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Mastiff Geyser (left) and **Giant Geyser** (right) erupting on May 31, 2007. Photo by Pat Snyder.

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Giant Geyser, June 6, 2006, by Sue Schroeder
Baby Daisy Geyser by Mike Newcomb
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Mortar Geyser
Photo by T. Scott Bryan

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, most articles have been written in past tense.

Crack Geyser erupting on July 27, 2006. Photos by Stacey Glasser.

Crack Geyser (White Dome Group, Lower Geyser Basin) experienced a brief reactivation in July 2006, its first known activity since 1988. Nearby Pebble Geyser was observed in overflow on July 7, indicating that it was probably reactivated well before it was first reported on July 18. In the minutes prior to Crack Geyser's eruptions, Pebble's water level dropped and Crack had small splashes. One closed interval of 6h19m was recorded, but other intervals may have been considerably longer. The photographs (above) show the last known eruption of Crack, on July 27, 2007.

[Paraphrased from Lynn Stephens, "July 2006 Activity of Crack Geyser," The Geyser Gazer Sput, v. 20, n. 4, August 2006, p. 27-30.]

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Recent Changes in Geyser Activity at Loburu, Lake Bogoria, Kenya Rift Valley

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Abstract

Major changes in hydrothermal activity have accompanied frequent fluctuations in the level of Lake Bogoria, Kenya, during the past decade. Even minor changes in the levels of the lake surface and the shallow lake-marginal groundwater can have an impact on geyser behavior. Some geysers that were active during 2001 and 2005 had become weak hot springs or steam vents by August 2006 following a fall in lake level, whereas activity at other springs had increased. At Loburu delta on the western shore of the lake, the geyser activity increased, and one of the geysers, KL30, erupted on a regular 45-minute cycle to 5 m height. When active, KL30 is probably the highest natural geyser in Africa. In contrast, a major rise in lake level in 2007 suppressed activity at many of the geysers, including KL30.

Introduction

Lake Bogoria in the central Kenya Rift Valley has the highest reported concentration of geysers in Africa. At least 18 geysers are known to have erupted during the past 30 years (see Figures 2–4 in Renaut and Owen [2005] for geyser locations). All the geysers lie near the shoreline of this saline lake, which fluctuates frequently in level and salinity in response to short (years) and longer-term (decades and longer) climatic changes. Renaut and Owen (2005) described the main geyser activity and its known history. Between August 2005 and August 2006, the lake level fell by about 30 cm, which led to major changes in the activity at several of the shoreline geysers. Eruptions ceased at some vents, whereas discharge at other geysers increased significantly. One of the geysers active during summer 2006, KL30, erupted regularly to a height of about 5 m, making it the highest reported geyser in Africa. In contrast, heavy rains during early 2007 led to a rapid rise in lake level. During August 2007, the lake surface was an estimated 15–20 cm higher than its August 2005 level. This led to the submergence of many hot spring vents and a decline in activity at KL30 and several other geysers. The main purpose of this paper is to record the changes in activity at KL30 and other geysers during the past three years. The close link between geyser behavior and lake level fluctuations at Lake Bogoria (Renaut and Owen, 2005) is confirmed.

Environmental setting

Lake Bogoria, with a salinity approximately twice that of seawater, lies just north of the equator in a narrow half-graben basin in the central Kenya Rift Valley (Fig. 1A). The lake catchment is composed mainly of densely faulted volcanic rocks of Miocene to Pleistocene age. Geothermal activity is abundant. Almost 200 hot springs discharge $Na\text{-}HCO_3\text{-}CO_3$ waters into the lake from three main spring groups located along the shoreline at Loburu, Chemurkeu, and Ng'wasis-Koibobei-Losaramat, respectively (Fig. 1B). The climate is semi-arid with about 700–900 mm annual rainfall, which is much less than the potential evaporation of more than 2,500 mm per year. With no surface outlet, the lake is hydrologically closed, and its surface level undergoes frequent and rapid changes mainly in response to variations in rainfall. Present lake level is approximately 990 m above sea-level and the local boiling point is approximately 97.5°C. Details of the general setting are given in Renaut and Tiercelin (1993, 1994), Harper et al. (2003), and Renaut and Owen (2005).

The new activity described here is present at Loburu, a small delta on the midwestern lake shore. About 60 hot springs discharge at Loburu from vents clustered along two north-south trending fault-lines (Fig. 1C). The number of onshore springs varies with

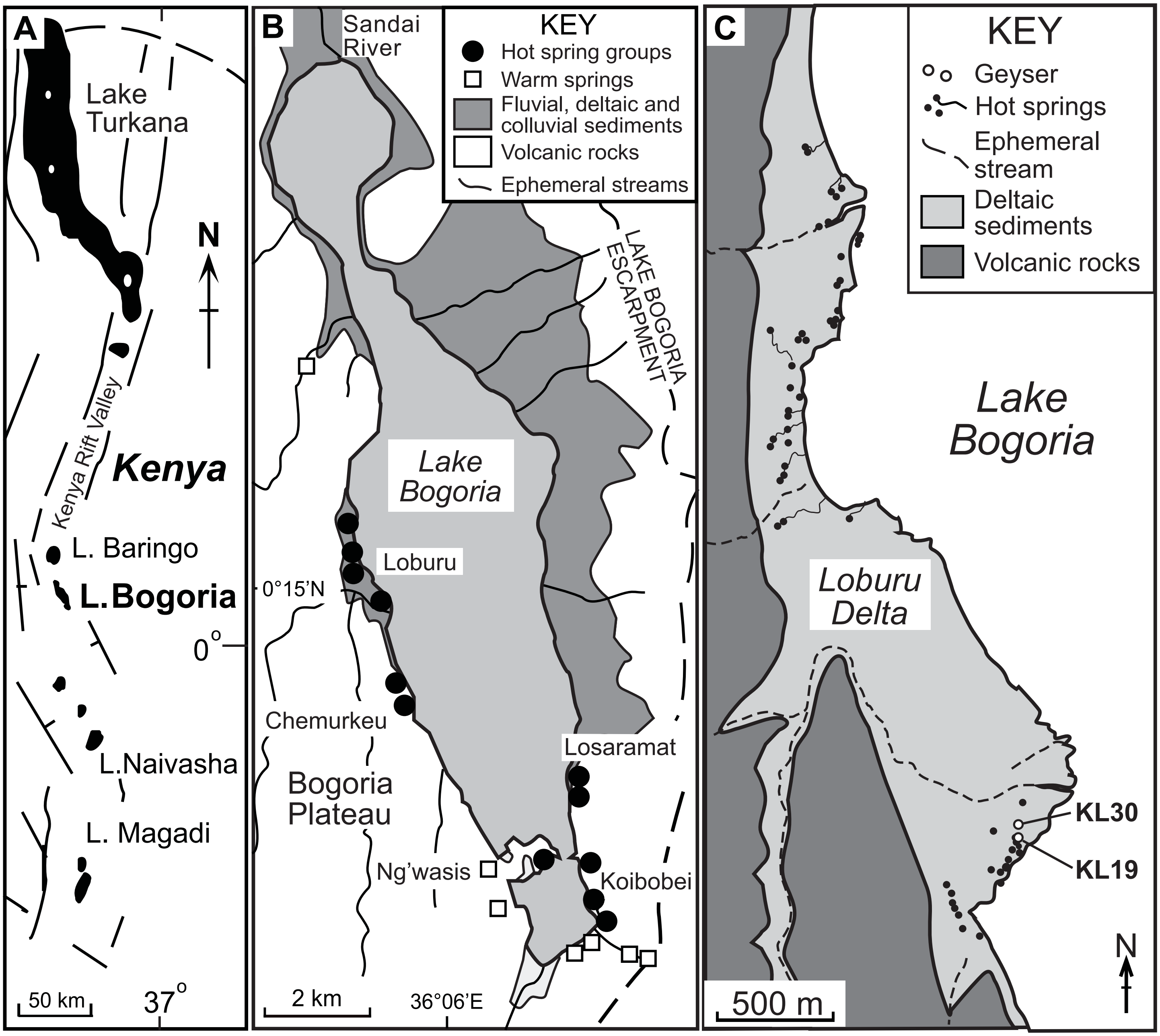


Figure 1. Location of the Loburu geysers. A: Kenya Rift Valley showing the location of Lake Bogoria. B: Location of Loburu and other hot-spring groups at Lake Bogoria. C: Distribution of the main hot springs at Loburu delta and location of the geysers.

the prevailing lake level; many vents are submerged when lake level is high. The northern group consists of about 32 springs, including three perpetual spouters, but there is no current (2005-7) geyser activity. About 11 of these springs have travertine deposits at their vents, much of which is fossil, but siliceous sinter deposits are absent except for thin, ephemeral opaline-silica crusts (Renaut et al., 1998). The southern group in August 2007 consisted of about 20 onshore hot springs with a few small offshore vents. Near the northern end of this group, a cluster of vents includes six geysers that were active at different times between August 2005 and August 2007.

The Southern Loburu Geysers

The southern Loburu delta-plain is a gently sloping surface composed mainly of bedded silts and sands, broken in places by small ephemeral stream channels and low wave-cut scarps. Most of the delta-plain surface consists of thin, pebbly, alkaline soils that are covered by patches of salt-tolerant grasses. Soft

Figure 2, right. Sketch map to show the relative positions of the southern Loburu geysers (August 2006). The location of KL19 and KL30 is shown on Figure 1.

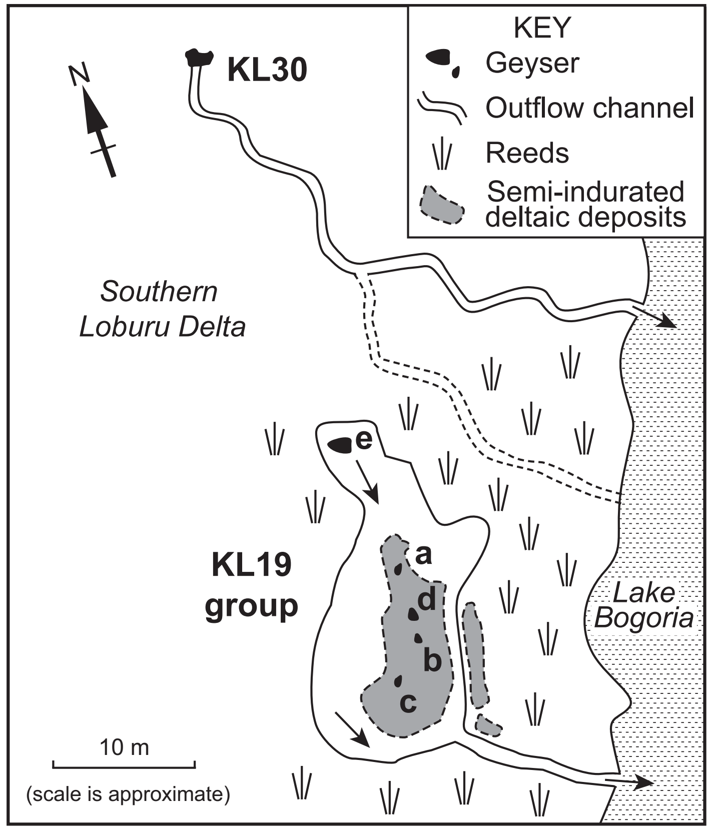
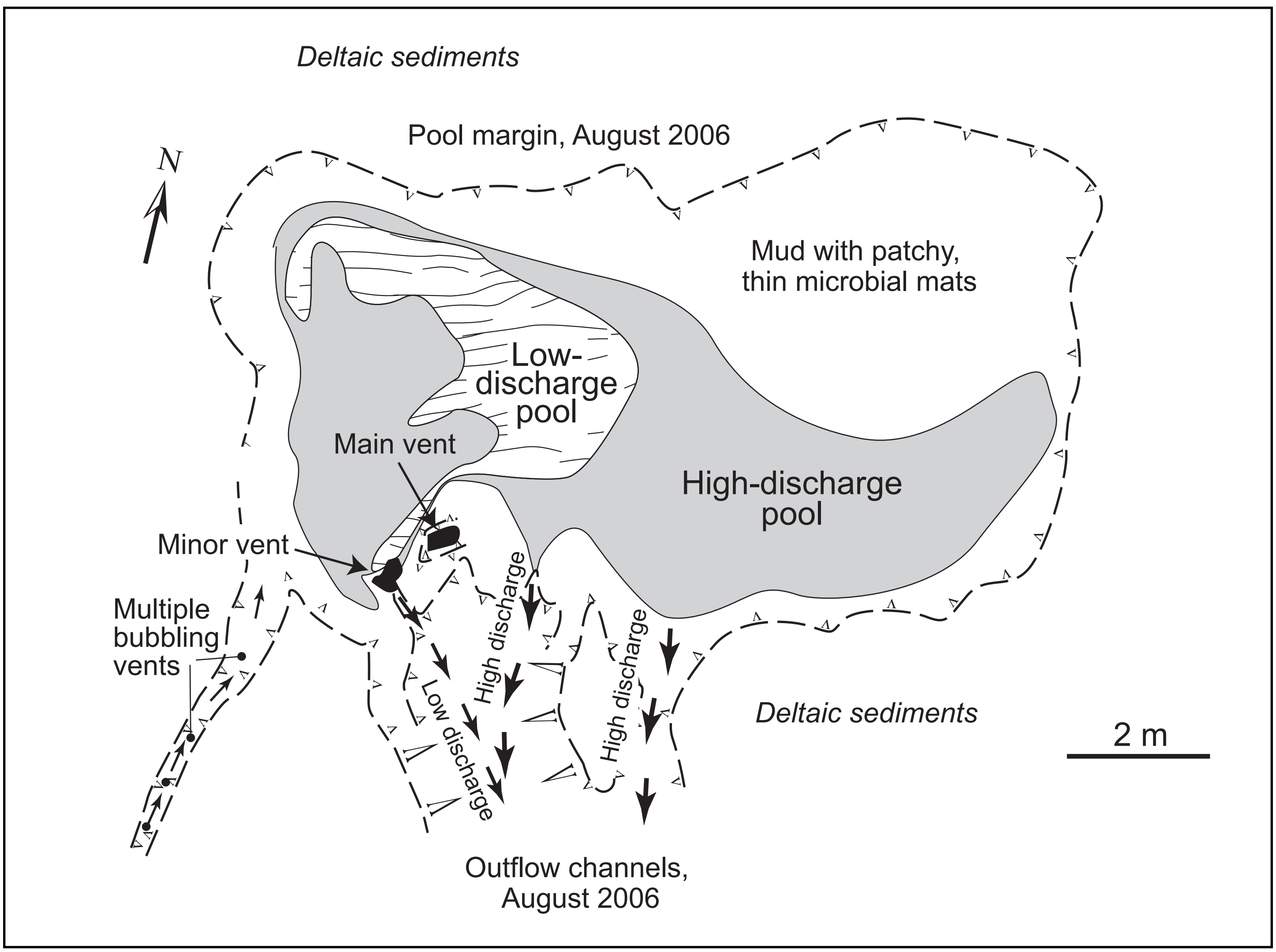


Figure 3, below. Plan of the vent area of geyser KL30 (August 2006). The high discharge pool shows the maximum extent of water during an eruption. The low discharge pool represents the area covered by water between eruptions. During eruptions water flows out of the pool through the high discharge channels, but flows only through the low discharge channel between eruptions.



swampy ground lies around some of the hot springs and in ephemeral stream channel floors. Most of the hot springs discharge quietly from shallow pools, 1–8 m in diameter, at measured temperatures of 39–98.5°C. A few springs are more than 2 m deep with steep plunging sides; others have cone-shaped vents with narrow, shallow platform margins, or nearly flat bases. All the active springs lie in reddish brown to pale brown deltaic silts, sands and muds.

Six geysers were observed during visits to the lake in August of 2005, 2006 and 2007. Five of these geysers lie in the KL19 group (*a-e*), together with geyser KL30. The vents of the KL19 group are only a few meters apart; KL30 lies approximately 30 m north of the KL19 group (Fig. 2).

Geyser KL30

Geyser KL30 lies in a small, shallow muddy depression in the delta-plain (Fig. 3). Over the three years of observations, the morphology and size of the vent pool increased significantly. In August 2005, the vent was located centrally in a shallow (20 cm) broadly circular pool approximately 3 m in diameter, with a single outflow channel toward the southeast.

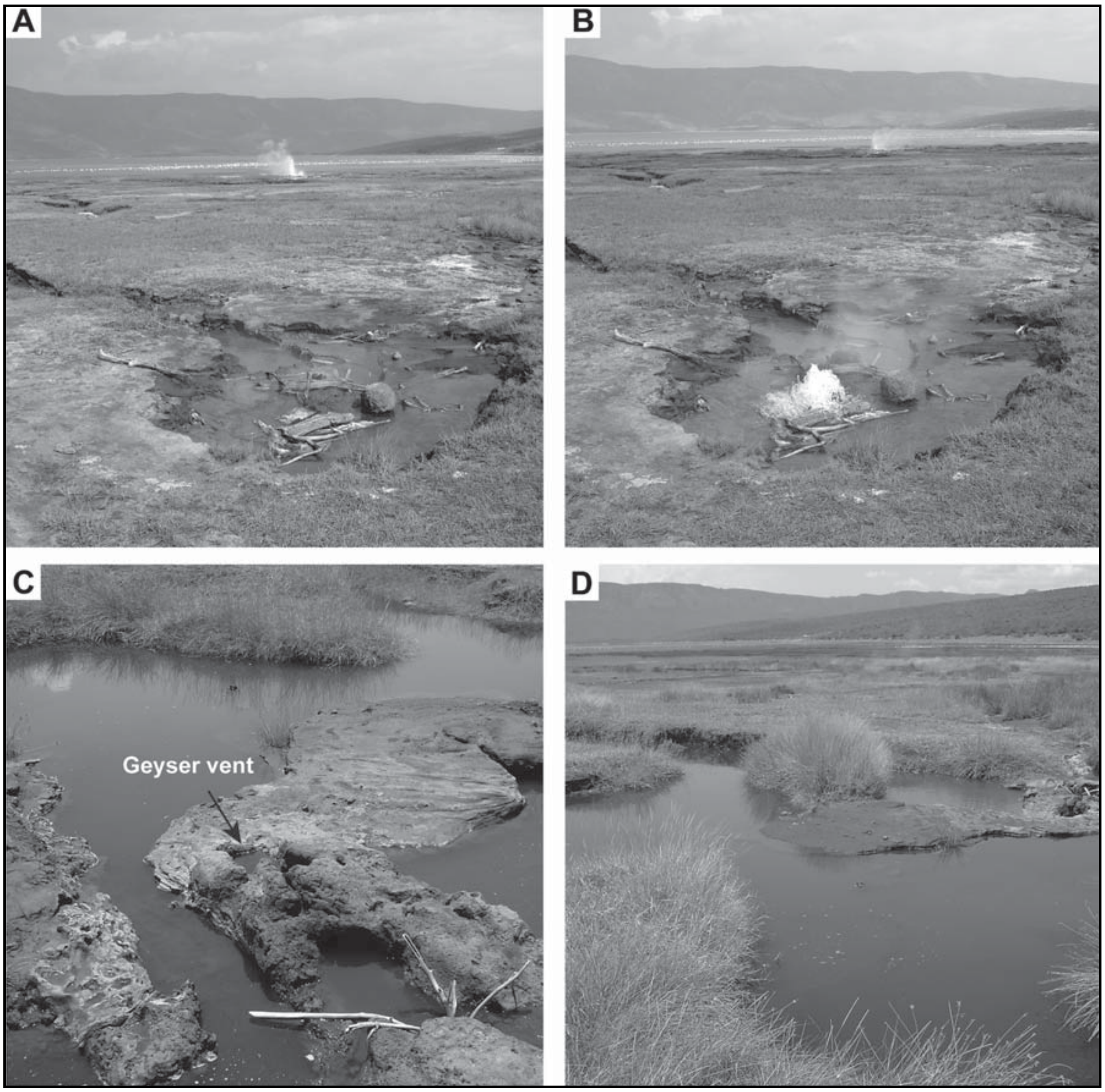


Figure 4. Geyser KL30 during 2005 and 2007. A: Vent pool of geyser KL30 during quiet stage between eruptions, looking south, August 2005. B: Geyser KL30 during a small eruption, looking south, August 2005. Local people commonly put wood and small boulders over the vent to try to stimulate eruptions. Both are visible in the pool. Geyser KL19*d* is active in the background. C: Vent pool, during August 2007, looking northeast. The vent is present in a small ridge of weakly lithified silts. D: Vent pool, during August 2007, looking south. The pool is flooded and has become a hot spring.

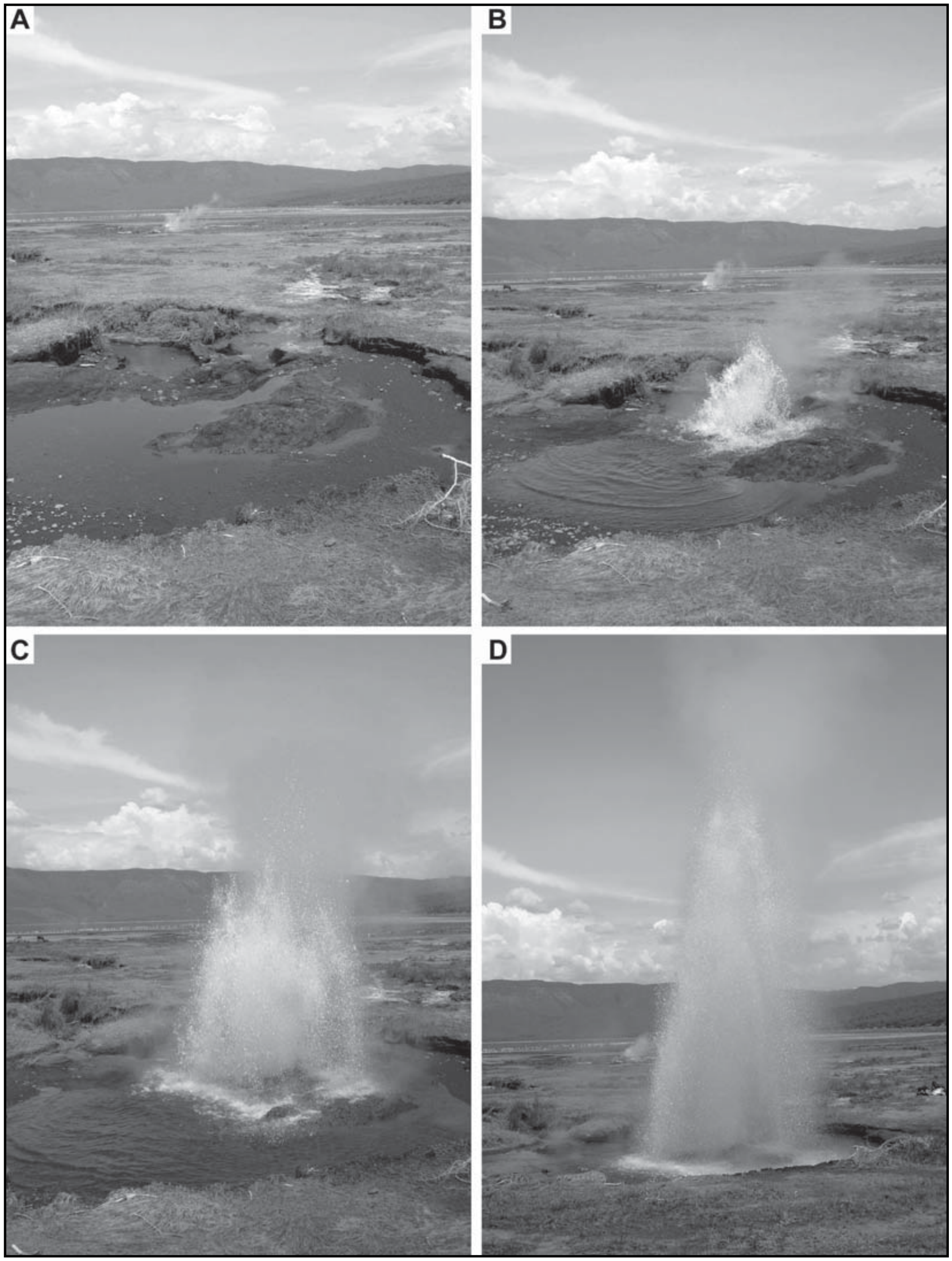


Figure 5. Stages during an eruption of geyser KL30 in August 2006. View southward with steam plume of geyser KL19*d* visible in the background. A: Quiet phase between eruptions. B: Beginning of eruption. C: 20 seconds after beginning of eruption. D: Full eruption, 34 seconds after beginning of eruption.

Eruptions occurred to a height of only 50 cm for 20–30 seconds (Fig. 4A, B). The periodicity in 2005 was not recorded, but the eruptions were infrequent with no more than one per hour.

In August 2006, the geyser was at its peak of activity. The vent pool had become kidney shaped, and had increased in area by at least 300% (Fig. 5A). The pool floor was also about 20–30 cm deeper than in August 2005. Three small outflow channels were present with flow toward the southeast during eruptions. The vent consisted of a small (25 cm wide) funnel-shaped hole in a narrow subaerial ridge of moderately consolidated, brown bedded silts and sands at the south edge of the depression (Fig. 4C).

The pattern of activity at geyser KL30 was recorded in August 2006. Before each eruption cycle began, the pool around the vent did not contain much water. A shallow (< 3 cm) pool of standing water lay directly north of the vent (Figs. 3 and 5A). A few small (< 4 cm diameter) steam vents and fumaroles discharged continuously from the pool floor and in the adjacent outflow channels. Following eruptions, the vent itself was initially water free, but water soon rose to about 15 cm below the rim. Over a period of

Table 1. Chemical analyses of hot springs at Loburu, Lake Bogoria, Kenya.

Sample	Date	Temp (°C)	pH (field)	Na mg/l	K mg/l	Ca mg/l	Mg mg/l	HCO_3 mg/l	CO_3 mg/l	Cl mg/l	SO_4 mg/l	F mg/l	SiO_2 mg/l
KL30 geyser	Aug-06	> 97	8.28	1440	42	< 0.1	0.34	2850	268	306	63	60	115
KL21 spring	Feb-94	96.5	8.80	1395	19.0	0.78	0.22	3020		240	65	57.4	111
KL8 spring	Jul-95	98.0	8.55	1350	14.5	1.02	0.43	3055		220	61.5	63.0	108
Lake Bogoria	Jul-05	27.6	10.15	26500	478	3.7	1.05	19600	21800	5720	160	585	227

Geyser KL30 was sampled immediately after eruption. KL21 is a hot spring in the southern Loburu group; KL8 is a hot spring (perpetual spouter) in the northern Loburu group.

about 25 minutes after the previous eruption, water in the vent was calm except for a few steam bubbles breaking the surface. Water temperatures during the calm phase were measured at 82–93°C. About 7–8 minutes before an eruption the activity in the vent gradually increased, with more ebullience and occasional splashing of water over the vent rim. About 1–2 minutes before an eruption, water periodically spurted out of the vent up to 20 cm high, followed suddenly by a full eruption (Fig. 5B and C). During eruption, the water and vapor column discharged up to a maximum height of about 5 m (Fig. 5D). Full eruptions were 2 to 2.5 minutes in duration, followed by about 30 seconds of waning flow and a very brief (10–15 seconds) steam phase during which some water retreated into the vent. At this point the next cycle began.

During eruptions, the pool filled to a depth of about 25 cm and overflowed southward through an incised channel network into the lake (Fig. 3). The pool drained rapidly and returned to its pre-eruption level about 3 minutes after each eruption. Three successive cycles were recorded. The time between the successive starts of the eruptions was 45 ± 2 minutes. Local residents confirmed that the eruptions during 2006 were generally predictable.

In contrast, Geyser KL30 was no longer playing a year later following the rise in lake level. By August 2007, the pool had enlarged in area again (Fig. 4C, D) and was permanently occupied by a hot spring with water up to 30 cm deep. Although hot water (93°C) discharged continuously from at least three springs on the pool base near the geyser vent, no geyser activity was seen during two days of observation.

Geyser KL19 group

The KL19 group consists of three small vents (*a, b, c*) and two large vents (*d, e*), all of which have been geysers at different times in the past 20 years (Figs. 2 and 6). Before 2007, only KL19*e* had a well-defined vent pool. The other geysers discharged from a slightly elevated platform of moderately indurated, bedded, gravelly silts and sands with a knobby surface. Drainage from the vents flows mainly southwards, then eastwards towards the lake.

Vent KL19*d* has been the most active geyser of the group, and at different times has been a vigorous spring, a perpetual spouter, and a geyser. Before 1994, the small spring vent discharged ebullient boiling water onto the adjacent apron. Activity in 1994 and 1995 included phases of true geyser activity with eruptions up to 3.5 m every 5 to 8 minutes (Fig. 6A) and periods when it behaved as a perpetual spouter up to 2.5 m high. By summer 1996, it had reverted to being a boiling spring with high steam flux. During 1997-8, all the vents of southern Loburu were fully submerged by rising lake level following heavy rains that were induced by an El Niño event. In July 2001, when the lake level was still relatively high, it was again a perpetual spouter playing to about 1.5 m high.

In summer 2005, KL19*d* behaved as a geyser but was never fully inactive between eruptions (Fig. 6B). During intervals between eruptions, which occurred about every 5 minutes, it became a small spouter discharging water up to 30–50 cm high. During the main eruptions a jet of water rose up to 3 m in the air in a series of short spurts. Some eruptions lasted more than 2 minutes (Fig. 6B). By August 2006, the geyser had reverted to being a small perpetual spouter

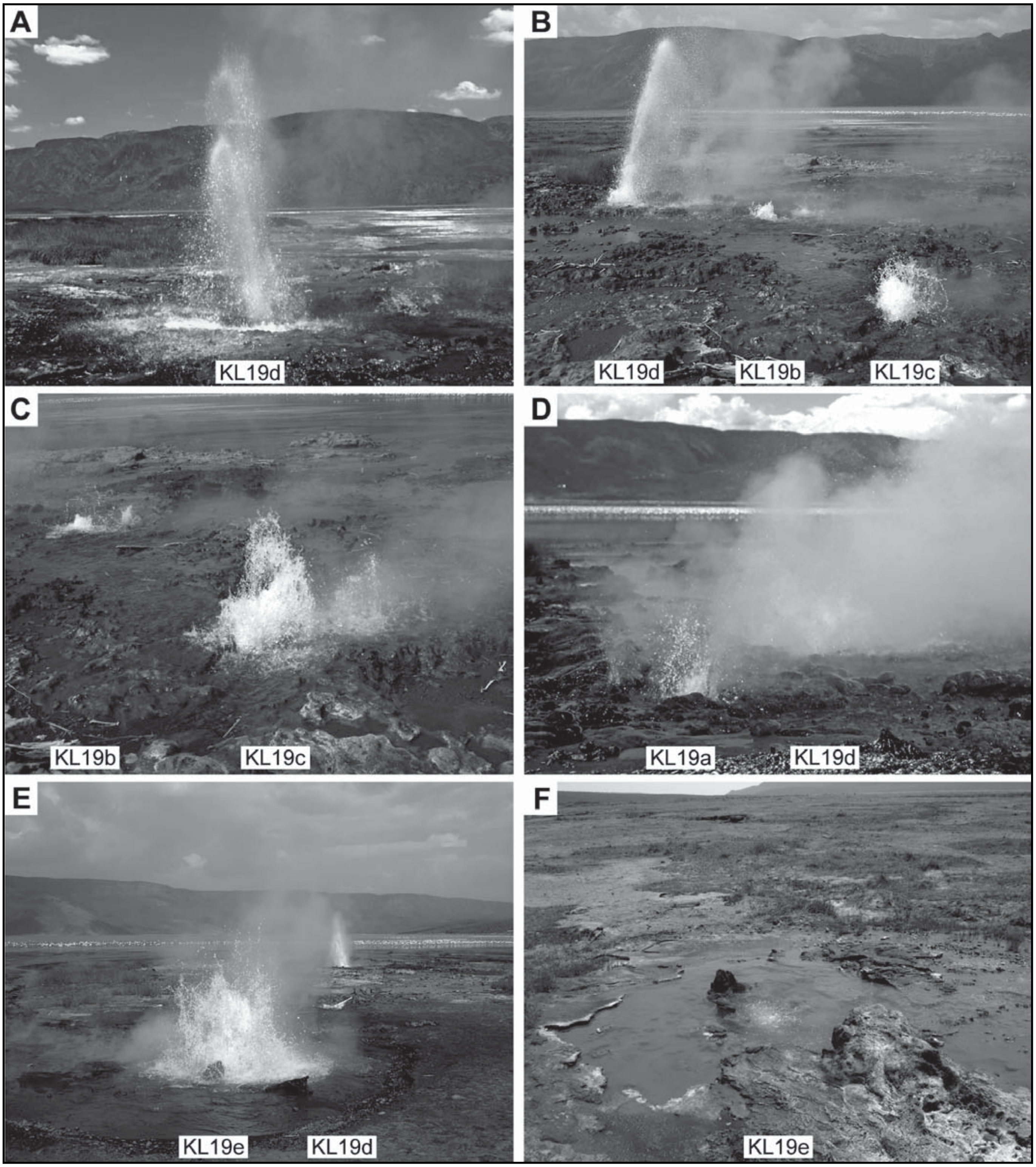


Figure 6. Geysers of the KL19 group. A: Geyser KL19*d* during eruption, July 1995. B: Geyser KL19*d* (left) during eruption, August 2005. Note different direction of discharge from 1995. Geyser KL19*b* is visible near the center at the beginning of a small eruption. Geyser KL19*c* is also erupting at bottom right. C: Geysers KL19*b* (left) and KL19*c* (center) during August 2005. KL19*c* played to more than 1 m the following year. D: Geyser KL19*a* (left) erupted to about 70 cm in 1994, but was inactive in 2005-6. KL19*d* (visible near center through steam) was a small vigorous spouting spring when this photograph was taken in July 1994. E: Geysers KL19*e* (foreground) and KL19*d* (in distance) during eruption, August 2005. F: Geyser KL19*e* during August 2006, when it appeared to be dormant.

playing from 50 cm to 1 m high, but with short bursts of spray that reached about 1.5 m.

During 2005 and 2006, two small geysers were present on the same platform. Geyser KL19*b* lay about 1.5 m south of KL19*d*, and KL19c was located 4 m southwest of KL19*d* (Figs. 6B and C). Both geysers discharged from small featureless depressions in the mud substrate. These two small vents also exhibited variable behavior. In August 2005, both were true geysers. KL19*b* erupted up to 70 cm every 5 minutes for 30-40 seconds, often in synchroneity with initial stages of the KL19*d* eruptions. KL19*c* played up to 40 cm high every 5 to 10 minutes for about 30 seconds. In August 2006, KL19*b* was a small perpetual spouter, whereas KL19*c* had higher discharge than in 2005. The width of its vent appeared to have increased from about 30 cm to 80 cm, and it played more or less in concert with KL19*d* to heights of up to 1 m. Vent KL19*a* (Fig. 6D), which was active in the 1990s, was no longer discharging in 2005 and 2006, but had formerly played up to heights of about 70 cm over intervals of about 40 to 60 seconds.

KL19*e*, the northernmost geyser of the group, plays from a shallow, 3 m-diameter pool, about 10 m north of KL19*d*. In August 2005, eruptions of about 25 seconds duration occurred from a vent in muds

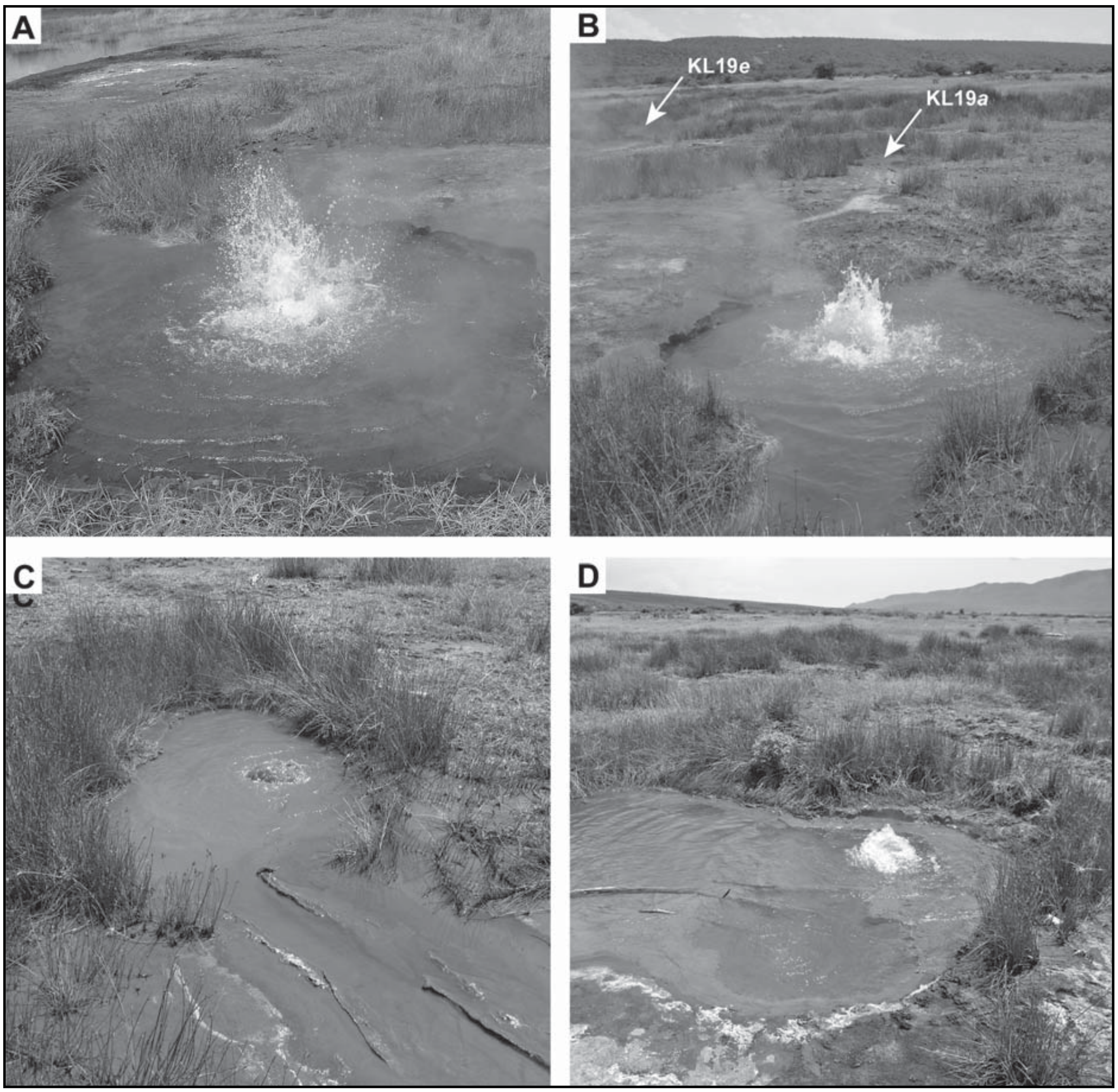


Figure 7. KL19 group during August 2007 following the rise in lake level. A: Geyser KL19*d* during eruption, looking south. B: Geyser KL19*d* during eruption, looking northwest. The locations of KL19*a* and KL19*e* are indicated. C: Small muddy spring 4 m north of KL19*d* that may be KL19*a*. The spring surges every four minutes sending a pulse of turbid water down the outflow channel into the vent of KL19*d*. D: Small eruption at geyser KL19*e*.

near the center of the pool (Fig. 6E). Most eruptions began and ended rapidly with little warning. The interval between eruptions was approximately 6–7 minutes. The maximum height of eruption was about 2 m followed by rapid draining. In August 2006, the vent was a boiling (97.5°C) hot spring, but no geyser activity was observed (Fig. 6F).

