GOSA

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A 190-foot second burst, Grand Geyser, with Vent Geyser in the foreground. September 1978. Photo by Paul Strasser.

Back cover photographs, top to bottom:
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White Dome Geyser by Pat Snyder
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Lion Geyser. Photo by Jeff Cross.

Lion Geyser, erupting in October, 2006, with Goggles Spring in the foreground. Lion Geyser's activity changed significantly in October of 2009, along with that of nearby Little Cub Geyser and Depression Geyser (see article by Ralph Taylor on page 4).

GOSA

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.

Dedication

Nancy Cross, March 16, 1944 – June 27, 2011

This volume is dedicated by the Transactions editors to Nancy Cross, geyser gazer and invaluable proofreader for The GOSA Transactions Volumes 10 and 11. Her perpetual smile, upbeat attitude, and professional skill will be greatly missed.

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Thermal Activity Change on Geyser Hill in October 2009

Ralph Taylor

Abstract

In October 2009 thermal activity on the northwestern portion of Geyser Hill increased greatly. Activity of Depression Geyser, Lion Geyser, and Little Cub Geyser changed in character and frequency. This paper describes the changes noted in the electronically recorded eruption patterns of these geysers.

INTRODUCTION

In October 2009, geyser activity on the northwestern part of Geyser Hill changed over a period of less than one week. Observers in the Park and webcam viewers noted unusually long Lion Geyser eruption series and greatly reduced eruption intervals in Depression Geyser. Later examination of the electronically recorded activity of Little Cub Geyser showed decreased eruption intervals there, also. This paper reports on the changes noted in the activity of these and other features on Geyser Hill beginning in October 2009 and continuing into 2010. The lack of change in the activity of other Geyser Hill features, notably all features south-southeast of a line from North Goggles Geyser to Scissors Spring, is noted.

BACKGROUND

Data Collection

Data for this article were collected as part of a long-term study using data loggers belonging to the National Park Service and to the author. The data were collected by the Geology Program of the Yellowstone Center for Resources and is available on request. The author performed the analysis of the raw temperature data to extract eruption times, intervals, and for some geysers, durations. This derived data is available on the GOSA website at http://www.gosa.org/electronicsummary.aspx.

Geyser activity on Geyser Hill has been electronically monitored during the summer months since July 1997 and for the full year since July of 2003 (with some gaps when equipment failures occurred). The geysers that were monitored over the winter of 2009-10 are Aurum, Beehive, Depression, Dome, Lion, Little Cub, Little Squirt, Plate, and Plume. Monitoring of these geysers continued for the summer of 2010, and a logger was also deployed on North Goggles Geyser in June of 2010. In August of 2009 data collection for all of the Geyser Hill features was interrupted from about 1600 on 13 August to about 1700 on 15 August when all electronic equipment was removed from Geyser Hill for security reasons during President Obama's visit to Old Faithful. Aside from that interruption, during 2009 the electronic record is complete for Aurum, Beehive, Depression, and Plume. The Lion Geyser data start in 2009 on 20 March because of an overwinter logger failure. The Little Cub Geyser data likewise begins on 20 March due to a logger failure, and is interrupted from 31 August to 14 September by a second logger failure. Plate Geyser data is complete until the logger failed on 24 November.

Although there had been a logger on North Goggles Geyser from 2003 to 2005, that logger was removed after a long period of dormancy. This proved to be unfortunate since eruptions of North Goggles Geyser have been linked to the activity of Lion Geyser in the past, so the large change in Lion Geyser's behavior could reasonably be expected to be associated with reactivation of North Goggles Geyser. When the author returned to Yellowstone in June of 2010 a logger was placed on North Goggles Geyser and recorded some eruptions.

Geyser Hill Activity through September 2009

For much of 2009, Geyser Hill activity was unremarkable other than around the time of Giantess eruptions (which occurred on 17 February and 06 July). Electronic data are available for nine Geyser Hill geysers: Aurum, Beehive, Depression, Dome, Lion, Little Cub, Little Squirt, Plate, and Plume. In general the Geyser Hill activity for 2009 through September was not very different from that of recent years. Beehive Geyser had been erupting more frequently than in recent years, and Plate Geyser was active only intermittently. Depression Geyser intervals had increased for several years and be-

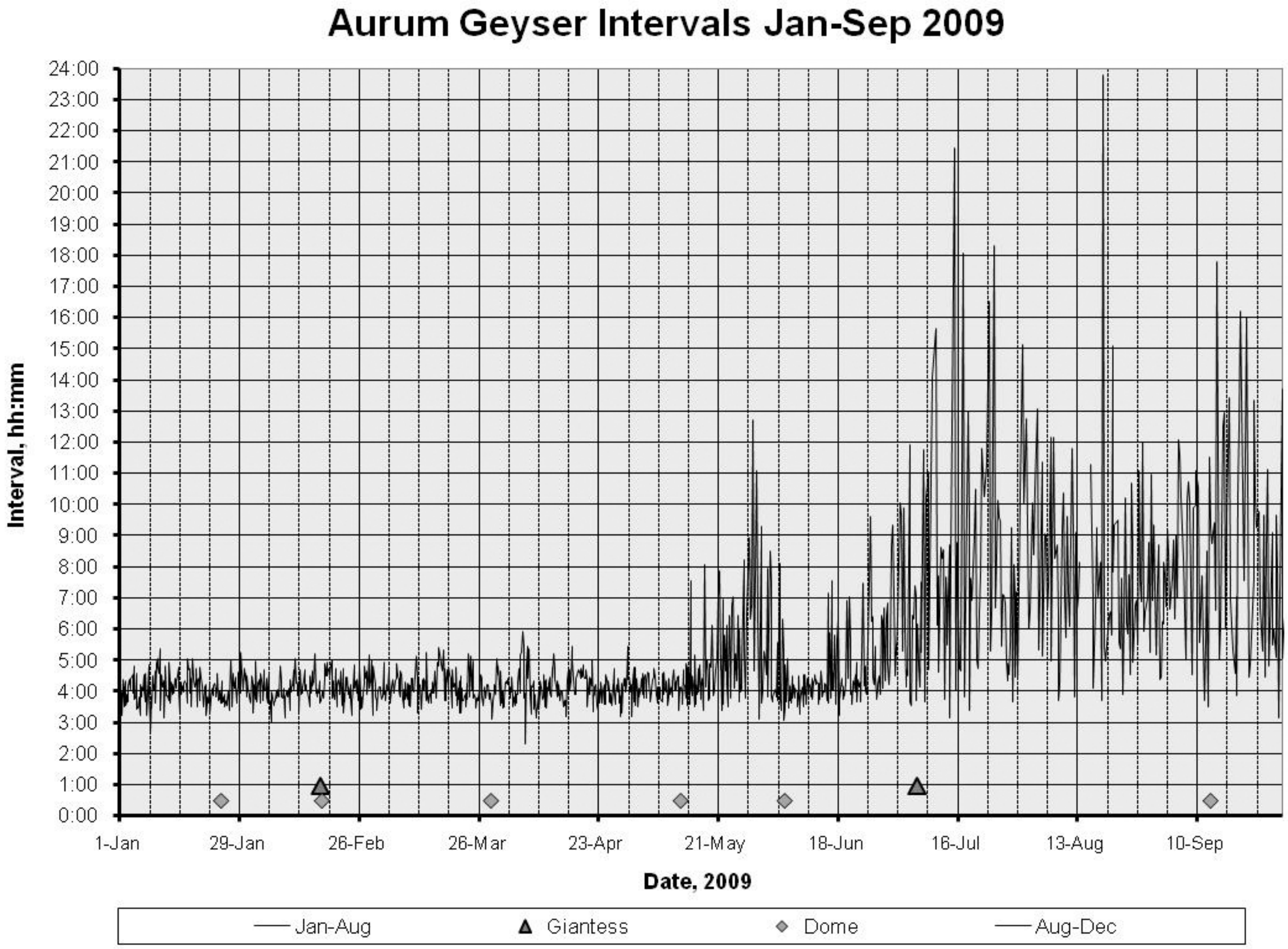

Figure 1.

came very long and erratic in the second half of 2008. Depression's intervals had decreased gradually throughout 2009, but remained over 10 hours. The activity of each of the recorded geysers is discussed in the following sections.

Aurum Geyser

Aurum Geyser behaved in its usual fashion, as shown in Figure 1 above. For many years, Aurum has been known to change its activity pattern on a year-long cycle as noted by Jens Day, reported in Bryan (1990). In the winter months, starting in late September or October, intervals shorten markedly and remain short until the following May or June, when intervals lengthen and become more irregular. The short-interval mode is commonly referred to as "winter mode" and is characterized by short eruption intervals (95% of intervals in early 2009 were shorter than 5h00m) and frequent intervals around the mean interval. The long-interval mode is commonly referred to as "summer mode" and is characterized by long and highly variable intervals. In 2009 the summer mode intervals were as long as 23h48m and only 5% of summer intervals were shorter than 5 hours.

In 2009 Aurum's intervals remained firmly in winter mode until 20 May with an average of four hours (ranging from 2h19m to 8h04m) and only a few intervals longer than five hours. Between 21 May and 30 June Aurum intervals increased until late May when a few intervals reached 10 to 12 hours, then dropped back to 4-hour intervals for the first two weeks of June. By 1 July, Aurum had begun its summer mode with longer and more erratic intervals, reaching nearly 24 hours at one point. During the summer (1 July to 30 September) the mean interval was 7h52m and 75% of intervals exceeded 5h27m. As usual, Aurum showed no evidence of influence by Giantess eruptions. Note that Giantess eruptions are indicated by a triangle in Figure 1 and Dome eruptions are shown by a diamond.

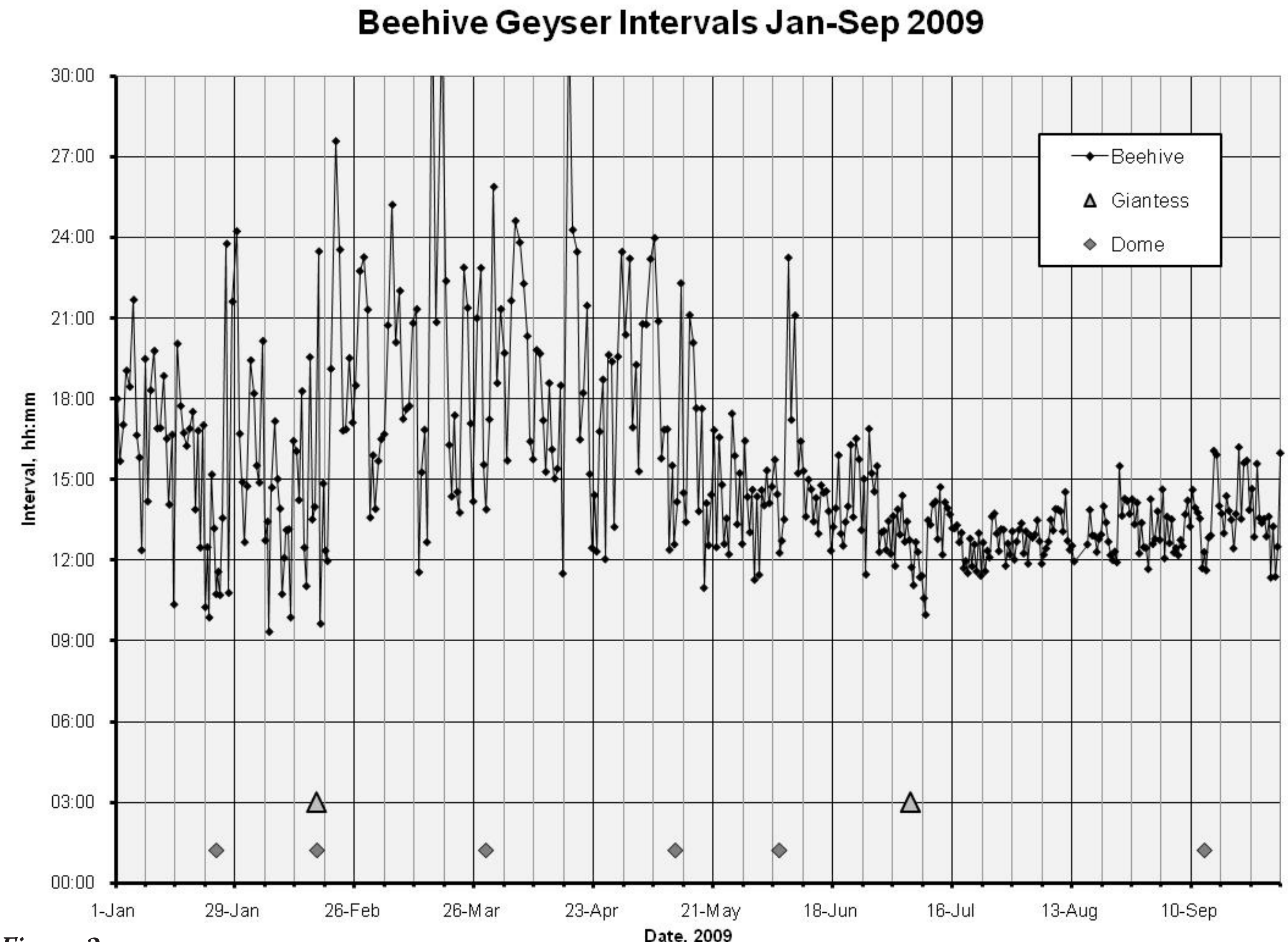

Figure 2.

Beehive Geyser

Beehive Geyser was a reliable performer in 2009 as shown in Figure 2. There were no periods of inactivity and only a few intervals over 24 hours, those occurring before May. With only two exceptions, Beehive's summer intervals, from 1 July to 30 September (the time Aurum was in summer mode), were less than 18 hours, and for much of the summer season Beehive's mean interval of 13h03m resulted in two daylight eruptions on many days. Beehive intervals were noticeably shorter for a day or two following the Giantess eruptions.

Depression Geyser

Depression Geyser's activity had been declining since early 2004. From 1997 through 2003 the electronic record of Depression's activity contains only summer season data, but for those years Depression generally maintained intervals near six hours, increasing somewhat to monthly mean intervals over 8 hours by July 2003. In 2004 and 2005 Depression's monthly mean intervals gradually increased to nearly 18 hours and the monthly range of intervals grew from 1h12m in May 2003 to 21h10m by November 2005. In 2006 and 2007 Depression tended to shorter intervals early in the year (around 12 hours) and much longer intervals in late summer (some intervals over 36 hours). From early October 2006 to the late summer of 2007 Depression's intervals decreased to around 12 hours, then fluctuated from 12 to 30 hours through mid-2008.

Beginning in June 2008 Depression's intervals increased rapidly reaching a weekly median of more than three days in September 2008. Between 10 and 25 December 2008 Depression's intervals fell to below 24 hours with two exceptions; the December median interval was just 17h45m as compared to November 2008's 44h10m. From 26 December 2008 to 3 February 2009 Depression returned to very long intervals, some exceeding 3 days. By February many intervals were less than 24 hours but occasional intervals of 30 to 40 hours occurred. Between 21 May and 13 August 2009 the majority of Depression's intervals were between 12 and 18 hours with only a few intervals exceeding 18 hours as shown in Figure 3. Depression did not show any noticeable

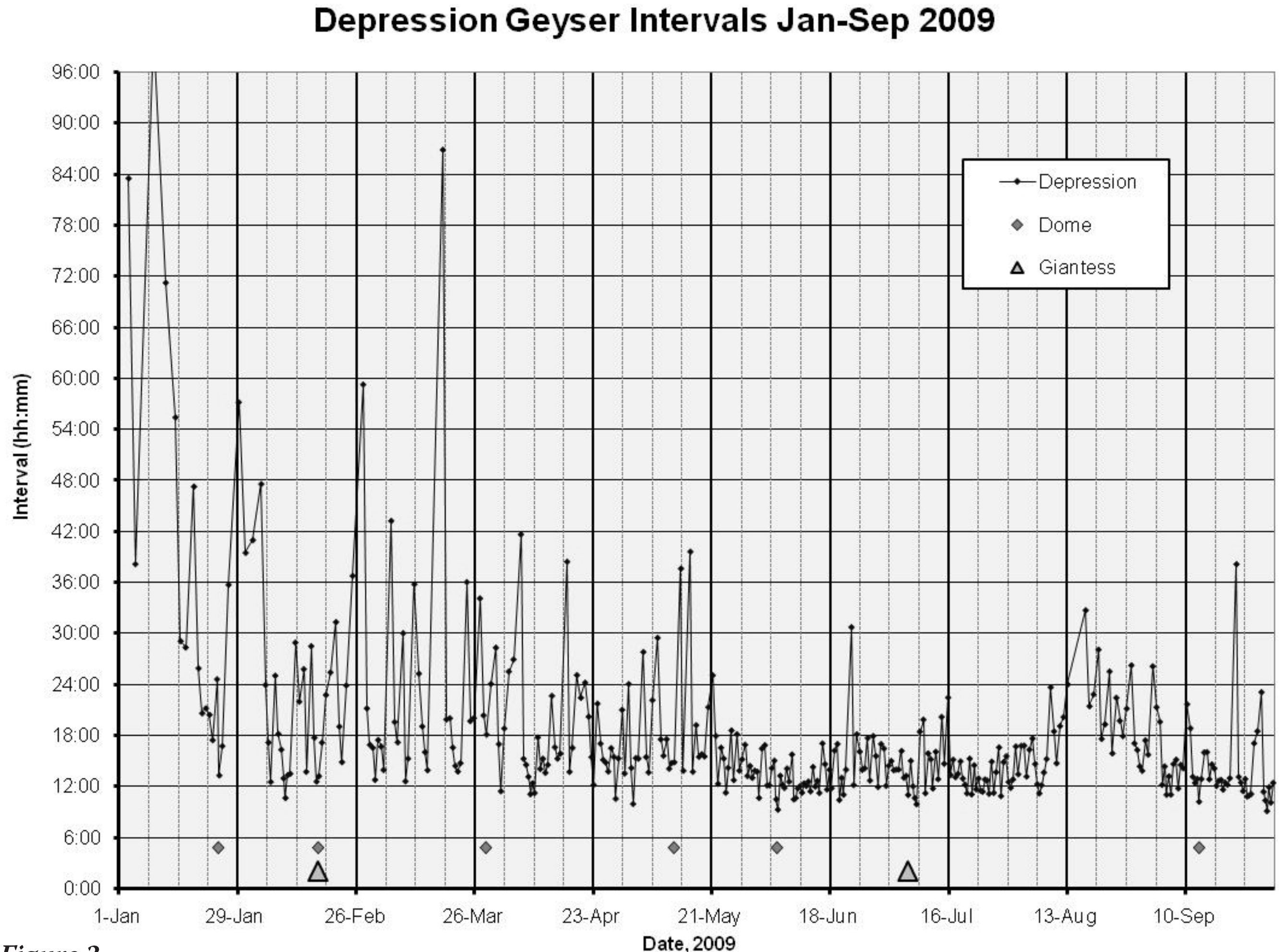

Figure 3.

reaction to Giantess eruptions, but was reported to have longer intervals on days with a strong west wind. Intervals began to increase in mid-August and remained elevated (18 to 30 hours) until early September when there was a decrease in intervals to 12 hours for the rest of September (albeit with some long intervals on windy days). From April through September there were intervals below 11 hours in every month except August, and some intervals were as short as 9h19m. While this did not reach the 6-hour intervals of the late 1990s, Depression had ended its gradual decline in activity.

Dome Geyser

Dome Geyser often erupts at times of high water on the south side of Geyser Hill, the so-called SMax which Bryan defines as the time when water levels are highest in Silver Spring and Bronze Spring (Bryan 1993). Bryan notes that Little Squirt Geyser generally erupts near SMax. In this paper the start times of Little Squirt Geyser's eruptions are used as the approximate times of SMax as the water levels in Silver and Bronze Springs are not available for much of the time period covered. Dome's eruptions occurred at about the time in the Geyser Hill water level cycle that Giantess Geyser might be expected to erupt (indeed, the 17 February eruption of Giantess Geyser was followed in about three hours by a Dome Geyser eruption). In 2009, Dome Geyser erupted on average every 44 days, including one summer interval of 99 days. The 2009 average is longer than the 29 day average of all intervals recorded from July 2009 through October 2009. Dome Geyser often goes dormant over the summer months, and 2009 was no exception. The eruption on 13 September was the first since 5 June, for an interval of just under 100 days. The annual mean intervals for 2007-09 were 30, 29, and 44 days; the annual maximum intervals were 73, 83, and 100 days. In summary, Dome Geyser's activity in 2009 was typical of the activity over the preceding several years.

Lion Geyser

Lion Geyser activity was electronically monitored after the data download at noon on 20 March; prior to that, a logger failure in late 2008 prevented

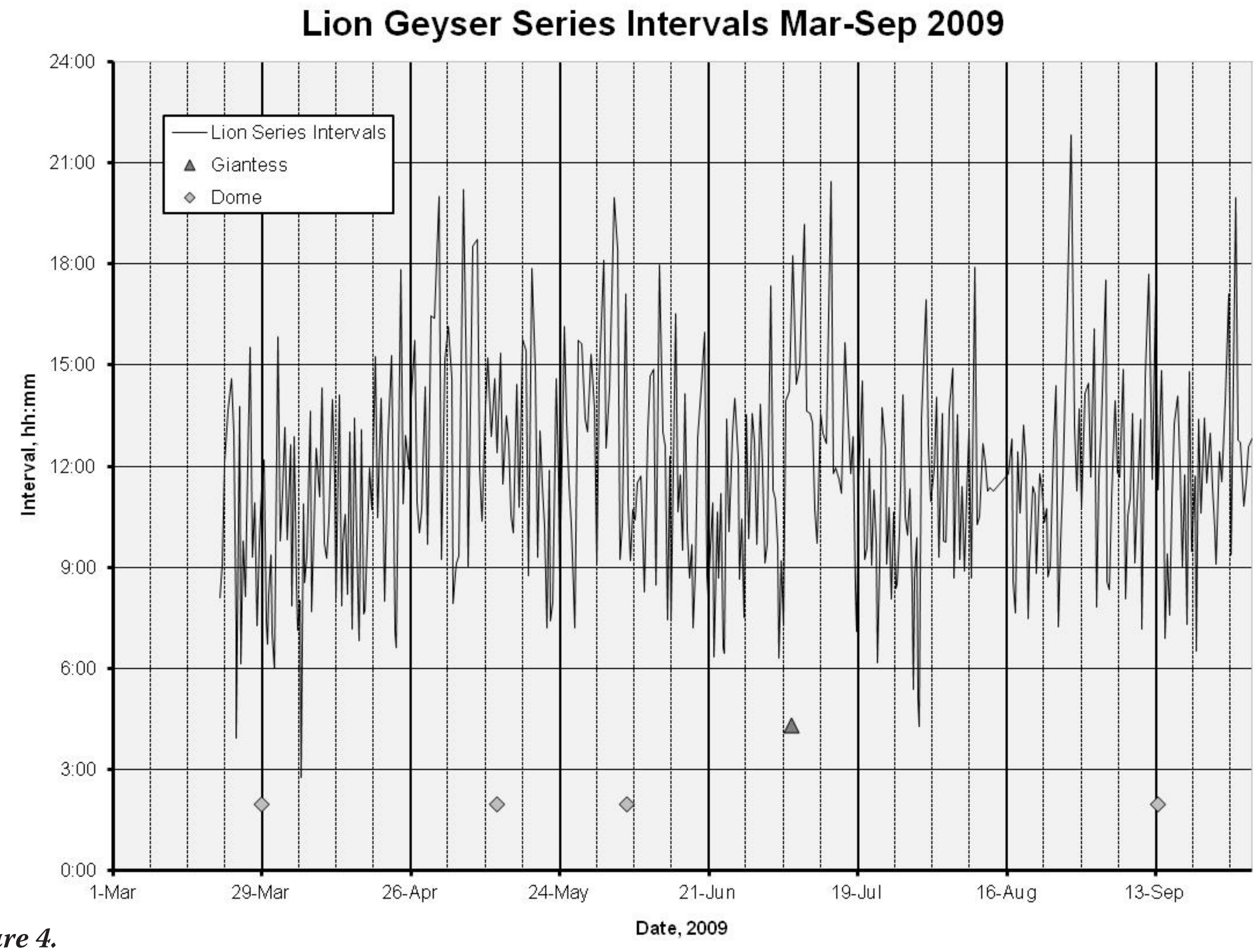

Figure 4.

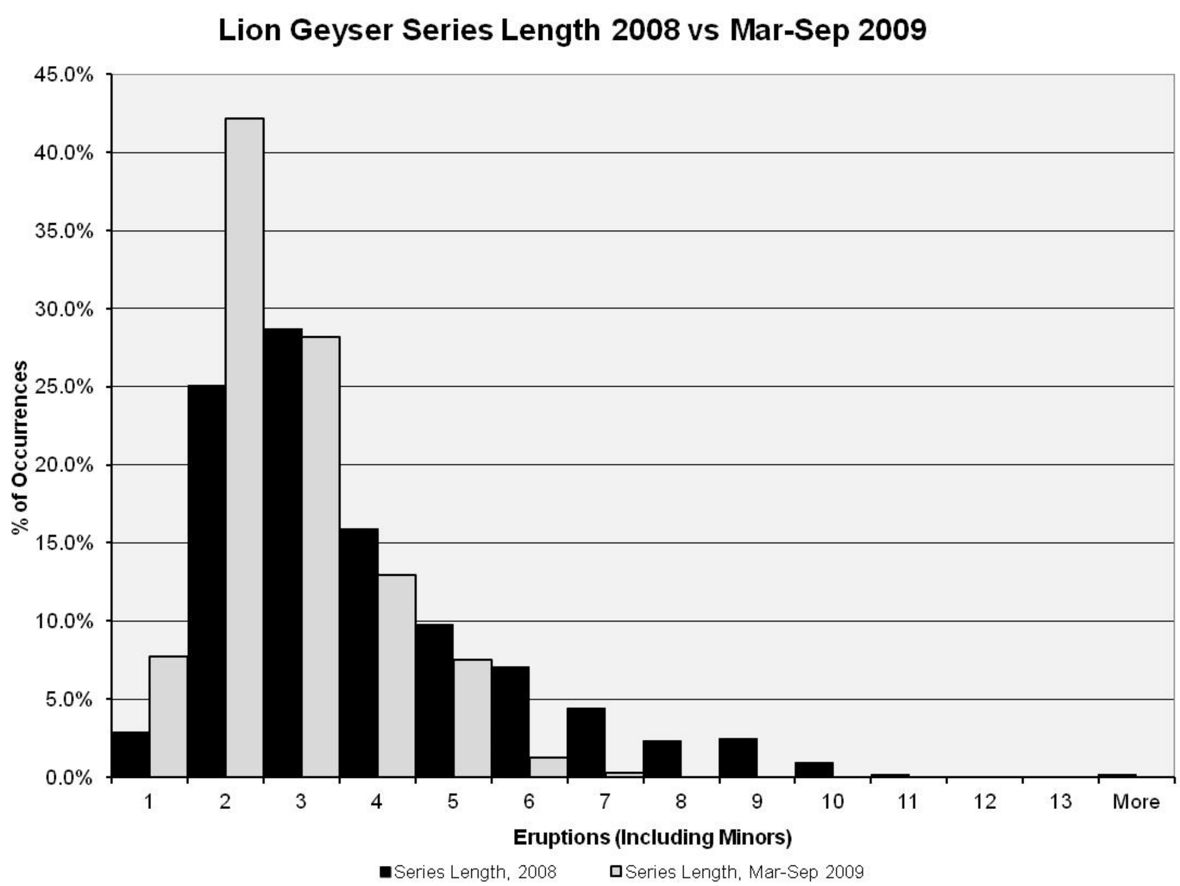

Figure 5.

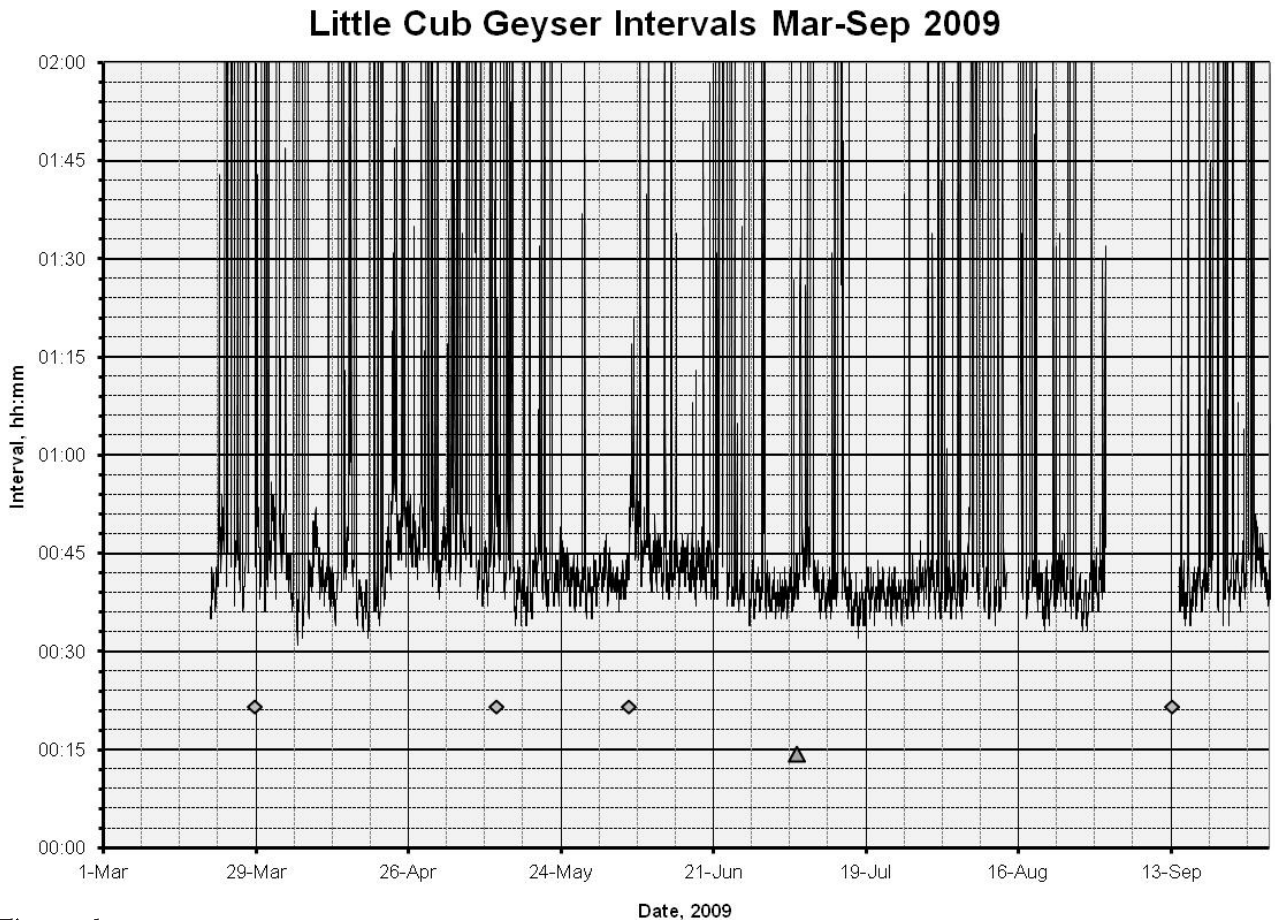

Figure 6.

any data collection. From the start of monitoring in March to the end of September Lion had about two series of eruptions per day. Figure 4 shows Lion's series intervals (measured from the start of one initial eruption to the start of the next initial eruption) for March to September. There was no noticeable reaction to Giantess or to Dome Geyser eruptions. The 2009 series intervals and series lengths were typical of the activity seen in recent years. In the first nine months of 2009, Lion had somewhat shorter series than in 2008, as shown in Figure 5. In 2008 the mean series length was 3.8; for March through September 2009 the mean series length was 2.75 eruptions. Lion Geyser's series intervals were not much different from those of the past several years and the series lengths were actually less in early 2009 than in 2008.

Little Cub Geyser

Like Lion Geyser, Little Cub Geyser was monitored after the 20 March download; the previous data was lost due to a logger failure. From March through September Little Cub continued the pattern seen for the past few years: periods of quiet overflow lasting from 2 to 18 hours, then regularly spaced eruptions with intervals under an hour as shown in Figure 6. The long intervals of quiet overflow were not noted until 2003; from 1998 until 2003 Little Cub's intervals dropped about 15 minutes each year, from 1h55m in 1998 to 0h55m in 2002. Once the periods of inactivity (which were often overnight) appeared, the intervals when Little Cub was active remained between 50 minutes and 1 hour most of the time, increasing to 1h10m some months and dropping to 45m on others. From March to October 2009 the active phase intervals averaged 50m11s and varied from 0h31m to 1h02m.

Plate Geyser

Plate Geyser had very few, widely scattered eruptions from January until mid-June when it began to erupt every day or so, often with short series of two or three eruptions spaced four to six hours apart. The Giantess Geyser eruption in February did not stimulate Plate Geyser into bursts of short intervals, short duration eruptions as it often does, but the 6 July Giantess eruption was followed by more than a dozen eruptions with intervals between 6 and 30 minutes. From the end of the July Giant-

Depression Geyser, September 6, 2009. Photo by Pat Snyder.

ess-related activity to the end of September, Plate returned to earlier activity—not exactly regular, but often erupting several times per day. July saw 133 eruptions with a mean interval of 5h33m, August had 107 eruptions with a mean interval of 6h58m, and September had 101 eruptions with a mean interval of 7h01m. Nearby Boardwalk Geyser did not erupt at all during this time.

Plume Geyser

Plume Geyser remained active for the January-September period, with occasional intervals in excess of 12 hours during the winter months. Monthly average intervals declined slowly from two hours in January (mean of 2h47m, median of 1h53m) to about an hour from June through September. Plume's intervals tended to drop at the time of Dome or Giantess eruptions, and to rise a few days after Giantess eruptions, but overall Plume was a regular geyser once the cold nights of winter were past.

To review, then, the activity on Geyser Hill up to the end of September gave no hint of unusual things to come.

October 2009 Changes in Activity

A series of changes to the activity on the western portion of Geyser Hill occurred in October 2009. Some of the changes were noted immediately by on-site and remote observers, while others became clear only when the complete electronic record was reviewed in early 2010.

First Reports of Changed Activity

Three anomalous events were noted by observers either on site on Geyser Hill or remotely using the Old Faithful streaming webcam. Although subsequent analysis revealed further changes, the initial reports noted three changes in Geyser Hill activity.

First, Giantess Geyser erupted on 14 October 2009. Based on webcam observations and the seismic record the start time for Giantess was determined to be 0448 MDT. Examination of the Plume temperature trace showed a temperature spike at 0453, which is consistent with a 0448 start time considering the distance the water must flow to reach the thermistor under the boardwalk below Plume Geyser. Giantess Geyser eruptions are infrequent (five occurred in 2009), but the eruptions are massive and affect several other geysers on Geyser Hill.

Second, one day after the Giantess eruption, Graham Meech reported "We have had a long Lion series of at least 11 eruptions spanning all daylight hours today Thursday 10/15. The times here are all

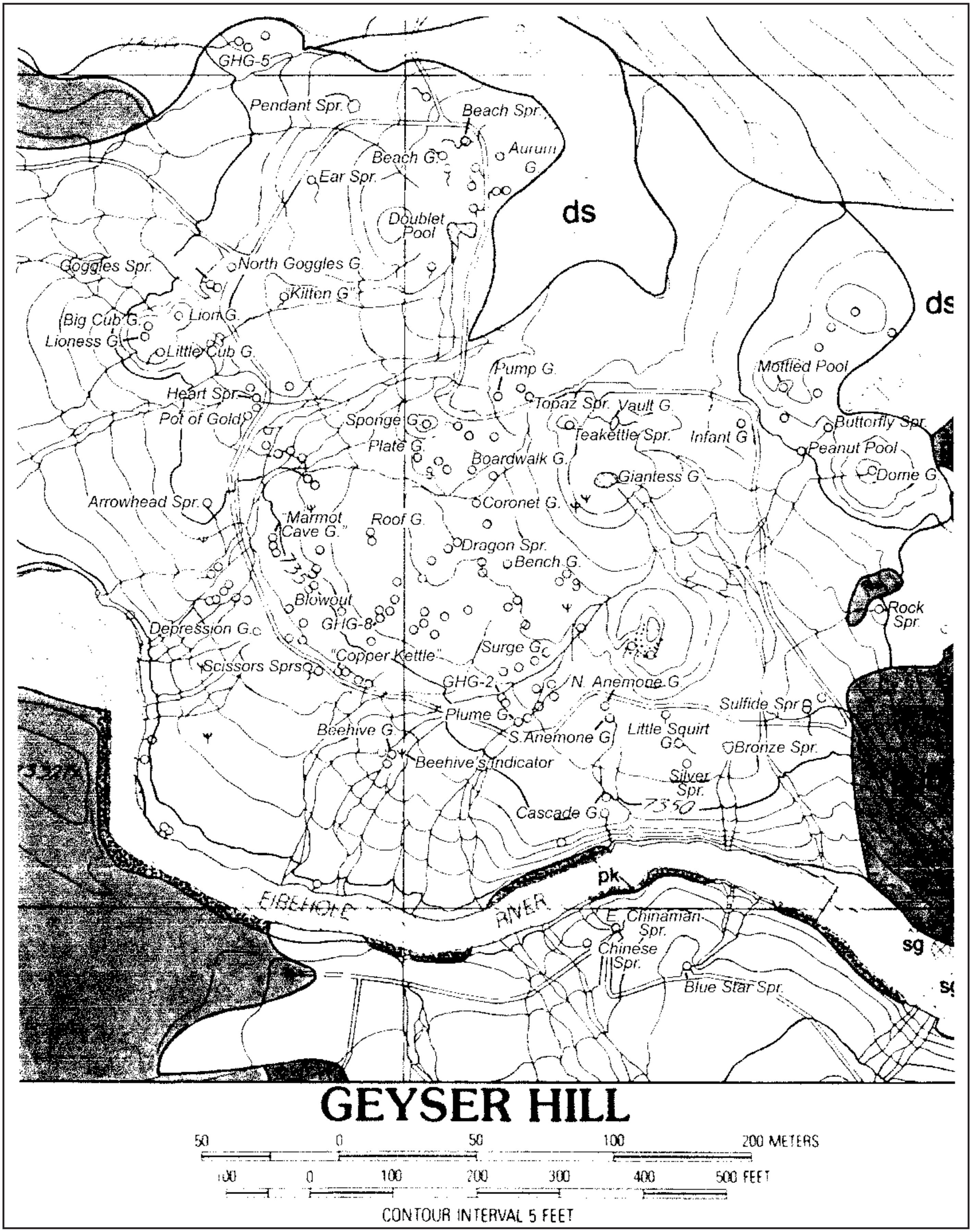
GHG-5
Pendant Spr.
Beach Spr.
Beach G.
Aurum G.
Ear Spr.
Doublet Pool
ds
Goggles Spr.
North Goggles G.
Kitten G.
Big Cub G.
Lion G.
Lioness G.
Little Cub G.
ds
Mottled Pool
Pump G.
Heart Spr.
Pot of Gold
Topaz Spr.
Vault G.
Sponge G.
Teakettle Spr.
Infant G.
Buttorfly Spr.
Plate G.
Peanut Pool
Boardwalk G.
Giantess G.
Dome G.
Arrowhead Spr.
Coronet G.
"Marmot Cave G."
Roof G.
Dragon Spr.
Bench G.
7350
Blowout
Rock Spr.
GHG-8
Depression G.
"Copper Kettle"
Surge G.
Scissors Sprs.
GHG-2
N. Anemone G.
Sulfide Spr.
Plume G.
Beehive G.
S. Anemone G.
Little Squirt G.
Bronze Spr.
Beehive's Indicator
Silver Spr.
Cascade G.
7350
pk
FIREHOLE
RIVER
E. Chinaman Spr.
Chinese Spr.
Blue Star Spr.
sg
GEYSER HILL
50 0 50 100 200 METERS
100 0 100 200 300 400 500 FEET
CONTOUR INTERVAL 5 FEET

Figure 7.

Lion Geyser, September 6, 2009. Photo by Pat Snyder.

courtesy of webcam watchers consolidated through the day (Caroline *[sic]* Aaronson, Pat Snyder, Derek Brice, Rich Henderson and myself)…" (Meech 2009) This was noteworthy since Lion had not had a series of more than seven eruptions for the activity between 21 March and 15 October. Indeed, the longest series recorded in all of the data from the summer of 1998 to September 2009 was fifteen, and just 19 series of ten or more eruptions (1.2%) occurred out of 1,625 series.

Third, Tara Cross reported that on 30 October 2009, the water level in Depression Geyser was observed to drop "several inches" following a strong overflow (Cross 2009). Since the water level had dropped to just below overflow in the overflow cycles, previously this large drop was unusual behavior. Further, Depression Geyser was observed in eruption at 1113, then again at 1425, and yet again at approximately 1800. Since Depression Geyser's mean intervals had been 18h20m for all of 2009 up to 27 September, there was clearly a big change in activity.

OVERVIEW

The changed activity was concentrated on the western edge of Geyser Hill, from the Lion Group through Depression Geyser. Figure 7 *(page 11)* is a map of Geyser Hill based on the USGS Geologic Map of Upper Geyser Basin, Yellowstone National Park, Wyoming (Muffler 1982). Additional feature names were added by Richard Powell. From the map it can be seen that the affected features are along a roughly north-south line. The only other features on the line are Arrowhead Spring and the numerous small springs (not named on the map) collectively known as "The Dwarves" No changed activity in any of these was noted either in late 2009 or in 2010.

The first changed activity in the electronic record was a sharp drop in intervals by Little Cub Geyser on 12 October. Next, Giantess Geyser erupted on 14 October, followed by the first very long series of eruptions by Lion Geyser on 15 October. Finally, on 22 October Depression Geyser's intervals began to decrease. Examination of the electronic record showed no changes to monitored geysers other than the Lion Group and Depression Geyser, aside from the Giantess Geyser eruption. The first reported eruption of North Goggles Geyser since 30 September 2004 was seen on 22 January 2010 by Graham Meech (2010) and confirmed by webcam later by David Monteith (2010).

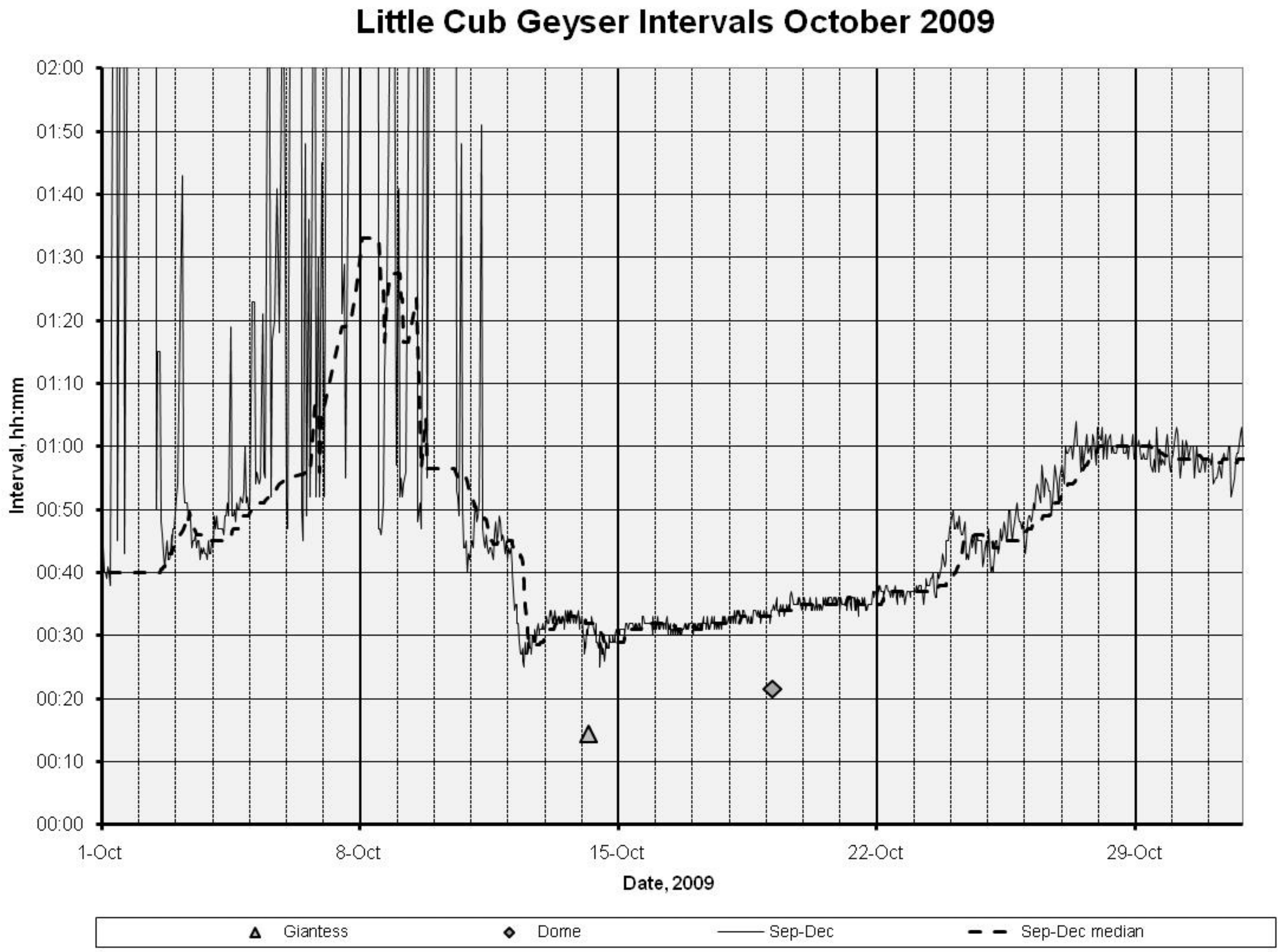

Figure 8.

Changes in Activity in Little Cub, Lion, Depression, and North Goggles Geysers

The activity increase on the west edge of Geyser Hill first manifested by a decrease in Little Cub Geyser's intervals, then by Lion Geyser having much longer series of eruptions, and finally by Depression Geyser's increased activity.

Little Cub Geyser

Little Cub Geyser was not mentioned in geyser reports on the geyser list during the time the changes occurred (October 2009 to February 2010) except for a few isolated eruptions. Examination of the electronic record revealed that a change in Little Cub intervals actually occurred a few days before the changes to Lion Geyser and Depression Geyser, and before the Giantess Geyser eruption on 14 October.

Figure 8 shows Little Cub's activity in October 2009. Up to 11 October, Little Cub behaved in the way it had previously in 2009; that is, there were series of consecutive eruption intervals in the 40 to 60 minute range separated by periods of quiet overflow lasting anywhere from 80 minutes to more than 15 hours (the longest interval in October was 15h53m). During the long intervals, Little Cub would overflow and boil to a few centimeters but would neither build into full eruption nor stop overflowing. Starting on 11 October, however, the long intervals stopped and began to decrease. By the next day, intervals were below 30 minutes for the first time in the electronic record going back to 1997. The shortest interval measured was 25 minutes. On 12 October, intervals dropped from about 45 minutes to around 30 minutes, and remained at that level until 18 October when a gradual increase in interval to about one hour started. By 27 October the intervals stabilized at about an hour until 6 November. At that time the intervals gradually increased to 1h10m by 13 November. From 13 November to the end of 2009 Little Cub's intervals varied from 0h50m to 1h25m. The intervals were stable for a few days, then rapidly changed to a different interval for a few days, then would shift again. The alternation between two sets of intervals has been

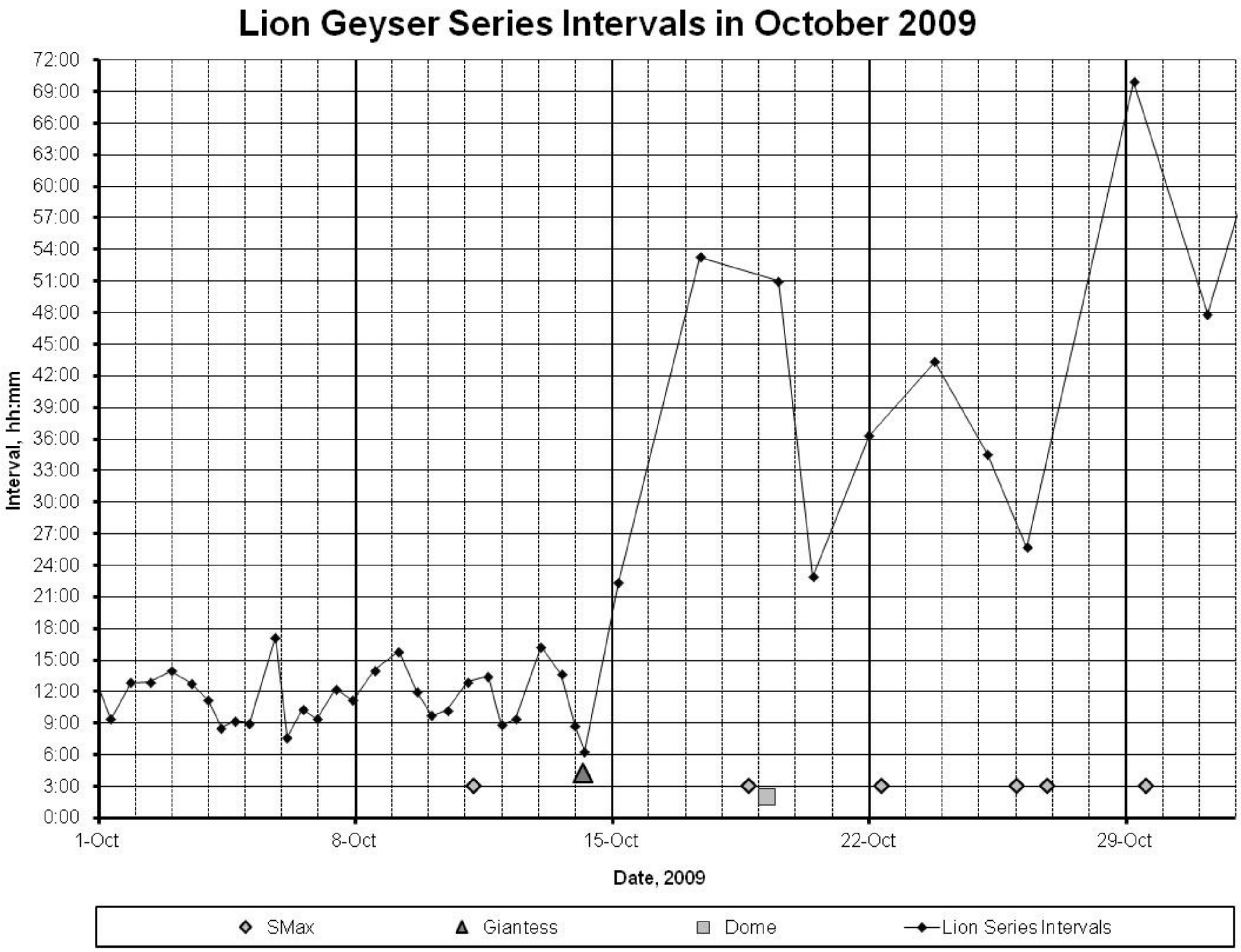

Figure 9.

typical of Little Cub's activity for much of the time covered by the electronic record.

Another change in Little Cub's activity was in the duration of the eruptions. Durations determined from the temperature files are not as precise as the intervals, but generally Little Cub's durations since mid-2004 have remained between 3 and 7 minutes, with most being either four or five minutes. For the 1998 to 2009 timeframe, Little Cub durations remained proportional to the intervals; i.e., when durations decreased there was a corresponding decrease in intervals. However, at about the time Little Cub intervals were decreasing starting on 11 October 2009, the durations increased, until by the end of October typical durations were between 9 and 11 minutes. The durations remained in that range until the end of data in February 2010.

The eruption of Giantess Geyser that started at 0448 on 14 October was followed by a second drop in Little Cub intervals to a minimum of 25 minutes at 1200. Intervals remained at or below 30 minutes until 2100 that evening. Whether the decrease in Little Cub's intervals during the Giantess Geyser eruption of 14 October is a result of the Giantess eruption is not clear, but a decrease in Little Cub Geyser intervals during Giantess Geyser eruptions has been observed on several occasions in the past decade.

Lion Geyser

Lion Geyser was the next geyser to exhibit altered activity. On 14 October Lion had a two-eruption series with the first at 0537 and a second at 0712. The next series did not start until 0401 on 15 October, a series interval of 22h24m, the longest interval of the year to that date. The series that started at 0401 on 15 October consisted of 15 eruptions, just two of which were minor eruptions. To put this series length into perspective, the electronic record from 1998 to 14 October 2010 contains data on 6,129 series, only one of which had more than 10 eruptions. Of the 6,129 series, only 93 series consisted of more than six eruptions.

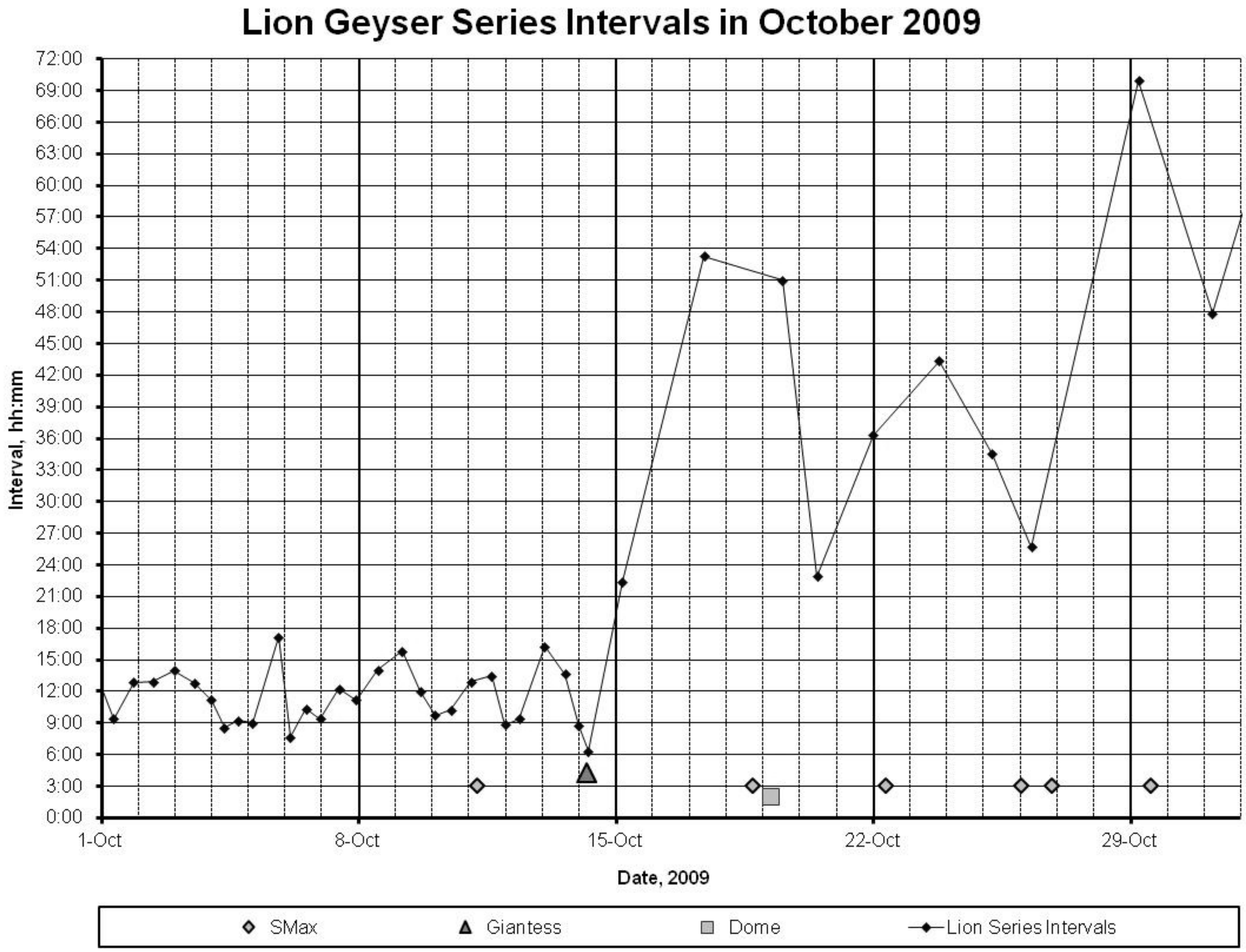

Figure 10.

The 15-eruption series that started on 15 October marked the beginning of a different mode of activity for Lion Geyser. From that series to the end of 2009 there were 31 series of eruptions ranging in length from one to 35 eruptions. The mean series length for the rest of 2009 was over 16 eruptions. The change in series intervals in October 2009 is shown in Figure 9.

The greater number of eruptions per series was accompanied by longer series intervals and longer quiet times between series. Table 1 and Table 2 *(page 16)* illustrate the changes in series interval and series length that occurred on 14-15 October. The mean series intervals increased from 11h29m before to 51h07m at the same time that the mean series length jumped from 2.75 to 16.19 eruptions per series. The change in activity continued past the end of 2009 into 2010, albeit with somewhat shorter series and shorter series intervals. Table 3 *(page 16)* illustrates the jump in the length of the quiet time that accompanied the longer series of eruptions.

Interestingly, although there is a tendency for long series of eruptions to be correlated with long series intervals, the first long series was preceded by an unusually long quiet period. The last "normal" series consisted of two eruptions at 0537 and 0712; the first long series (which eventually reached 15 eruptions) did not start until 0401 on 15 October, 20h49m after the end of the two-eruption series. Note that the Giantess Geyser eruption of 14 October occurred during this quiet phase, but previous and subsequent Giantess Geyser eruptions did not coincide with very long quiet phases.

Since the sudden change in activity on 14-15 October 2009 Lion Geyser has settled into a new pattern of longer series of eruptions, longer series intervals, and long quiet periods between series. In late 2009 Lion was having a series about every two days, but in 2010 the intervals dropped to the point that a new series started about every 36 hours.

Table 1 - Lion Geyser Series Intervals			
Series Interval	2009 Pre 14 Oct	2009 Post 14 Oct	Jan-Sep 2010
Minimum	2:46:24	18:29:00	3:28:00
Mean	11:29:28	51:07:39	36:23:26
Median	11:18:00	50:17:00	36:06:00
Maximum	21:50:00	91:51:00	69:36:00

Table 2 - Lion Geyser Series Lengths			
Series Length	2009 Pre 14 Oct	2009 Post 14 Oct	Jan-Sep 2010
Minimum	1	1	1
Mean	2.75	16.19	10.59
Median	2.50	13.00	10.00
Maximum	7	35	22

Table 3 - Lion Geyser Quiet Time		
Quiet Time	2009 Pre 14 Oct	2009 Post 14 Oct
Minimum	2:46:24	8:01:00
Mean	9:05:43	35:53:07
Median	8:56:14	37:31:30
Maximum	18:57:00	65:05:00

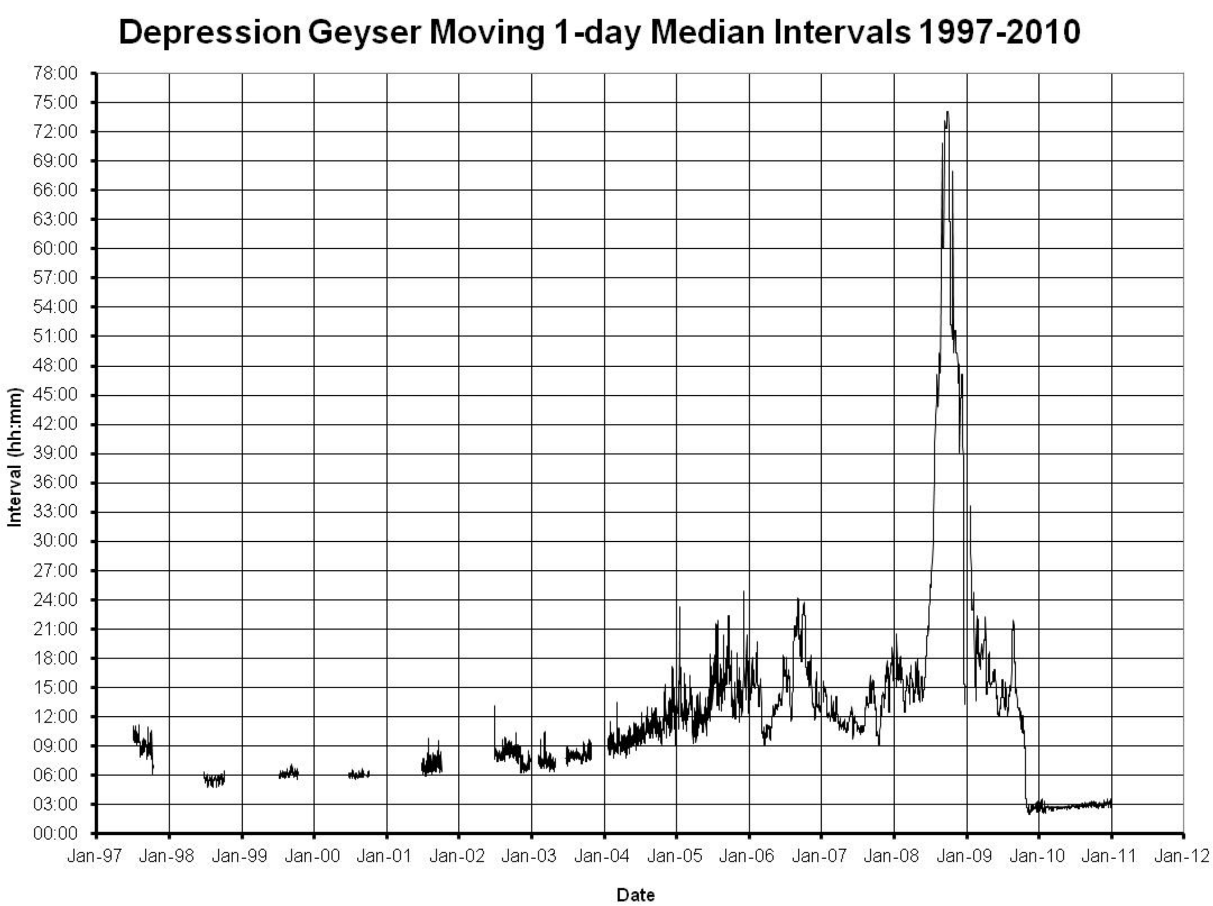

Figure 11.

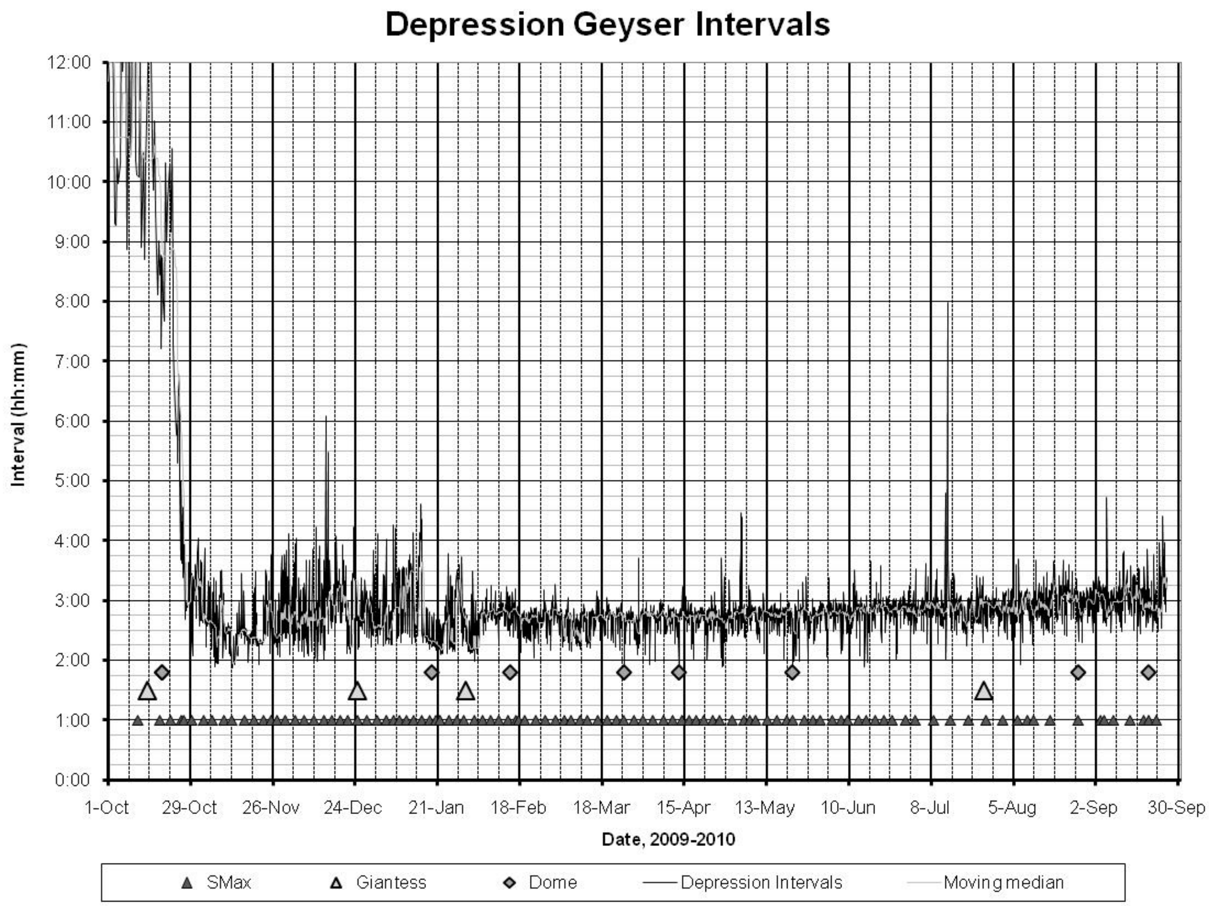

Figure 12.

Depression Geyser

Depression Geyser was the second-to-last geyser to exhibit changes in its eruption pattern. The activity of Depression Geyser continued the pattern of the summer and early autumn with eruptions occurring eight to eleven hour intervals until 17 October 2009. At that time Depression began to have shorter intervals, including one just over 7 hours. Compared to the past few years, that was frequent, but still within the span of intervals that had been seen in the past decade.

Then, starting at 2354 on 22 October, Depression's intervals dropped from 8h09m to 2h41m at 0304 on 27 October. Table 4 *(page 18)* shows the progression of intervals during this time. Figure 10 *(page 15)* shows Depression's October activity and clearly shows the dramatic decline in intervals. Intervals remained between two and four hours for the remainder of 2009 and into 2010. Depression's intervals rose to 3h30m in early January 2010, then dropped to 2h45m in mid-January and gradually increased to about 3h00m by mid-September 2010.

The magnitude of the change in Depression's activity is shown in Figure 11 which plots 1-day moving median intervals for all of the electronically recorded intervals since 1997. Figure 12 shows Depression intervals from early October 2009 to the end of data available as this is written in September 2010.

Depression Geyser is known to have reacted to large seismic events by erupting at short intervals, some as short as those seen in October 2009. The first such occurrence was noted by Marler following the 1959 Hebgen Lake earthquake. Marler (1973) notes that

> Prior to the earthquake I had observed but few eruptions; they were of infrequent occurrence. Steady overflow characterized it most of the time. Due to the earthquake apparently it was stimulated into a somewhat regular eruption cycle. Eruptions occur about every 3 to 4 hours; the duration is from 2 to 3 minutes. It is a splashing type eruption, the height being from 8 to 10 feet.

The second occurrence was reported by Hutchinson (1984) following the 1983 Borah Peak, Idaho earthquake. His summary notes that Depression Geyser's "Average interval decreased from more than 6 hours to 2-3 hours".

Table 4 - Depression Geyser intervals 22-27 October 2009	
Eruption Time	**Interval**
23-Oct-13 23:54:00	8:09:00
24-Oct-13 07:10:00	7:16:00
24-Oct-13 13:46:00	6:36:00
24-Oct-13 19:56:00	6:10:00
25-Oct-13 01:42:00	5:46:00
25-Oct-13 07:39:00	5:57:00
25-Oct-13 13:20:00	5:41:00
25-Oct-13 18:38:00	5:18:00
26-Oct-13 01:25:00	6:47:00
26-Oct-13 07:48:00	6:23:00
26-Oct-13 12:43:00	4:55:00
26-Oct-13 16:23:00	3:40:00
26-Oct-13 21:23:00	5:00:00
27-Oct-13 01:18:00	3:55:00
27-Oct-13 04:55:00	3:37:00
27-Oct-13 09:28:00	4:33:00
27-Oct-13 12:51:00	3:23:00
27-Oct-13 16:47:00	3:56:00
27-Oct-13 20:26:00	3:39:00
28-Oct-13 00:23:00	3:57:00
28-Oct-13 03:04:00	2:41:00

It would seem that Depression had reverted to the pattern of activity that followed its activation subsequent to the 1959 Hebgen Lake earthquake and the 1985 Borah Peak earthquake.

North Goggles Geyser

North Goggles Geyser is located about 25 meters (80 feet) northeast of Lion Geyser. It was dormant from 30 September 2004 through summer 2009. Historically, major eruptions of North Goggles occurred during Lion Geyser series while minor eruptions occurred after the end of a Lion series.. Given the previously established connection between North Goggles Geyser and the Lion Group, it is unfortunate that the electronic record does not include North Goggles Geyser activity for October 2009 and beyond. There are usually few observers during the winter, especially during the months when the Park is closed to visitors, so it is likely that activity by North Goggles Geyser would be overlooked. There was one report of an eruption of North Goggles Geyser over the winter of 2009-10 in a geyser report by Graham Meech (2010) in January but little other information is available. That eruption, a minor eruption, was isolated in the webcam archives by David Monteith who determined the eruption time as 1323 on 22 January 2010 (Monteith 2010), roughly at the time of the last eruption of a Lion series.

