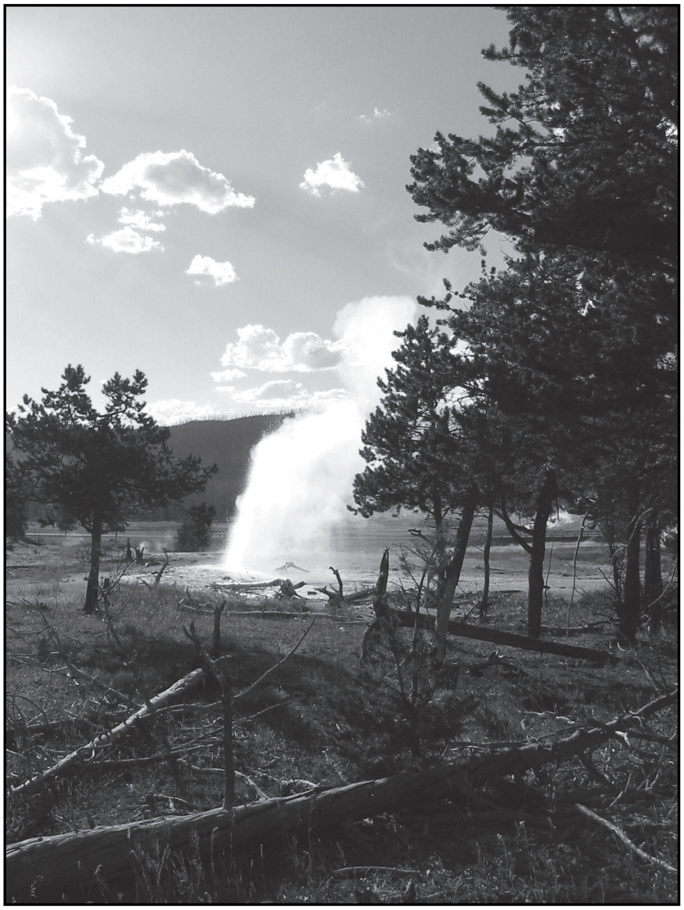

Figure 2. Baby Daisy Geyser in eruption, seen from the footpath along the old roadbed.

was observed from 1953 until the 1959 Hebgen Lake earthquake. Marler noted that the activity was the first in many years since a grove of lodgepole pine trees 9 meters (30 feet) from the geyser were killed by the spray, indicating that there had been no activity during the years that the trees had grown. Those trees were subsequently burned by the 1988 fires, and only scattered bits of wood remain.

The next activity was apparently initiated by the Hebgen Lake earthquake in 1959 and had ended by the 1960 season.

2003-4 Activity

The latest active period started during the winter of 2003. In an email to the geyser list, geyser gazer and NPS volunteer Mike Keller reported

> For the first time in many years Baby Daisy Geyser is active. NPS Rangers Dave Page and Tim Townsend both saw an angled geyser in the Cascade area erupting two days ago (2/20) around 1030ie. Over the past two days they kept seeing this geyser at least once a day. This evening (2/22) Tim and I went to see what feature was active and found it was Baby Daisy. While we were there it even erupted for us! The play lasted just over 3 minutes, was angled towards the old road, and reached from 20 to 25 feet. Based upon wash in the

Figure 3. Baby Daisy Geyser's formation from the location of the data logger. Note the large washed area around the crater.