The rise in lake level during 2007 led to major changes in the activity of this geyser group, which in August was located only 4 m from the lake shore. KL19*d* and KL19*e* remained small geysers, but activity at the other vents appeared to have ceased, at least temporarily. The vent of KL19*d* had become a small pool, 3 m in diameter and up to 40 cm deep. Several eruptions were observed and recorded. After each eruption, the water surface remained calm, with a bubble shower beginning 2 minutes 35 seconds after the previous eruption ceased. Thirty seconds later, a small geyser eruption began and continued for 85–90 seconds with water reaching about 60–70 cm above the pool water surface (Fig. 7A, B). Each cycle lasted 4 minutes 30 seconds (± 5 seconds). Maximum recorded vent water temperature was 97.6°C. A second vent showed minor eruptions from a small pool located 4.5 m northwest of KL19*d*. Most eruptions, which were weak surges, reached only about 15–20 cm above pool water level for about 30 seconds on an approximately four-minute cycle (Fig. 7C). From its location, this small vent, which has turbid waters, may be KL19*a*. Muddy sediment plumes from the pool flowed down a narrow outflow channel directly into the pool of KL19*d*.

Geyser KL19*e* was a small active geyser in August 2007, playing up to 30 cm height from a pool with two small adjacent vents. Eruptions occurred every 4 minutes, lasting about 30 to 45 seconds (Fig.7D).

Fluid chemistry

In August 2006, a water sample was taken from KL30 during the late stage of an eruption for chemical analysis. The sample, collected at the vent with a polyethylene container and placed immediately in a 500 ml bottle, was notable for its very high effervescence. The water had a similar chemical composition to other Loburu spring waters (Table 1). The fluid was alkaline (pH 8.28 at the vent) with a Na-HCO_3 composition, and contained about 5 g/l total dissolved salts.

Discussion

The new observations strongly support a link between geyser activity at Lake Bogoria and the contemporary lake level. The nature of the geothermal fluid system at Lake Bogoria has not been fully resolved, but there is general agreement that the fluids are derived mainly from rainwater falling on the neighboring margins and floor of the rift valley. Those fluids, which are then heated by hot gases (especially CO_2), magmatic intrusion, or contact with hot bedrock, rise towards the surface where at different depths they mix variably with shallow groundwater and minor lake water (Glover, 1972; Allen et al., 1989; Clarke et al., 1990; Cioni et al., 1992; Hochstein, 1999). At shallow depth, they undergo boiling. Almost all shoreline springs discharge at temperatures either at or a few degrees below the local boiling point. A fall in the level of the lake surface and local groundwater would likely decrease the hydrostatic pressure acting upon the rising thermal fluid column, which in turn should lower the depth of boiling. In contrast, a rise in lake level would increase the pressure on the rising fluid column, leading to shallower boiling. However, if that pressure increase were accompanied by greater mixing of the rising thermal fluids with cooler near-surface waters (i.e. rise in local groundwater or flooding by relatively cool lake water), then boiling might be suppressed.

It is tempting to relate the increase in geyser activity at KL30 during 2006 to the abrupt fall in lake level. The direct cause is unclear, but it seems that even a subtle change, such as a fall in the lake marginal water table, a minor drop in hydrostatic pressure, and an increase in temperature, is enough to modify the activity. This is supported by similar changes in activity at other shoreline springs and geysers. For example, during August 2006 geysers KS2 and KS3 at Koibobei (Photos 12a and b in Renaut and Owen, 2005) had become fumaroles, and geysers KS9 and KS10 (Photos 10 and 11 in Renaut and Owen, 2005) were quiet springs with little fluid discharge. In contrast, many shoreline springs that were passive or submerged in August 2005 were ebullient in August 2006, following the drop in lake level. Nonetheless, the locations of the main vents appear to be relatively stable, even though the thermal activity can change every few years. This implies that the plumbing systems at Lake Bogoria are probably mature.

As noted by Renaut and Owen (2005), the occurrence of geyser activity in the absence of siliceous sinter is very unusual, although not unique (Bryan, 2005). Most spring waters at Lake Bogoria are undersaturated with respect to amorphous silica when discharged (Renaut et al., 1998; Figure 11 in Owen et al., 2008), so silica does not precipitate upon cooling alone, and only minor amounts of silica (opal-A: $SiO_2.nH_2O$) form in sites of evaporation. Neither sinter nor travertine is present at the land surface around the southern Loburu geysers. It is possible that $CaCO_3$ (calcite or aragonite) has been precipitated in the shallow plumbing system of the southern Loburu geysers, particularly above the boiling zone where CO_2 is degassing, but direct evidence is lacking.

All the hot springs at Lake Bogoria are rich in CO_2. It is the dominant gas (excluding steam) in analyses of most Kenya Rift spring waters, including those at Loburu (Cioni et al., 1992). At Arus, 15 km southwest of Loburu, and at Esageri, which lies 35 km southwest of Lake Bogoria, fumaroles discharge CO_2 gas that is up to 99% pure (McCall, 1967; Walsh, 1969). The calculated partial pressure of carbon dioxide (P_{CO_2}) in the Loburu spring fluids is high (the log P_{CO_2} is up to -0.90) and is well in excess of that which would be in equilibrium with atmospheric CO_2. It is possible that the exsolution of CO_2 upon boiling may play a role in the geyser activity at Lake Bogoria. The subsurface fluids have boiled as in normal geysers, but the high CO_2 concentration may contribute to the high "effervescence" of the discharged fluids. Geyser activity due to CO_2 exsolution is well known in cold geysers (e.g., Baer and Rigby, 1978; Doelling, 1994; Glennon and Pfaff, 2005), and CO_2 exsolution has been reported as a contributor to eruptions at other thermal geysers (Glennon and Pfaff, 2005). Rapid degassing of CO_2 has also probably led to the formation of travertine (calcite, aragonite) around several of the boiling springs at northern Loburu and Chemurkeu (Fig. 1B) (Jones and Renaut, 1995; Renaut and Jones, 1997).

Although small by global standards (Bryan, 1995, 2005), geyser KL30, when active, is the highest known geyser in Africa. The vent of the Kwaibeipei (= Kwaipopei or Koibobei) geyser, which might have erupted to similar heights (3–5 m) on the foreshore at Ngairus in the 1960s (Plate IIIb in McCall, 1967; Figure 4 in Renaut and Owen, 2005), was inactive during August of 2005 and 2006. Although a subaqueous stream of gas bubbles discharged constantly from the submerged vent during August 2006, no eruptions were observed. The "Baringo geyser", which erupted in early April 2004 to a height of up to at least 50 m (80 m was claimed) at Chepkoyo village, 6.5 km west of Lake Baringo, was an artificial geyser produced during drilling for a water well. It was capped a few months later, and the ground around the well then subsided. Given the sensitivity of the hydrothermal activity at Lake Bogoria to climatically induced variations in lake level, the frequent changes in the behavior of KL30, KL19, and the other shoreline springs and geysers will likely continue.

Conclusions

An overall fall in lake level of approximately 30–40 cm between August 2005 and August 2006 led to important changes in hydrothermal activity at Lake Bogoria. Discharge at several geysers declined or ceased, while discharge at other vents increased. Most notable was the increased activity at the vent of KL30 at Loburu, which became a geyser with regular (45 ± 2 minutes) eruptions up to 5 m high. A rise in lake level during 2007 terminated geyser eruptions at KL30 and suppressed eruptions at several of the other Lake Bogoria geysers. Changes in the level of the lake-marginal water table and the degree of mixing of rising thermal fluids with shallow groundwaters are important controls of the geyser and spring behavior at Lake Bogoria.

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The Short Active Period of "Improbable Geyser" October-November 2005

Stephen J. Eide

Abstract

"Improbable Geyser," located on Geyser Hill, experienced a brief active phase in October and November 2005. This article summarizes its activity, describing major eruptions and physical changes to the geyser's formation.

"Improbable Geyser" is found down slope from Big and Little Anemone Geysers on Geyser Hill. There is an "S"-shaped bend in the boardwalk between Anemone and Beehive Geysers, and in the middle of the bend, Plume Geyser is on the west side, and Improbable Geyser is on the east side. Prior to the start of eruptive activity in 2005, Improbable had one vent about a foot in diameter. The eruptive ativity opened up a second vent beside the first. The old vent is on the east side of the pool, and the newer vent is on the west side.

Prior to fall 2005, Improbable was a very different spring that had no history of erupting or even overflowing. It normally could be heard bubbling in the vent, and at times small droplets of water could be seen rising above the vent, but that was the sum total of its activity. It had acquired the name of "Pathetic Little Hole" along the way. I do not know who first used this name, but David Goldberg told me he thought it was named by some of the tour guides who were tired of being asked "what that little spring did." The answer was that that pathetic little hole never did anything[1].

When it started erupting, there was some question as to what should this geyser should be named. At first it continued to be called "Pathetic Little Hole," but not everyone agreed with that name, and it did not fit well with the name-form rules of the Park Service/USGS. David Goldberg proposed the name "Improbable Geyser," and it was adopted by geyser observers. I consulted with park historian Lee Whittlesey, and he said that because Improbable better fits the park name-form rules for geysers, and because it is in general use, this thermal feature should be called Improbable Geyser.

During the summer of 2005, the water level in Improbable Geyser was somewhat higher than

Figure 1. "Improbable Geyser" in 2002. Photo by Stephen Eide.

Figure 2. "Improbable Geyser" erupting on Nov. 1, 2005. Photo by Stephen Eide.

usual, with splashing water easily visible, but no other significant change from the previous years was noted.

On October 8, 2005, Karen Low reported that Improbable Geyser was overflowing and intermittently boiling to heights of one to two feet. A runoff channel had formed and was about ten to twelve feet long before it disappeared into the sinter gravel[2].

On October 23, 2005, Kitt Barger and Doug Holstein saw a geyser erupting on Geyser Hill. At first it looked like Plume Geyser, but the eruption was steady and had a duration of about one minute. The height was similar to Plume Geyser, estimated to be about 20 to 25 feet (6 to 7.5 meters). The eruption was thicker than Plume, steady for the duration of the eruption, and the water had a brown-yellow color. They reported the eruption was to the east of Plume Geyser in the general area of Anemone Geysers, but the eruption did not look like an eruption of Anemone[3]. This is believed to be the first observed and reported eruption of Improbable Geyser.

On October 24, David Goldberg checked the area and found that Improbable Geyser had a runoff channel running all the way to the river. The water level was usually just below the crater rim, but Improbable was having intermittent boiling from one to four feet. During the periods of boiling, Improbable was overflowing into the channel. The water in the crater was milky. There were also chunks of sinter around the vent, which had enlarged to several times its previous size[4].

I could find no mention of any eruptions between October 23 and November 1, 2005. On November 1, the crater of Improbable was about four feet by four and a half feet with chunks of sinter around the vent. The area where the runoff occurred was undercut, forming a sinter bridge on the south side of the crater. The runoff channel had colorful cyanobacteria growing in it. Improbable continued to have intermittent boiling from one to four feet in height with a duration of 1 to 5 seconds and an interval of 5 to 20 seconds. Both the east and west vents were active during these periods of boiling, and the crater was filled with milky water. Improbable usually had overflow only during the periods of boiling.

On November 1, 2005, I was on Geyser Hill from about 0830 until about 1530. After noon I was walking around in front of Plume when a slightly louder and larger boil on Improbable at 1251 drew my attention. The boil on Improbable rose to six feet, then eight, then to a full eruption. The maximum height of the eruption was about 20 feet (6 meters) with the upper droplets, but the majority of the water was only about 12 to 15 feet (3.5 to 4.5 meters) high. At the start of the eruption Improbable erupted from both the old east vent and the new west vent. The eruption transitioned into a steam phase near the end, and the steam phase ended abruptly. For the last 10 to 15 seconds of the eruption only the old east vent was active. The duration of the eruption was about one to two minutes; this is approximate as I forgot to record the duration in my notes. The water was light brown and rocks were thrown out of the geyser during the eruption. The eruption was essentially vertical with no significant tilt to the water column. Due to the wind, the water falling outside of the crater made a light runoff channel to the west of the crater that flowed into the main runoff channel. When the eruption finished, all visible water drained from the crater. For several minutes afterward Improbable had occasional weak "chuffs" of steam.

At 1326 I again heard water boiling in the crater of Improbable. At 1419 I started to see the top few drops of water in the crater when Improbable had stronger boils. These occasional visible drops were more frequent by 1427, but there was still no visible standing water in Improbable when the second eruption occurred at 1427.

This second eruption was like the first in character. It started with both east and west vents being active, and the height was about 20 feet (6 meters) maximum with the bulk of the water in the 12 to 15 foot (3.5 to 4.5 meters) range. The eruption changed from water to steam phase towards the end, and for the last 10 to 15 seconds of the eruption, only the old east vent was active. The duration I recorded as two minutes. The water column was vertical

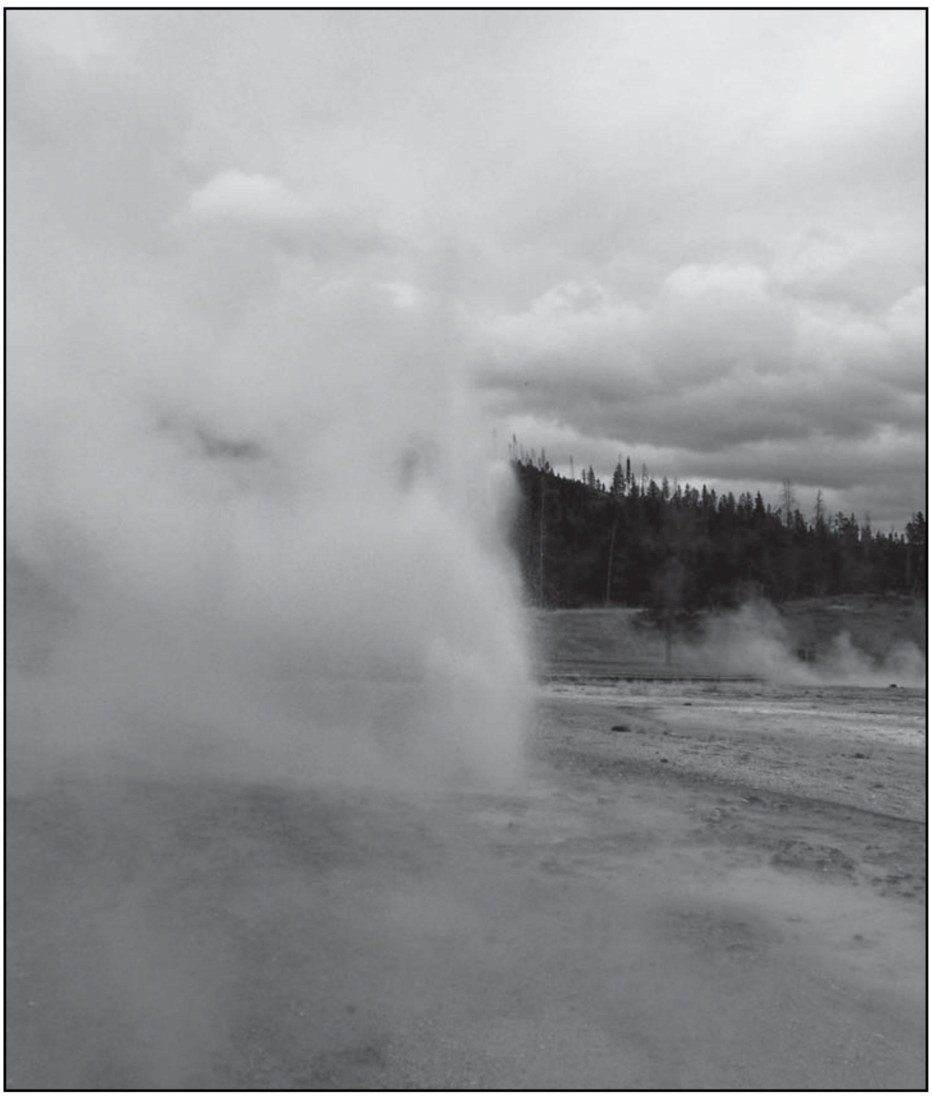

Figure 3. "Improbable Geyser" erupting on Nov. 1, 2005. Photo by Stephen Eide.

with no visible tilt. The water was light brown in color, and rocks were again thrown out during the eruption. The light runoff channel to the west of the crater was enlarged and deepened during the second eruption. The eruption was again followed by a period of occasional weak "chuffs" of steam for several minutes.

After the second eruption I stayed in the area for another hour. At 1514 I could hear no water in Improbable and could see no droplets. Soon after that I left the area.

The next day, on November 2, 2005, there was evidence of further eruptive activity overnight from Improbable. The sinter bridge over the southern part of the crater was gone, and new sinter chunks were visible around the crater. The secondary runoff channels to the west of the crater appeared to be larger and deeper. A marker was placed in the secondary runoff channel, but due to the weather it was not possible to know if the marker was washed by rain/snow or by another eruption. I saw no further eruptions over the next two days, just the usual boiling to 1 to 4 feet. There were no other reports of an eruption of Improbable between November 1 and the park closing on November 6.

I could find no evidence that any other eruptions of Improbable were observed in 2005. Jim Holstein was in the park frequently when the winter season opened, and he remembers no reports of an eruption of Improbable during the winter season 2005-2006[5]. No eruptions of Improbable were recorded in 2006 or 2007.

By the end of 2007, Improbable Geyser had a slightly larger crater that appeared to be about six feet (2 meters) in diameter. Its water was clear, and it had steady runoff, a well-developed runoff channel, and significant microbial mats. Improbable continued to boil on an intermittent basis to a height of 1 to 3 feet with a duration of 1 to 4 seconds and an interval of 5 to 15 seconds. Almost all of the boiling came from the west vent. When the sunlight was good, part of the sinter cone of the old east vent could still be seen within Improbable's crater.

A cursory evaluation of the other geysers in the area did not show any significant change in their activity during the active period of Improbable Geyser. However, no organized effort to discover such connections was performed.

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End Notes:

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The Behavior of the Grand Group During the Summers of 2005 and 2006

Vicki M. Whitledge and Ralph Taylor

Abstract

During the summers of 2005 and 2006 extra electronic 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 among these features.

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]. Turban Geyser eruptions and Grand's pool also have a distinct relationship as Grand's pool drops when Turban Geyser erupts and then rises again between Turban eruptions [Bryan, 1995; GOSA, 2007]. 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, 2006b; Bryan, 1989]. In this study, we take a more detailed look at the interactions of the four geysers (Grand, Turban, West Triplet and Rift) and Grand's pool. This is the first time that detailed electronic data have been gathered on Turban Geyser and Grand's pool for an extended length of time. We discuss the relationships between the eruptive patterns of West Triplet and Rift and eruptions of Turban and Grand.

Events During Grand's Interval

To understand the data, one needs an understanding of the events that occur during an interval of Grand Geyser. An interval starts with an eruption of Grand. During the eruption, Vent and Turban Geysers will also be erupting. Once Grand finishes erupting, its pool will be empty. Vent and Turban Geysers may continue to erupt after Grand finishes, or they may quit erupting. If they quit erupting after Grand, Vent and Turban will restart after 5 to 24 minutes [Koenig 1995; Strasser 2000]. Whether they quit or continue erupting after Grand, Vent and Turban will typically quit between 45 minutes to 1 hour and 15 minutes [Koenig 1995] after the end of Grand, but historically, this time has varied between 24 minutes to 3 hours after Grand [Strasser 2000]. In some years, Vent and Turban Geysers may restart a second time after 50 minutes of inactivity [Strasser 2000]. This latter behavior did not occur during 2005 and 2006.

For about an hour after the end of Vent and Turban, the entire group will be quiet [Koenig 1995]. Turban will then begin erupting approximately every 20 minutes. At first, Turban will erupt from a very low pool and will throw very little, if any, water out of its crater. After about 2 to 3 "low-pool" Turban eruptions, Turban will start erupting during a high-pool and the eruptions will throw water out of the crater [Strasser 2000]. When Turban Geyser first starts having its approximately 20-minute interval eruptions, the basin of Grand's pool is completely empty. Between Turban eruptions, the water beneath Grand rises higher until Grand's pool starts to fill. The first appearance of water in Grand occurs approximately two and a half to three hours after a Grand eruption [Koenig 1995], and this occurs at approximately the time that Turban starts having "high-pool" eruptions. This first appearance of water in Grand's empty crater is energetic, and the water may boil up in a way that is not seen later in the interval.

As Turban continues its typical eruption cycles, the water in Grand's pool falls whenever Turban erupts and then rises between eruptions of Turban to a higher and higher level. After approximately three hours and fifteen minutes to three and a half hours after the previous Grand eruption, water will remain visible in the basin of Grand's pool even when Turban is erupting. Between four to four and a half hours after the previous Grand eruption, the water level in Grand's pool will be high enough so that water will begin flowing out of the pool, an event called "first overflow."

Once the pool has experienced first overflow, the system behaves similarly until the next Grand eruption. The pool fills and overflows between Turban eruptions but drops below the full point during Turban eruptions. Grand will eventually erupt at about the time that Turban is due to erupt.

Because Turban erupts very regularly through large portions of Grand's interval, it can be used as a clock for events in the Grand Group. This has traditionally been done with "Turban Delays." A Turban Delay occurs when an interval of Turban is 25 minutes or greater in length. A delay is recorded in the Old Faithful Visitor Center Logbook with a capital "D" together with the number of Turban eruptions that occurred between the delay and the subsequent eruption of Grand. If Grand erupts on the Turban eruption whose interval is 25 minutes or greater, then it is denoted D0. Other events in the Grand Group can also be timed by the number of Turban eruptions that occur between them.

Methods

This study was conducted from July 06, 2005, to September 24, 2005 (length of study in 2005 was 79 days, 12 hours, 48 minutes), and from July 01, 2006, to September 22, 2006 (length of study in 2006 was 82 days, 15 hours, 16 minutes). The data were collected using data loggers [Taylor, 2000]. Data from West Triplet and Rift Geysers were used from the data loggers in 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. The advantage of this location over the year-round location is that only water from an eruption of Grand ran in this channel. Data from Turban Geyser were collected from a data logger in the run-off channel to the north of Turban. Due to logger malfunction, data for Turban Geyser were lost from August 20 to August 27 and September 3 to September 10 in 2005. All other data sets are complete for the study period.

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. This position was chosen because it was a place of well-defined, periodic flow accessible to a well-hidden data logger. The data from Grand's pool represented the periodic overflow from the pool rather than an eruption. Traditionally, a triangular formation on the edge of Grand's pool closer to the benches and highly visible has been used to determine when Grand's pool was in overflow [Schwarz, 2006]. To differentiate that common usage of the term overflow from flow through the back channel used in this study, 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 "First Fill." The traditional location for determining overflow will experience overflow within a few minutes of flow through the back channel once the cycles of pool filling and overflowing have been established. The front location will also often experience "First Overflow" within a few minutes of "First Fill," but this may be delayed approximately 20 minutes if Turban begins to erupt shortly after "First Fill" and before "First Overflow."

Eruption times were extracted by computer from the raw temperature data [Taylor, 2000]. To ensure accurate extraction, a graph of each interval of Grand was constructed with the temperature traces of all five loggers (Grand, West Triplet, Rift, Turban, and Grand's pool) and the extracted eruption times plotted. In the case of Grand's pool, the time that the water first started flowing over the sensor was determined and plotted. The time between subsequent eruptions or flows was computed. Traditionally, times between the start of two 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. Therefore an interval of Grand refers to the time between the start of two eruptions of Grand, and an interval of Grand's pool refers to the time between the start of two flows out of Grand's pool. Furthermore, when we talk about an eruption and *its* interval, this refers to an eruption and the interval which *preceded* the eruption.

During 2005 and part of 2006, the location of the monitor on Rift produced some temperature spikes that were indicative of steam in the system rather than an eruption [Taylor, 2006]. These events occurred under specific, easily identifiable circumstances and were excluded from the eruption data.

Results and Discussion

The results are grouped and presented based on the type of information given. We start with the basic statistics on the intervals of the features in

	Grand		West Triplet		Rift	
	2005	2006	2005	2006	2005	2006
Minimum	6:17	6:03	1:38	1:25	1:46	2:32
5th Percentile	6:27	6:27	2:15	2:08	6:19	5:15
1st Quartile	6:45	6:52	5:05	4:13	9:38	9:08
Median	7:15	7:31	6:10	5:42	13:02	11:38
3rd Quartile	8:09	8:35	7:49	7:15	14:31	13:51
95th Percentile	9:25	9:56	9:30	8:59	16:27	15:56
Maximum	10:38	11:18	13:35	11:45	22:11	20:25
90% Range	2:58	3:29	7:15	6:50	10:08	10:41
Range	4:21	5:15	11:57	10:20	20:25	17:53
Count	254	254	307	350	157	173

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

the study. After that, we present some results of an analysis of the times between certain events relating Grand, Turban and Grand's pool. After we discuss some characteristics of Turban intervals and delays, we discuss the timings of events in the Grand Group based on the number of Turbans between First Fill and an event. Lastly, we present results on the number of Turbans between an event and the subsequent eruption of Grand.

Basic Statistics of Intervals

Table 1 contains the basic statistics for Grand, West Triplet, and Rift Geysers for the two study periods. 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. Since the interpretive rangers at the Old Faithful Visitor Center try to predict geyser eruption times with 90% accuracy, the 90% Range may be considered the smallest possible window that they could have used to make predictions.

The study period in 2006 was slightly longer than in 2005 (3 days, 2 hours, 27 minutes longer), yet 254 entire intervals of Grand were recorded in both 2005 and 2006 study periods. This occurred because Grand's median interval increased by 16 minutes from 7h15m in 2005 to 7h31m in 2006. Even though the same number of intervals for Grand was recorded, there was quite a difference in the number of West Triplet and Rift intervals recorded. In 2005 there were 307 West Triplet intervals versus 350 in 2006 (an increase of 14.0% over 2005). In 2005 there were 157 Rift intervals versus 173 in 2006 (an increase of 10.2% over 2005). These increases occurred because the median interval for West Triplet dropped 28 minutes from 6h10m in 2005 to 5h42m in 2006, and the median interval for Rift dropped one hour and 24 minutes from 13h02m in 2005 to 11h38m in 2006. This is consistent with behavior that has been noted in the past, namely that increased activity by West Triplet and Rift has been associated with increased interval lengths in Grand. However, the increase in the median interval seems rather slight as the 16-minute increase in interval length is only 3.7% of Grand's 2005 median interval length. Interestingly, the 90% Range for Grand increased from approximately 3 hours (2h58m) to three and a half hours (3h29m). This change was approximately twice the difference in the median intervals.

The distributions of interval lengths for Grand are shown in Figures 1 and 2. Grand's distribution was distinctly right-skewed in both seasons, but the dramatic peak from 390 to 420 minutes (6½ to 7 hours) that occurs in 2005 is much less pronounced in 2006, dropping from 85 intervals in this class in 2005 to 59 intervals in 2006. Instead, in 2006, more intervals occurred between 510 to 630 minutes (8½ to 10 ½ hours) than in 2005. West Triplet (see Figures 3 and 4) appears roughly unimodal in both seasons, but with a distinct, pronounced peak between 270 and 360 minutes (5½ to 6 hours) in 2006, and with many more intervals between 120 and 360 minutes (2 to 6 hours) than in 2005. Rift (see Figures 5 and 6),

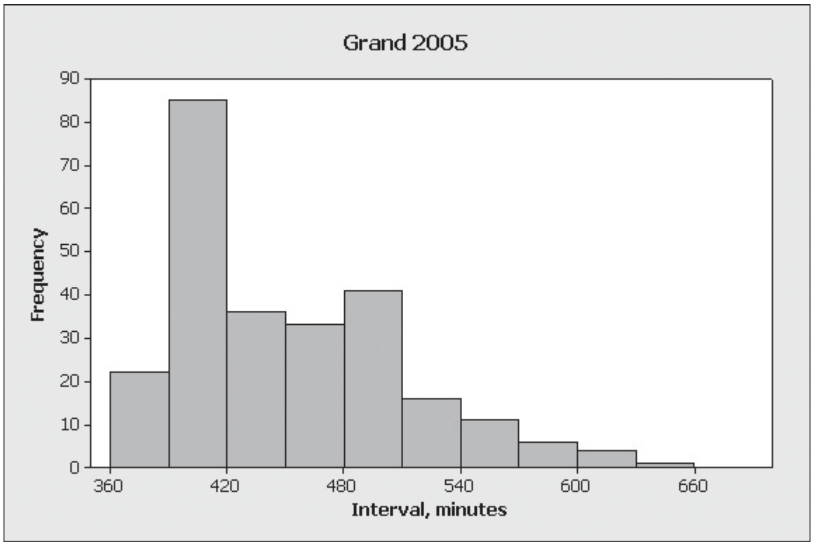

Figure 1.

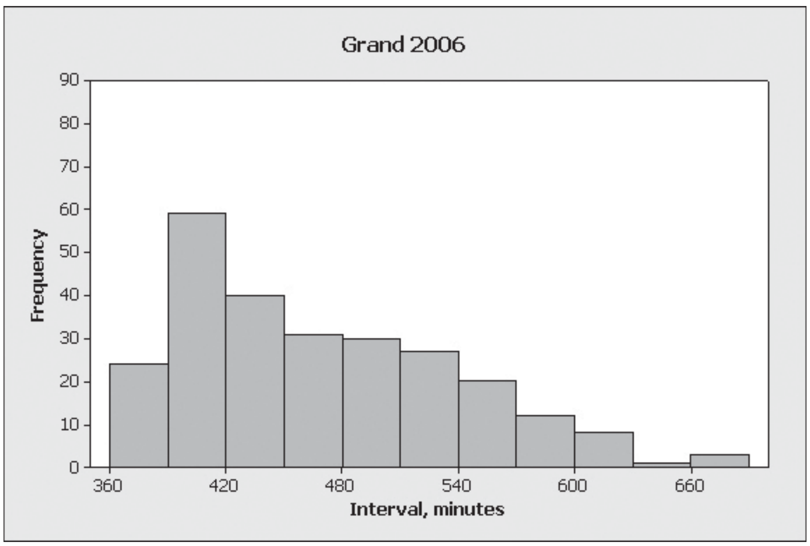

Figure 2.

	Turban		Pool	
	2005*	2006	2005	2006
Minimum	0:10	0:06	0:12	0:09
5th Percentile	0:18	0:17	0:17	0:17
1st Quartile	0:19	0:19	0:20	0:19
Median	0:21	0:21	0:22	0:22
3rd Quartile	0:23	0:23	0:24	0:24
95th Percentile	0:24	0:24	0:25	0:25
Maximum	0:40	0:46	0:43	0:44
90% Range	0:06	0:07	0:07	0:08
Range	0:30	0:40	0:31	0:35
Count	2833	3702	2303	2535

* Due to logger malfunction, Turban data was not available for the entire study period

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

on the other hand, appeared to be unimodal in 2005 with a dramatic peak between 780 to 840 minutes (13 to 14 hours) and bimodal in 2006 with a strong peak between 480 to 600 minutes (8 to 10 hours) and a lesser peak between 780 to 900 minutes (13 to 15 hours). In both distributions of Rift there is a dip in the number of intervals with lengths between 660 to 720 minutes (11 to 12 hours), but it is only in the 2006 data that there is a clear peak before this dip. It is interesting that for West Triplet and Rift, the shapes of the distributions are different between 2005 and 2006, more so than the distributions of Grand intervals for these two years.

Table 2 shows the basic statistics of intervals for 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 and not the long intervals that occur due to an eruption of Grand Geyser. Turban eruptions that occur with Vent are not discussed in this paper, and the event of First Fill is discussed later. The table shows that the actual median interval for Turban Geyser in both 2005 and 2006 was 21±3 minutes. The distribution of intervals is bimodal for 2006 as shown in Figure 7. In 2006, the first peak of the Turban intervals occurred at 19 minutes, and the second peak is centered at 23 minutes. The shape of the distribution was roughly the same in 2005 except that the first peak was centered a minute later at 20 minutes. The second peak occurred at 23 minutes as in 2006. Other than this small shift in the first peak between the two years, the distributions and statistics for the two years are remarkably similar.

The median for Grand's Pool interval was 22 minutes, and the middle 90% of pool intervals ranged between 17 to 25 minutes. There was little to no difference in the statistics for these intervals between 2005 and 2006. The distribution of pool intervals was also bimodal. Figure 8 shows the distribution for 2006. Unlike the Turban intervals, though, the first peak is much smaller than the second peak. Otherwise the distributions

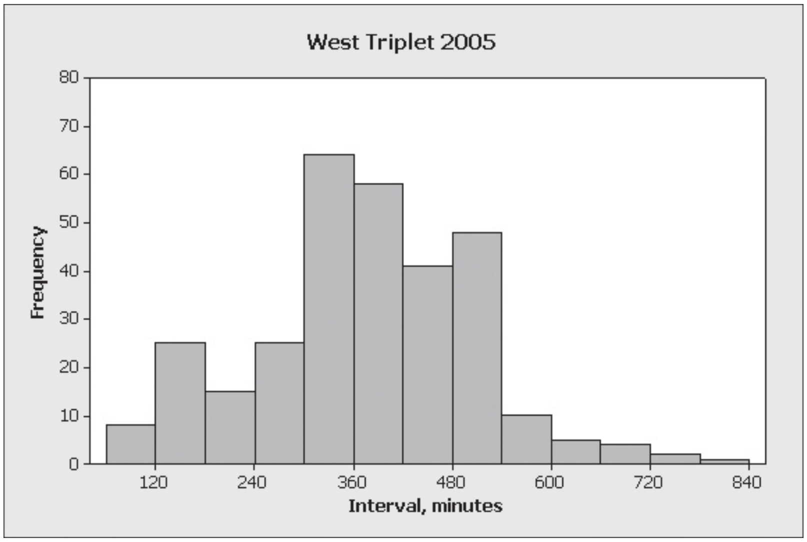

Figure 3.

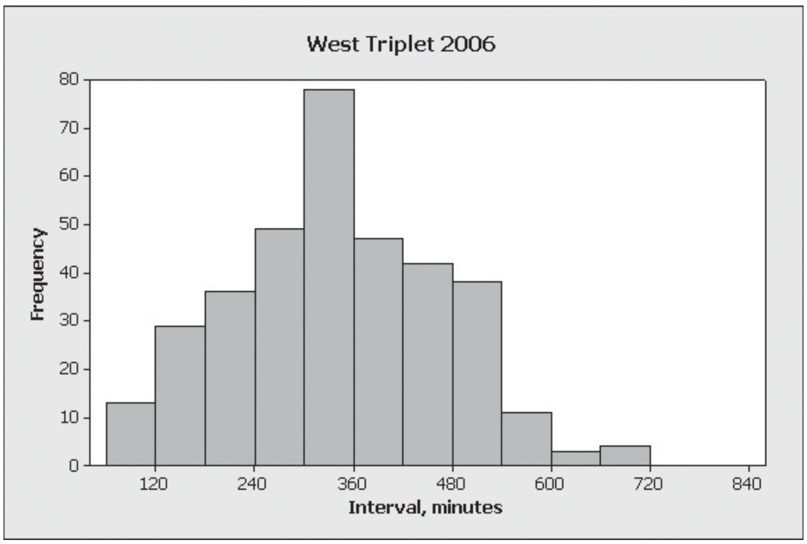

Figure 4.

follow the pattern of the Turban intervals: the first peak is centered at 20 minutes for 2005 and 19 minutes in 2006, and the second peak occurs at 23 to 24 minutes for both years. These similarities make sense since eruptions of Turban and fills of Grand's pool are events that alternate with each other. The difference in the median intervals of Turban and Grand's pool (21 versus 22 minutes) is due to the difference in the first peak of the distributions. Turban's distribution has a larger first peak than the distribution of Grand's Pool. This causes Turban's median interval to be slightly lower. The reason for this difference in the distributions will be discussed later when we look at the intervals of Turban Geyser more closely.