Geysers Not Affected

The remaining geysers for which electronic data is available, Aurum, Beehive, Dome, Little Squirt, Plate, and Plume, showed no unusual changes in activity in October.

Discussion

The changes on Geyser Hill in October 2009 were localized to the western edge of Geyser Hill. Although the changes were accompanied by an eruption of Giantess Geyser, the start of the Little Cub Geyser changes preceded the Giantess eruption by three days, the Lion Geyser changes occurred a day after the Giantess eruption, and the Depression Geyser change was three days after the Giantess eruption. All three of the noted changes in activity resulted in more eruptions, suggesting that the flow of hot water from the deep reservoir increased to the western edge of Geyser Hill, thus making more eruptive energy available. The change was not accompanied by any notable seismic activity, and the effects were localized to the three (four, if the reactivation of North Goggles Geyser is included) geysers and did not extend to other nearby features.

Since the onset of the changed activity on Geyser Hill occurred in October and continued into November and December when the Park was closed, few observations were made by experienced observers. The Ranger Interpreter staff in October is small and other duties occupy nearly all of the staff time. Few geyser gazers are in the park in October, and essentially no observers are present from closing in early November to the winter season start in mid-December. The streaming web camera did allow for some observations during the winter, but extensive detailed observations were not made until late spring of 2010.

The changed eruption patterns that first appeared in October 2009 continued for the rest of 2009 and all of 2010. Little Cub Geyser intervals increased somewhat during 2010, and the periods of continuous low-intensity boiling with long eruption intervals reappeared by April 2010. Little Cub's

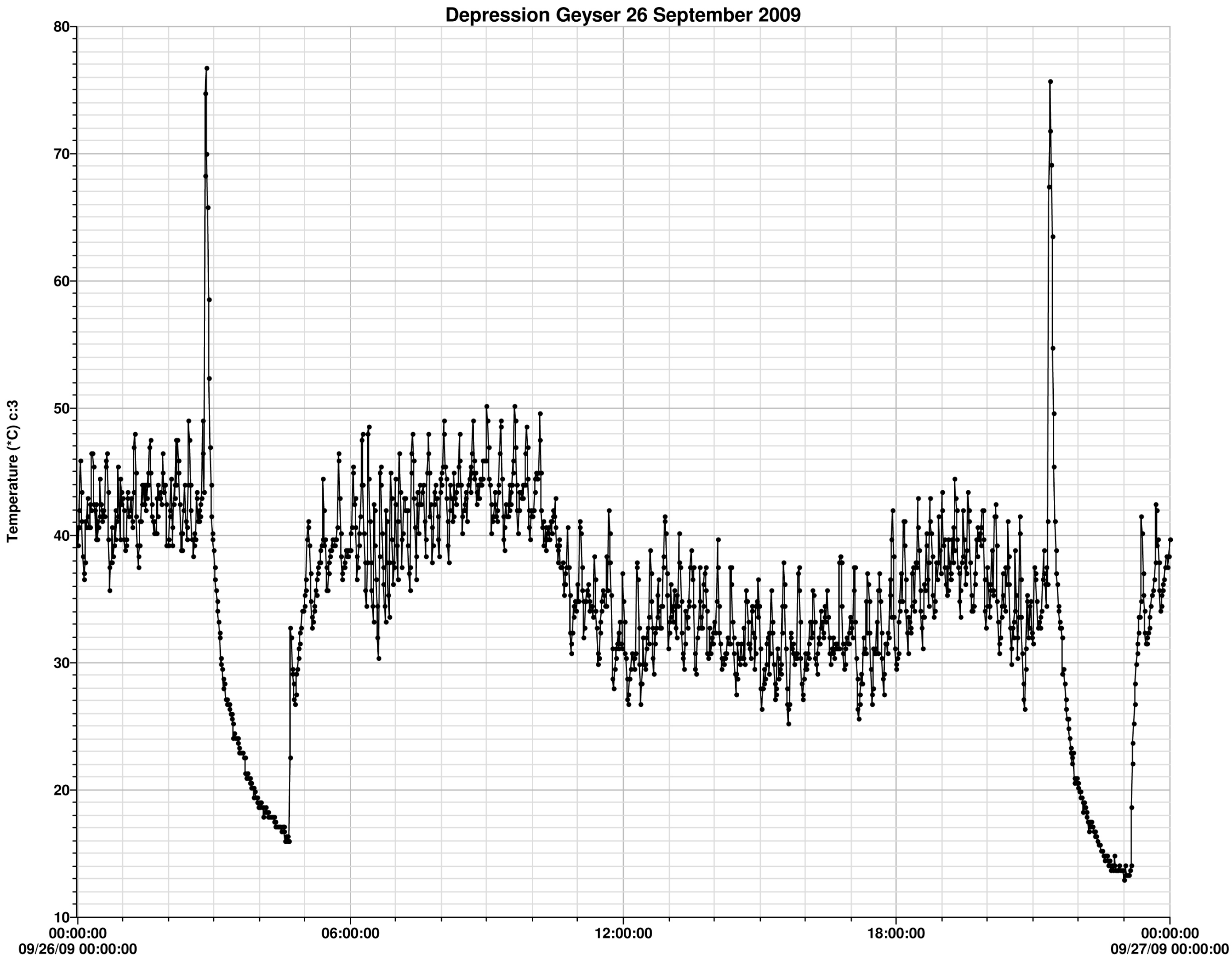

Figure 13.

intervals when it was not having the quiet overflow episodes remained shorter than before the October 2009 changes throughout 2010. Lion Geyser series lengths in 2010 and the first half of 2011 gradually shortened from the very long series noted late in 2009, but remained much longer than before the alteration, and the inter-series quiet phases were also much longer than before. Depression Geyser's intervals remained consistent (monthly mean intervals around 2h45m and interval ranges between 1h30m and 2h37m) and much shorter than any time in the previous ten years, although they slowly increased throughout 2010 and the first half of 2011.

The nature of Little Cub's activity was not noticeably different from the activity of recent years, with the exception of reduced intervals and a temporary cessation of periods of low intensity boiling and overflows. Lion Geyser series in 2010 were much longer than in recent years, averaging more than 10 eruptions per series as compared to 2.5 eruptions per series before the October change. The duration and character of the eruptions was not noted to be any different from that of recent years.

Depression Geyser did change its activity with the onset of short intervals. Throughout the 1990s and the 2000-2009 decade, Depression refilled within about an hour and a half of an eruption. Once the water filled the crater Depression overflowed constantly with the water level in the crater rising and falling two or three times per hour. This behavior shows clearly in Figure 13, the overflow temperature trace for 26 September 2009. The deep drop in temperature following the eruptions at 0250 and 2122 resulted from cessation of overflow during the recovery. The smaller peaks visible following the recovery up to the next eruption are the changing overflow during the periods of higher water and consequent greater water flow. The overflow at the

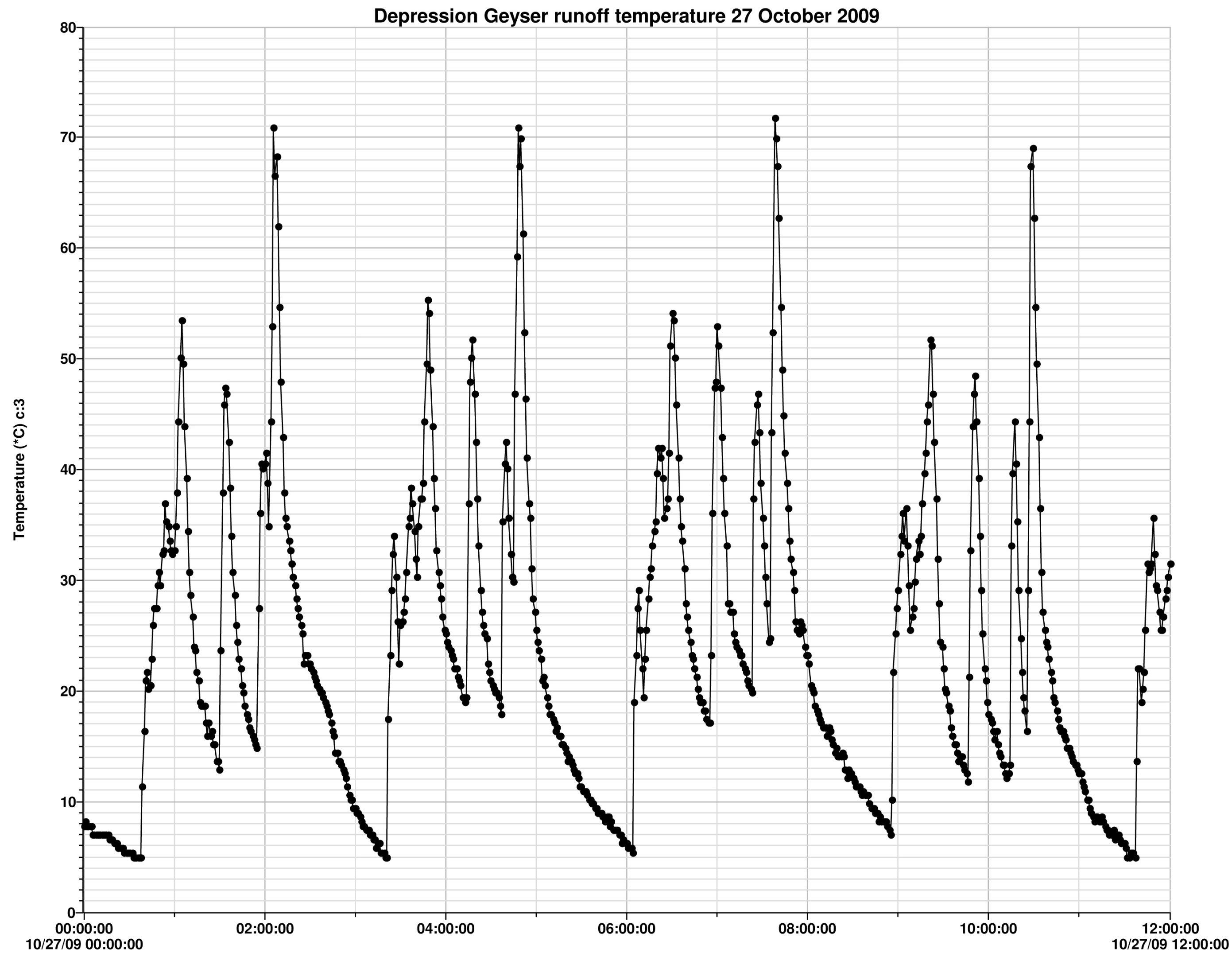

Figure 14.

sensor did not completely stop but was reduced to a slight trickle at low water. The variation during the day in the magnitude of the small peaks is a result of the effects of sunlight and ambient air temperature. Eventually one of the periods of high water level initiated the eruption. During the summer of 2009 bubbles were frequently seen over the main vent for several hours preceding the eruption.

Following the October change, Depression's water level recovered after an eruption in about 75 minutes, barely reaching overflow before dropping 5 to 10cm (2 to 5 inches) below the rim between periods of overflow. The late 2009 behavior is shown in Figure 14, which shows the temperature in the overflow channel for the 12 hour period from midnight to noon on 27 October. Typical intervals had one or two cycles with a trickle of overflow, followed by one to three 30-minute cycles of strong overflow followed by a drop in water level to 10 cm or more below overflow. After one to three such cycles one of the overflow periods ended with an eruption. Note the difference in the temperature following the overflow cycle peaks in Figure 13, before the October change, and in Figure 14, after the change. In Figure 13 the runoff temperature drops somewhat but quickly begins to rise while after the strong overflow cycles in Figure 14 the runoff ceased and the temperature declines toward ambient temperature before the sudden rise caused by the onset of overflow during the next cycle.

While the changes in Depression Geyser's activity sound similar to the changes reported after the 1959 Hebgen Lake earthquake and the 1983 Borah Peak, Idaho, earthquake, there was one significant difference. Both of these earthquakes resulted in Lion Geyser going dormant, while the October 2009

Little Cub, May 2009. Photo by Pat Snyder.

change in Depression Geyser was accompanied by a substantial *increase* in Lion Geyser activity.

SUMMARY

Activity on the western edge of Geyser Hill from the Lion Group to Depression Geyser underwent a substantial change in character consistent with increased flow of hydrothermal fluids. The changes did not extend to Beehive Geyser. The activity of minor features between the Lion Group and Depression Geyser did not appear to be affected, based on a lack of reports of unusual activity there during the winter and spring. The changes in activity by Little Cub, Lion, and Depression Geysers occurred over a period of five days with an eruption of Giantess Geyser occurring during the change. The cause of the changed activity is unknown; no large seismic events occurred during this time period and the rest of the Upper Geyser Basin did not show evidence of changes at the same time. A combination of electronic monitoring and webcam observation allowed the change to be noted and studied even though much of the change occurred when few observers were present at Old Faithful.

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The geysers E-mail mailing list is maintained by David Monteith and Carlton Cross. More information can be found at: lists.wallawalla.edu/mailman/listinfo/geysers.

Activity of Beehive's Indicator in 2009

Lynn Stephens

Abstract

This article provides information about durations of Beehive's Indicator for 2009, a year when an eruption of Beehive's Indicator was a reliable predictor of an impending eruption of Beehive Geyser. The duration of Beehive's Indicator consists of two components—time between the start of the Indicator and start of Beehive's eruption, or lead time, and time the Indicator continues after the start of Beehive, or continuation time. This article provides descriptive statistics about the total duration, lead time, and continuation time, and a quantitative analysis of the relationship between the lead time and continuation time, lead time exhibited by the Indicator and the duration of Beehive Geyser's eruption, and the continuation time exhibited by the Indicator and the duration of Beehive Geyser's eruption.

INTRODUCTION

Beehive's Indicator (hereinafter referred to as "the Indicator") is a member of the Geyser Hill Group of the Upper Geyser Basin in Yellowstone National Park. It is located about 11 feet 9 inches east of Beehive Geyser (Marler 1973). The Indicator has a history of acting as a precursor to an eruption of Beehive Geyser. An eruption of the Indicator is usually followed by an eruption of Beehive Geyser. However, Beehive Geyser may erupt without a prior eruption of the Indicator. Also, there have been seasons when the Indicator erupted without a subsequent eruption of Beehive. In 2009 the Indicator was a reliable indication of an ensuing eruption of Beehive Geyser.

The purpose of this article is to (1) review historical information about Beehive's Indicator, and (2) report information about eruptive characteristics of Beehive's Indicator during 2009.

When the Indicator precedes an eruption of Beehive Geyser, the total duration of the Indicator consists of two components. These two components are (1) the time between the start of the Indicator and the start of Beehive Geyser's eruption, hereinafter referred to as the lead time, and (2) the length of time between the start of Beehive Geyser's eruption

Beehive's Indicator with Old Faithful Geyser erupting in the background, Sept. 9, 2009. Photo by Pat Snyder.

Table 1: Historical Activity of Beehive's Indicator	
Year	**Nature of Activity**
1875	Active per Ludlow, Dana, Grinnell
1878	Active per Peale
1882	Active per Wylie guidebook
1883	Active per Haupt guidebook
1884, 1886	Active per Weed's notes
1890	Active per *Haynes Guide*; information about the Indicator continued to appear in *Haynes Guides* through the 1920s.
1896	Active per Wheeler
1920	Active per Monthly Report of Superintendent
1920's through 1951	Apparently dormant per Whittlesey and Marler. Information about the Indicator deleted from *Haynes Guides* beginning with the 1930 edition
1952-1955	Active per Marler's *Annual Reports* and 1973 *Inventory*.
1956-1967	Dormant per Marler's *Annual Reports* and 1973 *Inventory*
1968-1969	Active per Marler's Annual Reports, occasional false indicators
1970	No mention in Marler's 1970 *Annual Report*
1971	Active per Marler's 1971 *Annual Report,* occasional false indicators
1972-1978	Active per Hutchinson, frequent false indicators
1979	Active per Hutchinson, only one false indicator
1980	Active per Hutchinson, frequent false indicators during the summer
1981	No information found
1982	Active per Hutchinson, only one false indicator
1984-1987	Active per Hutchinson, Landis; only one false indicator in 1987
1988	Active per Landis; no reports of false indicators

and the end of the Indicator's eruption, hereinafter referred to as continuation time. Descriptive characteristics for the Indicator are presented for both components of the total duration of the Indicator—lead time and continuation time—as well as the total duration. The article also presents a quantitative analysis of the relationships between the lead time and the continuation time of the Indicator, the Indicator's duration and duration of Beehive's eruption, and the components of the Indicator's duration and the duration of Beehive's eruption.

HISTORICAL ACTIVITY OF BEEHIVE'S INDICATOR

A summary of reports of Beehive's Indicator's activity through 1988 is presented in Table 1, "Historical Activity of Beehive's Indicator."

First Usage of "Beehive's Indicator"

Whittlesey (1988) indicated that the earliest known usage of the name Beehive's Indicator appeared in Walter Weed's observations for 1884 and 1886:

> On August 12, 1884, following a late afternoon eruption of Giantess Geyser, geologist Walter Weed saw Beehive's Indicator: 'At 7:31 the Indicator of the Beehive began to play and at 7:36 the Beehive spouted a foot…at 7:38 the column rose some 150 to 200 feet…' Weed's usage of the name Beehive's Indicator is the earliest known and it appears that he gave the name or took it from established local usage sometime 1884-86. His 1886 notes stated that Beehive's Indicator erupted five minutes before Beehive Geyser.

Although the name "Indicator" was not applied until the early 1880s, observations of the geyser had been recorded nearly a decade earlier.

Earliest Known Observation of the Indicator

Both Whittlesey (1988) and Marler (1973) indicate that the earliest known recorded observation of Beehive's Indicator occurred in 1875. Captain William Ludlow reported "Near by [Beehive] is a small vent, which is the herald and precursor of its greater neighbor" (Ludlow 1876). Scientists Dana and Grinnell, who accompanied Ludlow on his trip to Yellowstone, also mentioned the Indicator. A vent acting as an indicator for an impending eruption of Beehive was also noted in 1878 by Peale (Hayden 1883), who stated "Just outside of the [Beehive] cone are several vents or steam-holes, one of which acts as a sort of preliminary vent or signal for the eruption of the geyser."

Early Information About the Indicator's Lead and Continuation Times

Whittlesey (1988) reported that Herman Haupt included information about the Indicator in his 1883 guidebook. Whittlesey stated Haupt noted the Indicator was "a little steam vent" about ten feet north *[sic]* of the cone

> ...which for fifteen or twenty minutes before an eruption gives warning by its vigorous action of the discharge which is to come; when this precursory action ceases, the grand spouting of the [Beehive] may be momentarily expected...during the whole eruption the little vent plays...

Haupt's information indicates the Indicator stopped erupting "momentarily" prior to the start of Beehive's eruption, but that the Indicator's eruption also continued "during the whole eruption [of Beehive]." Presumably the Indicator restarted as soon as Beehive started. Continuation of the Indicator's eruption throughout the entire eruption of Beehive Geyser has not been the case during at least the past four decades. Descriptive statistics for the Indicator's "continuation time" after the start of Beehive's eruption during the 2009 summer season will be presented in a subsequent section of this paper.

Additional historical information about the lead time between the start of the Indicator and the start of Beehive's eruption was provided by Whittlesey (1988):

> An 1885 [Wiley 1893] reference stated that "when the indicator bubbles and spurts, the geyser will go off within half an hour..." An 1890 [Guptil, 1890] reference had it that Beehive's eruptions followed the indicator "in about fifteen minutes" while a 1920 [Monthly Report of Superintendent, September, 1920] reference gave the time as twenty minutes.

Marler (1973) added an 1896 (Wheeler) reference stating the Indicator "boiled regularly about thirty to thirty-five minutes previous to an eruption."

Marler (1973) indicated most of the eruptions of the Indicator he had seen continued for 38 to 45 minutes before Beehive erupted. Whittlesey (1988) summarized the lead time the Indicator had historically exhibited as varying from "5 to 48 minutes."

References that the Indicator Was Not Always Reliable

Beehive's Indicator appeared in early guidebooks beginning in 1882. Wylie (1882) provided a more complete discussion of the Indicator's activity than had been included in Peale's (1878) report: Wylie's information about the Indicator (as reported in Marler (1973)) said:

> A little orifice about 12 feet above the cone of the geyser, almost without exception, gives warning from fifteen to thirty minutes before the eruption of the geyser. The writer never knew this faithful little monitor to fail before the present season, when he witnessed it play at two different times for thirty minutes, and then cease; and the geyser did not act. Although the geyser may fail to act always when the vent warns, the geyser never acts without the vent giving warning; so it is generally safe to heed the warning given by the little vent.

Wylie's statement is apparently the earliest recorded observation that the Indicator could erupt without an ensuing eruption of Beehive itself. Note that although Wylie had seen eruptions of the Indicator that were not followed by an eruption of Beehive, Wylie had never seen an eruption of Beehive that was not preceded by an eruption of the Indicator.

A review of *Haynes Guides to Yellowstone Park* for selected years (1894, 1898, 1900, 1903, 1905, 1906, 1908, 1909) showed this information:

> A miniature geyser, or indicator, a few feet from [Beehive's] base, is, generally speaking, a faithful forerunner of activity of the Bee Hive, by shooting up jets or spurts of water, which are followed in about fifteen minutes by a column of steam and water from the main crater, hurled upwards with great force and in a steady stream.

The wording changed slightly in the 1912 edition to read:

> Eruptions of the Beehive are foretold by the spouting of its indicator, a small, inconspicuous fissure in the formation ten feet north of the cone. Whenever this indicator plays, one should make for the Beehive without delay, and even though the indicator is not infallible, it usually signifies that in less than fifteen minutes the Beehive will erupt—a sight never to be forgotten.

Whittlesey (1988) noted a 1911 statement by Geologist Arnold Hague: "One of these secondary vents [near Beehive] is, however, a true geyser. It is known as the <u>Indicator</u>, as it plays for a short time before an eruption of the Beehive. Its jet never exceeds 15 feet in height, and frequently only half of that distance, but it seldom fails. The Beehive may be relied upon to burst forth within twenty minutes when the Indicator ceases to play."

Whittlesey stated "As early as 1888, soldier Thomas Moody had noted that the Indicator "could not always be relied on." Whittlesey also cited a 1911 letter from Jack Haynes to Hague in which Haynes said "sometimes the indicator plays but the Bee Hive does not." Apparently Haynes observed independent eruptions of the Indicator without follow-up eruptions of Beehive in 1911 and changed the information in *Haynes Guides* effective with the 1912 edition.

Editions of the *Haynes Guides* prior to 1912 noted the Indicator was "generally speaking, a faithful forerunner of the activity of the Bee Hive."

The information about the Indicator stayed the same in the 1913, 1914 and 1915 editions. The amount of information about the Indicator was shortened by the time the 1920 edition was prepared. The 1920 edition stated merely "[Beehive's] eruptions are foretold by the spouting of its indicator, an inconspicuous fissure in the formation ten feet north of the cone." This same information appeared in the 1923, 1924, 1926, 1927, 1928, and 1929 editions.

Despite inclusion of information about the Indicator in Haynes Guides published during the 1920s, neither Whittlesey (1988) nor Marler (1973) could find any references to eruptions of the Indicator between the September 1920 *Monthly Report of the Superintendent* and Marler's (1973) statement that he first saw it erupt in November 1951. Marler (1973) and Whittlesey (1988) both concluded the Indicator was apparently dormant for about 30 years, from 1920 through 1951.

It was not until the 1930 revision of the *Haynes Guides* that information about the Indicator disappeared from the text accompanying Beehive Geyser. Once the information was omitted, it did not reappear in editions published during the 1950s and 1960s, despite the fact that the Indicator rejuvenated during the 1952-1955 seasons.

Rejuvenation of Beehive From November 1951 through 1955

The first mention of Beehive's Indicator in Marler's *Annual Reports* appeared in the 1953 *Annual Report*. In the 1953 report Marler indicated "The function of the indicator was a more infallible sign of a consequent eruption of the Beehive than during the 1952 season." Although Marler did not mention the Indicator in his 1951 or 1952 reports, he reported he first observed an eruption of the Indicator on November 13, 1951 in his 1973 *Inventory of Thermal Features…*, and also provided additional information about activity of the Indicator during the winter of 1951 and the 1952 season.

Marler (1973) described the November 13, 1951 eruption:

> From the distance of Old Faithful this first observed function was very conspicuous and surprising. The water was jetting up about 3 feet. Previously I had observed nothing like it so close to Beehive. Being somewhat acquainted with the literature on the thermal springs I realized it must be

> the Indicator erupting. I hastened to the scene. After a 15 minute wait Beehive erupted.

Marler (1973) indicated the Indicator continued to act as a precursor for all observed eruptions of Beehive throughout the 1951 winter until June 1952. In June 1952 Marler observed the first eruption of the Indicator that was not followed by an eruption of Beehive. Marler noted his observation confirmed Wylie's discovery "some 70 years earlier" that the indicator "was not an infallible premonitory sign for Beehive."

Marler (1973) noted that beginning in June 1952 "the Indicator has sometimes functioned 2 to 3 times before Beehive erupted. At times even after a series of performances by the Indicator, Beehive has failed to come through. Also, during those seasons when the Indicator has been active Beehive is known to have erupted without precursory warning. From November 13, 1951 through 1955 the Indicator heralded most of Beehive's eruptions." Marler's observations are apparently the earliest observations of series of eruptions by the Indicator--some of which were followed by an eruption of Beehive, some of which were not.

Dormancy from 1956 through 1967

Marler (1973) stated the Indicator was dormant from 1956 through 1967. In his 1956 *Annual Report* he wrote "No activity of the indicator was noted prior to any of Beehive's eruptions. Why this indicator functions during some seasons or periods and is completely dormant during others is still without any adequate explanation." In his 1957 *Annual Report*, he indicated "It seems remarkable that this small geyser which is located about 10 feet from the Beehive's orifice will be completely dormant during some of Beehive's active cycles and function during others."

In his 1958 *Annual Report*, Marler surmised the dormancy was a result of human induced changes in behavior due to placement of a boardwalk near Beehive. He also described unsuccessful attempts to clean the Indicator's vent:

> For several reasons now there has been no activity in the Beehive's Indicator. There is a high degree of probability that its cessation of activity, which activity was premonitory of an eruption of the Beehive, resulted from its vent being filled with sand and gravel. When the boardwalk was laid near Beehive in 1953, it was put directly over the top of the oil-mat walk, the latter having been scarified and inadvertently not removed from Geyser Hill. This resulted in flooding water of erupting Giantess washing sand and gravel into Indicator's vent—completely filling it.
>
> During August an attempt was made to remove the debris from Indicator's Vent. The tortuous tube made it impossible to clean to a depth of more than two feet. Even had the tube been of a nature that would have permitted cleaning to a greater depth, all effort would have been frustrated by an eruption of Giantess during the night of September 22 when again great quantities of sand and gravel were strewn over the formation about the Beehive, some of which completely filled the portion of the vent that had been cleaned.

Reports of Activity of Beehive's Indicator from 1968 through 1988

The Indicator rejuvenated in 1968 and 1969, although "on a much reduced scale." Marler (1973) reported the activity was "feeble" and difficult to observe from a distance. In his 1968 *Report*, Marler indicated that when the Indicator rejuvenated, it was "active preceding most of the eruptions," but not all of Beehive's eruptions. Also, "on several occasions the indicator functioned without a followup *[sic]* eruption of Beehive."

This rejuvenation continued in 1969, when "some of Beehive's eruptions were preceded by the indicator; others were not." Also, the Indicator "performed a number of times without consequent eruption of Beehive." There was no mention of the Indicator in Marler's 1970 report, but in his 1971 report he said "The small indicator heralded all of Beehive's eruptions that were observed, however, the indicator is not infallible. Sometimes it will function without a consequent eruption of Beehive.

In his 1972 *Annual Report*, Hutchinson noted as the summer progressed, the Indicator became less reliable, with "1 false alarm in June (at the end of the month), 4 in July, and more than 6 in August."

These observations were recorded by Martinez in his monthly reports of June, July, and August geyser activity. Martinez' report of the independent eruption he observed on June 30th is the first usage of "false" for an eruption of the Indicator that was not followed by an eruption of Beehive that I have located. Martinez' report of July activity included more detail about the false indicators:

> The indictor gave false indications of an eruption of Beehive four times that I saw. These occurred on the 1st, 2nd, 10th and 11th. In each case Beehive would splash sometimes to 10 or 15 feet but after 30 to 50 minutes the indicator would stop and the splashing would subside for a few hours until the next eruption of the indicator which would then be followed by a normal eruption of Beehive.

In his report of August activity, Martinez stated:

> The indicator proved to be most unreliable this month. I observed six false indications and was informed of several more this month. The indicator seemed to erupt about 8 hours after Beehive's last eruption and if Beehive didn't erupt it would wait several hours more before erupting again. It was not unusual to have two false indications between eruptions of Beehive but the shortness of observation periods prohibited the determination of more consecutive eruptions of the indicator without Beehive. The false indications I observed occurred on the 3rd, 12th, 13th (two), 17th and 18th.

In his 1973 *Annual Report*, Hutchinson noted:

> Beehive's Indicator was very reliable during June, November, and December but became less so with more false alarms as the summer progressed. During early June the Indicator preceded Beehive's eruptions by 15-20 minutes to more than double that in some cases by September.

Martinez (1973) attributed at least some of the irregularity of the Indicator and Beehive to rainfall and ground water levels. In his June report Martinez noted:

> Beehive's Indicator during early June erupted 15 to 20 minutes before Beehive. As the month progressed it became longer until by the 26th it had increased to almost 40 minutes. On the 28th Beehive's Indicator gave its first reported false indication of the year. The indicator erupted for 37½ minutes and quit with a very large splash from Beehive. The dryness of the winter and spring and the unusually early start of irregularities seem to indicate some effect of local rainfall and ground water levels on beehive's activity.
>
> The discharge from Plume, as was the case last year, appears to have a smothering effect on Beehive's Indicator. The cooler water running down from Plume over the vents of the Indicator at times seemed to cause it to quit prematurely, delaying Beehive for another Indicator cycle and disappointing those waiting to see Beehive. It has been observed to do this several times in succession but there is not real evidence that it is anything but coincidence other than the extraordinary number of times the Indicator has been observed to quit soon after the overflow from Plume passes over its vents.

Martinez included one continuation time of 1m50s for Beehive's Indicator in his June 1974 report. In his August 1974 report he noted the Indicator erupted much more frequently than Beehive did.

> Beehive's Indicator was seen frequently but usually only as a solo. It erupted every few hours starting about 5½ hours after the last eruption of Beehive. After many of these solo eruptions, one leads into an eruption of Beehive.

Hutchinson (1975) noted that careful study of Beehive Geyser had been made "during each of the last four years." Hutchinson reported that Beehive was more regular during the winter and early spring months, with fewer false Indicators and a shorter average interval. However, "In the summer and early fall seasons just the reverse is true, so much so that [Beehive] is unpredictable and most people then are apt to ignore the Indicator."

Hutchison supported his conclusions by noting that there were no "false alarms" from the Indicator through May 17th. Then, "Starting on May 29th, it abruptly became unreliable as shown by the fact that there were at least as many, and in one month, as much as 84 percent more false alarms than recorded eruptions. This period of erratic performance covered mainly the months of June through October." Hutchinson cited two possible theories for this pattern of activity—(1) frozen soil in the areas around the Upper Geyser Basin prevents the influx of cooler, near-surface ground water into the reservoir; (2) a seasonal lag of several months for the amount of ground water of sufficient temperature and volume to be available from deeper in the reservoir convection system. He also noted that the average interval between Beehive Geyser's eruptions was shorter and the duration of the eruptions was longer in the winter and spring months. Hutchinson stated "none [of the theories] as of yet have the necessary data to support them." As far as I know, no evidence has as yet been presented supporting any theory that attempts to explain why false eruptions of the Indicator tend to occur during the summer months.

Hutchinson's 1975 *Annual Report* also included an analysis of the number and durations of Indicator eruptions. For the year 44 eruptions of the Indicator that preceded an eruption of Beehive had an average duration of 16 minutes. 136 false eruptions of the Indicator were observed during the year. The average duration of the 14 eruptions for which the duration was recorded was 45 minutes. (Hutchinson did not note whether the "duration" included both lead and continuation time.)

This pattern of frequent false eruptions of Beehive's Indicator during the summer months continued in 1976. In his August 1976 report, Martinez stated:

> False indications of Beehive occurred frequently during August. The indicator always heralded Beehive's eruptions, although at times the spouting from the indicator was reduced to boiling over the vent at the time of Beehive's eruption. One eruption of Beehive on the 6th during Giantess' activity was reported to be a solo without the customary eruption of the indicator beforehand. Although Marler does state this to be possible, it seems unlikely in view of the fact that the indicator is now much more active. However, Beehive is known to show sympathetic response to eruptions of the Giantess and an unusual eruption of Beehive at those times can be expected occasionally.
>
> Another unusual eruption of Beehive's indicator was reported by Marie Wolf, but instead of the regular fissur *[sic]* vent, a smaller hole nearer the cone was seen erupting. This is one of the most interesting observations made this month. The possibility of an alternate erupting vent near the Beehive has been considered previously due to the conflicting reports of the height of the Indicator. The spring presently known as the indicator has always appeared to deviate from the earlier descriptions, but since these are so vague in the more important aspects, they are of little use in confirming the existance *[sic]* of two distinct erupting vents near Beehive.
>
> The fissure vent indicator erupts about 2 to 2½ feet high from under a ledge of sinter in the old surface cover of geyserite. The vent angles back sharply underneath this ledge and enters a fissure openning *[sic]* directly into the deeper plumbing of the geyser. Early accounts of the Indicator give heights of 10 or 15 feet. To reach this height the water from the fissure vent would have to travel three times that distance horizontally due to the angle at which the vent enters the deposits. This being a most unlikely occurrence we have to consider the possibility that one of the other small opennings *[sic]* [near] Beehive's cone could be an indica-

Table 2: Summary of Beehive Indicator Eruption Parameters, 1976, 1977, 1980		
Duration	**Indicator**	**False Indicator**
1976		
Number of observations	36	14
Average	15m45s	38m00s
Standard Deviation	5.78 minutes	12.39 minutes
Minimum	10 minutes	24 minutes
Maximum	29 minutes	59 minutes
1977		
Number of observations	45	34
Average	12m36s	31m33s
Standard Deviation	7.31m	12.83m
Minimum	3 minutes	30 minutes
Maximum	14 minutes	66 minutes
1980		
Number of observations	73	11
Average	12m30s	42m16s
Minimum monthly average	9m20s (April)	35m00s (June)
Maximum monthly average	26m30s (July)	60m00s (August)

> tor, too. Opennings *[sic]* are located at various points around the cone and at varying distances. The most likely one would be the one nearest the present indicator and in a direct line with Beehive's cone. The one reported by Marie Wolf as erupting with some vigor was this small vent. It is a circular hole 2 inches or so in diameter with water visible, at times, pulsating a few inches below the top. A close watch of this vent the rest of the month produced no further reports of activity.

Marie Wolf's observation was the earliest known report of another vent around Beehive's cone acting as a "second" indicator.

In his 1976 *Annual Report*, Hutchinson reported that the 36 eruptions of the Indicator that were succeeded by an eruption of Beehive had an average duration of 15m45s. False indicators were observed on 121 occasions. Duration was recorded for 12 of these false indicators. The average duration of these 12 eruptions was 38m00s. As shown in Table 2, "Summary of Beehive Indicator Eruption Parameters, 1976," durations varied from a minimum of 10 minutes to a maximum of 29 minutes for eruptions succeeded by an eruption of Beehive Geyser, with a standard deviation of 5.78 minutes. For "False Indicators" the durations varied from a minimum of 24 minutes to a maximum of 29 minutes, with a standard deviation of 12.39 minutes. Again, Hutchinson did not note whether the duration included both lead and continuation time, although he noted "it can be expected that if the Indicator has been active for 30 minutes or more, the probability of an eruption from Beehive is extremely remote." This statement applies to the seasons of 1994, 1998, 1999, and 2010 when Beehive's Indicator also exhibited frequent false eruptions.

The pattern of activity did not change in 1977. Hutchinson reported "Beehive's Indicator had a perfect record of no false alarms in 1977 up until April 15….during the months of April through August the total of false alarms (108) almost equaled the number of eruptions recorded (107), yet in April taken separately, about five false indicators were recorded for every eruption of Beehive. This seasonal fluctuation must involve changes in shallow water levels or temperatures, or both, but no definite models have been developed as of yet." Although the average and minimum durations decreased, and the standard deviation and maximum durations increased, False Indicators continued to exhibit higher values for all parameters than did Indicators succeeded by eruptions of Beehive Geyser, so Hutchinson again concluded "if the duration of the Indicator is greater than 30 minutes, the probability of an eruption from Beehive is extremely remote."

In his *Geologic and Thermal Highlights of Yellowstone, 1979-1980* report, Hutchinson noted

> Surprisingly, there were no recorded false alarms from [Beehive's] indicator during the whole year [1979]—an accomplishment which has never happened before in recent years! The pattern of a reliable indicator continued until April 10, 1980. On April 2, 1980 Beehive's indicator vent was enlarged with a small portion of its sinter sheet roof-like deflector broken off—apparently due to weathering and the force of the water from below. Occasionally, since then, a narrow column of water has been observed from the Indicator vent to play as high as 2 ½ times the height of Beehive Geyser's cone.

In his 1980 *Report of Geothermal Activity*, Hutchinson noted frequent independent eruptions of the Indicator occurred during May (12), June (41), July (35), and August (17), while no false eruptions were recorded for September through December 1980. As shown in Table 2 *(page 29)*, statistics for durations of false indicators showed larger minimums, averages, and maximums than did durations of indicator eruptions that were succeeded by an eruption of Beehive.

I have not located any information for 1981. In his 1982 *Report of Geothermal Activity*, Hutchinson noted

> Only one single false indicator was recorded this year on July 28. It was in eruption at 1632 MDT when first seen; the next display of Beehive followed 2 hours 34 minutes later. At times as many as three indicator vents were active before Beehive's eruption. Maximum height was usually 1 to 3 meters.

Since Beehive "was a frequent performer this year," observers must have been delighted that the Indicator was reliable.

For the next few years, the Indicator was reliable. In his 1986-1987 *Thermal and Seismic Highlights* report, Hutchinson noted "Beehive's indicator had its first misfunction in years on January 8, 1987, according to a visitor report when it played for longer than an hour near noon without a follow-up eruption from Beehive."

According to Bryan (1987), Beehive itself was "entirely unpredictable" during the summer of 1987, even though the indicator was generally reliable. Bryan recorded 5 durations for Beehive's Indicator—10, 11, 8.5, 14, and 16 minutes.

Landis (1987) also included information about Beehive's Indicator in his report.

> Every eruption [of Beehive] that I observed was preceeded *[sic]* by an eruption of one, the other, or both indicators. I'm talking about the two vents directly N.E. of the main cone. The "main" indicator is about 10 feet N.E. of Beehive's cone, the second indicator is between the cone and the main indicator. I've referred to it as the "close-to-cone" (c-c) indicator. The main indicator preceeded *[sic]* all but one of the 10 eruptions I observed, and was always followed by an eruption of Beehive. The main indicator erupted to heights of 1 to 6 feet for an average of 10 minutes prior to Beehive's eruption; thus this indicator seems to have recovered from being clogged with debris from the non-excuseable *[sic]* boardwalk construction methods of the 1950's (Marler, 1973). Water was never visible in the main indicator prior to its eruption. Eruptions would suddenly appear as an overflowing, bubbling mess that built into an honest eruption (6 inches to 1 foot in height) within 60 seconds of the first visible water. The c-c indicator was not observed prior to early September. By late October, either both indicators

Beehive Geyser erupting with Close-to-Cone Indicator (center left) and Beehive's Indicator (center right) also in eruption. Photo by Tara Cross.

were always present or only the c-c indicator was present prior to Beehive's eruptions. The c-c indicator always erupted for a longer duration than the main indicator, prior to Beehive's eruption. Once the c-c erupted for an hour, followed by no eruption of Beehive. An eruption of the c-c indicator always began with just-visible 1 to 3 inch bubbling and minute waves of overflow. The wave size dependent *[sic]* on the bubble size. The small bubbling slowly developed into cyclical none-to-2 foot eruptions prior to Beehive's eruption.

Four other pools and vents were active prior to and during beehive's eruptions.

Landis mapped these vents, named them Valentine Pool, West Vent, West Pool, and Far West Vent, and provided detailed discussion of their patterns of activity.

Landis did not note any "false" eruptions of Beehive's (main) Indicator during 1987.

Although he noted there were two eruptions of Beehive that were not preceded by an eruption of Beehive's Indicator in 1988, Landis did not note any eruptions of the Indicator that were not succeeded by an eruption of Beehive. Landis described the activity of Beehive's indicators as follows:

> Two distinct modes of pre-eruptive activity presented themselves this year. Prior to mid-May, Beehive's intervals varied between one and three days. At this same time the second (close to cone or c-c) indicator accompanied the main indicator prior to beehive's eruptions. Activity by

> the c-c indicator also coincided with activity by four satellite vents near the main cone. Then about mid-May, there was a shift to one day intervals and away from activity by any of the satellite vents or the c-c indicator… .
>
> Over the course of the summer the main indicator played fairly consistently for an average of 12m30s prior to Beehive's eruption. Play by the main indicator included a sudden appearance of water, quickly followed by bubbling. Within 10 seconds of the first visible water, the indicator was bubbling/bursting at least 6-10 inches. The height of this play reached from typically 2-4 feet (the height of the main cone) to 10-15 feet on occasion. Play by the indicator was fairly steady prior to Beehive's eruptions….
>
> Around the end of august, Beehive's intervals suddenly jumped away from 1-2 day intervals to three or more day intervals. Activity by the c-c indicator and the four satellite vents also resumed at this time. Last year these vents and the c-c indicator were active all summer, and Beehive's intervals averaged 4 days. There is an apparent connection between activity by the c-c indicator and four vents, and longer intervals….
>
> The c-c indicator was observed to play 20-30 minutes before (and once 11 minutes after) the main indicator began to play. Eruptive heights were from 1-3 feet. Eruptions had the same form as the main indicator, but weaker and more bubbly. Both indicators quit at the same time (about 3 minutes into Beehive's eruption). This activity is the same as last year.

Landis recorded 38 Indicator "duration prior to Beehive Eruption," or lead times, in 1988. His observations varied from a minimum of 0 minutes (2 observations) to a maximum of 21 minutes (1 observation). The average lead time was 12m30s.

From 1989 through 2010, Beehive's Indicator was generally reliable, with the exception of the seasons of 1994, 1998, 1999, and 2010 when there were frequent eruptions of the Indicator that were not succeeded by eruptions of Beehive Geyser. Data about lead times exhibited by the Indicator was periodically reported in various issues of *The Geyser Gazer Sput* from 1989 through the mid-2000s. In 2009 Beehive Geyser erupted once and sometimes twice daily, providing an unprecedented opportunity to collect data on characteristics of eruptions by Beehive's Indicator. Analysis of this data is presented in the next section.

ACTIVITY OF BEEHIVE GEYSER DURING THE SUMMER OF 2009

During the summer of 2009, I collected data on eruptive characteristics of Beehive's Indicator and durations of Beehive Geyser. My data collection efforts were supplemented by utilization of data about start times for Beehive's Indicator and Beehive Geyser recorded by other observers in the logbook maintained at the Old Faithful Visitor Center.

"Reliability" of Beehive's Indicator

In 2009 all known eruptions of Beehive's Indicator were succeeded by an eruption of Beehive itself. There were only five known eruptions of Beehive that were not preceded by an eruption of Beehive's Indicator.

Time between Start of Beehive's Indicator and Start of Beehive (Lead Time)

Data from the OFVC logbook provided 192 lead times for Beehive's Indicator from January 1 through October 12, 2009.[1]

The 192 lead times varied from a minimum of 0 minutes to a maximum of 31 minutes with a mean of 13.3 minutes, a median of 14 minutes, and a standard deviation of 4.5 minutes. The distribution of lead times is shown in Figure 1 "Distribution of Beehive Indicator's Lead Times." "Most" (86%) of the lead times were from 8 to 18 minutes, frequently enabling people who heard the start of the Indicator called over the radio to position themselves for a good view of Beehive's eruption, even if they were in the north end of the Upper Geyser Basin when the radio call was made announcing that the Indicator had started erupting.

1 Beehive Indicator times recorded "ns" were used in the calculations as exact starts. Beehive Indicator times recorded "ie" were not included in this data analysis.

Figure 1: Distribution of Beehive Indicator's Lead Times

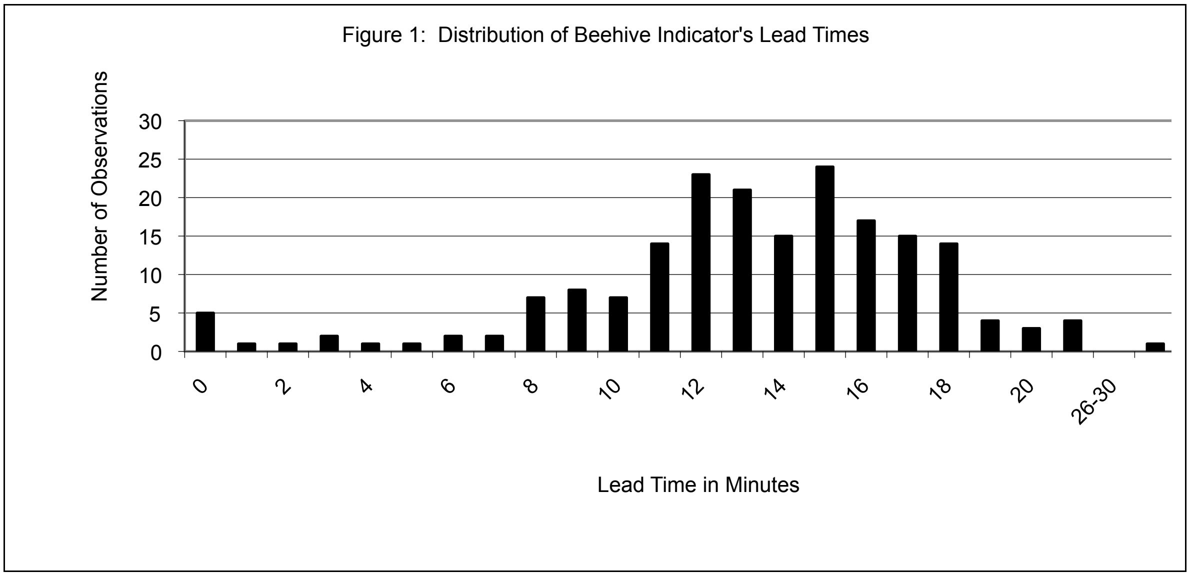

Table 3: Descriptive Statistics, Beehive's Indicator Lead Time, Continuation Time, and Total Duration, 2009

Statistic	Lead Time Between Start of Beehive's Indicator and Start of Beehive's Eruption	Length of Time the Indicator Continued After the Start of Beehive's Eruption	Total Duration of Beehive's Indicator
Count	192	24	17
Mean	13m37s	2m55s	16m30s
Median	13m17s	2m56s	16m16s
Minimum	8m13s	2m36s	11m14s
Maximum	17m29s	3m20s	20m26s
Standard Deviation	2m44s	11s	2m47s

The mean lead time of 13.3 minutes is comparable to the 12m30s average lead time reported by Landis in 1988. It is also comparable to Hutchinson's "duration" of 15m45s reported for 1976, 12m36s reported for 1977, and 12m30s reported for 1980.

Total Duration of Beehive's Indicator

It is my experience that when people say "The Indicator lasted, for example, "13 minutes," the activity measured is actually the lead time between the start of Beehive's Indicator and the start of Beehive's eruption itself.

During the summer of 2009, I recorded start and stop times for the Indicator to the nearest second when I was present on Geyser Hill or at the overlook across the Firehole River from Beehive to collect such data. Descriptive statistics for those observations are shown in Table 3, "Descriptive Statistics, Beehive's Indicator Lead Time, Continuation Time, and Total Duration, 2009."

The mean lead time of 13m37s calculated for the 18 durations where both the start of the Indicator and the start of Beehive's eruption were recorded to the nearest second is comparable to the 13.3 minute mean for the 192 lead times where both the start of the Indicator and the start of Beehive were recorded to the nearest minute. The median lead time of 13m17s calculated using start times recorded to the nearest second, is shorter than the median of 14 minutes calculated for the 192 lead times where start times were recorded to the nearest second.

Beehive's Indicator continued erupting for an average (both mean and median) of about 3 minutes after the start of Beehive, with a standard deviation of 11 seconds. Continuation time varied from a minimum of 2m26s to a maximum of 3m20s. The range of nearly 1 minute is almost 40% of the minimum continuation time. Haupt (1883) had stated the Indicator continued throughout Beehive's eruption. Martinez (1974) reported one continuation time of 1m50s. Landis (1988) reported a continuation time of about 3 minutes. With so few comparative historical observations, any conclusions about whether the continuation time has changed over the years would be at best tentative. However, it appears that continuation time has not changed substantially over the last 20 years.

In 2009, the total duration of Beehive's Indicator had a mean of 16½ minutes and a median of 16¼ minutes, with a standard deviation of 2¾ minutes.

I started collecting data about the total duration of Beehive's Indicator in an attempt to statistically evaluate the hypothesis that the total duration was independent of the lead time. In other words, I wanted to test the hypothesis that the Indicator's continuation time after the start of Beehive was about constant, regardless of whether the Indicator preceded Beehive by a short or long time. Lead time and continuation time for 15 observations where both lead time and continuation beyond the start of Beehive were recorded to the nearest second were collected in 2009. Regression statistics indicated that only 20% (adjusted R^2= .2017) of the variance in the continuation time could be explained by the lead time, when the intercept was not set to zero, although the regression formula (Equation 1):

$$Y(c) = 3m21s - .0318\ x(l) \qquad (1)$$

Where c = continuation time
l = lead time

was statistically significant at the 0.05289 level (F = 4.536478, df = 1, 13). In other words, a longer lead time produced a slightly decreased continuation time. This implies that the total energy available to produce an eruption of Beehive's Indicator is relatively constant. Longer lead time resulted in shorter continuation time and shorter lead time resulted in longer continuation time. The more energy used in the first part of the duration, the less energy there was available for the second piece of the duration. Further exploration of the relationship between lead time and continuation time of Beehive's Indicator as more longitudinal data is collected is a potential research project.

Beehive Geyser's Duration

Another potential avenue of exploration is examination of the relationship, if any, between the components of the Indicator's duration and duration of Beehive's eruption itself.

I collected data, to the nearest second, for duration of the water phase of Beehive's eruption for 13 eruptions of Beehive during the summer of 2009. Descriptive statistics for duration of Beehive's water phase for 1975 (Hutchinson) and 2009 are shown in Table 4, "Descriptive Statistics for Durations of Beehive's Eruptions, 1975 and 2009." Hutchinson

Table 4: Descriptive Statistics for Durations of Beehive's Eruptions, 1975 and 2009

Statistic	2009 Water Phase	1975 Water Phase	1975 Steam Phase
Count	13	59	28
Minimum	4m25s		
Maximum	5m14s		
Mean	4m52s	5m01s	2m23s
Median	4m57s		
Standard Deviation	15 seconds		

Table 5: Descriptive Statistics for 10 Cases of Concurrent Eruptions of Beehive's Indicator and Beehive Geyser				
	Beehive's Indicator			**Beehive Geyser**
	Lead Time	**Continuation Time**	**Total Duration**	**Duration**
Minimum	8m13s	2m45s	11m14s	4m42s
Mean	13m11s	2m58s	16m09s	4m57s
Median	14m03s	2m59s	16m58s	4m58s
Maximum	17m14s	3m10s	20m16s	5m14s
Range	9m01s	25s	9m02s	32s
Standard Deviation	3m04s	07s	3m00s	10s

also reported durations for Beehive's "steam phase" in 1975. Data on that aspect of Beehive's eruption was not collected in 2009.

In 2009 I recorded the end of Beehive's "water phase" as the time when a "solid stream" of water could not longer be seen. Hutchinson did not provide information about how the either the end of the water phase/beginning of the steam phase or end of the steam phase were determined. Another potential future research project is for someone to develop a definition for establishing the end of the steam phase and to collect information on durations of both the water and steam phases for comparative purposes.

Data to the nearest second was collected on lead time for the Indicator, continuation time for the Indicator, and duration of Beehive for 10 eruptions in 2009. Descriptive data for these 10 cases is shown in Table 5, "Descriptive Statistics for Concurrent Durations of Beehive's Indicator and Beehive Geyser."

Regression analysis using the Indicator's lead time as the independent variable and Beehive's duration as the dependent variable resulted in the following regression equation (Equation 2):

$$Y(d) = 5m27s - .037\ x(l) \qquad (2)$$

Where d = Beehive's duration
l = lead time

The regression formula was statistically significant at the 0.03 level of significance (F=6.856, df=1,8). The regression formula did support the hypothesis that a longer lead time exhibited by the Indicator resulted in a shorter duration of Beehive's eruption. The more energy used by the Indicator during its eruption before Beehive started, the less energy there was for Beehive's eruption. However, the adjusted R^2 of .394 indicated that the lead time explained only 39% of the variance in the duration of Beehive's eruption.

Analysis of the relationship between the Indicator's continuation time and Beehive's duration yielded a regression equation (Equation 3) of:

$$Y(d) = 1m38s + 1.21\ x(I) \qquad (3)$$

Where d = Beehive's duration
I = Indicator's continuation time

The regression formula was statistically significant at the .005 level of significance (F=14.74, df=1,8). The regression formula supports the hypothesis that duration of an eruption of Beehive is positively correlated with the length of time the Indicator continues after the start of Beehive's eruption. The longer continuation time results from less energy being released from the system during the Indicator's lead time. A shorter lead time means less energy was released, thus more energy is available for the both continuation of the Indicator and Beehive's eruption. Conversely, a longer lead time means more energy was released from the entire system, resulting in both a shorter continuation time and a shorter duration of Beehive's eruption. The adjusted R^2 of .604 indicates that 60% of the variance in the duration of an eruption of Beehive Geyser can be explained by the continuation time of the Indicator.

CONCLUSION

This paper reports descriptive statistics for Beehive's Indicator and durations of Beehive Geyser during the summer of 2009, a season during which eruptions of the Indicator were followed by eruptions of Beehive. Analysis of the data supports the hypothesis that the energy needs of the Indicator and Beehive are interrelated, with longer Indicator lead times resulting in shorter continuation times of the Indictor and shorter durations of Beehive's eruptions. Future research projects could include comparison of Beehive Geyser's durations for eruptions that are not preceded by activity of the Indicator with durations of Beehive Geyser's eruptions that are preceded by activity of the Indicator.

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The Behavior of the Grand Group During the Summer of 2009

Vicki Whitledge, Ralph Taylor, Trevor Hammann, Wai Ling Ho

Abstract

During the summer of 2009, extra data loggers were placed in the Grand Group. These loggers recorded the activity of Turban Geyser and Grand's pool. Loggers were also in place on Grand Geyser, West Triplet Geyser, and Rift Geyser. This paper analyzes the data obtained from these five loggers and discusses some of the relationships between these features. The results of this study are compared with a similar study done during the summers of 2005 and 2006, with emphasis on the data acquired in 2006.

Introduction

Grand Geyser and Turban Geyser have a clear relationship in that Grand begins erupting only at about the time that Turban is due to erupt (Bryan 1995). At times, activity by West Triplet and/or Rift has been noted to affect the length of Grand's intervals and at other times has seemed to have little effect (Strasser 1989, 2000; Bryan 1993). In part, the effect seems to depend on when West Triplet and Rift erupt during Grand's interval (Whitledge 2005, 2006; Bryan 1989). In 2005 and 2006, a study was undertaken to take a more detailed look at the interactions of the four geysers (Grand, Turban, West Triplet and Rift) and Grand's pool (Whitledge 2008). During 2005 and 2006, Grand Geyser was a regular performer with median intervals of 7h15m and 7h31m respectively. In 2009, the study was repeated. During 2009, Grand Geyser was less frequent with a median interval of 8h59m and the interval lengths were more variable. We discuss the relationships between the eruptive patterns of West Triplet and Rift Geysers and eruptions of Turban and Grand Geysers in 2009 and make comparisons with the eruptive patterns of these geysers in 2006.

Grand Geyser erupting on July 20, 2011. Photo by Jere Bush.

Methods

This study was conducted from July 7, 2009 to September 28, 2009 (length of study in 2009 was 83 days, 30 minutes). The data were collected using data loggers (Taylor 2000). Data from West Triplet and Rift Geysers were used from their data loggers at their year-round locations. Data from Grand Geyser were collected from a data logger located in the south run-off channel between the benches and Rift's runoff channel. Data from Turban Geyser were collected from a data logger in the run-off channel to the north of Turban. Data from Grand's pool were collected from a channel towards the back of Grand's pool (as seen from the benches) on the south side. These logger locations were the same for the 2005/2006 study. The data from Grand's pool represent the periodic overflow from the pool rather than an eruption.

Due to logger malfunction, electronic data for Grand Geyser were lost from August 17, 2009 to August 24, 2009. During this period, visual times re-

	Grand		West Triplet		Rift	
	2006	2009	2006	2009	2006	2009
Minimum	6:03	6:13	1:25	1:45	2:32	7:42
5th Percentile	6:27	6:55	2:08	3:01	5:15	13:31
1st Quartile	6:52	8:18	4:13	5:01	9:08	16:16
Median	7:31	8:59	5:42	7:45	11:38	18:15
3rd Quartile	8:35	9:57	7:15	9:50	13:51	20:09
95th Percentile	9:56	11:11	8:59	12:31	15:56	24:29
Maximum	11:18	12:40	11:45	14:54	20:25	26:33
90% Range	3:29	4:16	6:50	9:29	10:41	10:57
Range	5:15	6:27	10:20	13:12	17:53	18:51
Count	254	218	350	248	173	110

Table 1: Basic Statistics on Intervals for Grand, West Triplet, and Rift Geysers.

corded in the Old Faithful Visitor Center Logbook were used for this study. Visual times were obtained for all eruptions during this time except for one eruption that occurred at approximately 05:30 on August 20. This approximate time was inferred from data for Turban Geyser. This approximated eruption time was not used for this study. Due to logger malfunction, electronic data for West Triplet Geyser were also lost from July 8, 2009 to July 14, 2009. All other data sets are complete for the study period.

As in the previous study (Whitledge 2008), we will say that Grand's pool is "filled" when the back channel experiences flow and the first time that this occurs after an eruption of Grand is denoted "First Fill".

Eruption times/overflow times were extracted by computer from the raw temperature data (Taylor 2000). The times between consecutive eruptions or flows were computed. Traditionally, times between the start of two consecutive eruptions of the same geyser are called intervals. In this paper, we use this terminology but also refer to the time between the start of two consecutive flows out of Grand's pool as intervals. Furthermore, when we talk about an eruption and *its* interval, this refers to an eruption and the interval which *preceded* the eruption.

Results and Discussion

The results are grouped and presented based on the type of information being evaluated. We start with the basic statistics on the intervals of the features in the study. Next, we discuss the timing between eruptions of Grand and First Fill of Grand's pool. Lastly, we discuss the timings of eruptions in the Grand Group based on the number of Turbans between First Fill and an eruption. Throughout, we compare the behavior observed in 2009 with the behavior observed in 2006.

Basic Statistics of Intervals

Table 1 contains basic statistics for intervals of Grand, West Triplet, and Rift Geysers for the study period in 2009 and 2006 for comparison. The 5th and 95th percentiles are given in all the tables of statistics because the middle 90% of the data is contained between these two points. The *90% Range* given in the table is the length of time between the 5th and 95th percentiles. This statistic is a measure of variability and is included because the interpretive rangers at the Old Faithful Visitor Center try to predict geyser eruption times with at least 90% accuracy. The 90% Range may be considered the smallest possible window that they could have used to make predictions and achieve their desired accuracy.

The study period of 83 days, 30 minutes in 2009 was slightly longer than the study periods in both 2005 (79 days, 12 hours, 48 minutes) and 2006 (82 days, 15 hours, 16 minutes). Since the length of the study of 2006 was close to the length of the study of 2009, we use 2006 as the comparison year to 2009 when discussing our results.

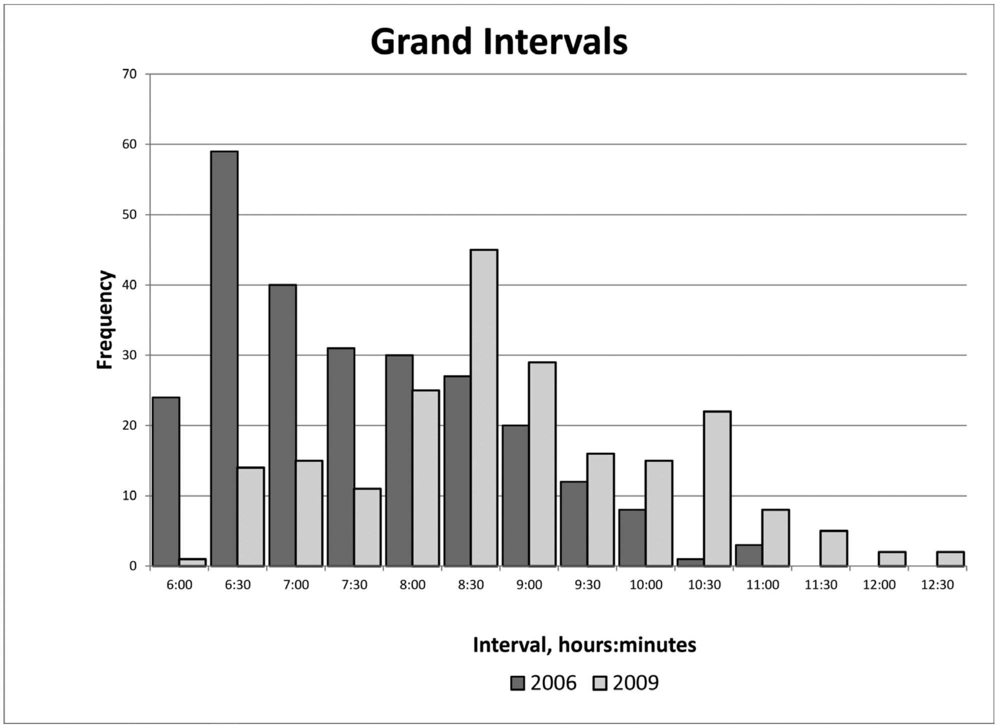

Figure 1: *Distribution of Grand Intervals in Summer 2006 and 2009.*

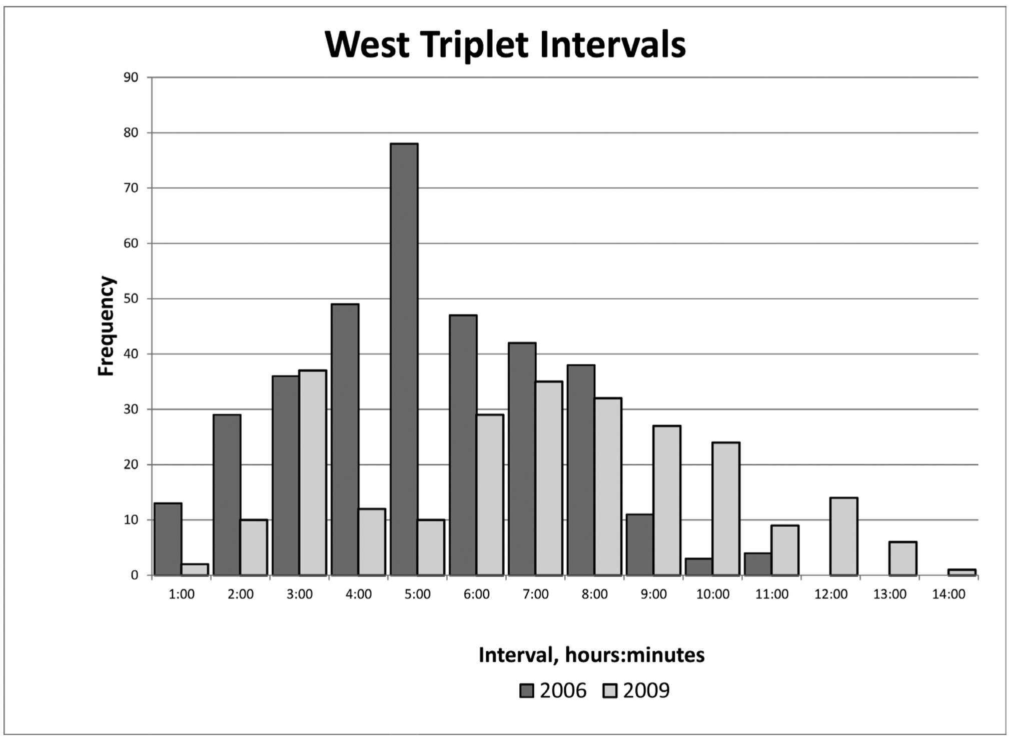

Figure 2: *Distribution of West Triplet Intervals in Summer 2006 and 2009.*

As can be seen in Table 1 *(page 39)*, Grand, West Triplet and Rift Geysers all had longer intervals in 2009 than in 2006. This was most pronounced for Rift Geyser. The increase in interval length resulted in fewer eruptions for each of the three geysers during the 2009 study than in the 2006 study. In addition, the intervals in 2009 displayed more variability than in 2006 for the three geysers as indicated by the larger values for the 90% range.

The distributions of interval lengths for Grand in 2006 and 2009 are shown in Figure 1. Grand's distribution was distinctly right-skewed in 2006 while in 2009 the distribution was more symmetric. In 2006, the distribution had a main peak from 6½ to 7 hours (390 minutes to 420 minutes). In 2009, the main peak of the distribution was later and occurred between 8½ to 9 hours (510 to 540 minutes).

West Triplet (see Figure 2) appears roughly

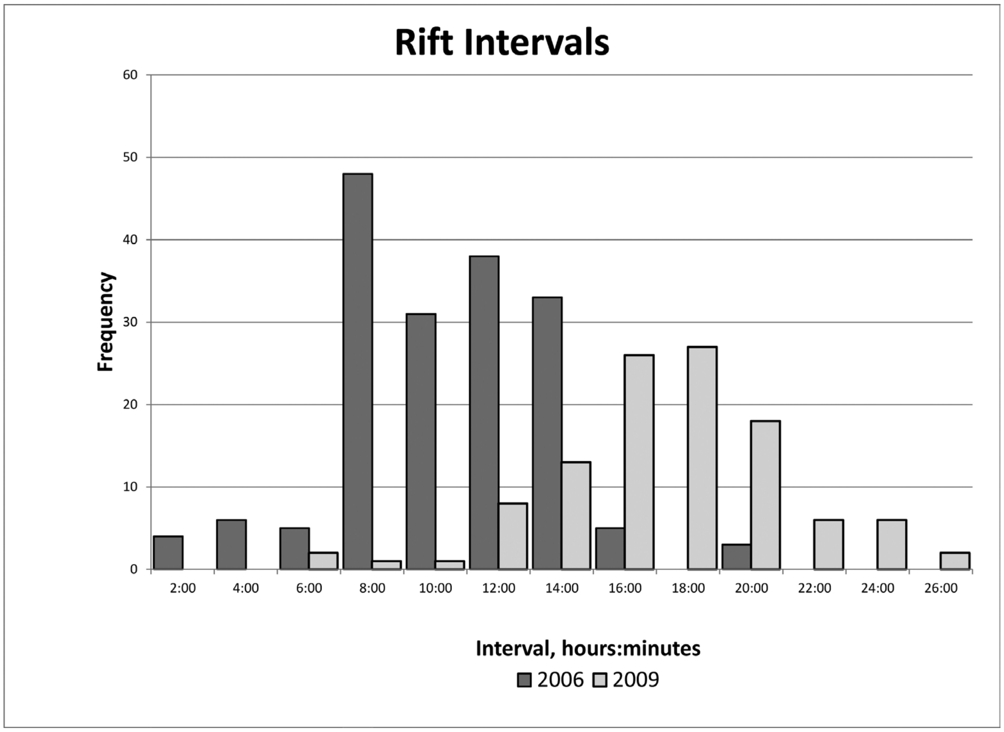

Figure 3: Distribution of Rift Intervals in Summer 2006 and 2009.

symmetric and unimodal in 2006, with a distinct, pronounced peak between 5 to 6 hours (300 to 360 minutes). In 2009, the distribution appears bimodal with a narrow peak from 3 to 4 hours (180 to 240 minutes) and a broader peak from 6 to 11 hours (360 to 660 minutes). In 2006, Rift (see Figure 3) had a strong peak between 8 to 10 hours (480 to 600 minutes) with large number of eruptions up through 16 hours (960 minutes). In 2009, the distribution of intervals was much more bell-shaped with the center of the peak occurring between 16 to 20 hours (960 to 1200 minutes).

Table 2 contains basic statistics of intervals of Turban Geyser and Grand's pool. The Turban Geyser and Grand's pool intervals summarized in this table are the ordinary ones that occur approximately every twenty minutes. The long intervals that occur due to an eruption of Grand Geyser are not included in the table. Turban eruptions that occur with Vent are not discussed in this paper and the event of First Fill is discussed later. The basic statistics of both Turban Geyser and Grand's pool presented in Table 2 are similar for 2006 and 2009. With the exception of the minimum and maximum intervals, which by their nature are highly variable, the statistics in 2009 were within 1 or 2 minutes of their corresponding 2006 values.