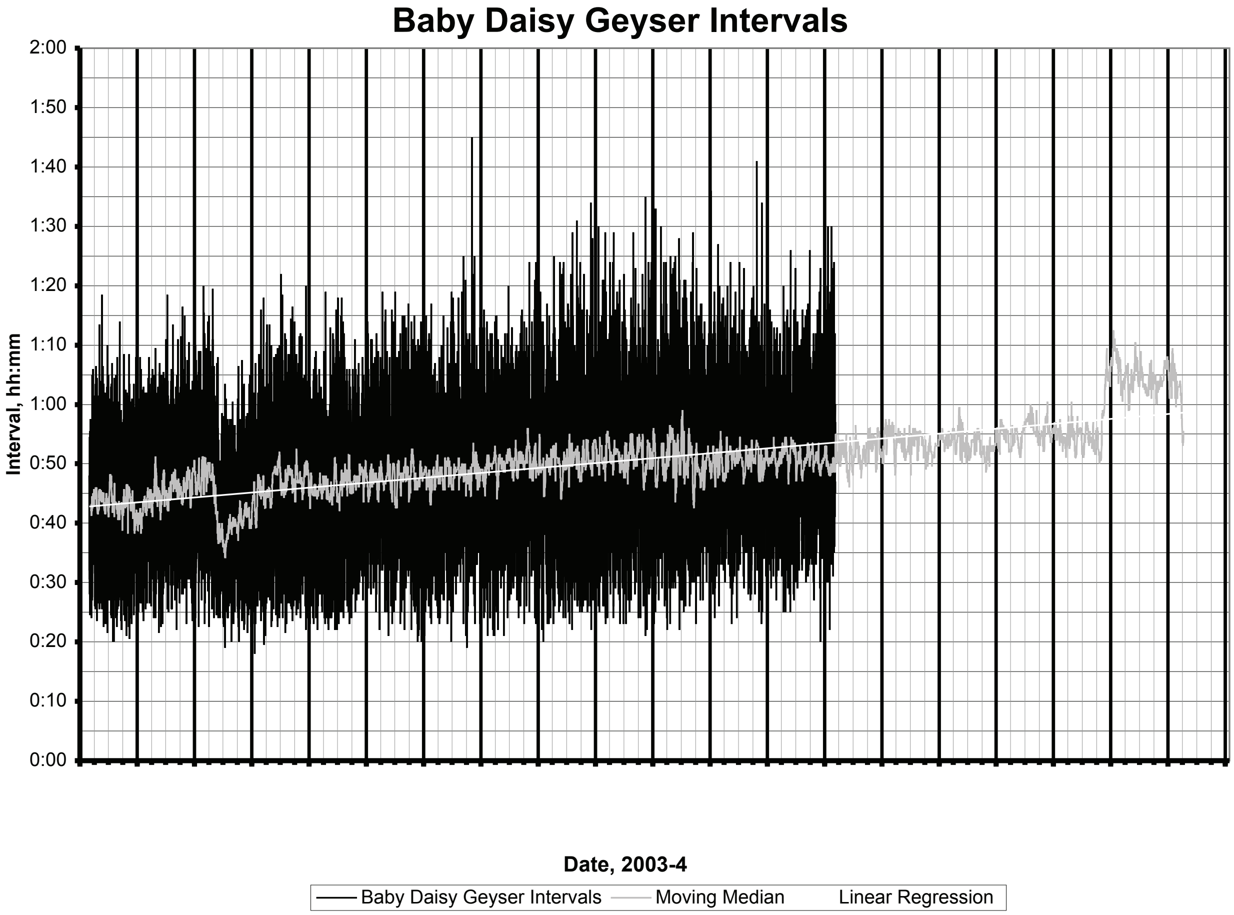

Figure 4. Baby Daisy Geyser eruption intervals (black) and 1-day moving median interval (gray).

> area it appears that Baby Daisy has been active for at least a week and possibly longer.[2]

The exact date of the reactivation was never determined due to the low number of visitors during the winter season. Activity reports continued through the winter and spring months with no reported periods of inactivity noted.

The author was a volunteer for the NPS during the active period. Upon my arrival at Old Faithful in June, I deployed an electronic data logger in Baby Daisy's runoff channel at the first opportunity. Electronic monitoring began at 1500 on 22 June 2003 and continued without a break until 25 June 2005. The last recorded eruption was at 0950 on 8 December 2004.

Description of Baby Daisy's Formation

Baby Daisy Geyser erupted from a roughly circular basin in a sinter mound covered by sinter gravel, as shown in Figure 3. The basin was approximately two meters (6.5 feet) in diameter and about 20cm (8 inches) deep. The vent was roughly circular, about 30cm (12 inches) in diameter, and located at the center of the basin. The sinter mound was washed clean of gravel for a meter or so uphill from the crater and for 8-10 meters (about 25-30 feet) to the north. There was a distinct berm of gravel around the washed area uphill from the vent. The basin from which Baby Daisy erupted was lined with ochre-colored sinter.