Time Relationships: Grand, Grand's Pool, Turban

While the basic statistics are informative, of more interest is the relationships among 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 vary from feature to feature because of the characteristics

	Grand to 1st High-Pool Turban		1st High-Pool Turban to 1st Fill	
	2005*	**2006**	**2005***	**2006**
Minimum	2:20	2:18	0:51	1:03
5th Percentile	2:23	2:26	1:07	1:06
1st Quartile	2:30	2:32	1:09	1:08
Median	2:38	2:40	1:25	1:25
3rd Quartile	2:46	2:47	1:27	1:27
95th Percentile	2:53	2:57	1:28	1:28
Maximum	3:12	3:08	1:29	1:51
90% Range	0:29	0:30	0:21	0:22
Range	0:52	0:50	0:38	0:48
Count	206	254	206	254

*Due to logger malfunction, Turban data was not available for the entire study period

Table 3: Relationships between Turban, Grand and Grand's Pool

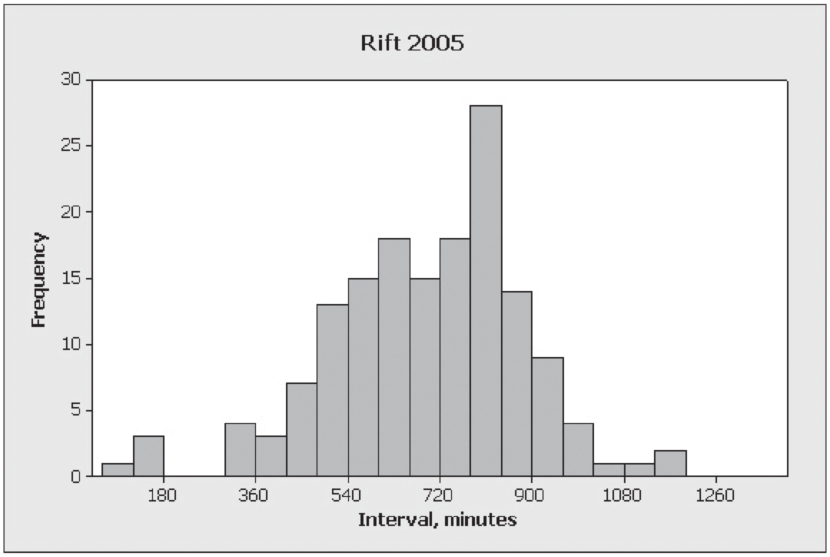

Figure 5.

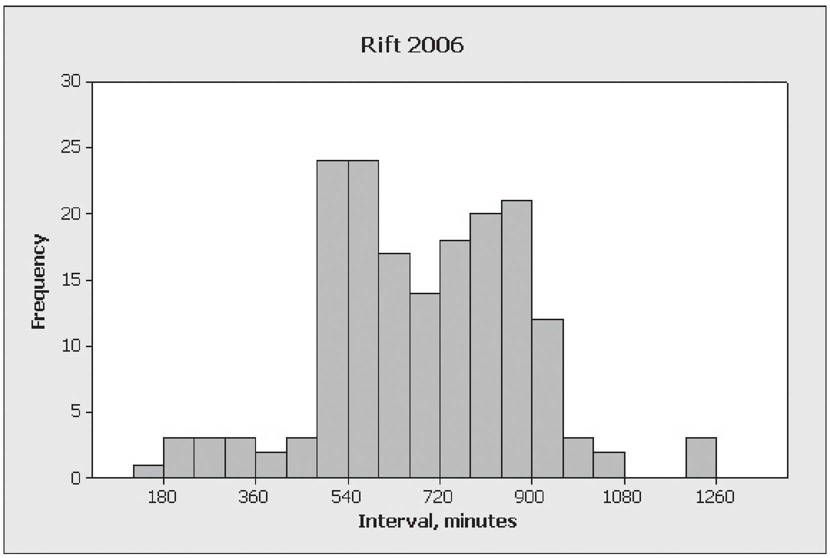

Figure 6.

of each feature's eruption and the location of the data logger. Logger delay times are determined by comparing the electronically derived eruption times to visual observations, both personal and from the Old Faithful Visitor Center Logbook [Stephens]. For more information on logger delay times see Whitledge, 2006a. Features with different logger delay times will have small errors in the times that are computed between their events.

Grand's eruptions had a logger delay time of 1 to 4 minutes with a strong mode of 2 minutes. Turban's eruptions had a logger delay time of 1 to 3 minutes with a mode of 2 minutes. This means that comparisons of Grand to Turban will most frequently have an error of < 1 minute (since both have a logger delay time mode of two minutes) but could rarely have errors of up to 3 minutes. Grand's pool filling had logger delay times of 0 to 1 minutes with a mode of 0 minutes. This means that comparisons between Grand or Turban and Grand's pool will frequently be 2 minutes short but may rarely be up to 4 minutes short for Grand and 3 minutes short for Turban. In all comparisons among these three features, the errors are less than five minutes.

Table 3 shows the relationships between the first detected Turban eruption, Grand, and Grand's pool. Because the data logger on Turban Geyser was in its runoff channel, the logger did not record any data on low-pool Turban eruptions, which do not throw water out of the crater, but recorded only high-pool eruptions. For the purposes of this paper we define a "high-pool" Turban eruption to be one which threw enough water out of Turban's crater to be electronically detected. The times in Table 3 from the last Grand eruption to the first detected (i.e. high-pool) Turban eruption show that this definition is consistent with previously reported descriptions of the change from low-pool to high-pool Turbans [Strasser, 2000].

The first thing to note is that the time between a Grand eruption and the first detected Turban eruption showed little variability during both parts of the study period. It would be fair to characterize the statistics by saying that the first high-pool Turban eruption occurred 2 hours and 40 minutes (+/- 15 minutes) after the prior Grand start. The time between the first high-pool Turban to the First Fill of Grand's Pool showed even less variability. The median time for this event in both seasons was an hour and 25 minutes. The range of the middle 90% was between 1h06m-1h07m to 1h28m. The small variability shows that the Turban/Grand system filled at approximately the same rate during the 2005/2006 seasons.

Table 4 shows the 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 also shows the small variability that was seen in Table 3. Generally speaking, the time between a Grand eruption and the First Fill of Grand's pool was approximately 4 hours +/- 15 minutes. The time from

	Grand to 1st Fill		1st Fill to Next Grand	
	2005	2006	2005	2006
Minimum	3:33	3:34	2:22	2:15
5th Percentile	3:42	3:48	2:32	2:30
1st Quartile	3:51	3:54	2:50	2:52
Median	3:56	3:58	3:15	3:32
3rd Quartile	4:01	4:03	4:12	4:31
95th Percentile	4:15	4:15	5:28	5:56
Maximum	4:39	4:33	6:42	7:19
90% Range	0:32	0:27	2:56	3:26
Range	1:05	0:59	4:19	5:04
Count	254	254	254	254

Table 4: Relationship between Grand and First Fill

First Fill to the next Grand eruption shows much more variability. In 2005, the median time from First Fill to the next Grand was 3h15m, and the range of the middle 90% of the times went from 2h32m to 5h28m, a difference of approximately 3 hours. In 2006, the median time from First Fill to the next Grand was 3h32m, and the range of the middle 90% of the times went from 2h30m to 5h56m, a difference of approximately 3½ hours. The time from First Fill to the next Grand eruption is the portion of the interval where most of the variability in Grand's interval length occurs. Looking back at Table 1, we see that the median of Grand's interval was approximately 15 minutes longer in 2006, approximately the same as the increase in the median time between First Fill and the next Grand between 2005 and 2006. The middle 90% of Grand's intervals had a range of 3 hours in 2005 and 3½ hours in 2006, the same as the range of the middle 90% of the times from the First Fill to the subsequent Grand eruption.

The Turban Interval

The preceding relationships were described in terms of time, but we can also use Turban as a counter to measure off relationships in the Grand Group. Before we do this, we need to discuss the nature of the intervals of Turban further. Turban's median interval was very consistent through both summers of observation. However, the lengths of the Turban intervals varied in a consistent way throughout Grand's interval.

Grand's pool experienced First Fill at a very consistent time after the previous eruption of Grand. Due to the location of the data logger, the detection of the time of First Fill electronically was also very reliable. Therefore we used First Fill as a benchmark from which to count the number of Turbans that occurred. First Fill always occurs between two Turban eruptions. The first Turban eruption after First Fill was designated as 1, and the subsequent Turban eruptions would be counted until the Turban that

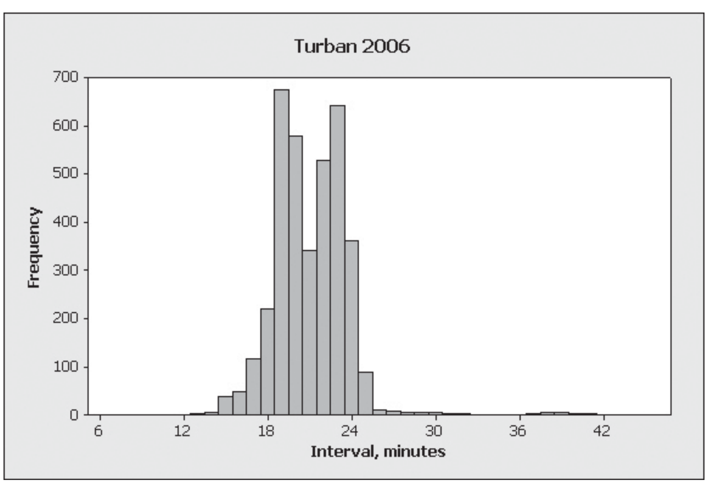

Figure 7.

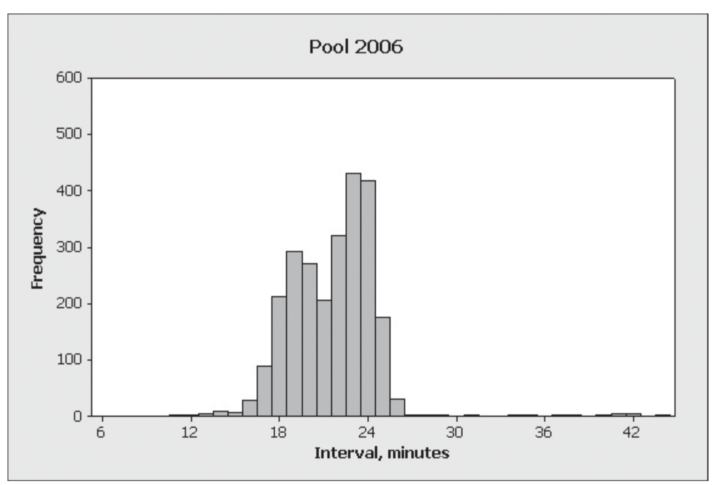

Figure 8.

The Turban from First Fill—Turban Delays				
	2005		2006	
Turban	**Count**	**Percent**	**Count**	**Percent**
2	1	1.09%	8	5.67%
3	6	6.52%	14	9.93%
4	13	14.13%	19	13.48%
5	19	20.65%	25	17.73%
6	18	19.57%	26	18.44%
7	20	21.74%	28	19.86%
8	10	10.87%	11	7.80%
9	4	4.35%	2	1.42%
10	0	0.00%	1	0.71%
11	0	0.00%	2	1.42%
12	1	1.09%	0	0.00%
13	0	0.00%	1	0.71%
14	0	0.00%	2	1.42%
15	0	0.00%	0	0.00%
16	0	0.00%	1	0.71%
17	0	0.00%	1	0.71%
Total	92		141	

Table 5: Turban Delays: Number of Turbans from First Fill

Turban Delays, 26 minutes or longer				
	2005		2006	
Interval	**Count**	**Percent**	**Count**	**Percent**
26	9	25.71%	9	13.37%
27	6	17.14%	7	12.96%
28	6	17.14%	5	9.26%
29	2	5.71%	5	9.26%
30	8	22.86%	5	9.26%
31	1	2.86%	4	7.41%
32	0	0.00%	2	3.70%
33	1	2.86%	0	0.00%
34	0	0.00%	1	1.85%
35	0	0.00%	1	1.85%
36	0	0.00%	1	1.85%
37	0	0.00%	2	3.70%
38	0	0.00%	4	7.41%
39	0	0.00%	4	7.41%
40	1	2.86%	1	1.85%
41	1	2.86%	3	5.56%
Total	35		54	

Table 6: Distribution of Turban Delay Intervals that are 26 minutes or longer

Grand erupted with. Turban eruptions that occurred before First Fill were counted using negative numbers: -1 would be the last Turban that erupted before First Fill, -2 would be the one before that, etc. This system allowed us to avoid concerns about how consistent, our detection was of the first high-pool Turban. Upon examining the data, we realized that our detection of the first high-pool Turban was fairly consistent but using a significant event like First Fill is better. This number scheme allows us to examine events in the Grand Group by their occurrence relative to the series of Turban eruptions from First Fill.

Figure 9 shows boxplots of Turban intervals that are separated out by their place in the series of Turban eruptions for 2005. The graph for 2006 is very similar except that more Turban Delays occurred in 2006. Intervals of eruptions that occurred before First Fill (they have negative number designations) have a median of around 20 minutes. The intervals of the Turban eruptions that occurred immediately after First Fill (numbered 1) had a median of exactly 20 minutes. The intervals numbered 2 through 7, however, consistently had medians that were 22 to 24 minutes in length. After the 7th interval, the medians decreased gradually until they hovered around 18 to 19 minutes. It is interesting to note that the 7th interval of Turban was about the earliest possible time for Grand to erupt. In 2005, Grand erupted no earlier than at the time of the 7th Turban after First Fill. In 2006, only 5 Grand eruptions occurred at the time of 6th Turban after First Fill; all others occurred later in the series. Clearly in 2005 and 2006, something changed in the Turban/Grand system at the time of the 7th Turban after First Fill. This change affected the length of the Turban intervals and made it possible for Grand to erupt.

Earlier we noted a difference in the distributions of Turban intervals and Grand's Pool intervals (Figures 7 and 8). Specifically, we noted that the first peak of the distribution of Grand's Pool intervals was much shorter than the first peak of the distribution of Turban intervals. This is troubling because the pool fills alternately with Turban eruptions, so the distributions would be expected to be more similar. The change in the interval lengths of Turban based on the place in the series relative to First Fill explains this difference in the distributions. Turban eruptions that occur before First Fill have intervals that are consistently around 20 minutes. This adds intervals to the first peak in the bimodal distribution

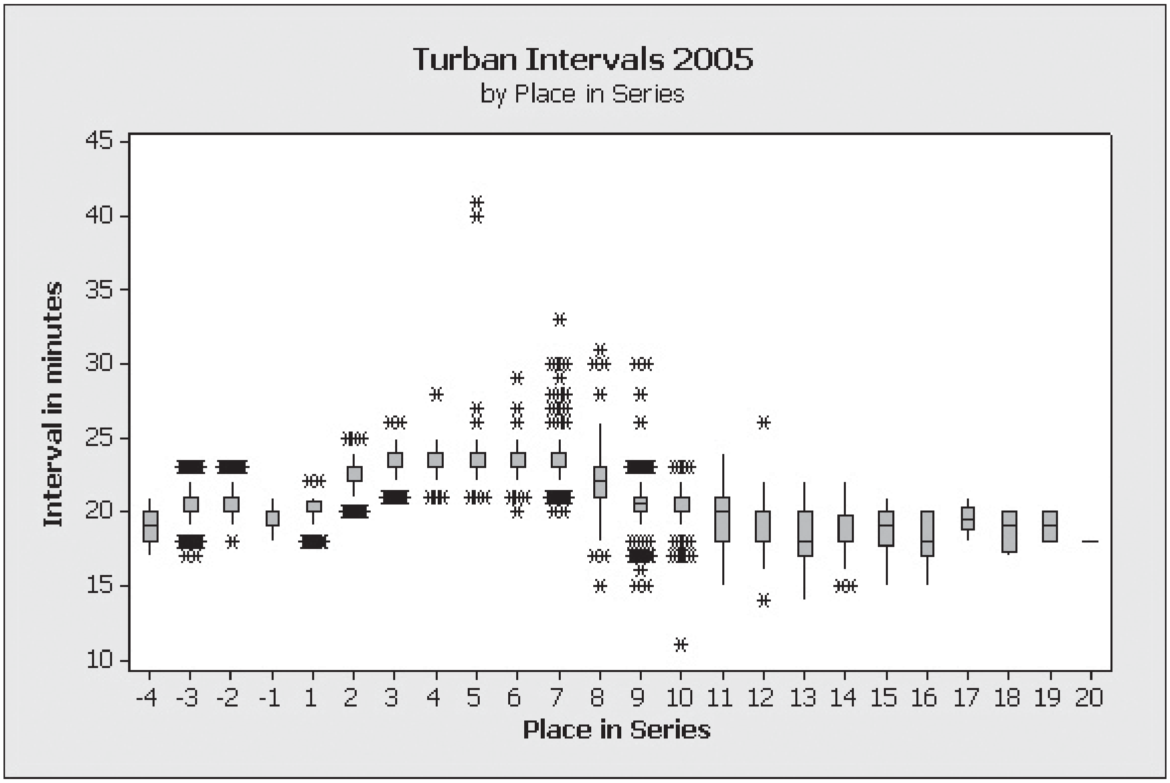

Figure 9.

of Turban intervals, making it much larger than the corresponding peak of the Grand's pool interval distribution because Grand's pool has no intervals before First Fill.

Turban Delays

Table 5 shows when Delays occurred by the number of Turbans from First Fill. For example, in 2005 one delay occurred on the second Turban after first fill (i.e. the interval preceding the second Turban eruption was 25 minutes or longer). In 2006, 8 delays of this timing occurred. In 2005, no Turban Delays occurred before first fill. In 2006, two delays occurred before first fill and are not included in the table. The first occurred on August 4 at 18:35 (two Turbans before first fill) and the other on August 6 at 02:14 (five Turbans before first fill). The first thing to note is that there were 49 more Turban Delays in 2006 than in 2005. In both seasons, most delays occurred from 4 to 7 Turbans after first fill. This makes sense because the median interval for Turbans in these locations is 23 minutes. In 2006 more delays occurred for Turbans numbered 10 or higher (8 delays in 2006 versus 1 in 2005). This corresponds to the increase in the number of longer Grand intervals (8h30m to 10h30m) in 2006.

Table 5 contains all ordinary Turban intervals that were 25 minutes or longer. However, the data logger recorded data every 30 seconds in 2005 and every minute in 2006. It is possible that an interval that was actually slightly shorter than 25 minutes would be computed as being 25 minutes due to rounding. We therefore separated the delays that were only 25 minutes from those that were 26 minutes or longer. Of the 92 delays in 2005, 57 (62%) of them were 25 minutes and of the 141 delays in 2006, 87 (62%) of them were 25 minutes. The distribution of the remaining delays (those 26 minutes or longer) is given in Table 6. It is interesting to note the increase in the number of delay intervals that were very long (34 to 41 minutes) from 2005 to 2006. In 2005 there were only 2 delays of 34 minutes or longer whereas in 2006 there were 17. These long delays showed an interesting pattern in the temperature trace for Grand's Pool. The temperature of Grand's Pool would dip briefly at about the time that Turban would ordinarily be expected to erupt. The decrease in temperature in the trace of Grand's Pool was never as great as it was when Turban actually erupted, and the trace would quickly return to the usual temperature for full fill until Turban finally erupted. This is important because the loggers for Turban and Grand's Pool were separated by a fairly large distance. The behavior of the temperature record of Grand's Pool confirms that a Turban eruption did not occur

	2005		2006	
Delay	**Count**	**Percent**	**Count**	**Percent**
D0	19	20.65%	23	16.31%
D1	3	3.26%	9	6.38%
D2	18	19.57%	16	11.35%
D3	10	10.87%	11	7.80%
D4	6	6.52%	20	14.18%
D5	8	8.70%	9	6.38%
D6	8	8.70%	11	7.80%
D7	6	6.52%	3	2.13%
D8	5	5.43%	6	4.26%
D9	2	2.17%	9	6.38%
D10	2	2.17%	7	4.96%
D11	1	1.09%	7	4.96%
D12	2	2.17%	5	3.55%
D13	2	2.17%	2	1.42%
D14	0	0.00%	1	0.71%
D15	0	0.00%	2	1.42%
Total	92		141	

Table 7: Distribution of Delay Types

The Turban from First Fill—Grand Start				
	2005		**2006**	
Turban	**Count**	**Percent**	**Count**	**Percent**
6	0	0.00%	5	1.97%
7	52	20.47%	39	15.35%
8	59	23.22%	48	18.90%
9	24	9.45%	20	7.87%
10	26	10.24%	20	7.87%
11	15	5.91%	22	8.66%
12	25	9.84%	24	9.45%
13	19	7.48%	14	5.51%
14	12	4.72%	18	7.09%
15	7	2.76%	11	4.33%
16	5	1.97%	12	4.72%
17	3	1.18%	6	2.36%
18	4	1.57%	6	2.36%
19	2	0.79%	5	1.97%
20	1	0.39%	1	0.39%
21	0	0.00%	1	0.39%
22	0	0.00%	2	0.79%
Total	254		254	

Table 8: Timing of Grand Starts relative to the number of Turbans since First Fill

rather than merely not being recorded by the data logger.

Table 7 shows the distribution of delays as they would have been recorded in the Old Faithful Visitor Center Logbook. "D" indicates a Turban delay occurred, and the number refers to how many Turban eruptions occurred between the delay and Grand's start. D0 indicates that Grand erupted around the time of the Turban that closed the delay interval. Not included in Table 6 are the two delays in 2006 that occurred before first fill. The delay that occurred two Turbans before first fill was a D10 and the one that occurred five Turbans before first fill was a D18. The distribution shows that the Turban Delays in 2005 and 2006 followed a well-known pattern. Grand frequently erupted on a delayed Turban, leading to a designation of D0. However, if Grand did not erupt on the delayed Turban, it would usually not erupt until at least the second Turban after the delay. Thus, D1 has been a rare (but not unheard of) designation [Strasser, 2000]. In 2006, this tendency to favor every other Turban appears to have persisted longer, with D4 being more common than D3 and D6 more common than D5. This pattern is not apparent in the 2005 data.

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

Using the number of Turbans since First Fill, we can now look at the eruptive relationships of the three main geysers in the Grand Group: Grand, West Triplet and Rift. As previously stated, we need to be concerned with logger delay times when relating these geysers to Turban. Grand and Turban present no problem since their logger delay times are similar. Furthermore, because of the logger delay time issue, we did not attempt to differentiate between Grand and Turban starts, so will count any Turban that is concurrent with Grand even if Grand started erupting slightly before Turban. Rift and West Triplet are more problematic since they may, or may not, start at the time that Turban starts. Rift's logger delay time is 0 to 2 minutes with a mode of 1 minute. Since Turban's logger delay time is 1 to 3 minutes with a mode of 2 minutes, the times between a Turban start and a Rift start will usually be only a minute short. This small error allows us to be comfortable determining the number of Turban starts that occurred before Rift erupted. West Triplet's logger delay time, however, is larger and more variable at 3 to 7 minutes with a mode

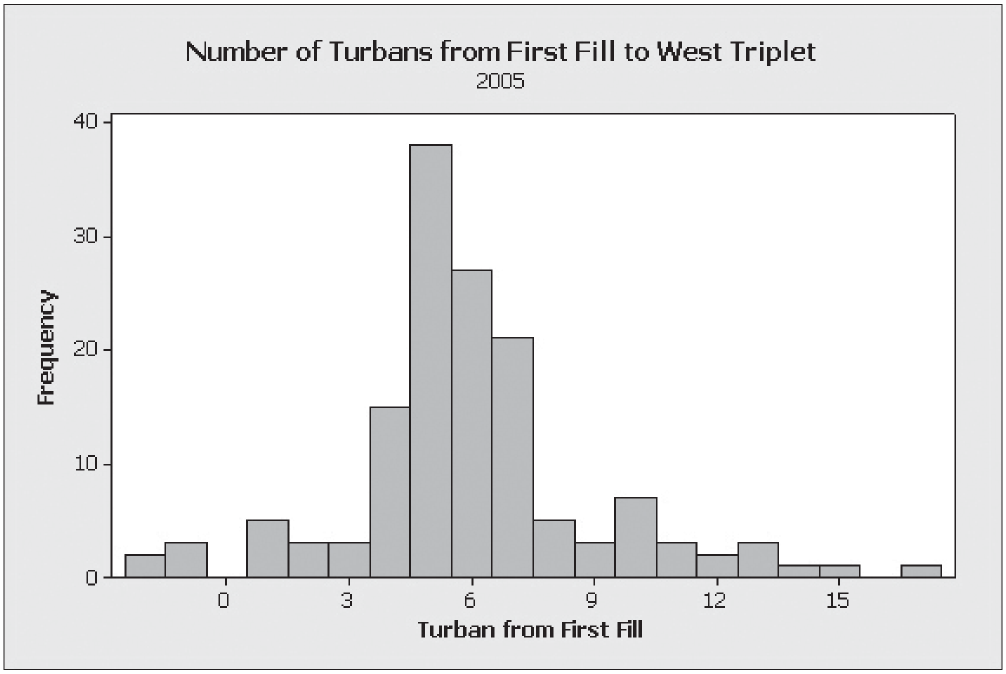

Figure 10.

of 4 minutes. This larger logger delay time is due to the fact that West Triplet begins erupting before it has reached overflow, and its data logger is under the boardwalk to comply with Park Service requirements that the logger be unobtrusive. It may be several minutes after the start of an eruption before the overflow reaches the data logger. In many cases this means that the error in the relative timing may be as short as 2 minutes, but it may be as long as 6 minutes. This is enough to occasionally cause a West Triplet eruption to be counted as starting 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 generally reliable in their general pattern.

Table 8 displays the number of Turbans after First Fill until Grand's start. Interestingly, Grand never erupted before the sixth Turban after First Fill and then only rarely on the sixth Turban. The most common timing for a Grand eruption was on the seventh and eighth Turbans after First Fill, especially in 2005. In 2005, Grand eruptions were also frequent on the ninth and tenth Turbans and the twelfth Turban with a noticeable dip at the eleventh Turban. In 2006, the number of Grand eruptions were more uniformly distributed from the ninth through the twelfth Turbans with the twelfth Turban occurring more frequently than the others. In 2006, the dip in frequency occurred at the thirteenth Turban with a slight increase in eruptions on the fourteenth Turban.

Figure 10 displays the number of Turbans between First Fill and a West Triplet start for 2005. 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. In 2005, most (70.63%) of the eruptions in the table occurred from the fourth to the seventh Turban with a mode of the fifth Turban. In 2006, this peak shifted to a slightly earlier time with most (78.57%) of the eruptions occurring after the third to the seventh Turban with a mode of the fourth Turban. Data for both 2005 and 2006 are included in Table 9. It is interesting that West Triplet, when it erupted before Grand, was most likely to erupt before it was *possible* for Grand to erupt, since Grand generally did not erupt before the seventh Turban. The time that West Triplet was erupting frequently was also the general time that Turban Delays were likely to occur.

Figure 11 displays the number of Turbans between First Fill and a Rift start for 2005. 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. Since Rift, under normal conditions, erupts only after West Triplet has erupted [Koenig, 1995], we would expect the distribution of starting

The Turban from First Fill—West Triplet				
	2005		2006	
Turban	**Count**	**Percent**	**Count**	**Percent**
-2	2	1.40%	1	0.60%
-1	3	2.10%	2	1.19%
1	5	3.50%	4	2.38%
2	3	2.10%	7	4.17%
3	3	2.10%	16	9.52%
4	15	10.49%	41	24.40%
5	38	26.57%	29	17.26%
6	27	18.88%	29	17.26%
7	21	14.69%	17	10.12%
8	5	3.50%	5	2.98%
9	3	2.10%	2	1.19%
10	7	4.90%	4	2.38%
11	3	2.10%	2	1.19%
12	2	1.40%	2	1.19%
13	3	2.10%	1	0.60%
14	1	0.70%	3	1.79%
15	1	0.70%	1	0.60%
16	0	0.00%	1	0.60%
17	1	0.70%	0	0.00%
18	0	0.00%	1	0.60%
Total	143		168	

Table 9: Timing of West Triplet Starts relative to the number of Turban Starts since First Fill

The Turban from First Fill—Rift				
	2005		2006	
Turban	**Count**	**Percent**	**Count**	**Percent**
1	1	1.67%	0	0.00%
2	2	3.33%	1	1.11%
3	1	1.67%	4	4.44%
4	0	0.00%	4	4.44%
5	3	5.00%	20	22.22%
6	12	20.00%	20	22.22%
7	20	33.33%	14	15.56%
8	12	20.00%	13	14.44%
9	7	11.67%	7	7.78%
10	0	0.00%	2	2.22%
11	1	1.67%	0	0.00%
12	1	1.67%	1	1.11%
13	0	0.00%	0	0.00%
14	0	0.00%	1	1.11%
15	0	0.00%	2	2.22%
16	0	0.00%	0	0.00%
17	0	0.00%	1	1.11%
Total	60		90	

Table 10: Timing of Rift Starts relative to the number of Turban Starts since First Fill

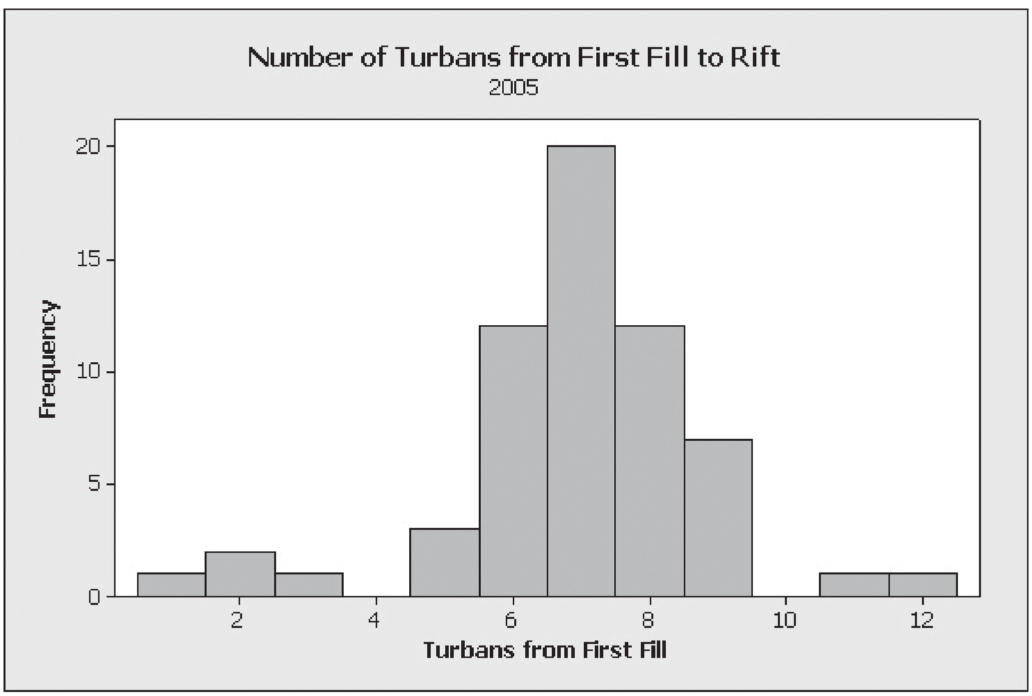

Figure 11.

times for Rift to closely resemble the distribution for West Triplet. This is confirmed in Figure 11 and Table 10, which displays the data for both 2005 and 2006. In 2005, most (73%) of the Rift eruptions occurred after the sixth to eighth Turban with a mode of the seventh Turban. In 2006, the peak is earlier with most (74%) of the Rift eruptions occurring after the fifth to eighth Turban with modes of the fifth and sixth Turbans. Tables 9 and 10 show that there is a pattern regarding when West Triplet and Rift are likely to erupt during a Grand interval, based on the number of Turbans since First Fill.

Tables 9 and 10 contain only those eruptions that start between the first detected Turban and the subsequent eruption of Grand. They do not contain any West Triplet or Rift eruptions that began after Grand's start but before the first detected Turban eruption. Rift did not have any eruption starts between the first detected Turban and First Fill, so Table 10 actually contains only eruptions after First Fill. West Triplet had a few eruptions before First Fill. They occurred after the second and first Turbans before First Fill. The West Triplet and Rift eruptions that are listed in Tables 9 and 10 are of interest because West Triplet and Rift eruptions that occur during that time have been associated with longer Grand intervals, while West Triplet and Rift eruptions that occur at other times do not appear to be associated with longer Grand intervals [Bryan, 1989; Strasser, 2000; Whitledge, 2005]. West Triplet and Rift erupted more frequently in 2006 than in 2005, and the number of eruptions occurring during this critical time also increased. However, while the overall number of West Triplets that occurred during this part of the interval increased from 143 to 168 from 2005 to 2006, the percentage of all West Triplet eruptions that occurred during this time increased only slightly from 46.6% to 48.0%. Rift, on the other hand, saw both an increase in the overall number of eruptions during this part of the interval (60 to 90) and an increase in the percentage of all Rift eruptions (38.2% to 52.0%).

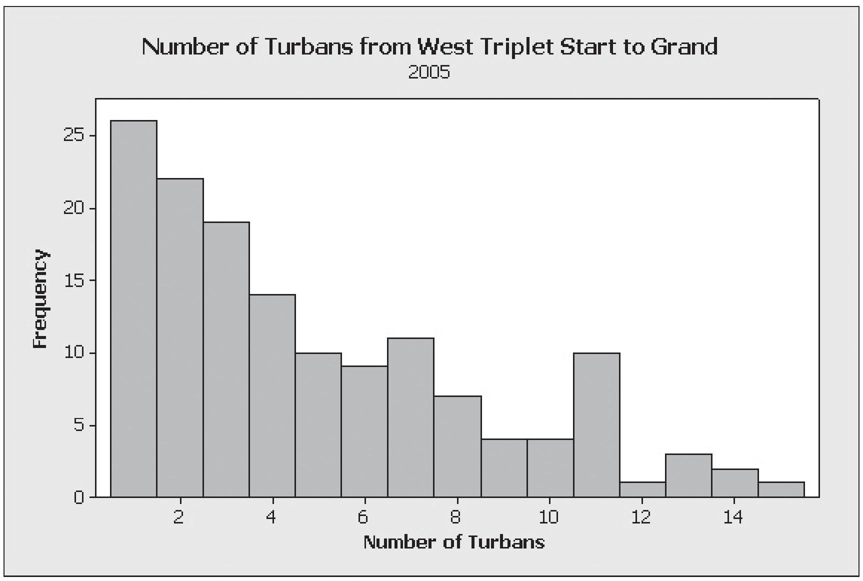

Figure 12.

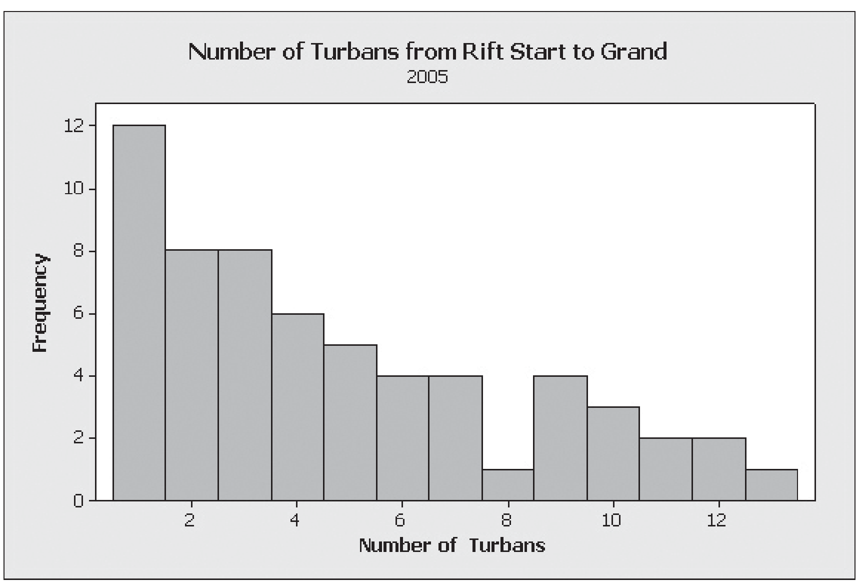

Figure 13.

Number of Turbans between Two Events

Once West Triplet or Rift has erupted, observers ask, "How many Turbans until Grand erupts?" Figures 12 and 13 display this information graphically for 2005, while Tables 11 and 12 give the Turban counts between the start of West Triplet and Rift and the next Grand eruption for both 2005 and 2006. This is similar to the method of designating Turban delays that has been customarily used. However, since West Triplet and Rift are not as closely associated with Turban as Grand is, a designation of "0" is confusing. If Grand erupts on the very next Turban after the start of West Triplet or Rift, it is given a designation of "1." The distributions from 2005 are fairly classically right-skewed. In 2005, Grand would fre-

# Turban from West Triplet Start to Grand				
	2005		2006	
Turban	**Count**	**Percent**	**Count**	**Percent**
1	26	18.18%	13	7.74%
2	22	15.38%	19	11.31%
3	19	13.29%	16	9.52%
4	14	9.79%	14	8.33%
5	10	6.99%	16	9.52%
6	9	6.29%	13	7.74%
7	11	7.69%	15	8.93%
8	7	4.90%	7	4.17%
9	4	2.80%	14	8.33%
10	4	2.80%	14	8.33%
11	10	6.99%	7	4.17%
12	1	0.70%	3	1.79%
13	3	2.10%	7	4.17%
14	2	1.40%	6	3.57%
15	1	0.70%	2	1.19%
16	0	0.00%	2	1.19%
Total	143		168	

Table 11: The number of Turbans between the start of West Triplet and the next Grand eruption

# Turban from Rift Start to Grand				
	2005		2006	
Turban	**Count**	**Percent**	**Count**	**Percent**
1	12	20.00%	8	8.89%
2	8	13.33%	11	12.22%
3	8	13.33%	9	10.00%
4	6	10.00%	9	10.00%
5	5	8.33%	9	10.00%
6	4	6.67%	5	5.56%
7	4	6.67%	6	6.67%
8	1	1.67%	6	6.67%
9	4	6.67%	10	11.11%
10	3	5.00%	4	4.44%
11	2	3.33%	5	5.56%
12	2	3.33%	5	5.56%
13	1	1.67%	2	2.22%
14	0	0.00%	1	1.11%
Total	60		90	

Table 12: The number of Turbans between the start of Rift and the next Grand eruption

# Turban from West Triplet End to Grand				
	2005		2006	
Turban	**Count**	**Percent**	**Count**	**Percent**
ie	55	38.46%	31	18.45%
1	13	9.09%	21	12.50%
2	17	11.89%	14	8.33%
3	4	2.80%	14	8.33%
4	13	9.09%	11	6.55%
5	9	6.29%	13	7.74%
6	8	5.59%	10	5.95%
7	4	2.80%	13	7.74%
8	8	5.59%	14	8.33%
9	4	2.80%	8	4.76%
10	2	1.40%	3	1.79%
11	3	2.10%	9	5.36%
12	2	1.40%	3	1.79%
13	1	0.70%	2	1.19%
14	0	0.00%	1	0.79%
15	0	0.00%	1	0.79%
Total	143		168	

Table 13: The number of Turbans between the end of West Triplet and the next Grand eruption

# Turban from Rift End to Grand				
	2005		2006	
Turban	**Count**	**Percent**	**Count**	**Percent**
ie	22	36.67%	17	18.89%
1	8	13.33%	13	14.44%
2	6	10.00%	6	6.67%
3	4	6.67%	8	8.89%
4	4	6.67%	4	4.44%
5	2	3.33%	9	10.00%
6	1	1.67%	7	7.78%
7	7	11.67%	8	8.89%
8	3	5.00%	6	6.67%
9	0	0.00%	4	4.44%
10	1	1.67%	3	3.33%
11	2	3.33%	3	3.33%
12	0	0.00%	1	1.11%
13	0	0.00%	1	1.11%
Total	60		90	

Table 14: The number of Turbans between the end of Rift and the next Grand eruption

quently erupt soon after a West Triplet or Rift start. The distributions from 2006 are still right-skewed but drop off much more slowly, indicating that there was more frequently a longer wait after West Triplet or Rift start than in 2005. However, there do not appear to be any unusual features in the distributions as there are in the distribution of Turban Delays.