The number of Turban intervals was similar between 2006 and 2009 (3702 versus 3703), but the number of pool overflows was larger in 2009 (2535 versus 2940). Presumably this reflects the increase in the length of Grand's intervals, allowing more overflows of Grand's pool before Grand eruptions. The distributions of intervals of both Turban Geyser and Grand's pool were bimodal as shown in Figures 4 through 7. For both Turban Geyser in 2006 and Grand's pool in 2006 and 2009, the first peak occurred at 19 minutes and the second peak occurred at 23 minutes. For Turban Geyser in 2009, the first peak occurred at 19 minutes, but the second peak

	Turban		**Pool**	
	2006	**2009**	**2006**	**2009**
Minimum	0:06	0:14	0:09	0:13
5th Percentile	0:17	0:17	0:17	0:17
1st Quartile	0:19	0:19	0:19	0:19
Median	0:21	0:20	0:22	0:20
3rd Quartile	0:23	0:22	0:24	0:23
95th Percentile	0:24	0:26	0:25	0:25
Maximum	0:46	0:47	0:44	0:44
90% Range	0:07	0:09	0:08	0:08
Range	0:40	0:33	0:35	0:31
Count	3702	3703	2535	2940

Table 2: Basic Statistics on Intervals for Turban Geyser and Grand's Pool

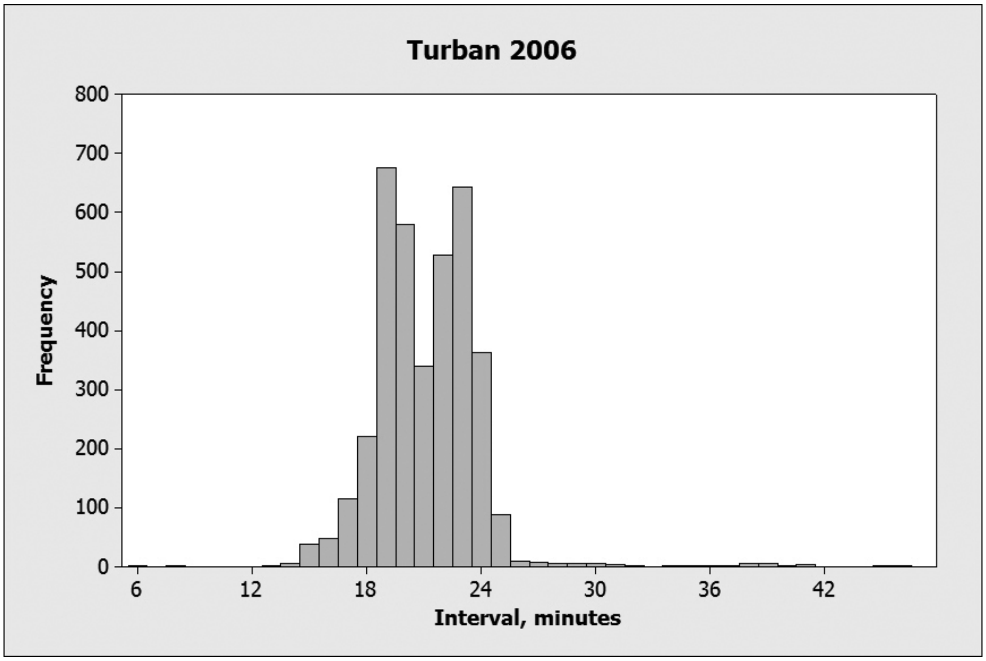

Figure 4: Distribution of Turban Intervals in Summer, 2006.

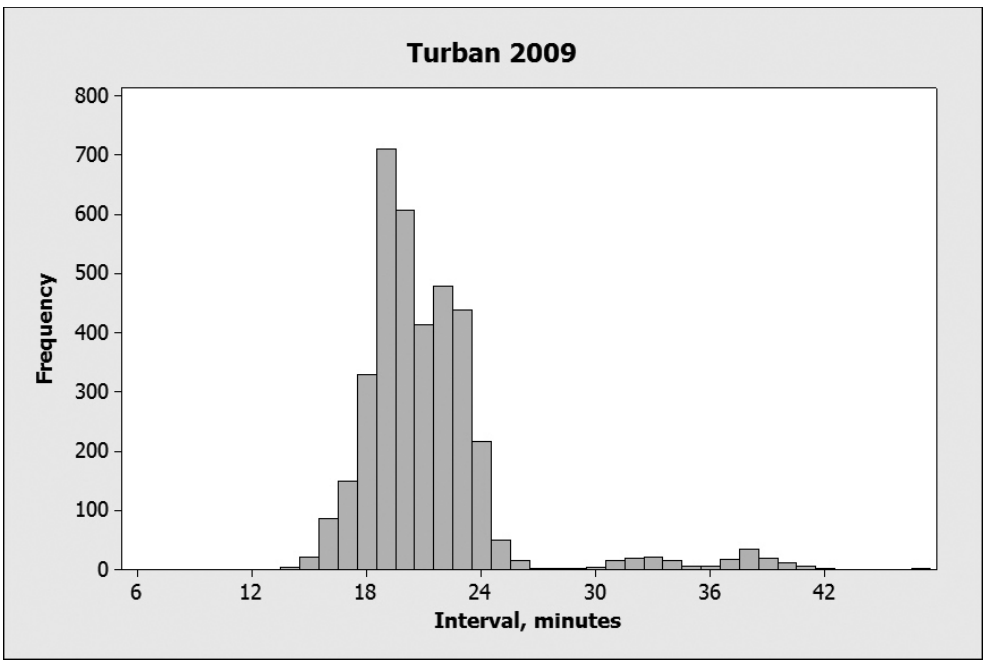

Figure 5: Distribution of Turban Intervals in Summer, 2009.

occurred at 22 minutes. In 2009, the height of the second peak was lower than in 2006 for both Turban Geyser and Grand's pool. For Grand's pool the first peak was higher in 2009 but for Turban Geyser the first peak was approximately the same as in 2006. In 2009, there were more intervals for both Grand's pool and Turban Geyser that were more than 30 minutes in length.

Time Relationships: Grand Geyser and Grand's Pool

While the basic statistics are informative, of more interest are the relationships between the features. When relationships between features are examined using electronic data, the logger delay time must be considered. The logger delay time is the time between the start of an event (eruption or fill) and the first time the event appears in the data logger record. Logger delay times were discussed by Whitledge (2008). In all comparisons between

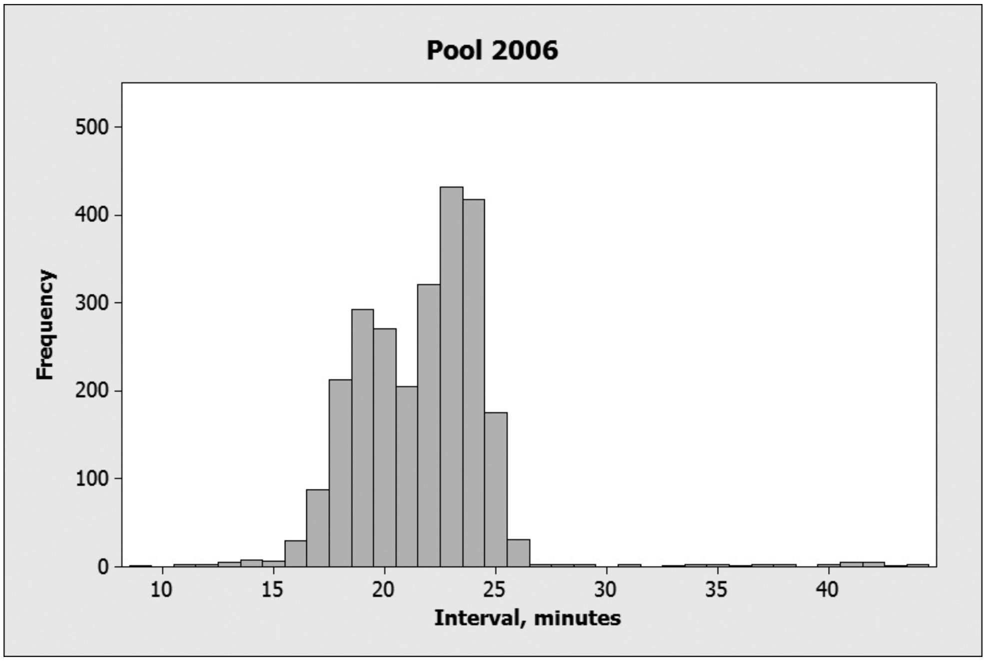

Figure 6: *Distribution of Grand's Pool Intervals in Summer, 2006.*

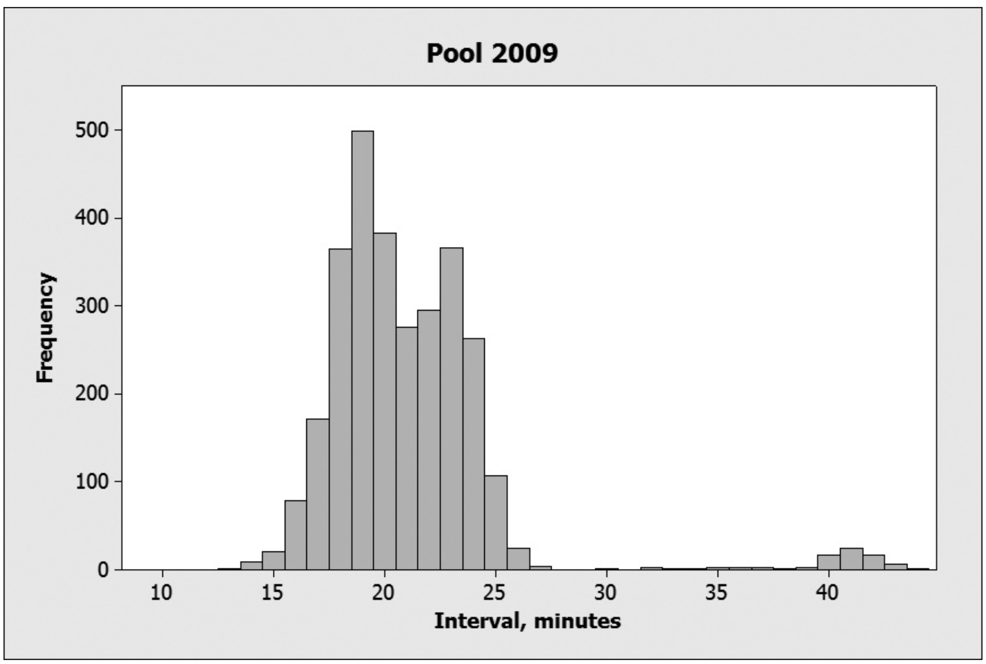

Figure 7: *Distribution of Grand's Pool Intervals in Summer, 2009.*

Grand Geyser and Grand's Pool the errors due to logger delay times are less than five minutes.

Table 3 *(page 44)* shows the time relationship between the First Fill of Grand's pool and the Grand eruptions that bracket it. The time between an eruption of Grand and the subsequent First Fill of Grand's pool had little variability relative to the time from First Fill to the next Grand eruption. Both times were greater in 2009 than in 2006, but the increase in the time from a Grand eruption to the subsequent First Fill was rather modest. The 90% range for this time for 2009 was 4h00m to 4h35m versus 3h48m to 4h15m for 2006, an increase of 10 to 20 minutes in terms of length and only an 8 minute increase in variability. The difference between 2006 and 2009 was more pronounced for the time from First Fill to the subsequent Grand eruption, both in terms of increase in time and in variability. In 2009, the 90% range was 2h49m to 6h57m (with a difference of 4 hours, 7 minutes) versus 2h30m to 5h56m (a difference 3 hours, 26 minutes). The upper end of the 90% range increased approximately an hour and the range itself increased by about 50 minutes.

	Grand to 1st Fill		1st Fill to Next Grand	
	2006	**2009**	**2006**	**2009**
Minimum	3:34	3:52	2:15	2:02
5th Percentile	3:48	4:00	2:30	2:49
1st Quartile	3:54	4:06	2:52	4:06
Median	3:58	4:11	3:32	4:45
3rd Quartile	4:03	4:17	4:31	5:38
95th Percentile	4:15	4:35	5:56	6:57
Maximum	4:33	4:56	7:19	8:32
90% Range	0:27	0:35	3:26	4:07
Range	0:59	1:04	5:04	6:30
Count	254	218	254	218

Table 3: Relationship between Grand and First Fill

Number of Turbans between First Fill and Eruptions in the Grand Group

The preceding relationships between Grand and Grand's pool were described in terms of time, but we can also use Turban as a counter to evaluate relationships in the Grand Group. As in our previous paper (Whitledge 2008), we will examine eruptions of Grand, West Triplet and Rift Geysers by the number of Turban eruptions from First Fill. As discussed previously (Whitledge 2008), logger delay times are not a concern when counting the number of Turbans between First Fill and subsequent eruptions of Grand or Rift Geysers. Logger delays are a concern when counting the number of Turbans between First Fill and eruptions of West Triplet. These counts may be off by one Turban eruption as the logger delays are long enough that a West Triplet eruption may be counted as having started after a Turban eruption when it actually started before. Therefore, the counts relating Turban and West Triplet should be regarded with some caution in detail but should still be grossly correct in its general pattern.

Figures 8 and 9 display the number of Turbans after First Fill until Grand's start for 2006 and 2009 respectively. The counts include the Turban with which Grand began even if Grand started before Turban. As in 2005 and 2006, Grand never erupted before the sixth Turban after First Fill and then only rarely on the sixth Turban with only 5 instances in 2006 and a single instance in 2009. In 2006, the most common timing for a Grand eruption was on the seventh or eighth Turbans after First Fill. This accounted for approximately 34% of the Grand eruptions in summer of 2006. In 2009, the most common timing for a Grand eruption was on the thirteen through fifteenth Turban eruptions, nearly double the most common number of Turbans in 2006. This timing accounted for nearly 35% of the Grand eruptions in summer of 2009.

Figures 10 and 11 *(page 46)* display the number of Turban eruptions after First Fill until West Triplet's start for 2006 and 2009 respectively. Since Turban and West Triplet do not necessarily erupt concurrently in the way that Turban and Grand do, the values are strictly the number of Turban starts after First Fill and *before* West Triplet starts erupting. Figures 10 and 11 contain only those eruptions of West Triplet that started between the first detected Turban and the subsequent eruption of Grand. The histograms do not contain any West Triplet eruptions that began after Grand's start but before the first detected Turban eruption. Negative numbers indicate that West Triplet erupted before First Fill. It is interesting to note that even though the overall number of West Triplet eruptions was much lower during the study in 2009 than in 2006, the number of eruptions that occurred between the first detected Turban eruption and the subsequent eruption of Grand were approximately the same with 168 eruptions in 2006 and 163 in 2009.

In 2006, the most common timing for a West Triplet start was after the fourth Turban after First Fill (24% of eruptions displayed). West Triplet starts after the fifth or sixth Turban were also common, with a total of 59% of eruptions displayed occurring after the 4th, 5th or 6th Turban. This timing placed

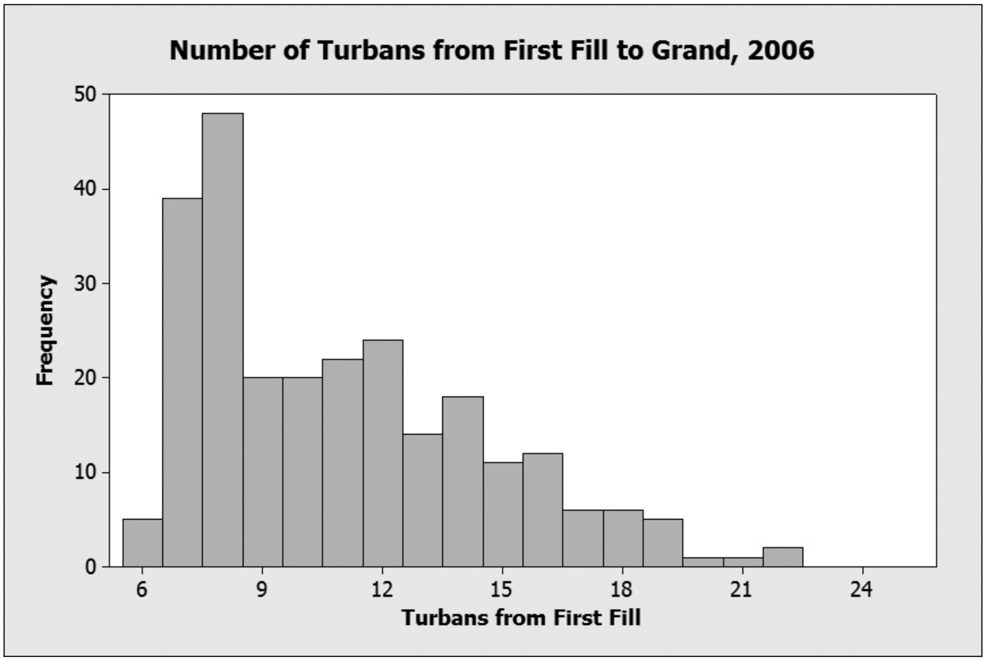

Figure 8: Timing of Grand Starts relative to the number of Turbans since First Fill, 2006.

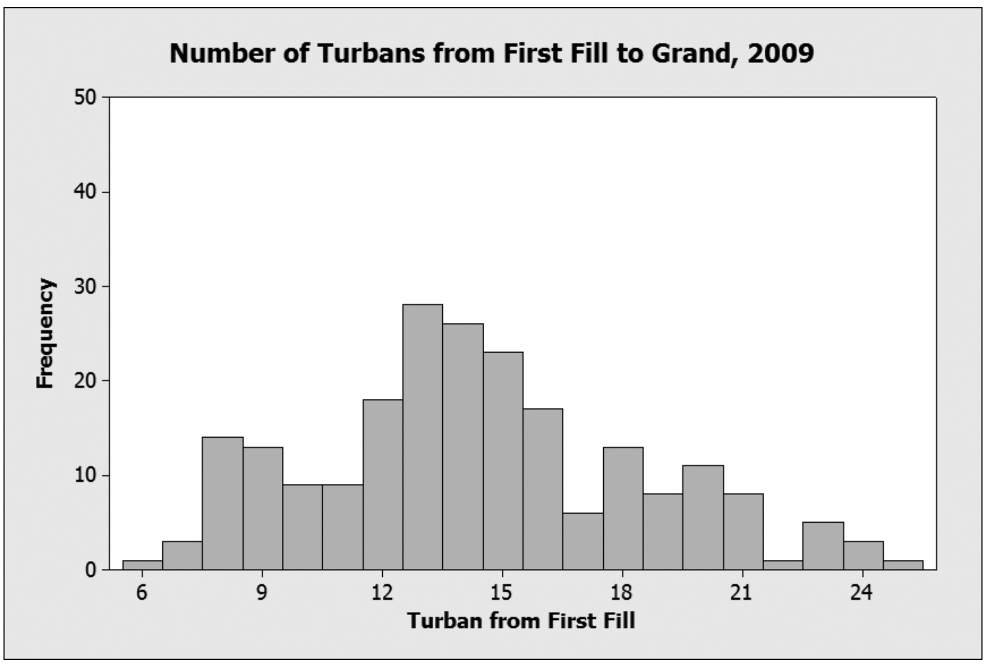

Figure 9: Timing of Grand Starts relative to the number of Turbans since First Fill, 2009.

West Triplet starts most often one or two Turban eruptions before the most common timing of Grand starts. In 2009, the timing of West Triplet relative to the number of Turbans from First Fill was later than in 2006 and more variable. The most common timings occurred after the seventh and eighth Turbans after First Fill but these represented only 23% of the eruptions displayed.

Figures 12 and 13 *(page 47)* display the number of Turban eruptions after First Fill until Rift's start for 2006 and 2009, respectively. Since Turban and Rift do not necessarily erupt concurrently in the way that Turban and Grand do, these are strictly the number of Turban starts after First Fill and *before* Rift starts erupting. The figures contain only those eruptions that started between the first detected Turban and the subsequent eruption of Grand. The histograms do not contain any Rift eruptions that began after Grand's start but before the first detected Turban eruption. Unlike West Triplet, the number of Rift eruptions that fell into this category in 2009 was much smaller than in 2006 with 59 eruptions in 2009 and 90 in 2006.

In 2006, the most common timing of Rift starts was after 5th to 6th Turban eruptions after First Fill with 44% of the displayed eruptions occurring

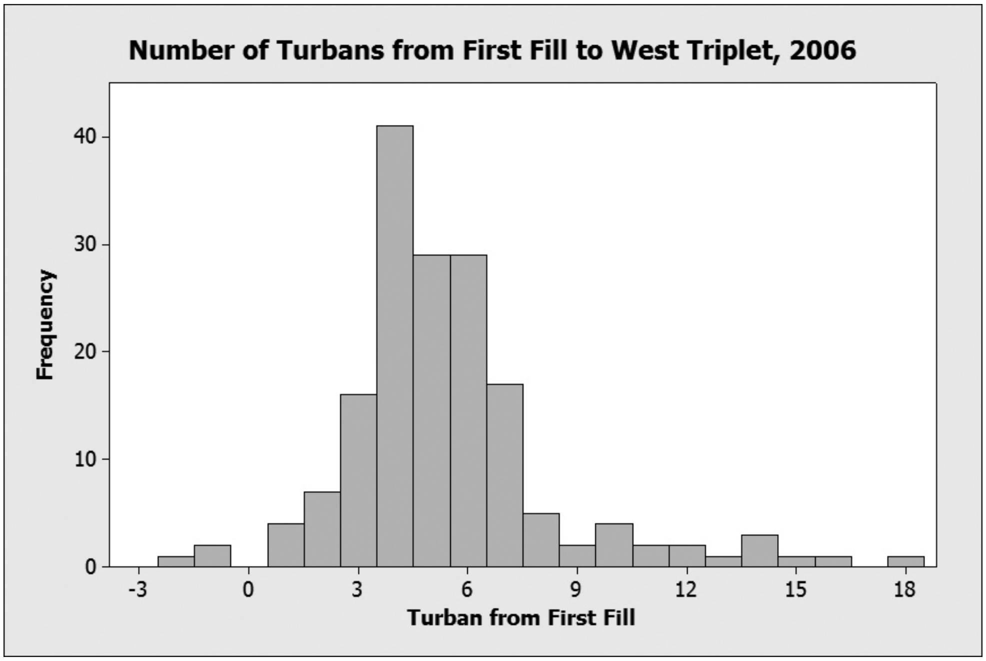

Figure 10: *Timing of West Triplet Starts relative to the number of Turbans since First Fill, 2006.*

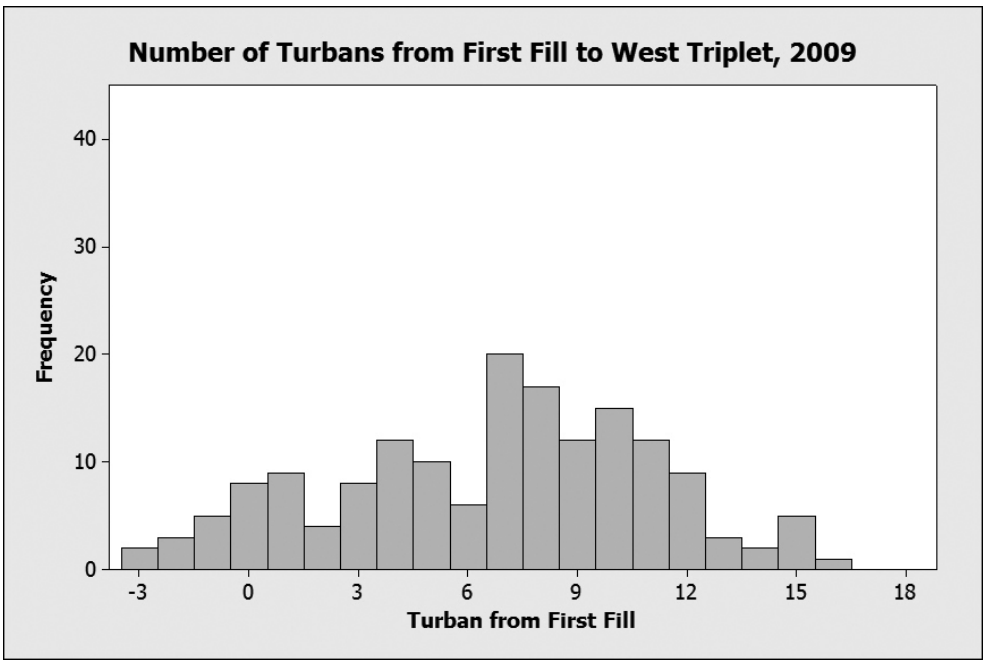

Figure 11: *Timing of West Triplet Starts relative to the number of Turbans since First Fill, 2009.*

at those times. The distribution in 2009 was much more spread out compared to 2006. The two most common timings of Rift in 2009 were after 5th and 9th Turban eruptions after First Fill but these times only had 11% and 12% of Rifts starts respectively.

Conclusions

It appears that whatever factors influence Grand Geyser to produce longer and more variable intervals between eruptions also affect West Triplet and Rift Geysers' pattern of eruption. These three geysers all had longer and more variable intervals in 2009 than in 2006 whether the interval length or the number of Turbans from First Fill was considered, although the time from an eruption of Grand Geyser to First Fill remained the same.

If activity by West Triplet or Rift were "causing" Grand intervals to increase in 2009, one would have expected their eruptions to have either increased in frequency or, in terms of the number of Turbans after First Fill, to have shifted to an earlier time to have possibly dissipated energy that Grand Geyser needed to erupt. Neither of these was seen in 2009. Indeed, both West Triplet and Rift in 2009

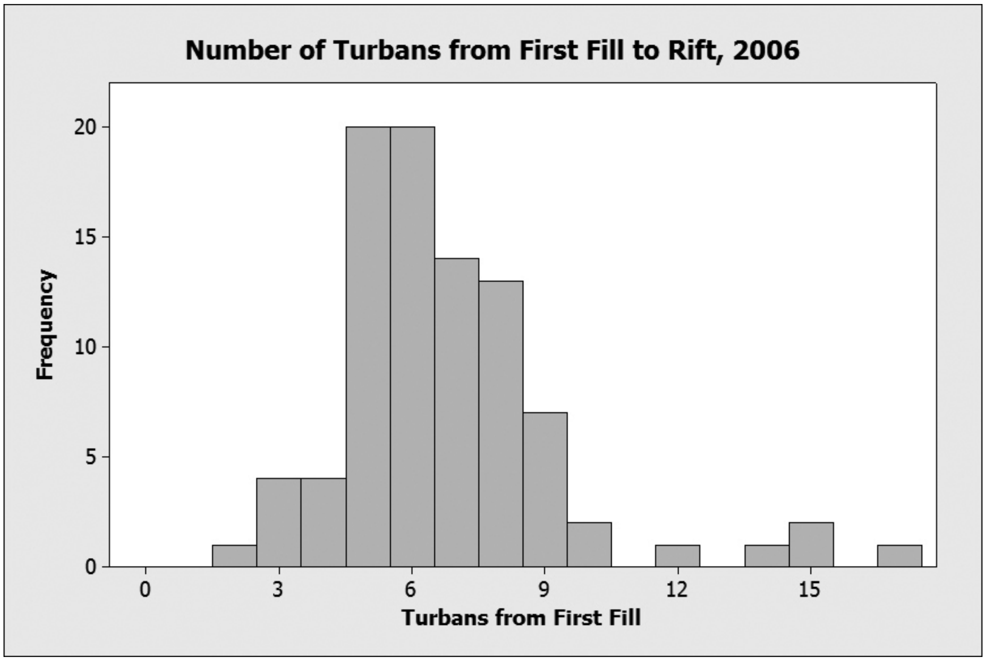

Figure 12: Timing of Rift Starts relative to the number of Turbans since First Fill, 2006.

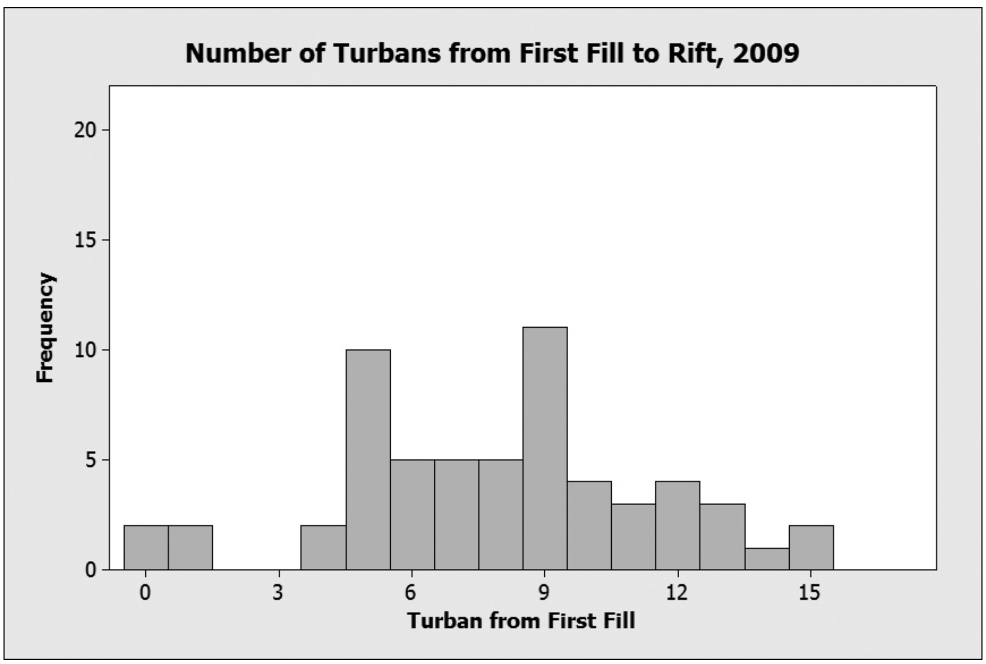

Figure 13: Timing of Rift Starts relative to the number of Turbans since First Fill, 2009.

had longer intervals, fewer eruptions and occurred later in the sequence relative to the number of Turbans from First Fill than in 2006.

Interestingly, whatever impact Grand, West Triplet and Rift Geysers experience, the behavior of Turban Geyser and Grand's pool from First Fill to a subsequent eruption of Grand are largely the same from 2006 to 2009. Possibly this is because the number of eruptions analyzed (approximately 2500-3500) is very large. Any variations in behavior are overshadowed by the majority of the large data set.

Since the recovery time for Grand remained the same but the time from First Fill to the subsequent Grand eruption (and eruptions of West Triplet and Rift) increased, the system may have had less energy, either in the form of lower temperature or volume of hot water inflow, in 2009 compared to 2006.

In conclusion, it appears that external factors, rather than interactions among Grand, West Triplet, and Rift Geysers were primarily responsible for the change in the eruptive pattern of Grand Geyser from 2006 to 2009.

Acknowledgments

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 Lynn Stephens for transcribing the Logbook into electronic form.

The Yellowstone Center for Resources and the Geology Program under Hank Heasler for their support of the program of electronic monitoring of geyser activity.

GOSA for making data (including the transcribed Logbook) available on the GOSA website, and Don Might for his work as Webmaster for the site. GOSA also helps support the monitoring program by donating electronic monitors.

Joshua St. Juliana for his work on extracting Turban eruptions times.

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Grand Geyser in eruption May 12, 2007, at 1223. Photo by Janet White-SnowMoon Photography.

Activity of Fan and Mortar Geysers 2007 - 2011

Tara Cross

Abstract

Fan and Mortar geysers' behavior during the active phase that lasted from June 2007 through October 2011 is summarized. Intervals, "event cycles," and unusual behavior are described, including details about eruption cycles and a list of eruptions.

Introduction

On June 5, 2007, Fan and Mortar Geysers reactivated after a dormancy of 22 months going back to August 8, 2005. The new active phase lasted for four years and four months, until October 14-15, 2011. Based on Fan and Mortar's history of cyclical dormancies every 3 to 5 years, the new dormancy was not unexpected. However, it was unusual for the dormancy to commence in October rather than the spring months.

This article is a summary of Fan and Mortar's behavior during the 2007-2011 active phase, which included 273 known eruptions. Of these, 73 eruptions were witnessed by a knowledgeable observer. The article provides information about intervals, describes minor activity, pre-eruptive activity, and major eruptions, and details unusual behavior.

Summary of 2007-2011 Active Phase

The first interval after June 5 was 36 days, and after that intervals were erratic for several months. By October, they had settled into a more usual pattern with most intervals falling between 2d22h and 5d15h. This continued through April 2008, with one long interval of 24 days thrown in. From some time before April 28 through June 24 there was a springtime short dormancy of at least 57 days, which was the longest interval of the active phase. Fan and Mortar quickly picked up the pace and from July to November 2008 intervals mostly ranged from 2½ to 5½ days with a little slowdown in October.

During the winter season from November 2008 to April 2009 information about Fan and Mortar's activity is sparse. It was active during this time based on wash patterns, but it was difficult to infer intervals. Another springtime short dormancy took place from sometime before April 25 through May 31, 2009, lasting at least 35 days. Then Fan and Mortar commenced an 18-month phase of remarkable consistency from June 2009 to December 2010. During that time, most intervals fell between 3 and 6 days. The longest interval of the spring in 2010 was just over 12 days, in the beginning of June.

From January through April 2011 intervals lengthened to 5 to 8 days, and once again there was a springtime short dormancy of approximately 46 days from May 3 to June ~18. Shorter intervals quickly resumed in late June, and ranged from 2½ to 6 days until mid-October. The final eruption of the active phase was overnight October 14-15, 2011. As with the 2000-2005 active phase, the cessation of activity was abrupt; there was no obvious indication that Fan and Mortar were slowing down prior to the final eruption.

Event Cycles

Terms and definitions

Since no new terms became relevant between 2007 and 2011, and no new vents developed during that time, this article will not include maps and definitions. Please refer to prior articles by Tara Cross on the activity of Fan and Mortar Geysers for this information (*GOSA Transactions* 7, 8, 9, and 11).

As a quick review, the "major vents" of the complex are Fan's Main and East Vents and Upper and Lower Mortar. The minor vents that are important to minor cycles are Fan's River, High, Gold, and Angle Vents and Mortar's Frying Pan. In a minor cycle, activity usually progresses from River to High and Gold to Angle and then possibly to Frying Pan if it is active.

Main Vent splashing

The first definitively positive sign for a strong cycle was splashing in Main Vent. This splashing could start 10 or more minutes after River shut off, or it could start during River and take control of the cycle, shutting River off for a pause. Usually, activity in Angle would need to stop before Main Vent started splashing, but on a few occasions Main Vent started splashing before Angle had completely shut off. Main Vent's activity usually began with at least a few huffs of steam or "roars." Sometimes splashing commenced right away, and other times it could wait as much as 10 minutes to start splashing. Once Main Vent had gained control of the system, observers looked for strong splashes that reached the height of the cone and continuous smaller splashing as indications that an eruption might occur.

Main Vent's activity could continue through several pauses, with splashing continuing when River came on, or it could lead to a long "off" period with no pause. Splashing usually continued until about the time that River started for the last time in the cycle. An exception that was seen more frequently in non-eruptive event cycles was that strong eruptions from Bottom Vent would diminish or shut down activity by Main Vent.

Once River turned on for the last time, there was sometimes a "power struggle" between Main Vent and Gold Vent. In general, observers wanted to see a smooth transition from Main Vent splashing to a strong Gold start, but sometimes the two would go back and forth before Gold finally took over.

Pauses

As mentioned above, Main Vent splashing could lead to pauses during event cycles. A pause could occur when Main Vent began to splash before Angle came on, or River could start during Main Vent splashing and be shut off by continued splashing. There were also times when there was a River or Gold pause without splashing in Main Vent. These cases were unusual except during "spring mode" behavior, described below. With only one known exception, these cycles did not lead to eruptions.

The nature of pauses did not change noticeably from the 2000-2005 active phase. There were both River and Gold pauses, which could last anywhere from 1 minute to over an hour. Most pauses lasted between 5 and 30 minutes. There were single, double, and triple pauses, and one reported incidence of a quadruple pause cycle that did not lead to an eruption.

Bottom Vent eruptions

The action of Bottom Vent did not change significantly from what was seen in 2004 and 2005. When cycles were stronger, lasting 30 to 60 minutes, Bottom Vent would start splashing about 5 to 10 minutes before the start of River. Usually, this splashing would subside when River started. In the case of an event cycle, though, Bottom Vent's splashing could continue to get stronger. During some event cycles, Bottom Vent just splashed, occasionally putting out enough runoff to reach to the Firehole River. During others, the splashing built into eruptions. These eruptions usually came on strong and steady, and could last as long as 24 minutes. Sometimes there were pauses in the eruption when it definitely stopped; those were usually counted as separate eruptions. Other times, it would pause but barely stop, and in those cases the duration was usually counted from the start of the behavior to when all action by Bottom Vent ended.

During weaker event cycles, Bottom Vent eruptions could sometimes "steal" the energy away from Main Vent. When this happened, Main Vent splashing usually lasted a few minutes into the Bottom Vent eruption and then ended, but it would continue to have roars of steam and River would continue to be off for 5 to 10 minutes. During stronger cycles, Main Vent would continue to splash even with Bottom Vent erupting. In these cases, the cycle could extend longer; River could come on and shut off again for a pause with continued Main Vent splashing. On a few occasions, Main Vent splashing gave way to a Bottom Vent eruption and the cycle was still strong enough to trigger an eruption.

If Bottom Vent had more extended activity, it would continue to erupt until a few minutes after River came on, and then it would gradually diminish until there were only a few drops of water being expelled. At this point the minor vents would take over, and Bottom would cease activity.

Frying Pan

Most observers did not pay close attention to the activity of Frying Pan, either in normal cycles or in event cycles. Based on the small amounts of data I found, Frying Pan had limited action in 2007. It was reported active during longer cycles (50 to 60 minutes), particularly event cycles, in 2008 and 2009. It was also seen in March and July of 2010.

There was just one report of Frying Pan in 2011, in an eruption cycle. When Frying Pan was active in event cycles, it typically turned on 13 to 25 minutes after River. When it was active during longer cycles in 2008 and 2010, it would usually start 25 to 30 minutes after the start of River. Neither I nor other observers found that Frying Pan's activity was significant to event cycles (as opposed to 2002, for example, when Frying Pan's action was a key component of eruption cycles).

Eruption Cycles

Events

The length of time between the start of Main Vent splashing and the eruption in normal eruption cycles did not change significantly from 2001-2005, with a range of 39 to 89 minutes. Main Vent splashing could last only 10 minutes or could go on for 60 minutes or more. Sometimes Main Vent would give way to Bottom Vent when it started erupting, but sometimes it would continue to splash even with Bottom Vent in eruption. After the start of River, if there was heavy steaming in Gold Vent, Main Vent usually stopped splashing. If Main and Gold seemed to be fighting for energy, it was less likely that Fan and Mortar would erupt on that cycle (but not impossible).

A majority of eruptions were preceded by River pauses. These could be single, double, or triple pauses, though triple pauses were unusual (only 6 known occurrences). Typical pauses lasted 2 to 20 minutes, but could be as short as 1 minute, and there were some cases of longer pauses, particularly in 2010 when several eruption cycles included pauses lasting 54 to 63 minutes. Gold pauses rarely led to eruptions but there were more Gold pauses in eruption cycles in 2008 than the other years combined (6 vs. 3) and none in 2010. A few normal eruption cycles included no pause. Instead, Main Vent started splashing after the end of a full cycle. As would be expected, these cycles had the shortest time from the first splash in Main Vent to the start of the eruption.

Despite the perception of being a bad sign for Fan and Mortar, Bottom Vent eruptions actually occurred in over half of eruption cycles from 2007-2010. These could range from short eruptions of 1 to 2 minutes to elongated eruptions of 20 or more minutes. However, in 2011 Bottom Vent was active only occasionally, and never preceded an eruption.

Gold Vent

Some have theorized that Gold needs to wait some time to start after River for a cycle to be promising. In reality there did not appear to be much connection between the delay of Gold and the likelihood of an eruption on that cycle. Gold tended to have longer delays (8 to 19 minutes) when the entire cycle was elongated, and the River-to-start time (discussed below) was also longer than usual. The time from the start of Gold to the start of the eruption had a wide variation of 12 to 46 minutes, but the most reliable time for the eruption to occur was 15 to 26 minutes after the start of Gold.

Water levels

While not a strict requirement, water levels in eruption cycles usually started high and stayed strong until lock was achieved. Once Gold Vent started, observers looked for strong activity from Gold to 3 to 5 feet and steady discharge from High Vent. Gold could drop a little bit below the rim of its vent, but if the level dropped down and its eruption was more steam than water, that usually meant that there would not be an eruption on that cycle. There were some exceptions to this, but usually in these cases the water levels came back quickly, within the next 1 to 2 minutes.

Duration of lock

In the 2007-2011 active phase, the duration of lock prior to an eruption varied from a few seconds to 15 minutes. Locks tended to be longer in 2008 than other years, when the maximum was 15 minutes and most were 5 to 9 minutes. For the other years, the maximum was 11 minutes and most were 2 to 6 minutes. The nature of lock was usually the same; High would begin the action with a steady column of water to 3 to 5 feet. This would begin to build, and usually Gold would join in with steady activity to 3 to 5 feet. Occasionally, Gold would not be doing much while High was already in lock-like behavior, but it would eventually join in. Angle's participation in lock varied. Sometimes it would erupt steadily, other times it would splash, and frequently it would go into a steam phase. The height of High was usually at least 6 to 8 feet, but there were some instances of 15 feet or more. All the vents could drop out of lock momentarily and the eruption would still commence once the lock

From left to right, the vents in lock before an eruption: River, High, Gold and Angle. September 5, 2011. Photo by Pat Snyder.

resumed. In one unusual case, the water levels rose and dropped three separate times before the eruption was finally triggered. There were also relatively rare occasions when a lock did not lead to eruption. I have detailed this behavior under "False locks."

River to start

The time from the start of River to the start of the eruption was about the same in 2007-2011 as in the 2000-2005 active phase. The range was 14 to 46 minutes, but most fell between 18 and 35 minutes. The average time from River to start did not vary significantly from year to year. In 2008, the range was 15 to 43 minutes with an average of 26.1 minutes. In 2009, the range was 15 to 46 minutes with an average of 25.7 minutes. In 2010, the average time shortened to 23.2 minutes, with a majority of eruptions coming 18 to 28 minutes after River. The two exceptions were 14 and 36 minutes. In 2011 the time lengthened to an average of 28.1 minutes, with a range of 19 to 39 minutes.

Start types

As seen in previous active phases, a major eruption of Fan and Mortar could be initiated in two ways. The most common start type was a "classic lock," in which High, Gold, and sometimes Angle would erupt steadily and in unison to at least 5 feet, sometimes more. As seen in 2004 and 2005, Angle's participation in lock varied from steady eruption to steam phase. All but three eruptions were initiated this way.

Three eruptions, two in 2009 and one in 2010, were initiated by Upper Mortar. It is important to note that in an Upper Mortar *initiated* eruption, the vents of Fan are not having "classic lock" behavior. If they are, then the eruption is considered a lock start. In 2001, 2002, and 2003 when Upper Mortar initiated eruptions were more common, the first water seen in Upper Mortar would usually be 10 to 20 minutes after the start of River. This held true for the three observed instances in 2007-11 as well; the first water was seen at 16, 17, and 18 minutes. In all three cases, the water levels in the minor vents were good prior to the Upper Mortar activity, but dropped down before the eruption was initiated.

Starting vent

When an eruption was initiated by a "classic lock," any of the four major vents of the complex could start the eruption. I have never investigated whether there is any significance to the starting vent in the past. Out of the 73 eruptions where eruption cycle information was available, 70 were initiated by lock. Out of these, the starting vent was reported for 59 eruptions. East Vent was by far the most common starting vent, triggering 41 eruptions. Main Vent was the first vent in 12 cases, Upper Mortar took the lead in five cases, and just one was started by Lower Mortar. In an analysis of various factors, including Main Vent splashing, pauses, Gold delay, and duration of lock, I found no obvious connections. The only "pattern" I found was that in the seven abnormal cases of Fan and Mortar erupting without Main Vent splashing prior to the start of River, the eruption started with East Vent. With so few data points, coupled with the fact that East Vent was the most common starting vent, it is doubtful that this means anything.

Major Eruptions

There were no significant changes in the nature of major eruptions during the 2007-11 active phase. However, as before, there were some variations in the activity of the individual vents during the eruption. A typical eruption began with surges from all four major vents. Then, after an initial surge to 10 to 20 feet, Upper Mortar and Lower Mortar would typically become quiet for 1 to 3 minutes while the vents of Fan erupted by themselves. Then Upper Mortar would begin surging again and commence

Fan's East Vent starts a lock-initiated eruption on November 6, 2010. Photo by Tara Cross.

Fan erupts by itself during the first minutes of a major eruption on September 12, 2009. Photo by Tara Cross.

major eruption. This behavior was common in 2004 and 2005 as well. However, sometimes Upper and Lower Mortar would continue after the initial surge. In these cases, Lower Mortar would pause several minutes into the eruption, then come back strong with vertical and angled jets of water to 20 to 40 feet. At times, Lower Mortar seemed to go into another gear, erupting vertically to as much as 50 feet. There were also a few reports of Lower Mortar having almost no activity during Fan and Mortar eruptions, with only a few spurts at the beginning before going into steam phase. Upper Mortar would continue its powerful water phase with a single column reaching 40 to 60 feet, gradually going into steam phase 5 to 8 minutes after the eruption had commenced. There were a few exceptional eruptions of Upper Mortar that reached 80 feet.

In the past, after 5 to 8 minutes of steady activity to 40 to 60 feet to start the eruption, East Vent would begin to have pauses in activity, with a quiet period of a few seconds followed by a strong burst of water to 20 to 30 feet. On several occasions in 2009, I noted that East Vent ceased all activity after its first pause and did not join in the eruption again until after the first pause of the entire system. On October 29, 2009, I observed East Vent having a fountain-type bursting eruption to 10 to 15 feet just as Upper Mortar was going into steam. I have not seen or heard of that phenomenon before or since.

Main Vent showed little variation in activity. Its initial surge was usually 60 to 90 feet high, with the angled column reaching Spiteful Geyser. Then, it would have a second surge with more power, and the angled column would reach at least as far as the trail and sometimes all the way to the other side of the trail. Height varied from 80 to 125 feet.

The first pause in activity took place from 12 to 20 (typically 15 to 16) minutes after the start of

Upper and Lower Mortar in full eruption on September 12, 2009. Photo by Tara Cross.

an eruption. After a brief pause, activity would resume, with jetting from Main Vent and East Vent and steam phase in Upper and Lower Mortar. As the eruption waned, activity in Mortar would cease, and only Fan would participate. The eruption was deemed over when no more water was being thrown from Fan. Durations ranged from 24 to 40 minutes, but were noticeably shorter in 2008 (24 to 32 minutes) than 2009-2011 (30 to 40 minutes).

During most major eruptions, the behavior of Spiteful Geyser and "Norris Pool" did not change from normal. However, there were exceptions. During Fan and Mortar's eruption on August 26, 2009, Ben Hoppe observed that one of Spiteful's spouter vents was "sending spurts of water at an angle of about 40 degrees from the horizontal towards the boardwalk" reaching 10 feet from the vent and 5 feet high (Hoppe 2009). During Fan and Mortar eruptions on March 2 and 6, 2010, Stephen Eide observed that Spiteful's spouter stopped splashing and "Norris Pool's" water level rose 2 to 3 inches (Eide 2010a). The water level rose in "Norris Pool" again on May 1 (Eide 2010b). This was unusual for the 2007-2011 active phase, but common in 2001-2005.

Unusual Activity

Spring-mode behavior

Data over the past 20 years have shown that Fan and Mortar have a tendency to have longer intervals during the spring months—April, May, and

June. It is believed that this is due to higher water levels in the Firehole River that partially drown the system. This was most evident in 2008, 2009, and 2011, when there were springtime short dormancies of greater than 57, greater than 35, and about 46 days, respectively. In 2010, there was hardly any slowdown at all, with only one interval of about 12 days in early June amid otherwise regular intervals of 4 to 7 days.

During the longer intervals, Fan and Mortar usually exhibited "spring mode behavior" evident in the minor cycles. This behavior was characterized by long, organized cycles, with River on for 30 to 60 minutes and Angle completely shutting off during the quiet period, which would last 20 to 45 minutes. Event cycles were less frequent, and could consist of pauses only with no Main Vent splashing or Bottom Vent eruptions.

In at least two cases, there were reports of better water levels in the minor vents prior to the first eruptions after the longer intervals. As Fan and Mortar came out of spring mode, event cycles became more frequent over the next one to two weeks but were often elongated. As intervals shortened in July, event cycles would return to more "normal" behavior, as described above.

No-event eruptions

With very few exceptions, Fan and Mortar eruptions since 2000 have been preceded by "events," as described earlier in this article. However, in 2009, five observed eruptions occurred after cycles that included no events prior to the start of River—no Main Vent splashing, no pauses, and nothing from Bottom Vent. I am indebted to Lynn Stephens for the information about these cycles because she was present for all of them.

The five "no-event" eruptions occurred on July 30, September 7, September 12, October 3, and October 7, 2009. The July 30 instance was an isolated event, but the other four occurred in two pairs of back-to-back eruptions. There was no consistent pattern to the cycles that led to these eruptions. Water levels in the minor vents looked good from the start of Gold on July 30, but in all other cases, they were poor until a few minutes before lock commenced. Eruption cycle behavior varied from no indication at all (September 7) to Main Vent splashing 16 minutes *after* the start of River (October 3). Main Vent and Upper Mortar both had numerous puffs of steam before the October 3 and 7 eruptions, but not before the earlier eruptions. On September 12, the only indication was that East Vent was steaming heavily about 10 minutes after River came on. The time from River to start could be relatively short (20 minutes on September 12) or exceptionally long (46 minutes on October 3). Likewise, the time from the start of Gold to the start of lock behavior varied from 16 to 44 minutes. Lock behavior lasted 3 to 5 minutes. Whether coincidental or not, the only common denominators were that all five started from a classic lock and the first vent to begin erupting was East Vent (Stephens 2009a, 2009b, 2009c).

Another "no-event" eruption cycle occurred on July 19, 2011. Fan and Mortar erupted after having a single Main Vent splash 5 minutes after River started. There were no other events. The water levels started good, dropped to poor, and then came back, with High Vent having lock behavior by itself for several minutes before being joined by Gold for a full lock (Panos 2011). As in 2009, East Vent started the eruption. This was the only instance of this type of behavior in 2011.

Another oddball eruption cycle occurred on July 8, 2008. Lynn Stephens witnessed an eruption cycle with a River pause followed by a Gold pause, and no splashing in Main Vent. There were a few large puffs of steam from Main Vent, but no actual water was seen (Stephens 2008). This was the only known eruption cycle with no Main Vent splashing in 2008 and was possibly still the result of "spring mode," since it was only the fourth eruption since Fan and Mortar's activation after a spring slowdown in April, May, and June. Also unusual was the order of the pauses. Neither Stephens nor I could recall ever seeing a River pause followed by a Gold pause; in our experience, if there was going to be a Gold pause, it would be the first pause to occur. This phenomenon was not seen again during the active phase.

False locks

While unusual, Fan and Mortar sometimes exhibited lock behavior without an ensuing major eruption. This phenomenon was extremely rare prior to 2004. It was seen a handful of times in 2004 and 2005. It is unknown how many times this happened during the 2007-2011 active phase, but it was observed once each year.

"False locks" occurred on otherwise normal event cycles, preceded by the usual Main Vent

Fan and Mortar on September 12, 2009. Photo by Tara Cross.

splashing and sometimes pauses and Bottom Vent eruptions. The minor vents would come on and in most cases had very good water levels that built into a lock, giving observers reason to believe that there would be a major eruption. However, after 4 to 11 minutes, the water levels would drop down, and within a few minutes after that River would shut off with no eruption.

False locks were usually accompanied by other promising behavior, such as splashes in Main Vent, splashes in East Vent, and Upper Mortar surging. On August 16, 2007, Main Vent splashed and East Vent gurgled. On July 1, 2008, there were several sizeable splashes in Main Vent and several cone-filling surges in Upper Mortar but no eruption. On September 6, 2009, East Vent splashed 9 and 10 minutes after the lock started, but a minute later the vents dropped. Experienced observers could not remember another instance of East Vent splashing during a lock without an eruption. On April 17, 2010, Main Vent splashed, though there was no steam in East Vent (Panos 2010). However, on September 17, 2011, there was no activity in Upper Mortar, Main Vent, or East Vent during the false lock (Meech 2011).

On three occasions, observers stayed behind to see what would happen next. Event cycles could follow immediately after or take many hours to resume. On July 1, 2008, observers reported a different type of activity. Following the false lock, there was a period of quiet, River Vent came on weakly and stayed on for 30 minutes without action from the other vents. It was as if Fan and Mortar had erupted and it was in a recovery phase (Schwarz 2008).

In three instances, major eruptions occurred the following day, 25 to 30 hours after the false lock. The other cases were 2 and 2½ days later, so false locks were not a reliable indicator for impending eruptions. They could also occur at any time during an interval, from 2½ days to 9 days. It is possible that they could have occurred "too early" in an interval as well, since Fan and Mortar were not observed carefully until the window opened.

30-minute High Vent eruption

Some unusual behavior occurred during the ~6d08h interval at the end of August, 2011. This description is based on verbal reports from Jim Scheirer and John and Karol Slivka. On the afternoon of August 29, about the 3-day point in the interval, there was an event cycle which seemed to be leading to an eruption. High Vent went into "lock" behavior, and observers expected Gold Vent to join in within a minute or two. However, Gold's activity never became steady and instead High Vent continued to erupt continuously for the next 30 minutes. When High died down, all of the minor vents ceased activity, and there was no eruption. After this, the minor activity seen at Fan and Mortar changed drastically. River Vent was on most of the time and when it did stop, it was only off for a few minutes. This continued for several days, with no event cycles. Finally, the cycles returned to a more normal pattern on September 1, and that night Fan & Mortar erupted. I have never seen anything like this before.

Possible Spiteful eruption

There was a "credible report" of a major eruption of Spiteful Geyser on January 22, 2009. According to the report, the eruption lasted over 5 minutes and reached 10 to 15 feet high (Loren 2009). This was the only known major activity by Spiteful during Fan and Mortar's active phase and the first since early January 2000.

Recovery Behavior

Based on limited observations, it appeared that Fan and Mortar were continuing to have "recovery" behavior similar to that seen in the 2000-2005 active phase. For the first few hours after an eruption, everything was quiet. Then River would begin having weak cycles, increasing in strength until other vents also joined in. Within about 18 hours of the eruption, Fan and Mortar would have event cycle behavior, with Main Vent splashing and Bottom Vent eruptions, but water levels were low, indicating to observers that the geysers were not ready to erupt yet.

Conclusion

Fan and Mortar Geysers were active for 4 years and 4 months from 2007 to 2011. During this time, about one quarter of known eruptions were seen. As in previous active phases, intervals varied, but most fell between 2½ and 5½ days. Minor activity and pre-eruptive events followed basic patterns that were established during the 2000-2005 active phase. A majority of eruption cycles included Main Vent splashing, most included at least one pause, and some included eruptions of Bottom Vent. As always, there were some exceptions, but the overall patterns allowed many observers to enjoy an eruption of these spectacular geysers.

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TABLE 1. Fan and Mortar eruption cycles in 2007.

Date	Time	Main?	Pause? (time on-off)	Bottom?	Start Type	R to start	Observer
7/11/2007	1054	?	?	yes	lock	>15	Kitt Barger
8/7/2007	1906	>66	R(9-22)	yes	lock	15	Dean Lohrenz
8/26/2007	2056	>60	R(5-8), R(9-23)	yes	lock	15	Dean Lohrenz
9/3/2007	1308	60	G(5-19), R(4-26)	yes	lock	21	Graham Meech
9/21/2007	0911	?	?	?	lock	?	Tom Carberry

TABLE 2. Fan and Mortar eruption cycles in 2008.

Date	Time	Main	Pause? (time on-off)	Bottom?	Start Type	R to Start	Observer
6/28/2008	0714	?	?	?	lock	?	Hans Kaufman
7/2/2008	1433	50	No	No	lock	39	Tara Cross
7/8/2008	0710	No	R(12-6), G(7-7)	No	lock	23	Lynn Stephens
7/14/2008	1951	59	G(6-13), R(7-6)	No	lock	32	Andrew Bunning
7/18/2008	0531	43	R(11-7), R(14-3)	No	lock	19	Kitt Barger
7/22/2008	2345	>45	G(13-42)	Yes	lock	15	Tara Cross
7/26/2008	2054	84	G(10-14), R(7-24)	Yes	lock	17	Tara Cross
8/7/2008	0821	63	R(10-16)	Yes	lock	23	Ben Hoppe
8/12/2008	1834	>58	R(?-5), R(12-5)	No	lock	35	Lynn Stephens
8/16/2008	1019	72	R(10-18), R(8-5), R(8-7)	No	lock	28	Lynn Stephens
8/21/2008	1313	>75	R(7-6), R(13-6)	No	lock	43	Jeff Davis
8/24/2008	0856	89	R(5-11), R(8-30)	Yes	lock	23	Jim Scheirer
8/26/2008	2227	>75	R(9-6), R(9-20)	Yes	lock	24	Tara Cross
8/30/2008	1356	39	R cough (off 16)	No	lock	30	Tara Cross
9/3/2008	1154	60	R(5-8), R(14-1)	Yes	lock	17	Cynthia Barwin
9/6/2008	0212	>82	R(4-5), R(8-14), R(6-6)	Yes	lock	24	Graham Meech
9/9/2008	0519	>48	?, R(>7-4)	Yes	lock	26	Graham Meech
9/12/2008	0310	68	R(7-3), R(3-27)	Yes	lock	26	Graham Meech
9/16/2008	1222	78	G(6-13), R(2-10), R(6-31)	Yes	lock	19	Lynn Stephens
9/20/2008	0439	60	R(6-4), R(6-5)	Yes	lock	26	Lynn Stephens
10/30/2008	2231	?	?	?	lock	?	Jens Day

TABLE 3. Fan and Mortar eruption cycles in 2009.

Date	Time	Main?	Pause? (time on-off)	Bottom?	Start Type	R to Start	Observer
6/29/2009	0032	63	R(4-9), R(7-8)	No	lock	29	Tara Cross
7/8/2009	2026	78	R(8-14), R(11-27)	Yes	UM	28	Lynn Stephens
7/13/2009	1730	49	R(6-16), R(11-4)	Yes	lock	21	Lynn Stephens
7/22/2009	1705	60	R(6-2), R(2-40)	Yes	lock	15	C. Barwin
7/26/2009	1240	75	R(7-8), R(13-10)	Yes	lock	25	Polly Panos
7/30/2009	0816	No	No events	No	lock	22	Lynn Stephens
8/4/2009	0930	67	No pause	Yes	lock	32	Lynn Stephens
8/15/2009	1240	69	2 River pauses	No	lock	?	Dirk Anderson
8/19/2009	1851	73	R(8-51)	Yes	lock	22	Ben Hoppe
8/23/2009	1254	76	R(2-9), R(11-17)	Yes	lock	23	Kitt Barger
8/26/2009	1710	80	No pause	Yes	UM	23	Ben Hoppe
8/30/2009	2331	44	R(10-27)	Yes	lock	20	Tara Cross
9/4/2009	0323	~65	R(10-14), R(15-18)	Yes	lock	21	Tara Cross
9/7/2009	1956	No	No events	No	lock	33	Lynn Stephens
9/12/2009	1230	No	No events	No	lock	20	Lynn Stephens
9/17/2009	0736	65	G(5-45)	Yes	lock	21	Lynn Stephens
9/21/2009	0942	?	?	?	lock	34	Lynn Stephens
3/10/2009	0740	No	No events	No	lock	46	Lynn Stephens
10/7/2009	1109	No	No events	No	lock	30	Lynn Stephens
10/21/2009	1421	?	?	?	lock	?	Cathy Bell
10/25/2009	1555	Yes	?	Yes	lock	21	Stephen Eide
10/29/2009	1009	48	R(9-7), R(11-1)	Yes	lock	25	Stephen Eide

TABLE 4. Fan and Mortar eruption cycles in 2010.

Date	Time	Main?	Pause? (time on-off)	Bottom?	Start Type	R to start	Observer
3/2/2010	1205	54	?	Yes	lock	21	Stephen Eide
3/6/2010	0853	44	?	Yes	lock	19	Stephen Eide
5/1/2010	0856	80	R(11-7), R(8-18), R(2-2)	Yes	lock	21	Stephen Eide
6/1/2010	1254	55	No pause	No	lock	36	Tara Cross
6/13/2010	1628	82	R(12-6), R(10-8), R(7-3)	No	lock	26	Kitt Barger
6/26/2010	2155	>64	R(9-9), R(14-4)	No	lock	26	Tara Cross
7/8/2010	1709	70	R(7-13), R(5-45)	Yes	lock	14	Ben Hoppe
7/23/2010	0726	76	R(?-59)	Yes	UM	24	Scott Grisso
7/27/2010	1956	74	R(9-20)	Yes	lock	25	Cynthia Barwin
7/31/2010	2330	>30	River pause	Yes	lock	~25	S. Strasser
8/10/2010	1253	~80	R(?-~60)	Yes	lock	20	Polly Panos
8/17/2010	2050	89	R(?-20), R(12-40)	No	lock	18	Scott Grisso
8/24/2010	2016	?	?	?	lock	?	Dean Lohrenz
8/28/2010	1744	>40	River pause	Yes	lock	25	Dave Leeking
9/5/2010	0504	74	R(5-54)	Yes	lock	21	Graham Meech
9/18/2010	0211	77	No pause	Yes	lock	22	Jake Young
9/21/2010	1335	65	R(5-1), R(6-10)	Yes	lock	27	Jake Young
9/27/2010	1027	55	R(7-21)	No	lock	24	B. Lasseter
10/14/2010	1042	71	R(13-13)	No	lock	28	Polly Panos
11/6/2010	1254	67	R(14-15), R(12-26)	Yes	lock	20	Tara Cross

TABLE 5. Fan and Mortar eruption cycles in 2011.

Date	Time	Main?	Pause? (time on-off)	Bottom?	Start Type	R to start	Observer
7/11/11	0715	>51	R(?-9)	No	lock	21	Chris Daubert
7/19/11	1348	33	NP	No	lock	38	Polly Panos
7/24/11	0034	>65	G(11-16)	No	lock	34	Tara Cross
7/27/11	0001	>45	?	No	lock	36	Chris Daubert
8/4/11	2043	>53	R(7-11)	No	lock	25	Dean Lohrenz
8/17/11	1259	61	R(5-19)	No	lock	19	Jim Scheirer
8/23/11	1020	68	R(5-3)	No	lock	19	Karol Slivka
8/26/11	1543	45	R(7-4)	No	lock	20	Jim Scheirer
9/5/11	1125	61	R(5-16), R(9-9), R (9-3)	No	lock	24	Cynthia Barwin
9/9/11	0039	52	R(9-4), R(9-7)	No	lock	32	Tara Cross
9/13/11	2339	>49	NP?	No	lock	39	Graham Meech
9/29/11	1607	69	R(3-21)	No	lock	24	Jim Scheirer

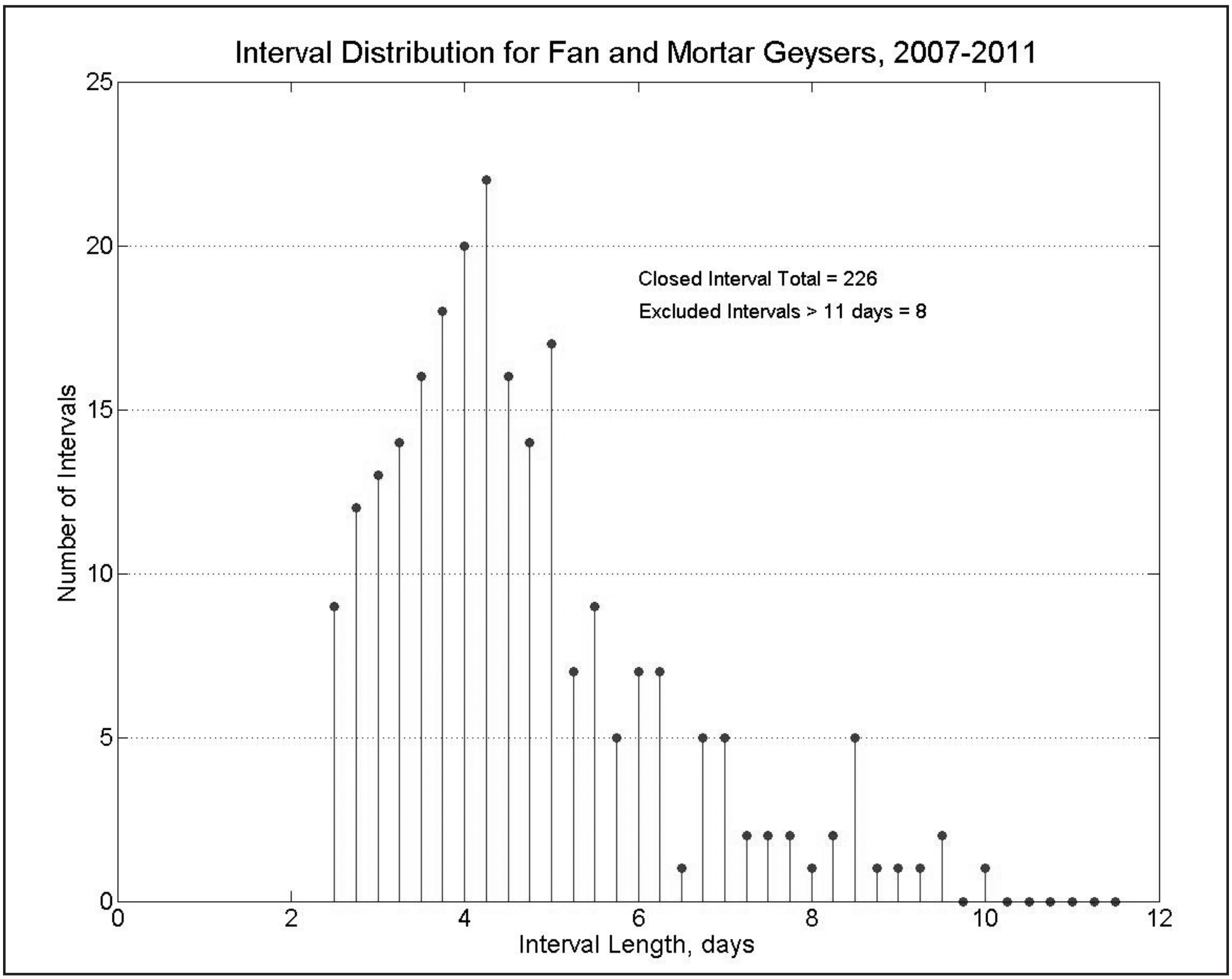

Figure 1. *Fan and Mortar interval distribution stem graph. Frequency Behavior of Fan and Mortar Geysers. Intervals were calculated from start time to start time. Eruption times for known but unobserved overnight eruptions were set to 0100.*

Fan and Mortar Geysers Eruption List 2007-2011

Note: There was a discrepancy between visual and electronic times for November 2009 through May 2010. In the few cases when a visual time was available, the electronic times were 7 to 9 minutes before the visual time. This was the case only during the winter of 2009-2010; all other electronic times matched closely with visual times and were 1 to 5 minutes after the visual time.