Eruption Characteristics

During the 2003-4 activity, eruptions of Baby Daisy Geyser occurred at intervals of between 18 minutes and 1 hour 50 minutes, averaging about 45 minutes in 2003 and 53 minutes between eruptions in 2004. Eruptions lasted between two and four minutes. As the start of an eruption approached, water rose in the vent until the inner basin was filled. The filling was accompanied by boiling that increased in vigor as the eruption neared. Once the eruption started, the water column rapidly reached its estimated maximum height of between 6 and 7.5

[2] *"REPORT: Baby Daisy Geyser (Keller)"*, geyser report posted on the Geyser List Server, Mike Keller, 22 February 2003.

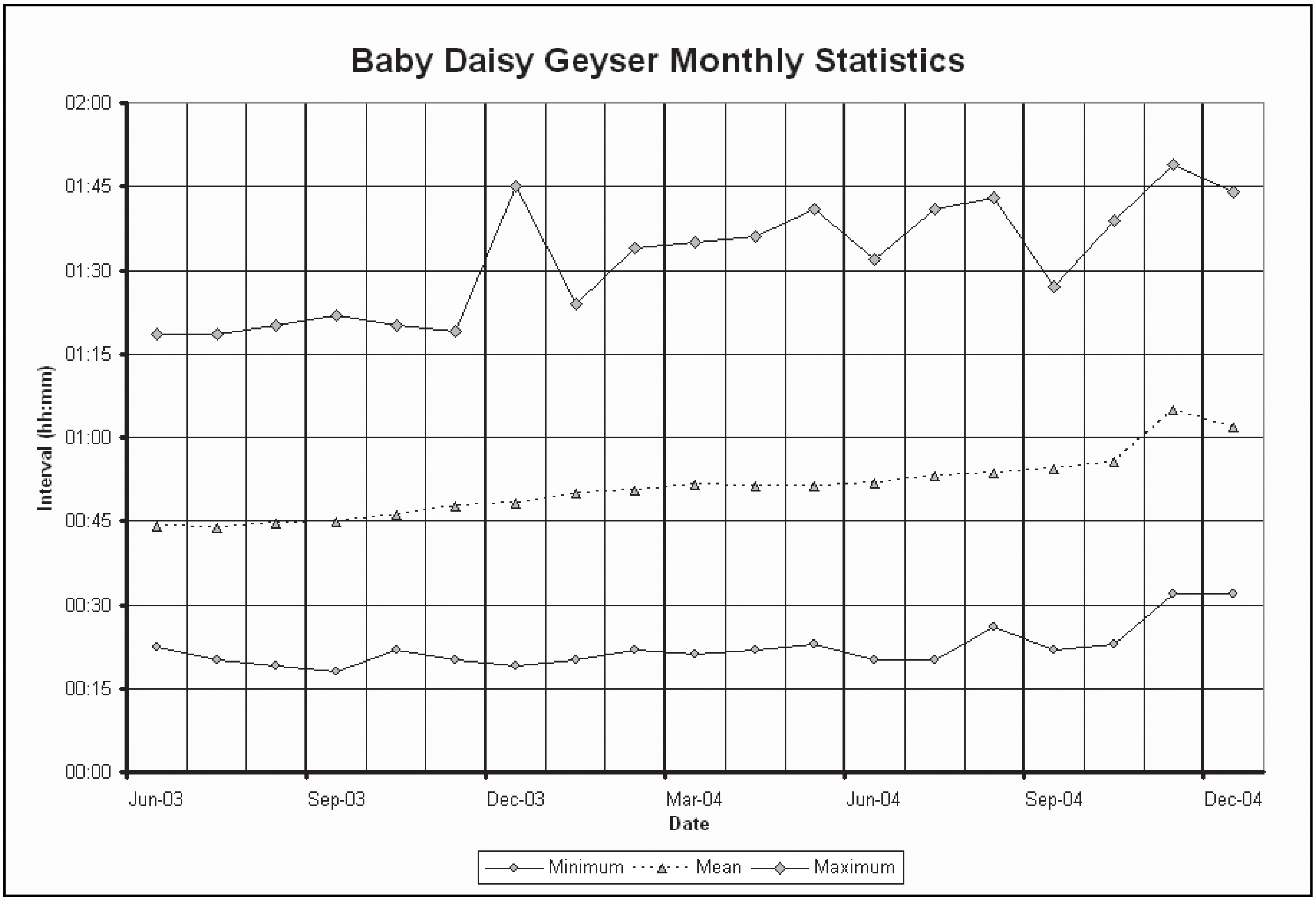

Figure 5. Baby Daisy Geyser monthly minimum, maximum, and mean intervals

meters (20 to 25 feet). The water jet was angled at about 30° to the vertical toward the north. It was the similarity of this angled eruption from a round basin to the eruptions of Daisy Geyser that inspired the name "Baby Daisy."