Tables 13 and 14 give the Turban counts between the end of West Triplet and Rift and the next Grand eruption. These tables contain a row "ie" to account for the eruptions that did not finish before Grand erupted. In 2005, West Triplet and Rift were frequently still in eruption when Grand erupted. In 2006, the mode was still that West Triplet and Rift would be in eruption, but this was much less common with longer waits after West Triplet and Rift ended being more frequent.

Conclusions

Several patterns emerged in the data from 2005 and 2006. First, the time between a Grand eruption and First Fill displayed little variability during the study period. During these years, the variability in Grand's interval lengths came from the time between First Fill and the subsequent Grand eruption. The lengths of Turban intervals and Grand's Pool intervals also showed very little variability between the two years.

Second, the geysers in the Grand Group showed common patterns of behavior in relation to two events in the group: the first fill of Grand's Pool and the time that it became possible for Grand to erupt. Events in the group were counted by the number of Turban eruptions that had occurred since First Fill. By these counts, Grand almost always erupted with the 7th Turban or later. In this sense one could say that it *was not possible* for Grand to erupt until the 6th or 7th Turban after First Fill. (On only 5 occasions in 2006, Grand erupted on the 6th Turban after First Fill.) Turban geyser showed a distinct relationship to these two events in that Turban's interval increased in length (median of 23 minutes) after First Fill, and the intervals stayed long until it was possible for Grand to erupt. After the 7th Turban after First Fill, Turban's interval length decreased (median 18-19 minutes).

Turban Delays and West Triplet starts were most likely to occur from the 4th to the 7th Turban after First Fill. Since Grand would typically not erupt

West Triplet Geyser before overflow, May 2007, with Percolator Geyser (back right) and Turban Geyser (far back). Photo by Graham Meech.

before the 7th Turban after First Fill, this meant that the delays and West Triplet starts were occurring before it was possible for Grand to erupt. While Grand rarely erupted before the 7th Turban after First Fill, the most common Turbans that Grand erupted with the 7th and the 8th. Since Rift most frequently erupted from the 6th to the 9th Turban, this meant that Rift was frequently erupting at around the time that Grand would be most likely to erupt. These relationships show that during the summers of 2005 and 2006, the period from the 4th to the 8th Turban was a time when many events occurred in the group.

In 2006, the eruptions of West Triplet and Rift were shifted slightly earlier by Turban count than in 2005. This slightly earlier timing could have allowed West Triplet and Rift to have a greater impact on Grand's interval length, which increased slightly in 2006. In addition, more West Triplet and Rift eruptions occurred overall in 2006 than in 2005, and more eruptions occurred during the more sensitive period before a Grand eruption. Also, more Turban Delays occurred during 2006 than in 2005. However, the impact on Grand's interval length by these factors was minimal. Grand's median interval increased only by approximately 15 minutes, and the window needed to capture 90% of the intervals increased only 30 minutes from 3 to 3½ hours.

In both of the seasons that this study was conducted, Grand was a regular and reliable performer. This study should be repeated in a year when Grand's intervals are longer and more variable. A comparative study of the behavior of the Grand Group between a period of regular and reliable eruptions of Grand to a period where Grand's intervals are more variable could clarify the relationship between activity by West Triplet and Rift geysers and activity of Grand Geyser, if the behavior of West Triplet and Rift changed significantly also.

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Rift Geyser, May 2007, photo by Graham Meech.

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Grand Geyser, May 26, 2007.
Photo by Pat Snyder.

The Activity of Giant Geyser August 2005 - April 2008

Tara Cross

Abstract

Giant Geyser had one of its best active phases in recorded history from August 2005 through April 2008. A thorough study of reports, electronic data, and personal observations has been summarized. The article discusses Giant and its related features; its major phases of activity from August 6, 2005, through April 29, 2008, focusing on the period from April 2006 through November 2007; and dominant patterns of activity during that time.

Introduction

For the first 30 years following Giant's remarkable activity of 1950-1955, it erupted just four times. Starting in 1986, Giant erupted at least once during each calendar year until it embarked upon its first major active phase in over 40 years in the fall of 1996. After erratic intervals ranging from 6 to 33 days, Giant maintained consistent intervals of 3 to 6 days from September 1997 to March 1998. Between April 1998 and July 2005, intervals ranged from days to months, with little regularity. Giant had its first eruption in over 7 months on August 6, 2005. This would be the first eruption of a remarkable active phase that spanned 33 months and included at least 126 eruptions.

Knowledge of Giant's historical activity and careful observation of its patterns during the 2005-08 active phase have revealed much about Giant's connections to its surrounding features and its pre-eruptive behavior. This article examines observations and electronic data and analyzes Giant's major behavior patterns from 2005-08 with a special focus on the summers of 2006 and 2007.

This article has three sections. The first section will introduce the reader to Giant Geyser and its related features, describing typical behaviors and Giant's most important indicators: Giant hot periods and the activity of Grotto Geyser. It will focus on Giant's predominant behavior and patterns. The second section will discuss Giant's 2005-2008 active phase chronologically, highlighting Giant's phases of activity and notable events. The final section will discuss Giant's related features specifically, noting overall patterns and unusual activity.

A word on visual and electronic data

I was fortunate enough to personally witness 17 eruptions of Giant during the span of this article: 9 eruptions between June 6 and September 15, 2006, and 8 eruptions between June 28 and November 1, 2007. Detailed information about eruptions I was unable to observe myself was shared via the Old Faithful Visitor Center geyser logbook, the geyser email listserv[1], and personal communication.

It is important to note that extensive information was available only for Yellowstone's summer season from late April through early November each year. Because information from the winter seasons was sparse, the reader is advised to recognize that the behavior patterns discussed here represent an incomplete picture of the entire active phase. For example, information about related geysers that are not monitored electronically, such as Grotto Fountain and Rocket, is based almost entirely on visual observations made during the summer seasons.

Electronic monitors placed on Giant, Grotto, and Oblong provided some information. The electronic monitor on Giant is maintained by Jens Day, and monitors on Grotto and Oblong are maintained by Ralph Taylor and the National Park Service. Data is analyzed by Ralph Taylor and made available at www.gosa.org. Special thanks to the NPS, GOSA, and these volunteers; without the electronic data, considerably less would be known about the relationship between Giant and Grotto.

Section One: An Introduction to the Giant-Grotto Complex

Note: Though most of the names given to vents in the Giant-Grotto complex are in entrenched usage, only the major geysers have official names. The informal names used in this article will receive quotation marks on first usage. Names that are not entrenched will always appear in quotations.

The Giant-Grotto Complex

The Giant Group

Giant is joined on its sinter platform by four other geysers: Bijou Geyser and Catfish Geyser on the far north side, Mastiff Geyser immediately north of Giant, and Turtle Geyser to the south. All of these geysers demonstrate close connections to Giant.

Giant's cone is surrounded by many small holes and cracks in its sinter platform. Many of these are distinct vents that are active during Giant hot periods, and most of them have names. Together they are known as the "platform vents." Most erupt to less than one foot, but "Feather Vent" is capable of ten-foot eruptions and is the most important vent to Giant's minor activity, known as hot periods.

"Giant's Indicator Pool," or "the GIP," occupies a rather inconspicuous hole on the east side of the boardwalk between Giant and Grotto.

The Grotto Group

The Grotto Complex is located about 450 feet northwest of Giant and is separated from it by a small stand of trees. Grotto Geyser is closely related to Giant, and its activity provided more clues to Giant's behavior in 2005-08 than any other related geyser. Simply put, Giant's behavior could not be understood without an examination of Grotto's behavior. Grotto Geyser is a major geyser in its own right, and its cycles control the rest of the geysers and springs in the group.

Grotto and neighboring Rocket Geyser have large cones that lie immediately east of the paved path. Between them are the diminutive "Central Vents." "Variable Spring" is located east of Grotto along the boardwalk that leads to the Giant area. The rest of the group lies north of Grotto. Grotto Fountain Geyser is the primary vent in a group that also includes South Grotto Fountain Geyser, "Startling Geyser," and "Grotto's Indicator Spring" (also called "Indicator Spring"). Spa Geyser and "Marathon Pool" are farthest from Grotto and Giant. Spa sits at the junction of the path that leads to Riverside, while Marathon Pool is just south of the path to the east of Spa. The Grotto group will be discussed beginning on page 67.

Features to the South of Giant

Though not as important as Grotto, the springs and geysers south of Giant also display connections to it. Oblong Geyser lies 475 feet directly south of Giant. The Purple Pools (North, East, and South) are located across the Firehole River from Giant. South of these are several small geysers with known connections to Giant; only one, "New Geyser," has been given a name.

The Daisy Group

Giant's connections may also extend 950 feet to the west to the Daisy Group. Giant's active phase in 1996-98 coincided very closely with an active phase of Splendid Geyser, a key member of the Daisy Group, suggesting that both may have benefited from the same increase in thermal energy. During 2005-08 there was no corresponding increase in the activity of Daisy or Splendid and no studies of this connection were attempted.

Description of Giant Geyser

Giant Geyser is located in the Upper Geyser Basin, about three quarters of a mile northwest of Old Faithful Geyser and immediately west of the Firehole River. It sits on a large sinter formation that includes several other geysers and small vents, but its tall, broken cone is highly distinctive.

Major Eruptions

The start of an eruption of Giant is one of the most spectacular sights in Yellowstone. It is capable of being the world's tallest active geyser, and expels a tremendous volume of water in the initial surges of an eruption. Observers fortunate enough to witness the start of Giant experience one of the superlative geyser gazing thrills. The eruption can be viewed from as close as 30 feet from Giant's vent on the spur boardwalk viewing platform, unusually close for a geyser of its size.

The eruption begins with voluminous surges that fill Giant's cone and emit small waves of water across the platform towards the boardwalk. The surges build in size until they are higher than Giant's cone, and one of these triggers the start of the eruption. A wave of water inches high washes across the platform, often washing the bulky log to which Giant's name sign is attached down the runoff channel. Giant's column

The start of Giant's eruption on June 28, 2007. Photos by Tara Cross.

rockets upward, with successive surges gaining in height until it has reached its maximum. The water then cascades down in large droplets that crash to the ground. A throaty roar issues from within the geyser, and an immense steam plume rises high into the sky.

The wind direction usually has a significant impact on the appearance of Giant's column, which has a natural angle slightly to the west, towards the boardwalk. A north or east wind often causes the angle to be more dramatic, while a south or west wind may cause the column to appear nearly vertical. Without wind, Giant's initial surge may land more than 50 feet away from its cone, and steam often obscures the top of the column.

Start Types

As in prior years, Giant eruptions in 2005-08 always started during activity of its platform vents, known as a "hot period." During the known history of Giant, a major eruption could be initiated in two ways. A hot period could lead to an eruption of Mastiff, which was then followed by Giant. These eruptions have been called "Mastiff Function" eruptions, though the use of this term after 1988 differed from the definition used by George Marler in the 1950s. Eruptions could also start during a hot period in which Mastiff did not erupt. These have been called "Normal Function" or "Giant Function" eruptions, though Marler called them "Regular Function" eruptions.

Both types of eruption starts were seen in the span from August 2005 through April 2008. All told, of the 63 eruptions seen from the start by a knowledgeable observer, 33 were preceded by an eruption of Mastiff. Though the activity of Mastiff with Giant did not seem to be of great significance prior to 2006, its unique behavior in April 2006 signaled a change in the dynamics of the group. From June 2006 through at least November 2007, Mastiff's activity defined the two modes, "North Function" and "South Function," observed during Giant's "bimodal phase," described on page 58.

Height

Very few eruptions of Giant in 2005-08 were actually triangulated to determine maximum height. Observers usually relied on their experience to estimate the height, with many eruptions nebulously designated as "over 200 feet." It is likely that Giant's height range was similar to its historical range of 160 to 270 feet, with most reaching between 180 to 220 feet. The activity of Mastiff did not appear to be significant in relation to Giant's size, as both types of eruptions showed a wide range in height.

Giant's full height usually lasts only a few moments within the first minute of the eruption, and the column quickly drops to a stable height of about 130 to 170 feet. Some eruptions maintain their height better than others. As the power of the eruption begins to wane, the eruption's character changes to pulsating jets of water.

Durations

The end of a Giant eruption is far less auspicious than the beginning. The pulsating surges of water and steam gradually diminish in strength until they contain mostly steam. A distinct change in the nature of the final surges was noted: the sound reverted to a low rumble, and no water was expelled from Giant's crater. Therefore, the duration of Giant was measured in minutes, starting with the first sustained water and ending with the last water that splashed outside Giant's cone. It should be noted that while this standard usually resulted in agreement among observers, this was not always the case.

A loose relationship appeared to exist between Giant's intervals and its subsequent durations. Giant's shortest durations occurred in April 2006, and after that time most of its shortest durations came after intervals under 5 days 3 hours. After Giant began having longer intervals in May 2006, the durations ranged from 86 to 104 minutes. Interestingly, this range was shorter than the range of 90 to 115 minutes given by George Marler for eruptions in the 1930s, 40s, and 50s,[2] but considerably longer than the reported range of 59 to 77 minutes for 1997-98.[3]

An examination of Giant's durations in 2006 revealed that eruptions were on average over 9 minutes shorter when Mastiff erupted prior to Giant. This pattern continued in 2007, with the average durations of each type being slightly longer. This is shown in Table 1.

Giant's Seasonal Patterns

In his examination of Giant's activity in the 1900s, Mike Keller noted that a pattern of seasonal activity began to emerge in the 1940s.[4] Excluding the unprecedented active phase of 1950-55, Giant showed a tendency towards erupting in August, September, October, and November. This pattern, well known to modern observers because it held true for much of Giant's post-1955 activity, was less prevalent during Giant's activity of 2005-08. While the start and end of the active phase followed previous tendencies, Giant's preference for the later months of the year was less dramatic than it had been. Figure 1 shows a monthly comparison of the 145 known eruptions between 1963 and 2004 and the 126 eruptions between August 2005 and April 2008.[5] This change is due in part to the regularity of Giant's intervals from April 2006 to April 2008, with no interval exceeding 16 days.

Table 1: Giant Duration Table

2006:

With Mastiff: 70, 85, 85, 86, 90, 94, 95, 96, 96, 97, 97 Avg = 90.1
Without Mastiff: 91, 95, 100, 101, 101, 101, 102, 104 Avg = 99.4

2007:

With Mastiff: 86, 87, 90, 90, 90, 91, 93, 96, 96, 98, 98, 98 Avg = 92.8
Without Mastiff: 95, 95, 98, 99, 99, 102, 102, 103, 104 Avg = 99.7

Total for 2006-2007:

With Mastiff (23 eruptions): 91.5
Without Mastiff (17 eruptions): 99.5

<u>*Introduction to the Giant Platform*</u>

The Platform Vents in 2005-08

Note: When the word "energy" is used in this article, it refers to visible activity in Giant and its related vents. Since underground processes within Giant's system cannot be seen or measured, observers must rely on surface manifestations to detect changes in activity.

The following descriptions are based on the appearance and behavior of Giant's platform vents during 2005-08.

"Feather Vent," the largest and most significant of the platform vents, is located a few feet west of Giant's cone. The size of Feather's eruption varied in accordance with the strength of a hot period. During strong activity, Feather's eruptions were usually 6 to 10 feet high; weak eruptions could be as little as 2 feet high.

Feather Vent is the first to be discussed here because it was common practice among observers in the 1990s and 2000s to use the activity of Feather to delineate the start and end of a Giant hot period. Therefore, the duration of the hot period could be defined as the duration of Feather. While it was common for Feather to be the first vent active in a hot period, it could sometimes be preceded by the "Southwest Vents" or, rarely, "Rust Vent."

"Feather's Satellite" is a smaller vent located just north of Feather. Its eruptions, typically 1 to 2 feet tall, began after the start of Feather. While Feather's Satellite was typically active only during stronger hot periods, it was occasionally seen during weaker ones. Thus, it was not a reliable barometer of overall hot period strength.

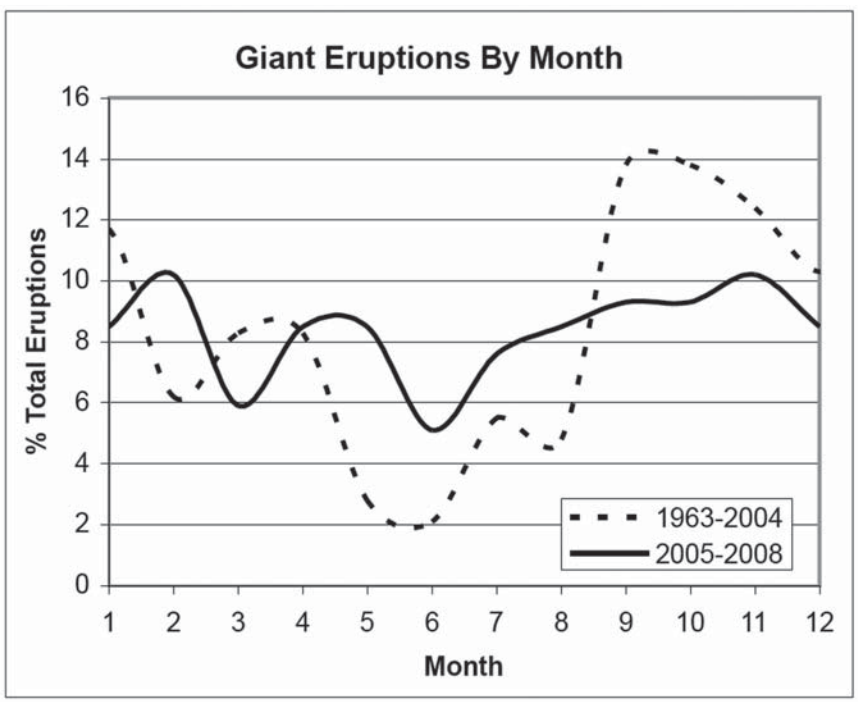

Figure 1.

A typical Giant Hot Period, with Mastiff (left), Feather's Satellite (center left), Feather (center) and surging in Giant's cone. Photo by Graham Meech.

Feather's Satellite sometimes showed a connection to energy levels in Mastiff Geyser. It would usually start quickly after Feather when Mastiff was more energetic, typically within the first minute of the hot period. If Feather's Satellite did not start early in a hot period, it often became active in correspondence with the first significant boiling in Mastiff, as many as 8 minutes after Feather's start.

"Rust Vent" is a crack-shaped vent situated in front of Giant's cone a few feet south of Feather Vent. Rust was active with most hot periods in 2005-08, though it did not always participate in weak hot periods. When Rust was active, it would fill and overflow and usually splash 2 to 6 inches high. Its activity was often stronger when energy was on the north side of Giant's platform.

The **"Southwest Vents"** is the common name for a cluster of vents located on the southwest corner of Giant's platform. The vents in this group usually erupt in concert and include "Horizontal," "Squirrel Tail 1," and "Squirrel Tail 2." In 2005-08, observers did not distinguish between the various vents but instead noted the activity of the group. Typical activity during a hot period consisted of steady sputtering to less than 1 foot with overflow.

"Cave Vent" is on the right. Photo by Mike Newcomb.

While the Southwest Vents started after Feather a majority of the time, it was not uncommon for them to precede Feather by as many as 90 seconds, primarily when energy was on the south side of the platform. This was distinct from the activity seen in 1997-98, when hot periods almost always started with Feather or Rust.[6] It was most typical to see the Southwest Vents start within the first minute after Feather, but some hot periods included little more than steaming from the Southwest Vents.

"Cave Vent" is located north of the Southwest Vents and is usually difficult to see unless it is active. In 2005-08, Cave's activity varied from nothing more than pulsating overflow to vigorous boiling to full eruptions, which could reach 3 to 5 feet during exceptional activity. Cave was most commonly active during strong hot periods when energy was on the south side of the Giant complex.

When Cave participated in a hot period, activity usually progressed gradually. Cave would boil a few inches high during the first few minutes of a hot period. Starting 4 to 6 minutes after the start of Feather, Cave's activity sometimes transitioned from boiling to a pulsating eruption reaching 2 to 4 feet high. At its strongest, Cave's column became steady; this type of behavior was observed only a handful of times in 2006-07.

"Posthole Vent" is located a few feet west of Feather Vent, or "in front" of Feather to observers standing on the boardwalk. Posthole typically did not play a role in a Giant hot period beyond overflow and light bubbling until after Mastiff had dropped. Feather would weaken and stop, and Posthole, along with nearby "Posthole's Satellite" and "Emerald," would begin to bubble and sputter to a few inches. During strong activity, Posthole could erupt to as much as 1 foot, or occasionally more.

"Posthole's Satellite" is several feet north of Posthole Vent along the same line with Emerald Vent. It nearly always acted in concert with Posthole.

"Emerald Vent" is the southernmost vent on a line with Posthole's Satellite and Posthole. Its vent is very hard to locate unless it is active. Emerald was usually active in sympathy with Posthole, and therefore was generally seen at the end of hot periods and during restarts. Its activity at these times usually consisted of burbling to 1 to 3 inches.

Emerald was sometimes active prior to marathon recovery hot periods (described on page 50). Within 6 to 8 hours after the end of Grotto, water could be seen in Emerald, periodically rising and falling every few minutes. Close observation revealed that it cycled in sympathy with Bijou, and therefore opposite to Mastiff's rises. When there was a particularly long delay of 12 or more hours before the marathon recovery hot period, Emerald could burble and even overflow lightly.

"Slit Vent" occupies a narrow slit-like opening at the base of Giant's cone, south of Rust Vent. Its activity was usually limited to oozing overflow or sputtering to a few inches during restart activity.

An **unnamed vent** between Bijou Geyser and Catfish Geyser was active during the span of this article. For lack of any accepted name or number designation, I referred to this vent as "B-C Vent" (Bijou-Catfish Vent) in notes and reports. This vent erupted from a hole located on the shoulder of Bijou's formation near the north vent of Catfish. The "B-C Vent" was active on occasion during 1997-98, but was rarely seen in the intervening years between 1998 and 2005. It erupted during many hot periods in 2005-08. Its height was usually 1 to 2 feet.

No systematic pattern was seen in the activity of this vent, but it was more likely to be active during stronger hot periods and prior to South Function Giant eruptions. It seemed to be associated with Bijou to some extent in that it was often seen about the time that Bijou turned on, or near the end of shorter hot periods when Bijou was going into steam phase in between hot periods. The "B-C Vent" would sometimes start splashing at the same time Bijou started while Mastiff Geyser went into eruption. At these times, it would go into steam phase along with Bijou during Mastiff's eruption.

"The GIP" has the appearance of being inactive, with an oddly shaped crater that recedes into the ground, looking more like a cave than an important thermal feature. Though it is about halfway between Giant and Grotto, it is closely connected with the Giant group, particularly Mastiff Geyser. The GIP received much attention from observers because it is easily seen from the boardwalk, and its water levels closely reflected the water levels in Mastiff. High water levels in the GIP usually meant that a hot period was imminent, and when Mastiff reached overflow, the GIP was usually at its peak level 4 to 6 inches from the rim of its crater.

Description of Platform Geysers

Bijou Geyser is farthest from Giant and sits above Catfish on a large, wide cone that is covered with dark orange-brown bacteria. Bijou's eruptions could vary from weak splashing to powerful jetting to 10 to 25 feet. Bijou was usually erupting more often than not, stopping only briefly for "pauses." However, Bijou's behavior could be affected by marathon eruptions of Grotto. When Grotto erupted for 5 hours or more, Bijou's activity would gradually weaken until it was not erupting at all, and it would only resume full eruptions after the marathon recovery hot period.

When Grotto was having normal eruptions, Bijou would respond to the cycles of Mastiff by pausing when the water level in Mastiff rose. Prior to 2006, it was common for Bijou pauses to occur every 8 to 25 minutes and last 1 to 2 minutes.[7] In 2006-08, when Grotto was having a series of normal eruptions, Bijou pauses normally occurred every 45 to 90 minutes and often led to further events, such as "bathtubs" and Giant hot periods. When Bijou resumed action after a pause, it would rapidly progress from small splashes to tall bursts, sometimes accompanied by steam. These restarts were more powerful in 2006-08 than they had been in the early 2000s.

When a Bijou pause led to a hot period, Bijou normally remained totally quiet until the hot period had ended. Though it remained unusual for Bijou to restart before the end of Feather, it occurred more in 2006-08 than it had in prior years. This behavior was seen during South Function hot periods and was most often observed during eruption hot periods. Bijou's restart was usually accompanied by jetting to 10 to 15 feet in Catfish and splashes from the "B-C Vent." When Bijou came on before Mastiff dropped in non-eruption hot periods, Mastiff normally stopped boiling, dropped slightly, and then dropped out of sight within a minute, though exceptions were seen. When Bijou's start preceded Feather's end, it was usually 6 to 8 minutes into the hot period; however, Bijou came on just 3½ minutes after the start of Feather prior to Giant's eruption on August 30, 2007.

Bijou responded to a Giant eruption by going into steam phase. When Mastiff erupted, Bijou would usually start within a few seconds of Mastiff and quickly go into powerful steam phase accompanied by a loud roar. When Mastiff did not erupt, Bijou would transition to steam after the start of Giant.

Catfish Geyser has a pair of vents situated in a cone slightly below Bijou Geyser on the same sinter mound at the north end of the Giant platform. Both vents participated in major and minor activity. The northern vent is closer to Bijou and could splash from 3 to 8 feet high during Bijou's eruptions. The southern vent could have small splashes as well, but it was most commonly seen during Bijou pauses. Like Bijou, both vents of Catfish responded to Mastiff's drop with splashing, which could reach as much as 20 feet.[8]

During its known history, Catfish has had major eruptions only in conjunction with eruptions of Giant. During the 1950s, Catfish usually commenced its eruption before the start of Giant. This remained the norm in 1997-98, though exceptions were seen. A change appeared to occur in the relationship of Catfish to the rest of the platform geysers during 2006.

Catfish Geyser, May 31, 2007. Photo by Pat Snyder.

While Catfish erupted with most Giant eruptions that were preceded by Mastiff, its eruptions started 1 to 3 minutes *after* the start of Giant.

The timeline of events leading into the start of Catfish followed the same basic pattern through much of 2006-08. After Mastiff started its eruption, Bijou went into steam phase and Catfish would begin to splash from both of its vents, continuing until after the start of Giant. Mastiff would continue to erupt until the start of Catfish 1 to 3 minutes after Giant. Catfish started with splashing that quickly became a steady column of water, with the north vent emitting the taller jet and the south vent expelling water mixed with steam. The eruption would continue for 2 to 4 minutes; both vents would progress into a steam phase that gradually weakened along with Bijou.

Though historical eruptions have been reported to reach 70 feet or more, the maximum observed height of Catfish during the span of this article was about 50 feet, with a more typical height range of 20 to 30 feet. More powerful eruptions tended to have longer water phases, and steam phases had a loud thunder-like roar. Catfish did not always erupt with Mastiff, but it was not known to erupt when Mastiff didn't precede Giant.

Mastiff Geyser's two vents sit in the middle of the Giant platform, between Giant's cone and the sinter mound of Bijou and Catfish Geysers. The vent closer to Giant has been called the "back vent" or "south vent." The vent closer to Bijou has been called the "front vent" or "north vent." This article will use the terms "front" and "back" in reference to Mastiff's vents. Mastiff is the closest major geyser to Giant, and the two share a close connection. Over time, Mastiff's activity has been an important key to Giant's behavior.

Observers at the viewing platform might initially conclude that the group's cycles are determined by Bijou, because it usually stopped before water became visible in Mastiff as viewed from the boardwalk. However, the cycles are actually controlled by Mastiff, which causes Bijou's play to stop when it rises. In the 1990s and early 2000s, observations from the Giant platform revealed that water began rising in Mastiff as many as 90 seconds prior to the cessation of Bijou. In 2006-07, Mastiff's water began to rise much closer to the time Bijou shut off.[9]

When Bijou stopped, there were three possible outcomes: Bijou could restart with no water seen in Mastiff; water could be seen in Mastiff but no hot period ensued; or water could be seen in Mastiff followed by a hot period. The term "bathtub" refers to cases when Mastiff's water level rises to within a few inches of its rim. When water was visible in Mastiff but did not fill the crater, it was not a bathtub.[10] From 2004-08 most observers called these latter events "footbaths." In 2006-07 a greater percentage of Bijou pauses were followed by visible water in Mastiff than in previous years. This was especially true as more time passed since the previous Grotto marathon.

Mastiff's behavior was an especially important element of a Giant hot period. Observers used the amount of discharge, in addition to the strength of boiling over Mastiff's front vent, as indicators of energy in the Giant complex. Mastiff's activity usually occurred in several stages. Weaker hot periods typically included very little activity by Mastiff, and after 30 seconds to 4 minutes, Mastiff would drop followed by the end of Feather. Moderate hot periods could include more discharge and boiling from Mastiff, but about 4 minutes into the hot period, Mastiff's activity would lessen. If Mastiff dropped at that time, the hot period duration was usually 3 to 6 minutes. If, however, Mastiff began to overflow and boil again, the hot period progressed to the next stage, which could include more substantial discharge and strong surging. If the surging continued, Mastiff could build into an eruption. If Mastiff did not erupt during the second stage of the hot period, it would drop, and Feather usually stopped erupting within a minute, though Feather could continue during strong hot periods.

After Mastiff dropped, it usually began to have splashing from the front vent, known to geyser gazers as "depth charging." The strength of this activity was variable; sometimes there was little or no splashing, but starting in April 2006 it became common for Mastiff to have bursts that were easily visible from the viewing platform and persisted until the next Bijou pause. When this activity was especially strong, the back vent would also participate, splashing outside its crater. Though unusual, Mastiff's back vent could also have large, sustained surges that reached 4 to 8 feet and lasted 5 to 10 seconds.

When Mastiff's surging led to a full eruption, the surging remained steady, reaching heights of 4 to 8 feet throughout both stages of the hot period with heavy discharge. Between 8 and 11 minutes after the start of Feather, the surging would transition to heavy bursting. Observers based the start of Mastiff's eruption on the moment that the action from the front vent became a steady column. Within a few seconds, the back vent would begin to erupt as well.

Mastiff is an impressive geyser. In 2005-08, Mastiff's eruptions were usually 20 to 40 feet high, with the tallest bursts from the back vent. However, the front vent could reach as high as 60 feet, jetting at an angle towards Bijou and Catfish, and the back vent erupted vertically to as high as 80 feet. The eruption was most spectacular when both vents were erupting simultaneously, but during most eruptions the action alternated between the two vents. Mastiff's eruptions usually lasted 1 to 3 minutes before the start of Giant. Prior to 2006, it was unusual for Mastiff to continue erupting for more than a minute after Giant's start, but after July 2006, Mastiff often erupted for 2 to 5 minutes after Giant as its water level gradually dropped. (The photo on the cover of this volume shows Mastiff in full eruption along with Giant.)

Two notable variations on this behavior were noted in 2006. In a thorough study of historical records of Giant and Mastiff, Mike Keller found no

Mastiff Geyser, erupting from both vents, July 23, 2007. Photo by Stacey Glasser.

evidence that Mastiff ever had a full eruption without being followed by Giant.[11] The first known Mastiff solo eruption in recorded history occurred on April 22, 2006. A second Mastiff solo eruption was observed on April 29, 2006. Mastiff solos may have occurred at other times during April 2006, but very few observations were made prior to April 21. These events are discussed in detail on page 54.

On two occasions, April 30 and July 23, 2006, Mastiff erupted much earlier than normal in a Giant hot period. Rather than erupting at its usual time, Mastiff started just 3½ minutes after Feather. In both cases, Mastiff erupted for about a minute before it stopped, along with all the platform vents, and dropped out of sight. After a pause of about 3 minutes, water came up in Mastiff and the platform vents and the hot period resumed, with Mastiff erupting in normal fashion. Similar behavior had been witnessed on only one other occasion. On May 9, 1999, Mike Keller saw Mastiff go into full eruption and then stop, along with the platform vents, before resuming its eruption prior to the start of Giant. The circumstances were slightly different, in that Mastiff started erupting simultaneously with the start of the hot period and its water level stayed within view during the pause between eruptions. Bijou's activity was different also, as it erupted normally during the pause rather than quitting when the other vents stopped.[12] These three are the only known instances of "double Mastiff" eruptions.

Turtle Geyser occupies a comparatively small cone to the south of Giant's cone, on the edge of Giant's sinter platform. Heavy erosion has taken place around Turtle's formation, causing an obvious separation from the main platform.

Turtle was not known to erupt between 1956 and 1997, and it remained rare until the early 2000s, when it occasionally erupted along with Giant. Both historical and modern observations confirm that Turtle's only significant activity has been at the time of Giant hot periods. In 2005-08, Turtle's minor activity varied from light overflow during weaker hot

Turtle Geyser erupting in June 2005. Photo by Tara Cross.

periods to strong boiling as much as 1 foot high during stronger hot periods. There did not seem to be any obvious significance to the strength of Turtle's activity, except that it corresponded with the overall strength of the hot period.

Turtle's major activity was not carefully documented in 2005-08, but observations imply that it erupted with Giant more often than not. The eruptions usually started 1 to 6 minutes after Giant and consisted of pulsating splashes 2 to 4 feet tall, though some reached 6 to 8 feet. Durations were not usually timed, but they were mostly in the 5 to 10 minute range, with a few lasting longer. Turtle was also seen on at least one occasion to be having splashes up to 3 feet high over an hour after the end of a Giant eruption.[13]

It is important to note that an apparent shift of energy in the Giant complex took place with Giant's eruption on August 6, 2005. In the months prior to that eruption, activity had increased substantially on the south side of the Giant platform. During this time, Turtle was frequently active during stronger hot periods that lasted 8 to 10 minutes. Turtle's action would progress from heavy boiling in the first minutes of the hot period to a steady column of water reaching anywhere from 2 to 6 feet high. Turtle usually reached full height 6 to 8 minutes into a hot period and lasted 1 to 3 minutes, sometimes continuing its eruption for a short time after Feather had stopped. This was first observed on October 29, 2004, and continued through July 2005. Turtle eruptions became a relatively frequent phenomenon, occurring every few days.

The energy shift to the south side of Giant's platform had other indications. Cave Vent sometimes erupted from 6 inches to 1 foot high during strong hot periods. While many hot periods had long durations of 7 to 11 minutes, strong surging in Mastiff was unusual, and it would often do little more than boil lightly and overflow during these hot periods. Bijou's activity was often weak, sometimes to the point that it was barely splashing or even totally quiet. This activity came to an end with the start of Giant's 2005-08 active phase, and Turtle eruptions independent of Giant were not observed after that time.

<u>*Description of Giant Hot Periods*</u>

The most important factor in understanding the behavior of Giant in 2005-08 was observation of Giant hot periods. The term "Giant hot period" refers specifically to an eruption of Feather Vent, which is usually accompanied by several other vents. Hot period activity has followed the same basic pattern throughout the recorded history of Giant, though many variations have been seen. When Giant is active, hot periods usually occur every few hours, depending on the activity of Grotto. When Giant is erupting on a regular basis, study of hot period activity provides clues as to when its next eruption might take place.

In 2005-08, hot periods could occur as frequently as 45 minutes apart. The longest breaks between hot periods were observed when Grotto had a marathon eruption. It was most typical for the final Giant hot period to occur 1 to 5 hours after a Grotto marathon had started. However, there were times when no hot periods occurred after Grotto's start, and there was evidence that hot periods may have occurred as many as 7 to 8 hours after the start of Grotto. The first hot period after a Grotto marathon, known as the "marathon recovery hot period," usually occurred between

3 and 12 hours after Grotto had stopped, with a range of 1 to 16 hours.

The sequence of hot period activity typically occurred as follows. Though invisible to observers on the boardwalk, water would begin to rise in Mastiff and the GIP. If Bijou Geyser was active, it would weaken and then stop for a pause. As noted earlier, the delay between these events became much smaller in 2006-07 than it had been previously. As Mastiff's water level approached the rim of its front vent, water became visible in the platform vents. Feather would pulse up and down, overflowing lightly. The Southwest Vents filled and began bubbling. Sometimes water pulsated in other vents such as Rust, Cave, and Posthole.

Though the Southwest Vents sometimes began erupting first, the beginning of a hot period was determined as the start of Feather's activity. Feather could then be followed by Feather's Satellite, Rust, and the Southwest Vents within the first 1 to 2 minutes. If Cave or Turtle participated in a hot period, they usually achieved maximum height 6 to 8 minutes after the start of Feather.

Mastiff's water would remain visible for a majority of the time that Feather was erupting. During very weak hot periods, Mastiff might not overflow at all, or have one or two small pulses of discharge. During stronger hot periods, Mastiff's activity consisted of overflow and some boiling over the vent of the north crater. This varied from a few inches to as many as 8 to 12 feet high. If Mastiff erupted, it would do so 8 to 11 minutes after the start of Feather, with the start of Giant following 1 to 3 minutes later.

If Mastiff did not erupt, its water level would drop, usually followed within a minute by the end of Feather and the rest of the platform vents. Bijou would resume its eruption, sometimes accompanied by depth charging in one or both of Mastiff's vents. Though most hot periods ended this way, there could be variations at the end of strong hot periods.

After a hot period lasting at least 5½ minutes had ended, Feather could begin erupting again after a pause of a few seconds to several minutes. This activity was commonly called a "Feather restart." However, Feather restarts were accompanied by activity in the other platform vents and geysers, and this activity could occur whether Feather had stopped and restarted or not. Therefore, this article proposes the new term "restart phase" for the resurgence of activity that sometimes occurred after Mastiff had dropped.