2007	June 5	~0640	~667d23h31m
2007	July 11	1054	~36d04h14m
2007	July 14	1845vr	~3d07h51m
2007	August 7	1906	~24d00h21m
2007	August 17	1910vr	~10d00h04m
2007	August 26	2056	~9d01h46m
2007	September 3	1308	=7d16h12m
2007	September 12	2320e	~9d10h12m
2007	September 21	0911	~8d09h51m
2007	September 28	2300e	~7d13h49m
2007	October 1	2100e	~2d22h00m
2007	October 4	2050e	~2d23h50m
2007	October 8	2320e	~4d02h30m
2007	October 12	0250e	~3d03h30m
2007	October 16	0635e	~4d03h45m
2007	October 24	2030e	~8d13h55m
2007	November 12	1401e	~18d17h31m
2007	November 16	1906e	~4d05h05m
2007	November 22	0951e	~5d14h45m
2007	November 26	0356e	~3d18h05m
2007	November 29	1441e	~3d10h45m
2007	December 2	1436e	~2d23h55m
2007	December 12	0306e	~9d12h30m
2007	December 16	0816e	~4d05h10m
2007	December 24	1411e	~8d05h55m
2008	January 2	1726e	~9d03h15m
2008	January 11	0411e	~8d10h45m
2008	January 17	1116e	~6d07h05m
2008	January 20	0426e	~2d17h10m
2008	January 28	1906e	~8d14h40m
2008	February 2	0446e	~4d09h40m
2008	February 6	0951e	~4d05h05m
2008	February 9	1851e	~3d09h00m
2008	February 23-26	unknown	unknown
2008	March 4-8	unknown	unknown
2008	March 9-10	overnight	unknown
2008	Mar. 20-Apr. 4	unknown	unknown
2008	April 4-28	unknown	unknown
2008	June 24	0646ie	>57d
2008	June 28	0714	~4d00h28m
2008	July 2	1433	4d07h19m
2008	July 8	0710	5d16h37m
2008	July 11	0901ie	~3d01h51m
2008	July 14	1951	~3d10h50m
2008	July 18	0531	3d09h40m
2008	July 22	2345	4d18h14m
2008	July 26	2054	3d21h09m
2008	July 30	~0100	~3d04h
2008	August 3-4	overnight	~5d
2008	August 7	0821	~3 ¼ d
2008	August 9-10	~0030	~2 ¾ d
2008	August 12	1834	~2d18h
2008	August 16	1019	3d15h45m
2008	August 19	~0330	~2d17h
2008	August 21	1313	~2d10h
2008	August 24	0856	2d19h43m
2008	August 26	2227	2d13h31m
2008	August 30	1356	3d15h29m
2008	September 3	1154	3d21h58m
2008	September 6	0212	2d14h18m
2008	September 9	0519	3d03h07m
2008	September 12	0310	2d21h51m
2008	September 16	1222	4d09h12m
2008	September 20	0439	3d16h17m
2008	September 23-24	overnight	~4d
2008	September 26-27	overnight	~3d
2008	October 3-4	overnight	~7d
2008	October 7-8	overnight	~4d
2008	October 13-14	overnight	~6d
2008	October 22	0950ie	~8¼d
2008	October 26	1317	~4d03h27m
2008	October 30	2231	4d09h14m
2008	November 3-4	overnight	~4d
2008	November 6	1224ns wc	~2 ½ d
2008	November	unknown	unknown
2008	November 24	unknown	unknown
2008	November 28	late a.m.	unknown
2008	December 4	unknown	unknown
2008	December 6	unknown	unknown
2008	December 9	unknown	unknown
2008	December 11	unknown	unknown

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2008	December 19	unknown	unknown
2008	December 21	0907	unknown
2008	December 25-26	overnight	~4 ½ d
2008	December 30	1700ie wc	~4 ¾ d
2009	January 1-2	overnight	~2½d
2009	January 5-6	overnight	~4d
2009	January 8-9	overnight	~3d
2009	January 14-15	overnight	~6d
2009	January 21-22	overnight	unknown
2009	February 2	unknown	unknown
2009	February 12	unknown	unknown
2009	February 20	unknown	unknown
2009	February 27	unknown	unknown
2009	March 6	unknown	unknown
2009	March 13	unknown	unknown
2009	March 17	unknown	unknown
2009	March 31	unknown	unknown
2009	April 15	unknown	unknown
2009	April 25	unknown	unknown
2009	May 30-31	overnight	>35d
2009	June 12	2029ie	~12 ¾ d
2009	June 18-19	overnight	~6 ¼ d
2009	June 23	1129ns	~4 ½ d
2009	June 29	0032	~5d13h03m
2009	July 3-4	overnight	~5d
2009	July 8	2026	~4 ¾ d
2009	July 13	1730	4d21h04m
2009	July 17-18	overnight	~4 ½ d
2009	July 22	1705	~4 ½ d
2009	July 26	1240	3d19h35m
2009	July 30	0816	3d19h36m
2009	August 4	0930	5d01h14m
2009	August 6-7	overnight	~2 ¾d
2009	August 11-12	overnight	~5d
2009	August 15	1240	~3 ½ d
2009	August 19	1851	=4d06h11m
2009	August 23	1254	=3d18h03m
2009	August 26	1710	=3d04h16m
2009	August 30	2331	=4d06h21m
2009	September 4	0323	=4d03h52m
2009	September 7	1956	=3d16h33m
2009	September 12	1230	=4d16h34m
2009	September 17	0736	=4d19h06m
2009	September 21	0942	=4d02h06m
2009	September 26	0128e	~4d15h46m
2009	September 29	1216vr	~3d10h48m
2009	October 3	0740	~3d19h24m
2009	October 7	1109	=4d03h29m
2009	October 12	0136e	~4d14h25m
2009	October 16	1139	~4d10h03m
2009	October 21	1421	=5d02h42m
2009	October 25	1555	=4d01h24m
2009	October 29	1009	=3d18h14m
2009	November 2	1348e	~4d03h39m
2009	November 7	2036e	~5d06h48m
2009	November 12	0556e	~4d09h20m
2009	November 17	0852e	~5d02h56m
2009	November 20	0924e	~3d00h32m
2009	November 24	2340e	~4d14h16m
2009	November 27	1652e	~2d17h12m
2009	December 2	0652e	~4d14h00m
2009	December 6	0332e	~3d20h40m
2009	December 12	0116e	~5d21h44m
2009	December 14	1812e	~2d16h56m
2009	December 19	2020e	~5d02h08m
2009	December 23	1410vr	~3d17h50m
2009	December 27	0644e	~3d16h34m
2009	December 30-31	~3 ¾ d	
2010	January 3	0628e	~3 ¼ d
2010	January 8	0316e	~4d20h48m
2010	January 12	1000ie	~4d06h44m
2010	January 18	0612e	~5d20h12m
2010	January 22	0004e	~3d17h52m
2010	January 25	0052e	~3d00h48m
2010	January 30	2300e	~5d22h08m
2010	February 2	2332e	~3d00h32m
2010	February 8	0340e	~5d04h08m
2010	February 11	0140e	~2d22h00m
2010	February 18	1212e	~7d10h32m
2010	February 23	1146wc	~4d23h34m

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2010	February 26	0020e	~2d12h34m
2010	March 2	1205	~4d11h45m
2010	March 6	0853	=3d20h48m
2010	March 9	1027wc	~3d01h34m
2010	March 11	2204e	~2d11h37m
2010	March 15	1952e	~3d21h48m
2010	March 18	1448e	~2d18h56m
2010	March 23	1528e	~5d00h40m
2010	March 26	0944e	~2d18h16m
2010	March 29	0616e	~2d20h22m
2010	April 3	0640e	~5d00h24m
2010	April 7	0744e	~4d01h04m
2010	April 10	1608e	~3d08h24m
2010	April 14	1552e	~3d23h44m
2010	April 19	1224e	~4d20h32m
2010	April 24	1048e	~4d22h24m
2010	May 1	0856	~6d22h08m
2010	May 5	1521vr	~4d06h25m
2010	May 11	0128e	~5d10h07m
2010	May 15	1200vr	~4d10h32m
2010	May 22	0000e	~6d12h00m
2010	May 26	0520e	~4d05h20m
2010	June 1	1254	~6d07h34m
2010	June 13	1628	=12d03h34m
2010	June 17	2208e	~4d05h40m
2010	June 22	2152e	~4d23h44m
2010	June 26	2155	~4d00h03m
2010	July 1	2303e	~5d01h08m
2010	July 8	1709	~6d18h06m
2010	July 14	2354e	~6d06h45m
2010	July 19	0655	~4d07h01m
2010	July 23	0726	=4d00h31m
2010	July 27	1956	=4d12h30m
2010	July 31	2330	=4d03h34m
2010	August 5	2328e	~4d23h58m
2010	August 10	1253	~4d13h25m
2010	August 17	2050	=7d07h57m
2010	August 21	1133ns	~3d14h43m
2010	August 24	2016	~3d08h43m
2010	August 28	1744	=3d21h28m
2010	September 1	0421e	~3d10h37m
2010	September 5	0504	~4d00h43m
2010	September 9	2256e	~4d17h52m
2010	September 14	0325e	~4d04h29m
2010	September 18	0211	~3d22h46m
2010	September 21	1335	=3d11h24m
2010	September 27	1027	=5d20h52m
2010	October 1	1856e	~4d08h29m
2010	October 5	0744e	~3d12h48m
2010	October 8	2024e	~3d12h40m
2010	October 14	1042	~5d14h18m
2010	October 17	1808e	~3d07h26m
2010	October 21	0628e	~3d12h20m
2010	October 23	2012e	~2d13h44m
2010	October 27	0544e	~3d09h32m
2010	October 30	~1355	~3d08h11m
2010	November 6	1254	~6d22h59m
2010	November 8	1640e	~2d03h46m
2010	November 12	0432e	~3d11h52m
2010	November 15	2316e	~3d18h44m
2010	November 20	1108e	~4d11h52m
2010	November 24	1608e	~4d05h00m
2010	November 30	0604e	~5d13h56m
2010	December 4	2204e	~4d16h00m
2010	December 9	1320e	~4d15h12m
2010	December 15	0716e	~5d17h56m
2010	December 22	1508e	~7d07h52m
2010	December 28	0608e	~5d15h00m
2011	January 2	1544e	~5d09h36m
2011	January 8	1712e	~6d01h28m
2011	January 15	0104e	~6d07h52m
2011	January 22	0304e	~7d02h00m
2011	January 27	1724e	~5d14h20m
2011	February 3	1408e	~6d20h44m
2011	February 9	2008e	~6d06h00m
2011	February 16	1520e	~6d19h12m
2011	February 21	2032e	~5d05h12m
2011	February 27	0720e	~5d10h48m
2011	March 7	0340e	~7d20h20m
2011	March 13	2000e	~6d16h20m
2011	March 18	2348e	~5d03h48m

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2011	March 23	2024e	~4d20h36m
2011	April 1	1412e	~8d17h48m
2011	April 10	0100e	~8d10h48m
2011	April 15	0604e	~5d05h04m
2011	May 3	0300e	~17d20h56m
2011	June 17-19	unknown	~45-46d
2011	June 29-30	overnight	~11-12d
2011	July 5	2235e	~6d
2011	July 11	0715	~5d08h40m
2011	July 16	0046	=4d17h31m
2011	July 19	1348	=3d13h02m
2011	July 24	0034	=4d10h46m
2011	July 27	0001	=2d23h27m
2011	July 31	2252e	~4d22h51m
2011	August 4	2043	~3d21h51m
2011	August 9	511	=4d08h28m
2011	August 13	0000-0500	~4d
2011	August 17	1259	~4¼d
2011	August 20	~0400	~2d15h
2011	August 23	1020	~3d06h
2011	August 26	1543	=3d05h23m
2011	September 2	~0000	~6d08h
2011	September 5	1125	~3d12h
2011	September 9	0039	~3d13h14m
2011	September 13	2339	=4d23h00m
2011	September 19	1921ie	~5d19h42m
2011	September 23	~0000	~3d4h39m
2011	September 29	1607	~6d16h07m
2011	October 4-5	overnight	~5½d
2011	October 10-11	overnight	~6d
2011	October 14-15	overnight	~4d

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The geysers E-mail mailing list is maintained by David Monteith and Carlton Cross. More information can be found at: lists.wallawalla.edu/mailman/listinfo/geysers.

Black Diamond Pool Eruptions 2006 - 2011

Richard L. Powell

Abstract

Black Diamond Pool erupted on July 13, 2006 after a 45-year dormancy. The Wall Pool area had not been active since 1961. Black Diamond Pool continued to have eruptions that usually occurred without warning, were very violent, were of very short duration, and ranged from about 6 feet to as much as 100 feet in height. No pattern or interval between eruptions has been established because of a lack of continuous observations and an inability to keep monitoring sensors in the pool due to the violence of the eruptions. Rocks used as markers on the north shore of the pool in the summer of 2010 were generally not disturbed, indicating a significant decrease of energy in Black Diamond Pool. Black Diamond reactivated in late October 2011 with eruptions continuing into November.

Below, a photographic overview of the Black Diamond Pool area from the boardwalk at Biscuit Basin. Photos by Janet White-SnowMoon Photography.

Introduction

Several pre-1900 descriptive accounts of Biscuit Basin and early 1900 period maps indicate no springs, pools or hydrothermal features of note in the area now known as Wall Pool and Black Opal Pool. These two pools are shown on the thermal map of the Upper Geyser Basin compiled from aerial photography by the U. S. Geological Survey in 1966 (Figure 1), and also appear on the Geologic map of the Upper Geyser Basin (Muffler, et al. 1982). Black Diamond Pool is in the eastern portion of Wall Pool (Paperiello 1998, p. 110). The paper by Paperiello presents evidence and reports of explosive or eruptive events circa 1912, 1918, 1925, 1934, 1937, 1947-1948, and 1959. Paperiello (1998, p. 109-110) attributed the name Black Diamond Pool to three reports by Frank W. Childs in 1934 that are in the Yellowstone National Park Archives. T. Scott Bryan (2008a, p. 143-145) shows the location and describes Black Diamond Pool. A large-scale sketch map shows features related to a series of eruptions of Black Diamond Pool from 2006 to 2010 (Figure 2).

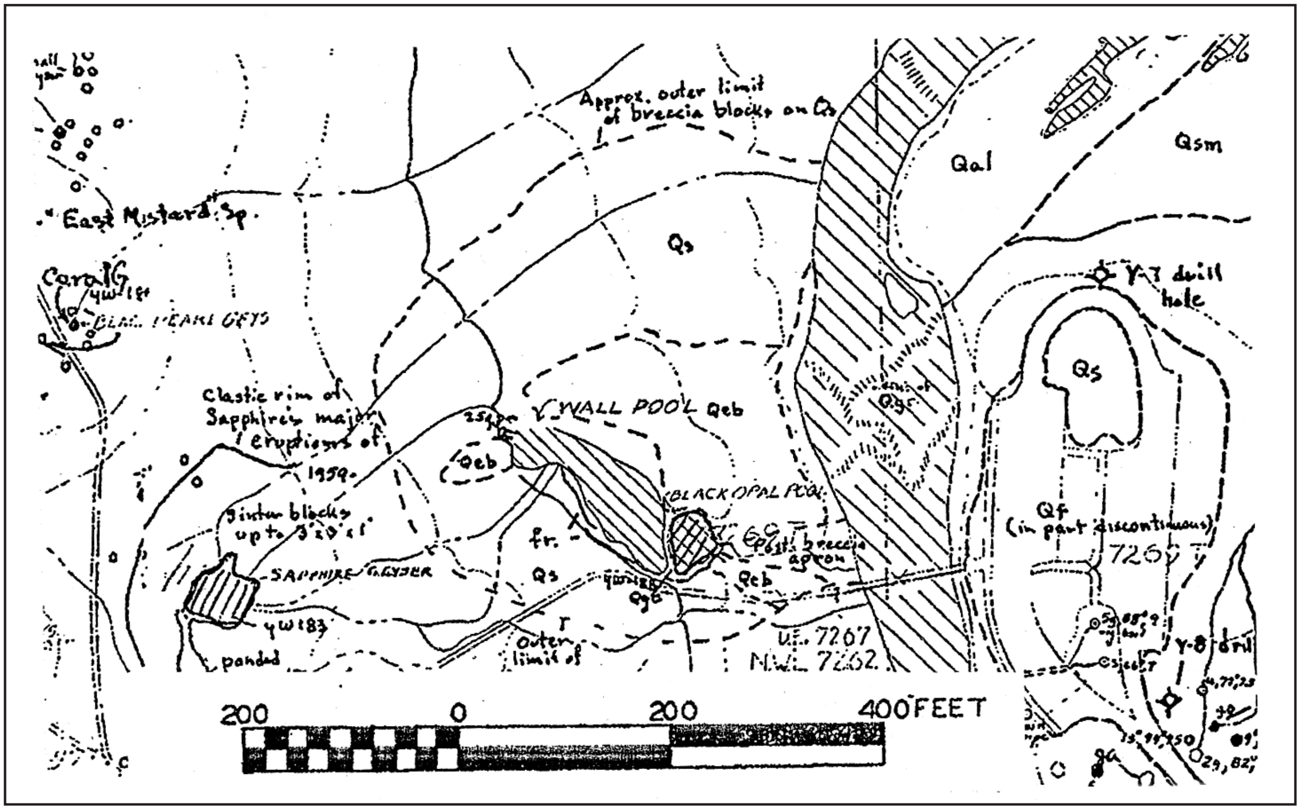

Figure 1: *The extent of Wall Pool as shown on the USGS Thermal Map of the Upper Geyser Basin, 1966, made from aerial photographs taken in August 1965. Modified from a black and white print.*

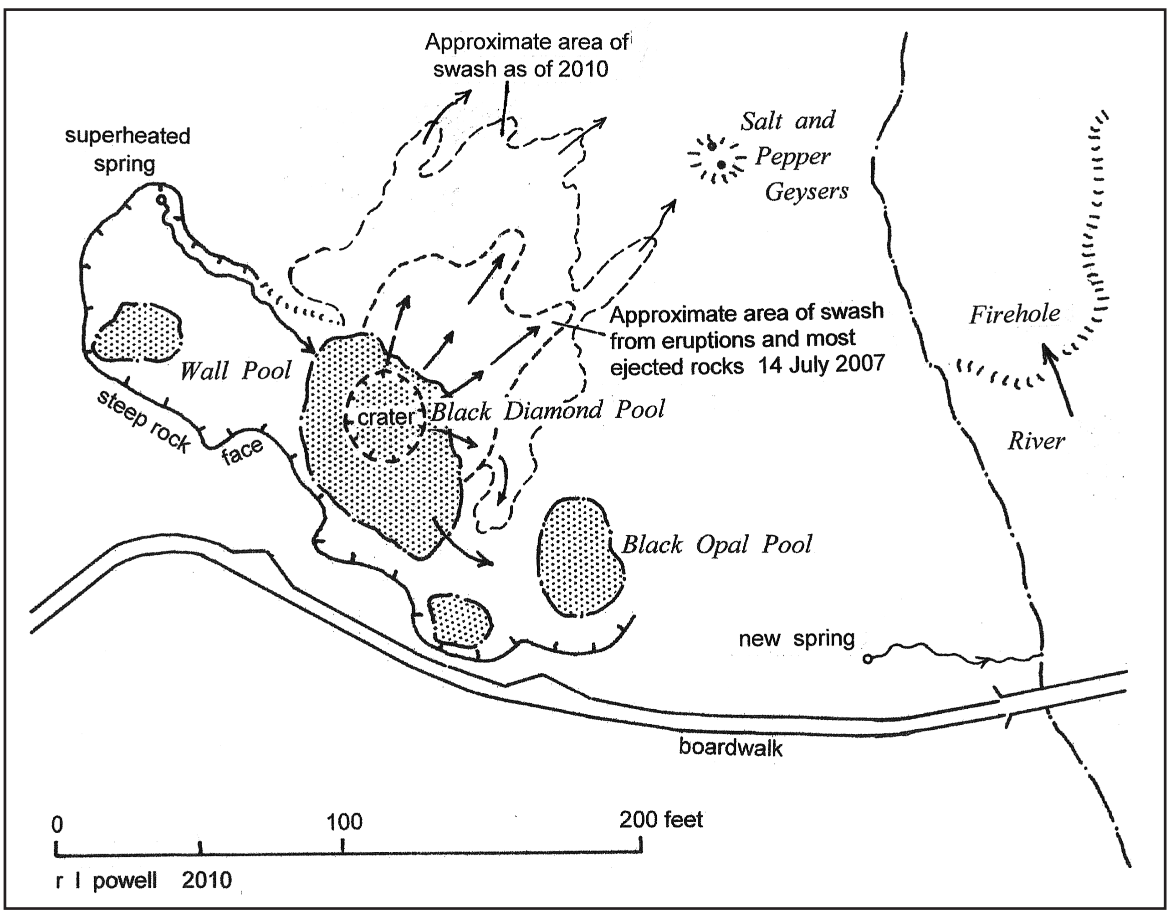

Figure 2: *Sketch map showing the location of Black Diamond Pool within the area of the formerly larger Wall Pool shown in Figure 1, above.*

The following is a sequential record of available data. Times given are Mountain Daylight Time unless indicated as Mountain Standard Time (MST). Times followed by an "E" are from electronic loggers. Electronic data were marshaled by Ralph Taylor. Observations by Richard L. Powell are designated RLP.

2006

July 11 Earthquake, 2.9 mag., 7 miles NE of Old Faithful.

July 13 2108

ERUPTION of Black Diamond Pool, 40 to 50 feet high, witnessed by Kendall Madsen and family and some unnamed visitors. The eruption of Black Diamond Pool was initially seen by Curtis Madsen and then the rest of the Madsen family who were viewing Mercury Geyser (located about 800 feet east of Black Opal Pool at Biscuit Basin). Kendall Madsen reported that one burst reached 40 to 50 feet, consisting of "dark black water and mud surging with powerful bursts. Chunks of debris could be seen as they were expelled from the pool." The Madsens ran towards the pool and arrived as the eruption ended, all within an estimated time of 40 seconds. A visitor in the parking lot told Kendall Madsen that the ground had thumped really hard and he thought it might have been an earthquake (Madsen 2006, p. 32).

July 14 0750 Deploy data loggers and thermistors. Pool water temperature 105.4 ^{o}F.

July 17 0345E

ERUPTION. Time from electronic logger.

0901

ERUPTION. "Four heavy concussions, muddy surges to 6 feet high and all three lower pools muddy. Lowest pool starting to clear by 1100. Mud and rocks ejected." (Bob Spoelhof, YNP interpreter, in Old Faithful interpreters' log book). Loggers 1 and 2 covered with about 1 cm of fine sandy sediment; thermistor 3 partly exposed; logger 2 totally washed with sensor out of water. Gray, gritty sediment deposited to within about 30 feet of Salt and Pepper geysers. Some new gray rocks on top of 13 July sediments.

1550 Redeployed loggers at 1550. RLP

July 20 2256E

ERUPTION. Data logger time. Apparently a small eruption, small increase in discharge, possible new rock in wash area, pools turbid. RLP

July 21 0740 Loggers intact. RLP

July 23 0824E

ERUPTION. Unknown visitor report to Visitor Center, they estimated height to 25 feet.

0850 Tan scum on SE half of pool, occasional bubbling in center of pool. RLP

1015 On site. About 1 cm fresh fine sediment over area, logger 2 exposed, thermistor washed out of pool. Water temperature 136.1 °F. White sinter fragments and grayish grit blown onto boardwalk at second (western) bench. RLP

1447 Bubble in pool about 2 feet wide and 1 foot high. RLP

1707 Bubble about 8 inches wide and 3 inches high. RLP

1713 Several bubbles about 4 inches wide and I inch high. RLP

July 24 0725

ERUPTION. An estimated 15 feet high, dark, vertical, single blast out of the deeper part of the pool, about 15 feet wide, lasting about 6 to 10 seconds. The major uplift was about 12 feet high with several spikes or plumes of water a few feet higher. The entire mass of water dropped back into the pool, creating a wave over a foot high. Very little water hit the north shore, within several seconds most of the runoff ran into the next lower pool on the east. RLP

Only a very minor vertical spike was recorded on the thermistor in the pool at the time of the eruption.

July 24-25 Time unknown

ERUPTION. "Black Diamond clearly erupted during the night, as my water level-marker rock of yesterday was gone today" (Bryan 2006a).

July 27 1710E

ERUPTION. Time from a major spike on the pool and one of the soil thermistors. "Apparently Black Diamond was seen yesterday [27 July], by visitors at around 1700 who described it as 40 or 50 feet high" (Bryan 2006b).

July 27-28 Time unknown

ERUPTION. "This morning [July 28] [Black Diamond Pool] had clearly erupted again, as the wash area to the northeast was quite wet. Rocks not visible yesterday were widespread today, and the flat 'muffin' rock that yesterday was within the pool is now about two feet outside of the pool (this rock is maybe 18 inches across and 6 inches thick)" (Bryan 2006b).

July 29 1753

ERUPTION. A 20-foot high sudden burst of black water 10 to 15 feet wide, lasting about 20 seconds. Witnessed by Mike Keller: "When I arrived, Black Diamond was in overflow with periodic bubbling seen over many areas of its basin. The water was grey/white and very murky. In the center, slightly off to the north, there appeared to be heavier, more consistent periods of upwelling and bubbling. Most of the bubbles were marble to golf ball sized. Over the next 7 hours, the water level slowly rose about ¼". Starting at 1604, the bubbles coming over the main vent would occasionally be softball sized. Finally, at 1753, Black Diamond erupted. There were about 7 of us staring at the pool when it started. It gave NO warning. There was another softball sized bubble, then suddenly the whole center of the pool heaved and it was in eruption. The eruption lasted about 20 seconds and reached as much as 20 feet in height, being as wide as it was tall. Loud thumping and popping sounds could easily be heard while it was erupting. The water color changed from the milky grey/white to obsidian black. It looked like it was erupting asphalt. The lower third of the water column was 'chunky' with rocks, gravel, and debris. As quickly as it started, the eruption stopped. Over the next 90 minutes there were several periods of heavy upwelling but no further eruption was seen. The periods of upwelling gradually diminished until they were no longer visible at 1940. When I left the area, Black Diamond looked exactly as it had when I arrived at 1100" (Keller 2006).

There was no identifiable spike on the electronic record. There was a temperature increase of about 3 °F near the time of the eruption. The water and ground temperature dropped about 9 °F about 25 minutes before the eruption. The thermistor in the pool was blown out onto the ground. RLP

July 31 0320E

<u>ERUPTION</u>. Electronic data shows that pool water temperature rose from 100 °F to 142.5° F and soil temperature from 76°F to 147°F within two minutes. The pool water thermistor leveled off at about 124°F within six minutes, then slowly declined to 122°F eighteen minutes after the eruption. The soil declined steadily to its original temperature in about an hour.

On-site inspection at 1650 showed the #1 and #3 soil thermistors washed away, with the pool probe wire moved. The area was coated with an olive-gray silty clay a few millimeters thick and abundant scattered fragments of silicious microbial mat. RLP

August 1 0937E

<u>ERUPTION</u>? Electronic data showed an abrupt pool water temperature rise from about 110°F to 119 °F, followed by a rise to 123 °F by about 1200. Soil temperatures rose about 5 °F at the spike, then about 2 °F by 1200. Another spike in pool temperatures, ranging from 110 °F to 114 °F, occurred at about 1838, with a corresponding rise and fall in soil temperatures of about 2 °F. Black Diamond appeared to have erupted. All loggers and attendant cover rocks were intact, with thermistor #2 still in the pool. New black and white rocks were blown to the southwest of Black Diamond Pool. Pool temperature 8 feet from the bank was 111.6 °F (44.1 °C). RLP August 2 at 1310

August 7 0111E

<u>ERUPTION</u>. Electronic data show an abrupt temperature increase from about 113 °F to 137 °F, after a drop to 104 °F. Soil temperatures abruptly rose 15 °F, then dropped to normal, about 166 °F to 167 °F within an hour.

August 8 0903 On site for downloading loggers. Pool temperature 6 to 7 feet from bank 107.6 °F (42.1 °C) and 107.8 °F (42.1°C). RLP

August 9 1455, 1605, 1750, and 1820 Small bubbles persist on surface for several minutes. Tan scum-like surface in bubble area, but no scum on edge of pool. RLP

August 17 0123E

ERUPTION. Abrupt spike in pool water temperature from 103 °F to 106 °F, then to about 111 °F by 0115 with about a 3-degree rise and rapid decline in soil temperature.

August 18 1415 Black Diamond Pool turbid, rocks covering wire to thermistor in pool moved, wire exposed. The other pools were not affected. RLP

August 20 1715 Black Diamond Pool clearing along edges. RLP

August 22 1040 Downloading visit. No footprints in logger areas from previous visit. No sediment on loggers, cables still in pool, but grass pointing toward pool, with a wash over much of the original area as a result of the 17 August eruption. RLP

1854E

ERUPTION. Electronic data shows an abrupt spike of pool water temperature from 108 °F to 129 °F with a decline to about 116 °F in 35 minutes. Soil temperature in logger #2 rose from 85 °F to 90 °F within seven minutes, then declined rapidly to night time temperatures.

The eruption lasted about 20 seconds to a height of over 20 feet witnessed by David Carr (student, SPEA, Indiana University) and Hal Shepard (student, chemistry, Indiana University) from the junction of the boardwalk west of Sapphire Pool. The event was announced by Paul Webb on the GOSA channel at about 1855. Rocks on the bank that covered the thermistor cable into the pool washed away. Tan scum was circulating on the surface of the pool. Loggers appeared intact as in the morning. Black "gunk" was thrown up by the eruption, some splashing onto the bank near the western (2nd) bench, but the lower pools were not muddy. RLP 1906-1925

August 23 0750-0840 Downloading loggers: Footprints gone, loggers coated with gray silty and very fine sand sediment Sediment extended towards Salt and Pepper Geyser, but most flow appeared to have been back into the pool. Cable for logger #2 moved, but still in pool. RLP

August 29 1132 Download loggers at Black Diamond Pool. Old footprints obvious but modified by rain. RLP

September 4 ~1850

ERUPTION? Visitor report of black mud, flood into Firehole River.

September 8 0325E

ERUPTION. Electronic data until the thermistor in Black Diamond Pool was thrown out of water after rise from 108 °F to 118 °F. Soil temperature rose from 78 °F to about 88.5 °F, then declined rapidly.

September 9 ~1750 Keith and Lotus Baker noted that rocks on the logger cable going into the pool had moved.

Sept. 10 0925-0940 View from boardwalk: rocks on cable (thermistor #2) into pool are gone and cable washed away from pool; cable on soil (thermistor #3 exposed owing to rocks on cable moved; rocks on loggers intact.

1100-1149 On site: no footprints visible; logger #1 covered with thin coating of fine sand with a new siliceous microbial mat rock on top of pile; loggers #2 and #3 coated with fine sand; no download on logger #1, the other two were downloaded. No footprints in sediments, rocks on loggers intact. RLP

September 23 1730vr

ERUPTION? "…Saturday [September 23], at 1730vr, Black Diamond had a powerful eruption that visitors caught on camera. The report is that the images indicate an eruption height of 100 feet. I was also told that the eruption put a lot of debris onto the boardwalk, but this afternoon I could see no sign of that whatsoever" (Bryan 2006c). No photographs or additional information were found to verify this eruption.

October 3 Report: "Black Diamond has not erupted in days – its water is the clearest I've seen since the first activity in July" (Bryan 2006d).

October 4 Report: "Black Diamond and all the other pools in that complex have now cleared to the point that their water is starting to get a blue tint to it" (Bryan 2006e).

Dec. 26 ~1305

ERUPTION. "A winter guide, Rowan [Laing], noticed black, muddy water flowing into the Firehole by the Biscuit bridge, went to investigate, and found visitors that saw Black Diamond erupt. I spoke with them this morning and what they saw was from the back boardwalk at Biscuit, and was they think near the end of the eruption. They were impressed by the very dark muddy water, which they estimated at 20 feet tall. The time was about 1305 on 12/26" (Loren 2006).

2007

April 4 Report: "Black Diamond and Wall Pool were both clear when I went by them today" (Keller 2007a).

April 7 ERUPTION? "Black Diamond and Wall Pool were murky at 1325. There was evidence of fresh wash around Black Diamond" (Keller 2007b).

April 20 Report: "At Biscuit Basin, the water in Black Diamond is murky gray-green, clear enough to see that orange bacteria extends well down into the crater" (Bryan 2007a).

May 31 1830 vr

ERUPTION. "Found out via a newspaper article, then looking at the logbook, that Black Diamond evidently erupted at 1830 on May 31. Indeed, there is now less orange bacteria in the crater than there was earlier" (Bryan 2007b).

July 14 1240 Black Diamond Pool dark olive green. RLP

July 30 0820 Black Diamond slightly turbid. RLP

Nov. 9 1830 Black Diamond murky (Keller 2007c).

2008

Feb 8 1428

ERUPTION. Black Diamond eruption to 7 feet (Old Faithful Visitor Center logbook)

March 3-4 Overnight

ERUPTION? Black Diamond "event." "Later on Rowan Laing reported a lot of sediment in the 'pool up from Opal'; Jim Holstein saw a wider runoff channel, and sediment, with some snow on top. Since Biscuit is visited daily by many guides, it seems likely an overnight event 3/3-4 also" (Loren 2008).

April 24 Evening

ERUPTION. Black Diamond eruption to 15 feet. "I stopped by Biscuit Basin to look at Black Diamond in driving snow. It bubbled. However, as I think I noted before, the surroundings look as though there has been a fair amount of activity, and, indeed, Mike said he saw it to maybe 15 feet last evening" (Bryan 2008b).

June 11 ~1220 vr

ERUPTION. "Black Opal or feature next to it erupted 'high' and dark with rocks for about 30 seconds" (Jane McHough, note to Ralph Taylor).

June 24 ~0900-1000

ERUPTION. Black Diamond (Old Faithful Visitor Center logbook).

July 7 ~1730 vr

ERUPTION. Black Diamond (Old Faithful Visitor Center logbook).

July 24 0923

ERUPTION. Black Diamond, 5-10 second eruption to 20-25 feet high. Seasonal interpreter Rich Jehle reported: "FYI today at 0923 seasonal interpreter Jane McHugh and I witnessed a 'forceful eruption' of Black Diamond pool at Biscuit Basin while Jane was leading an interpretive walk to Mystic Falls. We were standing at Jewel Geyser when the group heard a loud noise. Everyone turned to see the source, and we witnessed an eruption that lasted approx. 5-10 seconds, and was approximately 20-25 feet high. The water being erupted was very black and appeared to contain mud and gravel. From that distance we were not sure what feature it was. After Jane completed her walk to the waterfall we walked back to the area and could tell it was Black Diamond because the pool was very milky, opaque and discolored. It had been semi-clear when the group walked by it at about 0915. Wall Pool was still pretty clear (unchanged from when we had seen it about 0915), but Black Opal was also milky, apparently from the runoff flowing into it from Black Diamond. Unfortunately it all happened so quickly that no one in the group got photographs that we are aware of. Anyway it was pretty neat to see. I have never seen anything like it in my time in Yellowstone" (Kelli English, e-mail to Henry Heasler).

July 29 — 1200 Black Diamond gray and turbid. RLP

Aug. 14-16 — Time unknown

ERUPTION? At ~0915 on August 16, Black Diamond had turbid runoff, possible eruption within past few days. RLP

September 8 — ~1100 Put series of rocks in 3 rows on north shore of Black Diamond. RLP

September 14 — ~1200 End of monitoring for 2008.

2009

May 17 — 0943

ERUPTION. Black Diamond had 10-second eruption to 50 feet seen by Hank Heasler and group of geologists, geophysicists and graduate students (Angus M. Thuermer, AP news report). Time from anonymous photographs taken by a member of the group.

June 13 — No time given

ERUPTION. "I seem to have not previously mentioned that on June 13, in the rain from the parking lot, I saw a couple of 6-foot bursts by Black Diamond" (Bryan 2009).

June 29 — ~0830-0930

ERUPTION. "2 visitors claimed that they saw a big, black eruption from what is Black Diamond,…I showed them the photo of the May 17 eruption and they said that was it" (Joanne Kearney, note to Ralph Taylor, June 30, 2009).

July 7 — Time unknown

ERUPTION? At 1700 on July 7, Black Diamond was very turbid, 2-3 inch visibility into water, fragments of white bacterial mat washed into grass downstream in channel towards Black Opal Pool. Probable eruption prior to visit. RLP

July 12 — Markers placed on the far (North) bank of Black Diamond Pool, consisting of four rows, five rocks per row, spaced about a foot apart up the bank. Reported to Visitor Center to hopefully gain additional observations. RLP

July 16 — 1535 Markers in place, 4-5 inch visibility into water. RLP

July 18 — 1340 Markers in place, about 5 inch visibility into water. RLP

July 20	1215 Markers in place. RLP
July 21	1835 Markers in place. RLP
July 24	Time unknown
	<u>ERUPTION</u>. At 1825, markers were gone, about 1 inch visibility into water. RLP
July 25	0925 Markers replaced, consisting of three rows, five rocks per row. RLP
July 26	1820 Markers in place. RLP
July 30	Time unknown
	<u>ERUPTION</u>. Markers gone at 1905. RLP
July 31	0945 Markers replaced. RLP
August 1	0745 Markers in place. RLP Markers in place, about 4 inch visibility into water. RLP
August 1-2	Time unknown
	<u>ERUPTION</u>. Markers gone at 0910. RLP
	0930 Markers replaced. RLP
August 3	0845 Markers in place, about 3-to-4 inch visibility into water. RLP
August 4	1040 Markers in place, about 4-inch visibility into water. RLP
	1516 Markers in place. RLP
August 5	1905 Markers in place. RLP
August 6	1148 Markers in place. RLP
August 7	0830 Markers in place. RLP
August 7-8	Time unknown
	<u>ERUPTION</u>. Markers gone at 0755. RLP
	1230 Markers replaced. RLP
August 9	1005 Markers in place. RLP
August 10	1015 Markers in place. RLP

August 10-11 Time unknown

<u>ERUPTION</u>. Markers gone at 0850, about 1½- to 2-inch visibility into water. RLP

August 12 1240 Markers in place. RLP

August 13-15 Markers in place. RLP

August 16 0014E (MST)

<u>ERUPTION</u>. Black Diamond eruption (electronic time from Ralph Taylor).

0810 Markers gone – replaced. RLP

August 17 0820 Markers in place

August 18-21. Markers in place. RLP

August 22 1850 Markers in place, lots of small bubbles. RLP

August 23 0745 Markers in place. RLP

1642 Markers in place, some bubbling. RLP

August 24 0147E (MST)

<u>ERUPTION</u>. Black Diamond Eruption (electronic time from Ralph Taylor).

0935 Some markers gone, thermistor still in water. RLP

August 25 1830 No change from above. RLP

August 26 0900 Download recorder and replace markers. RLP

August 27 1825 Markers in place. RLP

August 28 and 29 Markers in place. RLP

August 30 0745 Markers in place. RLP

1531E (MST)

<u>ERUPTION</u>. Black Diamond eruption (electronic time from Ralph Taylor).

September 1 0845 Markers in place. RLP

September 2-20 Markers in place. RLP

September 21 1205 Markers in place. RLP

1800 Two or three rocks gone, microbial mat intact. End of marker monitoring. RLP

September 26 1853

ERUPTION. Visitor report of eruption of Black Diamond. They said "near Wall Pool but not Wall Pool itself" and that the eruption "was black and as tall as the trees" (Ralph Taylor, e-mail to author, September 30, 2009). The sign for Wall Pool is at the west end of the area.

2010

January 26 ~1455

ERUPTION? Possible eruption by Black Diamond, also possibly "Salt and Pepper"; reports inconclusive. Karen Low reported: "Nancy Olsen, guide for Yellowstone Expeditions, reported that she and her tour group at Sapphire Pool saw an eruption "about 25-30 feet high of black-looking water, from right by the river, about 50 feet downstream of the bridge across the river"…"and that it did three bursts. They said it was still splashing a few feet afterward" (Low 2010). Carolyn Loren reported: "talking to Nancy Olsen, noted that the eruptions may have been "Salt & Pepper (aka Salt & Salt): three 30 foot muddy bursts at about 1455 on 26 January. I skied by there yesterday [January 26] about 1330 and all was clear and as usual then (Loren 2010).

January 30 Report: "Black Diamond was boiling heavier than normal today" (Holstein 2010a).

Jan.-Feb. Time unknown

ERUPTION? "I believe Black Diamond may have erupted in the past three weeks, there are a couple of new rocks between Black Diamond and Black Opal Pool. There is a new runoff channel from Black Diamond that spills directly into Salt & Pepper. There is some bacteria mat that has been disturbed below Black Opal Spring. Keep in mind I have not been in for 3½ weeks, so it may have happened anytime" (Holstein 2010b). Note: The new runoff channel would only carry water during some larger eruptions. RLP

Feb.-Mar. Time unknown

ERUPTION? "Wall Pool/Black Diamond is now one big hole, and its level is only an inch or two higher than Black Opal Pool. I think this is due to the eruptions washing away the edge of the pool, but I'm not sure" (Eide 2010).

April to June Times and dates unknown

ERUPTIONS. Workmen on new boardwalks report two eruptions of Black Diamond at unrecorded times when asked by Henry Heasler. (Henry Heasler, personal communication, summer 2010)

July 11 Placed markers on Black Diamond. RLP

July 15-24 Markers in place. RLP

July 25 Markers in place. Pool milky blue color. RLP

July 26-31	Markers in place. RLP
August 2-19	Markers in place. RLP
September 1	Markers in place. RLP

2011

February	Report: "A guide reported that sometime between one and two weeks ago he noticed a disturbance in the bacterial mat around Black Diamond (flipped mat it sounds like), and murky water within it" (Loren 2011a).
February 28	Report: "On 2/28, I checked Black Diamond and saw numerous lighter green patches inside the pool, which looked near-black otherwise. The water was pretty clear" (Loren 2011b).
April 16-24	Report: "Black Diamond was warm and getting clearer and the algal mats between it and Black Opal Pool are intact so I doubt it has erupted recently" (Eide 2011a).
July 5	Westernmost row of three rock markers on North bank of Black Diamond Pool in place. RLP
July 17	Lower marker gone, possibly moved several feet east and into the edge of the pool. RLP
August 28	Two remaining markers surrounded by more silt. RLP
September 23	Two remaining markers gone or buried. RLP
October 27	Before 1645 ERUPTION. "…at 1645 a visitor reported that…there was an explosion of water and rocks in the Wall Pool area." Reported to be over 60 feet high and 30 feet wide at the Mammoth visitor center 28 Oct. (Warnock 2011a). The visitor who saw the eruption talked to a park ranger at the West Entrance and stated that the eruption was "very loud" and "most of the rocks and debris went into Black Opal Pool" (Warnock 2011b). NOTE: The sign in the bench area at the West end of the Wall Pool area incorrectly claims it to be "Black Diamond Pool," while the Black Diamond Pool area is labeled "Wall Pool," Black Opal Pool at the East end nearest the river is properly labeled.
October 28	Report: Bill Warnock visited Black Diamond around 1630 and noted that the area between Wall Pool and Black Opal Pool was "one huge pond, larger than before, of murky gray water, with ejecta mainly towards the river. There is some on the boardwalk as well. There were two places in Wall area with intermittent boiling" (Warnock 2011a).
October 29	Report: "…The new unified muddy gray pool was down slightly from yesterday, and rocks were visible in the area of Black Opal, and the rocks west of Wall were visible just under the surface. Another change: yesterday "Salt and Pepper" down near the river was white in the right vent and gray in the left vent (when viewed from the parking lot). Today both were brown-black and more vigorous" (Warnock 2011b).

October 29 ~1130

<u>ERUPTION</u>. M. A. Bellingham reported, "I arrived at Wall approximately 1140 and spoke with visitors who had seen another 'large' eruption about 10-20 minutes before I got there. I asked '60'? and the man replied that was accurate. He said flying rocks were visible in the eruption and the water was very dirty…. The small boys with him did excitedly confirm it was 'Big!!'" (Bellingham 2011).

October 30 Report: "…the water level appears to have dropped about ½ meter judging by the obvious runoff in the grass. It appears that Black Diamond may have filled Black Opal with debris. The runoff of this eruption(s) does not appear to have reached Salt and Pepper. By mid day, Salt and Pepper have cleared some, with the vent further from the river, erupting more vigorously than normal, shooting about 4 feet consistently" (Holstein 2011a).

On reconsideration, Holstein reported that "it does appear that Salt and Pepper's murky eruption was due to debris washing into the geysers. Also judging by the washed grass, this eruption(s) [of Black Diamond Pool] put out a tremendous amount of water" judging from the washed grass, extending to beyond Salt and Pepper Geysers. "Sandy, muddy water spots are visible on the boardwalk" (Holstein 2011b).

"Jim Holstein tells me that the Wall Pool group was in overflow at 1100, but it was not when I was there at 1540" (Warnock 2011c).

October 31 Report: "The Wall Pool group was in overflow when I arrived today (Oct. 31) at 1230, flowing from a northeast gap in Black Opal's ridge down into he [sic] Firehole. Another gazer said that it had not been in overflow at 0730…. I watched this afternoon (Oct. 31) until 1545, and it was still in overflow. No boiling seen but the water level is higher than yesterday afternoon" (Warnock 2011c).

Report: "While we were at Biscuit Basin we had two period[s] of heavy boiling out of Black Diamond, up to 3 feet high and increasing the runoff in the channels. … The boils were at 13:56 and 14:01" (Holstein 2011b).

November 1 Pre-1150

<u>ERUPTION</u>. "… as snow melted, it was apparent there had been a lot of Black Sand and geyserite rocks ejected sometime between when I left yesterday at 1545 and this morning" (Warnock 2011d).

November 1 1459

<u>ERUPTION</u>, witnessed by Bill Warnock: "When I arrived at 1150, there was overflow from Wall/Black Diamond/Black Opal Pool..it is all one level now with no barriers visible because of the muddy gray waters. … There was no visible boiling in the Black Diamond area…. I was in the parking lot …, when suddenly at 1459 came a loud noise and a powerful surge of black water and steam from Black Diamond. I estimate it reached at least 40-50 feet high and 30 feet wide. … it lasted only seconds, and there was no afterburst. There was tremendous runoff, including through Salt and Pepper, which afterwards erupted black water. I went up to the pool, and it had dropped several inches. Overflow ceased, and had not recommenced as of 1625. Black Opal showed a lot of debris in its pool. … What an experience! Go Black

Diamond!" (Warnock 2011d).

November 2 Report: "I checked Black Diamond this morning and Salt and Pepper was white again, it had washed out all the dark sand… The pool was in overflow. …I think … there was no eruption of Black Diamond overnight or during the day today" (Eide 2011b).

November 3 Overnight

ERUPTION. "No Black Diamond was seen, however Salt and Pepper was full of dark sand so it appears it erupted overnight. Oddly enough the Pepper vent is very weak and mostly clear now but the Salt vent has most of the obsidian sand so it is now dark" (Eide 2011c).

November 4 Report: "Most of the afternoon was spent watching Black Diamond. The pool does rise and fall a little, maybe half a centimeter up and down. It also sometimes has weak waves out of the vent. …Salt and Pepper has cleared a little compared to yesterday evening but still had obsidian sand and rocks in it all day" (Eide 2011d).

2012

January 13 1200ie vr

ERUPTION. "Visitors reported a black eruption behind the Wall Pool sign sometime around mid-day today: they had no watch. It lasted about 10 seconds. A snowmobile group also saw it, so the visitor center may get a better time at some point" (Loren 2012).

Editors' Conclusion

Based on electronic data, visual observations, and use of markers, the activity of Black Diamond was monitored from the time of its first known eruption on July 13, 2006 through September 2010. The highest concentration of eruptions appeared to be in the two months following its initial reactivation. Starting in September 2006, eruptions became uncommon and sporadic. Only two eruptions are known for 2007 and eight for 2008. Black Diamond was a bit more active in 2009, with eruptions every 1 to 2 weeks from May through August. In 2010, there were two possible eruptions in January and February and two known eruptions between April and June. Black Diamond was not regularly monitored after this time, but based on the lack of noted disturbance to the area, it is likely that there was no activity until several eruptions were seen in late October and early November of 2011.

Acknowledgments

Ralph Taylor deserves particular praise for trying to find ways to install monitoring equipment in Black Diamond Pool such that the thermistors were not merely blown out of the pool to indicate an eruption, and for interpreting the meager records obtained. Special thanks to the National Park Service and Park Geologist Henry Heasler for supporting the thermal monitoring program. Thank you to all the rangers, geyser gazers, and park visitors who reported on the activity of Black Diamond Pool. Thanks go to the anonymous reviewers whose comments were helpful in improving this paper.

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The geysers E-mail mailing list is maintained by David Monteith and Carlton Cross.
More information can be found at:
lists.wallawalla.edu/mailman/listinfo/geysers.

BLACK DIAMOND POOL 2011 ERUPTION PHOTOS

Bill Warnock's photo of the Black Diamond Pool eruption he witnessed on November 1, 2011 at 1459. In a note to the editors, he stated that the eruption was taller than this photo shows.

October 28, 2011

September 2011

Bill Warnock took the photo series on the left after Black Diamond Pool's eruption on October 27, 2011. Above are Janet White's photos, taken in September 2011, to show how the area looks when Black Diamond Pool is not active.

Twelve Hours in the Life of White Dome Geyser

Stephen Michael Gryc

Abstract

Eighteen successive eruptions of White Dome Geyser were observed on June 19 of 2011. The recorded data show that there is little correlation between the intervals (which vary widely) and durations (which do not vary widely).

Introduction

There are frequent reports of start times for White Dome Geyser that come from the many visitors who explore the Firehole Lake Drive area, but few people time the duration of the eruptions. One of the goals of my observation was to determine if the length of intervals between successive eruptions bore any relation to the duration of those eruptions. On June 19 of 2011, I observed 18 successive eruptions of White Dome Geyser in 12 continuous hours of observation.

The Cone of White Dome Geyser

White Dome Geyser features one of the largest geyser cones in Yellowstone. It is exceeded in size only by Castle Geyser and the old geyser cone known as the White Pyramid (Bryan 2008). The approximately twelve-foot cone sits atop a broad mound of hot spring deposits.

White Dome's formation is more colorful than its name suggests. The northern face of the cone has white deposits showing over darker deposits like a light snowfall on a mountainside. The southern face has red deposits in its upper half as well as a smaller area of black deposits. Runoff from the geyser has built low reddish terraces along the eastern base of the cone where the water flows north, dividing into two channels. The small orifice at the southern tip of the cone has a broken look that can be described as crenelated or toothed.

Photo 1: The northern face of White Dome Geyser's cone, June 19, 2011. The terraces being built by geyser runoff are the dark area seen to the left of the cone's base. Photo by Stephen Gryc.

Photo 2: The southern face of White Dome Geyser's cone, June 19, 2011. Photo by Stephen Gryc.

Eruption Characteristics

There was often no sign of imminent eruption. Occasionally eruptions were preceded by a weak splash, or a few splashes, and a brief pause before continuous jetting. The narrow plume-like water column of White Dome's eruption contrasts with its massive and rugged-looking cone. I found the pulsing jet to be remarkably quiet. There were brief pauses near the beginning and the end of the briefest and weakest eruption observed. The height of the water column gradually built to a maximum of 30 feet in 15 to 30 seconds after the commencement of the play. The water column declined very gradually in height and volume during the second minute of the eruption.

Recent Observations of White Dome Geyser by Lynn Stephens

Although I observed White Dome Geyser for a lengthy period on one day, the number of eruptions I observed is still a very small sample. Lynn Stephens has logged thousands of White Dome intervals over several years, 2,248 during the years of 2005 through 2009. Her statistics for those years show a pattern of intervals similar to what I observed in that there has been a sharp decline in the number of eruptions with intervals longer than 40 minutes.

Stephens (2004) summarized her eruption data for three years in her article "Activity of Selected Geyser—Second Part of Summer 2009 Season" in the October 2009 issue of *The Geyser Gazer Sput*:

> The minimum interval for all time periods [2007, 2008 and the second half of the 2009 summer season] was 13 minutes. The maximum interval of 2h28m in 2007 was 21 minutes longer than the maximum interval of 2h07m in 2008 and 20 minutes longer than the maximum interval during the second half of the 2009 summer season. The "average" interval has stayed basically the same across the three years. The median interval of all years was 29 minutes. The mean

Photo 3: The weather on June 19, 2011, was cloudy with sporadic rain and fog. The skies cleared briefly for this sunlit photograph of the eruption at 1554. The photo was taken from the boardwalk east of the geyser. Photo by Stephen Gryc.

> interval in 2007 was 34 minutes compared to the mean interval of 33 minutes in 2008. The mean interval went back to 34 minutes during the second half of the summer 2009 season.

My observations in 2011 fit into the general pattern that Stephens has observed in recent years, though the longest intervals she logged were significantly longer than any I recorded. Stephens hasn't reported eruption durations, so the chief interest in this article lies in the relationship between eruption intervals and durations.

Observations of June 19, 2011

The weather on June 19 of 2011, was cloudy, foggy and rainy, making it a good day for observing geyser activity from inside a car. The parking area at White Dome Geyser affords a close and unobstructed view of a beautiful and frequent geyser, so this observer spent twelve hours continuously monitoring this emblematic spouter.

Because White Dome is prominently situated in a heavily visited area of the Lower Geyser Basin, many visitors report start times. Most of White Dome's intervals are relatively short (half an hour or less), and these intervals are sometimes reported. Longer intervals may be under-reported as people get impatient or discouraged after the more frequent, shorter times are surpassed. Durations are only infrequently reported, so relationships between intervals and durations have not been noted.

Intervals and Durations, June 19, 2011

Most of the intervals I recorded were distributed equally around the half-hour mark with 9 of the 17 intervals observed in the range of 25 to 35 minutes. There were, however, three intervals that were much longer, around 80 minutes. There was a big gap between the one interval of 41 minutes, 13 seconds and the next longer interval of 1 hour, 18 minutes, 57 seconds. These long intervals caused the mean interval of those I measured to be around 39 minutes though 13 out of the 17 were shorter than that. The median interval was still around 30 minutes. The shortest interval I observed was 16 minutes, 39 seconds, and the longest was 1 hour, 23 minutes, 14 seconds.

The first two long intervals were preceded and followed by intervals much closer to the mean, so I wondered if there might be two or more longer intervals in succession. My 12-hour observation ended 43 minutes after a long interval, which at least suggested that I was in the middle of a consecutive long interval.

Durations fell in a relatively narrow range, from 1 minute, 46 seconds to 2 minutes, 6 seconds. The twenty eruptions observed had a mean duration of 1 minute and 56 seconds with five durations of 1 minute and 57 seconds that established the mode.

Relationship Between Intervals and Durations of Eruptions, June 19, 2011

The three eruptions that occurred after long intervals had durations of 1 minute 56 seconds, 1 minute 57 seconds, and 1 minute 58 seconds. For this admittedly small sample set, longer intervals did not result in any divergence from the mean duration (1 minute and 56 seconds) or the mode duration (1 minute and 57 seconds).

The shortest duration of 1 minute and 35 seconds occurred after a short interval of 19 minutes, 4 seconds, but the shortest interval of 16 minutes, 39 seconds was followed by a duration of 1 minute and 51 seconds which is much closer to the mean. Fig-

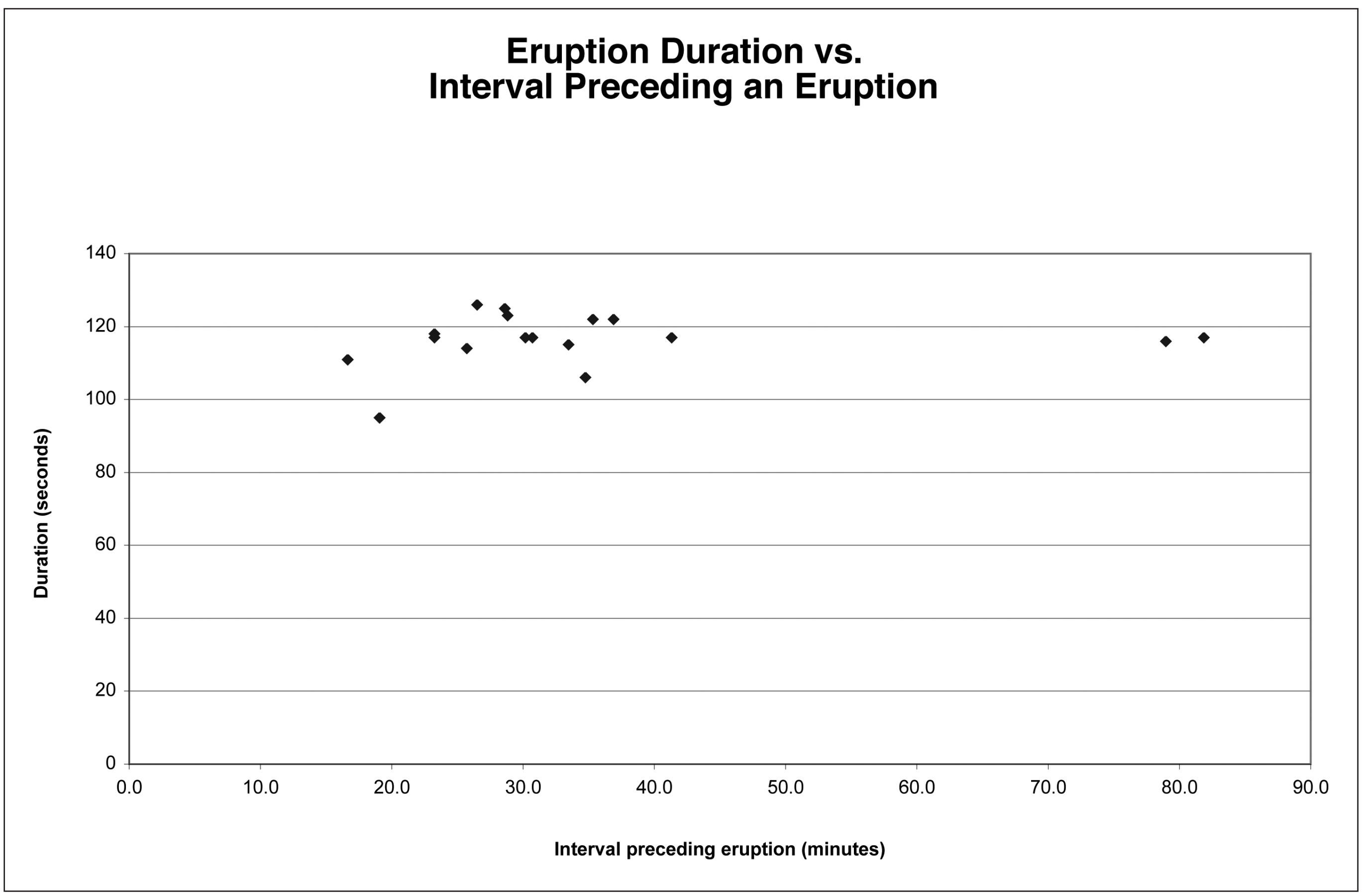

Figure 1: *Graph of eruption durations plotted against their preceding intervals for White Dome data obtained on June 19, 2011. Graph by Jeff Cross.*

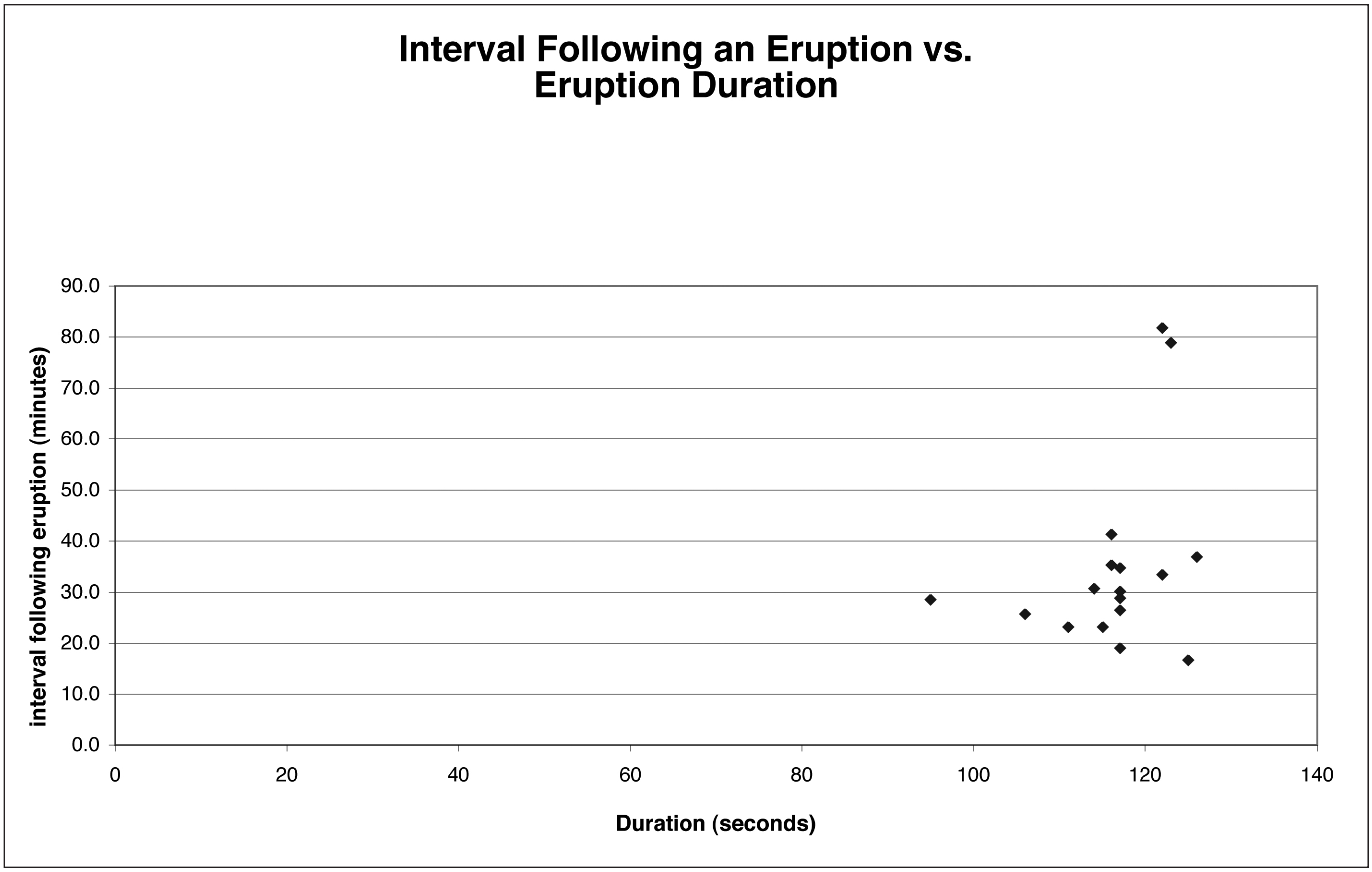

Figure 2: *Graph of interval lengths plotted against the eruption durations that they follow for White Dome data obtained on June 19, 2011. Graph by Jeff Cross.*

ures 1 and 2 summarize, in a graphic way, the data for interval and duration times.

The graph in Figure 1 *(page 87)* shows the general consistency of durations after long intervals in relation to durations after shorter intervals. The longest durations recorded followed intervals that were very close to the median interval of 30 minutes. Interval length was not a predictor of duration length.

The graph in Figure 2 shows that the length of an eruption's duration does not appear to affect the length of the following interval. That lengths of eruption durations and intervals are not strongly correlated suggests that the frequency of White Dome's eruptions may not be directly related to its energy supply.

Acknowledgments

Thanks to the readers who made helpful suggestions for this paper and to Jeff Cross for assistance with the graphs.

References

Bryan, T. Scott. 2008. The Geysers of Yellowstone. 4th edition. Boulder: University Press of Colorado. pp. 199-201.

Stephens, Lynn. 2009. Activity of Selected Geysers—Second Part of Summer 2009 Season. The Geyser Gazer Sput, 23 (5): 17.

White Dome Geyser Eruption Log, June 19, 2011

Start Time	End Time	Duration	Preceding Interval	Comments
(07:00)				observation commences
7:26:34	7:28:30	01:56	>26:34	strong eruption, tall spikes
8:01:53	8:03:55	02:02	35:19	slightly weaker
8:35:20	8:37:15	01:55	33:27	quicker to max. height
8:58:35	9:00:32	01:57	23:15	declined earlier than usual
9:25:05	9:27:11	02:06	26:30	
10:01:58	10:04:00	02:02	36:53	
(10:50:11)				a few small splashes
11:23:50	11:24:47	01:57	1:21:52	normal eruption
11:58:36	12:00:22	01:46	34:46	
(12:15:38 to 12:15:59)				a few weak splashes
12:24:18	12:26:12	01:54	25:42	weaker eruption never reached 30 feet
12:55:00	12:56:57	01:57	30:42	weaker eruption never reached 30 feet
13:23:50	13:25:53	02:03	28:50	reached max. quickly
(13:41:50)				a few 6-foot splashes
(13:47:47)				a few weak splashes
(14:03:50 to 14:04:08)				a few weak splashes
14:42:47	14:44:43	01:56	1:18:57	strong eruption, see Photo 3
(15:01:55)				one weak splash
15:24:06	15:26:03	01:57	41:13	eruption started with one splash and a brief pause
15:54:16	15:56:13	01:57	30:10	quick rise to max. height
16:13:20	16:14:55	01:35	19:04	brief pauses near beginning and end of weaker eruption with just one jet of 30 feet
(16:41:39)				splash
16:41:56	16:44:01	02:05	28:36	weaker eruption
16:58:35	17:00:26	01:51	16:39	weak eruption with low points in middle of play and pause near end
(18:11:44)				one weak splash
18:21:49	18:23:47	01:58	1:23:14	normal eruption
(18:53:37)				one splash
(18:55:11)				one splash
(19:05:00)				observation ends, next interval >43:11

A Brief History of King Geyser, West Thumb Geyser Basin

Tara Cross and Rocco Paperiello

Abstract

This article presents the recorded history of King Geyser, West Thumb Geyser Basin. The available records suggest that King Geyser has been only sporadically active over the history of Yellowstone National Park, with active phases occurring in 1904-1905, the 1930s, 1997, and 2009-2010.

Introduction

King Geyser is located in West Thumb Geyser Basin between Abyss Pool and Yellowstone Lake. It is often forgotten, as its activity has been relatively rare, and its pool is barely visible from the boardwalk between Abyss and Black pools. Its known history is brief, including active phases in 1904-1905, the 1930s, 1997, and 2009-2010.

The origin of the name "King Geyser" is unclear. It is approved as an official name by the U.S. Board of Geographical Names, but the information originally submitted in the name request is questionable. The USBGN decision card, filed in 1937, says that King Geyser was named in 1904 by Walter H. Weed.[1] Also in 1937, Clyde Max Bauer's *The Story of Yellowstone Geysers* gives the exact same information about the naming of King.[2] It seems likely that the name request originated with Bauer, as he was responsible for many of the name requests submitted in 1936-37.[3] However, there is no other evidence that King was named by Weed. A thorough search of historical records, including Weed's notebooks, shows no mention of the name "King Geyser" until 1933.

Interestingly, Bauer himself had written in the 1930s that

> During the first few years I was in Yellowstone one of the permanent rangers stationed at West Thumb during the summer season said the name of this geyser was King Geyser. I asked him where he got the name, and he said it was the only name he had ever heard for it, and he thought it a good name because he understood it was named by one of the parties accompanying a king that visited the park one time. I found no further references to it.[4]

The only clue for this possible origin is that Crown Prince Gustaf of Sweden toured West Thumb Geyser Basin in 1926, and could have been the referenced monarch.[5] King Geyser was also referred to as "King's Geyser" in various ranger station logbooks in the 1930s,[6] and a name sign dating from the 1930s shows the name "Kings Geyser."

Prior to that time, King had been named "Lake Geyser" during its active period in 1905, possibly due to confusion regarding USGS folio maps, which actually applied the name to today's Occasional Geyser.[7]

Early References

The first mention of King Geyser dates to 1886, when Walter H. Weed included a description in his notebook as No. 26 of the Lake Shore Group:

> No. 26. Rudely defined basin, or spring in break of fissure in laminated sinter. Water clear beryl green—Lining soft, light gray in color—Basin 20' x 25'—with white scalloped border. The central fissure part of [the] spring is 5'-6' wide and 10 ft. long, the rest of the so-called basin being but 1-2 feet deep. Deposit dark brown, and hard—inside the crater—The spring receives the overflow of #28 [Abyss Pool], and the overflow of a pool crossed by the trail. This spring #26 lies just east of the trail. It has a copious overflow running to the lake. Intermittent thudding noise noticed.[8]

Weed did not make any indication that the feature might be a geyser. He added the following in 1887:

> This spring has a brown mineral lining and the overflow channel is first

A glass slide image from the 1950s shows the pool of King Geyser next to the old boardwalk. The sign, which dates from the 1930s, reads "Kings Geyser." From the collection of David Monteith.

> white and then black lined (MnO_2) changing below to ordinary gray of the other springs. This is replaced below by lemon yellow green to emerald – where the water pours into the lake. [9]

Measurements taken in 1994 revealed that the main basin of King Geyser measured 27 feet by 35 feet, while the central fissure, which drops off into chasm-like depths, was fully 20 feet long, running generally parallel to the lake. The vent opening was triangular and about 12 feet across at its widest point.[10] The larger dimensions could possibly be accounted for by erosion during eruptive episodes, but it is more probably explained by Weed's tendency to underestimate the dimensions of the springs within this group.

The earliest eruptive activity of King Geyser that is known for certain was in 1904. However, there is some possibility that King was the "new geyser" described by Arnold Hague in 1891:

> The new geyser near the shore is situated in an old pool formerly characterized by a brilliant growth of algae. This algae is now dead owing to the pool being full of boiling water which has destroyed all brilliance in color.[11]

Admittedly, this description is too general to pin down the location of the "new geyser," and it should also be noted that Weed's description of King five years earlier did not refer to a brilliant growth of bacteria. However, a study of the known history of the West Thumb features would seem to pare down the possibilities to either the future King Geyser or (less likely) Winter Spring. If the first interpretation is correct, then King Geyser is also a possible candidate for Chittenden's 1895 reference to an "unnamed geyser of considerable power but very infrequent action."[12]

1904 and 1905

In 1904, King emerged as a significant geyser. Its activity was monitored by a Corporal Frank Clark, stationed at the West Thumb soldier station. In a June 30, 1904 letter to acting superintendent Major Pitcher, Clark reported that:

> In accordance with your order I report the following information in regard to the new geyser at this station. It plays irregularly.
>
> On the 26th inst at 3.55 P.M. it played for 12 minutes shooting a stream of hot water a distance of 75 feet high.
>
> On the 27th inst it played once at 2.25 P.M. throwing a stream of water about the same height.
>
> On the 28th inst it did not play.
>
> On the 29th inst it played for nine minutes at 3.40 P.M. throwing a stream the same height.
>
> On the 30th inst up until 12.30 P.M. it had not played.
>
> Have posted formation guard, which I found necessary owing to the number of tourists walking all over it.[13]

Later, in a July 24, 1904 letter, Clark wrote that King Geyser had not played for 8 days, but that another "new" geyser was playing to about 20 feet from Abyss Pool, about 120 paces away.[14] There were no further reports for 1904.

King Geyser reactivated on April 11, 1905 as reported in an April 30, 1905 letter from the now Sergeant Clark. Please note that the name "Lake Geyser" was used by Clark for today's King Geyser.