Analysis of Eruptions

Reports of Baby Daisy Geyser eruptions before 22 June 2003 are sparse. Short sets of eruption intervals and durations were reported in March and April by geyser gazers.[3] Activity reports noted durations of two to three plus minutes. Paperiello reported intervals averaging 34 minutes on 15 March, 30 minutes on 19 March, 33 minutes on 29 March, 36 minutes on 6 April, 34 minutes on 12 April, and 40 minutes on 19 April.[4]

Once the electronic data logger was deployed, the temperature trace showed 15307 intervals ranging from 0h18m to 1h49m. Figure 4 is a plot of all intervals recorded by the data logger for Baby Daisy Geyser. The black band illustrates the erratic nature of the intervals, which varied by 60 to 80 minutes from minimum to maximum in any given month. There did not appear to be any pattern to the variation; that is, intervals did not alternate long-short but appeared to vary randomly from interval to interval.

Over the nearly 20 months for which there is a complete record of intervals, the general trend was a gradual increase shown by the white linear regression line in Figure 4. The wide variation in intervals makes trends difficult to see. To help illustrate trends in intervals, Figure 4 also includes a plot of daily moving median intervals, shown in gray.[5]

Closer examination of the moving median interval (the gray line in Figure 4) shows two events that changed intervals abruptly. The first occurred between 21 and 28 August 2003, when the daily median intervals dropped from 50 to 35 minutes,

[3] Posts to the geyser list server were made by Michael Lang on 3 March 2003, by David Goldberg on 14 March 2003, and by Rocco Paperiello (several reports in March and April 2003)

[4] Paperiello, Rocco; report posted to the Geyser List on 19 April 2003

[5] Actually, the moving median covers 29 intervals, which approximates the mean of 28.6 intervals per day.