The restart phase was typically seen only when a hot period's duration had reached at least 5½ minutes, and was most common after hot periods lasting 7 to 10 minutes. Mastiff's drop was usually followed by the end of Feather, but during especially strong hot periods, Feather continued to erupt through the restart phase. This resulted in the longest hot period durations, ranging from 13 to 17 minutes.

Regardless of whether Feather stopped or not, the restart phase began with visible water in Posthole, Posthole's Satellite, Emerald, and sometimes Slit. Posthole's activity varied from bubbling to a few inches to stronger activity reaching up to 1 foot high. The other vents would join in with light burbling and overflow or sputtering to several inches. The activity of Posthole and Posthole's Satellite was confined almost exclusively to the restart phase of hot periods.

If Feather had stopped erupting, its activity could also resume during the restart phase. This could consist of anything from a few small splashes from Feather to full eruptions by Feather, Feather's Satellite, and Rust. The strongest Feather restarts occurred after a short break of 5 to 30 seconds in the eruption of Feather and could last up to 5 minutes.

During strong restart phases, Bijou and Mastiff would respond to Mastiff's drop with energetic activity. Bijou would often erupt with mixed water and steam, and Mastiff had powerful depth charging. However, observers were most interested in the response of Giant. As the restart phase commenced, Giant would often begin having surging in its cone. The strength of this surging usually corresponded with the strength of the platform vents, but not always. It was best for Giant's surges to be vertical or slightly angled to the left (north). If the surging was angled to the right (south), it indicated that the water level had dropped in Giant. Both vertical and angled surging was seen to reach over the top of Giant's cone without initiating an eruption.

When Giant started during the restart phase, Feather had usually continued to erupt after Mastiff's drop. However, Giant could also erupt from a Feather restart. Though restart activity was common prior to 2006, Giant was known to erupt during a Feather restart only once, on March 30, 1997.[14] It is reasonable to conclude that eruptions from Feather restarts became more common during the span of this article, with three instances each in 2006 and 2007. In most cases, Feather stopped but was only off for 5 to 20 seconds before it restarted. In one exceptional case on August 25, 2007, Feather was off for over 40 seconds before restarting.

The "double Mastiff" eruptions of April 30 and July 23, 2006, must be noted here because the eruption hot periods included a break in the action of Feather. In both cases, the entire Giant group experienced a pause in activity after Mastiff had started erupting much earlier in the hot period than usual. When Mastiff resumed its eruption after the pause, Feather erupted again as well. While it was tempting to call this behavior a "restart," a clear characteristic of the restart phase was the participation of platform vents that were not active during the main part of the hot period--namely Posthole, Posthole's Satellite, and Emerald. These vents were not active during the "double Mastiff" hot periods. Furthermore, Mastiff has never been known to erupt during restart activity. Therefore I believe that the term "restart" should not be used for this highly uncommon behavior.

Bathtubs

Like hot periods, bathtubs varied in strength. Mastiff's water level could remain static, or it could fluctuate by several inches, usually remaining below overflow. Bathtubs were once referred to as "minor hot periods," and indeed the platform vents sometimes participated. When Bijou was off long enough for Mastiff to rise to near overflow, Feather could overflow lightly or even bubble up to a few inches. During stronger bathtubs, the Southwest Vents sputtered and on rare occasions they went into full eruption. Mastiff would boil lightly from one or both of its vents, and Giant also had episodes of boiling with water visible in its cone. Bathtubs ended in similar fashion to weak hot periods: Catfish splashed from both vents, while Mastiff, Giant, and the platform vents dropped, and Bijou resumed its eruption. Ultimately, bathtubs usually resulted in a 5 to 8 minute pause in Bijou's action. In 2006-07 bathtubs were most commonly seen after strong hot periods and during series of weaker hot periods. In the latter case, strong pauses, footbaths, and bathtubs could act as a precursor to strong hot periods and sometimes eruptions of Giant.

The Giant Group's recovery from major eruptions

Very little data is available regarding Giant's recovery from major eruptions, given that a Giant eruption gave observers a chance to take a break from watching Giant and Grotto. Based on scattered data points during 2006-07, the Giant group recovered from eruptions relatively quickly. Hot periods were seen as early as 12 hours after Giant erupted, and usually a hot period was reported within 24 hours. Hot periods with Mastiff boiling to several feet were observed within a day of Giant's eruptions. Few details were reported about these hot periods, but I witnessed one hot period only 12 hours after a marathon recovery eruption of Giant. It lasted 2 minutes and included Feather, Feather's Satellite, and Rust, but not the Southwest Vents. Mastiff did not overflow, and Bijou was not active at any time prior to or following the hot period.

Giant's Relationship to Grotto

No study of Giant Geyser can be undertaken without an understanding of its relationship to Grotto Geyser. George Marler was the first to note a definite exchange of function relationship between Giant and Grotto, manifested most clearly during the activity of the early 1950s. Since 1955, Giant has never fully gained control of the energy in the complex, but in 2006-07 its activity had a clear effect on the Grotto group. Furthermore, Grotto's behavior was an important indicator of an impending eruption of Giant.

The information in this article regarding Giant's relationship to Grotto is based on both visual and electronic data. When visual observations were not available, the Giant-Grotto relationship was studied by comparing the electronic data from the two geysers, understanding that the electronic data is not as exact. A close comparison of visual observations to the electronic data for Grotto revealed some variations. First, because the temperature recording device was located about 16 feet away from Grotto, there was usually a small delay of 1 to 3 minutes between the visual start time of Grotto and the time registered by the logger. When Grotto had a slow start, the delay could be as long as 13 minutes. Second, the duration of Grotto as detected by the device was usually shorter than visual observations by 5 to 30 minutes. This difference was due to the gradual manner in which Grotto's eruptions came to an end; there was a delay between the time that Grotto stopped producing runoff and the actual stop time. Third, there were a few instances when weak eruptions of Grotto were not detected by the electronic logger, and therefore appear only in the visual record. Thus it is likely that other such eruptions occurred when no visual observations were being made. Finally, in the unusual circumstance of an eruption of Rocket Geyser occurring prior to the start of Grotto, its eruption registered on the electronic log as if it were the start of Grotto, causing the electronic time to be *before* the actual start time.

Grotto's Duration-Interval Relationship

Examination of Grotto's behavior shows a clear relationship between durations and intervals. In a study of Grotto's behavior in 1995-97, Lew and Jan Johns developed a formula by which Grotto's interval could be predicted based on the previous duration. The interval was computed in minutes as 1.7D + 192 (D=duration).[15] Interestingly, this pattern persisted during 1997 in spite of Giant's resurgence of activity in that year. The Johns analysis states that in 1997 Giant "evidently had no large or lasting effect on Grotto Geyser."[16] Though no systematic study of Grotto's duration-interval relationship was made during the span of this article, the Johns formula appeared to be applicable most of the time. However, an examination of both visual and electronic observations showed that Giant's activity had an obvious, and sometimes profound, effect on Grotto. This effect varied with Giant's phases of activity and will be discussed in detail in the chronological narrative starting on page 53.

Grotto Eruptions: Short vs. Marathon

Since the 1980s, Grotto's eruptions have been classed in two groups: "short mode" or "normal" eruptions with durations ranging from 50 minutes to 3 hours (h) 30 minutes (m), and "long mode" or "marathon" eruptions with durations of 7 or more hours.[17] This article will use the terms "normal" and "marathon" in reference to the two types.

Definitions of "marathon" Grotto eruptions have varied since the term was first used by Rocco Paperiello in the 1980s. The original definition was meant to distinguish eruptions of Grotto that were

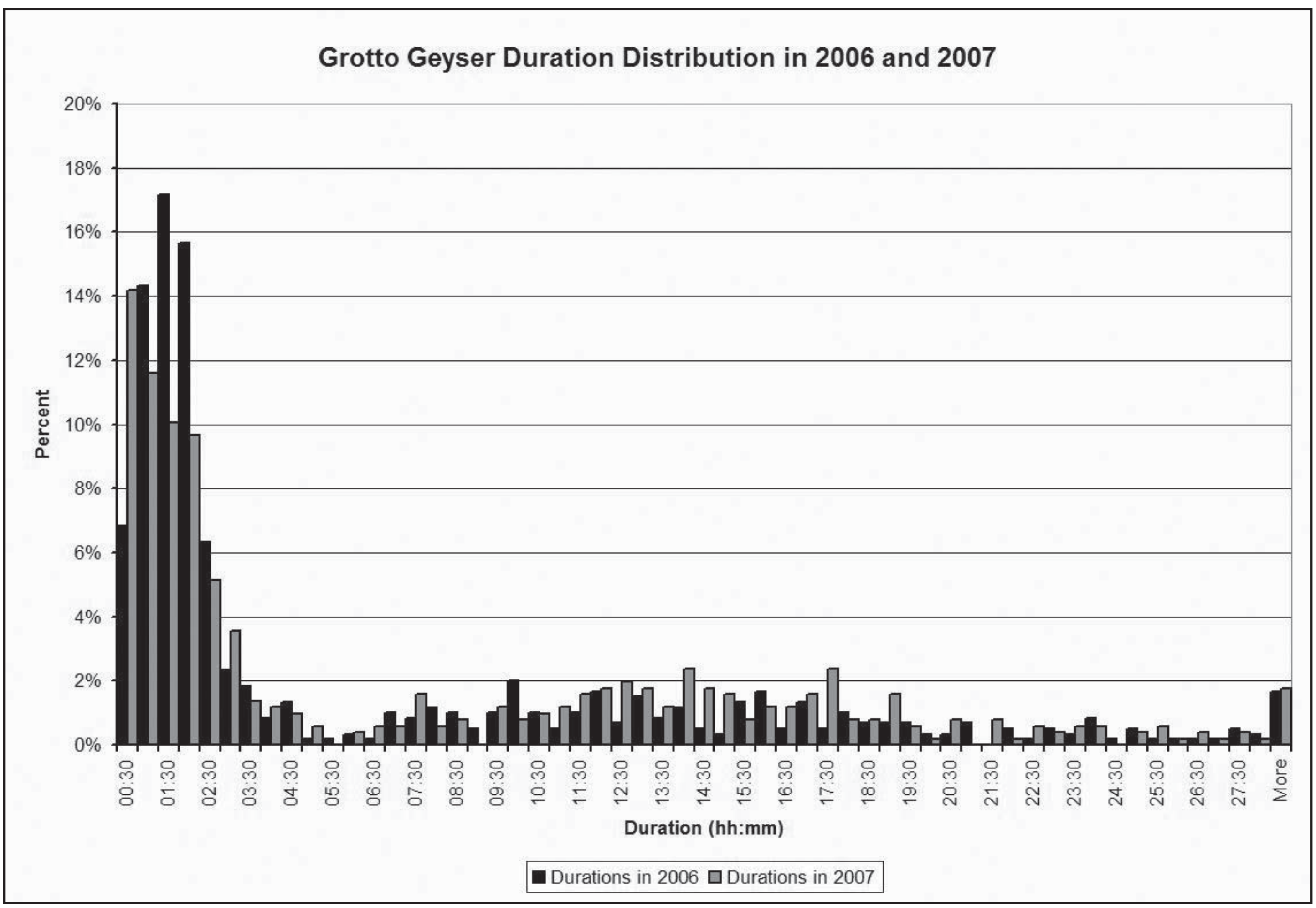

***Figure 2:** Note that this analysis is based entirely on the electronic data for Grotto and therefore does not include the small number of short, weak eruptions that the electronic logger did not detect.*

sufficiently long to cause Spa Geyser to erupt.[18] During the 1980s and early 1990s, Grotto's durations were highly bimodal, making the distinction between marathon and normal eruptions easy to determine. For example, Scott Bryan's study of Grotto in July 1988 showed that normal Grotto eruptions lasted 1h 15m to 4h 38m, while marathons lasted at least 16 hours.[19] The gap had become less extreme by 1995-97, when electronic and visual monitoring revealed marathon durations ranging from 6 to 26 hours.[20]

In his analysis of Grotto's electronic data from 2000-2007, Ralph Taylor used 3h 30m as the dividing point between normal and marathon eruptions.[21] However, Grotto's behavior changed when Giant became active. In 2006-07 its duration could be anywhere between 5 minutes and 38 hours, and the distinction between normal and marathon eruptions was more difficult to determine. Likewise, Spa's activity with Grotto marathons became sporadic and could not be used to distinguish marathon eruptions.

This article uses a visual duration of 5 hours as the cutoff based on the effects seen in the Giant Group (since electronic durations were consistently shorter, 4h 50m was used for electronic data). Visual observations showed that sometime around the 5-hour mark, Grotto's action would cause Bijou to shut off, and hot period activity would cease. A hot period would not occur for several hours after the end of Grotto, and the behavior in the Giant Group was consistent with marathon recovery activity. While Grotto durations between 3h 30m and 5h could cause activity at Giant to weaken somewhat, they did not create a sizeable break in hot period activity. Therefore, this article refers to all Grotto eruptions with durations under 5 hours as "normal" and all eruptions longer as "marathon." Marathons lasting from 5 to 17 hours were sometimes referred to as "mini-marathons" in 2006-07; this article uses the term "short marathon."

The histogram in Figure 2 shows Grotto's duration distribution for 2006 and 2007. There was a wide range of durations, and the percentage of Grotto eruptions that were marathons rose dramatically from prior years.

The Grotto duration distribution also reveals that a greater percentage of Grotto's eruptions were marathons in 2007 than in 2006. This was especially true for marathons in the 9 to 19 hour range. Interestingly, the increase in marathons did not cause a significant change in the incidence of marathon recovery Giant eruptions. The numbers for the two years were similar: 45.5% for 2006 (20 out of 44 known instances) and 49% for 2007 (25 out of 51 known instances).

The Grotto Cycle

In years when Giant was not active, Grotto's durations tended to be more bimodal, and its activity followed a cycle of 1 to 3 days of normal Grotto eruptions followed by a marathon eruption every 2 to 4 days. Consecutive marathons were uncommon, and Grotto's duration-interval relationship remained consistent. As demonstrated in Figure 2, this changed as Giant became more active in 2006-07, with a marked increase in the occurrence of marathons; in fact, consecutive marathons became commonplace. It was most common for zero, one, or two normal Grotto eruptions to occur between marathons, but there could be up to 13. Giant's activity could cause major changes in the duration-interval relationship as well. When Giant's eruption was not associated with a Grotto marathon, delays in Grotto were common. The first Grotto after a Giant eruption was nearly always delayed, and delays sometimes occurred prior to Giant's eruptions as well.

<u>*Discussion of Giant Eruption Types*</u>

I have created a classification system for the purpose of analyzing the relationship of Giant's eruptions to the Grotto cycle. I began by dividing Giant's eruptions into three basic categories: eruptions that occurred on the marathon recovery hot period, eruptions that coincided with the start of a marathon, and eruptions that were associated with normal eruptions of Grotto.

Type 1: Marathon Recovery

Throughout the 1990s and 2000s, the period of time following a Grotto marathon was often a time of increased energy in Giant. When Giant was active, some of its strongest hot periods occurred during the "marathon recovery" period, and this resulted in a large number of Giant's eruptions occurring at that time. This remained the case in 2005-08. The marathon recovery hot period could occur as soon as 90 minutes after the end of Grotto. However, Giant eruptions occurred only after recovery times of 5h 50m or longer. True to past behavior, of the 114 eruptions for which details were available, 54 occurred on the marathon recovery hot period.

Type 2: Prior to or during a Grotto marathon

Another common time for Giant to erupt was prior to or during a Grotto eruption that became a marathon. The question of whether Grotto had a marathon because of Giant's eruption, versus Grotto having a marathon regardless of Giant, has been a matter of debate amongst geyser observers. During some phases of activity, such as 1997-98, Grotto nearly always went into marathon following an eruption of Giant (excluding marathon recovery eruptions). This was not the case in 2005-07; of the 60 eruptions between August 2005 and April 2008 that were known not to have occurred on a marathon recovery, 31 took place prior to or during a marathon (Type 2), while 29 were prior to or during normal Grotto eruptions (Type 3, discussed below). Type 2 eruptions were most common within the first three normal Grotto eruptions after the previous marathon, with the exception of three eruptions prior that took place after a long series of normal Grotto eruptions (all of these occurred prior to June 6, 2006). Though the data was somewhat limited, it was also interesting that when Giant erupted during the first Grotto after the previous marathon, that Grotto eruption always became a marathon (11 out of 11 times).

Type 3: Between or during normal Grotto eruptions

Some Giant eruptions were not associated with marathons, but rather occurred between or during normal Grotto eruptions. It was more likely for Type 3 eruptions to start while Grotto was not erupting, and the most common time for these eruptions to take place was before or after the third Grotto after the previous marathon. There were no examples of Type 3 eruptions occurring after the sixth Grotto after the previous marathon. When activity at Giant caused a delay in Grotto, the eruption was usually a Type 3.

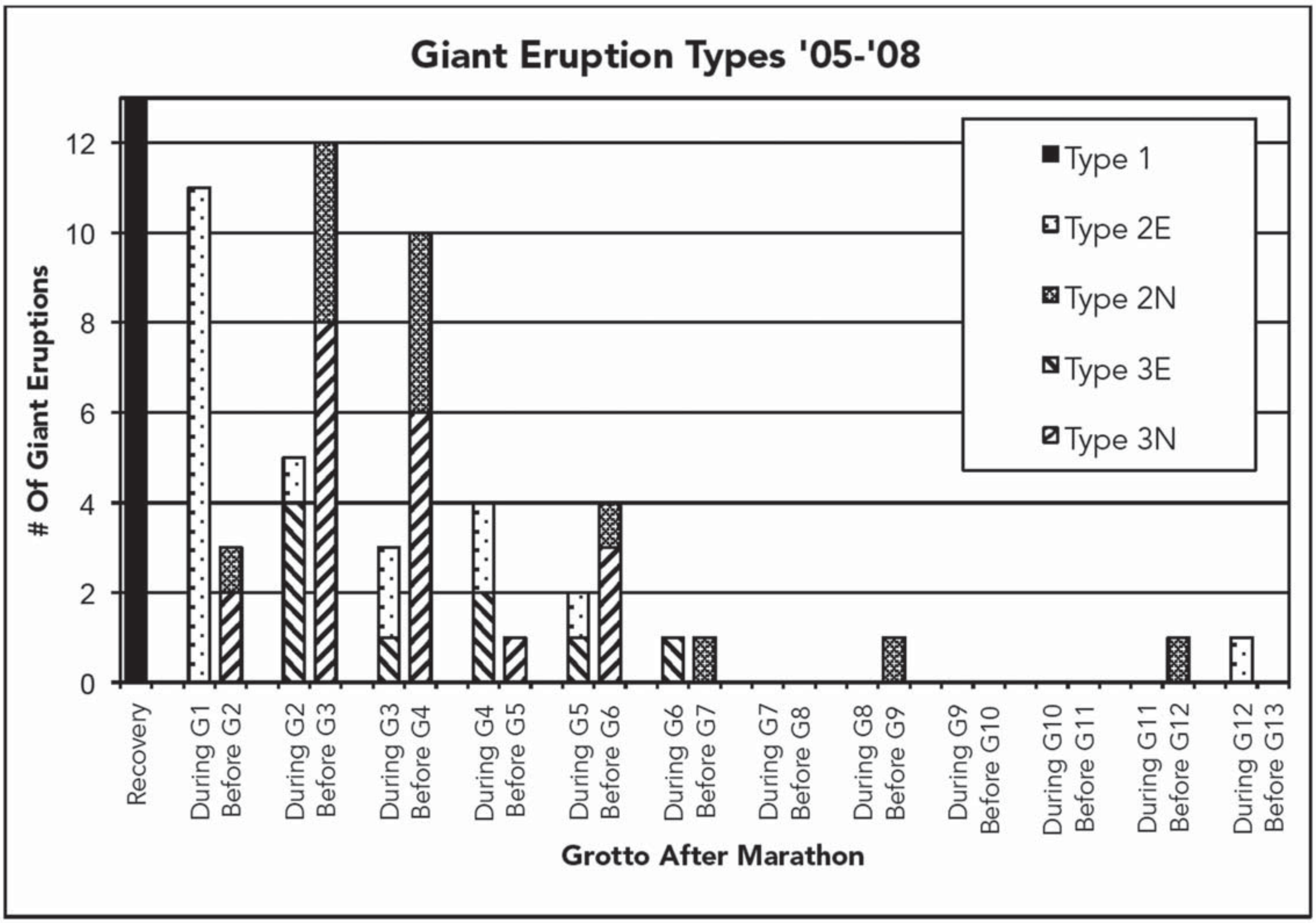

Figure 3: *Analysis of 114 eruptions between August 2005 and April 2008. Data for 12 eruptions were unavailable or inconclusive.*

Breakdown of Eruption Types

My interest in Giant's relationship to Grotto extended beyond the three basic types described above. I created additional notation as follows: **e** represents eruptions that started while Grotto was in **e**ruption, while **n** represents eruptions that started while Grotto was **n**ot in eruption. The inset in Figure 3 shows Type 2 and Type 3 eruptions subdivided into types **e** and **n**. I constructed a timeline for Giant eruptions in relation to the previous marathon by including the number of Grotto starts that had taken place since the end of the last marathon separated by a dash. For example, if Giant erupted between the second and third Grotto eruptions after the previous marathon and the next Grotto became a marathon, it would be classified as 2n-2. If Giant erupted during the third normal Grotto after the previous marathon, the classification would be 3e-3. The histogram in Figure 3 illustrates the distribution of types, showing the progression of normal Grotto eruptions after the previous marathon.

Aside from the 54 marathon recovery eruptions, the most common time for Giant to erupt was during the first Grotto after the previous marathon. This type, represented as 2e-1, did not become common until late 2006. The histogram emphasizes the fact that every time Giant erupted during the first Grotto after a marathon, Grotto proceeded to have another marathon. The rest of the timeline shows a mix of Types 2 and 3. As noted earlier, the most common types in this group were 3n-2 and 3n-3, with eight and six instances respectively.

I relied heavily on this classification system to analyze Giant's relationship to Grotto, especially during Giant's bimodal phase from June 6, 2006 through at least November 1, 2007.

Date	Time	Interval	Mastiff	Type	Observer
8/6/05	0850	~235d18h40m	0847	1	Steve Robinson
8/29/05	1100	23d02h10m	No	2n-3	Herb Simons
9/16/05	0956	15d22h56m	0954	3n-3	Graham Meech
9/29/05	0740	12d21h44m	No	3e-3	Lynn Stephens
10/11/05	~0540	~11d22h00m	?	2n-8	Lynn Stephens
11/2/05	1430ie	~22d09h50m	?	1	Electronic monitor
11/9/05	1605e	~7d01h30m	?	2e-4	Electronic monitor
11/24/05	1430e	~14d22h25m	?	1	Electronic monitor
12/1/05	2155e	~7d07h25m	?	2n-3	Electronic monitor
12/16/05	1740e	~14d19h45m	?	1	Electronic monitor
12/25/05	0555e	~8d23h25m	?	2n-2	Electronic monitor
1/7/06	1858	~13d13h03m	1855	1	Mike Keller
1/15/06	1315vr	~7d18h17m	?	1	Visitor report
1/26/06	1630e	~11d03h15m	?	1	Electronic monitor
2/3/06	0911e	~7d16h41m	?	3n-3	Electronic monitor
2/14/06	0036e	~10d15h25m	?	1	Electronic monitor
2/26/06	0446e	~12d04h10m	?	2e-5	Electronic monitor
3/8/06	1840ns	~10d13h54m	?	1	Electronic monitor
3/15/06	0341e	~6d09h01m	?	2n-3	Electronic monitor
3/24/06	0141e	~8d22h00m	?	2n-11	Electronic monitor
4/1-8/2006	unknown	unknown	?	?	Inferred

***Table 2:** Phase 1 Eruption Table, e denotes electronic time.*

Section Two: Giant's active phase of 2005-2008

Introduction

After months of frequent hot periods, Giant finally awakened from its 7½-month dormancy on August 6, 2005. The first interval following this revival was 23 days. After this, Giant assumed a long-short pattern that continued through March 2006. A clear shift in behavior occurred in early April 2006. Exactly how or when this change took place is unknown; what is known for certain is that for most of the month of April, Giant's intervals dropped to 3 to 4 days, the shortest known intervals since the winter of 1997-98. In May 2006, Giant shifted out of this phase and maintained intervals of 4 to 16 days through April 2008. This article discusses Giant's behavior in five phases: the period from Giant's reactivation through March 2006, the phase of short intervals in April 2006, the transitional phase of May 2006, the behavior of June 2006 through November 2007, and the activity between November 2007 and April 2008. The phases will be discussed chronologically, highlighting important events.

Narrative description of Giant's activity from August 2005-November 2007

Phase 1: August 2005-March 2006

After Giant's eruption on December 13, 2004, Giant entered a dormancy lasting 7½ months. This dormancy was unlike other inactive periods because Giant continued to have frequent, strong hot periods from January through July, 2005, without an eruption of Giant. Strong hot periods could include strong surging and discharge from Mastiff, and there were occasional Feather restarts. However, a shift of energy to the far south side of Giant's platform was evident by the activity of Cave Vent and eruptions of Turtle Geyser during strong hot periods. Whatever caused this shift also seemed to prevent Giant from erupting.

Though strong Giant hot periods were seen in late July and early August, no significant changes in hot period patterns were noted prior to Giant's eruption on August 6, 2005. That eruption appeared to signal that energy had shifted within Giant's system, because no further eruptions of Turtle were seen during strong hot periods. It was also the first known Type 1 eruption since December 2000 (data were available for 20 out of 23 known eruptions).

Promising hot period activity following the August 6 eruption led to another eruption on August 30, followed by eruptions on September 16 and 29. All of these eruptions were observed, and the activity seen was similar to what had occurred in prior years. After an eruption on October 11, Giant started November with the shortest interval since April 2002: 7d 2h. After this, a bimodal pattern emerged in Giant's intervals between November 2005 and February 2006. As shown in Table 2, short intervals ranged from 7 to 9 days while long intervals ranged from 11 to 15 days. Interestingly, the long intervals ended with Type 1 eruptions, while all but one of the short intervals ended with Type 2 or Type 3 eruptions.

The bimodal interval pattern ended in late February 2006, but the interval range remained the same until the beginning of April. The temperature recording device on Giant failed to record an eruption that occurred between April 1 and April 8, but visual observations suggest that it most likely took place on April 6. After that eruption, Giant entered a brief but remarkable phase of short intervals and unusual behavior.

Phase 2: April 2006

The activity of April 2006: Introduction

During the span of time from April 10 to 30, 2006, Giant's intervals shortened dramatically, ranging from 2d 17h to 4d 1h. The interval of just 65 hours was the shortest known since July 1955, which is remarkable given the consistently short intervals of 1997-98. The April eruptions were accompanied by visible changes in many of the features related to Giant.

Because Yellowstone was closed to visitors, few observations were made between April 10 and April 20, but the electronic monitor would later reveal that four Giant eruptions took place during that time. Rocco Paperiello witnessed one eruption during that span, but did not note the date. It is most likely that he saw Giant's eruption on April 16, and he reported a normal hot period and eruption of Mastiff prior to the start of Giant.[22] However, when the park opened on April 21, the behavior that observers found was quite extraordinary.

It was clear that energy had shifted in Giant and its related features. In the Giant Group, the shift was evident in the amount of water and strength of surging in Bijou and Mastiff. When Bijou was in eruption between hot periods, it was having powerful bursts to 10 feet or more. Its restarts after hot periods began with a steam phase and reverted to water. It could take Bijou as much as 10 to 12 hours to shut off during a Grotto marathon. At the same time, Mastiff had superlative depth charging between hot periods, with so much water being thrown out of its crater that Paul Strasser reported that "the little collecting pool to the north of Giant's cone stayed full, and from there flowed west and off the platform."[23] The GIP showed its connection to Mastiff with high water levels, which remained variable but were a foot or more higher than usual.

Changes were apparent in the geysers related to Giant as well. A majority of Grotto's eruptions were marathons, a trend that according to electronic data began on April 12. In fact, 15 out of 25 Grotto eruptions between April 12 and April 30 were marathons, with as many as three occurring consecutively. As noted earlier, back-to-back marathons had been unusual in the years prior to 2006. Though Grotto had scattered normal eruptions, each of the 6 Giant eruptions from April 13 to April 30 occurred during the period of time between the end of a Grotto marathon and the next eruption of Grotto. It is, however, unclear whether all of these eruptions occurred on marathon recovery hot periods.

The surge of energy also extended to Oblong Geyser. The electronic log clearly shows that on April 13 Oblong began to transition from highly erratic intervals ranging up to 29 hours to shorter intervals, and by April 18 Oblong's intervals had become highly regular at 3 to 5 hours. Along with short, regular intervals, Oblong was having powerful eruptions with tremendous discharge that overflowed its established runoff channel.[24] In addition, Oblong had boiling episodes when its normal up-and-down cycles were not at their peak.[25] This behavior, known as "mid-cycle boiling," had been unusual for Oblong, and was only seen a few other times in 2006.

South Purple Pool, which had normally been in overflow except in the hours immediately following an eruption of Giant, was not overflowing at any time in the period of April 21 to 23[26], and scattered observations from the following week confirmed that it did not resume overflow until May 11.

The hot periods seen during this time also displayed unusual behavior. Rather than shutting off 1 to 2 minutes prior to Mastiff's fill, Bijou continued to erupt until Mastiff was nearly overflowing. After a hot period ended, Bijou went into a steam phase eruption that gradually shifted to water over the next 30 minutes. The GIP rose to a very high level during hot periods, coming within an inch of its rim on several occasions.

The changes described above were distinct, but not unprecedented. However, the marathon recovery hot periods seen on April 22 and 23 included events that had not been known to occur at any prior time in the recorded history of Giant. For the descriptions of these events, I have drawn heavily from the first-hand accounts of Mike Keller and Paul Strasser. It should be noted that at the time the reports were made, observers were unaware that Giant was having 3-day intervals and had just erupted in the early morning hours of April 20.

April 22

A Grotto marathon lasting about 18h 40m ended at 0645 on the morning of April 22. As the day progressed, water levels gradually rose in the GIP, Mastiff, and Giant. By 1200 water was visible in Mastiff, cycling up and down. By 1600 the GIP had risen to within 8 inches of its rim, a level usually achieved only during Giant hot periods. At 1701 a hot period started in usual fashion with a rise in Mastiff and the start of Feather. Feather's Satellite started within a few seconds and Mastiff boiled to a few feet. However, two minutes after the start of Feather, the activity began to deviate from normal. Mastiff dropped and Bijou began erupting in steam, but Feather and Feather's Satellite did not stop erupting as they typically would. They continued to erupt, along with Bijou, for 8 minutes without participation from any other platform vents. Then Bijou paused.[27] The events that followed are described by Mike Keller[28]:

> …water in Mastiff suddenly filled and began to overflow heavily. With this, "Rust" and the "Southwest Vents" began to fill with water. Over a period of about 2 minutes, Mastiff began to overflow heavily, then surge several feet, and very quickly began to erupt [at 1713]. The front vent reached a height of about 25 feet with jets landing beyond Catfish's cone and the back vent had periods of vertical play as high as 20 feet. About 90 seconds later, Mastiff and the vents in front

> of Giant quit. Bijou resumed play briefly then paused again as the water in Mastiff and the vents in front of the cone once again came up. Mastiff started overflowing again with surging to a few feet and "Feather" started erupting to a few feet as well. Just as it seemed Mastiff would once again begin erupting, the water levels in all the vents around Giant dropped, Bijou resumed, and the hot period was over.

At no time during the eruption of Mastiff did Giant have the large surges in its cone that observers were accustomed to seeing when its eruption followed an eruption of Mastiff. As previously noted, this was the first known instance of Mastiff having a full eruption without an eruption of Giant following during the same hot period. In addition, Bijou erupted simultaneously with Feather, Mastiff rose and dropped three separate times, and Feather stopped and started without the typical restart behavior. The total duration of the events was about 19 ½ minutes.

April 23

The first Grotto eruption after the Mastiff solo on April 22 was another marathon that lasted 9h 11m and ended around 0345 on April 23. Once again, observers noted that water levels were very high during the recovery period. At 0806, just over four hours after the end of Grotto, water was visible in Mastiff. Paul Strasser noted that Mastiff's up-and-down cycles became progressively shorter and its water level higher over the next two hours, with a corresponding pattern in the GIP. As was typical of marathon recovery behavior later in 2006-07, Bijou responded to these cycles by splashing after Mastiff's water level dropped.

At 1047 Mastiff rose, followed by the start of Feather and Feather's Satellite. At first, the hot period progressed in a manner similar to the events of April 22. Mastiff boiled for about a minute before it dropped and Bijou started erupting, and Feather and Feather Satellite continued to erupt. However, this behavior continued for the next 21 minutes, until Mastiff rose again and Bijou stopped around 22m 15s after the start of Feather. Unlike the previous day, Mastiff did not surge, but rather dropped again, and Feather and Feather's Satellite gradually shut off for a total duration of 24m 42s.

Bijou restarted in steam, as it had done after hot periods on April 21 and 22. However, it weakened almost immediately. After 8 minutes water rose in Mastiff again, and Bijou paused.

At 1122 another hot period began, but this time events progressed in a more typical manner. The Southwest Vents and Rust erupted. Mastiff continued to overflow throughout the hot period, with episodes of strong surging to as much as 10 feet. When Bijou came on, Mastiff did not drop. Instead, Mastiff's surging built into a full eruption at 1131. The eruption was larger than that seen the previous day,

One of two known Mastiff solo eruptions, April 22, 2006. Photo by Kendall Madsen.

reaching at least 40 feet, and Giant's eruption began in typical fashion at 1133.[29]

Though Mastiff's surging throughout the hot period was superlative and Bijou restarted prior to the start of Mastiff's eruption, the 1122 hot period followed a relatively typical pattern of activity. Because the 1047 event was atypical, the question was raised as to whether it should be called a "hot period" in the traditional definition. Certainly the behavior was anomalous, bearing similarity only to the events of the previous day. The fact that another, more typical, hot period occurred only 10 minutes later also indicates that the activity did not expend energy in a normal way. This was likely another manifestation of the extremely high water levels throughout the system. This article does not propose an answer to the question of whether the event should be called a hot period, though by the traditional definition it was a hot period because of the activity of Feather. No further hot periods of this kind were seen at any time during 2006-07.

April 24-29

Few observations were made in the days after the April 23 eruption. A Grotto marathon lasting 22h 47m ended at about 0845 on April 26, and Giant erupted at 2136e. It is unknown whether or not this eruption took place on a marathon recovery hot period. Grotto started its next eruption just 81 minutes later at 2257e, and the delay of 13 hours was much longer than the more typical 5 to 10 hours observed in the days before and after. (The April 13 eruption presents a similar problem; hence, both are noted as "inconclusive" in the eruption list.)

A marathon recovery hot period occurred 5 hours after the end of Grotto on April 28. Once again, Mastiff surged to 10 feet, and the hot period lasted 6 minutes.[30] On April 29, Mastiff had another solo eruption, but it took place during a more normal hot period than the event observed on April 22. Both vents of Mastiff erupted to 20 feet for approximately 15 seconds before it abruptly stopped, and the hot period ended after a duration of 6 minutes.[31] Unlike April 22, Giant was having large surges in its cone while Mastiff was erupting, but its water level immediately dropped when Mastiff stopped.[32]

April 30

Additional unusual events occurred prior to Giant's eruption on April 30. Grotto ended another marathon at about 1220 after a duration of 16h 50m. Once again, the water levels in Mastiff and the GIP were extremely high. The recovery hot period started in normal fashion at 2200, with strong surging in Mastiff beginning almost immediately. However, Mastiff started erupting during the third minute of the hot period at 2203. Both of Mastiff's vents erupted for 30 to 40 seconds. Then Mastiff and the platform vents stopped, and Bijou came back on briefly. Mastiff was quiet for about two minutes before it boiled again, and Feather and the other platform vents started again at 2207. Mastiff immediately began surging, and at 2208 it started erupting again. Though Mastiff once again stopped, Giant's surges triggered an eruption at 2210.[33]

The two segments of the hot period lasted about 3 minutes each, but it should be noted that the timeline from the initial start of Feather to the start of Giant's eruption was in keeping with other eruption hot periods that included normal eruptions of Mastiff. A very similar eruption hot period occurred on July 23, 2006, well after Giant's intervals lengthened and Mastiff's water levels had returned to normal.

A brief comparison to prior activity

The April 30 eruption marked the end of Giant's short-interval phase. In total, this phase lasted 21 days and included 7 eruptions. Observers reported only two eruptions in detail, but both were preceded by previously unknown behavior. How did this phase of activity compare with previous periods of short intervals?

The shift of energy to Mastiff was reminiscent of the "Mastiff Function" behavior described by George Marler in 1951-52, though there were distinct differences. During Marler's Mastiff Function, Mastiff could erupt for as many as 10 minutes prior to the start of Giant, but it was never seen to erupt without Giant. Mastiff's eruptions were more powerful than those seen in 2006, reaching 100 feet or more.[34] It is also interesting to note that Giant's intervals shortened only *after* Giant shifted out of Mastiff Function in January 1952, a pattern essentially opposite to what occurred in April and May of 2006.

Giant had its first period of short intervals since 1955 in 1997-98. These were associated with more energy on the north side of Giant's platform,[35] but there were some clear differences between 1997-98 and April 2006. Giant's 3-to-6-day intervals lasted seven months between September 1997 and March 1998.

Though the period of short intervals lasted considerably longer, the average interval in 2006 was shorter at just 3 days. Though Mastiff was often active with Giant during 1997-98, it was not seen to erupt without an ensuing eruption of Giant. No hot periods of the kind observed on April 22 and 23 were seen. Water levels in Mastiff and the GIP were "normal," and consecutive marathons were unusual. However, a notable similarity was the length of Grotto marathons that resulted in Type 1 eruptions. Both phases maintained a typical range of 9 to 16 hours. This pattern changed dramatically as Giant moved into a new phase of activity for the rest of 2006 and 2007.

Phase 3: May 2006

May 2006 is treated separately because it proved to be a transitional phase between the intense activity of April and the bimodal activity that began in June. The change was clear: between May 1 and May 14, Giant's intervals doubled from 3 to 4 days to 6 to 7 days, Mastiff and the GIP returned to more normal water levels, Grotto reverted to a more usual cycle of marathon and normal eruptions, South Purple Pool began overflowing again, and Oblong gradually lengthened its intervals.