> Lake Geyser
>
> This geyser is situated about 100 yds N.E. of Elk Geyser and about 50 feet from the lake's edge. It is probably 30 feet lower than Elk Geyser. The formation at this point has a gradual slope toward the lake. The water from Elk Geyser flows into the Lake Geyser which in turn empties itself into Yellowstone lake. The formation between these geysers is soft and in some places visibly honey-combed. There is a continual washing away of this formation between these geysers.[15]

This "Lake Geyser" erupted throughout April:

> April 11th at 6.50 P.M. 40 ft. 10 minutes
> April 12th at 9.31 A.M. 80 ft. 8 minutes
> April 13th at 12.35 P.M. 60 ft. 8 minutes
> April 15th at 10.50 A.M. 60 ft. 8 minutes
> April do at 3.20 P.M. 60 ft. 8 minutes
> April 18th at 1.38 P.M. 60 ft. 8 minutes
> April 20 at 2.02 P.M. 60 ft. 8 minutes
> April 22 at 7.09 P.M. 80 ft. 10 minutes
> April 23 at 7.02 A.M. 80 ft. 8 minutes
> April 24 at 7.08 A.M. 80 ft. 8 minutes
> April 24 at 7.09 P.M. 80 ft. 8 minutes
> April 26th at 8.05 A.M. 80 ft. 8 minutes
> April 27th at 7.18 A.M. 60 ft. 8 minutes
> April 29th at 6.15 P.M. 80 ft. 10 minutes
> April 30th Had not played up to 8.30 P.M.[16]

Clark reported more eruptions in a May 31, 1905 letter:

> May Lake Geyser played
> 1st 11.40 A.M.
> 3rd 12.40 P.M.
> 4th 11.50 A.M.
> 7th 1.15 P.M.
> 9th 12.45 A.M.
> 10th 1.10 P.M.
> 12th 12.15 P.M.
> 13th 11.40 A.M.
> 15th 12.10 P.M.
> 16th 1.10 P.M.
> 18th 1.15 P.M.
> 19th 11.45 A.M.
> 21th 12.15 P.M.
> 22nd 1.10 P.M.
> 23rd 1.45 P.M.
> 26th 12.15 P.M.
> 27th 1.20 P.M.
> 29th 11.40 A.M.
> 31st 2.36 P.M.
>
> This geyser plays "on an average of" 8 minutes at a time, and throws a volumn*[sic]* of water about 60 ft. high.[17]

As can be seen from this list, King Geyser had erratic intervals that were mostly in the range of 1 to 3 days, but one interval of only 4½ hours was also recorded. Most durations were reported at 8 minutes, but a few lasted 10 minutes. Heights ranged from 40 to 80 feet.

Major Pitcher relayed Clark's reports to the Secretary of the Interior in May 1905:

> The basin near the Thumb Station seems to be considerably more ac-

tive than it has been for a number of years… Another old geyser, known as the Lake Geyser which is located a short distance from the Elk and near the Lake shore, has also resumed active operations, and now plays with considerable regularity.[18]

Note that the feature referred to as "Elk Pool" or "Elk Geyser" is today's Abyss Pool. It was also active in 1905. Clark wrote the following:

> Pvt. Ruck of Thumb station reports to Sgt. Clark at Norris station, that the pools at the Thumb known as Emerald & Elk, now "one" through and *[sic]* eruption, have played a distance of from 75 to 100 ft high. A loud rumbling noise preceeds *[sic]* the playing. These pools were situated about 300 yards from the road.[19]

On March 31st, 1905, Clark sent another letter saying that "The supposed geyser [Elk Pool] reported to me at Norris station, by Pvt Ruck of this station has not, since that time 'the 15th inst' shown any unusual signs of activity."

Unfortunately, there was no further correspondence from Sergeant Clark after May of 1905. If King continued to erupt that year, records have not yet been found.

1933 to 1940

If King Geyser was truly named for Prince Gustaf, it may have been active at the time of his 1926 visit. However, there is no written record of activity between 1905 and 1933. There are scattered reports of King in the West Thumb Ranger Station Logs for 1933 through 1940. Most accounts described King as erupting for 5 to 10 minutes at heights of 6 to 10 feet.

In 1933, King erupted twice on July 4. The first eruption was described as follows:

> At 9:55, during Hot Spot Walk, large crater farthest No. on formation and closest to the Lake Shore erupted for about 10 minutes. Boiled about 8 or 10 feet high from the entire crater, overflowing a great quantity of water and so much steam that Mt. Sheridan reported it as a possible fire.[20]

A second entry reported another eruption at 4:30, for an interval of 6 hours 35 minutes. Another source reported heights of 8 feet and durations of about 10 minutes for the eruptions.[21] These were the only eruptions recorded in 1933.

A larger eruption was reported on August 16, 1934:

> King Geyser erupted at 6:35pm for a period of ten minutes. Maximum height about 20-25 feet.[22]

There were no further reports for 1934.

King Geyser had an active phase in 1935, with at least six eruptions between July 9 and July 15. On July 9 it was reported that

> The Kings Geyser played twice today, once in the morning during the morning walk (Hot Spot) and again in the afternoon at a timed interval of about six hours. The height of the eruptions was about 6-8 feet and the duration was about 5 minutes.[23]

Another six-hour interval was reported on July 12.[24] King was once again mistaken for a fire on July 14 at 3:00pm,[25] and a single eruption was reported at 4:45pm on July 15.[26]

There were no reports of King in the logbooks in 1936 or 1937. However, there is a reference to it in Clyde Max Bauer's *The Story of Yellowstone Geysers*, published in 1937 but written in 1936. Bauer lists King Geyser as "a geyser at West Thumb.… Average height, 20 feet; Interval, twice daily."[27]

King Geyser had a few eruptions in 1938, as reported by Frank Obserhansley:

> Ranger Naturalist Randall Watkins Reports…
>
> The King geyser was observed in action only four times during the summer. The height was approximately six feet, the column of water six to eight feet in diameter, duration of play 10 minutes. King was observed in action twice, at 10:00 a.m. and again at 4:00 p.m., on August 5.[28]

Interestingly, this was another six-hour interval. The ranger station logs noted one eruption in 1938, on June 21:

> Kings Geyser started fine display at 9:35 AM-9:41:30 AM and erupted to a height of 6' and a spray of 12' wide. This was during bus party and the first time noted this season.[29]

Whether this eruption was among the four cited by Oberhansley is not known.

Three eruptions are known in 1939. The first took place on July 2:

> Kings Geyser played for the first time this season at 11:05 AM. The duration of the eruption was about 10 minutes and the height of the eruption was about 6 feet.[30]

Two more eruptions were observed on August 6, but no details were given.[31]

King Geyser was active in the summer of 1940. Between June and August, King played regularly:

> A record of the eruptions of King geyser were kept during the season and showed that the geyser played on an average of every seven and a half hours. Although fairly regular during the season, it was quite irregular during the late summer and has not been observed to play during the day since August 9th. Algal plants growing freely in the run-off show that the above observation is fairly correct. [In addition,] the Lakeshore geyser interval has gradually increased from 25 minutes in June to 40 minutes in August.[32]

A complete record of King's eruptions in 1940 has not been found. Only three logbook entries listed specific eruptions of King. The first eruptions were recorded on June 13 at 8 a.m., 2 p.m., and 8 p.m., for two intervals of 6 hours.[33] King was reported again on June 19 at 3 p.m. and June 20 at 11:30 a.m. and 6:30 p.m.[34] The June 20 interval was 7 hours. A logbook entry on July 6 reported that "King Geyser made a 5-minute display of unusual proportions at 9:38 to 9:43 P.M." Intervals of 6½ to 8 hours were reported.[35]

Interestingly, no heights are given for the eruptions, although it seems likely that they were much like those seen in the 1930s. While these eruptions clearly did not compare to the powerful eruptions of 1904 and 1905, 1940 was one of the best years on record for King Geyser.

1941 to 2008

After 1940, information about King Geyser is sparse. There are scattered reports by naturalists stationed at West Thumb for 1946 through 1959. Most of these notes recorded the temperature of King's pool. A logbook note from 1946 reported temperatures of 183.2 to 188.6 °F.[36] Notes in 1951 and 1954 reported no geyser activity, but heavy runoff.[37] Reports on King Geyser from 1957, 1959, and 1960 indicated slightly lower temperatures ranging from 171 to 182 °F.[38] It does not appear that King responded to the August 17, 1959 Hebgen Lake Earthquake.

George Marler, park geologist, wrote in his Hot Springs at West Thumb report in May of 1961:

> King Geyser: This geyser lies in the northwest corner of the main Thumb area. It is only periodically active. The eruptions are not high, from 5 to 6 feet, but they are very tumultuous and the discharge is impressive. The eruptive activity has gouged into surrounding formations.
>
> The principal cause of King Geyser's long periods of dormancy in all probability is due to the fact that its crater receives the near-continuous overflow from Abyss Pool. The algal colored overflow from Abyss, in connection with the blue of the water in King, present a very pleasing picture.[39]

This might seem to imply that there were periods of activity after 1940 and that George Marler saw some of this activity himself. However, Marler left no other records of King's activity, and the naturalists' reports don't mention any eruptions.

King Geyser was likely dormant from 1962 until 1997. Once again, naturalists reported on the temperature of King's pool, which usually ranged from 180 to 195 °F between 1962 and 1991.[40] An exception was in 1971, when King was superheated with a recorded temperature of 205 °F. The note "No Algae" was added to this observation.[41] In 1973 and 1974, Ron Dent noted "no activity" but a "large amount of runoff," along with temperatures between 184 and 188 °F.[42] Dent made the following note for 1975: "No activity. Runoff was measured on Oct. 12 as 460 gpm. Temp 173 [ºF] in Jan to 193 [ºF] in September."[43]

During the active phase of Abyss Pool in late 1991 and early 1992, King's temperature dropped to a low of 156 °F in August 1992 and had a "lowered water level" in September.[44]

After decades of probable dormancy, King reactivated during the summer of 1997. Eruptions were infrequent, and few were seen. There was evidence of discharge eroding well beyond the normal runoff channel, indicating heavy runoff with the eruptions. The authors have been unable to locate any further details about the 1997 activity, but it

Aerial view of the West Thumb area from 1959. Abyss Pool can be seen near the middle of the photo. King Geyser is located at the end of the boardwalk loop to the left of Abyss. The pair of dots at the bottom of the photo on the left is Goggle Spring, which was active in 1997.

should be noted that Goggle Spring (a feature about 300 feet north of King Geyser) and an unnamed geyser near it were both active that same summer.[45] The photos on page 96 shows Goggle Spring in 1995 with a lowered water level and moss growing near the vents and again in 1997 with a high water level and obvious scouring of the surrounding area. The unnamed vent, informally called "Garden Hare," can be seen in both photos; it is the small hole in the direction of Yellowstone Lake.

2009 and 2010

No further activity of King Geyser was reported until 2009. Ralph Taylor observed an eruption of King on August 9, but it had ceased activity by the time he put an electronic monitor on it later that month.[46]

King was active again in mid-July 2010. Based on visual and electronic reports, the active phase lasted about a week. The first known eruption was seen on July 14, and an electronic logger placed on July 17 revealed that the last eruption occurred on July 20.

List of known eruptions:

- July 14 @ 1645, 7-8 feet, d~15m
- July 15 @ 1348vr, 8-15 feet
- July 16 @ 1035vr, 4-15 feet, d~5-10m
- July 16 @ 1655vr, 5-15 feet, d~5m
- July 17 @ 2139e
- July 18 @ 1200e, I=14h21m
- July 19 @ 0528e, I=17h28m
- July 19 @ 1402e, I=8h34m
- July 20 @ 0238e, I=12h36m
- July 20 @ 1116 visual, I=8h39m[47]

Intervals were erratic. The shortest known interval was about 6 hours on the 16th. The final eruption on July 20 was seen by author Tara Cross. In the hour before the eruption, King was overflowing and having periodic boiling on the near side of the pool as seen from the boardwalk between Abyss and Black pools. The boiling reached approximately 6 inches at its peak and increased and ebbed about every 3 to 5 minutes. Based on observations several

Goggle Spring in 1995, with no evidence of recent activity. Photo by Rocco Paperiello with permission from the NPS.

Goggle Spring in 1997, with clear evidence of recent activity. Photo by Ralph Taylor with permission from the NPS.

days earlier, King could boil for many hours before eruptions with no real progression from weaker to stronger activity. The eruption started with a boil that suddenly spiked to three feet. Then the entire pool began to dome with roiling surges. The peak height of the eruption was in the first minute, with a few bursts as high as 20 feet. The rest of the eruption varied from 5 to 15 feet. The eruption was somewhat reminiscent of Oblong Geyser in the Upper Geyser Basin. The duration was about 5½ minutes.[48]

There may have been at least one more eruption of King in 2010. In late September, the Yellowstone Association West Thumb bookstore received a report that visitors saw Abyss Pool erupt. After questioning, however, it was determined that what they saw was probably King. The eruption was reported to be 30 feet high.[49]

King Geyser in eruption on July 20, 2010. Photo by Tara Cross.

Conclusion

Over the recorded history of Yellowstone National Park, King Geyser has been active in only a few seasons. Its most powerful activity was in 1904 and 1905, when it reached heights of 80 feet. Nothing of that size has been recorded since, but King had observed eruptions in 1933, 1934, 1935, 1938, 1939, 1940, 1997, 2009, and 2010.

Acknowledgements

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Endnotes

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The Number of Geysers in Yellowstone National Park

Jeff Cross

Abstract

Yellowstone National Park contains at least 1,283 geysers. The efforts of the author are combined with the contributions of T. Scott Bryan, Rocco Paperiello, Marie Wolf, Lee Whittlesey, other individuals, and The Geyser Observation and Study Association, to compile a list of every geyser known to have erupted in Yellowstone National Park from the time of its establishment in 1872 through 2011.

"Geyser—a hot spring characterized by intermittent discharge of water ejected turbulently and accompanied by a vapor phase." (White 1967)

Yellowstone National Park contains the largest geyser field on earth. The enormous size of the hydrothermal system (Fournier 1989), and the protection of its geysers within the boundaries of the national park, have contributed to Yellowstone's premier status. However, the total number of geysers that have erupted in Yellowstone has never been accurately determined. The most thorough historical count, listing exactly 200 geysers, was published by Allen and Day in 1935. The most thorough modern count is given by Bryan (2008), who cites a minimum estimate of 700 geysers. In 2008, I published a list of 529 geysers that are known to have erupted in Yellowstone's backcountry and undeveloped frontcountry thermal areas (J. Cross 2008a). In this paper, 754 additional geysers are listed, located mainly in Yellowstone's developed frontcountry thermal areas. The total number of geysers in Yellowstone is 1,283.

The number of geysers in each of Yellowstone's geyser basins is tabulated below:

Upper Geyser Basin	410
Midway Geyser Basin	59
Lower Geyser Basin	283
Norris Geyser Basin	193
West Thumb Geyser Basin	84
Gibbon Geyser Basin	24
Lone Star Geyser Basin	21
Shoshone Geyser Basin	107
Heart Lake Geyser Basin	69
Other areas	33
TOTAL	**1,283**

Certainly, only some of these geysers will be active during any calendar year. Efforts to list all the geysers active during each calendar year from 1987 through 1992 (excluding 1991) resulted in counts ranging from a minimum of 391 in 1987 to a maximum of 514 in 1992 (Bryan 1989a, 1990, 1992, 1993). The average number of geysers active during these years is 465.

The number of active geysers in Yellowstone National Park during 1987 through 1992 (excluding 1991) is tabulated below:

1987	391
1988	445
1989	492
1990	485
1992	514
Average	**465**

Yellowstone's significance as a geyser field will continue to grow as we more completely appreciate the resource that is preserved inside Yellowstone National Park. Yellowstone's global significance will also increase as more and more of the world's geyser areas are developed for geothermal power. Geothermal power plants and geysers are incompatible. In general, it is impossible to have both at the same time (White 2003). Geothermal power developments have completely destroyed the geysers that used to exist at Beowawe (White 1992) and Steamboat Springs, Nevada (Sorey 2000). New Zealand has lost many of its geysers to geothermal power developments (Barrick 2007; Scott and Cody 1999; Allis and Lumb 1992; Cody and Lumb 1992; White, 1993), largely because the geysers there were given no legal protection until the early-to-mid-1980s.

Detailed publications on Yellowstone's geysers are rare. The principal and most accessible source is *The Geysers of Yellowstone*, by T. Scott Bryan (2008). Other sources, made available through The Geyser Observation and Study Association (GOSA), include the bi-monthly newsletter (the *Geyser Observation and Study Association Sput*), and several extensive reports. The largest of these reports is Rocco Paperiello and Marie Wolf's *Report on Lesser Known Thermal Units of Yellowstone National Park* (1986).

Rocco Paperiello lists many geysers in his *Report on the Norris Geyser Basin* (1984) and in his *Heart Lake Geyser Basin: Report and Investigation* (1988). Ralph Taylor and Bronco (James B.) Grigg list many geysers in their *Potts Hot Spring Basin Survey* (1999). References to geysers that have erupted in Biscuit Basin and in Rabbit Valley are found in two reports written by Rocco Paperiello and Marie Wolf (Paperiello 1986; Paperiello and Wolf 1987). Copies of these previously uncirculated reports were kindly provided to me by Udo Freund and Genean Dunn. The archives of the geyser listserv have also been utilized. Finally, much information was uncovered by Lee Whittlesey (1988) and published in his unabridged *Wonderland Nomenclature*.

Because many different sources have been used to compile this list, it is necessary to ensure that each geyser is counted only once. For example, Bryan (1993) lists three geysers behind Graceful Geyser in Norris Geyser Basin. Paperiello (1984) lists one geyser (Paperiello UNNG #23) in that location. Because it is possible that Paperiello #23 is one of the three geysers listed by Bryan, a total of three geysers have been recorded for that location, not four.

Because different sources often use different names or identification numbers for the same geyser, I had to decide which name to use in this list. Generally, I decided in favor of the name or number used in the most accessible literature source. Many of the names used in this report are unofficial. Some are new names. Other names, though unofficial, are long-established. Names have been checked against the United States Board of Geographic Names database, and against Whittlesey (1988), who provides a thorough discussion of place names in Yellowstone National Park. Names listed as official by either of these sources are marked with an asterisk (*).

It should be noted that in the list, the abbreviation "UNNG" stands for "unnamed geyser." The abbreviation "UNNS" stands for "unnamed hot spring." Paperiello (1984) uses separate numbering schemes for unnamed geysers and unnamed hot springs at Norris, and the use of both UNNG and UNNS is necessary to avoid duplicating the identification number for the thermal feature.

J. Cross (2008a) counted 529 geysers in Yellowstone's backcountry and undeveloped frontcountry thermal areas. Further research has revealed that additional geysers exist in these thermal areas, and they are included in this list. Geysers that were counted in J. Cross (2008a) are counted here as part of the total, but are not referenced by name.

Geysers that developed recently, are obscure, or are notable for other reasons are discussed below.

UPPER GEYSER BASIN

Geyser Hill Group

A small, **unnamed geyser** erupts from a vent under the boardwalk northwest of Bronze Spring. It was active during August, 1994. Its eruptions were influenced by the eruptions of Bronze Spring.

Pygmy Geyser has small, sputtering eruptions that reach a few inches high. The vent is located uphill from Bronze Spring and Little Squirt Geyser. Its precise location is given by Eide (2009a) as being directly in line with Little Squirt Geyser and Silver Spring. At times, the boardwalk has been placed directly over the vent. Because of its position, runoff from Giantess Geyser and Dome Geyser often covers the site. The major eruptions of Butterfly Spring in 2003 washed a heavy layer of sand over the vent. Pygmy Geyser's eruptions can be influenced by eruptions of nearby Bronze Spring.

An **unnamed geyser** began erupting in 2010 from the easternmost of a group of vents across the boardwalk to the east of Depression Geyser. Eruptions were brief, frequent and reached 1 foot high (J. Cross, 2010).

Castle Group

The **Terra Cotta Complex** contains numerous erupting vents (Keller 2010). Known by letter designations, Terra Cotta Geyser A through Terra Cotta Geyser F erupt as independent geysers. Terra Cotta Geyser G through Terra Cotta Geyser M erupt with Terra Cotta A, but not at other times. Because they erupt only with Terra Cotta A, they are considered here as part of Terra Cotta A.

An **unnamed geyser** erupts from a hole just upstream from and within the sinter mound of Lime Kiln Spring (Goldberg 2003). The location was pointed out to me by Rocco Paperiello in 2009.

Sawmill Group

Bulger's Hole erupts from a vent just east of Bulger Geyser. It was first noticed in May, 2011, and enlarged its crater over the course of the summer. Its eruptions are related to those of Bulger Geyser. (Dunn 2011).

Cascade Group

Bench Spring was buried by construction crews when the Grand Loop Road was built along the hillside above Artemisia. It has acted as a geyser in the past. At these times, the erupted water vented through a clay pipe that was installed when the feature was buried (Paperiello, personal communication).

Old Road Group of Biscuit Basin

A tiny **unnamed geyser** erupted from a vent immediately next to the trail near Cauliflower Geyser in 2006. At first glance, it seemed to be a mud puddle. However, on closer observation, the puddle proved to contain boiling water. Intermittent sputtering eruptions a few inches high occurred on undetermined intervals.

Black Sand Basin

Snakebite Geyser erupted from "two vertical cracks in the riverbank halfway from Cliff to the bridge" (Dunn 1997a). The height was 1 to 2 feet, but no intervals were obtained.

Old Faithful Access Road

Hot Lips functioned as a geyser, mudpot, fumarole and hot spring during 1978. It erupted from a vent between the Old Faithful access road and the Grand Loop Road. It is described by Paul Strasser (2002) as follows:

> "Hot Lips had a small cone, maybe a foot high, made of very soft reddish mud. The cone's walls were extremely thin, and it looked something like a miniature Giant Geyser cone molded out of adobe. Every 40 minutes or so, it would erupt. The eruption consisted solely of heavy steam with small globs of mud interspersed in the steam. The maximum height of the show was maybe 10 to 12 feet. In another 40 minutes there was another eruption. I revisited Hot Lips in late June and it was gone, with only a warm puddle to mark its location. So it was a periodic fumarole/mud pot with geyser action that turned into a hot spring. In about two months it went through a phase in which it was every type of hot spring."

In a later post, Strasser (2003) gives the duration as 2 minutes.

Pipeline Meadows Group

"Bronco Grigg and Chase Ellison reported that a **mud feature** in [Pipeline Meadow] north of Bend Cone was erupting in the middle of September. The eruptions were in series and reached heights of 5 feet at best. The new activity killed grass around the crater" (Goldberg 2007).

MIDWAY GEYSER BASIN

Rabbit Creek Group

The Rabbit Creek Group contains 12 geysers. Below Silent Pool are **two unnamed geysers** that were not counted in J. Cross (2008a). The unnamed geyser north of MGB-3 appears twice in J. Cross (2008a)—first as MGB-5 and then as "unnamed geyser N of MGB-3."

Flood Group

The Flood Group contains 25 geysers. Newly counted here are **8 geysers near Flood Geyser** (including Circle Pool), along with **4 geysers** (#18, 21, 22 and 23) mapped on the west side of the Firehole River by Paperiello and Wolf (1986). Bryan (2008) lists 14 geysers on the west side of the Firehole River as part of his MGB-7. Ten of these are therefore not listed by Paperiello and Wolf, and are specifically counted as part of MGB-7.

Rabbit Valley

Rabbit Valley contains 17 geysers. Several unnamed geysers are listed by Paperiello and Wolf (1987) in their report *Rabbit Valley Group*, which has not been widely circulated. **Paperiello and Wolf #4** is a blue, funnel-shaped pool that is found in the northwestern part of Rabbit Valley, about 800 feet from the Grand Loop Road. In the southern part of Rabbit Valley, at the base of a hill, a group of hot springs forms the headwaters of a thermal runoff stream. The highest vent here is an **unnamed geyser** (Paperiello, personal communication). About 180 feet downslope is an **unnamed geyser** (Paperiello and Wolf #30; Bryan 1997). About 170 feet to the northwest, in the middle of an algae fan in the runoff stream, is a double vent (**Paperiello and Wolf #38**). The larger vent probably corresponds to today's **Tuba Geyser** (Dunn 1997b). The smaller vent, located in the same basin, is probably today's **Piccolo Geyser** (Monteith 1999a). About 150 feet downhill (to the northwest) from Tuba is **Belch Geyser** (Monteith 2001). Belch Geyser is not listed in Paperiello and Wolf (1987) at all. During most years, the small vent is buried deeply in mud and is therefore impossible to locate.

An **unnamed geyser** (Paperiello and Wolf #41c) and **Volcano Geyser (Paperiello and Wolf #44a)** are northwest of Tuba and Belch Geysers. These vents open along a distinct line of hot springs that extends to the northwest. Further downstream, another geyser (**Paperiello and Wolf #44a**) is found on the same fissure. Further west, and nearer the southern edge of Rabbit Valley are **two unnamed geysers** (Paperiello, personal communication). **Paperiello and Wolf #92** was not listed as a geyser by Paperiello and Wolf (1987). However, it is now a geyser that erupts from a silt-lined pool several feet below the ground surface (Monteith and Dunn 2001). It is noted as "unnamed geyser in pit" in J. Cross (2008a). An **unnamed geyser** erupts from a deep pit at the extreme northern end of Rabbit Highlands (Bryan 1993).

LOWER GEYSER BASIN

White Creek Group

Accounting for all the geysers in the White Creek Group is difficult. In 1996, a local earthquake swarm caused numerous changes in the group. Many small geysers were active immediately after the earthquakes and then ceased activity. The largest of these geysers erupted through the waters of White Creek near the former location of Verdant Spring. It was named Black Cat Geyser because the loud concussions that accompanied its eruptions sounded like an exploding pack of firecrackers. Several other geysers erupted near A-2 Geyser.

Black Cat Geyser was not included in J. Cross (2008a). Paperiello and Wolf (1986) list 5 geysers in their #6 complex, while J. Cross (2008a) accounts for only one of these. Several of the **small geysers** that erupted only in 1996 are newly counted here. **Buena Vista Spring**, which overlooks the Great Fountain Geyser parking lot, rarely acts as a true periodic geyser. The number of geysers in the White Creek Group is 28.

Tangled Creek Group

Bryan (1990) lists **Pair Geyser** and **Broken Coral Geyser** as active. Other informally named geysers in the Tangled Creek Group include: Bell, Rim, Sand, Ledge, Tiny, Wave and Tonsils. All were named by Butch Bach. (Bryan, 2003)

River Group

The River Group contains 57 geysers. Additions to J. Cross (2008a) are described, beginning on the west side of the Firehole River and moving southward. **Sand Geyser** (Bryan 2008) was not included in J. Cross (2008a). Immediately adjacent to M-190B are three **unnamed geysers** (Paperiello, personal communication). These three geysers are not part of Bryan's (2008) RVG-3, which is further north (Bryan, personal communication). An **unnamed geyser** erupts from a vent at the upstream edge of RVG-1 (Paperiello, personal communication).

Additions to the total listed in J. Cross (2008a) are continued on the east side of the Firehole River and moving southward. Immediately northeast of Pocket Basin Geyser is an **unnamed geyser**. **Three unnamed geysers** are found in the bog to the southwest of Pocket Basin Geyser and southeast of Horn Spring (Paperiello, personal communication).

At the north edge of the thermal area above Fortress Geyser is a very deep pool that has erupted as a geyser. Bryan (2008) lists it separately as RVG-8. Bryan (2008) lists 8 geysers as part of RVG-6. At least **17 known geysers** have erupted here. Paperiello and Wolf #14 consists of a fissure adjacent to a small pool, both of which are geysers. Four geysers are found up the slope to the east (Paperiello, personal communication). Thermopod Geyser and Lightsocket Geyser were listed in J. Cross (2008a). Two other geysers are found adjacent to these thermal features. **Spectrum Spring**, when full and overflowing, dominates the terrace above Fortress Geyser. Bryan (2008) suggests that this feature might have been called Azure Lake in 1878. A vent at the northwest corner of Spectrum Spring is a geyser. It was mislabeled as NW of Spectrum Spring in J. Cross (2008a). Two other geysers are found immediately next to Spectrum Spring, one to the north and one to the south (J. Cross 2008a). Three more unnamed geysers are found a short distance south-southwest of Spectrum Spring, and one final unnamed geyser is found at the western edge of the terrace, above Dark Pool and Brain Geyser (Paperiello, personal communication).

Bryan (2008) lists one geyser, informally called Dark Pool, along the east bank of the Firehole River as RVG-5. At least 6 geysers, in addition to Brain

Geyser, have erupted here. The name Dark Pool has been applied to two different thermal features. The original **Dark Pool** was named by Rocco Paperiello and Marie Wolf. It is about 5 feet long and 3 feet across, and the crater is tinted a very dark green-black. This thermal feature is a geyser that was listed in J. Cross (2008a) as "RVG-5a Three-by-Five Pool." When active, it erupted to 1 foot every 3 to 4 hours (Paperiello, personal communication). About 60 feet upstream (southward), beyond Brain Geyser, is the thermal feature that many have called Dark Pool. It is not dark at all; it is blue. A small **unnamed geyser** is found in a pit above this feature. Three other **unnamed geysers** are found in this area (Paperiello, personal communication). Two of them are north of the original Dark Pool, between it and Burple Geyser. The third unnamed geyser erupts from a small cone right next to Armored Spring.

NORRIS GEYSER BASIN

Porcelain Basin

All of the following information was communicated to me by Rocco Paperiello. The geysers described below are not found in Paperiello's (1984) *Report on the Norris Geyser Basin for 1984*. An **unnamed geyser** erupted from a vent directly beneath the boardwalk north of the Norris Geyser Basin Museum in 2010 and 2011. **Li'l Steam Vent** appears on a map by de Santo. It is next to Valentine Geyser. Li'l Steam Vent is a geyser. **Three unnamed geysers** are found near Ledge Geyser. The first geyser erupts from a presently-buried vent between the pressure pool vent of Ledge Geyser and Jetsam Pool. The second geyser erupts from a vent north of (below) Jetsam Pool. The third geyser erupts from a green pool north of (below) Ledge Geyser. Two **unnamed geysers** erupt from separate vents in Scummy Pool. **Moxie Geyser** is a separate feature from Arsenic Geyser. The original **Fan Geyser** is found on a line drawn between Pinwheel Geyser and Pinto Geyser, about two-thirds of the way to Pinto. Its eruption forms a thin column that spreads out like a hand-fan, hence the name. At the north edge of Crackling Lake is an **unnamed geyser** that erupts from a jumble of rocks. It is not the same as Paperiello's (1984) UNNG #5, which is located about 50 feet northwest of Crackling Lake.

Back Basin

All of the following information was communicated to me by Rocco Paperiello. Near Orby Geyser are four **unnamed geysers**. To the southwest is a geyser that erupts from three vents. To the west is a geyser that erupts from a grey crater. Two other small geysers lie a little further west. Paperiello (1984) maps **UNNG #20** as being straight west of Orby, on the far bank of a southern branch of Tantalus Creek. **Drum Geyser** is found between Mushroom Geyser and Monarch Geyser. A **geyser vent** is found on the flat west of Mushroom Geyser. It is capable of erupting to 25 feet. This may be the original Orpiment Spring (Paperiello 1984; Whittlesey 1988). **Branch Spring** is geyser that erupts from a greenish pool about 50 feet east of Minute Geyser.

One Hundred Spring Plain

Two large thermal features dominate the central portion of the One Hundred Spring Plain. The more prominent one is called The Reservoir. It is 400 feet long, 175 feet wide, elongated northeast-southwest, and narrower at the northeast end. Tantalus Creek flows into The Reservoir from the south and exits to the north. About 350 feet to the northeast is Horseshoe Spring, which is a large, shallow, pond-sized thermal feature. Paperiello (1984) suggests that the name "Horseshoe Spring" is misplaced on numerous maps, including the map in USGS Professional Paper 1456 (White, Hutchinson and Keith 1988), to a vent located 250 feet due north of The Reservoir, on the north side of Tantalus Creek. A total of 19 geysers are found in the One Hundred Spring Plain. Their locations are described below.

Tantalus Creek flows northward into the One Hundred Spring Plain from the Back Basin at Firecracker Pool. Near Firecracker Pool are **Perpetual Spouter** and **Venturi Geyser**. Venturi Geyser was named because the eruption causes a venturi to operate between the two vents of the geyser, so that one vent erupts while the other vent drains (Goldberg, personal communication). An **unnamed geyser** is found 250 feet to the northeast, on a direct line toward Rediscovered Geyser (Paperiello, personal communication).

Cinder Pool is 200 feet north of The Reservoir. It is a geyser (Paperiello, personal communication). Within the braided channels of Tantalus Creek directly north of Cinder Pool are three small **unnamed geysers** (Paperiello, personal communication). On the north side of Tantalus Creek, 400 feet north of Cinder Pool is **Breach Geyser** (Bryan 2002), which has a T-shaped vent. An unnamed geyser (Paperiello UNNG #2) erupts from a vent 35 feet northeast of Cinder Pool. Another **unnamed geyser** erupts from a vent 80 feet northeast of Cinder Pool (Paperiello, personal communication). Within the south branch of Tantalus Creek 150 feet northeast of Cinder Pool is **Tantalus Geyser** (Bryan 2002). A second **unnamed geyser** is found to the south, 100 feet closer to The Reservoir (Paperiello, personal communication). **Black Tentacle Geyser** is found 500 feet northeast of The Reservoir (J. Cross 2010). One **unnamed geyser** is found further to the northeast, near the southeast edge of Horseshoe Spring (Paperiello, personal communication).

To avoid confusion, it should be noted that the name "Tantalus Geyser" has been applied to two other thermal features at Norris Geyser Basin. Bryan (2008) describes a Tantalus Geyser west of Echinus Geyser. The name was applied in place of the name "Decker Island Geyser" to avoid the convention against naming thermal features after people (Whittlesey 1988). The name "Tantalus Geyser" has also been applied to a small geyser that erupted from a sintered vent about 35 feet south-southwest of the Carnegie II drill hole (Paperiello 1998).

Ledge Spring is 900 feet east-northeast of The Reservoir, at the base of a hill. It overflows intermittently on long cycles. When in overflow, there is a strong roll of water over the vent. However, because bursts do not break the surface, Ledge Spring is properly classed as an intermittent spring. **Amethyst Geyser** is 150 feet south of Ledge Spring, at the base of the same hill (Paperiello, personal communication). Receptacle Spring is 700 feet east-southeast of The Reservoir, and 500 feet south-southwest of Ledge Spring. A complex of mud pots is found in the trees to the south of Receptacle Spring. One vent in this complex acted as an **unnamed muddy geyser** in 1996 (Sturtevant 1996).

Realgar Creek drains the northeastern part of the One Hundred Spring Plain. Mountain Ash Spring, named for its green-and-orange coloring, is found on the northwest side of Realgar Creek. Two **unnamed geysers** erupt from vents on either side of it (Paperiello, personal communication).

The Gap is found at the southwest corner of the One Hundred Spring Plain, 1600 feet southwest of The Reservoir. **Elk Geyser** is 750 feet southwest of The Reservoir. Within The Gap are **Gap Geyser**, **Two Percent Geyser**, six **unnamed geysers** listed by Wolf and Paperiello (1999), and four other **unnamed geysers** (Paperiello, personal communication) that are not listed by Wolf and Paperiello (1999).

WEST THUMB GEYSER BASIN

An **unnamed geyser** erupting from a crater between Occasional Geyser and the road was observed in eruption by Neil Cochran in August, 2000 (Cochran 2008). He writes: "During the eruption the water splashed upward only on the south end of the pool to at most a foot over the water level. The duration of the eruption was significantly less than one minute and the interval was less than 30 minutes." At the time, the crater was surrounded by rocks that had been thrown up to 5 feet from the crater. The largest rocks were the size of a softball. This implied that larger eruptions had occurred previously.

An **unnamed geyser** in the main part of the West Thumb Geyser Basin was observed in January of 1997 by Leslie Quinn (1997). He reported that its vent is located

> inside the west loop of boardwalk just below the two mud pots. It is one of several pools there that are about one meter or so across. Eruptions of muddy water occur at intervals of slightly over four minutes and durations of 40 to 45 seconds, with heights of about 1 meter.

An **unnamed geyser** near Thumb Geyser was observed in 1996 by Gordon Bower, who described its location as being "just above Thumb Geyser" (Bower 1996).

An **unnamed geyser** near Venting Pool was observed by Mike Keller in 2005. He described it as follows: "There is a small unnamed geyser near venting pool. It is a vent that I have never seen erupt before. Intervals were about 10 minutes long and the eruption reached a foot or so" (Keller 2005).

GIBBON GEYSER BASIN

An **unnamed geyser** is found in the Sulfur Castle Group, high on the west side of Paintpot Hill. The area is named for the substantial sulfur deposits formed by the steam vents found there. One small discharging vent has been active as a geyser (Bryan 2008).

LONE STAR GEYSER BASIN

An **unnamed geyser** erupts with a loud sputtering sound from a small vent at the base of the hill to the north of Lone Star Geyser. Another **unnamed geyser** erupts from a vent just north of the Meadow Cones in the Channel Group. Divide Pool and an **unnamed geyser** in the Divide Group were omitted from J. Cross (2008a).

SHOSHONE GEYSER BASIN

Little Giant Group

An **unnamed geyser** mapped by Paperiello (1989) as #6 erupts from a pool about halfway between Trailside Geyser and Little Giant Geyser. It was active as a geyser in 1994 (Paperiello, 1994). An **unnamed geyser** erupts from a vent to the west of Little Giant Geyser. The vent enlarged significantly and its eruption became periodic in 2010.

North Group

An **unnamed geyser** (Paperiello #28) between Mangled Crater Spring and Grotto Spring broke out in 2008 (T. Cross 2009). The brief eruptions reached a maximum height of 6 feet. The shortest intervals seen were around 8 minutes, although the geyser was cyclic in its activity and sometimes simply overflowed intermittently instead of erupting. Individual eruptions from this unnamed geyser caused Grotto Spring to ebb.

Pothole Geyser, named for the manner in which the vent penetrates the sinter sheet, began erupting in 2008 from a vent immediately south of Terracette Spring. The eruption is subterranean.

Camp Group

A **mud geyser** was active in the Camp Group in September, 2006. At the time, the crater looked recently formed. It is the northernmost vent in a linear complex of vents mapped as #11 by Paperiello (1992). The eruptions occurred once a minute.

HEART LAKE GEYSER BASIN

In the Fissure Group, an **unnamed geyser** erupts from a vent on the southeast flank of Puffing Spring's sinter formation (T. Cross, personal communication). An **unnamed geyser** erupts form a vent (Paperiello #81) immediately north of the northernmost cone along the main fissure. Two **unnamed geysers** erupt from vents adjacent to the cones of Paperiello #75, 76 and 80. **Cap Geyser** erupts from beneath a small sinter cone that partially covers the vent. A second vent in **Paperiello #56** can erupt independently of #56a.

MUD VOLCANO

Edge Geyser erupts from a vent near the edge of a small lake 1 mile south of Mud Volcano (Paperiello, personal communication). This is one of two geysers named "Edge Geyser" in Yellowstone. The other geyser is found at Sedge Bay, described below.

HOT SPRING BASIN

Two unnamed geysers erupt from vents along Shallow Creek, below and to the west of the main thermal area at Hot Spring Basin (Paperiello, personal communication).

RAINBOW SPRINGS

An **unnamed geyser** probably exists at Rainbow Springs, on the Mirror Plateau. Its existence was reported in 1991 (SPUT 1991). Although it was not seen in eruption during a 3-hour visit, geyser activity was inferred from the existence of beaded sinter surrounding the vent and lining the runoff channel. It is found in the main part of Rainbow Springs, near Green Grotto Spring (Keller 2009).

SEDGE BAY

The small geyser that was reported in j. Cross (2008a) was named **Edge Geyser** by Rick Hutchinson (Paperiello, personal communication). The name likely derives from Rick's known love of introducing double meanings and wordplay in thermal names. In this example, the name "Edge" is formed by crossing out the "S" of "Sedge." The geyser is found at the *edge* of Yellowstone Lake, a second fact referenced by the name.

THE NUMBER OF GEYSERS IN YELLOWSTONE NATIONAL PARK

Geyser	Reference	Total
UPPER GEYSER BASIN		**410**
Old Faithful Group		**5**
Old Faithful Geyser*	Bryan (2008)	
Chinese Spring*	Bryan (2008)	
Blue Star Spring	Bryan (2008)	
Teapot Geyser	Bryan (2008)	
Split Cone	Bryan (2008)	
Geyser Hill Group		**87**
Lower Half		
Cascade Geyser	Bryan (2008)	
Bronze Spring	Bryan (2008)	
Little Squirt Geyser	Bryan (2008)	
Silver Spring	Bryan (2008)	
UNNG under boardwalk	J. Cross (personal observation)	
Pygmy Geyser	Eide (2009), Taylor (2009)	
Big Anemone	Bryan (2008)	
Little Anemone	Bryan (2008)	
Surge Geyser	Bryan (2008)	
Scuba Geyser	Bryan (2008)	
Spume Geyser (GHG-1)	Bryan (2008)	
Spew Geyser	Bryan (2008)	
Midget Geyser*	Whittlesey (1988)	
Improbable Geyser (GHG-12)	Bryan (2008)	
Plume Geyser	Bryan (2008)	
GHG-2 (2 geysers)	Bryan (2008)	
Beehive Geyser*	Bryan (2008)	
Beehive's Indicator	Bryan (2008)	
Beehive's 2nd Indicator	Bryan (1992)	
Beehive's West Bubblers	Bryan (2008)	
Borah Peak Geyser	Bryan (2008)	
Brink Geyser	Monteith (1999a)	
GHG-8	Bryan (2008)	
UNNG above Copper Kettle	Bryan (1992)	
Scissors Spring	Bryan (2008)	
Depression Geyser	Bryan (2008)	
UNNG E of Depression	J. Cross (2010)	
The Dwarves (9 geysers, GHG-3)	Bryan (2008)	
Blowout Spring	Bryan (2008)	
Marmot Cave (GHG-11)	Bryan (2008)	
UNNG in front of Marmot Cave (Mouth Geyser)	Bryan (2008)	
Inverted Geyser	Bryan (1989a)	
UNNG above Inverted	Eide (2009b)	
Arrowhead Spring	Marler (1973)	
Pot O'Gold	Bryan (2008)	
UNNG next to Pot O'Gold	Bryan (2008)	
Little Cub Geyser*	Bryan (2008)	
Big Cub Geyser*	Bryan (2008)	
Lioness Geyser*	Bryan (2008)	

Geyser	Reference	Total
Lion Geyser*	Bryan (2008)	
Goggles Spring*	Bryan (2008)	
North Goggles Geyser	Bryan (2008)	
Kitten Geyser (GHG-10)	Bryan (2008)	
Upper Half		
GHG-5	Bryan (2008)	
Ear Spring*	Bryan (2008)	
Pendant Spring	Bryan (2008)	
Exclamation Point Spring	J. Cross (2010)	
Beach Spring	Bryan (2008)	
Beach Geyser (GHG-6)	Bryan (2008)	
GHG-7	Bryan (2008)	
Aurum Geyser*	Bryan (2008)	
UNNG next to Aurum	Bryan (1990)	
Doublet Pool*	Bryan (2008)	
UNNG N of Doublet	Bryan (1990)	
Singlet Geyser	Bryan (2008)	
Pump Geyser*	Bryan (2008)	
Sponge Geyser*	Bryan (2008)	
Plate Geyser	Bryan (2008)	
Slot Geyser	Bryan (2008)	
UNNG next to Slot	Bryan (2008)	
Boardwalk Geyser	Bryan (2008)	
Coronet Geyser	Bryan (2008)	
Park Place Geyser	Bryan (2008)	
Model Geyser*	Bryan (2008)	
UNNGs near Model (2)	Bryan (2008)	
Roof Geyser	Bryan (2008)	
Dragon Geyser*	Bryan (2008)	
Bench Geyser	Bryan (2008)	
Clastic Geyser	Bryan (2008)	
Giantess Geyser*	Bryan (2008)	
Vault Spring	Bryan (2008)	
Infant Geyser*	Bryan (2008)	
Peanut Pool	Bryan (2008)	
Dome Geyser	Bryan (2008)	
Butterfly Spring	Bryan (2008)	
Mottled Pool*	Bryan (2008)	
Solitary Geyser*	Bryan (2008)	
Castle Group		**23**
Castle Geyser*	Bryan (2008)	
Gizmo Geyser	Bryan (2008)	
UNNGs next to Gizmo (2)	Bryan (1990)	
Tilt Geyser	Bryan (2008)	
Crested Pool	Bryan (2008)	
Sprinkler Geyser*	Bryan (2008)	
Sprinkler B Geyser	Bryan (2008)	
Heartbeat Spring	Bryan (2008)	
Spatter Geyser	Bryan (2008)	
Snake Eyes Geyser (CCG-8)	Bryan (2008)	

Geyser	Reference	Total
Rattle Geyser	Bryan (2008)	
South Scalloped Spring	Bryan (1989a)	
Scalloped Spring*	Bryan (2008)	
Deleted Teakettle	Bryan (2008)	
CCG-10	Bryan (2008)	
Terra Cotta A Geyser	Keller (2010)	
Terra Cotta B Geyser	Keller (2010)	
Terra Cotta C Geyser	Keller (2010)	
Terra Cotta D Geyser	Keller (2010)	
Terra Cotta E Geyser	Keller (2010)	
Terra Cotta F Geyser	Keller (2010)	
UNNG upstream from Lime Kiln	Goldberg (2003)	
Frog Pools		**5**
CCG-6	Bryan (2008)	
Frog Pools (2 geysers)	Marler (1973)	
Liberty Pool	Marler (1973)	
Fissure Spring*	Marler (1973)	
Sawmill Group		**14**
Churn Geyser*	Bryan (2008)	
Sawmill Geyser*	Bryan (2008)	
Uncertain Geyser*	Bryan (2008)	
Tardy Geyser*	Bryan (2008)	
Twilight Spring	Bryan (2008)	
Penta Geyser*	Bryan (2008)	
Spasmodic Geyser*	Bryan (2008)	
Oval Spring*	Bryan (2008)	
Old Tardy's Indicator (aka Nifty Geyser)	Bryan (2008)	
Old Tardy Geyser*	Bryan (2008)	
Slurp Geyser	Bryan (2008)	
Crystal Spring	Bryan (2008)	
Bulger Geyser*	Bryan (2008)	
Bulger's Hole	Dunn (2011)	
Grand Group		**11**
Rift Geyser*	Bryan (2008)	
The Sputniks (2 geysers)	Bryan (2008)	
West Triplet Geyser*	Bryan (2008)	
East Triplet Geyser*	Bryan (2008)	
North Triplet Geyser*	Bryan (2008)	
Percolator Geyser*	Bryan (2008)	
Grand Geyser*	Bryan (2008)	
Turban Geyser*	Bryan (2008)	
Vent Geyser*	Bryan (2008)	
Topsoil Spring	Bryan (2008)	
Features near Economic Geyser		**9**
Key Spring (CCG-9)	Bryan (2008)	
Economic Geyser Crater*	Bryan (2008)	
East Economic Geyser	Bryan (2008)	
Wave Spring	Bryan (2008)	
UNNG behind Wave	Bryan (2008)	
Crack Geyser	Bryan (2008)	

Geyser	Reference	Total
Bush Geyser	Bryan (2008)	
UNNGs (2)	Bryan (2008)	
Orange Spring Group		**7**
Pulsar Geyser (OSG-1)	Bryan (2008)	
Orange Spring	Bryan (2008)	
Orange Spring Geyser	Bryan (2008)	
OSG-2	Bryan (2008)	
UNNGs S of OSG-2 (2)	Bryan (2008)	
South Orange Spr. Geyser (OSG-3)	Bryan (2008)	
Giant Group		**16**
Inkwell Spring*	Bryan (2008)	
New Geyser	Bryan (2008)	
Solstice Geyser (GNT-4)	Bryan (2008)	
East Purple Pool	Bryan (2008)	
North Purple Pool	Bryan (2008)	
South Purple Pool	Bryan (2008)	
GNT-1	Bryan (2008)	
Oblong Geyser*	Bryan (2008)	
Turtle Geyser	Bryan (2008)	
Giant Geyser*	Bryan (2008)	
The Platform Vents	Bryan (2008)	
Mastiff Geyser*	Bryan (2008)	
Catfish Geyser*	Bryan (2008)	
Bijou Geyser*	Bryan (2008)	
GNT-3	Bryan (2008)	
The GIP (GNT-2)	Bryan (2008)	
Grotto Group		**14**
Variable Spring	Bryan (2008)	
Paperiello #3	Paperiello (1994b)	
Grotto Geyser*	Bryan (2008)	
Paperiello #2	Paperiello (1994b)	
The Central Vents	Bryan (2008)	
Rocket Geyser	Bryan (2008)	
Paperiello #4	Paperiello (1994b)	
Indicator Spring	Bryan (2008)	
Frying Pan Vents	Bryan (1989c)	
Grotto Fountain Geyser	Bryan (2008)	
South Grotto Fountain Geyser	Bryan (2008)	
Startling Geyser	Bryan (2008)	
Spa Geyser	Bryan (2008)	
Marathon Pool	Bryan (2008)	
Chain Lakes Group		**11**
Victory Geyser (CLC-3)	Bryan (2008)	
Square Spring	Bryan (2008)	
UNNGs behind Square (2)	Bryan (2008)	
Culvert Geyser	Bryan (2008)	
Link Geyser	Bryan (2008)	
Middle Chain Lake (2 geysers)	Koenig (1989)	
North Chain Lake Geyser	Bryan (2008)	
UNNG within N Chain Lake Geyser	Koenig (1989)	

Geyser		Reference	Total
	Clasp Geyser (CLC-1)	Bryan (2008)	
Riverside Geyser			**1**
	Riverside Geyser*	Bryan (2008)	
Morning Glory Group			**9**
	Mortar Geyser*	Bryan (2008)	
	Fan Geyser*	Bryan (2008)	
	Spiteful Geyser	Bryan (2008)	
	Norris Pool	Bryan (2008)	
	Morning Glory Pool*	Bryan (2008)	
	Sentinel Geyser	Bryan (2008)	
	Sentinel's Vents (MGG-2)	Bryan (2008)	
	West Sentinel	Bryan (2008)	
	Green Star Spring	Bryan (2008)	
Round Spring Group			**9**
	West Round Spring	Bryan (2008)	
	Pear Geyser	Bryan (2008)	
	Pear Spring	Paperiello (1994a)	
	Round Spring Geyser	Bryan (2008)	
	RSG-2	Bryan (2008)	
	UNNG near RSG-2	Paperiello (1994a)	
	Round Spring*	Bryan (2008)	
	Trefoil Spring	Bryan (2008)	
	East Round Spring	Bryan (2008)	
Daisy Group			**12**
	Bank Geyser	Bryan (2008)	
	Zig Zag Spring	Bryan (2008)	
	Bonita Pool	Bryan (2008)	
	Bonita's Sputs	Bryan (2008)	
	Radiator Geyser	Bryan (2008)	
	Daisy Geyser*	Bryan (2008)	
	Brilliant Pool	Bryan (2008)	
	Splendid Geyser*	Bryan (2008)	
	Daisy's Thief Geyser	Bryan (2008)	
	Murky Spring	Bryan (2008)	
	Pyramid Geyser	Bryan (2008)	
	Cyclops Spring*	Marler (1973)	
Punch Bowl Spring			**5**
	PBG-1	Bryan (2008)	
	UNNGs near PBG-1 (2)	Bryan (2008)	
	Black Sand Pool*	Bryan (2008)	
	Demon's Cave	Bryan (2008)	
Cascade Group			**17**
	Artemisia Geyser*	Bryan (2008)	
	Bench Spring	Paperiello (personal communication)	
	Atomizer Geyser	Bryan (2008)	
	Slide Geyser	Bryan (2008)	
	UNNG above Slide	Bryan (1992)	
	Horse Geyser	Paperiello and Wolf (1986)	
	Sprite Pool	Bryan (2008)	
	Calthos Spring	Bryan (2008)	

Geyser	Reference	Total
Seismic Geyser	Bryan (2008)	
Satellite Geyser	Bryan (2008)	
Aftershock Geyser	Bryan (2008)	
Hillside Geyser	Bryan (2008)	
Paperiello and Wolf #54	Paperiello and Wolf (1986)	
Broken Cone CDG-1	Bryan (2008)	
Paperiello and Wolf #41	Paperiello and Wolf (1986)	
Paperiello and Wolf #43	Paperiello and Wolf (1986)	
Westside Group		**8**
South Pool (YM-210)	Bryan (2008)	
WSG-5	Bryan (2008)	
Maelstrom Geyser (WSG-4)	Bryan (2008)	
Fracture Geyser (WSG-1)	Bryan (2008)	
Bigfoot Geyser (WSG-2)	Bryan (2008)	
Carapace Geyser (WSG-3)	Bryan (2008)	
Fantail Geyser	Bryan (2008)	
Ouzel Geyser	Bryan (2008)	
Old Road Group		**27**
Paperiello and Wolf #46	Paperiello and Wolf (1986)	
Baby Daisy Geyser	Bryan (2008)	
UNNGs NW of Baby Daisy	Bryan (2008)	
Baby Splendid Geyser	Bryan (2008)	
Biscuit Basin Geyser	Bryan (2008)	
UNNG NW of Biscuit Basin Geyser	Bryan (1993)	
Cauliflower Geyser	Bryan (2008)	
ORG-1 (2 geysers)	Bryan (2008)	
ORG-2	Bryan (2008)	
Demise Geyser	Bryan (2008)	
ORG-5	Bryan (2008)	
Mercury Geyser	Bryan (2008)	
UNNG 30' E of Mercury	Monteith (2000)	
UNNG immediately S of Mercury	Paperiello (2003)	
UNNG next to trail	J. Cross (personal observation)	
Rusty Geyser	Bryan (2008)	
Dusty Geyser	Bryan (2008)	
Paperiello #4	Paperiello (1986)	
Asphalt Spring	Paperiello and Wolf (1986)	
Island Geyser	Bryan (2008)	
Biscuit Basin Group		**32**
Black Opal Pool	Bryan (2008)	
Black Diamond Pool	Bryan (2008)	
Salt and Pepper BBG-8	Bryan (2008)	
UNNG next to trail BBG-9	Bryan (2008)	
Sapphire Pool*	Bryan (2008)	
UNNG W of Sapphire Pool	Paperiello and Wolf (1986)	
Jewel Geyser*	Bryan (2008)	
Shell Spring*	Bryan (2008)	
UNNG across boardwalk from Shell	Bryan (1993)	
Silver Globe A Cave	Bryan (2008)	
Silver Globe B	Bryan (2008)	

Geyser	Reference	Total
Silver Globe C	Bryan (2008)	
Silver Globe D	Bryan (2008)	
Silver Globe E Slit	Bryan (2008)	
BBG-3	Bryan (2008)	
Silver Globe Spring*	Bryan (2008)	
Avoca Spring	Bryan (2008)	
Sea Weed Spring	Bryan (2008)	
West Geyser	Bryan (2008)	
East Mustard Spring	Bryan (2008)	
West Mustard Spring	Paperiello (1986)	
North Geyser	Bryan (2008)	
UNNG near Outpost	J. Cross (personal observation)	
Outpost (BBG-4)	Bryan (2008)	
Sentry (BBG-5)	Bryan (2008)	
Green Bubbler (BBG-6)	Bryan (2008)	
Yellow Bubbler (BBG-7)	Bryan (2008)	
Red Mist Geyser (BBG-2)	Bryan (2008)	
Black Pearl Geyser	Bryan (2008)	
Coral Geyser	Bryan (2008)	
Fumarole Geyser	Bryan (2008)	
UNNG near Fumarole Geyser	Bryan (1990)	
Hillside Springs	J. Cross (2008a)	**1**
Black Sand Group		**20**
UNNG near Pentagonal	Bryan (1993)	
Whistle Geyser	Bryan (2008)	
Sunlight Geyser (BSB-6)	Bryan (2008)	
BSB-1	Bryan (2008)	
Spouter Geyser*	Bryan (2008)	
The Grumbler	Bryan (2008)	
Jagged Spring	Bryan (2008)	
Ragged Spring	Bryan (2008)	
Cliff Geyser*	Bryan (2008)	
Snakebite Geyser	Dunn (1997a)	
Green Spring	Bryan (2008)	
White Sand Geyser	Bryan (2008)	
BSB-2	Bryan (2008)	
Handkerchief Pool*	Bryan (2008)	
BSB-5	Bryan (2008)	
Handkerchief Geyser	Bryan (2008)	
Cinnamon Spouter (BSB-3)	Bryan (2008)	
Rainbow Pool*	Bryan (2008)	
BSB-4	Bryan (2008)	
Sunset Lake*	Bryan (2008)	
Pine Springs	J. Cross (2008a)	**5**
Old Faithful Access Road		**1**
Hot Lips	Strasser (2003), Paperiello and Wolf (1986)	
Myriad Group	J. Cross (2008a)	**49**
Pipeline Meadows		**7**
Dilapidated Geyser (PMG-1)	Bryan (2008)	

Geyser	Reference	Total
UNNG NW of Dilapidated	J. Cross (2008b)	
PMG-2	Bryan (2008)	
Midas Spring (PMG-3)	Bryan (2008)	
Secluded Geyser (PMG-4)	Bryan (2008)	
Bend Cone	Bryan (2008)	
UNNG in meadow N of Bend Cone	Goldberg (2007)	
Pipeline Creek	J. Cross (2008a)	**3**
Upriver Group	J. Cross (2008a)	**2**

MIDWAY GEYSER BASIN		**59**
Rabbit Creek Group		**12**
Till Geyser	Bryan (2008)	
MGB-1 through MGB-5 (5 geysers)	Bryan (2008)	
River Spouter	Bryan (2008)	
Pebble Spring	Bryan (2008)	
Silent Pool	Bryan (2008)	
UNNG 100 yards NE of Till	Bryan (1990)	
UNNGs (2) below Silent Pool	Paperiello (personal communication)	
Flood Group		**25**
East Side Of River		
Catfish Geyser	Bryan (2008)	
Flood	Bryan (2008)	
Paperiello and Wolf #2	Paperiello and Wolf (1986)	
Paperiello and Wolf #3 Toy Geyser	Paperiello and Wolf (1986)	
Circle Pool	Paperiello and Wolf (1986)	
Paperiello and Wolf #5 vent near Circle Pool	Paperiello and Wolf (1986)	
Tangent Geyser (Paperiello and Wolf #6)	Paperiello and Wolf (1986)	
Paperiello and Wolf #7	Paperiello and Wolf (1986)	
Paperiello and Wolf #10	Paperiello and Wolf (1986)	
UNNG on river bank	Goldberg (2008)	
West Side Of River		
West Flood	Bryan (2008)	
Paperiello and Wolf #18	Paperiello and Wolf (1986)	
Pentapus Geyser (Paperiello and Wolf #21)	Paperiello and Wolf (1986)	
Paperiello and Wolf #22	Paperiello and Wolf (1986)	
Paperiello and Wolf #23	Paperiello and Wolf (1986)	
MGB-7 (10 of 14 geysers)	Bryan (2008)	
Rabbit Valley		**17**
Paperiello and Wolf #4	Paperiello and Wolf (1987)	
Rabbit Creek Geyser	Bryan (2008)	
Wizard Spring (MGB-8)	Bryan (2008)	
UNNG at head of stream, S side of valley	Paperiello (personal communication)	
Paperiello and Wolf #30	Bryan (1997)	
Tuba Geyser (Paperiello and Wolf #38)	Dunn (1997b)	
Piccolo Geyser (Paperiello and Wolf #38)	Monteith (1999a)	
Belch Geyser	J. Cross (2001)	
Paperiello and Wolf and Wolf #41c	Bryan (1997)	
Volcano Geyser (Paperiello and Wolf #44a)	Paperiello and Wolf (1987)	
Paperiello and Wolf #46	Paperiello and Wolf (1987)	

Geyser	Reference	Total
UNNGs S side of valley (2)	Paperiello (personal communication)	
UNNG in pit (Paperiello and Wolf #90)	Barger (2001)	
Gravel Geyser	J. Cross (2001)	
Paperiello and Wolf #11	Bryan (1992)	
UNNG N end of Rabbit Highlands	Bryan (1993)	
Excelsior Group		**5**
Excelsior Geyser Crater	Bryan (2008)	
Opal Pool*	Bryan (2008)	
Tromp Spring*	Bryan (2008)	
UNNGs S of Excelsior (2)	Paperiello (personal communication)	
LOWER GEYSER BASIN		**283**
Serendipity Meadows		**3**
UNNGs (2)	Bryan (1993)	
UNNG	J. Cross (personal observation)	
White Creek Group		**28**
Buena Vista Spring	J. Cross (personal observation)	
WCG-7 near parking lot	Bryan (2008)	
A-0 Geyser	Bryan (2008)	
UNNG between A-0 and A-1	J. Cross (personal observation)	
A-1 Geyser	Bryan (2008)	
A-2 Geyser	Bryan (2008)	
UNNG near A2 runoff channel	J. Cross (personal observation)	
UNNGs (2) in pit S of A-2	J. Cross (personal observation)	
UNNGs between A-0 and A-2	J. Cross (personal observation)	
UNNG NW of A-2 (WCG-5/Paperiello and Wolf #12?)	Bryan (2008); Paperiello and Wolf (1986)	
Paperiello and Wolf #6 (5 geysers)	Paperiello and Wolf (1986)	
Botryoidal Spring	Bryan (2008)	
Paperiello and Wolf #7 near Botryoidal	Paperiello and Wolf (1986)	
Logbridge Geyser	Bryan (2008)	
WCG-8 near Logbridge	Bryan (2008)	
Black Cat Geyser	J. Cross (2008b)	
Diamond Spring	Bryan (2008)	
WCG-4 in pit	Bryan (2008)	
Tuft Geyser	Bryan (2008)	
Eclipse Geyser	Bryan (2008)	
Spindle Geyser	Bryan (2008)	
UNNG near Spindle	Bryan (1992)	
Filial Geyser (next to Five Sisters)	Bryan (1990); T. Cross (2010)	
Great Fountain Group		**4**
Great Fountain Geyser*	Bryan (2008)	
Prawn Geyser (GFG-1)	Bryan (2008)	
GFG-2	Bryan (2008)	
Surprise Pool*	Marler (1973)	
White Dome Group		**7**
White Dome Geyser*	Bryan (2008)	
Pebble Geyser	Bryan (2008)	
Crack Geyser	Bryan (2008)	
Gemini Geyser	Bryan (2008)	

Geyser	Reference	Total
WDG-1	Bryan (2008)	
WDG-2	Bryan (2008)	
Toadstool Geyser	Bryan (2008)	
Tangled Creek Group		**9**
TGG-1	Bryan (2008)	
UNNGs (7)	Bryan (2008)	
Spire Geyser	T. Cross (2011)	
Pink Cone Group		**13**
Pink Cone*	Bryan (2008)	
Dilemma Geyser	Bryan (2008)	
Pink Geyser	Bryan (2008)	
Bead Geyser*	Bryan (2008)	
Shelf Spring	Marler (1973)	
Box Spring	Bryan (2008)	
Labial Geyser	Bryan (2008)	
Labial's East Satellite	Bryan (2008)	
Labial's West Satellite	Bryan (2008)	
UNNG below Labial	Bryan (1989a)	
Narcissus Geyser	Bryan (2008)	
UNNG W of Narcissus	Paperiello (personal communication)	
Dragonfly Geyser (aka Underhill Spring Geyser)	Cross (2008b)	
Firehole Lake Group		**7**
Steady Geyser*	Bryan (1993)	
Young Hopeful Geyser*	Bryan (2008)	
Gray Bulger Geyser	Bryan (2008)	
Artesia Geyser	Bryan (2008)	
Sulfosel Spring	Bryan (2008)	
Primrose Springs	Bryan (2008)	
UNNG near Dart Spr	Bryan (1993)	
Fountain Group		**41**
Celestine Pool	Bryan (2008)	
Silex Spring	Bryan (2008)	
Leather Pool	Marler (1973)	
Volcanic Tableland Geyser (FTN-1)	Bryan (2008)	
Old Cone Geyser	Bryan (2008)	
Fountain Terrace		
UNNG at foot of stairs	Bryan (2007)	
Twig Geyser	Bryan (2008)	
Bearclaw Geyser	Bryan (2008)	
Jet Geyser*	Bryan (2008)	
Super Frying Pan	Bryan (2008)	
Spasm Geyser*	Bryan (2008)	
Fountain Geyser*	Bryan (2008)	
Morning Geyser	Bryan (2008)	
Morning's West Satellite	Paperiello (1993)	
Morning's Thief	Bryan (2008)	
Clepsydra Geyser*	Bryan (2008)	
Sub Geyser	Bryan (2008)	
Jelly Spring*	Bryan (2008)	

Geyser	Reference	Total
Gore Springs		
Paperiello and Wolf #21	Paperiello (1993)	
Fitful Geyser	Bryan (2008)	
New Bellefontaine Geyser	Bryan (2008)	
Paperiello #24-29 (6 geysers) UNNG N of New Bellefontaine	Paperiello (1993)	
Fissure Springs		
Stalactite Geyser (FTN-6)	Bryan (2008)	
Paperiello #30-32 (3 geysers)	Paperiello (1993)	
Pithole Springs		
Mask Geyser	Bryan (2008)	
Paperiello #37-40 (4 geysers)	Paperiello (1993)	
Geysers On Flat		
Bellefontaine Geyser*	Bryan (2008)	
Frolic Geyser	Bryan (2008)	
FTN-4 near Frolic	Bryan (2008)	
FTN-7 (2 geysers)	Bryan (2008)	
Kaleidoscope Group	J. Cross (2008a)	**38**
Fissure Group	J. Cross (2008a)	**23**
Thud Group		**11**
Fungoid Spring	Bryan (2008)	
Thud Spring	Bryan (2008)	
UNNGs (5)	Keller (1998)	
Gourd Spring	Bryan (2008)	
Jug Spring	Keller (1998)	
Oakleaf Spring*	Bryan (2008)	
Kidney Spring	Bryan (2008)	
Quagmire Group	J. Cross (2008a)	**3**
Camp Group	J. Cross (2008a)	**1**
Morning Mist Springs		**5**
Porcupine Hill Geyser	Bryan (2008)	
UNNGs near Porcupine Hill G. (4)	Bryan (2008)	
Butte Group		**1**
KIT-1	Bryan (2008)	
Culex Basin	J. Cross (2008a)	**6**
River Group		**57**
West Side Of River		
UNNG near Skeleton Pool	Bryan (1993)	
Mound Geyser	Bryan (2001)	
UNNGs N of Mound (2)	Bryan (2001)	
UNNG S of Mound	J. Cross (2008a)	
Sand Geyser	Bryan (2008)	
RVG-1	Bryan (2001)	
UNNG at upstream edge of RVG-1	Paperiello (personal communication)	
RVG-2 (3 geysers)	Bryan (2008)	
RVG-3	Bryan (2001)	
M-190B Geyser	Bryan (2008)	
UNNGs near M-190B (3)	Paperiello (personal communication)	
East Side Of River		
RVG-4	Bryan (2008)	

Geyser	Reference	Total
RVG-7	Bryan (2008)	
Azure Spring	Bryan (2008)	
Paperiello #7 (5 geysers)	Paperiello and Wolf (1986)	
Bath Spring	Bryan (1989a)	
Pocket Basin Geyser	Bryan (2008)	
UNNG NE edge of Pocket Basin Geyser	J. Cross (personal observation)	
Burple Geyser	Paperiello and Wolf (1986)	
UNNG deep pool N edge of thermal area (RVG-8)	Bryan (2008)	
Paperiello and Wolf #14 (2 geysers, RVG-6)	Paperiello and Wolf (1986)	
UNNGs (4) near Paperiello and Wolf #14 (RVG-6)	Paperiello (personal communication)	
Thermopod Geyser (RVG-6)	J. Cross (2008a)	
Lightsocket Geyser (Paperiello and Wolf #15, RVG-6)	J. Cross (2008a)	
UNNGs (2) near Lightsocket (RVG-6)	Paperiello (personal communication)	
UNNG N of Spectrum Spring (RVG-6)	J. Cross (2008a)	
UNNG NW corner of Spectrum Spring (RVG-6)	J. Cross (2008a)	
UNNG S of Spectrum Spring (RVG-6)	J. Cross (2008a)	
UNNGs S of Spectrum Spring (3 geysers, RVG-6)	Paperiello (personal communication)	
UNNG on crest of terrace above Dark Pool (RVG-6)	Paperiello (personal communication)	
UNNGs (2) N of Brain Geyser (RVG-5)	Paperiello (personal communication)	
Brain Geyser (Paperiello and Wolf #27)	Paperiello and Wolf (1986)	
original Dark Pool (aka Three-by-Five Pool, RVG-5a)	Bryan (2008)	
current Dark Pool (RVG-5)	J. Cross (2008b)	
UNNG in pit near current Dark Pool (RVG-5)	J. Cross (personal observation)	
cone vent above Armored Spring (RVG-5)	Paperiello (personal communication)	
Fortress Geyser	Bryan (2008)	
UNNG 1/4 mile S of Fortress	Bryan (1990)	
UNNG mud geyser N end of Microcosm Basin	J. Cross (2008a)	
UNNG NE of Rush Lake	Paperiello (personal communication)	
Sentinel Meadows Group		**10**
SMG-1	Bryan (2008)	
Convoluted Geyser (SMG-2)	Bryan (2008)	
Paperiello #8a (next to Mound Spr.)	Paperiello (1990)	
Steep Cone	Bryan (2008)	
Iron Pot	Bryan (2008)	
The Bulgers	Bryan (2008)	
SMG-3	Bryan (2008)	
Flat Cone	Bryan (2008)	
Rosette	Bryan (2008)	
Paperiello #6	Paperiello (1990)	
Boulder Spring		**2**
Boulder Spring	Paperiello (personal communication)	
UNNG near Boulder Spring	Bryan (2008)	
Fairy Meadows	J. Cross (2008a)	**11**
Spray and Imperial Geysers	J. Cross (2008a)	**2**
Marshall's Hotel Group	J. Cross (2008a)	**1**