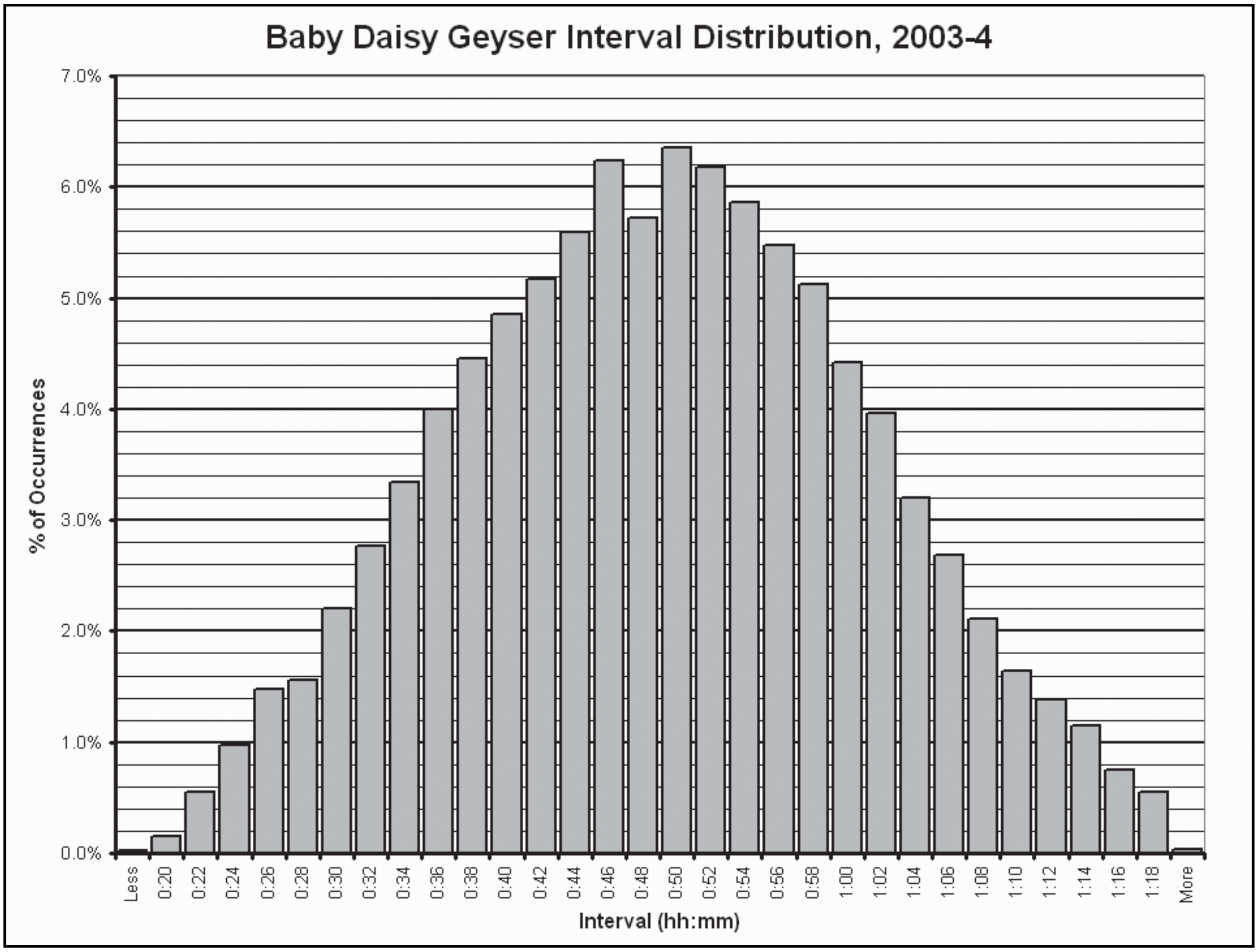

Figure 6. Baby Daisy Geyser interval distribution histogram

then recovered over the next three weeks to the long-term trend line. The second event occurred between 29 October and 2 November 2004, when the median intervals first dropped then jumped nearly 15 minutes in a three day period. After the latter change, intervals remained longer until the activity abruptly ceased on 8 December.

Figure 5 is a plot of the monthly minimum, mean, and maximum intervals, and provides a different look at the activity. The trend to longer intervals shows up on this plot also, as does the late October 2004 increase in intervals. The distance between the maximum and minimum curves clearly illustrates the variation.

Figure 6 is an interval distribution histogram for all of the Baby Daisy Geyser intervals recorded electronically. Bin labels are the center of the bucket; that is, the bin labeled "0:40" contains the percentage of intervals between 39m30s and 41m30s. The distribution is symmetrical about 0h50m with few extreme outliers. There does not appear to be a seasonal variation, and no other periodic fluctuations appear to be present.

Comparison with Historical Activity

Marler reports that during its initial observed activity in 1952 Baby Daisy's eruptions lasted "from about 2 to 2 ½ minutes"[6] and reported the eruption height as "about 30 feet"[7] and that "intervals ranged between about 90 and 120 minutes."[8] This activity is similar to what was seen in the 2003-4 activity but with rather longer intervals.

In the activity that followed the 1959 Hebgen Lake earthquake, Marler wrote:

> Again checked eruptions lasted from about 2 to 2 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.[9]

This activity is more similar to the 2003-4 activity. The intervals fall within the range of intervals

[6] Marler, George D. *Inventory of Thermal Features of the Firehole River Geyser Basins and Other Selected Areas of Yellowstone National Park*, USGS GD73-018
[7] ibid.
[8] ibid.
[9] Marler, George D., ibid

from 2003-4, but apparently the sub-hour intervals seen in the latest activity were not observed in 1959. Overall, the latest activity is quite similar to the earlier activity, although there appears to have been more water or energy available in the most recent active period since longer durations and shorter intervals were observed.

Baby Daisy Geyser Returns to Dormancy

On 8 December 2004, with no premonitory signs, Baby Daisy Geyser simply stopped erupting. Aside from the abrupt increase in intervals in late October 2004 discussed above, there was no warning of waning power or declining activity. The last observed eruption intervals were no different from the preceding intervals. The final intervals are shown in Figure 7. At 0950 on 8 December Baby Daisy erupted for the final time in the 22-month-plus active period. The eruption was not observed, but the data logger trace shows nothing unusual about that eruption. There were no temperature variations following the last eruption that suggest any periodic overflows or other activity. When the logger was removed in June of 2005, the area was beginning to acquire a covering of dust and debris.