Interestingly, the first interval of May spanned a period in which Grotto had 7 eruptions, 5 of them marathons. Steve Eide described the behavior from May 2 to 5 as follows[36]:

> After the marathon ended there was a 6-10 hour recovery period, then Giant usually had a reasonable to great hot period. Then Grotto started again, sometimes almost the same time as the initial Giant hot period, sometimes a few hours later. Giant had one or two additional weaker hot periods during the start of the next Grotto marathon, then quieted down. So, you had only one good hot period each day with a chance for Giant to erupt.

Mastiff continued to have strong surging during marathon recovery hot periods, with one exceptional instance in which Mastiff surged to 15 feet for a few seconds, but did not have a full eruption.[37]

After a series of short marathons, Grotto had a marathon lasting 19h 07m. During the marathon recovery period on May 6 observers noted a marked change from the behavior seen in April. The water in the GIP was about 12 inches lower at its peak than it had been, and water was not visible in Mastiff until the marathon recovery hot period took place.[38] Giant's eruption was preceded by Mastiff in typical fashion 10 hours after the end of Grotto.

On May 7, a notable series of events occurred at Grotto about 12 hours after the eruption of Giant. Scott Bryan was waiting for Grotto to start its

Date	Time	Interval	Mastiff	Type	Observer
4/10/06	1416e	unknown	?	3e-4	Electronic monitor
4/13/06	1821e	~3d04h05m	?	1?	Electronic monitor
4/16/06	1131e	~2d17h10m	?	1	Electronic monitor
4/20/06	0221e	~3d14h50m	?	1	Electronic monitor
4/23/06	1133	~3d09h12m	1131	1	Paul Strasser
4/26/06	2136e	~3d10h03m	?	?	Electronic monitor
4/30/06	2210	~4d00h34m	2203, 2208	1	Andrew Bunning
5/6/06	2220	6d00h10m	2217	1	Kitt Barger
5/14/06	0804	7d09h44m	0803	3n-5	T. Scott Bryan
5/21/06	overnight	~ 6 3/4 d	?	?	Inferred
5/31/06	0715	~10 1/4 d	Yes	2e-12	Mike Frazier

Table 3: *Phase 2-3 Eruption Table.*

first eruption after the previous day's marathon and observed that Grotto Fountain started more quickly than usual at 0940, and this was accompanied by overflow from nearby Indicator Spring. After several large splashes, Rocket erupted at 1006. Meanwhile, Grotto Fountain continued erupting with periods in which its water was mixed with steam. Grotto Fountain's eruption ended at 1009 for a duration of 29 minutes. Rocket continued to erupt, and as its eruption ended, Grotto started weakly at 1012. Grotto went on to have a duration of 1h 20m.[39]

Prior to 2006, it was extremely rare for a Rocket major to precede an eruption of Grotto. This was the first such instance witnessed in 2006, but it became more common, occurring twice in 2006 and three more times in 2007. While Grotto Fountain was seen to have powerful eruptions with mixed water and steam on other occasions in 2006-07, May 7 was the only reported time when its eruption ended *before* the start of Grotto. Likewise, Indicator Spring was not reported to overflow at any other time during the span of this article.

In the week following the May 6 eruption, the energy shift in the group became more evident. Of the 23 eruptions of Grotto between May 7 and 16, only 4 were marathons. South Purple Pool had resumed overflow by May 11.[40] Between May 9 and 21, Oblong became more irregular and its average interval lengthened. At Giant, Mastiff's surging decreased, reaching a maximum of 6 feet during strong hot periods. However, strong Bijou restarts and Mastiff depth charging continued throughout 2006-07.

The energy shift was further demonstrated in Giant's eruption on May 14. Grotto ended its third normal eruption after the previous marathon around 0700. The water level in the GIP was low, so observers were at Grand Geyser when a hot period was seen in progress. Mastiff erupted, followed by Giant a minute later. This was the first eruption in over a month that had not taken place during the span of time between the end of a Grotto marathon and the start of the next Grotto eruption.

The third Giant eruption of May occurred overnight and was not seen, but evidence suggests that it occurred on the 21st near the start of the first Grotto after a marathon, an eruption that itself became a marathon. Hot periods were mostly weak until May 26, when there was a strong hot period on the recovery from a 27½ hour Grotto marathon. Starting on May 28, Grotto had an unbroken string of 11 consecutive normal eruptions. During this time, Giant's strong hot periods occurred about every 7 to 10 hours and showed a gradual shift in energy to the south side of Giant's platform. For the first time since April, the Southwest Vents sometimes preceded Feather, Turtle was more active, and Cave erupted up to 1 foot high. Weaker hot periods and bathtubs occurred at hourly intervals. The activity immediately prior to Giant's eruption on May 31 is unknown, but Giant started about 10 minutes after the start of the twelfth Grotto since the previous marathon, and that eruption became a marathon.

While this progression of events was reminiscent of the pre-eruptive activity seen before three of Giant's eruptions in 2004, it was not seen again between June 2006 and November 2007. As stated earlier, no eruption of Giant occurred after the sixth Grotto after the previous marathon. When energy shifted to the south side of Giant's platform, an eruption usually occurred within 36 hours. A handful of eruptions occurred between 40 and 47 hours after the end of the previous marathon, but even these were only slightly more than half of the 87 hours that elapsed between May 27 and 31.

Phase 4: June 2006-November 2007

Beginning on June 6, Giant entered a phase of behavior that persisted throughout the rest of 2006 and 2007. Though intervals varied from a short of 4 days 8 hours to a long of 16 days, definite behavior patterns emerged, and Giant was not seen to stray from these for at least 19 months. Even more remarkable was the span of 7 months from May to November 2007 in which Giant's intervals exceeded 7 days 23 hours only twice. In total, Giant had 71 eruptions between June 6, 2006, and November 1, 2007; 49 of them were seen by a knowledgeable observer.

Summary of Bimodality

Over a period of months, a bimodal pattern emerged. When Giant erupted with a marathon recovery hot period, Mastiff erupted prior to Giant. When Giant erupted at some other time in Grotto's cycle, Mastiff did not erupt. This was distinct from any previously described behavior pattern and will be referred to as the "bimodal phase" in this article.

The distinction between the two modes could be most easily seen in the timing of Giant's eruptions relative to Grotto marathons and the behavior of Mastiff during eruption hot periods. Grotto marathons, particularly those lasting 17 hours or more, often resulted in a shift of energy to the north, with stronger activity in Mastiff and Mastiff-initiated Giant eruptions. Once this window passed, the energy would begin to shift to the south, with greater energy in the vents to the south of Giant and Giant-initiated eruptions.

No consistent connection between the two functions and Giant's intervals was apparent, nor was there a distinguishable pattern in the sequence of North and South Function eruptions. As many as four South Function eruptions and three North Function eruptions occurred consecutively. Since the functions were closely related to Grotto's activity, further examination of Grotto's behavior might reveal more complex patterns; such analysis was not attempted for this article.

To avoid any confusion in terminology with George Marler's Mastiff Function or later uses of the term, Paul Strasser suggested that the new modes of behavior be called "North Function" and "South Function," based on the concentration of energy on Giant's platform.

Table 4 summarizes the general patterns that developed for North Function and South Function.

North Function

When energy was on the north side of Giant's platform, the strongest hot periods occurred on marathon recoveries. While these bore a strong resemblance to marathon recovery hot periods seen in prior phases of activity, North Function displayed distinguishing characteristics during the bimodal phase.

Strong marathon recovery hot periods showed definite indications of a concentration of energy on the vents and geysers north of Giant. Feather had its tallest eruptions during these hot periods, often reaching 8 to 10 feet tall. Feather's Satellite would usually begin within a minute of Feather's start. The timeline was roughly the same for Mastiff's first heavy boiling, and strong surging could follow within 1 to 3 minutes.

North Function eruption hot periods were distinguished by strong, steady surging in Mastiff before it built to full eruption. During this time, Mastiff's

North Function	South Function
Between eruptions:	**Between eruptions:**
GIP levels higher and more indicative	GIP levels lower and less indicative
Strongest hot periods occur on marathon recoveries	Marathon recovery hot periods may be weak or moderate
	Mastiff depth-charging and strong Bijou recoveries may occur after weak hot periods or bathtubs
Hot periods between eruptions:	**Hot periods between eruptions:**
Hot periods occur every 1-5 hours	Hot periods and/or bathtubs occur every 1-2 hours
More Mastiff discharge during hot periods	Strong hot periods occur every 6-12 hours
More Mastiff surging during hot periods	Variable Mastiff discharge; sometimes very little
Cave seldom seen, even with strong hot periods	Little to no Mastiff surging on weaker hot periods
Feather starts before Southwest Vents	Cave commonly seen with stronger hot periods
	Southwest Vents start before Feather
Grotto's behavior:	**Grotto's behavior:**
Longer marathons - 17-38 hours	Shorter marathons
	Grotto delays and extended activity by South Grotto Fountain sometimes seen prior to Giant eruptions
Eruption hot periods:	**Eruption hot periods:**
Always occur on marathon recoveries	Do not occur on marathon recoveries
Feather Satellite begins quickly (10-50 seconds)	Feather Satellite may delay up to 8 minutes
Mastiff strong surging throughout hot period	Mastiff surging variable (maximum 3-12 feet)
Giant accompanied by Mastiff and often Catfish	Mastiff did not erupt
Giant starts 1-3 minutes after the start of Mastiff	Giant starts 2-4 minutes after Mastiff has dropped
Eruptions:	**Eruptions:**
Shorter durations - 86-98 minutes, avg. 93.3 minutes	Longer durations - 91-104 minutes, avg. 99.2 minutes

Table 4: *North Function vs. South Function Chart*

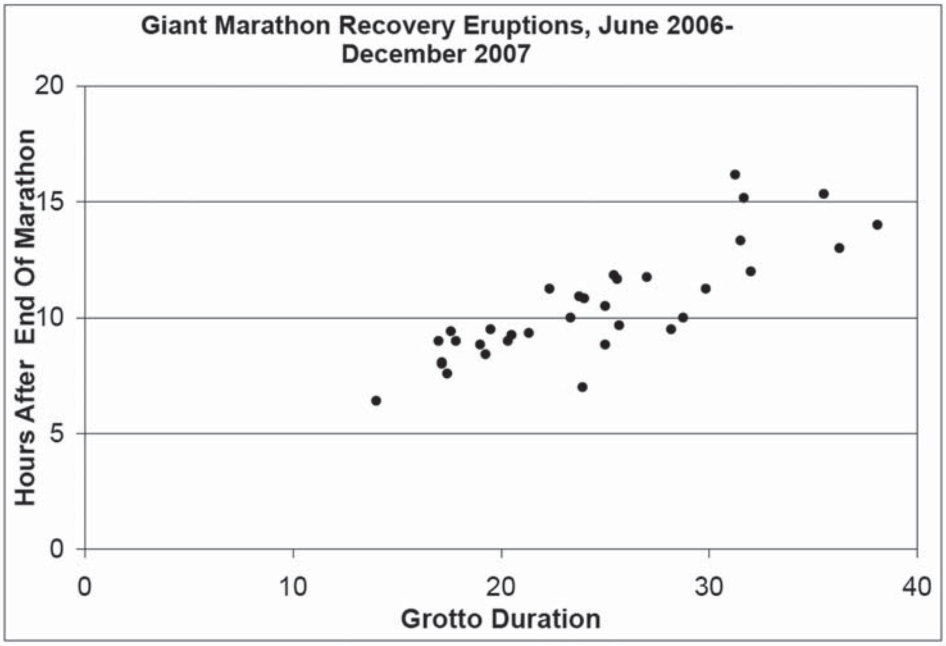

Figure 4: *Marathon recovery eruptions, June 2006-December 2007*

range of 29 to 52 percent.

As noted earlier, Giant's duration was shorter when Mastiff erupted, and consequently North Function eruptions were on average shorter than South Function eruptions. North Function durations ranged from 86 to 98 minutes with an average of 93.3 minutes, nearly 6 minutes shorter than the average of 99.2 minutes for South Function eruptions, which ranged from 91 to 104 minutes.

South Function

South Function eruptions did not occur on marathon recoveries, but Giant gave clear signs of an impending South Function eruption. Once a marathon recovery hot period had occurred with no Giant eruption, the energy would begin to shift to the south. The first strong hot period after the marathon recovery usually coincided with the start of the first Grotto after a marathon, and Giant erupted at that point in the Grotto cycle 10 times during the bimodal phase.

As long as strong hot periods were occurring, Giant could erupt at any time in Grotto's cycle. If Giant erupted during Grotto, it was most likely to do so with the first or second eruption after the previous marathon. As shown in Figure 3 (page 51), it was most common for Giant to start while Grotto was not erupting, either before or after the third eruption after the previous marathon.

If Grotto had several normal eruptions before its next marathon, Giant hot periods would usually continue at 1 to 3 hour intervals, with strong hot periods usually occurring every 7 to 12 hours. The known extremes were 6 and 15 hours. An exception to this could occur early in Giant's interval when there was not enough energy in Giant's system to produce stronger hot periods. This would result in a series of short, weak hot periods, bathtubs, and footbaths that would come to an end only with the next Grotto marathon.

During the progression of hot periods, it was not uncommon for the Southwest Vents to start prior to Feather. When this occurred, they usually started between 5 and 30 seconds before Feather, but could precede it by as much as 90 seconds. Feather's Sat-

surging could rise and fall, and even cease briefly, but if an eruption occurred surging would resume at equal or greater strength. The lone exception to this was the "double Mastiff" eruption of July 23, 2006. Once Mastiff commenced its eruption, Giant would follow within 3 minutes. With few exceptions, Catfish participated in North Function eruptions, starting 1 to 3 minutes after Giant.

With only one exception, marathons that resulted in Giant eruptions were at least 17 hours long and could be up to 38 hours long. This was a distinct change from April and May 2006, when Giant followed marathons lasting 9 to 22 hours. Interestingly, with one exception, when Giant erupted after marathons that were shorter than 23 hours, its interval had reached at least 7 days.

During the bimodal phase, the time from the end of Grotto to the start of Giant also increased significantly. Between August 2005 and May 2006, this recovery time ranged from as short as 5h 10m to as long as 9h 55m. Between June 2006 and November 2007, recovery times ranged from 6 hours 30 minutes to 16 hours 15 minutes, with most falling between 8 and 12 hours. Thus, the recovery time tended to be longer and demonstrated a much wider range than it had previously.

The amount of recovery time showed some degree of proportionality to the length of Grotto's marathon, as can be seen in the linear regression shown in Figure 5. This proportionality centered on a recovery time of about 43 percent of Grotto's duration with a ellite was not active with weaker hot periods, and Mastiff discharge was usually minimal. Significant Mastiff discharge generally occurred only with hot periods lasting at least 5 minutes. Likewise, there was very little strong boiling or surging in Mastiff during weaker hot periods, and some hot periods produced no overflow.

There could be stronger boiling and surging from Mastiff during stronger hot periods, but it was not a requirement, even for eruption hot periods. When Giant erupted on South Function, there was a wide variance in Mastiff surging, from a few boils 1 or 2 feet high to surges to as large as 12 feet. However, there was nearly always enough Mastiff discharge for overflow to reach the boardwalk viewing platform.

South Function behavior was also indicated by the activity of Cave Vent. Strong South Function hot periods usually included some activity from Cave, though it varied from boiling and overflow to full eruptions reaching 3 to 4 feet high. While eruptions of Cave to a foot or more were a good indication of energy in Giant, they were neither necessary for an eruption, nor did they guarantee an eruption. Cave's activity often increased as more strong hot periods transpired since the last marathon, but it could also be active during the hot period that coincided with the first Grotto after a marathon.

There was no formula for eruption hot periods during South Function. Feather's Satellite, usually an indicator of a strong hot period, could delay up to 6 to 8 minutes after the start of Feather during an eruption hot period. Mastiff surging was variable, but it never erupted. Giant started 2 to 4 minutes after Mastiff had dropped. Feather usually continued to erupt after Mastiff dropped, but 6 eruptions from restarts are known.

There was also distinctive South Function activity between hot periods. The strong Bijou restarts with mixed water and steam that were seen in April 2006 continued with South Function behavior during the bimodal phase. These could occur after hot periods of any length, bathtubs, or even pauses. Strong Bijou restarts were often accompanied by depth charging in Mastiff. As the activity progressed towards a Giant eruption, splashing would strengthen in both the front and back vents. The water level in the GIP was usually lower during South Function behavior, and its level was less indicative of the energy in Giant.

When the energy at Giant shifted to the south, the effects could sometimes be seen at Grotto as well. There could be significant delays in the start of Grotto prior to South Function Giant eruptions. These delays were usually in the range of 2 to 5 hours and were often accompanied by other distinctive behavior in the group such as series of eruptions by South Grotto Fountain and activity by the Central Vents. During longer delays, Grotto Fountain could cycle up and down opposite the South Grotto Fountain eruptions, along with extended overflow from Spa. Usually a significant delay in Grotto's interval *after* a South Function Giant eruption as well, even if Grotto was not delayed prior to Giant's start.

These general patterns held for the eruptions seen during the bimodal phase. The following chronological narrative will highlight the unusual events.

Narrative of Noteworthy Events

The eruption on **June 6**, 2006 occurred on a marathon recovery and included an eruption of Mastiff. The short interval of 6 ½ days gave hope that the shorter intervals of early May would persist, but the next intervals were just over 11 and 16 days, respectively.

Prior to the **June 17** Giant eruption it was noted that Mastiff was not having strong boiling or surging during longer hot periods, and no significant restart activity was seen. However, the powerful Mastiff depth charging that had been seen in April and May continued, and throughout the day on June 17 the water levels in Giant and Mastiff appeared to be much higher than they had been in previous days. In a significant change from eruption hot periods seen between April 23 and June 6, Mastiff did not have any major surging during the eruption hot period. The eruption was initiated by Giant after Mastiff had dropped.

In contrast to the activity prior to June 17, many long hot periods in late June included strong surging in Mastiff. These occurred at intervals of 2½ to 7 hours. Mastiff could reach 4 to 7 feet high, regardless of the timing in relation to Grotto's cycle. It seemed that the timing between Grotto and Giant was off somehow, and that may account for the longest interval of the bimodal phase, just over 16 days.

The events of **July 3** showed a clear change from this behavior; these will be described in detail because they exemplified South Function behavior. When observations commenced at 0700, Grotto Fountain was having periodic overflow cycles as if it were building up to an eruption. The water level in Indicator Spring

Date	Time	Interval	Mastiff	Type	Observer
6/6/06	1727	6d10h12m	1724	1	Tara Cross
6/17/06	1920vr	11d01h53m	No	3n-4	Visitor report
7/3/06	1925	16d00h05m	No	3n-2	Tara Cross
7/13/06	0835	9d13h10m	No	2e-1	Steve Robinson
7/23/06	1319	10d04h44m	1313, 1318	1	Tara Cross
7/30/06	0239	6d13h20m	0237	1	Tara Cross
8/5/06	1541	6d13h02m	1539	1	T. Scott Bryan
8/19/06	0121	13d09h40m	No	3n-5	Tara Cross
8/27/06	1143	8d10h22m	No	2e-3	Tara Cross
9/4/06	1325	8d01h42m	No	3n-2	Tara Cross
9/9/06	1242	4d23h17m	1240	1	Tara Cross
9/15/06	1410	6d01h28m	1407	1	Tara Cross
9/22/06	1006	6d19h56m	1003	1	Jeff Cross
9/27/06	2250	5d12h44m	No	3n-2	Jeff Cross
10/4/06	0256	6d04h06m	No	3n-2	Jeff Cross
10/8/06	1341	4d10h45m	No	3n-3	Jeff Cross
10/15/06	1329	6d23h48m	1326	1	Kitt Barger
10/22/06	1544	7d02h15m	No	3e-2	Jeff Cross
10/27/06	1834	5d02h50m	No	3e-6	Jeff Cross
11/6/06	1935e	~10d02h01m	?	2e-1	Electronic monitor
11/14/06	0440e	~7d09h05m	?	1	Electronic monitor
11/19/06	1610	~5d11h30m	No	3n-3	David Goldberg
11/26/06	1758	7d01h48m	1757ie	1	David Goldberg

***Table 5:** Phase 4a Eruption Table, June-November 2006*

rose and fell with Grotto Fountain, but did not vary by more than 4 inches. After each drop in Grotto Fountain, South Grotto Fountain filled and erupted for several minutes until Grotto Fountain began to rise again. Spa was full and pulsating, and one 5-foot burst was observed.

South Grotto Fountain continued to erupt at intervals of 7 to 15 minutes for the next 8 ½ hours. Series of eruptions by South Grotto Fountain had been seen in prior years but had usually lasted a maximum of 1 to 2 hours. The electronic monitor revealed that the previous eruption of Grotto had occurred at 0318e and lasted only 10 minutes. The ensuing interval of 12 ½ hours was highly unusual; it was the most significant delay of Grotto prior to Giant during the bimodal phase.

Starting at 1000, Grotto began to rumble and have occasional small splashes. Grotto Fountain had stronger cycles with episodes of boiling at 0711, 1100, and 1400. Interestingly, these occurred about mid-way between hot periods at Giant, as though the energy was shifting back and forth between the two areas. Around 1445 the Central Vents started to erupt, and Grotto Fountain's cycles became stronger, leading to a full eruption at 1545. The weak eruption lasted just 5 minutes, but Grotto started normally at 1548 and erupted for 75 minutes.

At Giant, the first observed hot period on July 3 took place at 0737 and lasted 8m 15s. It became apparent that energy had shifted at Giant when Cave began erupting to 3 feet about 4 minutes into the hot period. This was a major change from the hot periods seen in the previous week, during which Cave had never done more than bubble to a few inches.

Events occurred hourly at Giant for the next 10 hours: first a bathtub, and then a series of eight weak hot periods. The hot period durations ranged from 58s to 4m 33s and Mastiff's activity varied from no overflow at all to light discharge with boiling to 1 foot or less. Only one hot period included Feather's Satellite. Each hot period was preceded by the Southwest Vents erupting 30 to 45 seconds prior to the start of Feather. Surprisingly, one hot period included a restart with several large vertical surges in Giant.

After each event, Bijou came on strong with mixed water and steam, and both vents of Mastiff depth charged energetically. Bijou's eruption would transition to water after 10 to 15 minutes, but Mastiff's activity remained strong throughout the interval between hot periods and got progressively stronger throughout the day. Immediately prior to the hot period at 1533, Mastiff had a sustained surge from its back vent that was 6 feet wide and 5 feet tall and lasted about 5 seconds. This type of activity was seen again, but remained uncommon during the bimodal phase.

The series of hot periods was followed by two Bijou pauses that did not result in a hot period. After this, the activity in Bijou and Mastiff weakened significantly. The next Bijou pause led to a Giant hot period displaying behavior that would come to typify South Function eruption hot periods. The Southwest Vents started prior to Feather, Cave erupted to 3 to 4 feet, and Feather continued after Mastiff dropped. Giant quickly began to have large surges that became progressively larger until its eruption began at 1925. Grotto had a normal eruption at the expected time during Giant.

The events of July 3 provided a blueprint for South Function Giant eruptions during the bimodal phase. Though the Grotto delay of 8 hours was the longest known prior to Giant, similar long delays usually signaled an impending Giant eruption. Series of eruptions by South Grotto Fountain with overflow from Spa were seen on a number of occasions prior to South Function Giant eruptions. Likewise, series of short, weak hot periods at Giant with strong depth charging in Mastiff in between were an indicator for Giant, and the activity of Cave during strong hot periods showed that the energy was on the south side of the platform.

Fears that Giant would continue to slow down as it had during the summer months of 1997 were allayed when the next interval was 9d 13h. During the days prior to Giant's eruption on **July 13**, observers noticed an increase in the strength of restart activity following strong hot periods. My report for July 9 and 10[41] states that

> Probably the most remarkable thing about the restarts was the strength of the vertical surging in Giant, which was voluminous and usually reached about one third of the way up the cone, and at times poured water out of the cone. This was a major departure from hot periods seen during the previous interval, which included very weak restarts, if any.

This information was of special interest because on July 13, Giant had its first known eruption from a Feather restart since 1997, and only the second known since at least 1955. Though this behavior had been extremely rare prior to 2006, it occurred on at least two other occasions in 2006 and three more times in 2007 for a total of six during the span of this article.

The eruption of **July 23** was distinctive in that it was the second known case of a "double Mastiff" eruption in 2006. It took place on a recovery hot period after a marathon lasting 32 hours and events progressed in a similar fashion to the events seen on April 30, 2006, described on page 56. The eruption itself was superlative in nearly every sense. Though it was not measured, observers agreed that it was one of the tallest of 2006, possibly reaching 250 feet or more. Mastiff continued to erupt for about 5 minutes after Giant started, and Catfish had a strong eruption with a powerful steam phase.

Normal North Function eruptions followed at intervals of 6 ½ days on **July 30** and **August 5**. These

Date	Time	Interval	Mastiff	Type	Observer
12/3/06	0810e	~6d14h12m	?	3n-1	Electronic monitor
12/13/06	0500e	~9d20h50m	?	2e-1	Electronic monitor
12/23/06	1940e	~10d14h40m	?	2e-1	Electronic monitor
1/3/07	0215e	~10d06h35m	?	2n-2	Electronic monitor
1/11/07	0950e	~8d07h45m	?	1	Electronic monitor
1/16/07	1335e	~5d03h45m	?	2n-5	Electronic monitor
1/23/07	1030e	~6d20h55m	?	2e-1	Electronic monitor
2/1/07	0800e	~8d21h30m	?	1	Electronic monitor
2/12/07	0510e	~11d21h10m	?	1	Electronic monitor
2/18/07	0232e	~5d21h22m	?	2e-4	Electronic monitor
2/22/07	2057e	~4d18h25m	?	2e-1	Electronic monitor
2/27/07	0442e	~4d07h45m	?	2n-2	Electronic monitor
3/4/07	1325ie	~5d08h50m	?	3e-2	Electronic monitor
3/13/07	1431	~9d00h06m	1428	1	David Goldberg
3/22/07	0810wc	~8d17h39m	?	3n-2	Electronic monitor
3/29/07	0222e	~6d18h12m	?	2n-1	Electronic monitor
4/13/07	0332e	~15d01h10m	?	1	Electronic monitor
4/24/07	1540vr	~11d11h08m	?	3n-2	Electronic monitor

Table 6: *Phase 4b Eruption Table - November 2006-April 2007.*

eruptions were notable for the size of the preceding Mastiff eruptions, estimated at 60 to 80 feet in both cases.

During the span from August 6 to August 16, Grotto entered a phase in which 9 out of 11 eruptions were short marathons with durations ranging from 8 ½ to 19 ½ hours. While this type of activity had been seen during the superlative April 2006 activity, in August it appeared to stall the buildup of energy in Giant, and the end result was an interval twice as long as the previous two, 13d 10h, when Giant finally erupted on **August 19**. Throughout the bimodal phase, series of Grotto "mini-marathons" resulted in many of Giant's longest intervals. This activity was characterized by series of 3 to 6 consecutive marathons with most durations less than 17 hours. In most cases, normal Grotto eruptions would not occur consecutively. When Giant finally erupted, it could be either North or South Function, but it was most common for the eruption to occur during the first Grotto after the previous marathon (Type 2e-1).

Grotto's activity returned to a more normal pattern after August 19, and typical South Function eruptions occurred on **August 27** and **September 4**. On **September 9**, Giant closed its shortest interval since April at 4 days 23 hours. Giant's intervals stabilized even more in September and October, with all intervals during those months falling between 4 days 10 hours and 7 days 3 hours. Notable during this time were consecutive eruptions on **October 4** and **October 8** that occurred during Feather restarts.[42]

On **November 6**, Giant erupted during the first eruption of Grotto after a marathon, and that Grotto also became a marathon. This eruption type, represented as 2e-1 in my previous discussion of Giant's relationship to Grotto, had occurred on only one other known occasion since August 2005 and was uncommon prior to that time. However, it merits mention here because eruptions of this kind became noticeably more common after November 2006, occurring a total of eight times[43] over the next 12 months.

Interestingly, this type of eruption occurred after Grotto marathons lasting 10 to 17 hours, showing almost no overlap in duration with marathons that produced North Function eruptions. These eruptions could start at any time during the first three hours of Grotto.

Little is known about Giant's behavior during the winter months due to lack of observations. Electronic monitors revealed that Giant's intervals became more erratic between November 2006 and April 2007, ranging from 4d 8h to 15d 1h. Eruptions were

Table 7: Phase 4c Eruption Table - May-November 2007.

Date	Time	Interval	Mastiff	Type	Observer
5/1/07	1911	~7d03h31m	1910	1	Steve Eide
5/9/07	1413	7d19h02m	No	3b-3	T. Scott Bryan
5/14/07	1209	4d21h56m	No	3a-2	T. Scott Bryan
5/19/07	1209	5d00h00m	1206	1	T. Scott Bryan
5/24/07	0532	4d17h23m	No	3e-5	Graham Meech
5/31/07	0939	7d04h07m	0937	1	Graham Meech
6/7/07	0333	6d17h54m	0331	1	Heinrich Koenig
6/13/07	0216	5d22h43m	No	3e-4	Heinrich Koenig
6/20/07	1412	7d11h56m	1410	1	T. Scott Bryan
6/28/07	1233	7d22h21m	1231	1	Tara Cross
7/6/07	1949	8d07h16m	No	2?-1	Lynn Stephens
7/13/07	0714	6d11h25m	No	3e-2	Karl Hoppe
7/18/07	0808	5d00h54m	0805	1	Lynn Stephens
7/24/07	0006	5d15h58m	No	3n-1	Tara Cross
7/28/07	0747	4d07h41m	0744	1	Tara Cross
8/4/07	0440	6d20h53m	0438	1	Lynn Stephens
8/10/07	0548	6d01h08m	No	2n-3	Kitt Barger
8/17/07	1251	7d07h03m	No	2e-1	T. Scott Bryan
8/25/07	0528	7d16h37m	No	3n-2	Tara Cross
8/30/07	1017	5d04h49m	No	3n-5	Tara Cross
9/8/07	1532	9d04h15m	1530	1	Tara Cross
9/15/07	2137	7d06h05m	No	2e-1	Dean Lohrenz
9/23/07	~0300	~7 1/4 d	?	1	inferred
9/28/07	~2345vr	~5d21h	~2340vr	1	Dave DeWitt
10/5/07	0645ie wc	~6d07h	?	3e-2	webcam
10/10/07	1034	~5d04h	No	2e-2	Gary Einstein
10/16/07	1325	6d02h51m	1322	1	Bill Warnock
10/22/07	1231ie wc	~5d23h06m	?	3n-3	Visitor report
10/26/07	2347	~4d11h16m	2345	1	Tara Cross
11/1/07	0825	5d08h38m	No	2e-1	Tara Cross

of all types, though most South Function eruptions occurred prior to or during a Grotto marathon.

When observations resumed in April 2007, Giant was in the midst of its longest intervals since June 2006. However, the patterns of the bimodal phase had persisted through the winter, and starting with the eruption on **May 1** Giant became remarkably consistent, having just two intervals longer than 7 days 23 hours from May through November.

The activity of Giant and Grotto on **May 9** displayed the patterns of South Function behavior as established in 2006. A delay of several hours at Grotto was accompanied by eruptions of South Grotto Fountain and Spa overflow. At Giant, a strong hot period with Cave erupting to 1 foot was followed by a series of hourly weak hot periods, leading to the eruption hot period 5 hours later. Though the buildup to the eruption was similar to past behavior, the eruption hot period itself was unusual. Everything seemed to be sluggish, from a slow rise of water in Mastiff to Feather's start nearly 2 minutes after the start of the Southwest Vents. After overflowing weakly for only 5 minutes, Mastiff dropped. Ordinarily such weak activity would result in a short hot period, but Feather and Feather's Satellite continued to erupt, Bijou restarted, and Giant began to have voluminous vertical surges that triggered the eruption just 7 minutes after the start of Feather. This was by far the weakest observed hot period activity leading to a Giant eruption during the bimodal phase.

Also notable was the eruption of **May 24**, which took place after 30 hours of hourly events at Giant. Most hot periods were weak and included very little activity in Mastiff, and Cave was not active. However, as with other South Function intervals, Bijou and Catfish responded to events with powerful activity. In contrast with typical South Function behavior, with strong hot periods usually lasting 8 to 10 minutes, the eruption hot period was the first that day to exceed 6 minutes. Giant's eruption occurred on a Feather restart.

In all, May 2007 was the best single month of the bimodal phase, with 6 eruptions. The pace slowed slightly in June, but not to the extent that it had in prior years. The Grotto marathon that resulted in Giant's eruption on **June 7** was the longest during the bimodal phase at 38 hours. The Giant and Grotto groups exhibited behavior that was not seen at any other time during the bimodal phase prior to Giant's eruptions on **June 13** and **June 20**. Normally, Bijou's eruptions were strong, except for the time during and after Grotto marathons. On June 12 and again on June 19, Grotto erupted for about 3 hours, but Bijou reacted as though Grotto was entering a marathon. Its eruption weakened until it was barely splashing or stopped erupting. Mastiff also became weak, and water levels dropped in the GIP. However, hot period activity continued in relatively normal fashion.[44] [45] It is interesting to note that in both instances, Giant erupted within 24 hours after this behavior occurred. The eruption of **June 20** was also notable because it occurred on the recovery after a marathon lasting just 14h. This was the only instance during the bimodal phase when Giant erupted on a marathon recovery hot period after a marathon lasting less than 17 hours. The recovery time of 6h 25m was also the shortest known for the bimodal phase.

Following the end of a Grotto marathon on **July 6**, there was a Grotto Fountain solo. A Rocket major followed at 1941 prior to the start of Grotto, which was not seen because observers were watching a Giant hot period that led to an eruption 8 minutes after Rocket's start.[46] From June 30 to July 11, Grotto had 12 eruptions, 10 of them marathons. Giant responded with South Function eruptions on July 6 and July 13 before having three intervals under 5d 16h. Giant closed the shortest interval of the bimodal phase, 4d 7h 41m with a North Function eruption on **July 28**. A North Function eruption followed on **August 4**.

Between August 10 and 30, Giant had four consecutive South Function eruptions. Three of the eruptions (August 10, 25, and 30) occurred after behavior that was similar to that seen prior to the May 24, 2007 eruption. During series of hourly events, Giant's stronger hot periods did not exceed 8 minutes, and there was little activity from Mastiff. Eruptions on **August 10** and **August 25** occurred on Feather restarts. Activity prior to Giant's eruption on **August 30** was of interest because stronger hot periods were also characterized by early Bijou restarts. Following the start of Bijou's activity about 4 minutes after Feather, Mastiff would drop slightly below overflow, but the hot period would continue for about 2 minutes until Mastiff dropped out of sight and Feather stopped. The eruption hot period showed a change in this pattern, as Mastiff continued to boil and overflow even though Bijou restarted only 3 ½ minutes after Feather.

After a series of short marathons, Giant's eruption on **September 8** closed the longest interval since

April. On **September 15**, the activity at Grotto prior to Giant's eruption was similar to what had occurred on July 6. Grotto's first eruption after a marathon was preceded by a Rocket major, but rather than erupting immediately after Rocket, Giant started 45 minutes later, 31 minutes after the start of Grotto.[47]

Starting on September 23, Giant finished its remarkable 7-month period of regular intervals with 2 full months in which its intervals did not exceed 6d 14h. Observations on Giant's pre-eruptive activity became scarce, but no major changes in behavior were reported. On **October 26**, Giant erupted following its longest known recovery time after the end of a marathon, 16h 15m. It should be noted that this estimate is based on Grotto's electronic monitor rather than visual observation.

Phase 5: November 2007-April 2008

It is unknown how long the bimodal behavior persisted after November 1 due to lack of observations. Starting in December 2007, Giant's intervals became more erratic, ranging from 5d 10h to 14½d. Electronic data were not available for Giant from September 2007 through February 2008; consequently, specific information about Giant eruptions that were not seen during that period is not known. However, based on electronic data and visual observations from February through April 2008, it was clear that there were changes in Giant's behavior, and the bimodal phase had definitely come to an end by mid-February.

The first obvious indication that the bimodal phase had ended came when a tour guide reported that Mastiff erupted prior to Giant's eruption on February 27, even though it was not a marathon recovery eruption. The electronic data for Grotto also showed a change in February as well, as Grotto had only one eruption exceeding 24¼ hours between February 14 and the end of April.

Giant surprised observers on April 29 by erupting 5h 20m into a Grotto marathon. Giant had not erupted more than 3 hours into a marathon at any previous time during the span of this article. Whether coincidence or not, this eruption also brought the 2005-08 active phase to a close. Due to trail closures, little is known about the events surrounding the eruption of April 29, but changes were noted in Giant and its related geysers in late April and May that showed a clear shift of energy. Starting on April 22, Oblong reverted to its pre-2006 behavior with longer and more erratic intervals. Sometime between April 29 and May 3, South Purple Pool stopped overflowing and North and East Purple Pools started overflowing.[48] Throughout May, Grotto seemed to be returning to its pre-2006 patterns, with long series of short eruptions between marathons.

At Giant, the last known strong hot period occurred on May 3. After this, hot period activity gradually decreased. Hot periods became shorter, and intervals between them increased. By May 11, Bijou was rarely pausing, and Mastiff was having powerful depth-charging almost constantly.[49] Though Cave Vent was active with some hot periods in mid-May, it was not considered an encouraging sign because no hot periods lasted longer than 4 minutes. By the end of May the only events seen at Giant were occasional bathtubs, and Bijou showed no signs of slowing down. As of press time, the interval following the April 29, 2008 eruption had reached over two months.

Section Three: Related Geysers

Giant and its related features represent one of the largest networks of connected springs and geysers in Yellowstone, and as seen earlier with Grotto Geyser, the relationships can be very complex. This section will describe the activity of geysers related to Giant, focusing on the activity during the summer months of 2006 and 2007, since only Oblong was monitored electronically.

The Grotto Group

The behavior of springs and geysers in the Grotto Group was determined by the cycles of Grotto. Prior to an eruption of Grotto, water levels rose in Grotto Fountain, "Indicator Spring," and South Grotto Fountain. Grotto Fountain usually started the action, though it could be preceded by South Grotto Fountain, "Startling," and the "Central Vents." If Rocket erupted, it most often did so 1 to 2 hours into an eruption of Grotto, while Spa was active only during Grotto marathons. The water levels in "Marathon Pool" and "Variable Spring" dropped while Grotto was in marathon.