Geyser	Reference	Total
NORRIS GEYSER BASIN		**193**
Porcelain Basin		**85**
Central And SW Portions		
Harding Geyser	Bryan (2008)	
UNNG under boardwalk	Paperiello (personal communication)	
Dark Cavern Geyser	Bryan (2008)	
Valentine Geyser*	Bryan (2008)	
Li'l Steam Vent	Paperiello (personal communication)	
Guardian Geyser	Bryan (2008)	
Pistol Geyser NPR-6	Bryan (2008)	
Black Growler*	Whittlesey (1988)	
Ledge Geyser	Bryan (2008)	
UNNG above Ledge	Bryan (1993)	
UNNG between Ledge and Jetsam	Paperiello (personal communication)	
Jetsam Pool	Bryan (2008)	
UNNG below Ledge Geyser	Paperiello (personal communication)	
UNNG below Jetsam Pool	Paperiello (personal communication)	
Basin Geyser	Bryan (2008)	
Scummy Pool (2)	Paperiello (personal communication)	
Geezer Geyser	Bryan (2008)	
Arsenic Geyser*	Bryan (2008)	
Lava Pool Complex (7)	Bryan (2008)	
UNNG #10	Paperiello (1984)	
Moxie Geyser	Paperiello (personal communication)	
Africa Geyser	Bryan (2008)	
Fireball Geyser	Bryan (2008)	
Pinto Geyser	Bryan (2008)	
Fan Geyser	Bryan (2008)	
Christmas Geyser or 1V Geyser (Paperiello UNNG #11)	Bryan (2002), Paperiello (1984)	
3V Geyser (Paperiello UNNG #12)	Paperiello (1984)	
UNNG	Paperiello (personal communication)	
original Fan Geyser	Paperiello (personal communication)	
Paperiello UNNG #13	Paperiello (1984)	
Paperiello UNNG #14	Paperiello (1984)	
Little Whirligig Geyser	Bryan (2008)	
Whirligig Geyser*	Bryan (2008)	
Constant Geyser*	Bryan (2008)	
Splutter Pot	Bryan (2008)	
UNNGs btw Splutter Pot and Pinwheel (2)	Bryan (2008)	
Pinwheel Geyser	Bryan (2008)	
UNNG E of Pinwheel	Bryan (1992)	
UNNG N of Pinwheel	J. Cross (personal observation)	
Pequito Geyser	Bryan (2008)	
Ramjet Springs	Bryan (1989b)	
Crown Jewels Spring	Paperiello (personal communication)	
Bear Den Geyser	Bryan (2008)	
Ebony Geyser	Bryan (2008)	
Junebug Spring	Bryan (1989b)	
Paperiello UNNG #5	Paperiello (1984)	

Geyser	Reference	Total
UNNG N of Crackling Lake	Paperiello (personal communication)	
Crackling Lake Geyser	Bryan (1989b)	
Cats Eye Spring	Bryan (2008)	
Glacial Melt Geyser	Bryan (2008)	
Teal Blue Bubbler	Bryan (2008)	
Transit SE Corner To NE Corner		
Sunday Geyser	Bryan (2008)	
UNNG E of Sunday	Bryan (1989a)	
Colloidal Pool*	Paperiello (1984)	
Hurricane Vent*	Bryan (2008)	
Congress Pool*	Bryan (2008)	
UNNG behind Congress Pool (aka Tantalus Geyser)	Bryan (1989a)	
Feisty Geyser	Bryan (2008)	
Incline Geyser	Bryan (2008)	
Lambchop Geyser (NPR-5)	Bryan (2008)	
Blue Geyser	Bryan (2008)	
Iris Spring	Bryan (2008)	
Onyx Spring	Bryan (1989b)	
Green Apple Cider Spring	Bryan (2002)	
Apple Green Geyser*	Bryan (2008)	
Norris Geyser	Bryan (2008)	
Primrose Springs*	Bryan (2008)	
Ragged Spouter	Bryan (2008)	
Paperiello UNNG #8	Paperiello (1984)	
Mound Geyser Cone	Paperiello (1984)	
Collapsed Cave Geyser	Bryan (2008)	
Paperiello UNNG #16	Paperiello (1984)	
Paperiello UNNG #17	Paperiello (1984)	
Graceful Geyser	Bryan (2008)	
UNNGs beyond Graceful (3)	Bryan (1990)	
Back Basin		**70**
Eastern Part		
Steamvalve Spring*	Bryan (2008)	
Bathtub Spring*	Bryan (2008)	
Paperiello UNNG #1	Paperiello (1984)	
Emerald Spring*	Bryan (2008)	
UNNGs N of Emerald (at least 2)	Bryan (2002)	
Steamboat Geyser*	Bryan (2008)	
Cistern Spring	Bryan (2008)	
Paperiello UNNG #4	Paperiello (1984)	
Echinus Geyser*	Bryan (2008)	
Crater Spring	Bryan (2008)	
Arch Steam Vent	Bryan (2008)	
Tantalus Geyser (formely Decker Island Geyser)	Bryan (2008)	
Paperiello UNNG #7	Paperiello (1984)	
Southwestern Part		
Mystic Spring	Bryan (2008)	
Mud Spring	Bryan (2008)	
Paperiello UNNG #24	Paperiello (1984)	

Geyser	Reference	Total
UNNG 80 feet S of Yellow Mud Spring	Paperiello (1984)	
Puff-n-Stuff Geyser	Bryan (2008)	
Gray Lakes*	Bryan (2008)	
Big Alcove Spring*	Bryan (2008)	
Little Alcove Spring	Surtevant (1997)	
Medusa Spring	Bryan (2008)	
Hydrophane Springs (2 geysers)	Paperiello (1984)	
Spearpoint Geyser (NBK-4)	Bryan (2008)	
Sinter Bridge Geyser	Paperiello (personal communication)	
Tangled Root Complex	Paperiello (1984)	
Yellow Funnel Spring	Bryan (2008)	
Son of Green Dragon Spring	Bryan (2008)	
Pebble Geyser	Whittlesey (1988)	
Pebble Geyser (Cone)	Whittlesey (1988)	
UNNG S of Pebble Geyser Cone	Keller (2006)	
Dabble Geyser	Bryan (2008)	
Paperiello UNNG #6	Paperiello (1984)	
Orby Geyser	Bryan (2008)	
UNNGs near Orby (4)	Paperiello (personal communication)	
UNNG #20	Paperiello (1984)	
Recess Spring	Bryan (2008)	
Bastille Geyser	Bryan (2008)	
Sagebrush Lizard Spring	J. Cross (2010)	
Porkchop Geyser	Bryan (2008)	
Second Erupter	Bryan (2008)	
Pearl Geyser*	Bryan (2008)	
UNNG across trail from Pearl	Meech (2006)	
Northwestern Part		
Vixen Geyser*	Bryan (2008)	
UNNG below Tantalus bridge	Bryan (1989a)	
UNNG in Tantalus Creek btw Vixen and Veteran	Monteith (2001)	
UNNGs in same area (2)	Sturtevant (2003)	
Rubble Geyser	Bryan (2008)	
Corporal Geyser*	Bryan (2008)	
Dog's Leg Spring	Bryan (2008)	
Veteran Geyser	Bryan (2008)	
Veteran's Auxiliary	Bryan (2008)	
Palpitator Spring*	Bryan (2008)	
Fearless Geyser*	Bryan (2008)	
Orpiment Spring (?)	Paperiello (personal communication)	
Mushroom Geyser	Paperiello (1984)	
Paperiello UNNG #18	Paperiello (1984)	
Drum Geyser	Paperiello (personal communication)	
Monarch Geyser*	Bryan (2008)	
Minute Geyser*	Bryan (2008)	
Branch Spring	Paperiello (personal communication)	
Forgotten Fumarole	Bryan (2008)	
Rediscovered Geyser	Bryan (2008)	
Downfall Geyser (Paperiello UNNG #22)	Paperiello (1984)	

Geyser	Reference	Total
One Hundred Spring Plain		**19**
Perpetual Spouter	Bryan (1989b)	
Venturi Geyser	Goldberg (personal communication)	
UNNG 250 feet ENE of Firecracker Pool	Paperiello (2010)	
Breach Geyser (Paperiello UNNS #12)	Bryan (2002), Paperiello (1984)	
UNNGs (3) in Tantalus Creek N of Cinder Pool	Paperiello (personal communication)	
Cinder Pool	Paperiello (personal communication)	
Paperiello UNNG #3 35 feet NE of Cinder Pool	Paperiello (1984); Bryan (2002)	
UNNG 80 feet NE of Cinder Pool	Paperiello (personal communication)	
Tantalus Geyser (Paperiello UNNS #2)	Paperiello (1984); Bryan (2002)	
The Reservoir	Paperiello (personal communication)	
UNNG 100 feet N of The Reservoir	Paperiello (personal communication)	
Black Tentacle Geyser	J. Cross (2010)	
UNNG SE of Horseshoe Spring	Paperiello (personal communication)	
Amethyst Geyser	Paperiello (2009)	
unnamed muddy geyser	Sturtevant (1996)	
UNNGs near Realgar Spring (2)	Paperiello (2010)	
The Gap		**13**
Elk Geyser	Wolf and Paperiello (1999)	
Wolf and Paperiello Geyser #1	Wolf and Paperiello (1999)	
Wolf and Paperiello Geyser #2	Wolf and Paperiello (1999)	
Wolf and Paperiello Geyser #3	Wolf and Paperiello (1999)	
Wolf and Paperiello Geyser #4	Wolf and Paperiello (1999)	
Wolf and Paperiello Geyser #5	Wolf and Paperiello (1999)	
Wolf and Paperiello Geyser #6	Wolf and Paperiello (1999)	
Gap Geyser	Paperiello (2010)	
Two Percent Geyser	Paperiello (2010)	
UNNGs (4)	Paperiello (2010)	
Norris Annex		**1**
Norris Annex Geyser	Paperiello (1984)	
Elk Park		**2**
UNNGs (2)	Bryan (2008)	
Unnamed area 2.4 miles WNW of Norris Jct.	J. Cross (2008a)	**3**

WEST THUMB GEYSER BASIN		84
Lower Group		**26**
Twin Geysers*	Bryan (2008)	
New Twin Geyser	Bryan (2008)	
UNNG SW of Twin on grassy slope	Bryan (1990)	
Roadside Steamer	Bryan (2008)	
Hillside Geyser	Bryan (2008)	
Abyss Pool*	Bryan (2008)	
Black Pool*	Bryan (2008)	
UNNG edge of Black Pool	Bryan (1993)	
Skinny Man Geyser	Bryan (2008)	
North Star Geyser	Bryan (2008)	
King Geyser*	Bryan (2008)	
Big Cone	Bryan (2008)	
Fishing Cone*	Bryan (2008)	

Geyser	Reference	Total
Lakeshore Geyser	Bryan (2008)	
Beach Geyser (WTL-1)	Bryan (2008)	
UNNG near Venting Pool	Keller (2005)	
UNNG inside W loop of boardwalk, below the paint pots	Quinn (1997)	
Surging Spring	Bryan (2008)	
Ledge Spring	Bryan (2008)	
Collapsing Pool	Bryan (2008)	
Percolating Spring	Bryan (2008)	
Perforated Pool	Bryan (2008)	
Ephydra Spring	Bryan (2008)	
Footprint Geyser (WTL-2)	Bryan (2008)	
Thumb Geyser	Bryan (2008)	
UNNG 20' WNW of Thumb Geyser	Bower (1996)	
Lake Shore Group		**8**
Goggle Spring	Bryan (2008)	
Garden Hose Geyser	Grigg (personal communication)	
Occasional Geyser*	Bryan (2008)	
UNNG at roadside near Occasional	Cochran (2008)	
Lone Pine Geyser	Bryan (2008)	
Guidebook Spring	Bryan (2008)	
Blow Hole	Bryan (2008)	
Overhanging Geyser	Bryan (2008)	
Potts Hot Spring Basin	J. Cross (2008a)	**50**

GIBBON GEYSER BASIN		**24**
Artists' Paint Pots	J. Cross (2008a)	**1**
Geyser Springs	J. Cross (2008a)	**16**
Sulphur Castle Group		**1**
UNNG, magenta vent	Bryan (1997, 2008)	
Gibbon Hill Group	J. Cross (2008a)	**2**
Sylvan Springs	J. Cross (2008a)	**3**
Gibbon Canyon	J. Cross (2008a)	**1**

LONE STAR GEYSER BASIN		**21**
Halfway Group	J. Cross (2008a)	**2**
Lone Star Group		**4**
Lone Star Geyser	Bryan (2008)	
Black Hole Geyser	Bryan (2008)	
Perforated Cone Geyser	Bryan (2008)	
UNNG at base of hill	J. Cross (personal observation)	
Bassett Group	J. Cross (2008a)	**1**
Channel and Bridge Groups		**5**
UNNG N of Meadow Cones	Paperiello (personal communication)	
other geysers (4)	J. Cross (2008a)	
Campsite Group	J. Cross (2008a)	**6**
Divide Group		**3**
Divide Geyser	J. Cross (2008a)	
Divide Pool	Monteith (1999b)	

Geyser	Reference	Total
UNNG below Divide	Monteith (1999b)	
SHOSHONE GEYSER BASIN		**107**
Little Giant Group	J. Cross (2008a)	**12**
Paperiello #6	Paperiello (1994)	
unnamed vent W of Little Giant	J. Cross (2010)	
Other geysers (10)	J. Cross (2008a)	
Minute Man Group	J. Cross (2008a)	**14**
Orion Group	J. Cross (2008a)	**15**
Camp Group	J. Cross (2008a)	**5**
Other geysers (4)	J. Cross (2008a)	
Paperiello #11	J. Cross (personal observation)	
North Group	J. Cross (2008a)	**35**
Pothole Geyser	J. Cross (personal observation)	
UNNG below Mangled Crater	T. Cross (personal communication)	
UNNG 250 feet NW of Blowout Pool	Paperiello (personal communication)	
Other geysers (32)	J. Cross (2008a)	
South Group	J. Cross (2008a)	**13**
Western Group	J. Cross (2008a)	**7**
Horse Camp Group	J. Cross (2008a)	**2**
Yellow Crater Group	J. Cross (2008a)	**1**
Lake Group		**2**
UNNG in Lake Group	Paperiello (personal communication)	
UNNG near pine tree	J. Cross (2008a)	
Shore Group		**1**
Burning Eyes Geyser	J. Cross (2008a)	
HEART LAKE GEYSER BASIN		**69**
Rustic Group	J. Cross (2008a)	**8**
Lower Group	J. Cross (2008a)	**13**
Middle Group	J. Cross (2008a)	**2**
Fissure Group	J. Cross (2008a)	**39**
UNNG below Puffing Spring	T. Cross (personal communication)	
Paperiello #81	J. Cross (personal observation)	
UNNGs (2) near Paperiello #75, 76, 80	J. Cross (personal observation)	
Cap Geyser (next to Paperiello #70)	J. Cross (2010)	
Paperiello #56b or c	J. Cross (personal observation)	
Other geysers (33)	J. Cross (2008a)	
Upper Group	J. Cross (2008a)	**7**
OTHER THERMAL AREAS		**33**
Lewis Lake Hot Springs		**2**
Reverse Geyser (aka Oscillator Geyser, in upper group)	J. Cross (1998)	
UNNG (on lake shore)	Paperiello (personal communication)	
Ferris Fork of the Bechler River	J. Cross (2008a)	**3**
Boundary Creek	J. Cross (2008a)	**2**
Mud Volcano		**2**
Mud Geyser	Bryan (2008)	

Geyser	Reference	Total
Edge Geyser, 1.1 miles S of Mud Volcano	Paperiello (personal communication)	
Sulphur Hills Hot Springs	J. Cross (2008a)	**1**
Alabaster Springs	J. Cross (2008a)	**1**
Glen Africa Basin	J. Cross (2008a)	**1**
Highland Hot Springs	J. Cross (2008a)	**1**
Grand Canyon of the Yellowstone	J. Cross (2008a)	**6**
Seven Mile Hole	J. Cross (2008a)	**3**
Joseph's Coat Hot Springs	J. Cross (2008a)	**1**
Bog Creek Hot Springs	J. Cross (2008a)	**3**
Hot Spring Basin		**2**
UNNGs (2)	Rick Hutchinson (communication to Rocco Paperiello)	
Pelican Valley		**2**
West Pelican Geyser	Bryan (2008)	
Pelican Creek Mud Volcano	Bryan (2008)	
Sedge Bay		**1**
Edge Geyser	Bryan (2008), Paperiello (personal communication)	
Calcite Springs		**1**
Paperiello and Wolf #5	Paperiello and Wolf (1986)	
Clearwater Springs		**1**
Semi-Centennial Geyser*	Bryan (2008)	
GRAND TOTAL		**1,283**

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Geyser listserve messages posted from 2004 to the present are archived at:
https://lists.wallawalla.edu/mailman/listinfo/geysers

The Short Life of Mickey Geyser, Mickey Hot Springs, Harney County, Oregon

Jeff Cross

Abstract

During its brief period of activity in the early 1990s, Mickey Geyser was the only natural geyser in Oregon. The reports from 1990 through 1994 that are collected here show that Mickey Geyser began having eruptions to 1 foot in May of 1990. In March and May of 1991, Mickey Geyser had larger eruptions to 5 feet. At times, the intervals and durations were bimodal. By March of 1992, Mickey Geyser had regressed to a perpetual spouter. A new vent developed between March of 1992 and March of 1994.

Mickey Geyser was the only known natural geyser in Oregon during its brief period of activity in the early 1990s. During the years from 1990 through 1994, Mickey Geyser was visited by several different parties:

May, 1990:	Jan Roberts (Roberts 1990)
October 13, 1990:	Lynn Stephens (Stephens, 1990)
March 23, 1991:	Marie Wolf and Rocco Paperiello (Wolf and Paperiello 1991)
May 18, 1991:	Lynn Stephens and Bob Berger (Stephens 1991)
March 24, 1992:	Lynn Stephens (Stephens 1992)
March 27-29, 1992:	Jeff Cross and Carlton Cross (Cross,1993)
March 25-27, 1994:	Jeff Cross (Cross 1994)

Reports from these visits show that Mickey Geyser began having small eruptions in 1990, progressed through a period of activity characterized by eruptions as high as 5 feet in 1991, and, by 1992, regressed to relatively minor perpetual and semiperiodic activity.

In May of 1990, Jan Roberts (Roberts 1990) visited Mickey Hot Springs and reported that

> The geyser's activity is cyclical, with definite periods of quiet alternating with small but rather boisterous eruptions. The overall timing of both the quiet and active periods is remarkably even and short—each is perhaps 20 +/- seconds long. The eruptions begin with a sudden rise in the water level within the crater (which is two feet in diameter), and culminate with bursts of water ejected at an angle. The jets are about 2 feet long and 1 foot high. None of the eruptions cleared the crater rim while I was watching it, but it appears that there have been other eruptions that are more vigorous. Photos taken only a few days before the field trip showed a dark, probably wet, ring completely surrounding the crater. This ring was not evident when I was at the site. Its occasional appearance seems to indicate that some sort of more powerful activity takes place at unseen times.

Five months later, in October, 1990, Lynn Stephens (Stephens 1990) reported similar activity:

> The activity is periodic, with cycles ranging from 10 to 20 seconds, as noted by Jan Roberts. The water level fluctuated about two inches, but never drained. Most of the bursting/boiling action is contained within the crater. However, I did observe some bursts two to three feet above ground level and measured some drops that landed four feet from the edge of the crater.

Major eruptive activity was first reported in March, 1991, by Marie Wolf and Rocco Paperiello (Wolf and Paperiello 1991). Their report can be found on page 134 of this volume. Both intervals and durations were longer on March 23, 1991, than noted by Stephens (1991) during the previous October. Wolf and Paperiello recorded 19 eruptions of Mickey Geyser. The eruptions occurred every 3.5

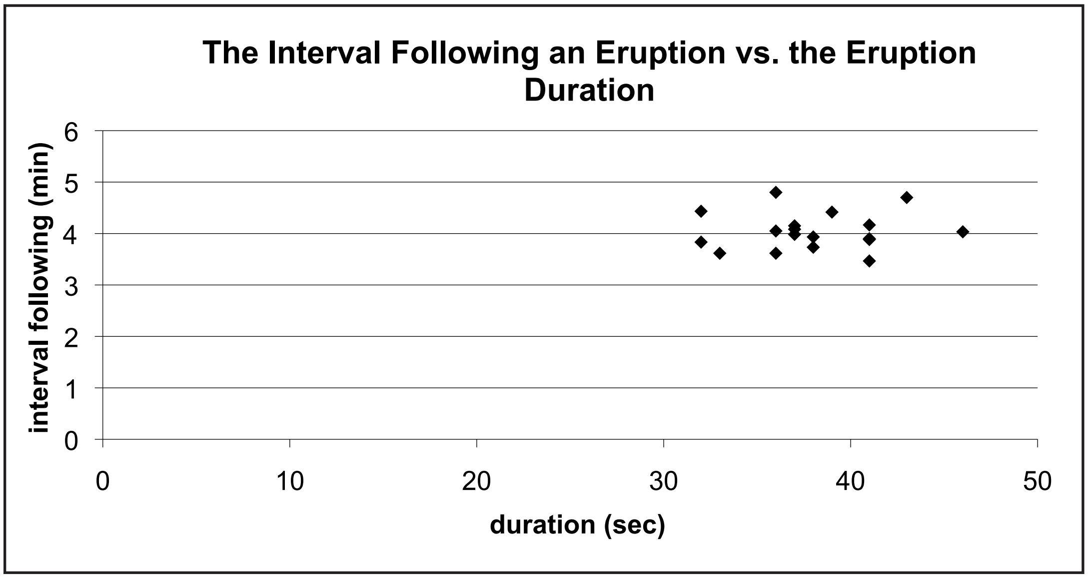
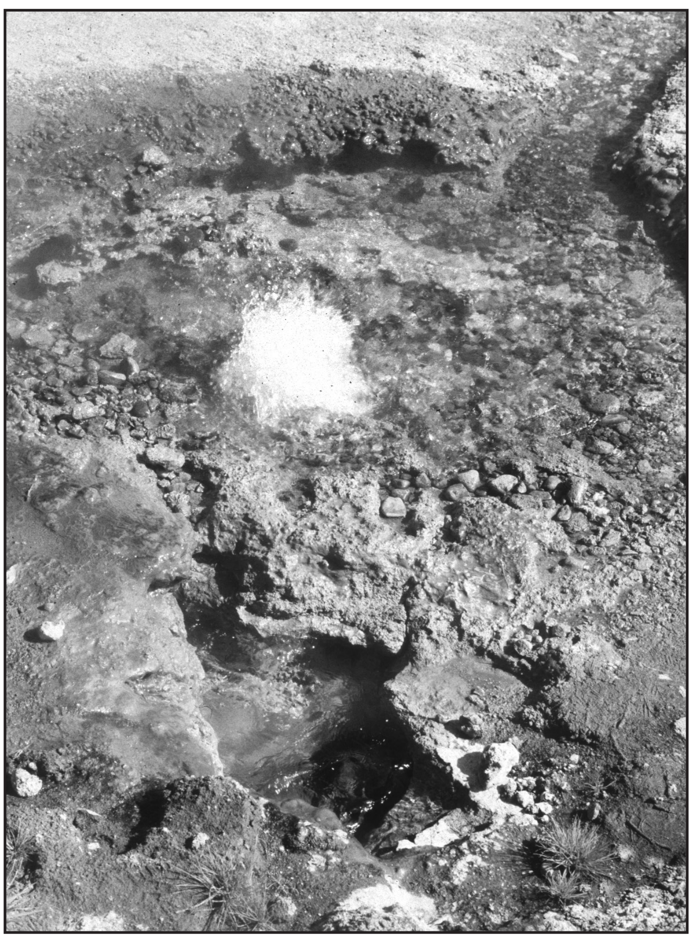


Table 1.

count	19	18
mean	38	4.0
%stdev	10	9.3
min	32	3.5
max	46	4.8

Figure 1 (above) and Table 1 (left): *In March, 1991, Mickey Geyser erupted 3 to 5 feet high every 3.5 to 4.8 minutes. Intervals and durations were unimodal at this time. Data from Wolf and Paperiello (1991).*



Left, Mickey Geyser in 1994. The erupting vent (top) formed between March 1992 and March 1994. Overflow left the splash basin via a runoff channel (upper right). The original vent is seen in the foreground. Tufts of grass growing next to the original vent indicated that it had not had major eruptions for many months.

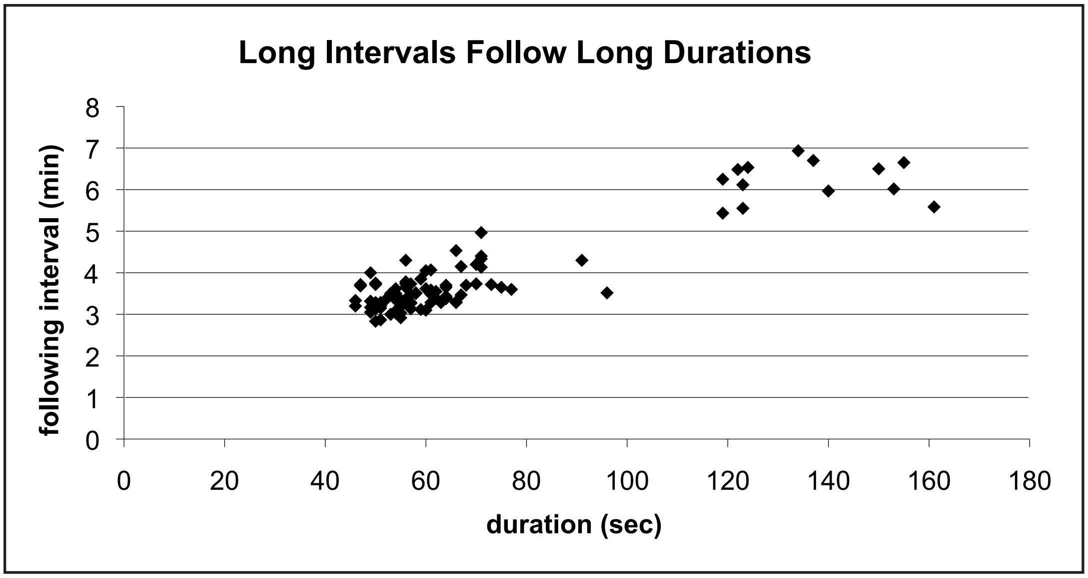


Figure 2, left, and Table 2, below: *By May, 1991, the intervals and durations of Mickey Geyser were bimodal. Long intervals followed long durations, and short intervals followed short durations. Data from Stephens (1991).*

Table 2.

		Durations (sec)	Intervals (min)
All data	count	96	93
	mean	69	3.9
	%stdev	41	26
	min	38	2.8
	max	161	6.9
Short mode	count	83	80
	mean	59	3.5
	%stdev	16	11
	min	38	2.8
	max	96	5.0
Long mode	count	13	13
	mean	135	6.2
	%stdev	11	7.7
	min	119	5.4
	max	161	6.9

to 4.8 minutes, with an average of 4.0 minutes and a standard deviation of 9.2%. The eruptions lasted from 32 to 46 seconds, with an average of 38 seconds and a standard deviation of 10.0%. Water was thrown 3 to 5 feet high.

By May, 1991, both the intervals and durations of Mickey Geyser were strongly bimodal. Long intervals, which made up 14% of the 93 intervals recorded by Stephens (1991) followed long durations, which made up 14% of the 96 durations recorded. Short intervals followed short durations. The short intervals ranged from 2.8 to 5.0 minutes, with an average of 3.5 minutes and a standard deviation of 11%. They followed short durations of 38 to 96 seconds, with an average of 59 seconds and a standard deviation of 16%. The long intervals ranged from 5.4 to 6.9 minutes with an average of 6.2 minutes and a standard deviation of 7.7%. They followed long durations of 119 to 161 seconds, with an average of 135 seconds and a standard deviation of 11%.

Table 3.

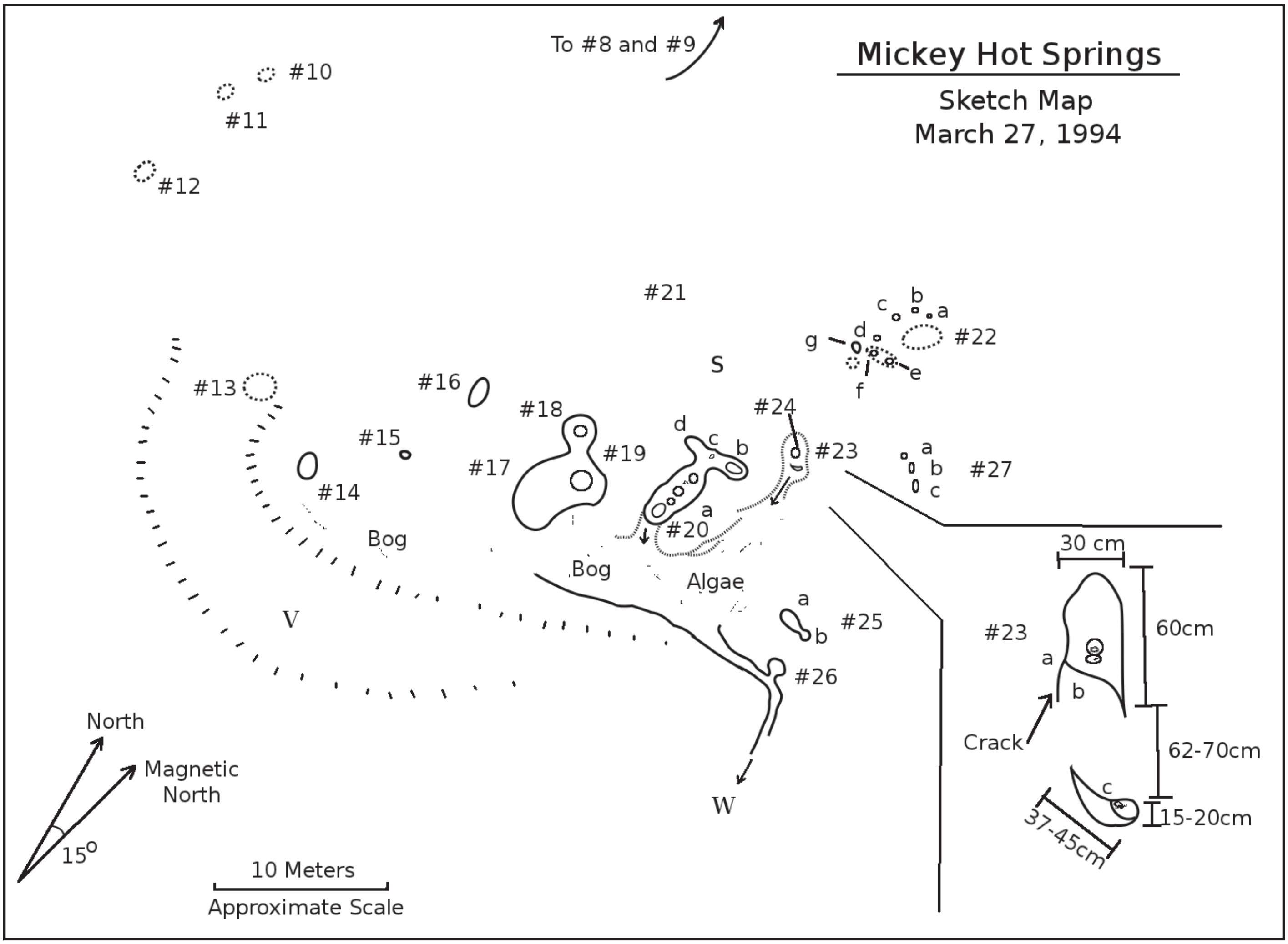
Vent	1992 Temp. °C	pH	1994 Temp. °C	pH	Change in Temp.
1	53	8.4	48	8.9	-5
2	NA		NA		
3	93		86		-7
4a	39	7.8	66.3		27.3
4b	58	7.6	42.3		-15.7
5	42	6.7	38.6	7.1	-3.4
6	34	8	37.6	8.4	3.6
7	35	8.4	32.6	8.4	-2.4
8			74.7		
9	54	8.8	50.7	8.8	-3.3
10	92		96.5		4.5
11	steaming		warm		
12	70		92		22
13	96.6		96.7		0.1
14	57.2	6.8	59.8	8	2.6
15	88		93.2		5.2
16	96.8		96.5		-0.3
17	68		49	8.8	-19
18	60		57.3	8.7	-2.7
19	NA		NA		
20	87		82		-5
21	steaming		NA		
22	98		97		-1
23	boiling		boiling		
24	steaming		NA		
25	91	9.2	78	9.2	-13
26	82	9.1	68.3	9.6	-13.7
average	69.73	8.08	68.719048	8.59	-1.31

Table 3 lists temperature and pH values taken in 1992 and 1994. The vent numbers correspond with the map on page 132.

In March, 1992, Mickey Geyser was visited twice (Stephens 1992; Cross 1993). Both parties reported that the geyser had regressed to a perpetual spouter, although the eruption was of variable intensity.

In March, 1994, Mickey Geyser was active as a perpetual spouter (Cross 1994). A second vent had developed since 1992. This vent was about 26 inches southeast of the original vent. Its nearly-constant eruption sprayed water to 3 feet. One of two vents in the original crater splashed occasionally to a few inches, technically fulfilling the definition of a geyser. Grass growing next to the original crater implied that no major eruptions had occurred from that vent for some time.

Temperature and pH measurements for most of the vents at Mickey Hot Springs were made in 1992 (Cross 1993) and in 1994. Comparing the temperatures obtained in 1992 with those obtained in 1994 shows an average change of -1.3 °C.



Acknowledgements:

I thank Lynn Stephens for providing me with the original copies of her reports, and those of Marie Wolf and Rocco Paperiello. I thank Tara Cross for reading this article and for offering suggestions for its improvement, and I thank David Monteith for helping to format the tables, maps and graphs.

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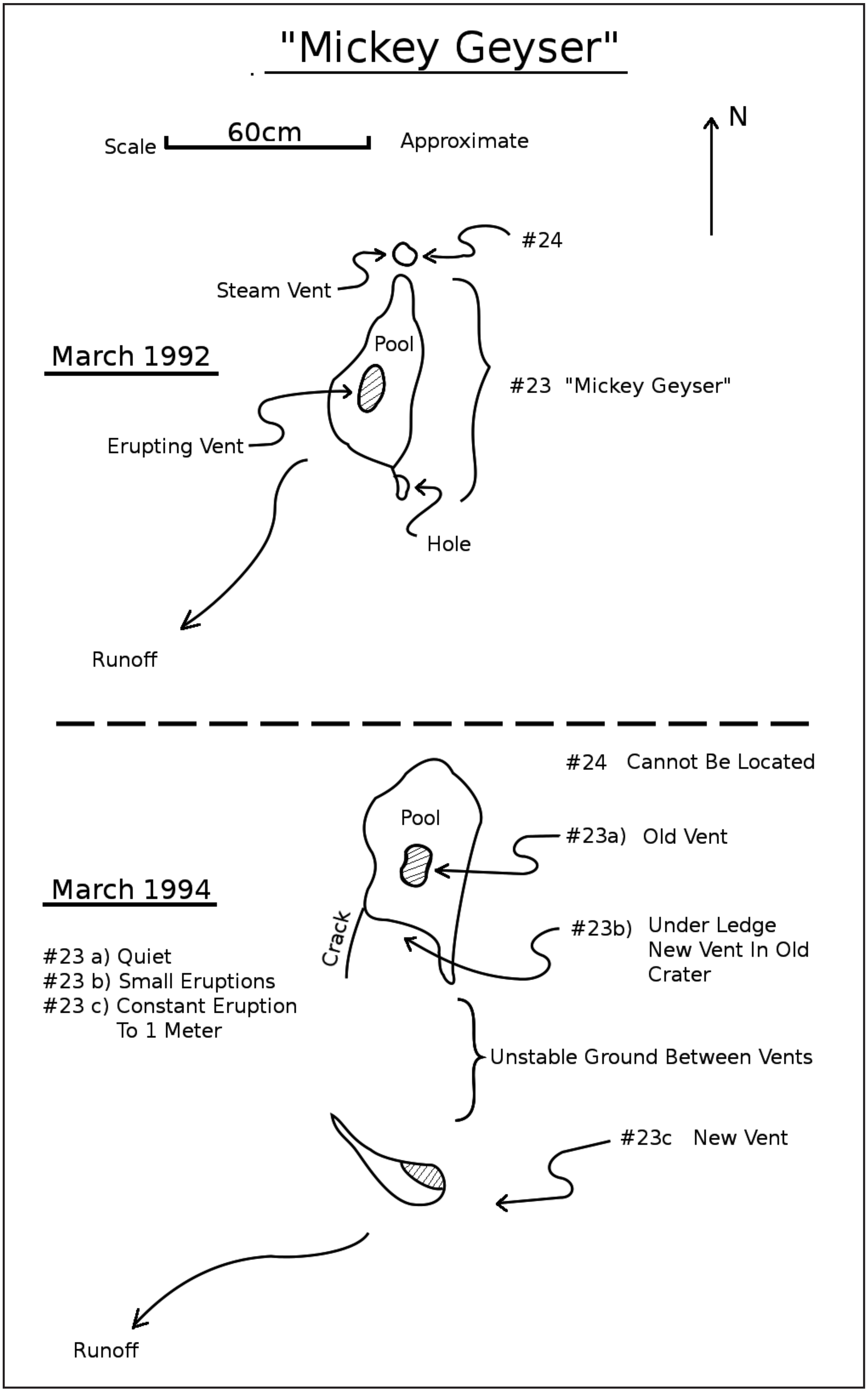

Figure 3: *Between March, 1992, and March, 1994, the crater of Mickey Geyser expanded, and a new vent developed.*

Geyser Activity at Mickey Hot Springs March 23, 1991

Marie Wolf and Rocco Paperiello

Abstract

Marie Wolf and Rocco Paperiello visited Mickey Hot Springs, Oregon on March 23, 1991. Their previously unpublished report on Mickey Geyser, including a table of their data and a map of the geyser's crater, is reproduced here with a few typographical corrections.

UNNAMED GEYSER AT MICKEY HOT SPRINGS

Our attention was first brought to a possible geyser at Mickey Hot Spring in the Alvord Basin of southeastern Oregon by an article in the July-August 1990 issue of the *Sput*. This article, contributed by Jan A. Roberts, mentioned that the 1988 issue of "The Hot Springs GAZETTE" indicated that "a boiling geyser" was included among the thermal features present at Mickey Hot Springs. This site has been considered unique enough to have been declared as an Area Of Critical Environmental Concern by the BLM. Jan Roberts visited this area in May of 1990 (see article in the above mentioned issue of the *Sput*). Jan indicated that she believed this feature to be a true geyser; however, Terry Ann Spitzer described it, as only a "slightly variable boiler." In Jan Roberts' article the activity was described as follows:

> The geyser's activity is cyclical, with definite periods of quiet alternating with small but rather boisterous eruptions. The overall timing of both the quiet and active periods is remarkably even and short – each is perhaps 20 (+or-) seconds long. The eruptions begin with a sudden rise in water level within the crater (which is two feet in diameter), and culminate with bursts of water ejected at an angle. The jets are about 2 feet long and 1 foot high. (Terry Ann took this as surficial [*sic*] boiling, not bursting, and feels that this can only be called "geyser-like.") None of the eruptions cleared the crater rim while I was watching it, but it appears that there have been other eruptions that are more vigorous. Photos taken only a few days before the field trip showed a dark, probably wet ring completely surrounding the crater. This ring was not evident when I was at the site.

Jan's article goes on to state that this geyser has the highest water temperature (207 °F) of all the Mickey Hot Springs. A BLM report gave temperatures of up to 210 °F. Since the elevation is near 5,000 feet, either temperature would indicate substantial superheating.

In the next Issue of the *Sput* (September-October, 1990), it was reported that "per the BLM, the spring in question is definitely a geyser, showing true intermittent action at above-boiling temperatures."

After her trip to Mickey Hot Springs in the beginning of October, 1990, Lynn Stephens described activity for this feature as similar to that previously described by Jan Roberts. In addition, Lynn's photos of the reported geyser showed a crater very similar to that photographed by Jan. (This photo was reproduced in the September-October 1990 issue of the *Sput*.)

But the condition found on March 23, 1991, was considerably different. On our way back from northern California, Rocco and I decided to visit Mickey Hot Springs to check out the "geyser-like thing" Lynn Stephens had told us about. We arrived at the area not quite sure where to locate this spring. Our attention was drawn to a considerable amount of steam lower down the slope. This turned out to be coming from a vigorously sputtering mud pot and intermittently steaming "mud-volcanoes."

Then, looking further, beyond two large, discharging hot springs, our attention was drawn to a small crater with a new, sharply defined runoff channel. The small pool within lay quietly about a

Marie Wolf observing an eruption of Mickey Geyser at Mickey Hot Springs, Oregon, March 23, 1991.

foot below overflow. The spring looked very different from the photo we had seen. The crater, for example, was quite a bit larger than the one in the Roberts photo; there was a new runoff channel two or three inches deep; and the gravel within the crater, shown in the Stephens photo, was largely removed. Considerable amounts of bare rock were exposed in the crater; some of this rock was of a crumbly, unconsolidated nature, and it was being washed away, exposing a harder, more firmly cemented rock surrounding the vents.

Realizing the significance of what we initially saw, we sat down and waited. Within three minutes of our arrival, the pool began to palpitate. As it began to gradually rise, boiling started on either side of a narrow partition at the pool's west end. The boiling grew more vigorous, until there was an initial splash to about three inches. Things accelerated rapidly after this: splashing grew quickly to as much as three feet all along the fracture-vent and the water rose fast and soon spilled over the crater's lower south edge. Soon, bursts of two to five feet reached two to four feet outward. After about 35 seconds, splashing lost vigor, then ceased — and overflow stopped a couple of seconds later; then the water dropped about nine inches.

We recorded data on the next eighteen eruptions, including starting and stopping times of both eruptions and overflow. (See table of data on page 137 [Table 1]). The pattern of eruption was very regular; there was some variation of vigor and maximum height of eruption. The latter ranged generally from 3 to 5 feet, and the main splash zone covered an area of about 9 feet across; occasional droplets would reach out an additional 2 to 3 feet. Overflow typically began about 16 to 20 seconds after the start of the eruption and ended within a few seconds of its termination. A noisy sputtering steam vent was also seen within the small undercut alcove in the western edge of the geyser's immediate basin. (See diagram below for detail [Figure 1, page 136].)

Most of the present activity at Mickey Hot Springs was consolidated in a small "lower" area, extending generally in a curving southwest-northeast line. At the western edge of this "lower" area was a small but vigorous mudpot (described above), apparently much wetter than when seen in early October by Lynn Stephens. The next two irregular pools were quite hot, the second of these, next to the above geyser, was bubbling vigorously. Except for the discharge from Mickey Spring itself at the northwestern edge of the "upper" level, the discharge from the Mickey Hot Springs area came mostly from these two pools and the geyser. (A signboard recently placed at the upper limit of the thermal area claimed water flow to be about 30 gal/min.) Beyond the geyser to the north was another small mudpot, and to the northeast there was a very hot frying-pan type area. We really did not spend much time visiting the area beyond the geyser. The "upper" area contained quite a number of mostly extinct heavily sintered mounds in various states of disintegration. A few of these still had the remnants of warm pools within the depression of their sintered walls. These mounds were evidently built up by the dense, slowly accreting sinter typical of alkaline waters. In fact, in the two main flowing springs below we obtained a pH of about 7.2. The geyser showed a pH of about 7.6, and a temperature of 199.2 °F was obtained shortly before an eruption. A possible temperature of 206 °F was obtained during an eruption, the doubt due to the fact that the liquid crystal on the thermometer was ruined by the rising steam and could barely be read.

Most of these features are described in more detail in Lynn Stephens' report of October 13, 1990. When we last talked to her, she mentioned that she planned a detailed reconnaissance and mapping of this hot spring area in the near future.

On our way to Mickey Hot Springs, Rocco and I passed by the other two known eruptive features in Oregon – both geothermal wells. The Crump Geyser, a few miles north of Adel, was completely filled with rocks. Heavy gurgling could be heard, but any eruptive activity is long passed. Crump himself used to initiate eruptions by taking a bucketful of rocks on a long rope extended into the geyser well; he would then take the other end of the rope while on horseback and gallop as fast as he could. The resulting eruption would shoot rocks, bucket, and water into the air.

The other erupting feature is at Hunter's Hot Springs, just north of Lakeview, and presently erupts from a small geothermal well, only 20' deep. Activity was cyclic and very frequent. Intervals ranged from 30 to 60 seconds with durations of 5 to 10 seconds. Heights easily reached 20 to 30 feet or more. It was difficult to tell exactly with all the steam in the cold blustery wind. This well was drilled on October 20, 1923. Two other much deeper wells displayed eruptive activity for only a very short time.

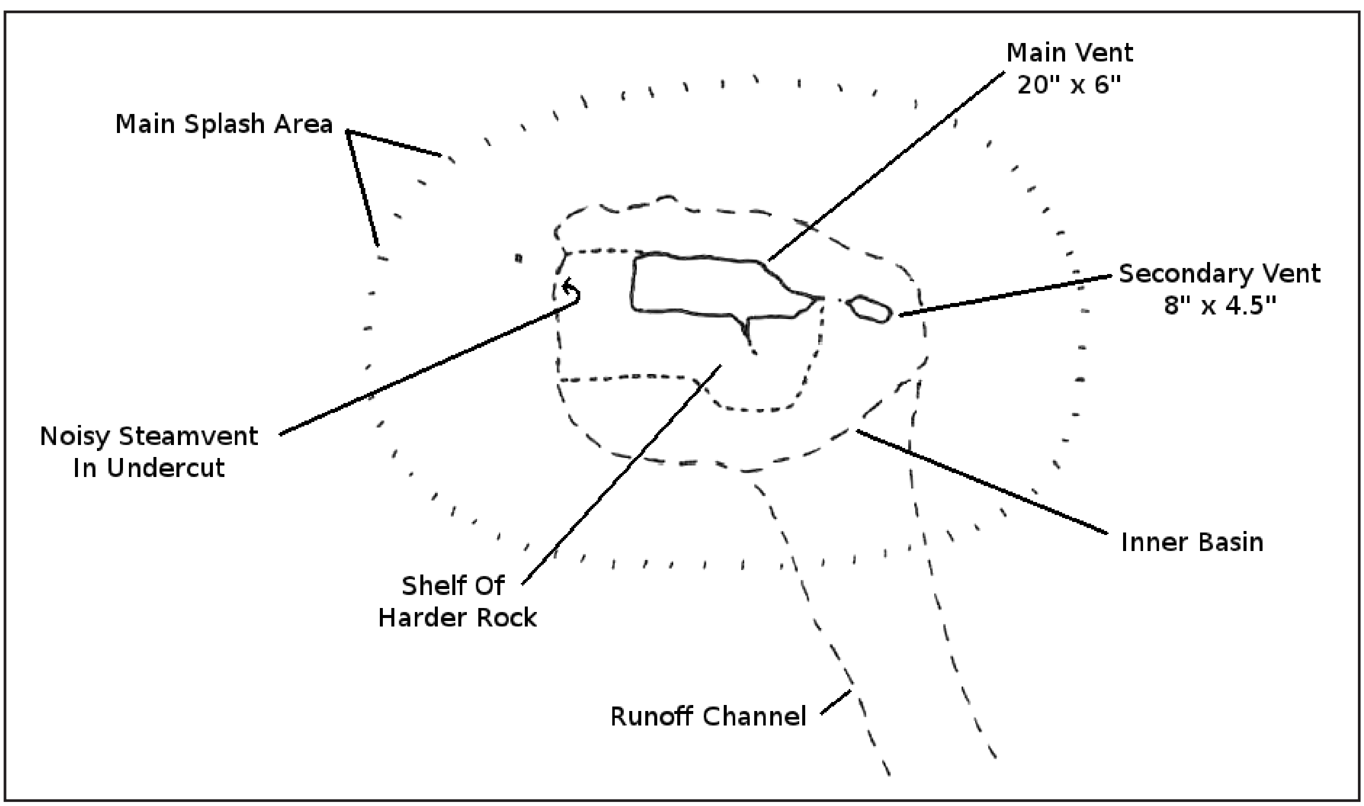

Figure 1: Map of the crater of the Unnamed Geyser at Mickey Hot Springs.

TABLE 1

Unnamed Geyser	**Mickey Hot Springs** **northeast of Alvord Ranch, OR**

Date	Time	To 1st Overflow	Duration	Interval
March 23, 1991	15:38:51	:21	:37	--
	15:42:50	:21	:41	3:59
	15:47:00	:16	:37	4:10
	15:51:09	:24	:41	4:09
	15:55:02	:19	:41	3:53
	15:58:56	:11	:32	3:54
	16:02:46	:22	:39	3:50
	16:07:11	:17	:36	4:25
	16:11:14	:20	:38	4:03
	16:15:10	:19	:37	3:56
	16:19:15	:16	:36	4:05
	16:24:03	:14	:33	4:48
	16:27:40	:18	:38	3:37
	16:31:24	:23	:46	3:44
	16:35:26	:23	:43	4:02
	16:40:08	:12	:32	4:42
	16:44:34	:19	:41	4:26
	16:48:02	:17	:36	3:28
	16:51:39	:16	:37	3:37

For Interval:

μ = 4:03 σ = :22 [n = 18]

For Duration:

μ = :38 σ = :04 [n = 19]

Crystal Geyser, Green River, Utah: A Summary of Observations from 1972 - 2008

Richard L. Powell

Abstract

Crystal Geyser, located on the east bank of the Green River about four miles south of the city of Green River, Utah, is a test boring for petroleum completed in 1936. The well is a frequent producer of copious amounts of CO_2-laden ground water. The boring quickly became known as "Crystal Geyser" because it had eruptions of white, foamy water. Eruptions from the well have progressively developed longer intervals and durations, and generally lower heights.

Introduction

Crystal Geyser is a "soda-pop" well located on the east bank of Green River about four miles south of Green River, Utah (Figure 2). The site is owned by the City of Green River and overnight camping is permitted. The drill hole currently periodically discharges cold, foamy, carbon dioxide laden water to estimated heights of 40 feet or higher (Figure 1), usually at a variable interval less than 24 hours. Eruptions are on a progressive time table, and occur at an earlier time each succeeding day. However, the eruptions have been reported to have been higher and more frequent in the past. Crystal Geyser eruptions overflow over a broad mound of terraced travertine about 150 to 200 feet across and about 35 feet above the Green River immediately west of the drill site (Figure 3, page 139, and Figures 4 and 5, page 140).

Background Information

The first published reference to the site is probably that by John Wesley Powell recorded 13 July 1869 at a site a few miles downstream of Gunnison's Crossing, now the city of Green River. J. W. Powell wrote, "An hour later, we run a long rapid, and stop at its foot to examine some curious rocks, deposited by mineral springs that at one time must have existed here, but are no longer flowing" (Powell 1875, p. 51-52).

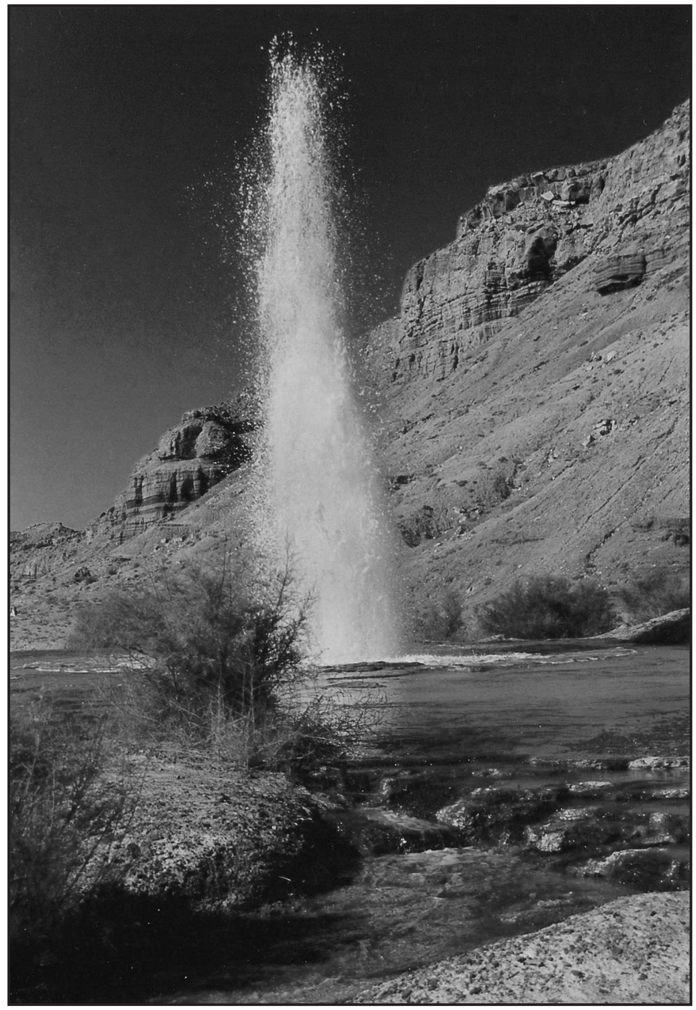

Figure 1. Eruption of Crystal Geyser, height estimated as about 50 feet, taken 4 October 1999 by Marion Powell.

The geology of the area was first reported in 1914 by C. F. Lupton, who was investigating the oil and gas prospects in the area. Lupton (1914, p. 130) noted an east-west trending fault with about 450 feet displacement on the south side and Goin's oil seep near the fault. He also noted "…a former spring, now marked by a calcareous deposit…closely related genetically to the disturbed strata adjacent to the fault in that the disturbed rock, being more porous, furnished an outlet to the surface for the oil and the calcareous material." Neither the Goin's oil seep nor any oil prospect pits reported by Lupton

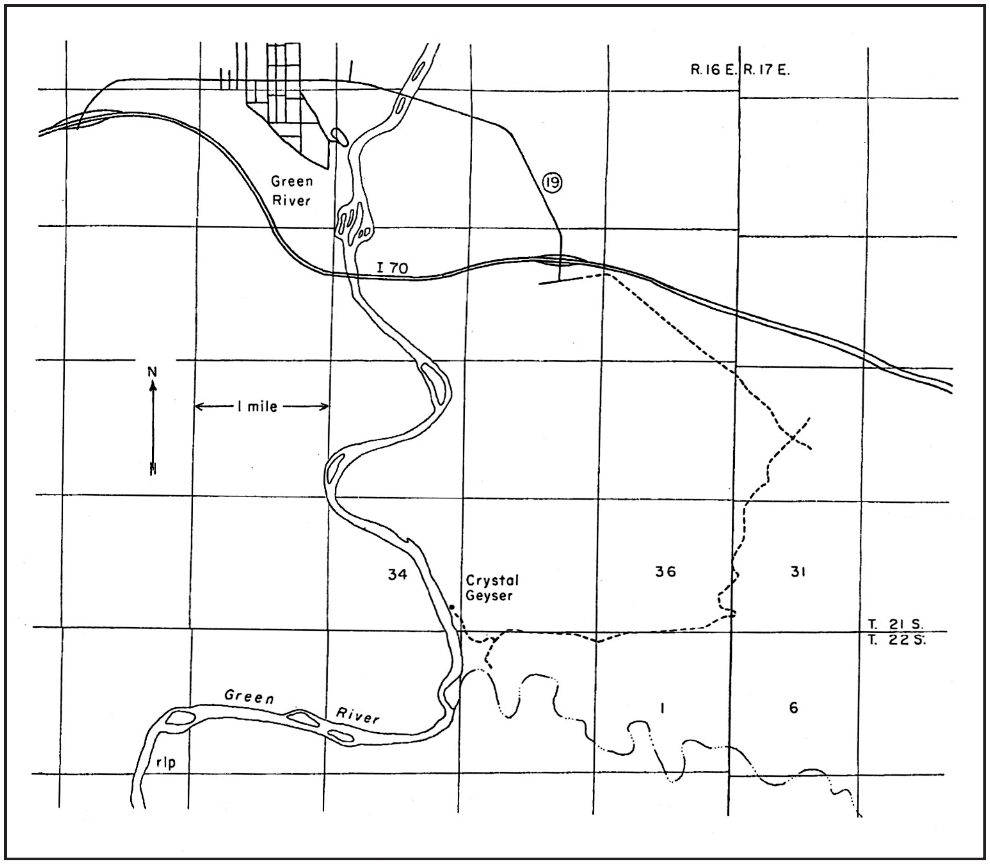

Figure 2. Location of Crystal Geyser south of Green River, Grand County, Utah.

(1914, p. 120) were mentioned as located by subsequent investigators nor by this author.

Edwin T. McKnight (1940) wrote a report on the economic geology of the area between the Green and Colorado Rivers in Grand and San Juan counties, Utah, that was more extensive and comprehensive than that by Lupton. McKnight stated that the report of the Goin's oil seep on the Little Grand Fault (now the Little Grand Wash Fault) probably influenced the drilling of two wells on the north side of the fault (p. 133). The No. 1-X State well was cable tool drilled by Glen Ruby, a renowned geologist, and others between 27 November 1935 and July 1936 to a depth of 2,627 feet. McKnight (1940, p. 143-144) included a log of the hole showing that the travertine was 59 feet thick with a show of gas and that oil and gas were encountered at 128 feet, water and gas at 280 feet, 290 feet, much gas at 355 feet, and gas at 487 to 490 feet (Figure 3, page 140). The geologic formations named, probably by Ruby, in the log have been changed by later writers.

Clark Murray (personal communication, 2002) provided a newspaper article from the *Times-Independent,* Moab, Utah, for 11 November, 1935. It stated the well had reached a depth of 44 feet and encountered a flow of 1,000 barrels of water per hour. By 16 January 1936 the paper stated that the test well had encountered gas at a depth of 360 feet, with sufficient pressure to displace 105 pounds of drilling mud 60 feet into the air. The carbon dioxide level was determined to be 94 percent. The last report, 18 June 1936, stated that the drilling operation had been abandoned that week, after the company had drilled for nine months to a total depth of 2,227 feet, a figure 400 feet less than the 2,627 feet reported on the driller's log. The front page of the 1 October 1936 *Times-Independent,* reported a 100-foot geyser, a new scenic attraction of Grand County that spouted a column of water as high as 150 feet into the air at regular intervals. A visitor to the site stated, "The geyser spouts at regular intervals of about 15 minutes to a height of around 80 feet. At longer intervals—about every nine hours—the column of water, accompanied by rocks and mud, is shot to a height of about 150 feet."

Crystal Geyser was touted as "Utah's Old Faithful 'Geyser'" in *American Guide Series* (1941, p. 397). Admission to see the geyser was 50 cents per car for several years.

Photogeologic maps of the areas covered by the Green River quadrangle, which includes the Crystal Geyser, and the eastward abutting Green River

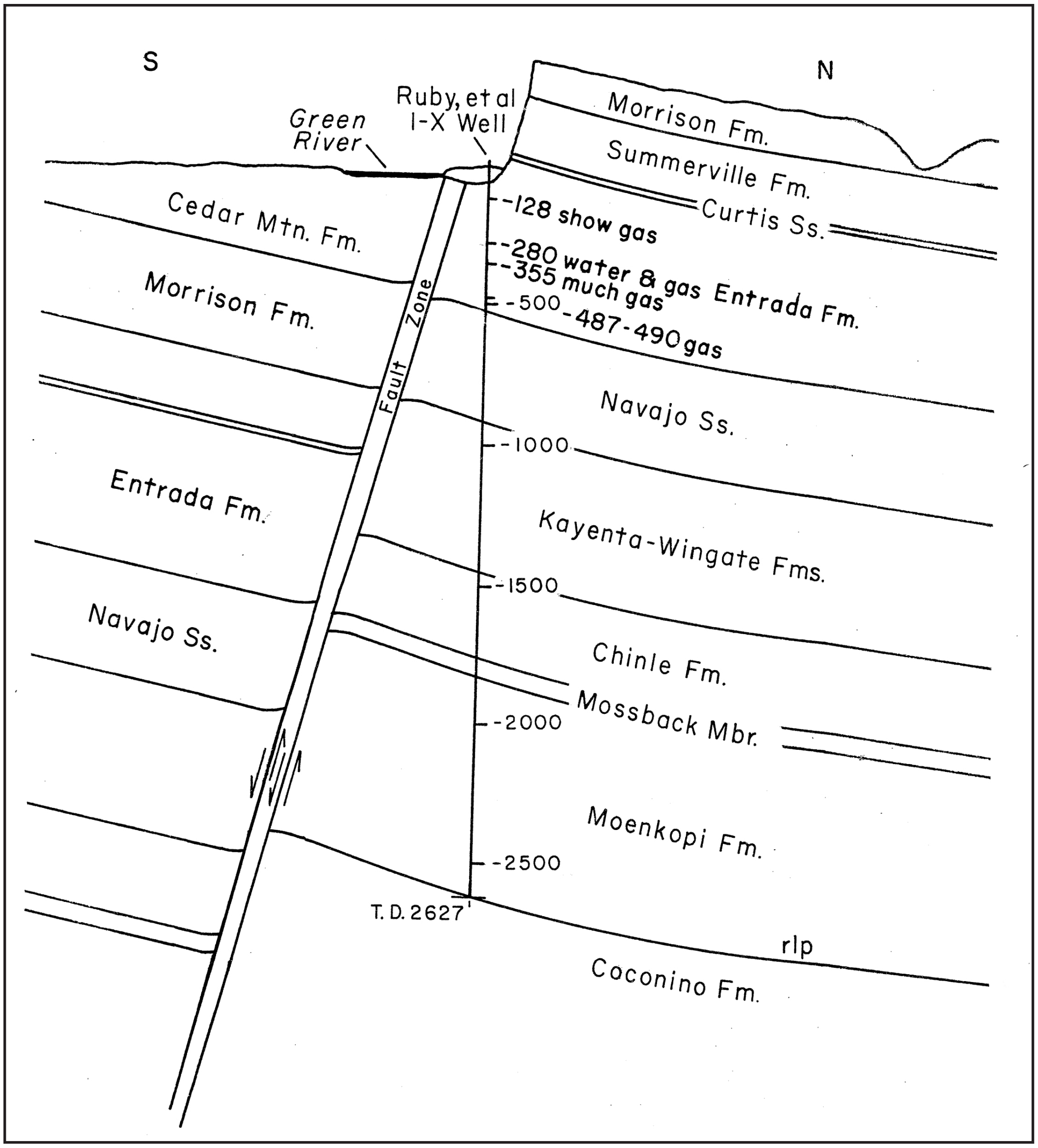

Figure 3. Idealized geologic cross section showing the rock units penetrated by the Ruby No. 1 Well. Data from McKnight (1940) and Hager (1956).

NE quadrangle, which includes the roads leading to Crystal Geyser and the eastern extension of the Little Grand Wash Fault zone, were prepared by V. H. Sable (1955 and l956, respectively). These are the largest-scale geologic maps available (1:24,000) and probably the most stratigraphically correct.

In 1969, a river runner's guide stated that the geyser erupted about once an hour when escaping carbon dioxide spouted a column of water several feet into the air (Mutschler 1969, p. 15). The guide also noted the terraced deposits of "tufa" (actually travertine) stained red, yellow and brown by hydrous iron oxides around the well. He recognized the older deposits of travertine as being aragonite.

James L. Baer and J. Keith Rigby (1978) published a report on the geology of Crystal Geyser that had probably been prepared as an appendix to the report by Barton and Fuhriman (l973, p. 1). Baer and Rigby relied heavily on the work by E. T. McKnight (1940) but also presented some new information. They mapped the location of travertine deposits scattered along the Little Grand Wash Fault zone for a distance about 1.5 miles east of Crystal Geyser, and identified three levels or ages of these deposits (Baer and Rigby 1978, p. 127 and Figure 2).

The following is Baer and Rigby's interpretation of the various travertine levels, "tufa" in their words, with level 3 being the lowest in elevation and level 1 being the highest. All of the lower deposits are likely of Holocene Age (post Pleistocene), but the highest level likely is of Pleistocene Age.

> The youngest tufas (Level 3) are currently being deposited by the geyser and presently active springs, at an elevation of approximately 1262 meters (4085 feet). Older tufas, at a slightly higher elevation than the geyser, (Level 2) are adjacent to the

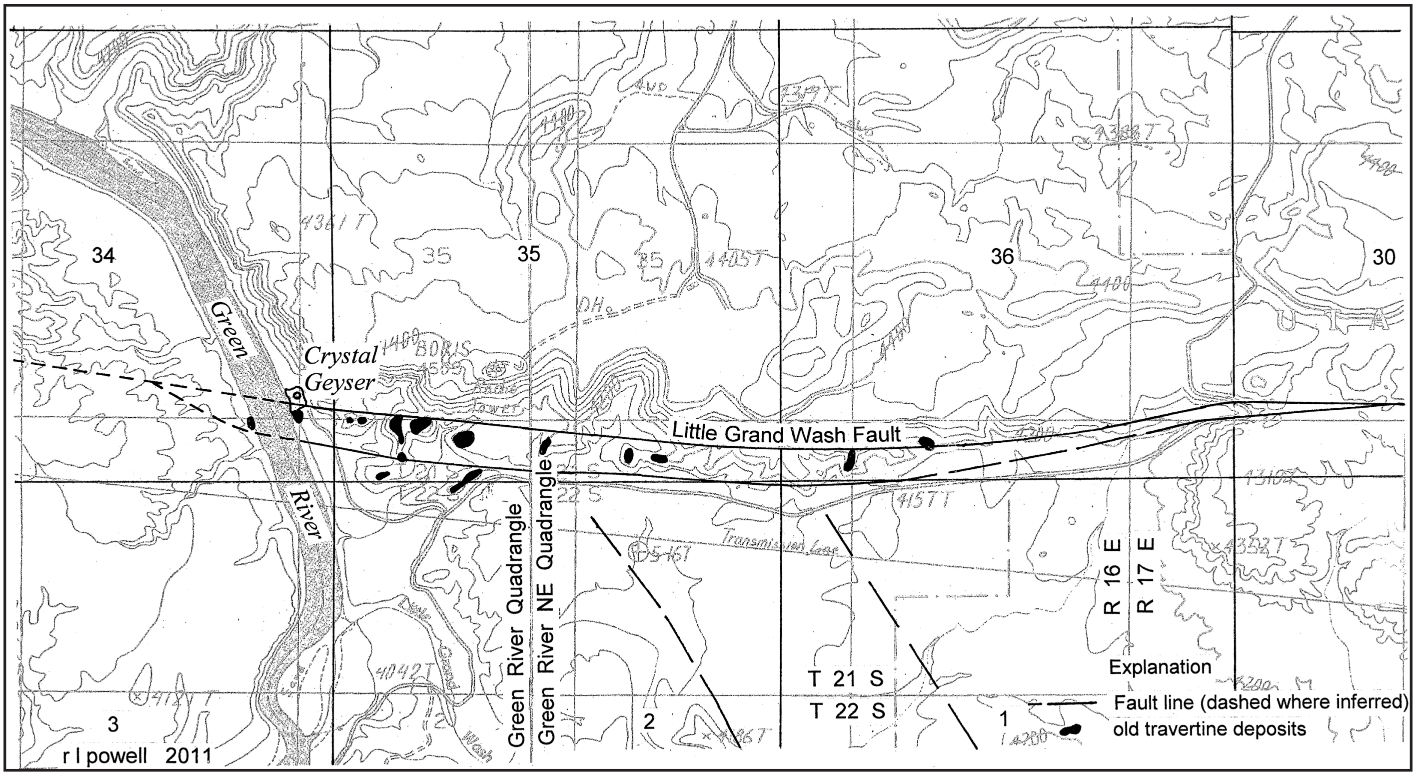

Figure 4. Map showing the location of Crystal Geyser relative to the Little Grand Wash Fault and locations of some of the old travertine deposits. Modified from McKnight (1940) and Baer and Rigby (1978).

> currently active southward…geyser. They are most prominent in the general vicinity of the turn-around point on the access road. Considerably older tufas (Level 1) are located at higher elevations, approximately 1297 meters (4200 feet), and occur mainly east of the geyser in a linear belt across the southern part of Section 35.

Two small cones about 75 and 100 feet south of the well are former springs that predate the current deposition (Baer and Rigby 1978, p.127-128). They deferred to Barton and Fuhriman (1973) for eruption data.

Modern Studies of the Eruption of Crystal Geyser

The first detailed study of note, the Crystal Geyser Project, was conducted in an attempt to find a way to reduce the salt pollution from Crystal Geyser eruptions entering the Green River. James R. Barton and Dean K. Fuhriman, researchers with the Center for Environmental Studies, Brigham Young University, conducted a series of experiments in 1972 which are summarized here. They noted several features at the site aside from Crystal Geyser, the Ruby No. 2 State Well, which they referred to as the "North Spring," and one of the two features that erupt about 50 feet east of the well which they called "east hole" in the text but named East Spring on the maps (Figures 16 and 17 in Barton and Fuhriman, 1973, p. 7). They noted the 16-inch surface casing and stated that it probably was less than 100 feet in depth. They plumbed Crystal Geyser to discover a major obstruction at 365 feet, but by bouncing the weight they were able to get it to a depth of 400 feet. They believed the source of the carbon dioxide was from the Navajo Sandstone at a depth of about 700 feet.

Rhodamine, a red fluorescent dye, was poured into the well on two occasions about two hours before it erupted. Within an hour the water in the Ruby No. 2 Well and the east hole (Spouting Pool) was a bright red color, indicating an open connection as the water level rose in the Ruby No. 1 Well (Figures 5 and 6, page 142). The spring discharges in the bed of the river were watched, but the river was muddy, making it impossible to determine a connection with Crystal Geyser (Rhodamine is readily absorbed by colloids, clays and small organic particles). The elevation of the geyser is generally 30 to 35 feet above the river and the water level in the well is commonly about 20 feet above the river even after the geyser has finished erupting.