Eruption Time/Date	Interval
12/08/04 01:30:34,	0:32:00
12/08/04 02:37:34,	1:07:00
12/08/04 03:23:34,	0:46:00
12/08/04 03:57:34,	0:34:00
12/08/04 05:05:34,	1:08:00
12/08/04 06:05:34,	1:00:00
12/08/04 07:03:34,	0:58:00
12/08/04 08:02:34,	0:59:00
12/08/04 08:51:34,	0:49:00
12/08/04 09:50:34,	0:59:00

Figure 7. Baby Daisy Geyser's last ten eruptions.

Summary and Conclusions

Geysers in the northern part of the Old Road Group have tended to be episodic in activity. Examples other than Baby Daisy Geyser include Cauliflower Geyser and Biscuit Basin Geyser, both of which have had brief periods of activity but did not sustain their activity over long times. Although the exact start of the active period is not known, it is likely that the total span of the 2003-4 activity was just short of two years.

Intermittent reports for the first four months did not note any activity that differed markedly from the activity recorded during the 534 days of electronically recorded eruptions. Analysis of the electronically recorded eruptions indicates a gradual increase in interval, amounting to a change of about 15 minutes in daily moving median intervals from June 2003 to December 2004. Both the beginning and end of the series of eruptions were not associated with any known external events.

Baby Daisy Geyser, May 2003. Photo by Mike Newcomb.

Acknowledgements

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About the Authors

T. Scott Bryan (M.S., geological sciences, University of Montana) has been in Yellowstone in 1949, 1951, 1952, and during every summer starting with 1970. He worked in the park as a summer seasonal employee from 1970 to 1977 and 1980 to 1986 and served as a volunteer in the summers of 1987 and 1993. He has also visited the geysers in California, Nevada, Oregon, Mexico, Russia, Fiji, and New Zealand. One of the founding directors and the first president of GOSA, Scott began the publication of *The Geyser Gazer Sput*, served as the editor of several volumes of these *GOSA Transactions*, and is the author of *The Geysers of Yellowstone* (University Press of Colorado, new 4th edition was published in July 2008) and Geysers" What They Are and How They Work (Mountain Press, 2nd edition). With his wife, Betty, as co-author, he is also the author of The Explorer's Guide to Death Valley National Park (University Press of Colorado, new 2nd edition October 2009). Professor emeritus at Victor Valley College in California, his permanent residence is now in Catalina, Arizona.

A native New Englander, **Suzanne Cane** graduated from Wellesley College, where she studied French and then earned a master's degree from Simmons School of Library Science. For many years she was a practicing librarian at the Lincoln School in Providence, Rhode Island, as well as a teacher of French to students of all levels and an occasional translator of French texts. On her visits to Yellowstone Park, Suzanne has been an enthusiastic user of Janet Chapple's *Yellowstone Treasures* and has worked in partnership with her to translate *The Land of Wonders* (*La Terre des Merveilles*), by Jules Leclercq. Suzanne lives in Rhode Island with her husband, David Cane, professor of chemistry at Brown University; they have two grown children.

Janet Chapple was born and brought up in Billings, Montana, and spent four summers of her early childhood living in sight of Old Faithful Geyser while her father worked as transportation agent in the Inn. She attended Stanford University, the University of Washington, and the University of Southern California, receiving a bachelor's degree in music performance from the latter. After her three daughters were grown, she completed a music performance master's degree from Indiana University. Near the end of a forty-five-year career as a performer and teacher of cello in Rhode Island, Janet began working on what was first intended to be an update of the twentieth edition of the C. Haynes Guides. In 2002 this became the award-winning guidebook, *Yellowstone Treasures: The Traveler's Companion to the National Park.* The third edition of this full-color, 392-page book was published in April 2009. Janet has also assembled an anthology of early writings published about Yellowstone in addition to working with colleague Suzanne Cane on translating Jules Leclercq's book, *The Land of Wonders* (*La Terre des Merveilles*). She now lives in Menlo Park, near San Francisco, with her husband, Bruno Giletti, geology professor emeritus of Brown University.