Grotto Fountain Geyser is located to the north of Grotto Geyser. Its small cone sits within a shallow basin, and its eruptions are typically 20 to 40 feet high. Grotto Fountain usually acted as an indicator for Grotto, erupting a few minutes beforehand. Af-

Date	Time	Interval	Mastiff	Type	Observer
11/6/07	1704	5d09h39m	1703ie wc	1	Kate Parry
11/12/07	0934ns wc	~5d16h30m	?	?	webcam
11/18/07	1159ns wc	~6d02h24m	?	1	webcam
11/25/07	0151ns wc	~6d13h52m	Yes	1	webcam
12/3-7/07	unknown	unknown	?	?	inferred
12/10/07	1645ie wc?	unknown	?	1?	webcam
12/14-20/07	unknown	unknown	?	?	inferred
12/21/07	1315vr	unknown	?	1	Visitor report
12/30/07	0843	~8d19h28m	0841	1	Kitt Barger
1/13-14/08	overnight	~14 1/2 d	?	?	inferred
1/21-22/08	overnight	~8d	?	?	inferred
1/26-27/08	unknown	~5d	?	?	inferred
2/4/08	0700ns	~8d	?	1	Visitor report
2/9/08	2205e	~5d15h05m	?	2n-6	Electronic monitor
2/19/08	0932	~9d11h27m	?	1	Graham Meech
2/27/08	1533 wc	~8d06h01m	Yes	2n-2	Visitor report
3/4/08	0415e	~5d13h42m	?	1	Electronic monitor
3/11/08	1830e	~7d14h15m	?	1	Electronic monitor
3/22/08	2310e	~11d04h40m	?	3n-2	Electronic monitor
3/28/08	1751ns wc	~5d18h41m	?	2e-3	webcam
4/4/08	2245e	~7d4h54m	?	1	Electronic monitor
4/16/08	1039ns wc	~11d11h54m	?	2e-1	webcam
4/29/08	1502	~13d04h23m	Yes	2e-1	Steve Eide

Table 8: *Phase 5 Giant eruption table, November 2007-February 2008.*

ter a marathon, the time between the start of Grotto Fountain and the start of Grotto was usually longer, ranging from 10 to 30 minutes. While it was not typical for Grotto to erupt without being preceded by Grotto Fountain, this circumstance was observed a handful of times in 2006-07.

Grotto Fountain's duration was highly variable in 2006-07. A typical eruption lasted 15 to 25 minutes, but durations were usually longer with the first Grotto after a marathon. These eruptions ranged from 25 to 40 minutes and could also be more powerful, sometimes alternating between water phase and mixed water and steam. Grotto usually started during Grotto Fountain's eruption, though it could start a few minutes after Grotto Fountain was finished.

Prior to 2006, Grotto Fountain eruptions without an ensuing eruption of Grotto were rare. This behavior was first observed during the span of this article on March 19, 2006 and was described by Mike Keller as follows[50]:

> I saw something I have never seen before at Grotto today. Grotto was definitely post marathon and had not erupted yet at 0845. The pressure pool and Grotto Fountain kept filling and dropping until 1116, when Grotto Fountain finally started. After 21 minutes, it stopped. Grotto NEVER erupted! The Fountain was a typical 25-35 foot eruption, but Grotto just sat there. Over the next hour South Grotto Fountain erupted every 7-14 minutes. At 1327 Grotto Fountain started again. This time Grotto erupted (start at 1338). Grotto Fountain lasted 18 minutes and reached 25-35 feet as before. When I left the basin at 1905, Grotto was still in eruption. Spa was in overflow and looked ready to start erupting.

Solo Grotto Fountain eruptions continued to occur in similar fashion throughout 2006 and 2007. In all observed cases, these occurred when the start of Grotto was expected after a marathon.

Solo Grotto Fountain eruptions usually lasted 19 to 23 minutes, during which time Grotto would make grumbling noises and sometimes splash a few times. Once Grotto Fountain had finished without an eruption of Grotto, the whole group could be quiet for a period of time. However, it was not uncommon for the rest of the group to demonstrate behavior indicating a delay of Grotto: activity by the Central Vents, series of eruptions from South Grotto Fountain, and, rarely, eruptions of Startling.

Most solo Grotto Fountain eruptions occurred 2 to 3 hours prior to the eventual Grotto start, with a normal range of 1 to 5 hours. Table 9 is a list of all known solo Grotto Fountain eruptions along with the eventual Grotto start time and the delay in between. Note that there was an increase in observed solo Grotto Fountain eruptions in 2007, with 21 known cases as compared with 14 in 2006. One likely reason for this was their association with Grotto marathons. As noted in the earlier discussion of Grotto, a greater percentage of eruptions were marathons in 2007 as compared with 2006, which provided more opportunities for solo Grotto Fountain eruptions to occur.

Also of interest was the trend for solo Grotto Fountain eruptions to be more common during some intervals of Giant than others, especially in 2007. The table shows that eruptions tended to come in clusters. While it is true that this often coincided with a cluster of Grotto marathons, solo Grotto Fountains were not always seen at times of consecutive marathons. Note, for example, the period from September 2-7, 2007, when Grotto had five consecutive mara-

Solo Grotto Fountain 2006

Date	GF solo	Grotto	Delay
3/19	1116	1338	2h22m
5/28	0715ie	0926	~2h11m
6/21	0929	1159	2h30m
7/7	1946ie	2305ns	~2h19m
7/24	0850ns	0951ns	~1h01m
8/15	1236ie	1513	~2h37m
8/28	1520ie	2000	~4h40m
8/31	0856	1212	3h16m
9/4	0015	0242e	~2h27m
10/2	1006ns	1322e	~3h16m
10/3	1057	1536e	~4h39m
10/12	1032ie	1343	~3h11m
10/13	1903	2130	2h27m
12/21	1511ie	1727e	~2h16m

Solo Grotto Fountain 2007

Date	GF solo	Grotto	Delay
1/18	1027ie	1304ie	~2h37m
5/21	1442	1713	2h31m
5/22	2300	0504	6h04m
5/26	2004ie	2357e	~3h53m
5/28	1837	2128e	~2h51m
6/22	1540	1722	1h42m
7/1	2012	2218e	~2h06m
7/3	2204	0106	3h02m
7/6	1815	?1947-2007	>1h32m
7/9	1325ns	1546e	~2h21m
7/10	1451ie	1704	~2h13m
7/11	1448	1713	2h15m
7/30	1838ns	2139e	~3h01m
8/11	1359	1701	3h02m
8/13	1144	1441e	~2h57m
8/14	1751	2047	2h56m
8/16	0925	1402	4h37m
8/21	1058	1403	3h05m
8/23	1152	1430	2h38m
10/30	1825	2149e	~3h24m

Table 9: *Solo Grotto Fountain Eruptions.*

thons but no solo Grotto Fountains were seen. It is postulated that solo Grotto Fountains were a result of decreased energy in Grotto due to Giant's activity. The "clusters" may have been related to the extent that Giant was affecting the energy level of Grotto.

"Indicator Spring," also called the "pressure pool," is a large hole located west of Grotto Fountain Geyser. Its water level corresponds with that of Grotto Fountain. It is capable of erupting, but there were no indications that it did so during 2006-07. Its water level was only visible from the trail when Grotto Fountain appeared to be close to an eruption and its water cycled up and down with Grotto Fountain's periodic phases of boiling. Indicator Spring rarely exceeded its usual maximum level of 2 to 3 inches below its rim, but on May 7, 2006, it was observed to overflow in conjunction with other unusual events in the Grotto complex, described in detail on page 58.

South Grotto Fountain Geyser is located southeast of Grotto Fountain. A pair of vents participate in its eruptions, which range from small splashes to a few feet to powerful bursts to 12 to15 feet. South Grotto Fountain was usually active around the time of a Grotto start in concert with Grotto Fountain. Prior to 2006-07, South Grotto Fountain was known to have independent eruptions in conjunction with activity by the Central Vents at times when Grotto's start appeared to be delayed.

When South Grotto Fountain erupted independently in 2006-07, it was of special interest to observers. Though series of South Grotto Fountain eruptions had been seen in prior years, significant delays in Grotto could be a precursor to South Function Giant eruptions during the bimodal phase. This behavior was first noted on July 3, 2006, when Grotto's start was delayed for a full 8 hours. During this time, Grotto Fountain cycled up and down opposite to the cycles of South Grotto Fountain. Full eruptions of South Grotto Fountain took place every 7 to 15 minutes. Although this behavior was seen again during Grotto delays, it usually progressed over a shorter time, typically 1 to 2 hours.

Independent series of South Grotto Fountain eruptions could also be seen in the first day or two after a Giant eruption. They were also sometimes seen between a solo Grotto Fountain and the ensuing Grotto. This activity was also seen during or at the end of normal eruptions of Grotto on a few occasions.

"Startling Geyser" is invisible from the trail unless it is erupting. Its small vent is located just southwest of South Grotto Fountain's crater. Startling usually erupted around the time of an expected Grotto start, but was reported only six times in 2006 and four times in 2007. Its eruptions did not appear to be related to Giant's activity, and it did not participate in the series of eruptions by South Grotto Fountain that were often a precursor to South Function Giant eruptions.

The **Central Vents** sit on the sinter formation between Grotto and Rocket. Their eruptions usually reach a foot or less, and their activity has often been associated with delays in the start of Grotto. The role of the Central Vents in delayed Grotto eruptions in 2006-07 was not closely studied. As seen in the 1990s, the Central Vents were often active along with series of independent eruptions by South Grotto Fountain.

Rocket Geyser occupies a broad cone immediately north of Grotto. Rocket often splashes prior to and during eruptions of Grotto, but also has major eruptions that usually occur during eruptions of Grotto. Rocket majors are usually 20 to 50 feet tall and last 1 to 8 minutes, though some may be longer. From the 1980s through 2006, Rocket majors typically occurred within 1 to 2 hours of Grotto's start. While this behavior was seen a majority of the time in 2006-07, variations became more common, especially in 2007. A total of 35 eruptions were observed in 2006, while 24 were seen in 2007. An undetermined number of Rocket majors may have been missed.

In 2006, 30 of Rocket's 35 eruptions occurred in the range of 50m to 2h 6m after Grotto's start. In 2007, there were two clusters within the ordinary time for a Rocket major: four eruptions between 56 to 66 minutes, and six eruptions (including a pair of eruptions that occurred 16 minutes apart during the same Grotto eruption) between 100 and 120 minutes. Prior to 2006, instances of Rocket eruptions prior to the start of Grotto were rare. Rocket erupted prior to Grotto on five known occasions in 2006-07, with Rocket's eruption preceding Grotto by 4 to 14 minutes. Another two eruptions occurred within 10 minutes after Grotto's start.

Rocket eruptions prior to or within the first 3 hours of Grotto are shown in the histogram in Figure 5. The comparison of data for 2006 and 2007 shows that Rocket was more active in 2006, and the timing of its eruptions was more variable in 2007.

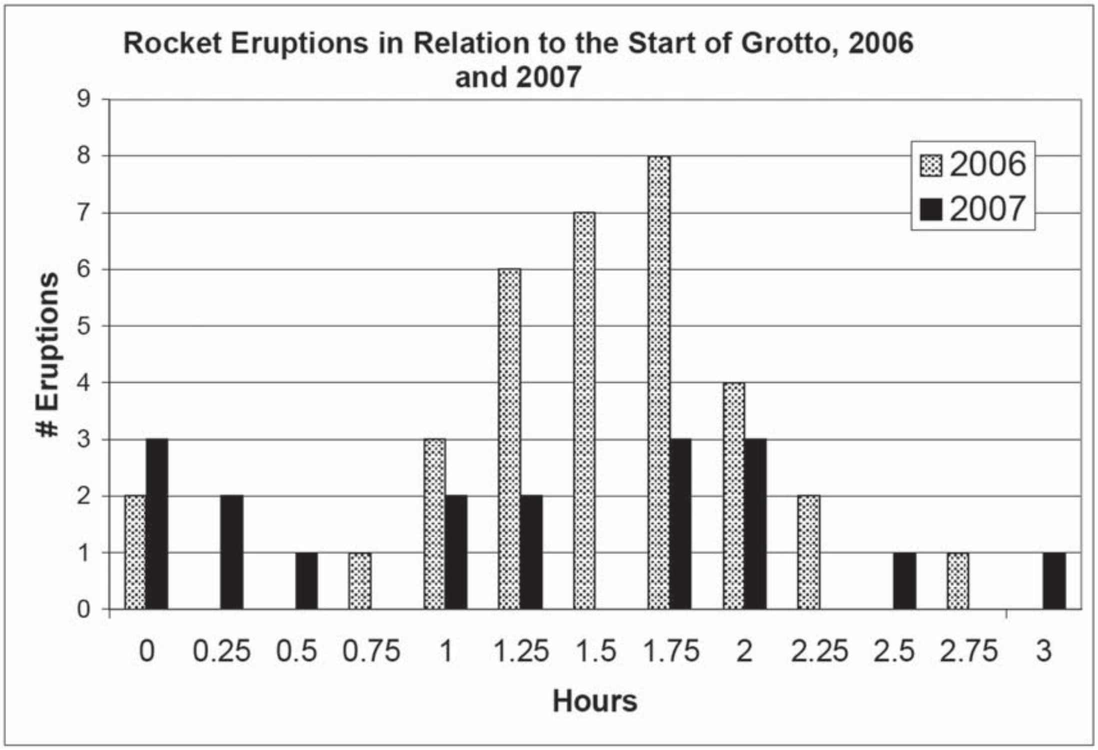

Figure 5: *Rocket Eruptions in Relation to the Start of Grotto.*

Date	Grotto Start	Rocket	Delay	Grotto Dur.
5/20/06	0009e	0750	~7h41m	7h48m e
8/12/06	2241e (8/11)	1005	~11h24m	11h31m e
6/24/07	1722 (6/22)	1248	19h26m	19h48m
7/4/07	0106	1158ie	~10h52m	12h15m e
7/18/07	0920 (7/16)	1636	31h16m	31h38m
8/7/07	1631e (8/5)	0624	~13h53m	~14h15m
11/1/07	0623e	1905ie	~12h28m	12h44m e

Table 10: *Rocket Eruptions at the End of Grotto Marathons.*

While most Rocket majors were followed by the end of Grotto within 20 to 30 minutes, Rocket occasionally erupted at its typical time during a marathon. The increase in Grotto marathons in 2007 as compared to 2006 was a possible factor in the decline of Rocket's activity in 2007. However, Rocket sometimes erupted at the *end* of a Grotto marathon, as seen twice in 2006 and five times in 2007. Table 10 shows that these eruptions could occur during marathons of almost any length, and Grotto usually ended within 20 to 30 minutes of Rocket.

"Variable Spring" is located east of Grotto Geyser and occupies a steep-sided pool with water that is normally a clear, bluish color. Variable Spring was aptly named. During normal cycles of Grotto, it was usually full and overflowing, with gentle bubbling. However, starting 3 to 6 hours into a marathon, Variable's water level would gradually drop until it was 4 to 8 inches below its rim. While this behavior helped observers determine when Grotto was having a marathon, its water level was not a reliable way to estimate how long the marathon had been in progress. Likewise, the recovery of the water levels after the end of a marathon was only loosely helpful in guessing when Grotto had stopped. When Grotto's duration extended beyond 25 to 27 hours, Variable's water level would sometimes drop over a foot below the rim. The water became muddy, accompanied by splashing and churning. The frequency of this behavior in 2006-07 is unknown because it was not carefully documented.

Spa Geyser has a gently sloping, oval crater north of Grotto at the intersection of the main paved path and the spur path to Riverside Geyser. Eruptions of Spa are usually associated with Grotto marathons. During the 1980s and 1990s, Spa's activity was considered to be part of the definition of a Grotto marathon. However, as Grotto began to have more eruptions of intermediate length, action by Spa was not always seen. When Spa was active in 2006-07, it usually commenced activity 5 to 6 hours after the start of a Grotto marathon and continued having occasional bursts for several hours. Spa was also known on rare occasions to have a second series of eruptions shortly after the end of a marathon.

Spa sometimes participated in the abnormal activity seen during delays of Grotto. When South Grotto Fountain was having series of independent eruptions, Spa was sometimes full, pulsating, and overflowing, which was not typical of its behavior when an eruption of Grotto was imminent. Spa could have sporadic small splashes during this behavior as well.

"Marathon Pool" is the northernmost spring of the Grotto Complex, located northeast of Grotto Fountain Geyser along the paved path to Riverside Geyser. Marathon Pool occupies a shallow, gravelly basin that does not capture much notice. It shows its connection to Grotto by its lowered water level when Grotto has a marathon. In 2006-07 it would drop anywhere from several inches to near empty during marathons. On rare occasions at times of exceptionally low water, Marathon Pool was observed to have small splashes to 1 to 2 feet. The typical water level in Marathon Pool was usually several inches below its rim. However, on August 10, 2007, Marathon Pool overflowed following a South Function eruption of Giant.[51] This was the only such report in 2006-07, but it may have happened at other times since observations immediately after Giant eruptions were scarce.

Oblong Geyser occupies a large pool ensconced

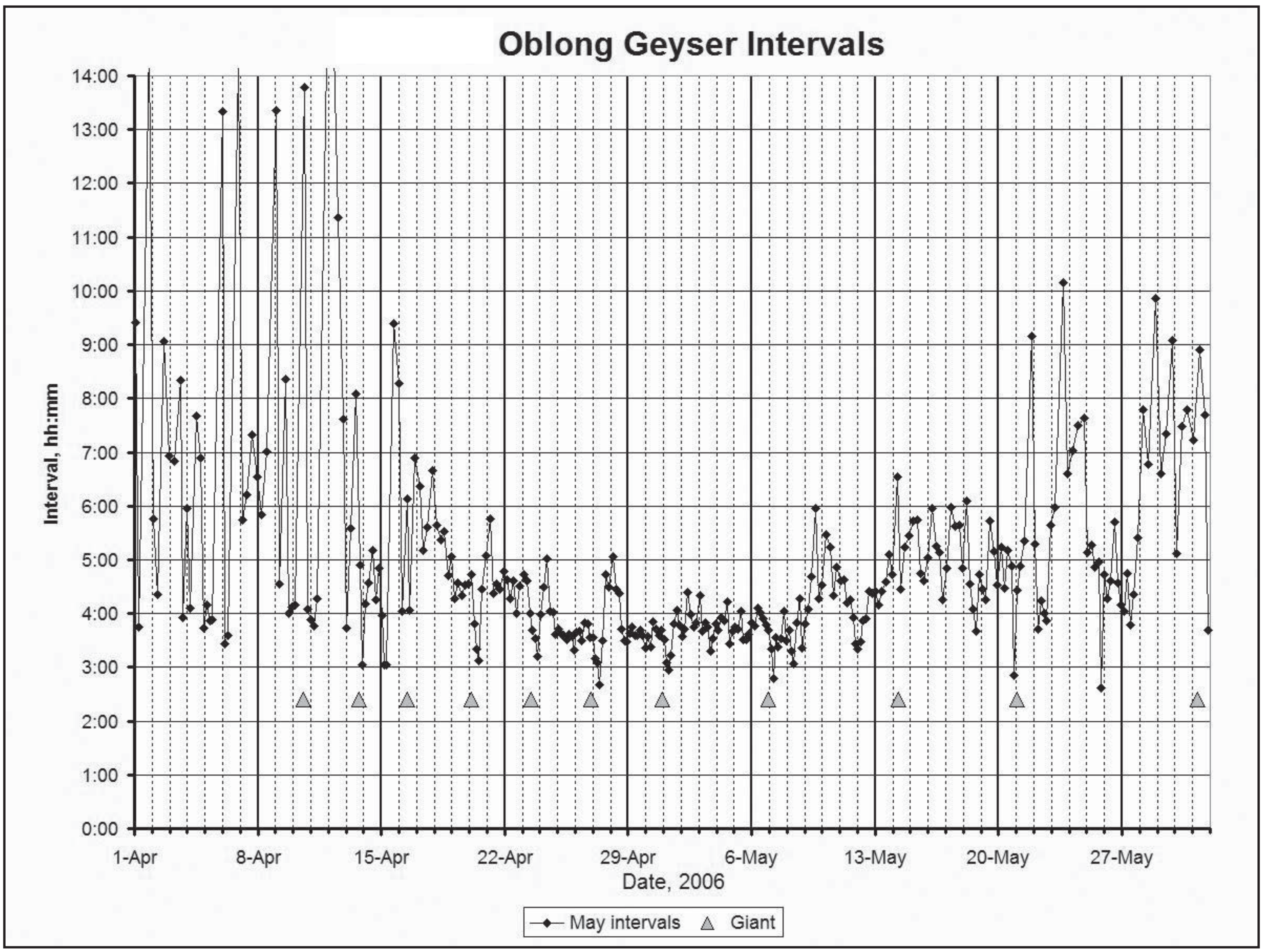

Figure 6: Oblong intervals, April-May 2006.

in a broad sinter formation south of Giant next to the Firehole River. Oblong's eruptions usually reach 20 to 30 feet and are accompanied by thumps that can easily be heard from the boardwalk. The connection between Oblong and Giant has been variable over the years. While no systematic study of the relationship between Oblong and Giant was attempted in 2005-08, the connection was easily seen in Oblong's activity.

The most obvious evidence of the Oblong-Giant connection was the correlation between Oblong's intervals and Giant's activity. As previously discussed, Oblong reacted to Giant's increased activity in April 2006 with dramatically shortened intervals. When Giant's intervals lengthened in May, Oblong's intervals also increased. This can be seen in Figure 7. The triangles below the interval graph show when Giant's eruptions occurred. This also demonstrates that Oblong often reacted to Giant eruptions with anomalously short or long intervals. This pattern persisted throughout the bimodal phase, while Oblong maintained a usual range of 3- to 6-hour intervals.

Other changes were seen at Oblong during the exceptional activity of April 2006. The size of Oblong's eruptions noticeably increased, along with the amount of discharge expelled. In contrast to its usual behavior, Oblong was boiling almost constantly between eruptions on April 22 and 23, 2006. This "mid-cycle boiling" was reported only twice following April 2006. On July 1, 2006, and again on September 2, 2006, mid-cycle boiling occurred in conjunction with Giant hot period activity.

In keeping with this, it was not unusual for Oblong to erupt near the time of a Giant hot period. This connection was particularly notable on October 15, 2006, during a marathon recovery. Instead of having its usual up and down cycles, Oblong's water level had been static in the hour prior to Giant's marathon recovery hot period. Oblong finally rose and erupted about 24 minutes after the start of Giant.[52]

The **Purple Pools** are located across the Firehole River to the east and slightly south of Giant. They are best seen from a distance at Giant's viewing platform. South Purple Pool is the largest of the three springs, consisting of two vents. It is the only one that overflows, and its runoff channel can be seen from the Giant area. East Purple Pool is the middle spring and sits next to a rather steep hillside. North Purple Pool is the northernmost spring and the easiest to see from the boardwalk. All of the Purple Pools are capable of geyser activity, but eruptions have been extremely rare in recorded history. It is believed that eruptions of the Purple Pools can occur only when the energy has shifted away from Giant. It is therefore not surprising that no eruptions were seen during the span of this article.

The Purple Pools were not closely monitored in 2006-07 due to their distance from existing boardwalks, but a few notes merit mention. When the Purple Pools were checked with permission from the NPS, South Purple Pool was cool enough to have chunks of bacteria growing in it. North and East Purple were down 1 to 2 feet, though North Purple had occasional superheated boiling, the strongest of which could be seen from the viewing platform at Giant.[53]

In prior years, the Purple Pools displayed a connection to Giant via lowered water levels after an eruption of Giant. South Purple Pool also was known to drop slightly after Giant's strongest hot periods. These behaviors appeared to persist through the span of this article, with one notable exception. During Giant's phase of short intervals during April 2006, South Purple Pool was not overflowing at all. South Purple Pool resumed overflow on May 11, shortly after Giant's intervals lengthened.

It is also notable that the behavior of the Purple Pools changed following the final eruption of Giant's active phase on April 29, 2008. By May 3, South Purple Pool had stopped overflowing, and North and East Purple Pools were overflowing with runoff channels that reached to the Firehole River.[54] Though South Purple Pool resumed light overflow by late May, North and East Purple Pools were still overflowing as of June 2008.

Conclusion

The active phase of 2005-2008 was truly remarkable. The 47 eruptions in 2006 tied it with 1997 for the most in any calendar year since 1955, and this record was subsequently broken with 54 eruptions in 2007. Of equal significance to geyser enthusiasts, Giant's post-1955 pattern of avoiding the summer months was far less prevalent, allowing many eruptions to be seen during Yellowstone's peak visitation time. Giant's phases of activity were also highly intriguing. The behavior of April 2006 saw the shortest known interval since 1955 and observers also saw a previously unknown event: a solo eruption of Mastiff Geyser. The bimodal phase from June 2006 through November 2007 was the longest period of reliable activity in over 50 years and demonstrated clear patterns for predicting the next eruption. With the help of electronic monitoring, observers gained new insights into Giant's relationship to Grotto that may be useful for future study. As always, observers will have to wait and see what this incredible geyser does next.

Acknowledgements:

This article would not have been possible without the collaborative effort of the many geyser observers. Thank you to all of the geyser gazers, NPS rangers, and volunteers for providing information, especially those listed in the Giant eruption tables. I owe specific thanks to the following individuals:

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I conclude by thanking the reviewers for this article who provided valuable corrections, suggestions, and support: Suzanne Strasser, Andrew Bunning, Pat Snyder, Nancy Cross, and David Monteith.

ENDNOTES:

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Giant Geyser, Feb. 19, 2008. Photo by Graham Meech.

Novel Methods for the Analysis of Grotto and Giant Geysers in the Years 2000 through 2007

Thomas F. Magnera

Abstract

The eruptions of Grotto and Giant Geysers for the years 2000 through 2007 are analyzed by methods based on the duty cycle, the reset time, the maximum energy efficiency, the Hilbert transform of a frequency-modulated telegraph series, and Grotto-to-Giant intervals. Grotto's transformation from a regular to irregular geyser after September 2005 is related to changes in the long-period modulation and increased average eruption duration. The reset time and duty cycle concepts allow the division of Grotto eruptions into two new types, each associated with a distinct average reset time. The Grotto-to-Giant interval analysis confirms a recent 9-hour rule for 'recovery' Giants, and puts a lower bound on the marathon interval that precedes an eruption of Giant.

Introduction

The interconnection of the Grotto and Giant Geyser complexes is well known and the focus of intense interest because of the spectacular nature of the Giant Geyser eruptions. Recently there has been exceptional activity by Giant with dozens of eruptions in each of the last three years. It is fortunate that this upsurge in Giant activity has happened simultaneously with the start of a program to monitor Grotto electronically. This program has produced an extensive record of Grotto's activity since 2000 by the efforts of Ralph Taylor and others.[1] In this paper, the electronic data log for Grotto Geyser has been compared to a mostly manual compilation of Giant Geyser start times assembled by T. Scott Bryan.[2] Numerous observers and sporadic electronic monitoring contributed to the Giant Geyser database. The Grotto and Giant data sets are limited to the start and stop times of Grotto Geyser's active phase and the start time of Giant. They do not include information about Giant Geyser hot periods nor the activity of Grotto Fountain, South Grotto Fountain, Rocket, Mastiff geysers, etc. The following observations are consequently myopic in scope, but nevertheless useful towards understanding some aspects of the relationship between Grotto and Giant Geysers in the years between July 2000 and August 2007.[3]

For clarity some definitions and qualifications are necessary: A non-dormant, periodic geyser cycles through an active or eruptive phase during which boiling water and steam are ejected, and an inactive or recovery phase during which only minor activity is seen by an above-ground observer. Duration is defined as the time length of the active phase. Interval is defined as the sum of the time lengths of the active and inactive phases and is assumed to begin at the onset of the active phase. The duration and interval recorded by the electronic log are likely to be different from that measured by a nearby observer, since the ejection of water during the active phase is not instantaneously recorded but incurs a delay determined by the distance of the sensor from the geyser water source. Absolute times in this data set have not been corrected for this delay, whereas relative times are expected to be mostly self-corrected. Grotto Geyser has occasional very long durations commonly called marathons, imprecisely defined as being greater than about five hours. A Giant hot period is a cyclic occurrence of a minor active phase of Mastiff and other associated geysers and vents in the Giant complex. The first hot period following a Grotto Geyser marathon is commonly called a 'recovery hot period.'

[1] Available on the Geyser Observation and Study Association (GOSA) website (www.gosa.org).

[2] Updated versions are posted informally by T. Scott Bryan to the geyser listserv.

[3] Data were not available for October 4 through December 31, 2001. Observations in the paper are further limited as follows: The eruption start time of Giant must be known and not inferred so that it can be coupled with the corresponding Grotto electronic data set of start time, duration and interval.

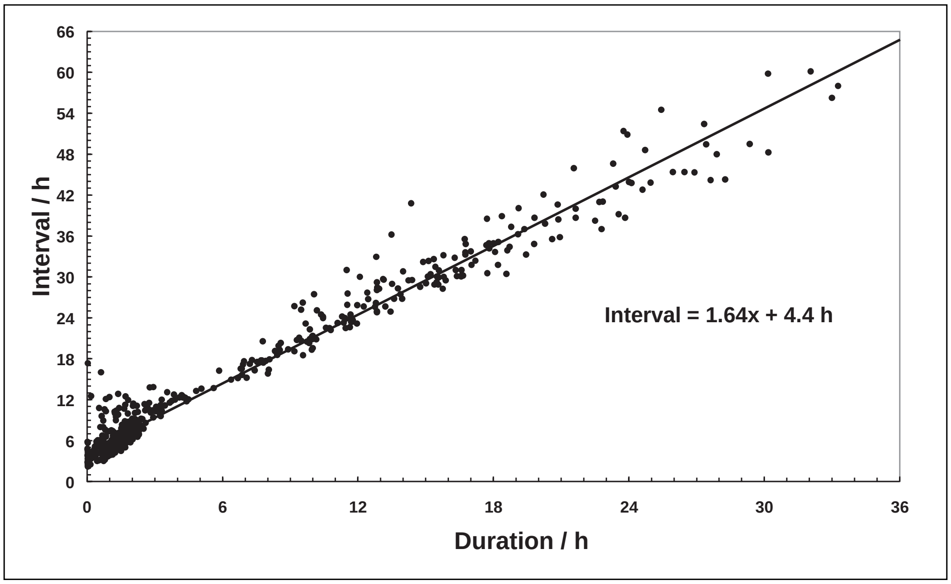

Figure 1. Grotto Geyser interval vs. duration for 2006: The solid line is a least-squares fit to the data. A rough prediction of the interval can be made using the inset equation with x = duration in hours.

Table 1.

Year	Interval/Duration (m)	Reset Time (t_0, hours)	Max. Avg. Efficiency
2000	1.53	3.84	0.65
2001	1.57	3.58	0.63
2002	1.60	3.48	0.62
2003	1.57	3.48	0.63
2004	1.55	3.78	0.64
2005	1.56	4.08	0.64
2006	1.64	4.40	0.61
2007	1.71	4.56	0.58

General behavior of Grotto Geyser from 2000 to 2007

Grotto is a well-behaved geyser with a nearly linear relationship between its interval and duration (Figure 1). Such a strong linear relationship indicates a direct proportionality between the time spent in the active eruptive phase and the time spent in the inactive recovery phase. After adjustment for its short-duration offset, it allows the rough prediction of the interval from a known duration. An observer who sees Grotto erupt briefly for a few minutes cannot expect another eruption for several hours as the system must refill and reheat the copious water that is usually expelled during even extremely short eruptions. This is the meaning of the non-zero intercept of the fitted line in Figure 1, which is defined here as the reset time t_0 or the minimum interval for Grotto. Table 1 is a summary of this interval-duration proportionality given as the slope m and t_0 of similar plots for the years 2000 through 2007 and shows that there has been little variation with no clear trends over the period.

The data points in Figure 1 are not uniformly distributed and are very densely clustered for short durations. Figure 2 shows the distribution of Grotto's durations for 2006 in greater detail; it is continuous between 0 - 35 hours and bimodal with a very strong branch peak at 1-2 hours and a weaker second branch that broadly peaks between 9 – 16 hours. Roughly two-thirds of the Grotto durations are less than 3 hours in duration. The distribution for 2006

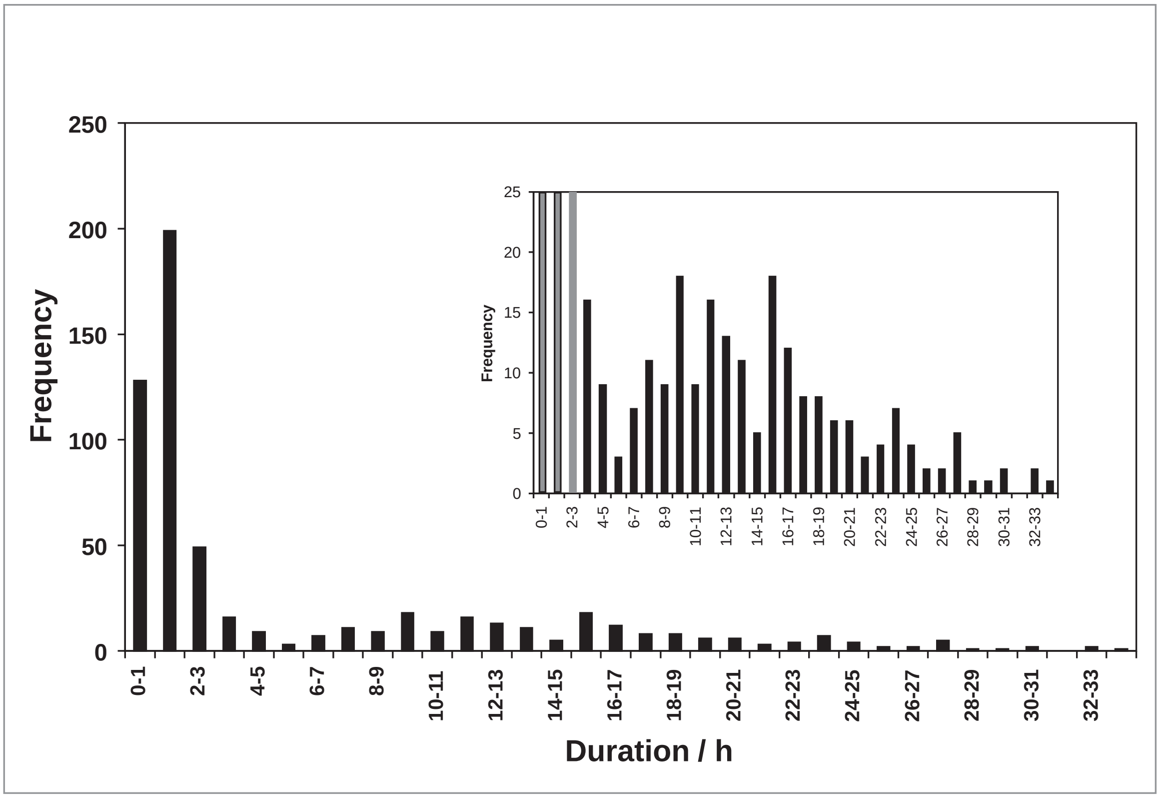

Figure 2. Frequency of Grotto Geyser durations for 2006. The insert shows a five-times magnification with the off-scale bars for short durations shown in gray.

is qualitatively similar to those for other years,[4] although there is some year-to-year variation in the total number of eruptions found in each branch.

It is useful to connect the observed linear interval-duration relationship to an engineering concept called the duty cycle, which is used to describe intermittently operated machinery like an elevator hoist motor or a heater coil connected to a thermostat. For a geyser, the duty cycle is defined here as the duration divided by the interval and equals the fractional time that the geyser is in its active phase over one interval. Mathematically, the duty cycle D is given by the duration Δt divided by the interval, represented by a linear relationship that was validated by the plot in Figure 1, to give the simple formula,

$$D = \frac{\Delta t}{m\Delta t + t_0} \quad (1)$$

The duty cycle thus defined is split into two regimes by the value of the reset time t_0: (i) for very short durations, when $m\Delta t << t_0$, the duty cycle becomes $D = \Delta t / t_0$ with an approximately linear time dependence, and (ii) for very long durations, when $m\Delta t >> t_0$, the duty cycle becomes almost time independent as it asymptotically approaches the limit $D_\infty = 1/m$. The long duration limit is just the inverse of the slope of Figure 1 and can be thought of as the maximum average efficiency that Grotto attains. In Table 1 the inverse slope of the interval-duration plots for different years is listed as the maximum average efficiency.

Figure 3 shows a plot of the Grotto duty cycle as a function of the duration along with a plot of (1) with (m, t_0) = (1.59, 5.28 h), values close to the fitting parameters (1.64, 4.4 h) found from Figure 1. This treatment divides the data into two distinct groups relative to the duty cycle curve (1): (i) Grotto type 'A" (solid circles in Figure 3) are a tight cluster of short duration Grotto outlier eruptions above the plotted curve (1) for durations less than 2.5 hours with duty cycles mostly between 0.17 and 0.35; (ii) Grotto type 'B' (open circles in Figure 3) are eruptions that fall nearby the plotted curve (1) for durations between zero and 36 hours. The distribution of type 'B' eruptions is fairly uniform along the curve with some thinning between 5 and 7 hours. For intervals less than two hours the combined 'A' and 'B' duty cycle distribution is broad and even becomes distinctly bimodal between 2 and 2.5 hours.

The observation that (1) provides a good description of the data over a wide range of durations is no surprise given that (1) is just a reformulation of the linear interval-duration relationship. The misfit of the type 'A' eruptions in this formulation, however, is striking. The shape of the type 'A" Grotto group suggests that they can be fitted with a smaller t_0 and

[4] The reader is referred to the GOSA website for duration distributions for other years.