The Bureau of Reclamation made three measurements of the flow from Crystal Geyser on 13 June

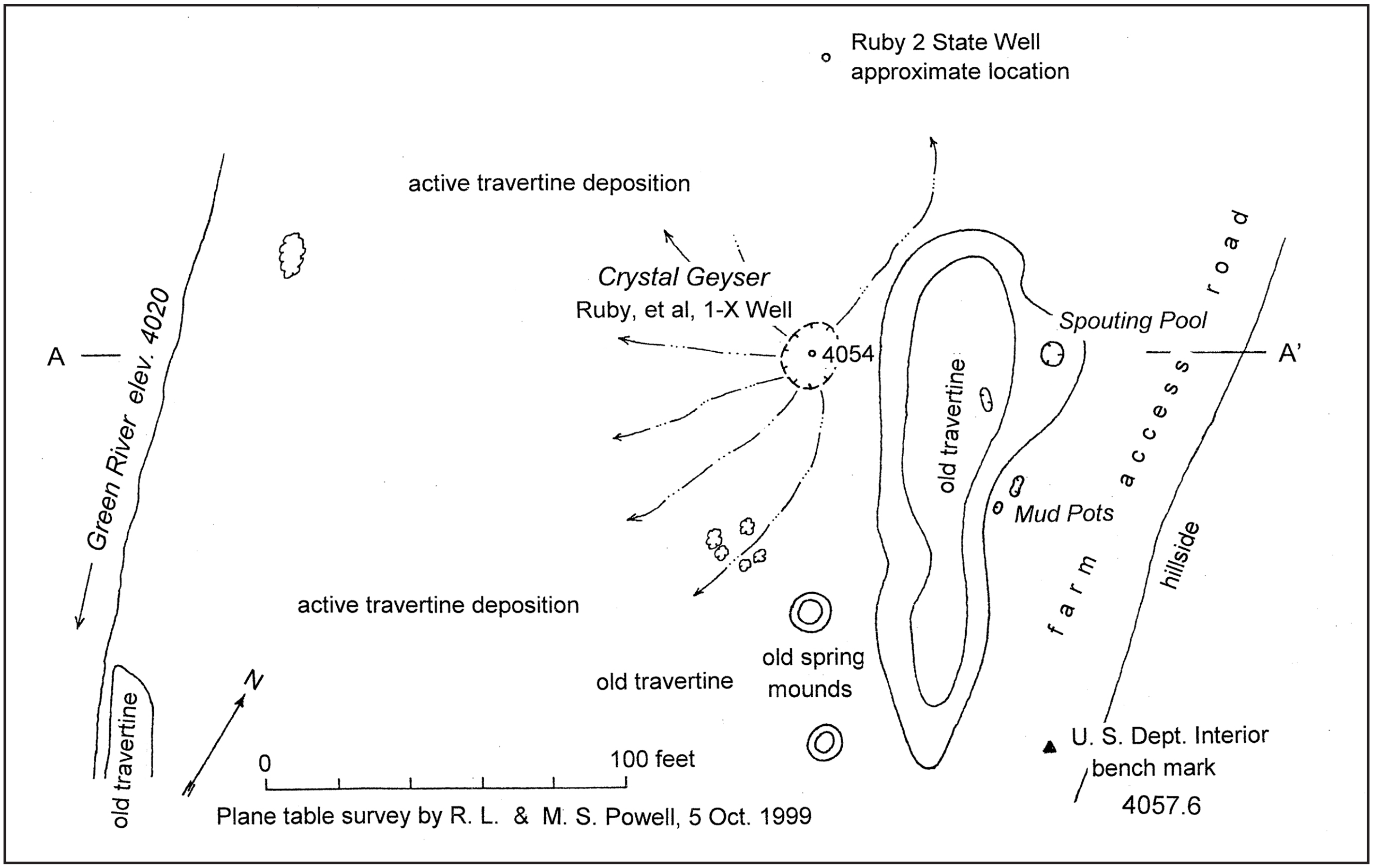

Figure 5. Map of Crystal Geyser, Line of cross section, A – A', shown as figure 6.

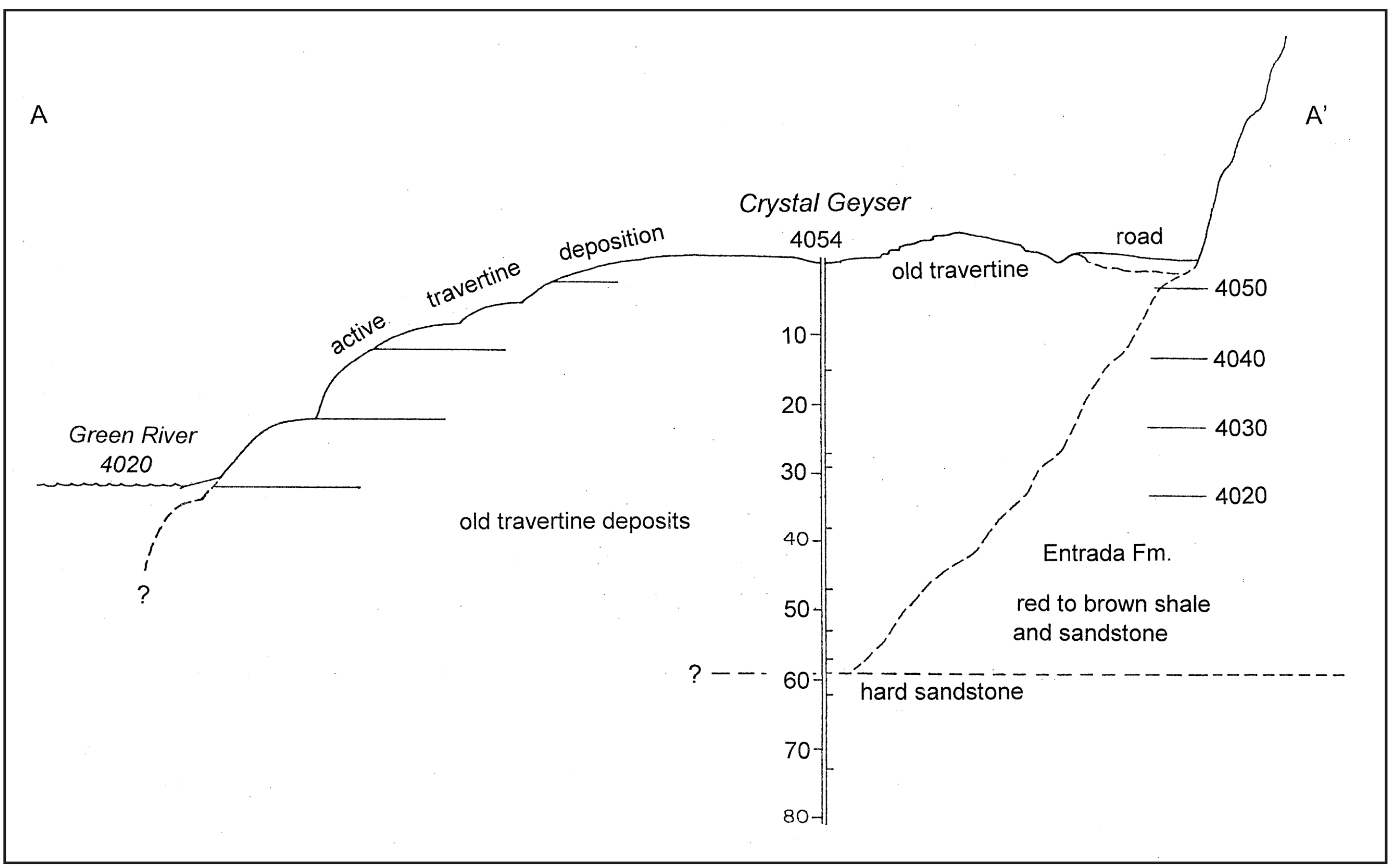

Figure 6. Cross section showing relation ship of the Crystal Geyser bore hole to travertine deposits and bedrock. Line of section shown on Figure 5.

1968 (Barton and Fuhriman, 1973, p. 9). Sandbag dikes two to three bags high were stacked on a black plastic sheet that was folded over the sandbags. Two Parshall flumes, one being one foot wide and the other two feet wide, were placed in natural channels through the sandbag dike. There was only negligible leakage beneath the sandbag dike and where the flumes were installed. The water level of runoff during an eruption was read from a staff gauge every 30 seconds. The eruptions lasted about seven minutes each and discharged about 31,000 to 33,500 gallons per eruption (Barton and Fuhriman 1973, p. 11, Table 1). Barton and Fuhriman (1973, p. 10, 11 and 15) repeated six measurements on 19 and 20 July 1972 using three flumes. They summarized their results as follows: heights of eruptions 40 to 50 feet, duration of eruptions seven minutes, interval between eruptions four to six hours, water temperature 60 to 64 degrees, volume discharged during eruption about 30,000 gallons, amount of salts discharged ranged from one and a half to two tons per eruption.

A series of experiments were conducted to attempt to limit the discharge of Crystal Geyser (Barton and Fuhriman 1973, p. 15-31). The first experiment amounted to pumping 250 gallons per minute (gpm) of river water into Crystal Geyser as soon as it quit erupting. An hour of pumping into the geyser caused the Ruby No. 2 Well to start flowing at 250 gpm. This action, which was conducted eight times, seemed to decrease the interval between the next eruptions as well as decrease the volume discharged and the height of the eruption.

The second experiment was to erect a 55 gallon drum open on both ends as a standpipe over the Ruby No. 2 Well, which caused the water in Crystal Geyser to rise about 30 inches in the casing (the height of the casing is not given in the report, but appears from photos to be about three feet high). Barton and Fuhriman (1973, p. 20) reported that "the results of the standpipe experiments…are not clearly defined," but after the standpipe was installed on the Ruby No. 2 Well the interval to the next eruption increased from 5 hours for the last interval to 11 hours 35. The range of intervals for seven subsequent eruptions with the new standpipe in place was 3 hours 30 minutes to 9 hours 23 minutes.

The third experiment entailed construction of a temporary earthen dike enclosed in plastic around Crystal Geyser, the north drill hole and the holes to the east of the geyser. The height of the dike was not given. After the initial three eruption intervals, which decreased from seven hours and fifteen minutes to four hours and fifty-one minutes, the range of intervals of the next 27 observed eruptions was one hour and thirty-four minutes to three hours and fifty-six minutes and fifteen heights were indicated as from 80 feet to 105 feet (Barton and Fuhriman, 1973, Table 4). Most of the erupted water drained back into the geyser.

John S. Rinehart (1974, p. 1056) stated that Crystal Geyser erupted on a five hour interval for five to ten minutes to a height of 60 meters (195 feet). Each major eruption is succeeded by a minor one 25 minutes later which attained a height of about 6 meters (20 feet). Rinehart (1980, p. 88-90) provided a slightly more detailed description.

Sam Martinez visited Crystal Geyser on 12 to 14 September 1976. His report is quoted in full on pages 152-156 of this volume. The following is a summary of his observations.

Martinez noted that Crystal Geyser and Ruby No. 2 Well erupted together but that Crystal Geyser was the more powerful of the two (Martinez 1976, p. 1). He stated that the No. 2 well was filled with rocks, but that Crystal Geyser was able to eject rocks from the hole. Apparently the drums installed in 1973 were still in place (Martinez 1976, p. 3). The second well erupted three to five feet above the drum for a few minutes during each eruption and it overflowed first owing to its lower elevation.

Regarding eruptions, Martinez reported that "after the end of the eruption the water in all vents drops several yards…. Five to twenty minutes after the end of some of the eruptions there is a sudden burst from the main cone, 4 to 8 feet high." After these afterbursts came a period of quiet.

Then, "the second well begins overflowing about 80 to 90 minutes after the time of the last eruption. The water in both wells stays at about the same level once overflow is established. Three hours after the last eruption the main cone has its first overflow period…. The overflow periods are repeated at about hourly intervals until one is strong enough to initiate the major activity…. The water starts spouting up very quickly from the main well, reaching the maximum height in 4 to 5 seconds, but only for a brief moment…. After the maximum the height slowly decreases until it gets to the 15 to 30 foot level, where it remains for the rest of the eruption" (Martinez 1976, p. 6-7).

Figure 7. Eruption of foamy water at an overflow prior to a Crystal Geyser eruption (above center) and eruptions of the Mud Pots (lower left) and Spouting Pool (lower right), the later two the Aragonite Pools of Murray (1990). The Green River in the background. Photo by Richard L. Powell 9 June 2000.

The other vents in the area became active during the activity at Crystal Geyser. The No. 2 well erupted 2 to 5 feet high during the first minute and a half of the Crystal Geyser eruption but simply overflowed at a higher-than-normal rate for the rest of the eruption. Water drops below the top of the casing to disappeared into the rocky fill 30 seconds after the geyser quit. The other vents erupted 3 to 8 feet high and usually eruption heights diminished one at a time until the geyser ceased. Three to 15 minutes after the end of an eruption in the geyser, air in the well casing began whistling out followed by a short burst of white foaming water 4 to 8 feet above the barrel (Martinez 1976, p. 7).

Martinez also noted that J. S. Rinehart reported regular eruption intervals of about five hours while the intervals Martinez observed were about seven hours. Rinehart (1980, p. 89) noted that a second well erupted about the same time as Crystal Geyser, but to a height of only 3 to 6 feet.

Observations on Crystal Geyser by Clark Murray are summarized as follows. He noted that during the 1980s the intervals between eruptions increased, but that the eruptions had a longer duration with sustained height (Murray 1990, p. 135). Murray referred to the Ruby No. 2 Well as "Ruby Geyser," and the pools east of Crystal Geyser as the "Aragonite Pools," which were the "East Spring" of Barton and Fuhriman (1973) and are the "Spouting Pool" and "Mud Pots" of this report (Figures 5 and 7). He also mentioned cave vents on the mound immediately east of Crystal Geyser. A linear crack east of Crystal Geyser sputtered a few inches high during some eruptions. A typical eruption cycle (Murray 1990, p. 137-138) started 5 to 8 hours after the previous eruption as effervescent water rose in the well and caused periodic overflows out openings in the base of the casing and through bullet holes in the casing. The overflows produced a heavy runoff over the terrace at 15- to 45-minute intervals that lasted 5 to 15 minutes. As Crystal Geyser overflowed the Aragonite Pools began to ebb as water flowed from the north pool and drained into the south pool. The south pool began to fill when the geyser stopped overflowing. The water in the Aragonite Pools rose a bit higher with each overflow of the geyser. The closer to the time of eruption of the geyser, the closer the combined pools were to spilling into an overflow channel. Ruby Geyser began to overflow about two hours after the previous eruption and continued until the next eruption. The eruption began when foamy water erupted over the top of the casing. The water reached from 60 to 120 feet high soon after the eruption started. Water issued from the bullet holes and holes in the exposed base of the casing. The eruptions usually lasted 16 to 26 minutes. The average interval was about 13 hours, ranging from 12 hours and 20 minutes to 15 hours and 54 minutes (Murray 1990, Table 1).

Murray (1990, p.136 and 138) documented an erratic set of eruptions on 13 August 1989. The overflow periods of Crystal Geyser were indicative of an early eruption at noon, only 11 hours after the previous eruption. An overflow cycle began at 1334 and in less than two minutes Crystal Geyser was overflowing its casing, which is less that the ten minutes of overflow prior to an eruption. Ruby Geyser, the Aragonite Pools and both of the cave vents began to erupt. Crystal Geyser was surging to ten feet, but abruptly stopped at 1339 and all the vents stopped erupting and drained. Ruby Geyser and the Aragonite Pools had eruptions independent of Crystal Geyser. Ruby Geyser erupted to about two feet at 20-minute intervals and the Aragonite Pools erupted to five feet high at 30- to 35-minute intervals. Weak and short overflows resumed at Crystal Geyser from 1419 to 1547, then quit. The eruptions of Ruby and the Aragonite Pools coincided at about 1715 and Crystal Geyser erupted violently after an interval of 16 hours and 1 minute. Most of the eruptions consisted of superbursts over 200 feet high. The duration was about 11 minutes.

Murray reported further observations in 1990: "Crystal Geyser, south of Green River, has been a comparative disappointment. The biggest eruptions seen have reached 'only' about 120 feet high, this versus the 150-200 foot "superbursts" that were common during 1989. The intervals are 'normal' at 13 to 16 hours" (Bryan 1990).

On another visit by Murray in 1992, Crystal Geyser was "having intervals of 12 to 14 hours, per Clark, 'short for this time of year.' Occasional superbursts reach 150 feet" (Bryan 1992).

In 1993, the idea of using Crystal Geyser to draw tourists to Green River resurfaced, leading to plans to modify the geyser. T. Scott Bryan reported in *The Geyser Gazer Sput* that

> Now, however, the people of Green River, Utah have determined that the intervals as long as 14 hours are unsatisfactory. In the words of Alan L. Mayo, hydrologist with Brigham Young University, "It's discouraging for folks to have to sit there 14 hours and then miss it."
>
> According to an article in the *Salt Lake Tribune* newspaper forwarded by Clark Murray, Mayo is working with the city "to get the geyser on a schedule more accommodating to visitors." An attempt to clear the drill hole was unsuccessful this past summer, but Mayo doesn't feel that doing so would improve the action. So he is instead working on a valve mechanism. Apparently the eventual hope is to produce a controllable geyser. "Someday we'd like to have a boat ride down the river past the geyser and then serve folks a dutch-oven dinner" (Bryan 1993).

Neither the valve mechanism nor the boat ride ever became reality.

Kyle Ross visited Crystal Geyser on several occasions in 1994 and 1995 and reported the following:

> Despite visits to Crystal Geyser on five different days during 1994 and 1995, I have still not been afforded a view of a full daylight, photographable eruption. Intervals after a major eruption seem to be 18 hours or longer. The major eruption was preceded by a minor eruption lasting six to ten minutes (with the side pool erupting in one vent). About six hours later there was a full major eruption lasting 16 to 18 minutes to a height over 30 meters [100ft], followed by some afterburst activity. I learned in conversations with Jens Day and Clark Murray that this type of behavior is common. There is still talk in Green River of "developing" this site and possibly redrilling the geyser to shorten its intervals, although no concrete plans exist as yet (Ross 1996).

Richard and Marion Powell visited Crystal Geyser over part of three days on 3 to 5 October 1999 and timed three major and 2 minor eruptions (Figure 8). The interval from major eruption to major eruption was remarkably consistent with a 2-minute difference between 20 hours 55 minutes and 20 hours 57 minutes and only a 10-minute difference for the interval of the minor eruptions to the major eruptions, 4 hours 42 minutes and 4 hours 52 minutes, respectively. The major eruptions had durations of 42, 46 and 35 minutes, while the two minor eruptions were

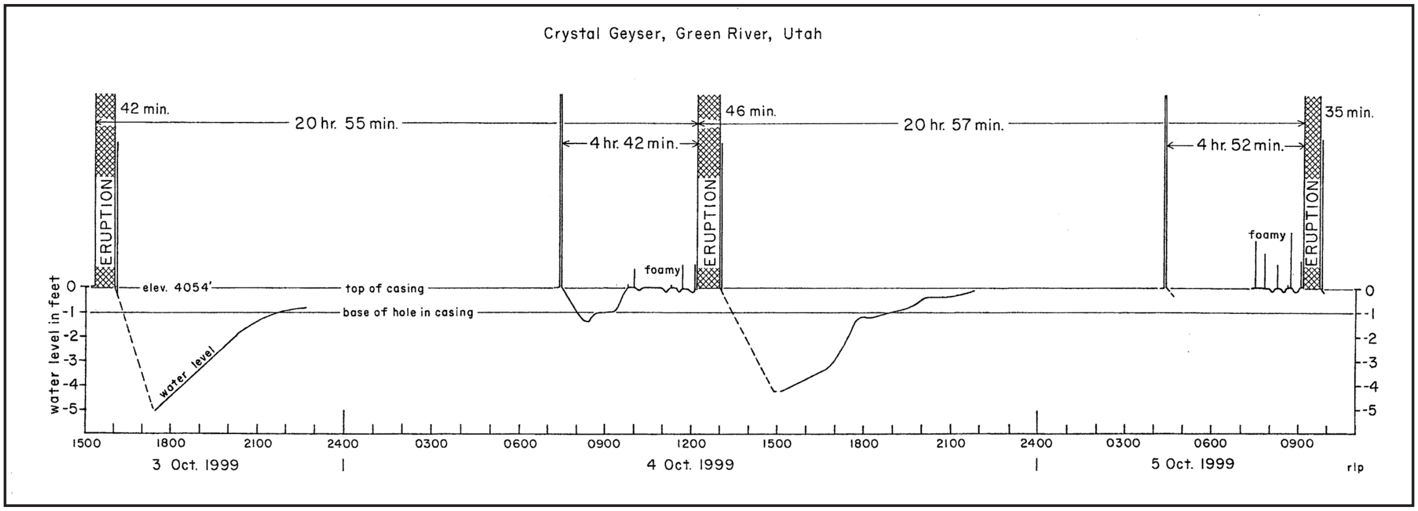

Figure 8. Graph showing eruption times and related water levels at Crystal Geyser, 3 to 5 October 1999.

about five minutes long. The stick-up of the casing on the well was very close to one foot at this time and there were large holes in the base of the casing such that the water in the shallow pool could easily drain back into the casing. A post-eruption burst of gas with water to a height of about ten feet closely followed the end of each of the major eruptions such that this author barely avoided drowning his camcorder positioned into the casing. The ragged bottom end of the casing measured about 10 to 11 feet below the top of the casing. The hole at the bottom has a much greater diameter than that of the 16-inch casing. Two other geysers, Spouter Pool and the Mud Pots ("Aragonite Pools" of Murray (1990)), may erupt in unison with Crystal Geyser. These discharge points were normally dry, but progressively filled and drained as the water level in Crystal Geyser rose and fell and they began to sputter when foamy discharges issued from the geyser. They did not cause any significant loss of water from the system inasmuch as they no longer had any runoff except from Spouting Pool to the Mud Pots.

Obvious changes, primarily the longer interval between major eruptions, the addition of minor eruptions, and the change in the casing that keeps rocks from being ejected, had occurred since the nine-year lapse since the report by Murray (1990).

A six-day return visit by Powells from 29 June to 4 July 2000 provided some variations of the eruption sequence. The major to major eruption times for six intervals ranged from 17 hours 9 minutes to about 27 hours 23 minutes (Figure 9). The last three eruptions were somewhat the same as those in 1999, the three intervals from major eruption to major eruption were 22 hours 10 minutes, 21 hours 8 minutes and 20 hours 52 minutes, with the first one of the three amounting to what appears to have been a recovery of an erratic preceding series of eruptions. The major eruptions all had durations in the 40 minute range. The last three major eruptions were preceded by minor intervals of 4 hours 36 minutes, 4 hours 20 minutes and 4 hours 39 minutes, respectively, only about 10 to 20 minutes shorter than the two in October 1999. The water levels dropped about 4 to 5.5 feet after the minor eruption and 12 to 16 feet after the major eruptions. The Ruby No. 2 Well bubbled and seeped at times during the eruptions of Crystal Geyser, but haphazard checking resulted in a lack of sufficient data to make any definitive statements.

The shortest interval, 17 hours 9 minutes, lacked a significant minor eruption. The entire interval was not much different than the interval to the first minor after an eruption for the following four eruptions. Unfortunately, a dozen or so partying young people showed up at about 2200, and drove out on the travertine, causing no noticeable damage, with a couple of enthusiastic lads deciding to drop big rocks down the hole. This may or may not have caused the short interval. Owing to the broken casing and the eroded out area below the bottom of the casing the rocks did not come out during the eruption. Two of the intervals had dissimilar minor eruptions before the major eruption. No after bursts were seen.

A written report incorporating much of the above was submitted to the deputy sheriff of Grand County, stationed in Green River, who visited the site twice while we were there. He was very interested in the geyser and its preservation. My report indicated that we had seen toddlers and pets near the 16 inch wide, foot high, open well casing, reminding us of "baby Jessica," an 18-month-old who fell into an eight inch well in Texas in 1986 and was rescued. A five-foot section of new casing was welded onto the top of the old casing, dated "Nov. 27 2000."

Jeff Cross visited Crystal Geyser 11 November 2000 for 14 hours. A 6-minute minor eruption was followed 4 hours 28 minutes later by a second minor eruption lasting 11 minutes. A major eruption occurred 5 hours 13 minutes later and lasted 48 minutes. The major eruption was succeeded by six afterbursts within a period of 28 minutes. The Spouter Pool and Mud Pots (Aragonite Pools of other reports) erupted prior to each eruption of Crystal Geyser, with the upper pool nearest the road being the most active. Ruby Geyser did not erupt at any time, but overflowed sometime in the morning but stopped when the third eruption ended (Jeff Cross 2011, personal communication from written notes).

Clark Murray commented on Cross' observations, pointing out changes since his observations in the early 1990s:

> It sounds like you saw two minor eruptions, what Jens Day and I called "aborted" eruptions, followed by a small major. In the early 1990's minors were rare and only occurred in the winter time. Since then they have become more frequent, and now seem to be the norm. Without a minor, eruptions were 14-16 hours apart, and the eruptions were much higher. Also, afterbursts only occur after a major eruption. I have not visited Crystal "Geyser" for a couple of years now, so based on what Jeff and Dave saw it seems to have changed its pattern once again (Monteith 2000).

Tom Till (2001, p. 6), apparently an impatient photographer, reported photo captions in reference to Crystal Geyser "Even geysers don't last forever. LEFT AND BOTTOM: Orange travertine at the now dead Green River Geyser, Green River, Utah. BELOW: The same location in the days when the geyser still erupted." However, Crystal Geyser was not defunct as claimed by Till.

On 10 June 2004, Alan Glennon observed overflow cycles similar to those seen by Cross and others that led to a major eruption. He noted one change from previous activity: "Unlike the observations in 1995 and 2000, no afterbursts or secondary eruptions occurred. A closed interval was not observed but the interval is estimated to be 11-18 hours based on local accounts and previous activity" (Glennon and Pfaff 2005).

Frank Gouveia and S. Julio Friedmann (2006) published a report than cannot adequately be summarized here. From the abstract:

> Special instruments were deployed at Crystal Geyser, Utah, in August 2005 creating a contiguous 76-day record of eruptions from this cold geyser. Sensors measured temperature and fluid movement at the base of the geyser. Analysis of the time series that contains the start time and duration of 140 eruptions reveals a striking bimodal distribution in eruption duration. About two thirds of the eruptions were short (7-32 min), and about one third were long (98-113 min). No eruption lasted between 32 and 98 min. There is a strong correlation between the duration of an eruption and the subsequent time until the next eruption. A linear least-squares fit of these data can be used to predict the time of the next eruption. The predictions were within one hour of actual eruption time for 90% of the very short eruptions (7-19 min), and about 45% of the long eruptions (Gouveia and Friedmann, 2006, p. 1).

They mistakenly claim "the periodic eruptions from Crystal Geyser had never been objectively monitored. Previous studies relied on anecdotal evidence and personal communication to reconstruct the timing of this geyser" (p. 2). They did not reference a single published paper other than Baer and Rigby (1978, p. 130) who summarized the data from the unpublished report by Barton and Fuhriman (1973) that included observational data. They also did not reference any of the observations recorded in Geyser Observation and Study Association publications. Consequently they failed to interpret any of the "foam" eruptions or other differences in the

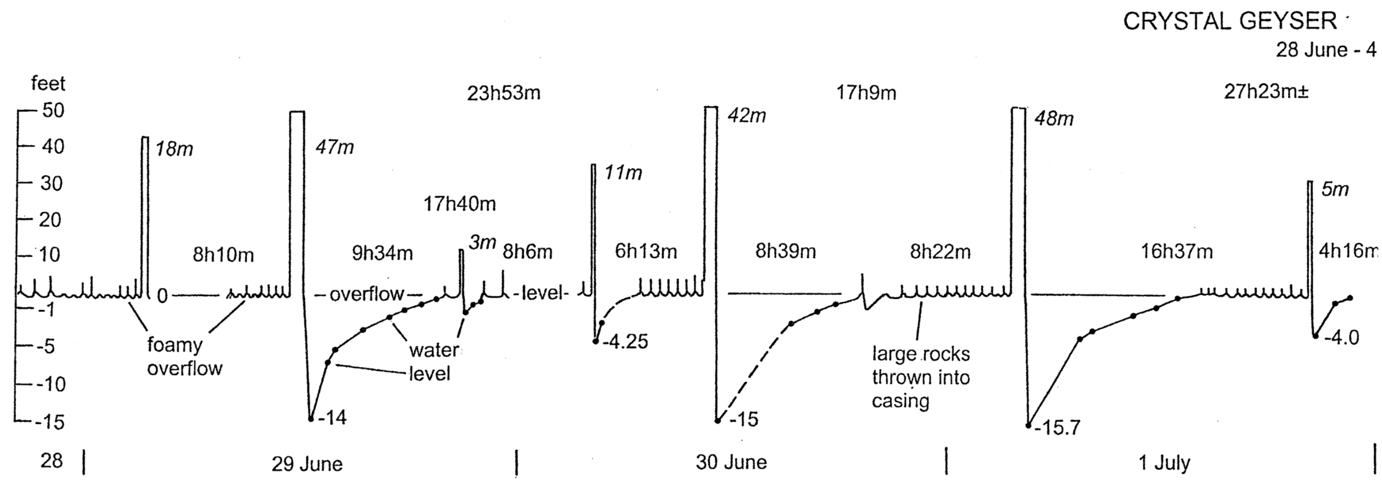

Figure 9 (page 148 and 149). Graph showing eruption intervals, durations, estimated heights and some water levels from tape-downs, 29 June to 4 July 2000. Dashed lines are approximations of two major eruptions. Some foamy overflows at night were not recorded. h = hours, m = minutes

sequence of various types of cycles.

Alan Glennon made further observations of Crystal Geyser in 2005:

> Over the last year, Crystal Geyser appears to be following the cycle: a ~20 minute minor eruption, a pause of eight hours, another ~20 minute minor eruption, a pause of seven hours, two hours of major activity, then a 24-hour pause. Recent major eruptions last approximately an hour, after which Crystal's pool drains. The geyser continues to have intermittent afterbursts for about another hour (Glennon 2006).

Glennon visited Crystal Geyser on 24 November 2005. He observed one minor eruption that reached 60 to 80 feet and lasted about 19 minutes. He conjectured that it was the second minor since the previous major. He observed that Spouter Pool and the Mud Pots (Aragonite Pools) had alternating activity with Crystal overflows, with cycles lasting about 20 minutes.

Glennon also noted that "In October, Penny Martens of Colorado reported to me that monitoring equipment had been placed in the geyser, down the well. The equipment was not present at our Thanksgiving visit…" (Glennon 2006).

Penny Martens (2006, p.18-19) tabulated data to record events at Crystal Geyser and Aragonite Pool (Mud Pots, Figure 5) during a visit on 3 March to 6 March, 2006. Her data generally show that the Mud Pots started erupting about one to ten minutes after the beginning of a surge at Crystal Geyser. The first set of data show a 21-minute minor eruption of Crystal Geyser after a greater than 13-hour interval since arrival. A second minor eruption lasting 20 minutes was observed 6 hours 36 minutes later. This was followed 6 hours and 15 minutes later by a major eruption of Crystal Geyser that lasted 1 hour 56 minutes. This eruption was followed with four afterbursts. The next recorded eruption was a 17-minute minor eruption 25 hours later. The last eruption recorded was 11 hours and 6 minutes later, no duration given, that had three afterbursts, which suggest an eruption duration of about 2 hours 10 minutes.

Jennifer and Dan Cooke (2008) made a brief visit to Crystal Geyser on 3 September 2008 and observed an eruption lasting 22 minutes and reaching 30 feet. They did not obtain an interval as they spent only a few hours in the area.

Dick and Marion Powell returned to the site on 28 September 2008. A visitor report by two overnight campers claimed an eruption at about 0200 that lasted 30 to 45 minutes and another at 0930 that had a duration of about 30 minutes. The author saw a first overflow at 1258 then 15 foaming events prior to a 2 hour 35 minute eruption at 1628, followed by three afterbursts. Fifteen foaming events on 29 September preceded an 18-minute eruption of Crystal

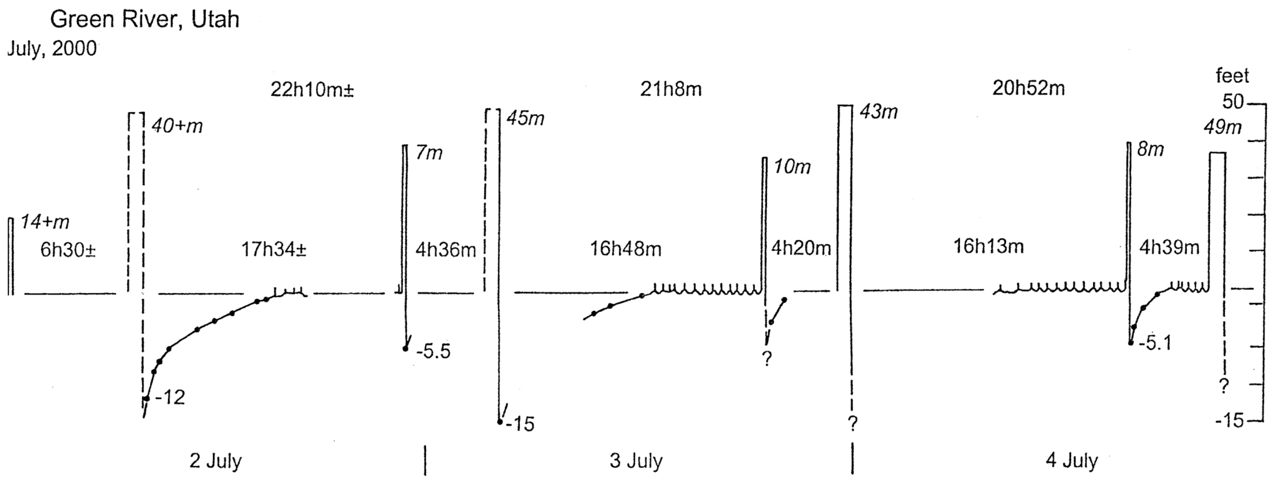

Figure 9, part 2.

Geyser at 1412, after an interval of 21-hours 44 minutes from the day before. Crystal Geyser erupted after an interval of 6 hours 39 minutes for 21 minutes with four hours of pre-eruption foaming events. A noise at about 0400 on 30 September woke the author up for an eruption that ended at 0619, with a duration longer than 2 hours 19 minutes after an interval of about 7 hours 11 minutes.

Conclusion

Crystal Geyser is a very interesting man-made feature; that is, a test boring for petroleum that went wrong. As should be expected, as time progressed the artesian water and gas pressure that caused the eruptions diminished, resulting in fewer evenly-spaced eruptions, if such ever existed, and decreased heights of eruptions. Man-made changes at the site also appear to have affected the eruption intervals and heights. Even so, the existing conditions, with variation of timing and size and a lack of certainty, are more interesting than a steel casing stick-up that erupts every hour on the hour. Be warned however, do not drive a great distance to see a major eruption of Crystal Geyser in the daytime unless you are prepared to camp there a night or two, or three….

Acknowledgements

Thank you to Clark Murray, Jeff Cross and Tara Cross for access to unpublished data and copies of references. Thanks also to the anonymous reviewers for helpful comments that improved this paper.

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CRYSTAL GEYSER AND SURROUNDING AREA: PHOTOS BY BARBARA LASSETER

Barbara Lasseter has photographed Crystal Geyser at least once a year from 2007 through 2010. Top left, the terraces, taken on May 14, 2007. Center left, the "Side Pool," taken October 25, 2008. Bottom left, Crystal filling the pool and casing, May 15. 2007. And above, Crystal Geyser in eruption, October 2009.

Geyser Activity at the Crystal Geyser September 1976

Sam Martinez

Abstract

Sam Martinez and Jamie Espy visited Crystal Geyser, a CO_2 driven cold-water geyser that has had periodic eruptions from a drill boring since 1936, on September 12, 13, and 14, 1976. Martinez's previously unpublished report on the activity of Crystal Geyser is reproduced here, with a few typographical corrections.

Following our stay in Yellowstone this year, Jamie Espy and I stopped in Utah to visit the cold water geysers there, not only to satisfy our curiosity but to study their behavior and geology of the area. The Roadside geyser [Ed: Woodside Geyser?] was closed to the public, but we were able to visit Crystal Geyser without any difficulty. The only scientific information available at the time of our trip was supplied by a few articles by Dr. John S. Rinehart and some notes taken from conversations we had a few weeks earlier, while he was in the Park. We stayed at Crystal nearly two whole days, September 12 through the 14th, and during that time recorded a total of six eruptions. The records of these eruptions and the information we gathered during our stay are the basis for this report.

HISTORY

The Crystal Geyser is one of two wells drilled at the site by geophysical prospectors in search of geothermal energy. [Ed: Actually petroleum.] We presumed that they concluded there was a good chance of finding it because of the geyser-like deposits already there before drilling was started. Even today, the ancient deposits show old vents and cones sealed long ago by internal accretion of mineral deposits. What they struck was more like a buried reservoir of carbonated drink. The water is entirely cold and no agency other than dissolved gas drives the geyser to erupt. It is not known why two wells were drilled unless they were sunk at the same time. They both erupt together, but Crystal is by far the more powerful of the two.

Much of the early history of the area is sketchy and gained by word of mouth from the locals in Green River. The earliest account of these springs I was able to find was a passing note of discovery by J. W. Powell on July 13, 1869.

> This afternoon our way is through a valley with cottonwood groves on either side. The river is deep, broad, and quiet. About two hours after noon camp we discover an Indian crossing, where a number of rafts, rudely constructed of logs and bound together by withes, are floating against the bank. On landing, we see evidences that a party of Indians have crossed within a very few days. This is the place where the lamented Gunnison crossed in the year 1853, when making an exploration for a railroad route to the Pacific Coast.
>
> An hour later we run a long rapid and stop at its foot to examine some interesting rocks deposited by mineral springs that at one time must have existed here, but which are no longer flowing.[1]

Dr. Rinehart reports part of the early history, but there is a great gap in the record, where nothing about the geyser has been recorded. The geyser has been recognized as a source of pollution for many years. The government has been after tffhe owner for some time to plug the well and stop the erupting water from entering the river. The casings may have been capped at one time, but, as I understand, a stick of explosive was employed by vandals to reopen it, belling out the upper part of the casing and leaving the top in the shape of a ragged, diverging nozzle. Remnants of a plastic-sheet-protected levee shows that ponding of the water was tried at least once to prevent or restrain the eruptions. This method, based on the theory that increasing the hydrostatic head would cause eruptions to cease due to the overloading of the energy source, is fine for regular geysers, which run on heat energy, but a geyser operating on dissolving gases would hardly be affected by such manipulation. Conversations with the locals confirmed that the geyser continued to erupt and eventually washed out a good portion of the dam after the water topped it. Apparently the geyser tube developed enough gas lift power to keep the pool from draining after the eruption and finally overcame the excess head necessary to flow over the levee. During the winter the water would undoubtedly freeze in the pool and allow the flow to run unhindered to the river. The levee was eventually abandoned and only traces remain to this day.

Other than filling the well with rocks and large cobbles, I know of no other methods tried to stop the eruptions. The Crystal well was able to eject the rocks from this tube, but the #2 well is still filled to the top of the casing with them.

At present the geyser erupts without constraints of any sort. The owner does not advertise its existence and probably wishes the thing would plug itself up. The Roadside Geyser [Ed: Woodside Geyser?] is owned by the same man and I understand he is interested in selling the two properties together for a reasonable sum. All you geyser nuts can investigate this on your own.

LOCAL INFLUENCE

While we were in camp at the geyser, three groups of people came by to see the eruption, a group of ten rafters, a family from Oklahoma passing through, and two girls from Green River on their lunch break. Considering the quiet reputation enjoyed by Crystal, that's an unusually large number of visitors. We found that the people of Green River evidently use the area frequently for picnics or parties, since the large numbers of empties [bottles] decorate the landscape for a half mile in both directions along the river.

Lack of supervision doesn't seem to have affected the geyser adversely. The familiarity with which the locals treat the geyser is quite shocking, especially to anyone brought up in a protected area such as Yellowstone, where tricks and manipulations are strictly forbidden. On our second day there, two girls on their lunch hour drove up while we were mapping out the deposits. They marched directly up to the main vent and proceeded to toss a number of large rocks down inside. If the geyser hadn't erupted only five hours earlier, it would certainly have taken off immediately. The rocks caused the foaming mass of water 12 feet below the surface inside the vent to rise and splash 2 or 3 feet above the drum-cone for a few seconds. The geyser settled back, but the next eruption came a little sooner than expected. The tremendous flow of water also brought all the rocks clattering out of the well and onto the deposits. Some of these rocks weighed over 15 pounds, which explained why the upper edge of the drum-cone is so heavily dented. A total of 22 rocks were expelled, the largest measuring several inches in diameter and weighing 35 pounds.

CONDITION OF THE DEPOSITS

The deposits, although very bizarre looking at first glance, were in a very natural condition. I was only able to find one spot where signs of collecting were still visible, in an inactive section near the river. The rapid rate of deposition quickly obliterates any evidence of vandalism in the areas which receive water. The drums or cones of the wells, however, are the only thinly coated and show the effects of years of abuse. Bullet and shotgun pellet holes of various sizes puncture both drums and even the upper casing of the main well. This has some effect on the interval and magnitude of the eruptions and will be discussed in some detail later in this report.

Not only are there missing sections of the deposits, but a great amount of additional deposits in the immediate area. Aside from the remains of the levee, numerous specimens of [aluminum cans] dot the area for a good distance in either direction along the bank of the river. The presence of these undesirables is by far the greatest eyesore in the geyser area. While we were there, we collected over 200 specimens of these, which we transported to the Green River depository before our departure. As long as the area remains completely unrestricted, the abuse will continue with great frequency. It is a remarkable fact that Crystal has continued to erupt with frequency and power in spite of the rough treatment it has been forced to endure.

DESCRIPTION OF THE AREA

The Crystal Geyser is on the north bank of Green River, south and east of the town with that name. It is reached via a torturous, mostly dirt road, slightly wider than one lane when you get beyond the paved portion. It winds up and down through the hills until it reaches the river, about 5¾ miles from the interstate highway. The road passes through restricted government land and branches in several places where no indication of the correct route is visible.

Care should be taken in making the trip for the first time, since the nearest telephone or house is several miles away. The road is very rough and rutted, making the route a slow but passable one. At no time is the way barred by gates or fences, so one can drive over the entire length without stopping. Once the geyser is reached the road simply ends in a large open area suitable for both parking and partying, making it popular with the younger crowd.

The area around the geyser contrasts sharply with the duller surrounding rocks. The deposits from the spring waters are bright red and orange, which are evidently derived from an iron-rich deposit a short distance below the surface. There is a hill of very dark red rock immediately behind the area which may be an extension of this colorizing rock layer. The major constituent of the deposits was found to be calcium carbonate (travertine). The hardness varied considerably, becoming greater with increasing iron content. Other minerals are present in deposits, but their contribution is negligible.

The water from both wells has a powerful taste and, after contacting the skin for many minutes, will cause burning and slight inflammation. I would certainly hesitate before using it for anything. We were obliged to use the river water for washing while in the area and, although it appeared quite muddy, did a fairly decent job once the dirt settled out.

The diameter and size of the two wells are similar. The casings appear to be schedule 10, 18" steel pipe, but the depths of the tube were not measured. The first or main well is clear of debris as far as one can see from the top and is in quite good condition for its age. The casing extends about 1½ feet above the surrounding deposits, but is ragged and flaring at the top. Slots are cut around the bottom of the above-ground extension to allow water to flow out at the base of the drum, which is at the level of the surrounding deposits. The foaming of the water does transport some of the liquid over the top during the preliminary activity in spite of these other openings, which measure about 1½ by 7 inches. The 55 gallon drum placed over the casing is without top or bottom and shot so full of holes that water streams out in all directions when the geyser erupts. It did not appear to be fastened firmly to the flange of the casing at the ground level, but the mineral deposits have partially cemented the gap between the two and prevented the rusting of the surfaces to some degree. The scouring action of the water has scooped out a shallow basin all around the well, which is never completely emptied of water. Stepping stones are conveniently placed to allow easy access to the "cone" and also provide a fair indication of how long ago the geyser erupted.

The second well is a short distance from the main well and erupts in sympathy whenever the main vent erupts. Although the vent of this second well is filled to the ground surface with rocks, it erupts 3 to 5 feet above the top of the drum for a few minutes during each eruption. The casing ends at a flange at the ground surface, which is cemented to the bottom edge of a 55-gallon drum by deposits of travertine. This drum is at a lower level than the main vent so it begins overflowing first. During the quiet interval the water in both wells rises and falls more or less in sympathy. We found the second cone so riddled with bullet holes that the water would only rise about a foot up into the drum during overflow.

Besides the two well vents there are several others which also participate in the eruption. Directly behind the main vent there is a large pool with a series of vents located in a fissure at the edge nearest the main well. That edge of the pool is quite steep, because it is formed by the ancient deposits of former springs. The remainder of the pool is shallow and was created by the wave action against the soft, red deposits of soil from the small hill behind the geyser area. Above the pool fissure in the rocky deposits are two more fissures which spout. In addition to the erupting vents already mentioned, there are several old vents and cones, which have been sealed for a very long time by internal deposition. These appear to pre-date the drilling of the wells and provide an explanation for the choice of the drilling site.

ERUPTION DETAILS

The eruption details taken during our stay are included, in part, at the end of this report. Most of the activity occurred during or just after the major eruptions of Crystal. The basic pattern for a complete cycle is quite simple. After the end of the eruption the water in all vents drops several yards. The water is visible only in the main well, 25 feet below the flange. The foaming of the fluid continues but at a subdued level of vigor. Five to twenty minutes after the end of the eruptions there is a sudden burst from the main cone, 4 to 8 feet high. The burst comes with very little warning, following a rushing sound made as the water in the tube travels from 25 feet below overflow to the top of the cone in about 2 seconds. The pool vents growl for several seconds during the outburst, but no water is visible there. On one occasion a similar second burst occurred 12 minutes after the first.

The long interval of quiet between eruptions is routine for most geysers. This one is no different. The second well begins overflowing about 80 to 90 minutes after the time of the last eruption. The water in both wells stays at about the same level once overflow is established. Three hours after the last eruption the main cone has its first overflow period. The water in the main vent and the pool rise to the surface with an increase in foaming and hissing. For less than a minute the water flows out of the main cone, and finally ceases when the water drops back down to its normal level. The overflow periods are repeated at about hourly intervals until one is strong enough to initiate the major activity. The vigor of these flowings gradually increases along with the duration, and by the time the second or third period is reached, the water is forced over the top of the casing and drum for a few seconds. As the time of the next eruption grows near, the duration of the overflowing is about 2 minutes, and the water in the pool reaches 10 inches or better in depth near the vents.

The major eruption begins with one of the regular overflowing periods. The foaming water tops the barrel and casing and hesitates for a few seconds instead of dropping back inside the drum. The water starts spouting up very quickly from the main well, reaching the maximum height in 4 to 5 seconds, but only for a brief moment. The column has the appearance of a gradually tapering obelisk of the most perfect form. After reaching the maximum, the height slowly decreases until it gets to the 15- to 30-foot level, where it remains for the rest of the eruption. At the end it simply drops smoothly to the level of the vent, then splashes a few times before dropping below the overflow level. For the several seconds the water level in the main well is out of sight, while water from the collecting basin around the cone flows back into the tube through the slots cut in the casing at the base. When the level finally comes into view, it is usually 15 to 25 feet below the surface of the ground.

During the active periods of the main well the other vents in the area become active as well. The #2 cone erupts for the first minute and a half of the main eruption, 2 to 4 feet high. For the rest of the eruption it overflows quietly at the higher-than-normal rate. Thirty seconds after the main vent ceases the level in the second cone drops below the casing flange level, disappearing into the rocky fill. The pool and fissure vents erupt 3 to 8 feet high and usually fade away one at a time until, just before the main vent ceases, the last one is reduced to a boiling point in the water of the pool. A few minutes after the spouting ceases the pool drains to some level out of sight in the rocks filling the vents. The water in all the features becomes quieter for a time, but gradually becomes more active during the next hour in the quiet interval. A very thin crack near the edge of the basin around the main cone has a period of growling about 4 hours after the eruption, but no water is discharged from it.

Following the end of the eruption, the main well is almost completely inactive. The foaming is reduced to a very low level and the water is kept in sight mainly from the back-flow from the collecting basin around the cone. After the backflow ceases, the water level in the well is around 25 feet below the ground level. In between 3 and 15 minutes, the air in the main well suddenly begins whistling out, followed by a single, short burst of white, foaming water, 4 to 8 feet above the top of the barrel. On rare occasions two such bursts occur. We observed one such eruption, which nearly caught us with our heads in the barrel. The first burst had come about 4 minutes after the eruption ended. Only 12 minutes later, or 16 minutes after the end of the eruption, a second minor burst came out of the cone, surprising us just as we were approaching the drum to look inside. These minor bursts are interesting but not very impressive. They are believed to be the result of accumulations of gas released from a trap in the plumbing system as the tubes re-fill after the eruption.

EXPERIMENTS IN GEYSER ACTION

Since we were under no restrictions during our stay, we tried a few harmless experiments on Crystal to test some theories regarding cold geysers. In the short time available we limited our manipulations to the level of water in the #2 well. In addition to these results, we were able to get some valuable information from some of the other people who came while we were there.

The water from the geyser is highly mineralized and slightly acid as well. It is reputed locally to be very bad for shoes and clothing and absolutely unfit for drinking. We found it acid enough to redden our skin after only a few minutes of contact and left a white powder upon drying. Chemical tests proved the deposits were mainly calcium carbonate, with some significant amounts of iron, coloring the rock various shades of red and orange. Along the western edge of the area the colors are almost golden. Strangely enough we found no algae or bacteria growing in the runoff channels, only some grass and small willow trees along the river and next to the back pool of the geyser.

The manipulation of the level in the #2 well produced some interesting results. The numerous holes perforating the drum normally allowed the water inside to rise only 8 inches above the flange at ground level. It stayed at the level around 6 or 7 hours during the quiet period. To determine the effect of increasing the hydrostatic head, we blocked enough of the holes to raise the level to the top of the drum, about 3 feet higher than normal. Effects were seen most easily in the height and discernable in the interval and preliminary behavior.

The two intervals during which the drum was plugged were significantly longer than normal. The first of these was 10h54m and the second one was 9h41m. They were separated by one normal interval and probably would have been more nearly equal if the two girls from town had not tossed rocks into the well before the second of these eruptions. Dr. Rinehart reported regular intervals of 5 hours in the late '60's.[2] The normal intervals we saw were around 7 hours in length. He also reports the minor eruptions to be a minute in length and reaching 20 feet in height. Those we saw were only single puffing bursts a few seconds long and 4 to 8 feet in height. Apparently a change in the pattern has taken place since Dr. Rinehart made his studies in the area.

The increase in the hydrostatic head seemed to increase the power and height of the eruption. The three normal eruptions we saw reached up to 150 feet, always with no wind to affect the play. The two eruptions supplemented by 3 feet of additional hydrostatic head were 200 feet in height and more impressive to the ear as well as the eye. The change certainly made the additional wait worthwhile, but it also raised some questions about the limits to which such methods could be employed. Barbee, in his calculations for Old Faithful ,discussed the effects the depth of a geyser tube can have on the height to which it plays.[3] Although more complicated, similar methods can be used to calculate the depth of cold water geysers, through the use of solubility tables rather than steam tables.

It would seem from the observations we made that Crystal has gradually become less active over the years. However, our visit was in late summer, when the ground water is at its highest temperature. At other times of the year the geyser may be more vigorous, due to an increase in the amount of gas it is able to hold in solution. The people from town we talked to visit the geyser often in the summer but never during the winter season. Whether the colder ground water makes it more energetic, or the formation of ice restricts the activity is not known. Crystal Geyser is definitely an amazing curiosity and could provide some important answers about geyser activity if it were studied more closely.

My deep thanks go to Dr. Rinehart for providing information which proved to be invaluable in planning the trip, and especially to Jamie Espy who helped in the field work at the site.

Endnotes

1 Powell, J.W., The Exploration of the Colorado River and Its Canyons, Dover, 1961, p. 199. (Formerly Canyons of the Colorado, Flood and Vincent, 1895.)

2 Rinehart, John S., "Geysers," EOS, Transactions of the American Geophysical Union, vol. 55, no. 12, Dec. 1974, pp. 1052-1062.

3 Barbee, James H., "The Internal Structure of Old Faithful as Deduced from Physical Evidence," WGA Earth Science Bulletin, vol. 4, no. 4, Dec. 1971, pp. 9-16.

Crystal Geyser Observations in 2000

Jeff Cross

Abstract
Crystal Geyser, near Green River, Utah, erupts carbonated water following periodic overflow and related activity of Upper and Lower Aragonite Pools. Data for two eruptions are tabulated and analyzed. The observed behavior is reminiscent of the Grand Geyser complex in Yellowstone National Park.

Crystal Geyser was visited on 11 November 2000. Its activity during a 14-hour period included three eruptions, which were part of an eruptive series. The activity of two nearby vents, called the Upper Aragonite Pool and the Lower Aragonite Pool, was also recorded.

Crystal Geyser erupts carbonated water from a drilled well on the east bank of the Green River, 3.5 miles (8.7 km) south of Green River, Utah. The Upper and Lower Aragonite Pools are found immediately to the east of Crystal Geyser. In 2000, both pools were full of sediment that had been bulldozed into the craters in a vain attempt to prevent them from erupting. A fourth vent, called Ruby Geyser (also a drilled well) is found immediately to the north of Crystal Geyser. Its vent was completely filled with debris. The activity in each vent varied with the activity of Crystal Geyser (see below).

Three eruptions of Crystal Geyser were observed. They occurred at the following times:

Time	Interval (hrs:min)	Duration (min)	Height (feet)
02:59		6	40
07:28	4:29	11	50
12:41	5:13	48	80

The final eruption was distinctly different from the preceding two eruptions. It was longer, higher, and was followed by six afterbursts, which occurred over a period of 28 minutes at steadily lengthening intervals of 3 to 10 minutes. The Aragonite Pools surged in concert with the first afterburst, but were quiet during subsequent afterbursts. Recorded data appears in Table 1 and is illustrated by the timelines in Figure 1 (page 158).

Prior to its eruption, Crystal Geyser overflowed at regular intervals of 28 to 38 minutes. These intervals showed no tendency to change prior to the eruption of Crystal Geyser. The duration of the overflow varied from 8 to 12 minutes. The duration lengthened as an eruption of Crystal Geyser approached. The first eruption of Crystal Geyser began after 13 minutes of overflow while the third eruption followed after 6 minutes of overflow. No record of the activity prior to the second eruption was obtained.

The Aragonite Pools erupted periodically prior to each eruption of Crystal Geyser. Upper Aragonite Pool, nearest the road, was the most active. Each eruption of Upper Aragonite Pool, characterized by vigorous bubbling to 1 foot, began 5 to 12 minutes after Crystal Geyser began to overflow. The length of time between the start of overflow from Crystal Geyser and the start of an eruption in Upper Aragonite Pool did not vary as the next eruption of Crystal Geyser approached. However, the length of time that Crystal Geyser overflowed while Upper Aragonite Pool was in eruption did increase from 0 to 4 minutes as the next eruption of Crystal Geyser approached. Upper Aragonite Pool was in eruption when the first and third eruptions of Crystal Geyser began. No record of its activity prior to the second eruption was obtained. After the first and second eruptions, Upper Aragonite continued to erupt for 32 and 29 minutes, respectively. After the third eruption, Upper Aragonite Pool stopped erupting when Crystal Geyser drained. It surged in concert with the first afterburst of Crystal Geyser, but it was quiet thereafter.

Lower Aragonite Pool was less active than Upper Aragonite Pool. It did not erupt on every overflow cycle of Crystal Geyser. Lower Aragonite Pool became more active as the eruption of Crystal Geyser approached. It erupted on the last three overflow cycles prior to the first eruption of Crystal Geyser, and on the last two overflow cycles prior to the third eruption of Crystal Geyser. No record of its activity prior to the second eruption was obtained. The length of its eruption varied from 5 to 8 minutes and the height of its eruption was 1 foot. Lower Aragonite Pool began to erupt 10 to 13 minutes after an overflow of Crystal Geyser started. As an eruption of Crystal Geyser approached, eruptions of Lower Aragonite Pool shifted from initiating just after Crystal Geyser stopped overflowing to initiating just before Crystal Geyser stopped overflowing. A similar trend was noted in the activity of Upper Aragonite Pool (see above). Following the first and second eruptions of Crystal Geyser, and while Upper Aragonite Pool was still in eruption, Lower Aragonite Pool had series of brief eruptions. Following the third eruption of Crystal Geyser, Lower Aragonite Pool stopped erupting when Crystal Geyser drained. It surged in concert with the first afterburst of Crystal Geyser, but it was quiet thereafter.

Ruby Geyser did not erupt at any time during the observation period. It began to overflow some time during the morning, and it stopped overflowing at around the time that the third eruption of Crystal Geyser ended.

It is likely that Crystal Geyser erupted in series during the observation period: the three eruptions of Crystal Geyser showed a smooth progression toward greater height and longer duration; the third eruption was distinctly larger and longer than the two that preceded it; and the complex drained deeply following the third eruption. The form of the series is minor eruptions leading to a major eruption, in the style of Atomizer Geyser or Lone Star Geyser.

The relationship between Upper Aragonite Pool and Crystal Geyser is similar to the relationship between Grand Geyser and Turban Geyser in the Upper Geyser Basin of Yellowstone National Park. It was the continuation of overflow from Crystal Geyser after the start of an eruption of Upper Aragonite Pool that indicated when an eruption of Crystal Geyser was imminent.

Table 1. Recorded Data for Crystal Geyser - 11 November, 2000

Crystal Overflow				Upper Aragonite Eruption					Lower Aragonite Eruption				
Start	Stop	Int	Dur	Start	Stop	Lag	Dur	Ovrlp	Start	Stop	Lag	Dur	Ovrlp
0028	0036		08	0036	0049	08	13	00					
0106	0114	38	08	0112	0125	06	13	02	0118		12		-2
0140	0150	34	10	0147	0159	07	12	03	0151	0156	11	05	-1
0213	0225	33	12	0221	0232	08	11	04	0224	0232	11	08	01
0246		33		0253		07			0257		11		
	(Eruption 0259)												
	(No data)												
	(Eruption 0728)												
1002	1014		12	1014	1027	12	13	00					
1040	1048	38	08	1047	1058	07	11	01					
1109	1117	29	08	1115	1127	06	12	02					
1137	1146	28	09	1143	1155	06	12	03	1147	1153	10	06	00
1205	1215	28	10	1212	1222	07	10	03	1215	1221	10	06	-1
1235		30		1240		05							
	(Eruption 1241)												

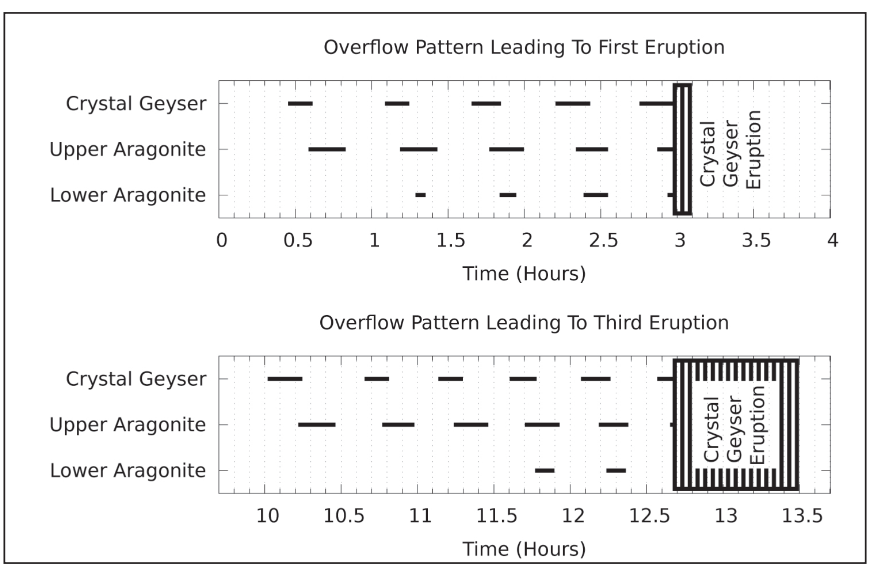


Figure 1, left. Crystal Geyser Timelines. Timelines for two eruptions of Crystal Geyser show the overflow of Crystal Geyser (upper line) leading to the eruption in relation to the eruptions of Upper and Lower Aragonite (lower two lines).

Observations of Small Model Geysers with Variable Plumbing

Brian Davis

Abstract

The subsurface conduit structure of geysers is not well understood, primarily due to the difficulty in direct observation. Yet at least some characteristics of the eruptive patterns may be closely tied to the details of the conduit geometry, such as style of the eruption, regularity and series or "wild phase" behavior. A series of very closely related physical models were studied to try to determine how plumbing variations might influence the eruptive behaviors. Even for these very simple models, dramatic differences in behavior occurred with different geometries, even while holding the heat input, volume and depth constant.

Introduction

Geyser surface behavior has been extensively studied, with observations of long-term periodicity, eruptive characteristics (like duration, multiple bursts, or "wild phase" behavior), exchange of function between multiple vents, etc. However the critical physics and structure of a geyser that determine these behaviors is generally out of reach and less understood. With the exception of the rare extinct geyser conduit that can be entered (Rinehart 1980), or exceptional cases like lowering a small camera down the accessible conduit of Old Faithful (Keiffer 1997), direct observation of even the near-surface portions of a geyser system is sharply limited. Indirect methods, such as seismic measurements and the chemistry of the erupted waters, are helpful in many ways, but not in determining the detailed underground geometry of the conduit system. Furthermore, the accessible portions of the system appear to be an order of magnitude smaller than the volume involved in an eruption. Giant Geyser, for instance, ejects an estimated 4 million liters during a single eruption (Bryan 2008), yet the plumbed depth of the conduit is just 21 feet (6.4 meters) (Allen and Day 1935). If the subsurface conduit was optimistically modeled as a simple cylinder 10 feet (3.06 meters) in diameter (significantly larger than the observed surface vent size), this erupted volume would imply the conduit to be roughly 1,800 feet (550 meters) long.

As an alternative to mapping natural geysers, a number of experimenters have constructed small models that mimic at least some of the features observed in natural systems. Most of these have been fairly simple vertical conduits of fixed geometry. But natural geyser systems certainly contain much more complex conduit systems. Correlated behavior between physically separated vents or apparently completely separate geysers (such as Turban Geyser and Grand Geyser, or Giant, Grotto and Oblong Geysers, with a horizontal separation of in excess of 1,000 feet (300 meters)) as well as the volume discharged shows that horizontal segments of the system are likely significant in both linear extent and volume. An obvious possibility then is to use some simple models with variations in their conduit geometry to try to determine how these variations might change the eruption characteristics.

Model Description

The models utilized are all simple, small-scale systems, analogous to models studied by previous authors (Anderson 1978, Cross 2010, Lasic 2006) (Figure 1, *page 160*). A chamber (a 500 ml side-ported laboratory flask) at the base is topped by a rubber stopper with a 10 cm long pipe fit flush with the bottom of the stopper to form the chamber outlet. The base of the flask is heated by an external electrical hotplate. Above the chamber is a 50 cm long pipe vertical segment, followed by a second 30 cm long vertical pipe segment, finally ending in a 10 cm long pipe that mated to a small partially covered bowl that acts as a catchbasin at the top of the system. When the system is running, the water level was filled to 1 cm over this "vent," forming a very shallow pool that allows cooled post-eruption water to drain back in and refill the system. The order of the 30 cm and 50 cm sections can be changed, and the 50 cm straight conduit can be exchanged for one of four variations (Figure 2, *page 160*).

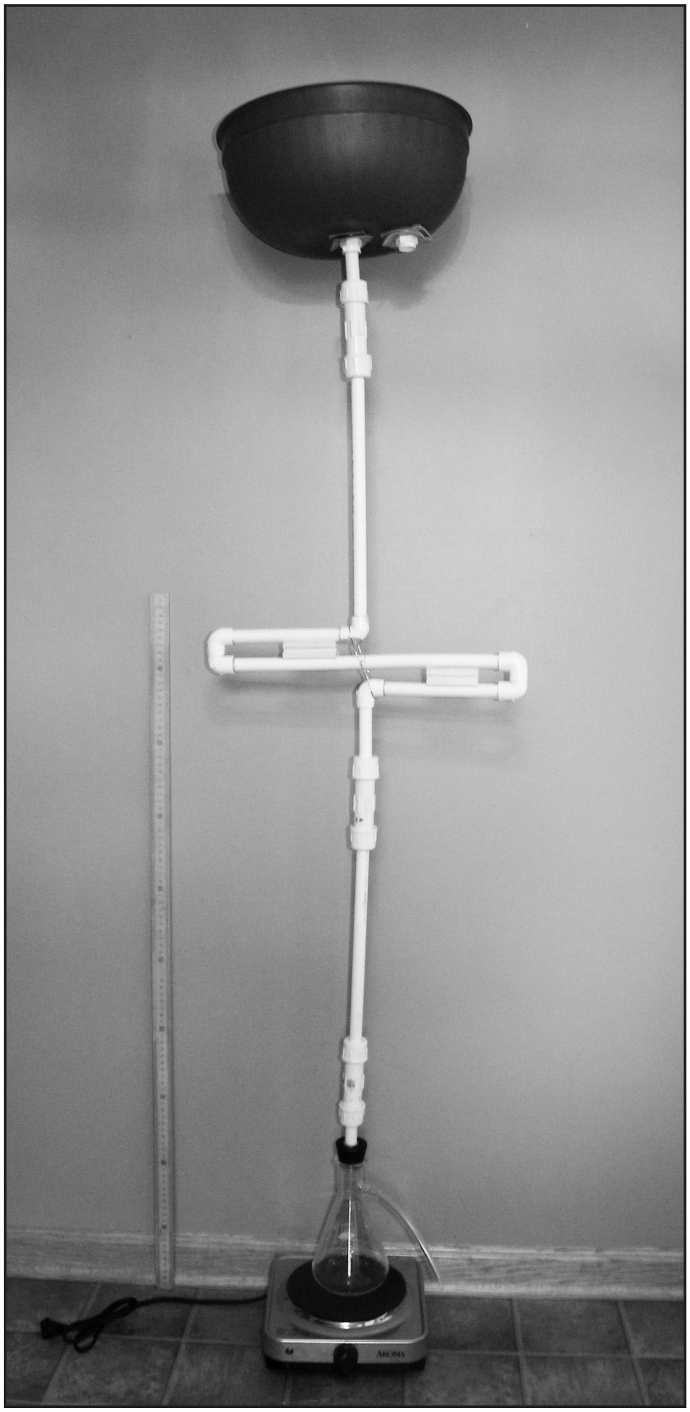


Figure 1: An example model configured with one of the optional geometries near the middle.

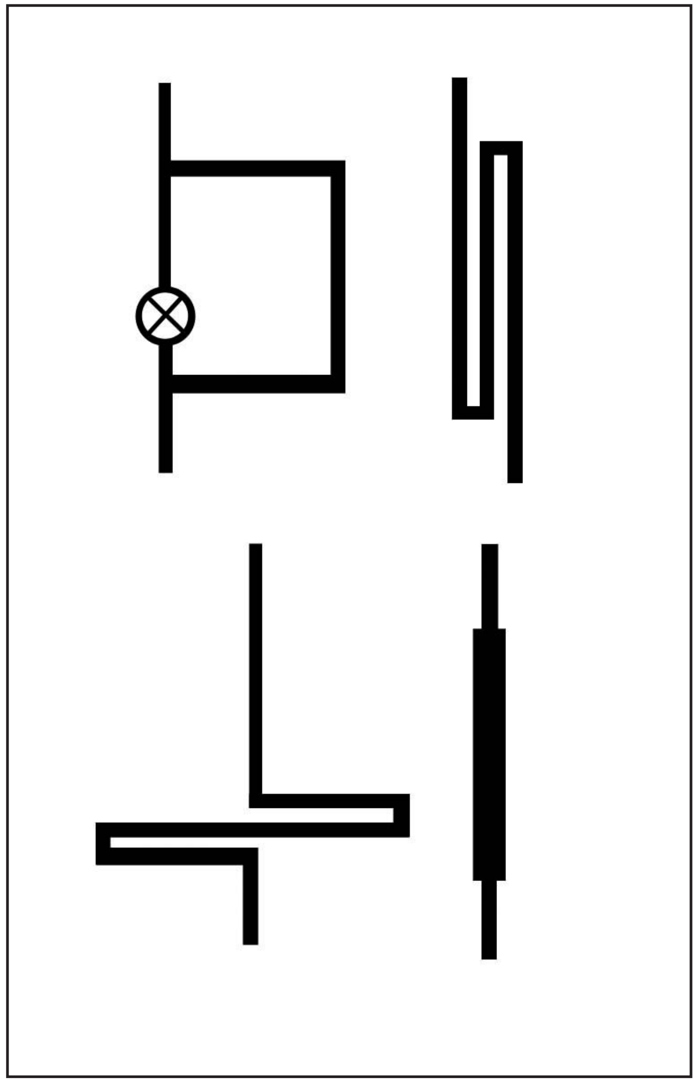


Figure 2: Four conduit variations. Clockwise from the top left, these are the "D Ring" (with closable ball valve) "Steam Trap," "Wide," and "Bedding Plane."

All four of these interchangeable sections were constructed to have different geometries but identical internal volumes (149.5 cm^3), so that only the geometry of the plumbing system was varied: the total volume for all runs was fixed at 748.5 cm^3 (with the chamber volume 537.5 cm^3, or 72% of the total volume) and the total depth was 139 cm from base of the chamber to the water surface. All models were run with the same heat input and environmental conditions (20 °C). The conduit consists primarily of standard ½ inch CPVC plumbing pipe (1.27 cm) to make it easy to construct, as well as significantly reducing the heat loss associated with glass or metal uninsulated pipes. All pipe segments were joined with standard CPVC ½ inch compression repair fittings (1.27 cm) with the pipe segments inserted completely into them, allowing the system to be easily rearranged (often while still very warm).

Experimental runs took place indoors to minimize possible variations in external conditions (such as heat loss to the room air) and were instrumented to have a continuous running record of the eruptions. A digital pressure sensor on the side port 15 cm above the bottom recorded the pressure near the top of the chamber, and two digital thermometers recorded temperatures during the run: one at the top of the chamber, and one in the mouth of the vent. A small laser beam traversed the chamber and was recorded by a light sensor as well, providing a proxy for the boiling behavior in the chamber (vigorous boiling reduced the amount of transmitted laser light). Time resolution was variable, but could be set as short as about 0.1 seconds during an eruption.