Jeff Cross (M.S., chemistry, Colorado State University) first visited Yellowstone in 1979. His main interests are 1) the lesser known geysers of the Park's backcountry and undeveloped frontcountry thermal areas and 2) model geysers. He has contributed several articles on these topics to the *GOSA Transactions* and currently serves as co-editor of that publication. He spent the last three years teaching chemistry, most recently at Whitman College in Walla Walla, Washington.

Tara Cross (Master of Library and Information Science, University of Washington, 2007) has been studying geysers in Yellowstone since 1988. Upon receiving her B.A. in history from Southern Adventist University, she worked at the Yellowstone Research Library and Archives from 2001 to 2004. She is currently serving as co-editor of *GOSA Transactions* and has published articles on Giant Geyser, Fan and Mortar Geysers, Link Geyser, and numerous backcountry geysers in that publication. She is a regular contributor to *The Geyser Gazer Sput*, writing bi-monthly geyser activity summaries and other articles on Fan and Mortar Geysers, Giant Geyser, and the geysers of New Zealand.

Ryan Frank is a statistics major at University of Wisconsin--Eau Claire. After graduation, he plans to study statistics at the graduate level.

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Stephen Michael Gryc is a classical composer whose music is heard throughout the world in live performance and in recordings. He earned four degrees in music from the University of Michigan and is currently professor of music composition and theory at the Hartt School of the University of Hartford in Connecticut. His interest in both sound and geysers led him to make digital audio recordings of Yellowstone's thermal features and other environmental sounds. His Yellowstone recordings have been used in the soundtrack of the educational film, *A Symphony of Fire and Water,* and in the exhibits at Yellowstone's Canyon Museum. Dr. Gryc has been visiting Yellowstone National Park since 1963 and has contributed articles to *The Geyser Gazer Sput* and the *GOSA Transactions*, Volumes VII, IX and X.

Andrew Hafner (Bachelor of Science, Eastern Michigan University, 1996) has held an interest in Yellowstone National Park and its geysers since childhood and began his geyser gazing career in 1997. From 1996 through 2001, and again in 2004, he held seasonal positions with the concessionaires at Yellowstone, first at Mammoth Hot Springs and then at Old Faithful. While he enjoys all geysers, his main area of interest is the Fountain Geyser Complex in Yellowstone's Lower Geyser Basin. This is his first contribution to the *GOSA Transactions*. He is also an occasional contributor to *The Geyser Gazer Sput*, the GOSA newsletter, with articles covering a variety of topics such as historical perspectives, geyser activity reports from his park visits, and his own experiences in the geyser basins. Mr. Hafner currently resides near Ann Arbor, Michigan.

James Hollman is a business major with an actuarial science minor at University of Wisconsin--Eau Claire. He is planning to pursue a career in the actuarial sciences.

Dr. Ron F. Keam has been interested in hot springs and geysers since the age of five. His early career was in mathematics and theoretical physics, but interests geothermal were greatly stimulated by his fellow university student, E.F. ("Ted") Lloyd. Keam later transmuted into a geophysicist. He has conducted geological and historical research in many of New Zealand's geothermal areas, favoring Waimangu above all. Now "three-quarters retired" from the Department of Physics, University of Auckland, he holds postgraduate degrees in mathematics and physics and the equivalent of a bachelor's degree in geology.

Mike Keller has lived in Yellowstone National Park for over twenty years and has spent extensive time studying the thermal features around Yellowstone. Mike has volunteered off and on with the National Park Service in several capacities between 1984 and 2010. Beginning in 2003, Mike joined the GOSA Board of Directors; he was named president of GOSA in the spring of 2009. Mike is currently the executive director of operations for Xanterra Parks and Resorts and resides in Mammoth Hot Springs.

Tadashi Maruyama holds a Doctor of Science degree in biology from Tokyo Metropolitan University, Tokyo, Japan. He is a program director of the Marine Biodiversity Research Program of the Japan Agency for Marine-Earth Science and Technology, Japan. He has studied symbiotic relationships between marine invertebrates and microorganisms, biochemistry of hyperthermophiles and ecology of marine picophytoplankton.

Masayuki Nagao holds bachelor's, master's and doctoral degrees in civil engineering from Tohoku University, Sendai, Japan. He is a senior research scientist of the Institute of Geology and Geoinformation (IGG), National Institute of Advanced Industrial Science and Technology (AIST). Prior to accepting the position at AIST, he worked for Tokyo Institute of Technology. He has worked on a variety of projects as a scientist of environmental hydraulics relating to environmental issues for coasts, coral reefs, natural lakes and artificial reservoirs. He has conducted overseas research at the University of Victoria and the University of Western Australia.

Pat Snyder fell in love with Yellowstone National Park and the geysers in the 1970s; she even photographed Ledge and Spiteful geysers erupting in August 1974. However, in the '80s, Pat became distracted by rock and roll, and spent 23 years photographing musicians before she finally returned to Yellowstone in 2001. Pat's photography skills quickly adapted from rock bands to the geyser "performers", and her pictures have been featured in the Yellowstone Association's annual calendars; on the cover of T. Scott Bryan's book, *Geysers: What They Are and How They Work* (2nd Edition); and in many issues of the *Geyser Gazer Sput.* In addition, Pat has more than 30 years of editing, writing and layout experience, most recently with Boyd Coffee Company in Portland, Oregon, where she works in the marketing department. Pat has her B.A. in English and Education from Boise State University, and her M.S.T. in English from Portland State University.

Lynn Stephens (Ph.D., accounting, University of Nebraska) retired in 2007 from Eastern Washington University where she was a professor of accounting and taught courses in accounting, business statistics and decision making. Her first season as a thermal volunteer for Rick Hutchinson, Yellowstone Park geologist, was summer, 1988, the year of the big fires. In recent years she has volunteered for both the park geologist and the Old Faithful Visitor Center. Some of her duties include collection and analysis of geothermal data, preparation of the electronic version of the Old Faithful Visitor Center logbooks (posted on gosastudy.org), and predictions of Great Fountain Geyser. Lynn has contributed several articles in previous volumes of the *GOSA Transactions*, including pieces about Old Faithful, Giant, Atomizer, Slide, Till, Flood, and a series of articles on geysers in the Fountain Complex. She is a regular contributor to *The Geyser Gazer Sput*, where her articles cover a variety of topics, including technical analysis of geyser behavior patterns, reports on current geyser behavior (with particular emphasis on geysers in the north end of the Upper Geyser Basin, Midway, Firehole Lake Drive, and the Fountain Complex in the Lower Geyser Basin), human interest articles about geyser gazers, and whimsical articles such as geyser quotes and doggerel. Her most recent contributions have included a series of articles about the 1959 Hebgen Lake Earthquake, preparation of the Index to Volume 22 of *The Sput,* and an article about stamps featuring Old Faithful with remembrances of John Muller. Lynn currently serves as GOSA treasurer.

Atsushi Suzuki holds bachelor's, master's and doctoral degrees in geology and paleontology from Tohoku University, Sendai, Japan. He is a leader of the Biogeochemical Cycles Research Group, Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology (AIST). His major research topics are global change reconstructions based on coral skeletal records, the carbon cycle in coral reef ecosystems, and biodiversity of coral reefs and their conservation. He has experience with overseas research as a visiting researcher at the Australian Institute of Marine Science and a visiting fellow at the Australian National University.

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List of Readers: Two or more content reviewers read each GOSA Transactions article for copyediting and corrective comments to the editors and authors. Some articles received additional review at the authors' respective colleges and universities. With great thanks for their time and effort, they are as follows:
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Victory Geyser in Rare Eruption, September 2009

Victory Geyser in eruption on September 21, 2009. Victory emerged as a new hot spring in 1998 and was active as a geyser in 1998 and 1999 before falling dormant. It was a small, quiet pool with bacteria growing in its vent until September 21, 2009, when it began having major eruptions. Intervals were usually 2 to 3 hours, with durations of 30 to 45 minutes. Eruptions were 2 to 4 feet tall with occasional bursts to 5 to 8 feet, sometimes throwing rocks out of the crater. Victory also showed a connection to Square Spring, Persistent Geyser, and Culvert Geyser, located on the other side of the paved path. The three springs cycled up and down in sympathy with Victory's cycles, and their water levels dropped during Victory's eruptions. Photo by Lotus Baker.