The small scale of these systems deserves comment. Due to the rapid heating at the base and the narrow nature of the conduit used, thermal convection in the model conduit itself is very limited. While there was evidence that heat was actively convected up once significant steam bubbles began to form, all the evidence seems to indicate that eruptions in small model systems like this are initiated and sustained at the chamber base, not due to a local hot spot somewhere above along the upper conduit. This may be in sharp contrast to at least some natural geyser systems. In situ measurements of Old Faithful, for instance, indicate that the boiling point is likely reached near the top of the conduit first (Hutchinson 1997), as do measurements of some other geysers such as Geysir, and an eruption may proceed in a "top down" sense (similar to a "shock tube" model (Kieffer 1989)) instead of a "bottom up" configuration such as these models demonstrate. In terms of the temperature-depth curve, many natural geysers seem to most closely approach boiling conditions in the upper reaches of their conduits, while small systems such as these almost invariably first approach boiling conditions at the heated base of the system. Likewise almost all natural geysers seem to be recharged from below, not refilled primarily by the eruption waters draining back into the surface vent. A final significant difference is the thermal conditions in which the model functions. Exposed models (especially small ones) will lose heat to the generally cooler surroundings. This is not the case with natural systems, where the conduit is enclosed in a material of low thermal conductivity with a high specific heat, resulting in very low heat losses out of the conduit to the surrounding media. While these issues should be kept in mind, such simple models may still point out some interesting behaviors and closely mimic at least some geyser systems.

Two calibration tests were done on the system. The first used just the 500 ml flask chamber with the rubber stopper and 10 cm pipe on top of the hotplate, to establish what the power input to the system was by heating a fixed quantity of water. With the hotplate on full, 537.5 cm^3 of water heated at a rate of 0.0942 °C/s, implying a heat input to the chamber of roughly 210 W. With the heat turned off, the cooling of the isolated uninsulated flask with 90 °C water showed that thermal losses for this portion of the system are around 26 W. A second test of the system was done to determine if the compression fittings would affect the results. Two runs were made, comparing a system with little or no slightly wider segments in the conduit (due to gaps within the compression fittings), and one with several such slightly wider sections. There was no discernable change in the behavior of the model geyser in these systems, implying that the model is insensitive to the slight changes in geometry due to the presence of the compression fittings.

Baseline system

To establish a baseline for the behavior of the system, a simple model with a long, continuous ½ inch (1.27 cm) conduit was studied first. While this does not have exactly the same total volume as the variable geometry systems, it does have the same chamber volume, heat source, total depth, and vent structure, so it provides a reasonable example of how such models might be expected to behave. During the pre-eruption period, the chamber temperature increases nearly linearly, while the pool temperature slowly decreases as it cools in the ambient air (Figure 3, page 162). (The water in the narrow conduit is also presumably cooling at this time, more rapidly than the pool water due to the large effective surface area of a narrow pipe.) As the chamber temperature rises steam bubbles form and collapse as they ascend into cooler water, generating tremors registered by the pressure sensor (from about 1 minute onward in Figure 3, page 162). As the chamber approaches local boiling conditions, small steam bubbles that form on the bottom of the

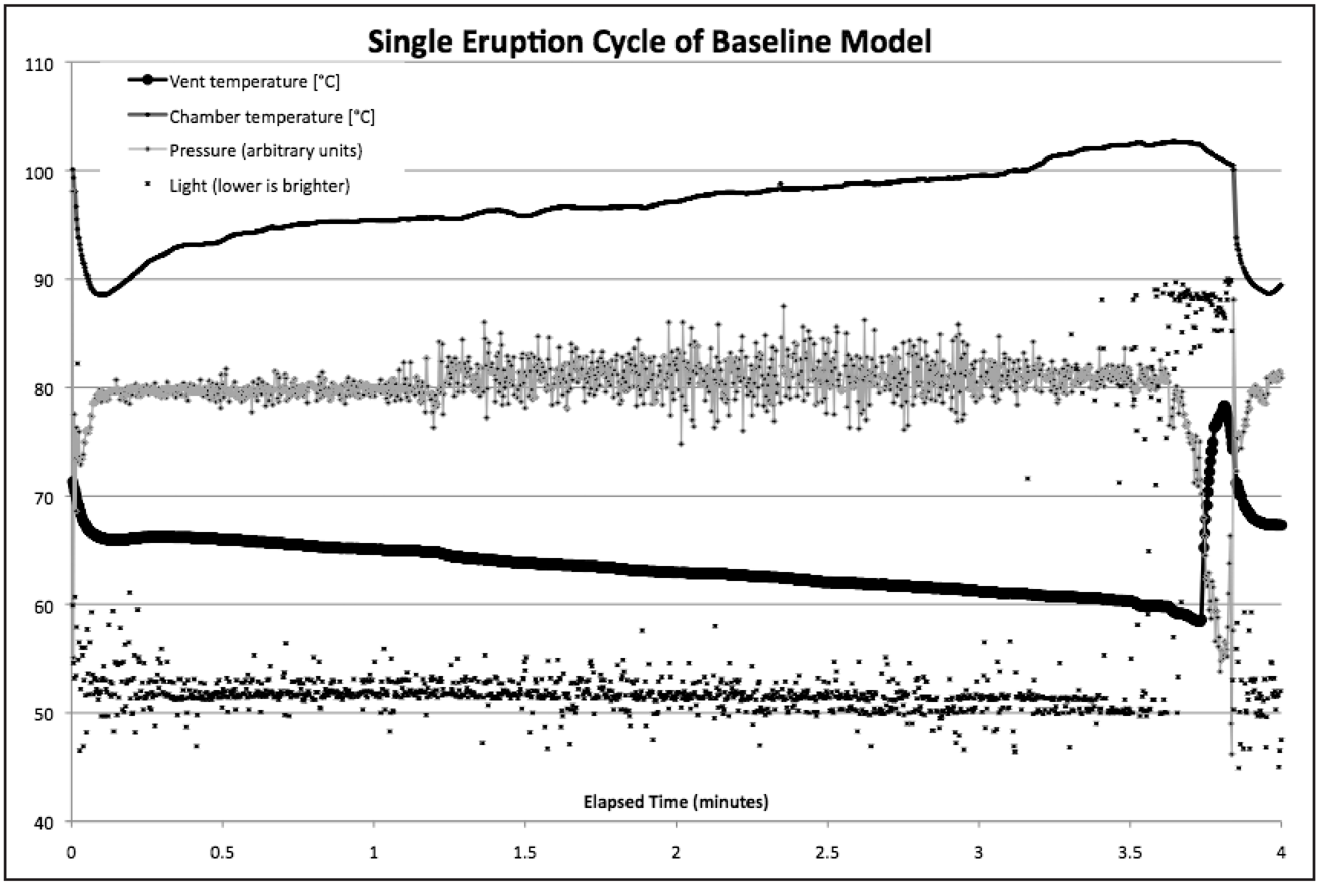


Figure 3: Conditions in the Baseline system over one complete cycle.

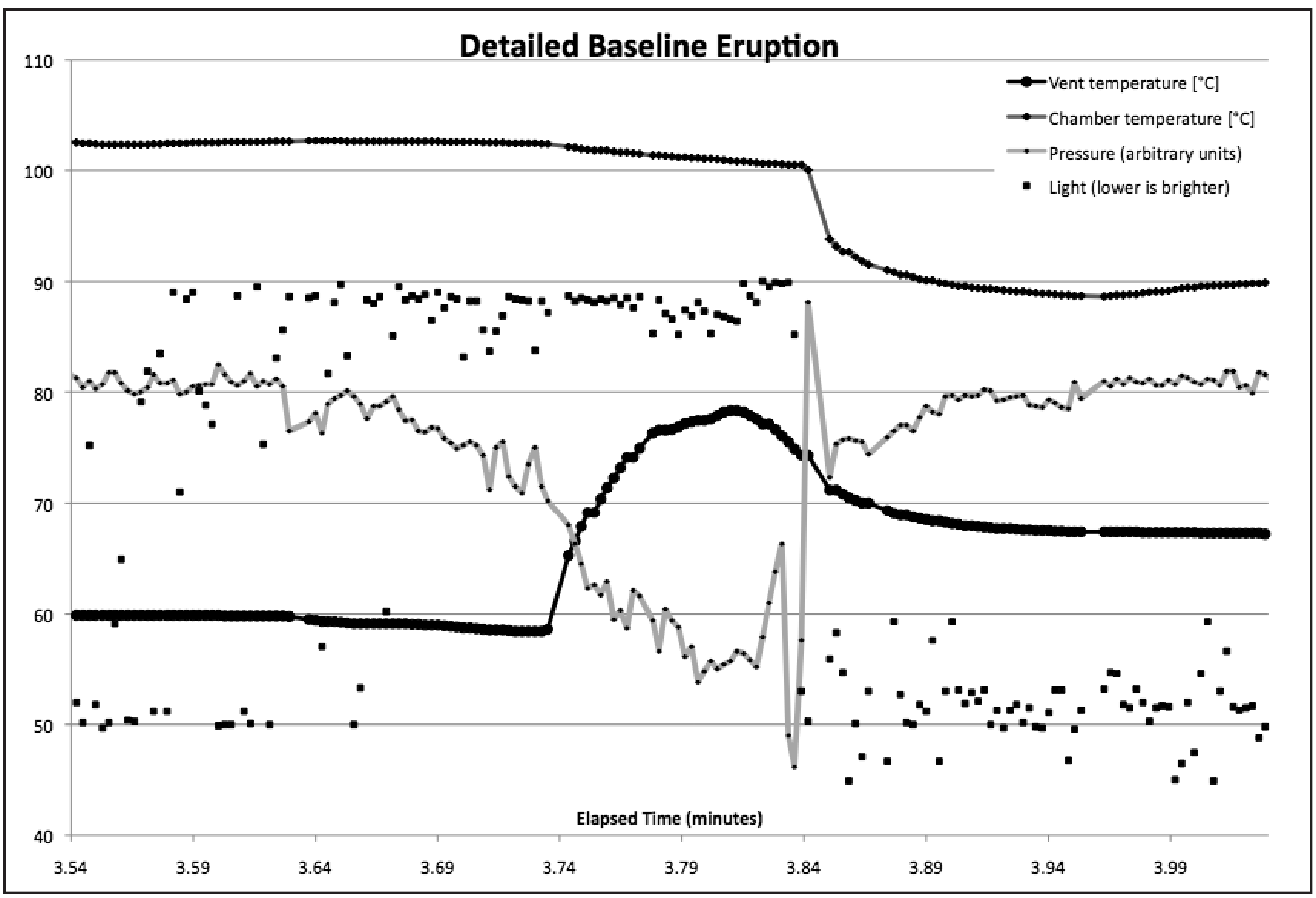


Figure 4. Detailed conditions during an eruption.

chamber can grow and rise up to the level of the laser, thereby reducing the amount of light transmitted through the chamber (shown by the light level readings jumping from around 52 up to 88, indicating almost no light transmission through the chamber; note that larger values correlate with less light transmission in this implementation). An eruption (Fig 4) begins promptly when the chamber temperature reaches 102.6 °C, close to the boiling point at a depth of 139 cm. The light sensor readings show that boiling becomes furious in the chamber, and the chamber pressure (initially near 114 kPa, or 81 units in Figure 4) begins to drop as water is pushed out of the vent by the expanding steam. This ejected water, pushed out from the upper regions of the conduit, is actually cooler than the pool water initially, resulting in a slight *decrease* in the measured vent temperatures. As the chamber continues to boil and the pressure is reduced still further, very hot water and steam from the chamber are finally expelled from the conduit, marked by a very sharp increase in vent temperature as live steam hits the sensor. The chamber temperature also begins to subtly decrease at this time as it loses heat due to the rapid generation of steam. As the chamber pressure drops to 104 kPa (near ambient), the eruption ends, leaving a steam-filled, low-pressure conduit and chamber under a pool of water, sealing it from the outside air. As this water starts to flow back into the conduit, it raises the conduit and chamber pressure while at the same time bringing the steam in the conduit into contact with cooler liquid water coming down from the pool. The steam condenses immediately as it contacts the returning water, reducing the pressure still further to sub-ambient levels (100 kPa). The water is driven down the conduit by this pressure differential, violently slamming into the chamber in a "water hammer" effect that briefly raises pressure to higher than hydrostatic levels, at the same time dropping the measured chamber temperature as the sensor is bathed in cool water returned from the pool. This sudden variation from low to very low pressure followed by an immediate spike to higher than normal levels is very distinctive in Figure 4, but generally only occurs for the baseline model (i.e., it is not a general feature of eruptions

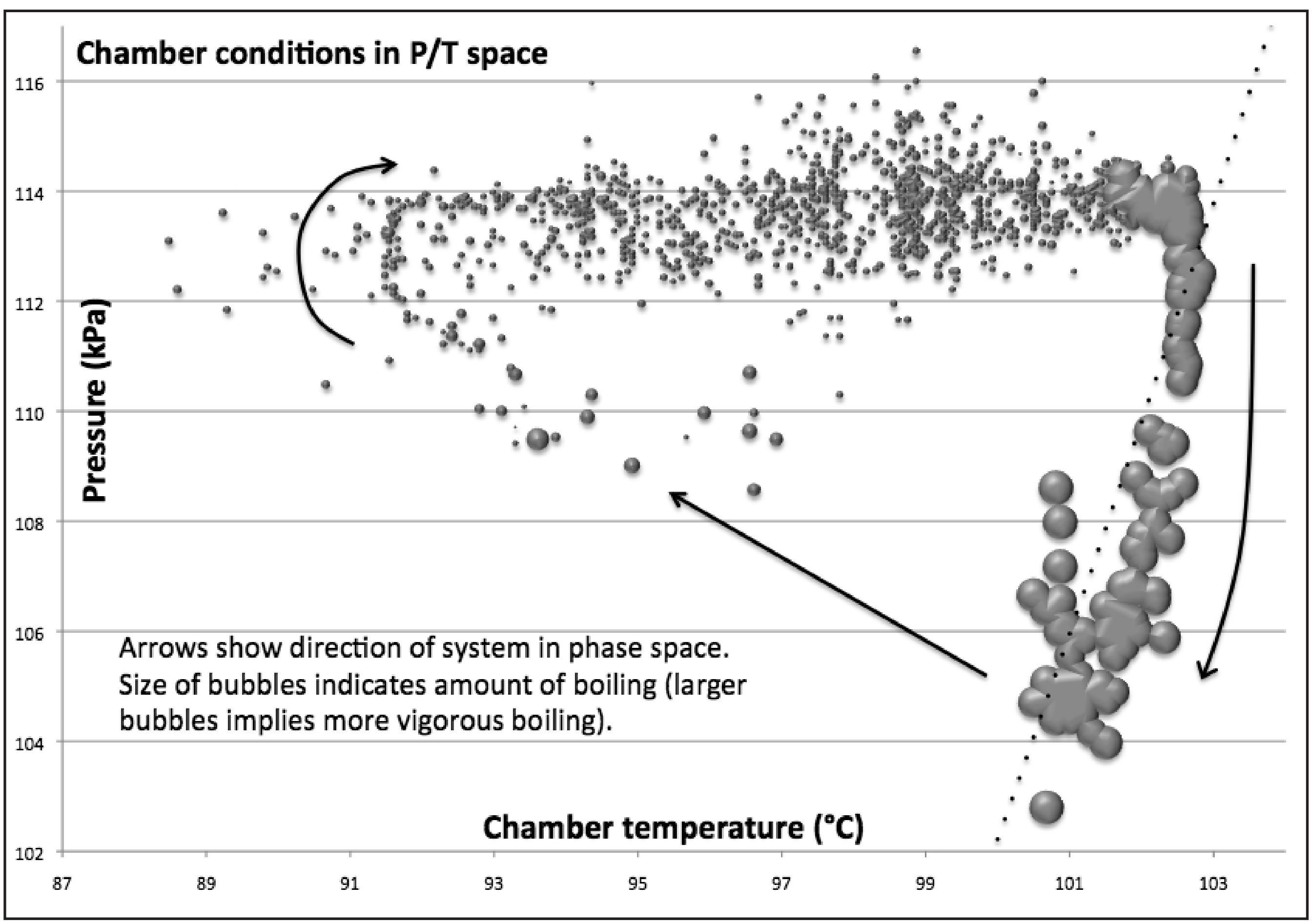


Figure 5: Behavior of Model Geyser in P/T Phase Space.

from more complicated geometries). This high pressure along with cooler water immediately quenches all boiling in the chamber, which then completes refilling and begins to heat for the next cycle.

Another way to understand such an eruption is as a trajectory in phase space (Figure 5, *page 163*). A complete eruption cycle starts with the conduit full of cool water near the upper left of the diagram. As the chamber heats, the system moves horizontally to the right as the temperature increases at constant pressure, with slight pressure variations becoming more pronounced at higher temperatures as steam bubbles form and collapse. When the temperature in the chamber approaches the local boiling point in the chamber (delineated by the diagonal dotted line), the eruption begins as water is lifted out of the vent by steam production. This reduces the pressure significantly while only slightly reducing the temperature, driving the system vertically downward in phase space, and pushing it firmly across the line into a mixed liquid/vapor state (located to the right of the boiling point curve). The resulting dramatic boiling is shown by the size of the bubbles on the graph (larger bubbles corresponding to lower light transmission and therefore more vigorous boiling). Eventually the pressure becomes low enough that cool pool water can re-enter the conduit, and as the water rapidly reinfiltrates the system the pressure is driven up as the temperature drops, moving the system very rapidly diagonally up and left to complete the cycle.

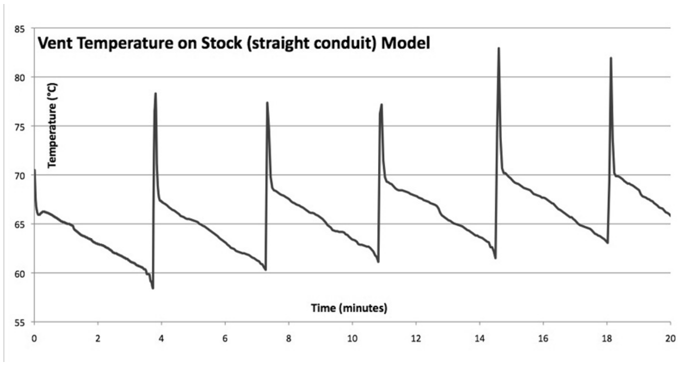
The entire eruption, from first detected ejection of water from the vent to the end of the refilling, takes about 17 seconds, with a "steam phase" of roughly 5.5 seconds. This simple system is remarkably regular, with eruptions occurring every 3.22 minutes (standard deviation of 0.216). The chamber temperature drops 12.5 °C from 102.6 °C to 89 to 91 °C during an eruption, with the pool temperature climbing 8 °C from 63° to 71° due to hot water expelled from the vent. The vent temperature actually provides two very useful measures of the model behavior: the periodicity, and the increase in pool temperature (a proxy for the magnitude of the eruption).

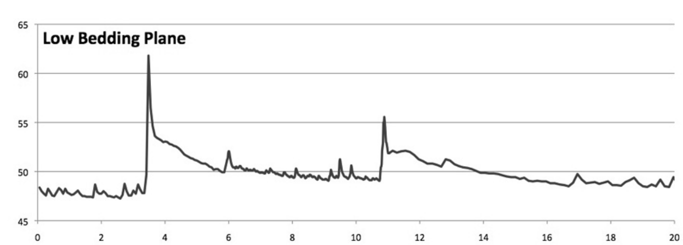
Effects of geometric variations

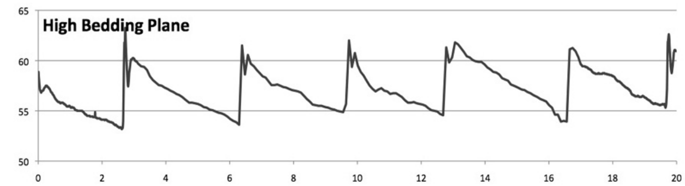
The four conduit configurations were selected both to provide significant variation, and to imitate possible realistic (but exaggerated) components that might occur in natural conduit systems. Each variation was constructed to have an identical depth of 50 cm, and an identical volume of 149.5 cm^3:

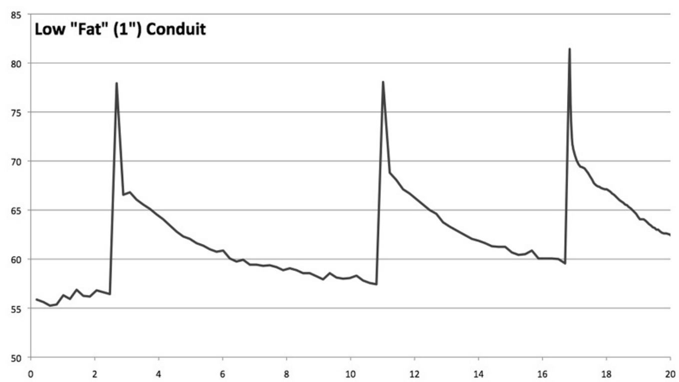
1) "Wide" variation: replaces a ½ inch (1.27 cm) section with a 1 inch (2.54 cm) section, mimicking a wide section of an otherwise narrow, uniform conduit.
2) "Steam Trap" variation: forms a 30 cm long section like the trap on a sink, with a section of conduit bending back down or "descending" 30 cm before rising back up toward the vent. While natural systems almost certainly never approach this extreme, this was selected to try to model a system where steam could gather in a trapped "head space" of the conduit.
3) "Bedding Plane" variation: the conduit deflects horizontally, doubling back horizontally over itself twice before continuing vertically. While the known plumbed sections of geysers are vertical, this may be largely due to the ease of lowering a weighted line vertically. It might be expected that the underground conduits would have significant horizontal or near horizontal segments due to existence of systems where multiple vents are interlinked in a common conduit system.
4) "D Ring" variation: a straight conduit with a square side loop of similar diameter. A natural conduit could be branched or multiply connected, or have formed along a vertical fissure with different widths in different places, forming multiple pathways for thermal waters to follow. This also has a ball valve located near one end of the straight pipe, allowing the geometry to be changed without altering the plumbing to simulate a system with "blind" ends as well as a longer path length with horizontal sections.

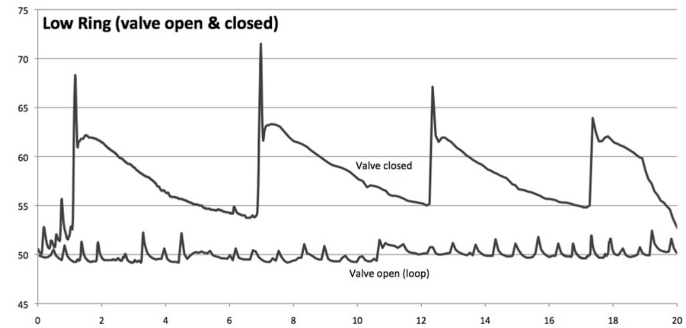
Each of these systems was tested with the variable section either in a "low" (deep) orientation (directly above the chamber and 10 cm standpipe, with a 30 cm straight pipe segment above the variable section to form a straight upper segment to the conduit) or a "high" (shallow) configuration (the 30 cm straight pipe located immediately above the chamber, with the variable segment located above

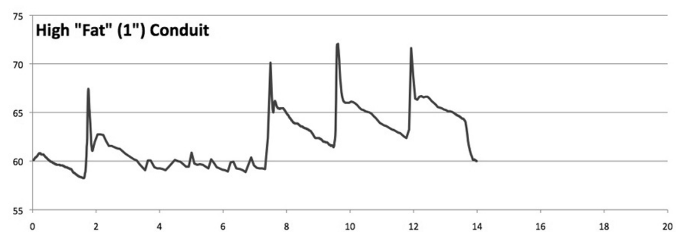


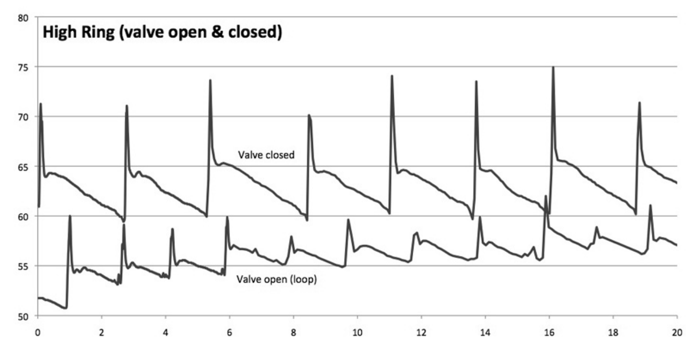












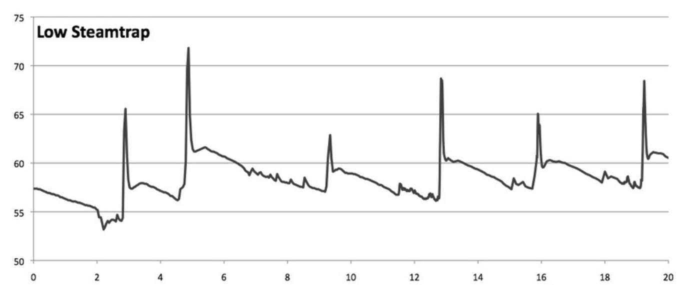


Figure 6: Eruption series (vent temperatures) for all geometric variations studied. Identical scales are used in all graphs for comparison.

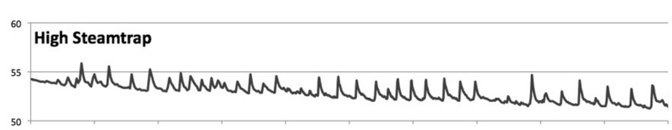


Table 1 – simple summary of model observations; "P" is the period from the start of one eruption to the start of the next.

Baseline		very regular, P=3.22 min
Wide	- Low	regular, P=6.10 min, with possible series behavior
	- High	major (P=2.2 min) & minor (P=36 sec) eruptions, minors precede major
Steam Trap	- Low	semi-regular, P=3.41 min, & sometimes P=1.4 min triplet eruptions
	- High	very tiny (almost unobserved) & semi-regular, P=0.43 min
Bedding Plane	- Low	significant but slightly irregular eruption (P=8.8 min)
	- High	regular but smaller than for baseline, P=3.47 min
D-Ring (open)	- Low	regular but very weak or cool eruptions, P=0.63 min
	- High	semi-regular, P=1.74 min, cool pool
(closed)	- Low	slightly irregular eruptions, P=5.4 min
	- High	semi-regular, P=2.70 min

that). Each variation was run to near steady state conditions (so that the pool water warmed during an eruption as much as it cooled during an interval) so that as much as possible variations would not be due to the system as a whole slowly warming or cooling. Data were collected for at least 20 minutes on each variation, and in some cases much longer. A brief summary of the experimental runs shows significant differences in eruption styles (Table 1, above, and Figure 6, *page 165*).

"Wide" Low

With the "wide" section, 1 inch (2.54 cm) conduit, placed low in the model, eruptions are regular, but with a significantly longer period than the baseline case: 6.10 minutes (standard deviation 0.8412), more than 2.4 times as long. While the eruptions appear very similar, the behavior of the chamber temperature is significantly different, dropping from 102.6 °C to only about 94 °C (a drop of 8.6 °C), significantly less than in the baseline case. Within just 2 minutes of a eruption the chamber temperature has already rebounded to 102.6 °C and resumed a furious boil, but the system does not erupt for a further 6 or 7 minutes. During this interval the pressure shows a slow steady decrease of 1.5 kPa (equivalent to ejecting about 15 cm of water from the system, roughly half the length of the "wide" 1 inch (2.54 cm) section), presumably due to a mixture of steam and water replacing the water in the conduit above the chamber itself. Visually the eruptions themselves are almost indistinguishable from the baseline case, raising the pool temperature exactly as in the baseline case as well.

Since heat is being delivered to the system steadily, a longer interval would seem to imply a significantly greater amount of hot water or steam being generated — however, this is not obvious in the measurements taken on the system. One possibility that seems plausible is that as steam bubbles start to form in the chamber at around 2 minutes, they rise into the conduit above and heat the water there by condensing. The result is a larger volume of water is being heated, and additional heat is being lost due to the high relative surface area of the small cylindrical conduit, leading to a longer interval. It is uncertain what triggers an eruption here; it is certainly not simply the water hitting the local boiling point at the base of the conduit, as this occurs after just 2 minutes.

"Wide" High

With the 1 inch (2.54 cm) wide conduit shifted to the upper part of the model, a very different behavior occurs. There appear to be both major and minor eruption types. A minor occurs when the chamber temperature hits 102.6 °C. The chamber starts to furiously boil, but for some reason the eruption "aborts" or "stalls," dropping the chamber temperature only about 2.6 °C and ejecting a very small amount of water from the vent. During such a minor, the pressure drops 5.9 kPa (equivalent to around 60 cm of water depth, less than half the height of the overlying water column). Successive minors occur every 36 seconds, with perhaps smaller and smaller temperature drops (e.g., the minors earlier in the series drop the chamber temperature slightly more than minors later in a series). A series of minors can be terminated by a major at the time of the next expected minor. A major eruption can occur after a minor series or after the previous major, and looks in every way like the eruptions previously described for the "wide low" case: chamber temperature drops 8.6 °C, rebounding to the critical 102.6 °C temperature after 1.6 to 2 minutes. The result is that a long interval (very roughly 2.2 minutes) always follows a major, and a short interval (0.63 minutes (standard deviation 0.0507) or 38 seconds) always follows a minor.

It seems clear that the major-style eruption here is a simple eruption like that seen in the previous "wide low" case, and similar to that of the baseline model. The mechanism of a minor series is slightly less clear. One possibility is that an eruption starts and begins to send a steam/water mix up the conduit, pushing water out of the vent. But as the expanding steam enters the wide section, it can more efficiently mix with cooler water. This can quench the incoming steam, stalling the eruption (and very effectively transferring heat from deep in the system to the upper wide section via latent heating). As the eruption stalls, any slight increase in pressure can condense still more steam, stopping the eruption completely to generate a minor. If this is the mechanism, a major must either have a significantly greater production of steam, or more likely the water in the upper wide section is warm enough to only partially condense the steam, keeping a net flow out of the vent and thus continuing to lower the pressure. In support of this, it is interesting to note that the pressure decrease corresponds closely to a steam-filled conduit below the wide section (i.e., the lowest pressure during a minor is what would be expected if the expanding steam from an eruption only just entered the bottom of the wide segment). This may be another mechanism for producing major/minor behavior in some natural systems.

"Steam Trap" Low

While eruptions look fairly typical visually, occurring every 3.41 minutes (standard deviation 0.3528), the detailed behavior of the system during the interval is very different than in the baseline case. Immediately following a normal eruption, the chamber reheats in an identical way to the baseline case, climbing from 92 to 94 °C to 102.6 °C after 2 minutes. After this initial "quiet" reheating happens there is a very small eruption (almost unnoticed visually), and the system seems to enter a "primed" mode: the pressure drops 2.6 kPa (equivalent to a reduction in water depth of 26 cm), and begins a series of tiny eruptions, while the chamber temperature becomes remarkably stable (variation of less than 0.12 °C over a minute or so). This pressure drop occurs with no entry of air into the system at the vent, implying that the reduced pressure is most likely due to steam, not a non-condensable gas introduced during a refilling of the system. During this "primed" phase the pressure stays low the entire time the tiny eruptions occur, until finally a full eruption begins, soon dropping the pressure almost all the way to ambient and resetting the system. The irregularity in the interval appears to depend on the duration of this "primed" phase.

One interpretation of the low pressure "primed" period is that when the chamber hits 102.6 °C, it manages to erupt until the rising steam/water mixture enters the descending middle leg of the steam trap. Normally the expanding steam must do work against the overlying water, and the power required to do this decreases linearly as less and less water is above the expanding column of steam. For a "Steam Trap" arrangement, this is true only as the steam is pushing up a simple vertical segment. As it expands into the first upward leg of the trap, the pressure from the water above no longer decreases: instead, it remains constant as the steam advances through the first two legs of the "steam trap." This hydraulic consequence should help reduce or stall an incipient eruption, at least partially filling the first two legs with steam (frictional losses due to the sharp turns may also play a role). Over time, continued steam production can fill those legs until the first steam bubbles can "spill over" into the third and final, rising tube of the steam trap, again starting to reduce the pressure and completing the eruption by driving it all the way to the surface. The interval during which the steam trap is filled varies because of cooling, or small bubbles being pushed out and up the conduit. Apparently, the bubbles are small enough not to initiate an eruption, but significant enough to carry away some heat and lift some water out of the vent, producing the tiny eruptions measured during this phase.

In addition to the typical eruptions, a less common variation was observed. On at least two occasions, in place of a typical single eruption, the system had a "triplet": three smaller eruptions separated by 1.0-1.6 minutes. Unlike a typical eruption, where the pressure drops to ambient and then goes quickly back up to a high level as the entire conduit refills, the first two eruptions in a triplet series did not end with the complete refilling of the conduit, but by slowly (over more than a minute) refilling only to the "primed" state, where the pressure is lower by about 26 cm because the system is still filled with gas (according to the recorded data, the chamber was also in a furious boil after these first two eruptions). When the system had refilled to the "primed" state it immediately initiated the next triplet in the series. In the two examples recorded, the third eruption in such a triplet acted like a typical eruption and reset the system (completely filling the conduit again), although the eruption was smaller. It is unclear why these occurred, or if they need always occur as triplets (although the two examples recorded were very similar). They were not obviously different visually from a typical eruption, but show up very clearly in the vent temperatures and other logged variables.

"Steam Trap" High

Visually it appears as if the vent never erupts, but the digital record shows that there are many very small "micro-eruptions," ejections of lukewarm water with an irregular period of around 26 seconds (or 0.43 minutes; standard deviation 0.1446). While these are tiny, to the point of being too small to visually notice, they do appear to be true eruptions, with tiny drops in the chamber temperature and even small drops in the pressure. The chamber pressure was very low in this model, 5.51 kPa below normal, even in between eruptions, indicating that much of the conduit was not full of water but remained full of steam the entire time. The low pressure corresponded to 56 cm of the conduit height filled with steam, not water. The implication is that most of the conduit between the furiously boiling chamber and the bend in the steam trap remains constantly full of a bi-phase steam/water mix. It may be that in this configuration almost all the heat flux into the system is lost through walls in the conduit, and there is not enough energy to erupt the system at any time. It is questionable if this has any implications for natural geysers in rock systems, as heat loss through the walls of the conduit would seem to be negligible.

"Bedding Plane" Low

In this configuration eruptions were significant, but with long and irregular intervals (around 8.8 minutes). Eruptions always proceeded from a partially full conduit: at the start of an eruption the pressure is about 2.7 kPa lower than when the system is full, implying 28 cm of gas in the conduit, and the chamber temperature is at 102.0 °C (boiling for the reduced pressure). A small eruption usually builds to a complete eruption, dropping the pressure down significantly and bringing the chamber temperature down to about 93 °C. After an eruption the system refills completely with water and remains "quiet" for about 2 minute as the chamber reheats to boiling (102.6 °C). At this point there is a "steamless eruption": a significant "burp" of warm conduit water is ejected from the vent as the chamber pressure drops again by 2.7 kPa, and the chamber resumes furiously boiling at the slightly lower 102.0 °C. In this "primed," or waiting state, the system has many small eruptions until one of them initiates a major eruption, emptying the entire conduit and restarting the cycle.

Based on the geometry and the reduced pressure, when the system is in a "waiting" mode the conduit above the chamber is filled with steam up to the horizontal branches of the overlying conduit. It may be that a single phase fluid (liquid water) can easily be pushed through the sharp turns in this section, but when the two-phase water/steam mixture of an eruption encounters it, either the increased friction or the increased cooling in this section contributes to stalling an eruption, leading to a system partially primed with steam trapped below an overlying water-filled conduit. Here again further expansion of the steam below the horizontal conduit will not result in a reduced pressure (and therefore further steam generation) in the lower conduit, contributing to "stalling" such an eruption. Only when enough steam has been generated (possibly filling all the horizontal elements of the system) can a further eruption drive out more water, resulting in a runaway reduced pressure condition as the steam enters the long vertical upper conduit. The minor eruptions during this phase may be due to significant steam volumes forming and collapsing in the horizontal branches as this part of the system warms.

“Bedding Plane” High

With the horizontal segments very high in the system eruptions were periodic and reminiscent of the baseline case, with a period of 3.47 min (standard deviation 0.3168). These eruptions, however, did not show much of a high-temperature spike that is normally the signature of a steam release. Instead they were mostly hot water eruptions with very little steam. Eruptions take place from a full conduit when the chamber temperature reaches 102.6 °C, and drop the chamber temperature to around 91 °C. These eruptions often end with a “water hammer” effect like that seen in the baseline model, but unlike the baseline model, the refilling is not prompt: even after the water hammer, the chamber pressure indicates that the conduit is not completely full of water, but contains roughly 20 cm of gas. Complete refilling (presumably due to water infiltrating through the bends and horizontal segments) takes place over the next few seconds. With the system refilled, it resumes heating until the chamber is once again ready to erupt. Note that unlike the previous variation, at no time does the system appears to have significant quantities of trapped steam: other than during the actual eruption, pressure measurement indicates that the conduit is completely filled with water.

With the horizontal segments located far above the chamber, they appear to have little role in altering the quality or timing of the eruption cycle. While both the increased resistance to a two-phase fluid and the constant chamber pressure as the eruption proceeds through the horizontal segments should still be factors, perhaps neither is sufficient to abort the eruption once it has progressed this high in the system. The reduced steam content could be due to these effects.

“D Ring” Low

Although eruptions occurred, the surface manifestations were minimal. Closely spaced, with a period of 38 seconds (or 0.63 min, standard deviation 0.1301), these ejections of lukewarm water changed the vent temperature little, and the long-term average was only slightly above 50 °C, indicating that very little hot water was being ejected into the pool, in spite of vigorous boiling and steam at depth. Eruptions, however, did produce distinct drops in chamber temperature from 102.6 °C to just under 100.0 °C at regular intervals, and corresponding brief pressure drops.

These weak or aborted eruptions are likely due to two aspects of the system. Like the steam trap and the “bedding plane” examples, the presence of such a loop would be expected to maintain constant pressure on the conduit and chamber below even as an eruption proceeds through it. A rising bubble below the loop can eject water and reduce the pressure on the chamber below, but as rising bubbles or an eruption enter one of the arms of the loop (the ascending arm), the other arm remains full of liquid water. As a consequence, even as water is driven out of one branch, the pressure does not drop below the loop. In addition to that, as steam rises into one branch it will drive a circulation through the loop, ejecting water out of the bottom of the other (descending) side of the loop. This addition of cool water will quench some of the steam, which will also hamper any eruption. The result of both of these effects appears to completely stall the eruptions, with none of them proceeding above the loop.

“D Ring” Low (valve closed)

With the ball valve closed, the geometry of the “D Ring” is similar to the “Bedding Plane” example: a series of two horizontal segments, in this case joined by a significant vertical displacement instead of a series of tight U-bends. And indeed the eruptions have some similar characteristics. Significant eruptions occur with a period of 5.4 min (standard deviation 0.3845), and show a similar structure in that they consist of a reheating period as the post-eruption chamber heats from 90 °C back up to 102.6 °C, followed by a series of minor eruptions that do not eject steam (i.e., they are clear in the pressure and chamber temperature records, but the vent temperatures do not show them). However, unlike the previous case with the “Bedding Plane” low in the system, at no time is there a significant steam-filled component to the system. The interval preceding an eruption always occurs with a full conduit. The minor eruptions that occur during this time drop the pressure by 2.9 kPa, showing that at least 29 cm of conduit end up steam-filled, which implies that during these steam reaches to at least the base of the loop. Two minor eruptions showed lower pressures, with a drop of 4.0 kPa (equivalent to slightly more than 40 cm of vertical conduit being filled with steam); both these were just prior to a major eruption.

It seems that this case parallels the "Bedding Plane" low case, but with some interesting variations. First, a steam trap does not seem to form, even though the first horizontal segment is located at the same effective height (30 cm above the pressure port) in both examples. This suggests that the occasionally steam-filled lower conduit in the previous case may have owed its existence to the sharp bends or some other feature, not just the presence of horizontal segments. Second, the observation of two types of minors (ones with 2.9 kPa pressure drops, and occasional ones with slightly higher pressure drops) fits nicely with the idea that later eruptions in the pre-major lead-up extend further and further along the conduit, with the penultimate minors extending beyond the first horizontal segment. The longer interval in this case may be due to heat lost through the conduit walls again reducing the net heat supplied to the water in the system.

"D Ring" High (valve open & closed)

With the valve open (so both branches are available for flow), eruptions were again very regular, with an interval of 1.74 minutes (standard deviation 0.2568). The eruption proceeded promptly after the chamber temperature reached 102.6 °C, dropping the chamber temperature to about 96 °C immediately following an eruption. The average pool temperature during the run was around 57 °C. With the valve closed, both the pool temperature (average 63 °C) and the interval (increased to 2.70 minutes, standard deviation 0.2561) increased, but the eruptions looked otherwise very similar, initiating when the chamber temperature hit 102.6 °C and dropping to 93 °C (somewhat lower than for the "valve open" case). There were no unusual aspects to the pressure or boiling details; it appears that with the "D Ring" element high in the system, it does not influence the eruption dynamics, but most likely contributes varying amounts of cooled water to the system during refilling as well as changing the amount of exposed surface area, again altering the cooling of the system.

Discussion and Conclusions

Clearly, variations in the conduit geometry can have dramatic effects on the behavior of these small model systems. It would seem that a minor alteration, similar to a the valve being closed in one of the "D Ring" models (perhaps analogous to a stone lodging in a sub-surface constriction), can result in a dramatic change in the surface expressions of such systems. Minor vs. major eruptive behavior could be generated by a mechanism like the "Wide" model, with minors being formed via a "deep" eruptive thrust stalling out in a wider cooler upper section of the conduit. While this is not the only possible mechanism for major/minor behavior (Cross 2010) it represents an interesting alternative, certainly a possible one from the standpoint of the likely irregular conduit geometry. Both the "Bedding Plane" and "Steam Trap" style systems show that hydrostatic effects of significant non-vertical components of conduits can greatly alter their behavior and periodicity, and need to be considered in more depth. In many cases these systems can have "occult" or hidden steam volumes trapped within them during intervals that determine the eruptive characteristics. While such mix-phase deep portions of conduits have not been plumbed in natural settings, they are almost by definition inaccessible by such measurement methods (weighted thermal probes). Yet the significant horizontal extent of such systems strongly suggests they may be important to understanding such dynamics.

While studying these simple systems is informative and suggestive, there are significant features that do not resemble natural geysers. One difference that seems to influence such models is heat loss from the conduit itself. This is unlikely to occur in natural systems, so its influence on model systems is something that should be considered. A larger model would be less influenced by heat loss (scaling up, the conduit surface area to conduit volume ratio will drop, reducing heat loss relative to the heat capacity of the system), but a more likely improvement might be to add insulation to these models, repeat the experiments and then compare the results. Another obvious problem, previously mentioned, is the "deep" nature of such small-scale models. Clearly a "top-down" eruption with the first boiling taking place at a very shallow depth would result in dramatic difference from these simple "bottom-up" models. As an example, if a "Steam Trap" style system started erupting at the top of the conduit, unloading pressure from everything below it, steam would not accumulate in the trap as it does in these models, but steam might be generated in the trap during the eruption as the conduit pressure drops. Convection in small-scale models also requires further consideration, especially in models where the steam can be trapped. In all cases, adding insulation to the conduit and adding heat along the conduit will likely produce significant changes in the experimental results.

Appendix: Instrumentation and Data Collection

To obtain a detailed understanding of the processes occurring in the conduit several different instruments were used. Temperature measurements both in the chamber and the vent were done with a temperature probe produced by LEGO, the NXT Temperature Sensor. The sensor is based on the Texas Instruments TMP275 chip, which can provide a temperature measurement with a maximum resolution of 0.0626 °C and an accuracy of 0.5 °C. The sensor itself is encased in a thin steel probe to protect the electronics and performs temperature conversion on-board, communicating by standard I^2C protocols. Pressures within the chamber were determined using a barometric pressure sensor (BAR-BTA) from Vernier hooked up to a small air-filled tube connected to a port in the chamber at the base of the system. To monitor the boiling in the chamber itself a small laser (commercial laser pointer, < 5mW) was directed through the chamber so that the beam fell onto the phototransistor of LEGO light sensor. Strong thermal gradients or bubbles deflected the beam, reducing the amount of light falling on the sensor. All three of these sensors are inexpensive, stable, and easily interface with the NXT, a small computerized "brick" also produced by LEGO. The NXT has four sensor ports that can communicate directly with an I^2C sensor or perform 10 bit analog-to-digital conversion to digitize a sampled analog voltage. The small 128K memory can hold both data and simple programs, allowing data collection to occur at rates of up to roughly 50 Hz independent of an attached computer. In addition the NXT is small enough to easily shield from the splashing water and steam.

The NXT was programmed to sample all four of the attached sensors at a user-selectable rate. The measurements of the temperature sensors (vent and chamber) and pressure sensor (chamber) were instantaneous (not time averaged) responses from the sensors, which was sufficient since these variables changed only slowly and generally nearly linearly over the course of a measurement interval (this was determined by obtaining high time resolution records on the models prior to as well as during the runs). The light sensor response, however, was averaged over the duration of the sampling interval. Since the light sensor normally either detected a bubble (laser beam deflected from the sensor) or didn't detect a bubble (laser beam unobstructed and impinging on the sensor), it functioned as an effective binary sensor. By oversampling the sensor during the interval and recording the average, the response could be used as a reliable (if not linear) proxy for the rate of boiling (bubble generation) along the small volume traversed by the beam. The result was an estimate of the number of bubbles crossing the beam path during the interval, not just the instantaneous response of the sensor.

Using the NXT allowed all of this data manipulation to be done prior to recording instead of in post-processing, greatly reducing the amount of data generated while still preserving the response of the system. The duration of the sampling time could also be manually adjusted by simply turning a small lever that the NXT could read the position of, varying the time resolution on the fly. For a long time series, a time resolution of 1 or 2 Hz was sufficient (or even slower), but for selected events this could be quickly increased to 30 Hz or so, providing a detailed record embedded within a longer time series. Due to the flexibility of programming the device, this process could even be automated, with the resolution under control of the data collection program and only switched to high resolution mode when the program detected rapidly changing variables. This was attempted, but not pursued further due to the number of false "eruption detections" the software often generated.

While this represents a rather uncommon instrumentation suite, it was very well suited for a model of this type. Inexpensive and durable (the entire suite of sensors and NXT datalogger cost approximately $300, and are designed to survive in educational settings with very inexperienced users), it is easy to change both the deployment of sensors and the data collection strategy very rapidly, while at the same time providing data of sufficient time resolution and accuracy for long time series on small models such as these. In the event that more than four sensors need to be sampled, a second NXT (or even more) can be added for a very small cost in order to record more sensors, making the logging system easy to extend.

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The Significance of Violent Steam Phases

Jeff Cross

Abstract

The eruptions of some natural geysers are characterized by an atomized eruption column that is ejected from the geyser vent with a loud roaring sound. Through experiments with model geysers, it is demonstrated that the violence of the eruption, manifested by the sound of the eruption and the degree to which the erupted water is atomized, correlates with the initial temperature of the water over the range of 222 °F (106 °C) through 293 °F (145 °C). It is suggested that, since maximum permissible temperatures of liquid water within a geyser increase with depth, the violence of the eruption may be used to estimate a minimum depth for the geyser's plumbing system.

INTRODUCTION

The thunderous steam phases that develop during some geyser eruptions are among the most spectacular occurrences in a geyser basin. The roaring sound created by the eruption is sometimes audible to people standing more than a mile away from the geyser, and any water that is erupted with the steam appears not as a distinct column, but is atomized into curtains of fine mist that drift on the wind, capturing brilliant rainbows. The occurrence of a steam phase also has scientifically interesting aspects because it indicates that the erupted water had a relatively high temperature, and therefore had to reside at considerable depth within the geyser immediately prior to its discharge at the surface.

How is the steam phase defined? Two types of steam phase are defined by Fix (1939):

> *Passive steam stage*—That portion of the phase during which emission of steam is at low velocity and is not accompanied by roaring or puffing sounds.
>
> *Violent steam stage*—That portion of the phase during which steam is emitted from the mouth in violent puffs or in a continuous column and is accompanied by a distinctive sound.

Each type of steam phase is attributable to a specific cause.

In the passive steam phase, the force of the eruption dwindles to the point where the boiling within the geyser tube is no longer sufficient to loft water out of the vent. The steam then rises above the churning water deep within the geyser tube and issues from the vent in quiet billows. Old Faithful Geyser is a prime example of a geyser with a passive steam phase.

In the violent steam phase, the force of the eruption grows as the fraction of steam in the erupted fluid increases. It is important to note that although the term "steam phase" might seem to refer to the part of the eruption where vapor is the sole phase emitted, the term in general use refers audibly to the onset of loud roaring, or visually to the disappearance of any well-defined water column. The term does not indicate that steam is emitted as the sole fluid—steam and water are often emitted together, even during the most violent steam phases. The significance of both phases occurring together will be discussed later. The ejected water is partially or completely blown into a fine mist that drifts for hundreds of feet on the wind. If the degree of atomization is great enough, it can become difficult to estimate the height at which the vertically ascending eruption column separates into the billows of spray. Yellowstone's Steamboat Geyser and Giantess Geyser are prime examples of geysers with a violent steam phase.

The eruption of Steamboat Geyser is the loudest in Yellowstone.

> Those individuals who are fortunate to see a major eruption... can attest to the extraordinary volume of noise, especially during the phase change from water to steam. It is often so loud that one must shout to be heard. Many observers have stated that the volume is painful.

At the Norris Campground, 1.2 miles north of Steamboat, the sound of nighttime eruptions is loud enough to awaken campers. During eruptions in the early 1980s:

> The noise of the steam phase was

Giantess Geyser going into steam phase on July 16, 2001. Photo by Tara Cross.

> normally comprised of two distinct frequencies. One was subsonic, felt as much as heard. It pounded against one's chest in palpable waves. The other frequency was higher, a pitched roar so loud that the air seemed incapable of carrying such a load of sonic energy. The sound was distorted into a tortured, rapid-fire series of crackles and pops. (Strasser, Strasser and Pulliam 1990).

The eruption of Giantess is the second-loudest in Yellowstone. During one eruption, Bryan (2007) recalled "people swarming like ants out of the Inn and Lodge because of the noise." The sound of that eruption was plainly audible at Riverside Geyser, which is 0.9 miles away. During a violent steam phase, the erupted water is often atomized. Weed, in 1884, observed an eruption of Giantess Geyser. A little over three hours into the eruption,

> The grandest outburst of all occurred… continuing until 7:28 when but little water was emitted, but a great volume of steam accompanied by [a] loud roaring noise, issued from the vent. This column of steam was 300 ft [high] and, condensing, fell as fine spray around the crater, floating off in banners in the light breeze." (Whittlesey, 1988) The eruption of Beehive Geyser has a similar character: "The great volume of steam breaks the column into innumerable droplets and spray, which are wafted away by air currents, forming a beautiful rainbow. (Marler 1978).

How might the thermodynamics of a violent steam phase operate? In contrast to the passive steam phase, in which steam separates from liquid water, in a violent steam phase the liquid water and the water vapor erupt together. The erupting water, which, prior to eruption, had been kept in the liquid phase at temperatures high above 212 °F (100 °C) by the confining pressure of the overlying water, boils freely until its temperature falls to 212 °F. The fraction of water that converts to steam during this boiling is a function of the initial temperature of the water, as shown in Table 2. Since steam at 212 °F is 1,603 times more voluminous than water at the same temperature, erupted fluid with an initial temperature of 222 °F (106 °C) is 1.0% steam by mass and 94% steam by volume. Any erupted fluid with an initial temperature of 252 °F (122 °C) or greater will be at least 4.2% steam by mass and 99% steam by volume. Also shown in Table 2 is the minimum depth at which the erupted water must have rested beneath the surface to have attained such a temperature.

The relationships shown in Table 2 suggest that the fraction of steam in the erupted water could be correlated with the depth of the geyser. The water confined at the stated depth could also have a temperature below the one listed in Table 2. Thus, the depth extrapolated by this method is a minimum value. Measuring the fraction of steam in a column of erupting water is difficult. It is far easier to correlate the violence of the eruption with the initial temperature of the water in a qualitative fashion, as described below.

EXPERIMENT

To establish a correlation between the violence of a geyser eruption and the initial temperature of the water, a 10-gallon (37.9 L) tank, fitted with two heating elements, temperature and pressure gauges, and a safety valve, was filled with water (Diagram 1).

Geyser	Distance in miles	Reference
Steamboat	1.2	Strasser, Strasser and Pulliam (1990)
Giantess	0.9	Bryan (2007)
Beehive	0.4	Holstein (2011)
Castle	0.4	Cross (personal observation)
Splendid	0.8	Strasser (2011)
Bijou	0.2	Cross (personal observation)
Catfish	0.2	Wang (2011)
Mortar	0.6	Cross (personal observation)
Atomizer	0.3	Stephens (2011)
Clepsydra (back vent)	0.3	Holstein (2011)
Ledge	0.1	Monteith (2011)
Dark Cavern	0.5	Monteith (2011)
Africa	0.5	Bryan (2011a)
Porkchop	0.4	Cross (personal observation)
Bastille	0.8	Sturtevant (2011)
Avalanche	0.2	Cross (personal observation)
Lone Star	0.2	Cross (personal observation)
Union	0.3	Bryan (2011b)

Table 1: A selection of Yellowstone geysers that exhibit violent steam phases, and the distance, if known, at which the sound of the eruption is plainly audible.

T_i (°F)	Minimum Depth Necessary (ft)	Mass % Steam	Volume % Steam
222	7	1.0	94
232	16	2.1	97
242	26	3.1	98
252	37	4.2	99
262	50	5.2	99
272	66	6.3	99
282	83	7.3	99
293	105	8.5	99

Table 2: A correlation exists between the initial temperature, the amount of steam in the erupted water, and the depth from which the water was erupted, assuming a column of water with a specific gravity of 1.0. The depth beneath a column of hot water would be greater because the specific gravity of liquid water falls as the temperature rises. Liquid water has a specific gravity of 0.96 at 212 °F (100 °C) and 0.92 at 293 °F (145 °C). The mass percent of steam is calculated by finding the difference in enthalpy between water at the given temperature and water at 212 °F, and using the heat of vaporization of water at 212 °F to calculate the mass of steam that is formed. The specific volumes of steam and water at 212 °F are then used to calculate the volume percentage of steam. Pressure-temperature, heat of formation, and specific volume data are taken from the Keenan and Keyes steam table (1951).

T_i (°F)	Height (ft)	Sound	Droplet size
223	22 (jetting)	quiet	several millimeters
232	34 (jetting)	quiet	distinct column
241	39 (steady column)	roaring	atomized on descent
251	32 (steady column)	roaring, thunderous	atomized on ascent
263	39 (steady column)	roaring, thunderous	atomized on ascent
273	41 (billows)	roaring, thunderous	atomized on ascent
286	43 (billows)	roaring, thunderous	atomized on ascent
293	43 (billows)	deafening, vibrations	atomized on ascent

Table 3: Observations on the eruption of water with a known initial temperature. Note that the height of the eruption remained roughly constant between T_i = 273 °F and 293 °F. Heating the water above 273 °F resulted only in greater atomization. It did not cause the water to be thrown to a greater height.

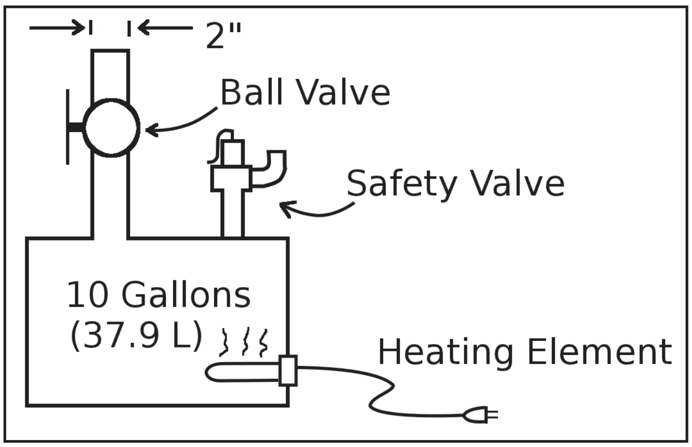

Figure 1. Experiment apparatus.

The water was heated until it had reached the desired temperature, at which time a 2-inch (5.1 cm) diameter ball valve on top of the tank was opened to vent the water inside the tank directly into the air. The height of the water column and the violence of the eruption were noted. The experiments were performed at an altitude of 835 feet (255 meters) above sea level. All data other than temperature were qualitative.

The violence of the steam phase correlated with the initial temperature of the water, as shown in Table 3. Two parameters, the loudness of the eruption and the size of the water droplets, correlated with the initial temperature of the water.

At T_i = 223 °F (106 °C), water was thrown from the vent with a quiet gushing sound. The droplets were pea-sized, and they followed parabolic arcs. At T_i = 232 °F (111 °C), the eruption was similar, except that the gushing sound was more pronounced and the droplet size was smaller. At T_i = 241 °F (116 °C), the eruption became more violent. Water was thrown from the vent with a roaring sound. Some of the erupted water droplets became atomized and drifted away as fine spray. At T_i = 251 °F (122 °C), the violence increased. Water was atomized upon ascent and descended as a drifting, fine spray. At a distance, the sound of the eruption resembled thunder. At T_i = 263 °F (128 °C), the appearance was similar, but with a higher degree of atomization. At T_i = 273 °F (134 °C), the water immediately disintegrated into fine spray and rose as a nimbus. The high degree of atomization made it difficult to estimate the height—the entire column billowed upward and drifted on the wind. A column of water erupting from this initial temperature, though initially all liquid, had the appearance of converting almost entirely steam. Any observer in Yellowstone would say that the geyser is in steam phase upon observing a column like this one. At T_i = 286 °F (141 °C), the roaring sound and degree of atomization increased further. At T_i = 293 °F (145 °C), the entire eruption column was atomized. The erupted fluid was thrown from the vent with a loud roaring sound, accompanied by pounding vibrations.

DISCUSSION

The correlation demonstrated above shows that roaring sounds occur when the erupted fluid has an initial temperature of at least 242 °F. To get water this hot, it must be under the hydrostatic pressure exerted at the base of a column of water that is, at minimum, 26 feet (7.9 meters) deep. If the water column is atomized upon descent, the initial water temperature is at least 252 °F, which correlates with

An eruption of water with T_i = 223° F (107° C), showing a well-defined eruption column formed from relatively large water droplets.

An eruption of water with T_i = 271° F (133° C), showing complete atomization of the eruption column.

An eruption of water with T_i = 271° F (133° C), showing complete atomization of the eruption column.

T_i (°F)	Depth at sea level (ft)	T_i (°F)	Depth in Yellowstone (ft)
222	7	209	6
232	16	219	13
242	26	229	21
252	37	239	30
262	50	249	41
272	66	259	54
282	83	269	69
293	105	281	87

Table 4: Correlation of the depth at which water must lie in a geyser in Yellowstone as compared to the depth at which water must lie in a geyser at sea level for the same mass fraction of steam to be produced. The depth in Yellowstone is calculated as in Table 2, but using the enthalpy of water at 199 °F (93 °C) as the end point, the heat of vaporization for water at 199 °F, and the specific volumes of water and steam at 199 °F. Data are taken from the Keenan and Keyes steam table (1951).

a minimum depth of 37 feet (11 meters). If the water column has no distinct top but dissolves into billows, the initial water temperature is at least 272 °F, which correlates with a minimum depth of 66 feet (20 meters). If the eruption is deafening, producing vibrations that are both heard and felt, the initial water temperature is at least 293 °F, which correlates with a minimum depth of 105 feet (32 meters).

A correction must be made when comparing geyser eruptions that occur in Yellowstone to those that occur at lower elevations. The boiling point of water in the geyser basins of Yellowstone, where the elevation is between 7,200 and 7,600 feet (2,195 and 2,316 meters), is around 199 °F. Because the boiling point is lower in Yellowstone than it is at sea level, the initial temperature that is necessary to give the same enthalpy change upon cooling to the boiling point is also lower. Because the relationship between

An eruption of Aurum Geyser, on Geyser Hill, showing a well-defined eruption column formed from relatively large water droplets. Photo by Tara Cross.

enthalpy and pressure is non-linear, the minimum depths are also different. In a geyser at sea level, it is calculated that water erupting from an initial temperature of 293 °F, for which the minimum depth is 105 feet (32 meters), will generate the same enthalpy change as water erupted from an initial temperature of 281 °F, for which the minimum depth is 87 feet (27 meters), in a geyser in Yellowstone. Table 4 correlates the depth of a geyser at sea level with the depth that is necessary in Yellowstone to produce the same enthalpy change in the liquid.

How closely could the experimental results described above correlate with real conditions? The experimental apparatus and its operation are different from natural geysers. The path taken by the water in the experimental apparatus is much shorter than the path taken by water in a natural geyser. The walls of the vent pipe in the experimental apparatus are far smoother than the walls of any natural geyser conduit. The vent pipe in the experimental apparatus is of uniform diameter, but the walls of a natural geyser may create nozzles (Kieffer 1989) or constrictions that cause the natural geyser to operate differently from the experimental apparatus. Most natural geyser vents are much larger at the surface than the 2-inch diameter pipe in the experimental apparatus. It should be noted, however, that similar experiments using pipes with diameters of 0.5 to 4 inches gave similar results to those using a 2-inch diameter pipe. I have also assumed that the mass fraction of steam

An eruption of Beehive Geyser, on Geyser Hill, showing an atomized eruption column. Beehive Geyser was plumbed to -17 feet (-5.2 meters) by Bloss and Barth (1949), who found a maximum temperature of 104º C at this depth. The eruption, however, is characteristic of water having an initial temperature of at least 251º F (122º C), which implies a minimum depth of around 30 feet (9.1 meters) in Yellowstone. Photo by Tara Cross.

is the sole contributor to the apparent violence and sound of the eruption. It is worth mentioning that the size and number of dispersed droplets within an eruption column could also affect the sound of the eruption (Kieffer 1977). Because of these and other differences, the conclusions of these experiments must not be over-interpreted.

Although the experimental apparatus differs from the real geyser systems that exist in nature, it is interesting to note that the experimental onset of a deafening eruption with pounding vibrations occurs at 293 ºF (145 ºC), which correlates with a geyser that is at least 105 feet (32 meters) deep. If an eruption in Yellowstone were to have the same visible and audible characteristics, the water would have an initial temperature of 281 ºF (138 ºF), which requires a geyser pipe that is at least 87 feet (27 meters) deep. The deafening noise and pounding vibrations of Steamboat Geyser's eruption are possible if the water at the bottom of the tube is 281 ºF, which is the boiling temperature for water 87 feet (27 meters) beneath the surface. Notably, Steamboat Geyser has been plumbed to a depth of 85 feet (26 meters).

Weir (1992) calculated that the reservoir of Pohutu Geyser at Whakarewarewa, New Zealand, lies at a depth of 30 feet (9.1 meters) below the surface, and that it contains water at 244 ºF (118 ºC). Notably, the eruptions of Pohutu produce roaring sounds, with a distinct water column visible on ascent, and water atomized on descent. These conditions are similar to those observed experimentally for water at an initial temperature of 241 ºF (116 ºC).

The method has limitations. Consider the simultaneous eruptions of Giant and Mastiff Geysers with the major eruptions of nearby Bijou and Catfish Geysers. These four geysers are connected intimately underground. Yet, Catfish and Bijou Geysers have roaring eruptions that atomize the water column, while water that erupts from Giant and Mastiff is not atomized at all. Perhaps water that erupts from Giant is diluted by a significant quantity of cooler water from nearer the surface, while Catfish and Bijou erupt water that rises directly from great depth, without dilution.

CONCLUSIONS

To the degree that the model geyser apparatus described above represents the eruption of a natural geyser, the appearance of a geyser eruption column and the sound of the eruption may be used to estimate the initial temperature of the water and the minimum depth at which the water rested prior to its eruptive discharge at the surface. Water with an initial temperature of 293 °F (145 °C) erupts with a deafening sound and pounding vibrations. In Yellowstone, where the altitude is higher, eruptive discharge of water with an initial temperature of 281 °F (138 °C) would result in the same enthalpy change of the liquid phase. This water could lie at a minimum depth of 87 feet (27 meters) beneath the surface. Since this is very nearly the same depth as the known depth of Steamboat Geyser, and Steamboat produces the most violent eruptions known in Yellowstone National Park, the other geyser tubes found there need be no deeper than this.

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North Goggles Geyser Activity from September 2010 through June 2012

Photos by Karl Hoppe, Article by Tara Cross

North Goggles Geyser in major eruption on September 8, 2010. North Goggles had no observed eruptions between September 2004 and January 2010. Eruptions remained rare until an unprecedented change in activity occurred on February 12, 2012. Webcam observations confirmed 22 minor eruptions in daylight that day, and an additional 23 minor eruptions on February 13, implying that the series had continued overnight. The North Goggles activity started during a Lion series and ended long after Lion had finished. Lion responded with an apparent inactive period of about 7½ days. After the initial North Goggles series, it continued to be active, having series of minor eruptions every few days during Lion series and occasional major eruptions near the end of Lion series. This behavior continued through at least June 2012.

About the Authors

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 thse topics to *The GOSA Transactions* and currently serves as co-editor of that publication. He has also written articles for *The Geyser Gazer Sput*. After four years of teaching chemistry, including two at Whitman College in Walla Walla, Washington, he is pursuing a PhD in chemistry at the University of Utah.

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 *The 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 and Iceland.

Brian L. Davis (PhD, Physics, University of Michigan) is a stay-at-home father of three and has been employed teaching introductory physics & astronomy at Indiana University at South Bend for the last decade. He became reinvigorated with the geysers of Yellowstone after a family trip there in 2006, and began trying to model them on the inspiration of his daughter. His current focus is on scaling issues with model geyser conduits.

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 were 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 to the *GOSA Transactions*, Volumes VII, IX, X and XI.

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Sam Martinez was a volunteer for Yellowstone park geologist Rick Hutchinson in the 1970s. He conducted various research projects for the National Park Service, including making detailed observations of Yellowstone's geysers. His areas of study included Shoshone Geyser Basin, Norris Geyser Basin, and the thermal features along the Firehole River.

Rocco Paperiello has been studying geysers for over 30 years. His research includes detailed field observations and extensive study of historical records. He served as a thermal volunteer for the National Park Service and has written numerous reports and articles on the history and current activity of geysers in Yellowstone and other areas, many in partnership with Marie Wolf.

Richard L. Powell obtained A.B., 1959, and M.A., 1961, degrees in Geography with minors in Geology and Archaeology from Indiana University, and Ph. D., 1976, in Geosciences from Purdue University.

Dick worked 15 years full time as a geologist in the Coal Section of the Indiana Geological Survey, with one year as Acting Section Head. He worked about five years as an independent consulting geologist, including part of a year on site investigations for a nuclear power plant in Iran. He is Licensed Professional Geologist No. 3 in the State of Indiana. He was one of four founding partners of a geological and ecological consulting firm in Bloomington, Indiana, Geosciences Research Assoc., in 1979. Dick's work consisted mostly of environmental monitoring related to coal mine reclamation and part time for18 years as the karst expert and onsite geologist for U.S.E.P.A. at eight PCB contaminated sites in and near Bloomington. He compiled three reports for the National Park Service related to the National Natural Landmark Program and assisted on another. He is currently a Research Affiliate with the Indiana Geological Survey. He was an avid spelunker for more about 25 years and occasional caver until 2002. A fly fisherman and fly tier who came west in 1990, but became a geyser gazer in about 1993 with seven years as a "thermal cleaner" with Ralph Taylor. Current summer resident geyser gazer geezer.

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. Lynn has contributed several articles in previous volumes of the *GOSA Transactions*, regularly writes articles for *The Geyser Gazer Sput,* and currently serves as GOSA treasurer.

Ralph Taylor graduated with a Bachelor of Science degree in Electrical Engineering from the University of Cincinnati in 1964. A lifelong resident of the Cincinnati, Ohio area, he retired in 1997 after a career in the machine tool industry designing computers and real-time software systems for machine control. His first visit to Yellowstone was a short visit in 1966 with a friend from college and work. Four days in Yellowstone initiated a lifelong interest in geysers and how they work along with a deep appreciation for the aesthetic beauty of the hydrothermal features. Ralph served as a Director of GOSA for many years, and was GOSA's second President, serving from 1994 to 2008. Ralph was a Volunteer for the National Park Service since 1987, and after his retirement in 1997 spent fifteen summers in Yellowstone as a volunteer for both Resource Management (cleaning the thermal areas in the Firehole geyser basins) and for the Park Geologist, primarily maintaining a number of electronic data loggers on various geysers and providing analysis of the data. As an outgrowth of his work in monitoring and analysis of geyser activity, he has been a co-author of papers relating geyser activity to earthquake activity and hydrological data. He has authored several previous GOSA Transactions papers. Ralph is no longer active in GOSA and is no longer working as a volunteer in Yellowstone.

Vicki Whitledge holds a Bachelor of Science degree in marine biology from Long Island University-Southampton, New York, and master's and doctoral degrees in applied mathematics from the University of New York-Stony Brook. She is a professor of mathematics at the University of Wisconsin-Eau Claire. Prior to accepting the position at the University of Wisconsin, she worked for an environmental consulting firm modeling pesticide transport in the environment. She has worked on a variety of mathematical models dealing with biological and environmental systems and is interested in the application of mathematics to analysis of complicated physical systems such as geysers.

Marie Wolf began studying geysers in the 1970s. As a thermal volunteer for the National Park Service, she conducted research projects on many of Yellowstone's geysers and authored numerous reports, many in partnership with Rocco Paperiello. Her areas of greatest interest were the Daisy Geyser Complex and backcountry features.

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