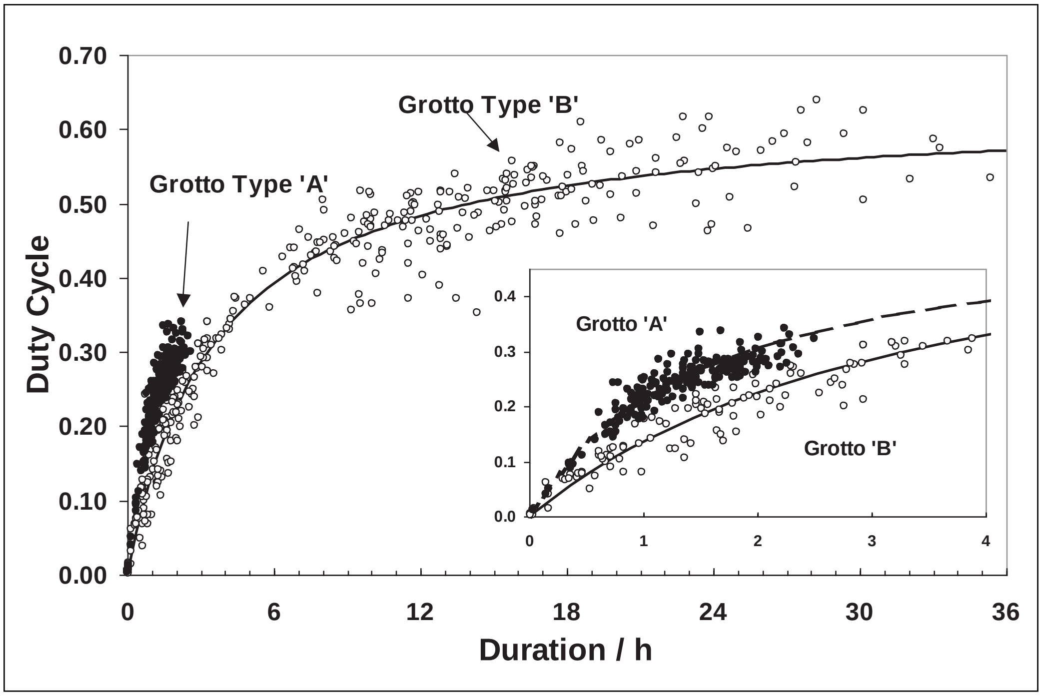

Figure 3 A plot of duty cycle vs. duration for Grotto Geyser divides all 2006 Grotto eruptions into two groups: Grotto type 'A' (*solid circles*) and Grotto type 'B' (*open circles*). The solid line represents (1) with (1.59, 5.28 h) and the upper dashed line in the inset is the same except with (1.59, 2.64 h).

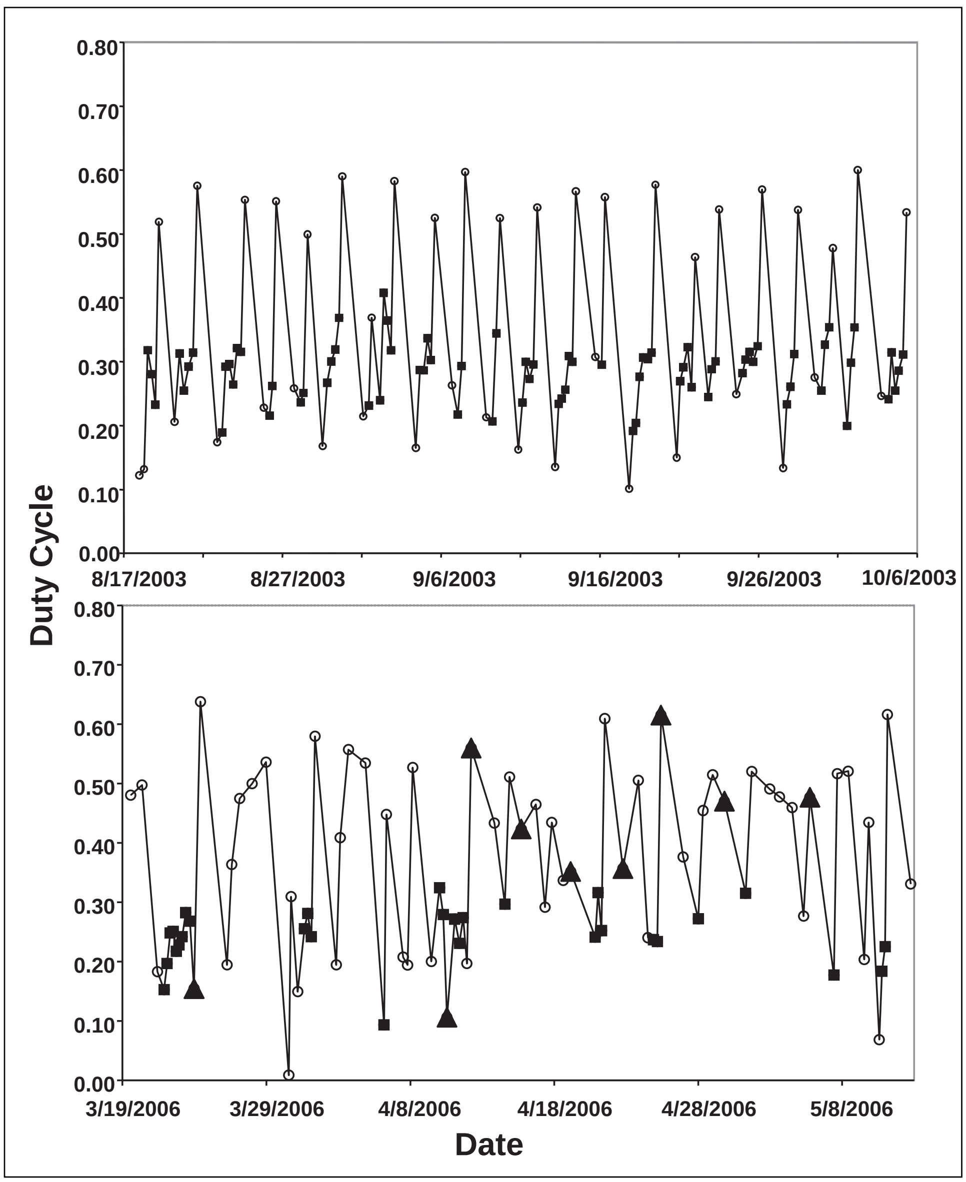

Figure 4. Time series of the duty cycle for Grotto in 2003 (*top*) and 2006 (*bottom*). Eruptions of Giant (*solid triangles*), Grotto type 'A' eruptions (*solid squares*), and Grotto type 'B' (*open circles*) are marked as they occur along the time line.

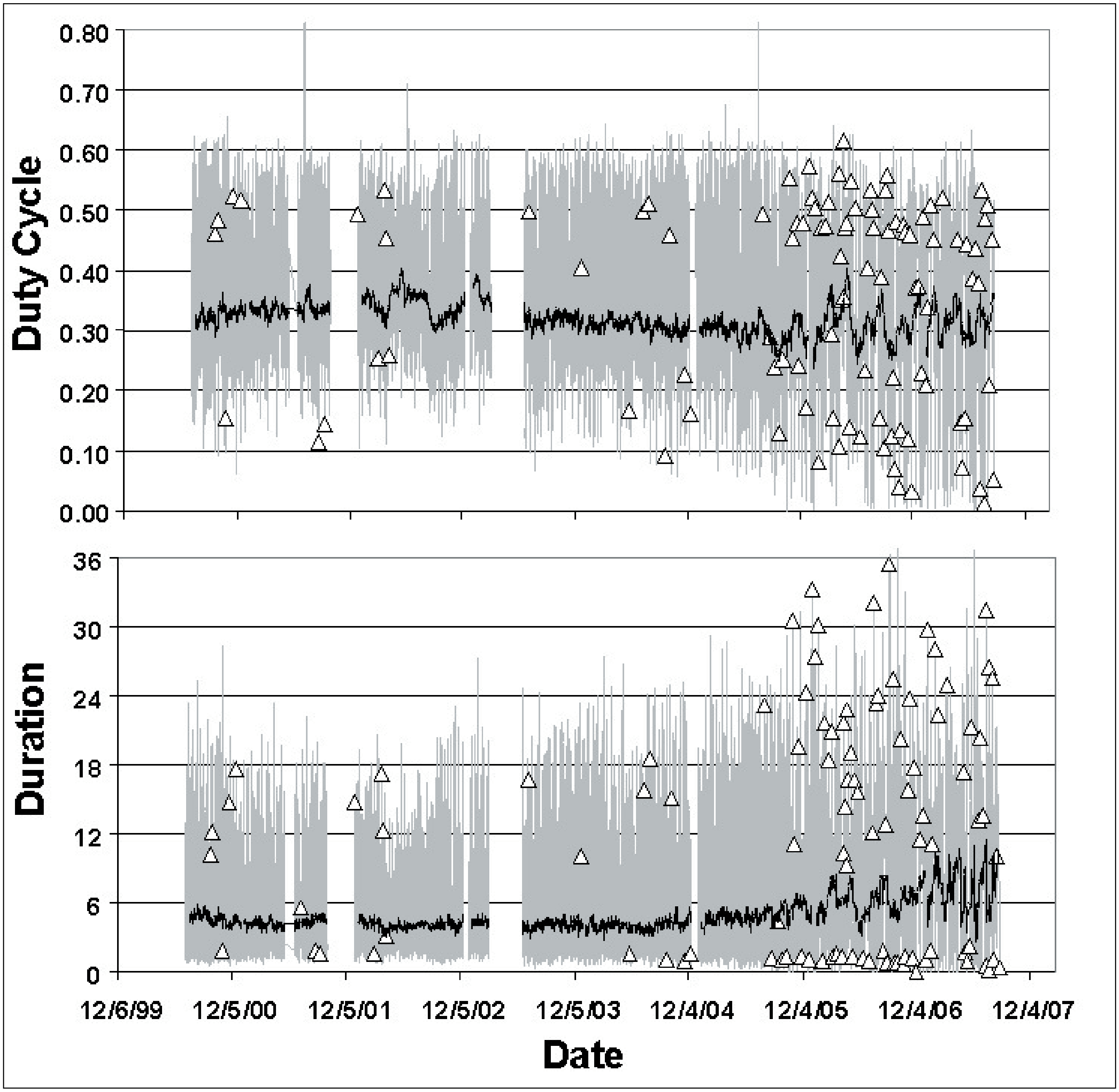

Figure 5. Time series plots for the duty cycle (*top*) and the duration (*bottom*) of Grotto. The solid line is a 30-day moving average. Eruptions of Giant are marked by open triangles. The time axis is the same for both plots.

therefore, as a group, have a shorter reset times. The insert in Figure 3 shows a dashed-line plot of (1) with t_0 reduced by half (1.59, 2.64 h), which fits the slightly bent distribution of type 'A' Grottos well and implies that the type 'A' and 'B' groups statistically overlap at very short durations. The cause for the difference in the group average reset times t_0 is unknown, but may be guessed to be related to the action of Grotto at the very start of the eruption, to some quenching mechanism that leads to a premature Grotto shut down, or to some other event that leaves Grotto better primed to erupt.

Continuing the investigation of Grotto's duty cycle, Figure 4 shows two short segments of the Grotto duty cycle time series for an inactive Giant year (2003) and a very active year (2006). In 2003 the oscillation of the duty cycle is remarkably regular and closely resembles a sawtooth wave. The peaks in the wave correspond to marathons after which the duty cycle plummets to its minimum. Between the peak

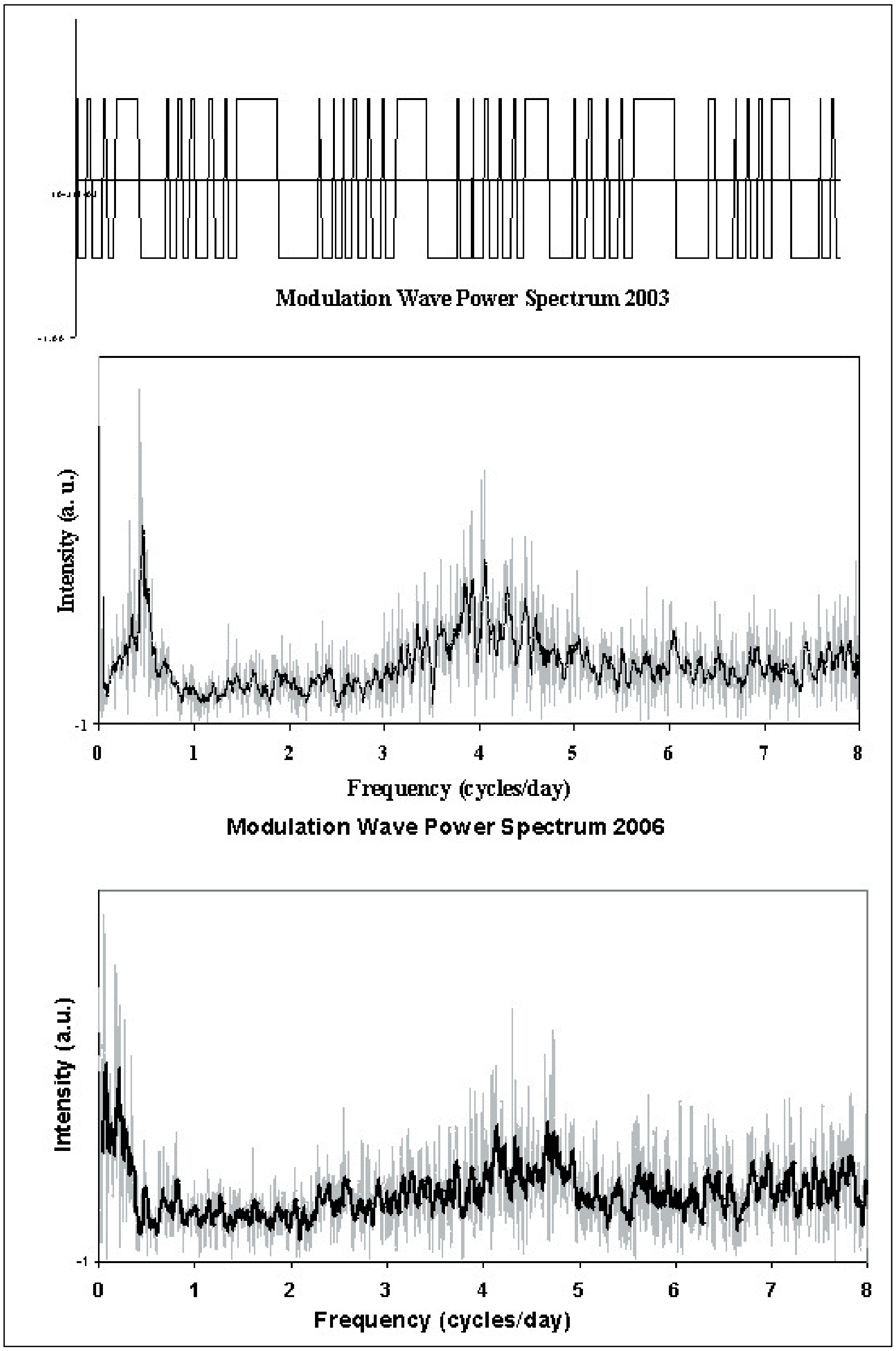

Figure 6. (*top*) Short segment of the full 2003 telegraph series of Grotto switching between active and inactive phases showing the frequency modulation. (*middle*) The modulation-wave power spectrum for 2003. (*bottom*) The modulation-wave power spectrum for 2006.

and trough, the duty cycle roughly increases as the system slowly recovers before the next marathon. The type 'B' Grottos are found most often at the extrema of the sawtooth wave. The short, mid-cycle eruptions are found often to be Grotto type 'A' and become very numerous overall because the cycle sometimes stalls within this duty-cycle range. In 2006 the sawtooth wave is almost indiscernible due to the chaotic character of the duty cycle series. The system often has several high duty-cycle type 'B' eruptions in sequence without entering a recovery phase and will switch erratically between 'A' and 'B' modes with only infrequent type 'A' clusters. This chaotic character, which began in mid September 2005 and continued past August 2007, coincides with the upsurge in the activity of Giant as marked by the increased density of triangles in Figure 5, where Grotto's duty-cycle and duration time series are plotted for the entire period from 2000 through 2007. Prior to September 2005 the sawtooth pattern is mostly quite regular, including those times when Giant was modestly active.

The moving averages for both duty cycle and duration plots clearly indicate that Grotto has become a less regular geyser with longer durations since 2005. Although the average duration has increased, the maximum average efficiency, which is listed in Table

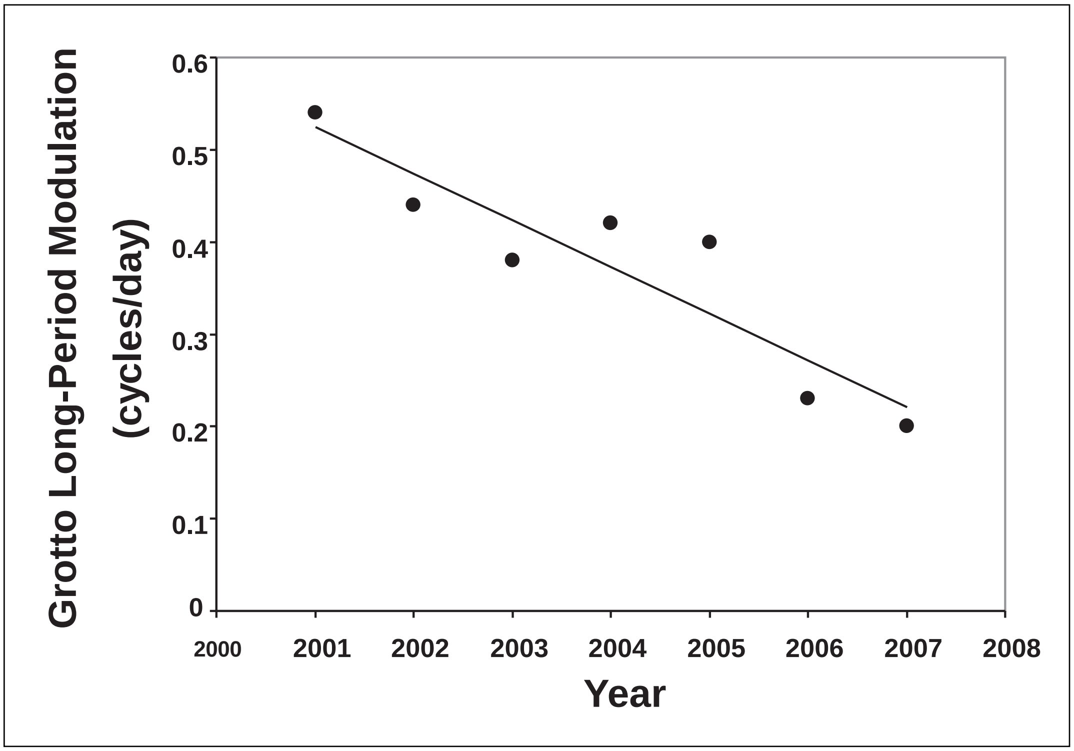

Figure 7. Yearly variation in the long-period modulation frequency of Grotto.

I, has not. Its constancy implies that the average net system energy and water flows are unchanged after this point. The variability in the duty cycle may stem from a new variability in Grotto's energy flow that does not alter the average flow, or a new variability in strength of the quenching mechanism that ends Grotto's active phase and therefore affects t_0, producing more random switching between 'A' and 'B' modes and more frequent type 'B' eruptions.

The full sequence of Grotto's eruptions can be analyzed by treating it as a frequency-modulated telegraph series,[5] which for Grotto is generated by writing a 1 for all times that Grotto is active and 0 when it is inactive. An example is shown in the upper part of Figure 6. In this representation it is easy to see that Grotto has alternating periods when it erupts with either high frequency or low frequency and thus acts as if it is under the influence of a modulator that controls its eruption interval. The series is not perfectly regular but quasiperiodic with variable frequencies. The action of Grotto in some ways resembles the changing height of an ocean buoy under the influence of variable wind-driven waves. Quasiperiodic series of this type are well studied[5] and can be analyzed by Hilbert transform methods to obtain the influencing modulation frequencies.

The above conjecture, that Grotto Geyser can be represented as a frequency-modulated (FM) system, requires some further elaboration. An FM system is represented mathematically as a combination of functions of the type $\cos(f_0 t + b_n \sin(f_n t))$ and behaves as if there were some kind of mechanistic dial, the $b_n \sin(f_n t)$ part, which changes the frequency of the geyser intervals in a periodic way, with the complete telegraph series given by $A\cos(f_0 t + \sum_n b_n \sin(f_n t))$. The Hilbert transform is a procedure to obtain all the b_n and f_n pairs from the Grotto telegraph series by direct mathematical analysis. The power spectra, plots of b_n vs. f_n, for Grotto in 2003 and 2006 abstracted by this method are shown below the telegraph series in Figure 6. The intensity of any particular frequency in this plot is proportional to how strongly Grotto is modulated at that frequency. In 2003 there are two very distinct modulation frequency bands,[6] a narrow one centered at 0.42 cycles/day and one centered

[5] Huang, H.; Shen, Z.; Long, S. R.; Wu, M. C.; Shin, H.H.; Zheng, Q.; Yen, N.-C.; Tung, C. C.; Liu, H. H. "The empirical mode decomposition and the Hilbert spectrum for nonlinear analysis and non-stationary time series analysis" *Proc. R. Soc. Lond. A* 1998, *454*, 903-995.

[6] The usual methods for distinguishing true peaks in the power spectrum from noise and numerical artifacts that can occur when using FFT transform methods where applied including testing for aliasing effects, and testing for constancy with respect to the number of points and the subdivision of the transformed data. Further, in this instance it was possible to directly connect the peaks in the power spectrum from one year to the other by sliding the transform window across the time series except where there was an interruption in the electronic data set.

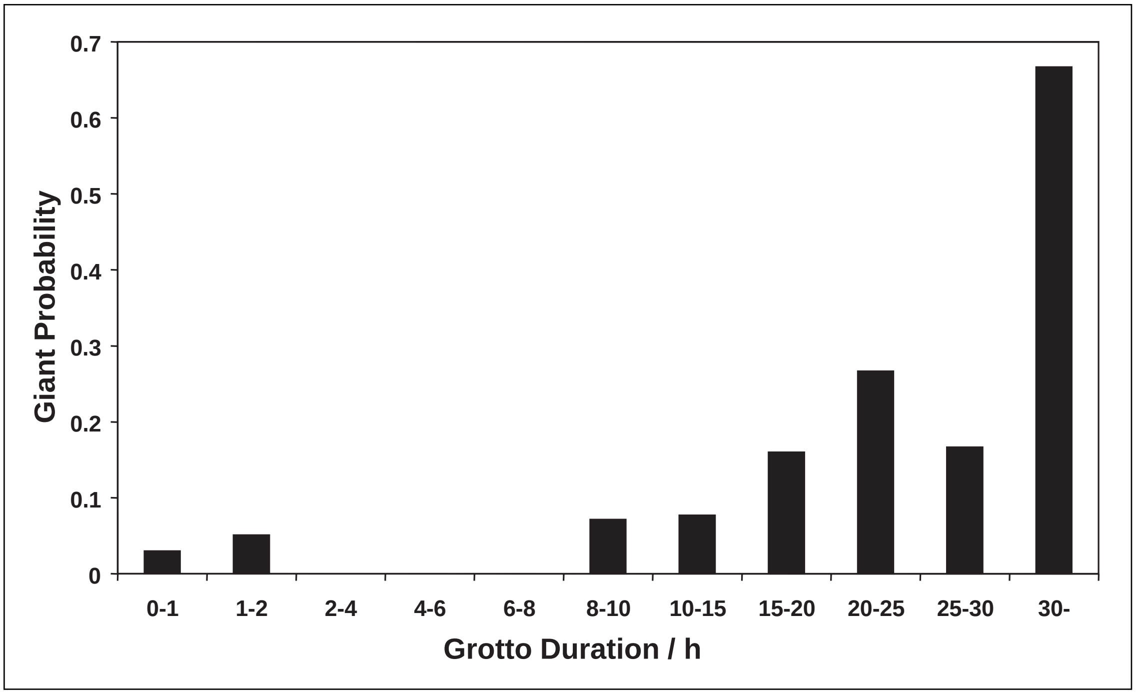

Figure 8. Fractional probability of Giant Geyser after Grotto in 2006 defined as the number of Giants divided by the total number of all Grottos for the specified duration interval.

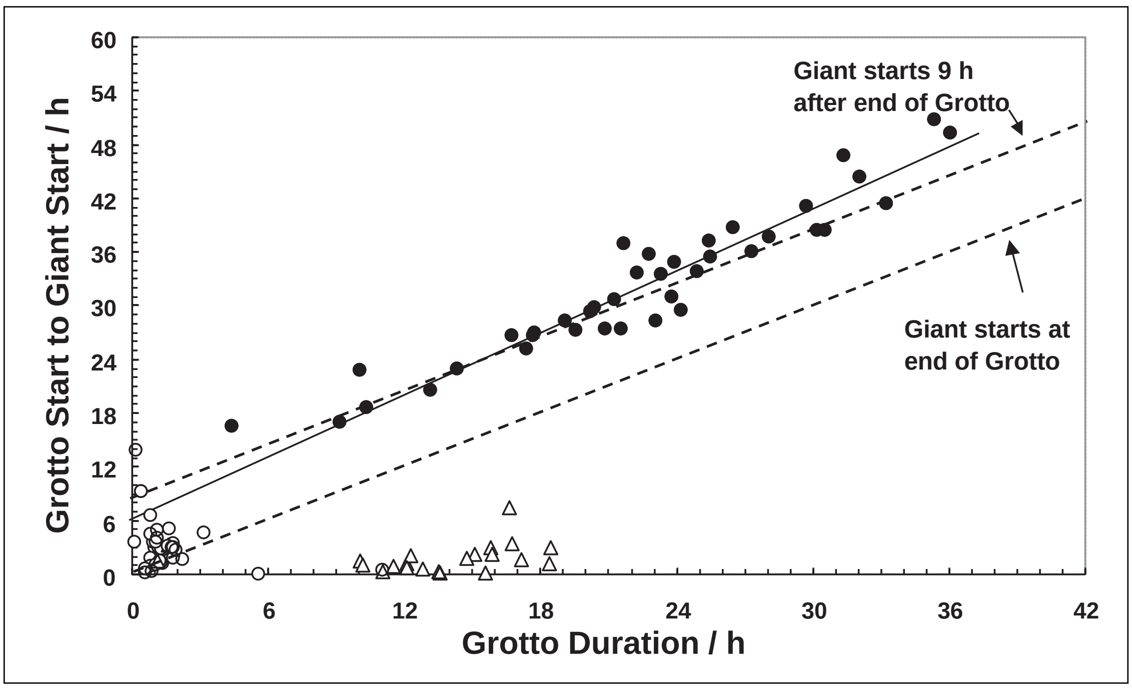

Figure 9. Grotto-to-Giant intervals for *Group 1* Giants (*open circles*), *Group 2* Giants (*closed circles*) and *Group 3* Giants (*triangles*) vs. Grotto duration for the years 2000-2007: The bottom dashed line indicates where Giant eruption data points would fall if they all occurred exactly at the end the active phase of the preceding Grotto eruption. The upper dashed line is drawn exactly parallel to the end-of-Grotto line but offset by 9 hours. The solid line is a least-squares fit of the *Group 2* (*closed circles*) data points.

at 4.0 cycles/day. For 2006 the power spectrum is weaker and the low-frequency band is pushed to 0.23 cycles/day or about one-half the value in 2003. The high-frequency band is much weaker and very broad. The plot in Figure 7 shows the yearly variation in the center frequency of the long-period modulation band. The short-period band is not plotted because it does not change much. In 2003 the long period corresponds to about 30 hours of short Grottos followed by a 30-hour marathon interval. The short-period band is related to the asymmetry of Grotto's numerous short eruptions. If a time series were random, all modulation frequencies would have equal intensity.

The peaks in Figure 6 are not harmonic frequency modes, as in a series represented by the sum of sine waves of different frequencies, but instead are the relative contribution of the different modulation frequencies. When the modulation wave has a positive amplitude Grotto erupts more frequently, and conversely, when it is negative, Grotto erupts less frequently. In a year like 2003, when the telegraph series is fairly regular, it is easy to discern a modulation of this kind, but this is clearly not the case for a chaotic 2006 series (Figure 4). One of the reasons for doing the Hilbert transform is to prove the FM model conjecture by "rediscovery" of some

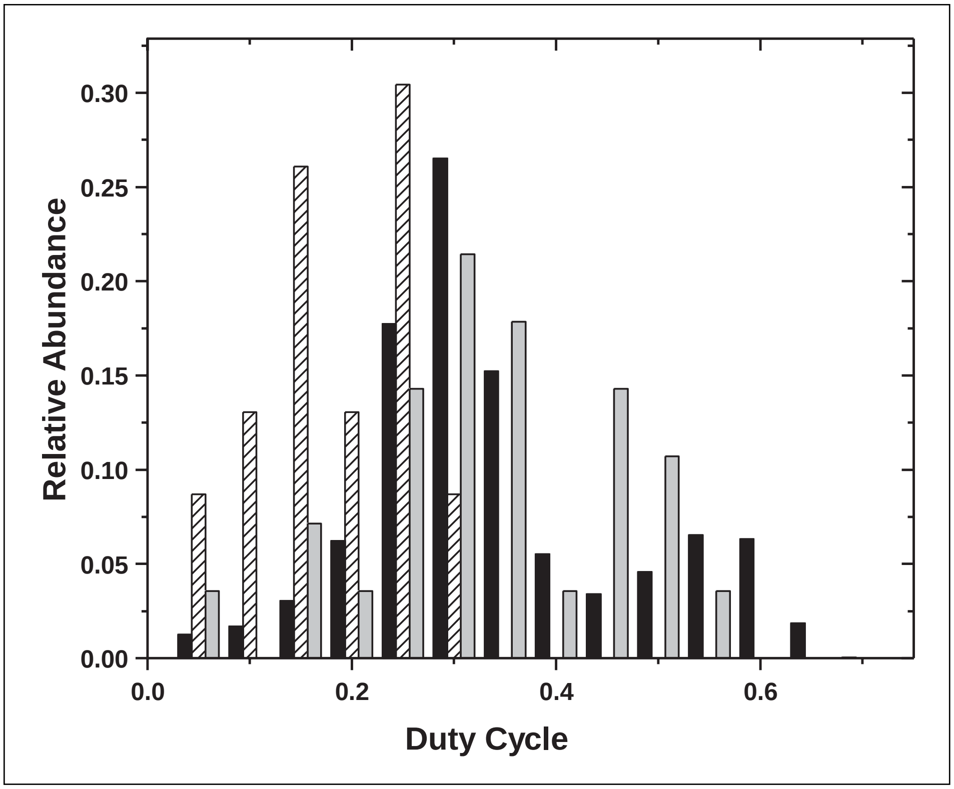

Figure 10. Distribution of duty cycles: All Giant eruptions between 2000 and 2007 (*solid bars*), *Group 1* Giants (*hatched bars*), *Group 3* Giants (*gray bars*).

things that are already known, like the long and short period action of Grotto in a non-chaotic year like 2003 when the behavior of the geyser is fairly obvious. The transform would not work if the FM model did not have some validity, and the results for 2003 give the FM model support. The power of the Hilbert transform method is that it can uncover information from the less regular and random-appearing 2006 series that would confound simple observation. The reader might agree that the application at least worked for 2003, and this exercise has successfully demonstrated that we have a novel geyser model and, with it, new tools for analysis that can potentially reveal new information. In addition to the power spectrum, the Hilbert transform provides phase information, which is an analysis tool that can reveal unobvious local connections between proximate geysers like Oblong–Giant or a basin-wide phenomenon that connects Grotto to Castle, or conversely, the absence of a connection. A preliminary examination so far has indicated that Giant eruptions in any year seem to occur randomly with respect to the amplitude and phase of Grotto's long-period oscillation. This is a disappointing discovery.

Relationship between Grotto and Giant Geysers in the years between 2000 and 2007

From the electronic data logs for Grotto and the Giant Geyser eruption-time compilation it is possible to compute a probability of seeing Giant for any preceding Grotto Geyser duration (Figure 8). Giant Geyser had a good chance of erupting after a Grotto in the second branch of Figure 2 for any duration that exceeds 8 hours, whereas there was only a small chance after any single Grotto found in the first branch. About three-fifths of all Giant Geyser eruptions followed Grotto durations of 8 hours or more in 2006, with significantly increasing probability as the Grotto duration becomes longer. For durations of Grotto between 3 and 8 hours, there were no Giant Geyser eruptions.

Figure 9 is a plot of the Grotto-to-Giant interval for 2000-2007, defined as the time between the start of the preceding Grotto and the start of Giant, as a function of the duration of the preceding Grotto. This Grotto-to-Giant interval spans only one, or part of one, Grotto active phase and usually some part of the recovery phase. The data divide into regimes: a tightly-clustered, unstructured group (*Group 1*) in the short Grotto duration regime (< 3.5 hours) at the lower left of Figure 1 (*open circles*); a structured group (*Group 2*) that has a strongly linear behavior, in the long duration regime (> 8 hours) (*closed circles*); and a cluster of points (*Group 3*) in the bottom middle that correspond to Giant eruptions that began shortly after the start of Grotto Geyser and which subsequently continued into a marathon (*open triangles*). The lower dashed line in Figure 9 marks the end of

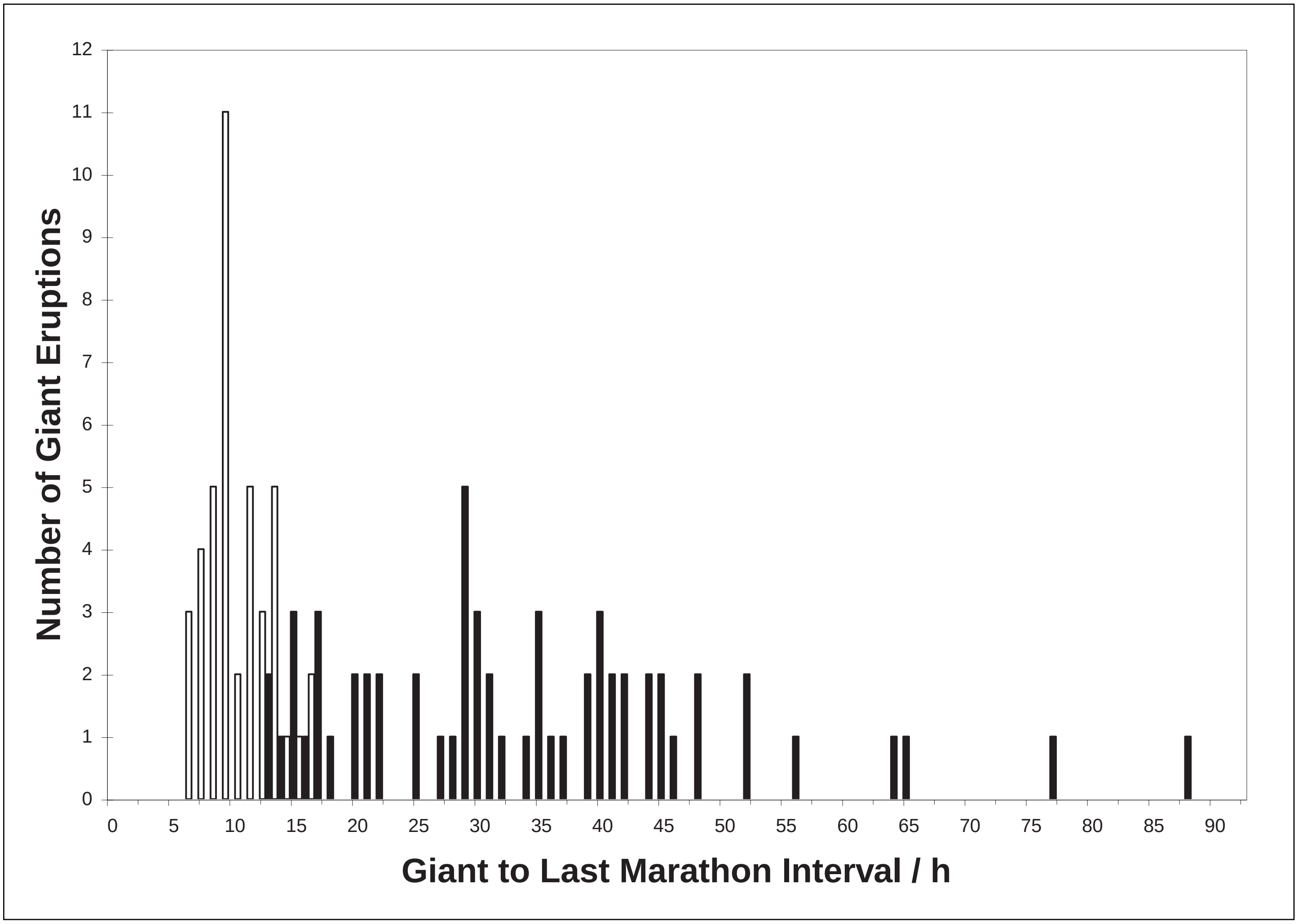

Figure 11. Distribution of the interval between Giant and the end of the preceding marathon for the years 2000 - 2007. The 'recovery giant' group (*Group 2*) is represented by the light bars and all other Giant eruptions by the dark bars.

Grotto; no eruption start times fall near this line for durations < 3 hours; however, a second parallel line that marks a 9-hour interval after the end of Grotto nicely fits the *Group 2* points. The slightly steeper solid line is a least-squares-fit line drawn through the *Group 2* points and indicates that Giant waits a little more than 9 hours after the end of a very long Grotto or a little less for shorter marathons before erupting. *Group 2* eruptions of Giant Geyser are commonly referred to as 'recovery hot period' Giants. It is noteworthy that there was only one *Group 2* Giant prior to 2005 in the data set examined in this paper. Most of the *Group 1* Giant eruptions fall much closer to the end-of-Grotto line rather than the 9-hour line that extends towards short durations. The three outliers to this rule all occurred in 2007.

Figure 10 shows duty-cycle distributions for the Grotto intervals completed immediately before the *Group 1* and *Group 3* Giant eruptions and the distribution of all Grotto duty cycles. The duty-cycle distribution for *Group 1* is centered at low values and connects the *Group 1* Giants with type 'B' and some type 'A' Grottos that occur within an eruption or two of a marathon, while Grotto is still in its recovery phase. On the other hand, the *Group 3* distribution more closely resembles the distribution of all duty cycles except for the bimodal hump between 0.4 and 0.6.

To examine how intervening Grotto eruptions affect the influence of a marathon, the distribution of intervals between the start of Giant and the end of the last marathon is plotted in Figure 11. As expected, there is a strong peak at the 9-hour mark comprised of the *Group 2* 'recovery Giants.' The remainder of the intervals is for Giant eruptions that had at least one intervening Grotto eruption. This group of intervals is broadly distributed with the hint of a mode at

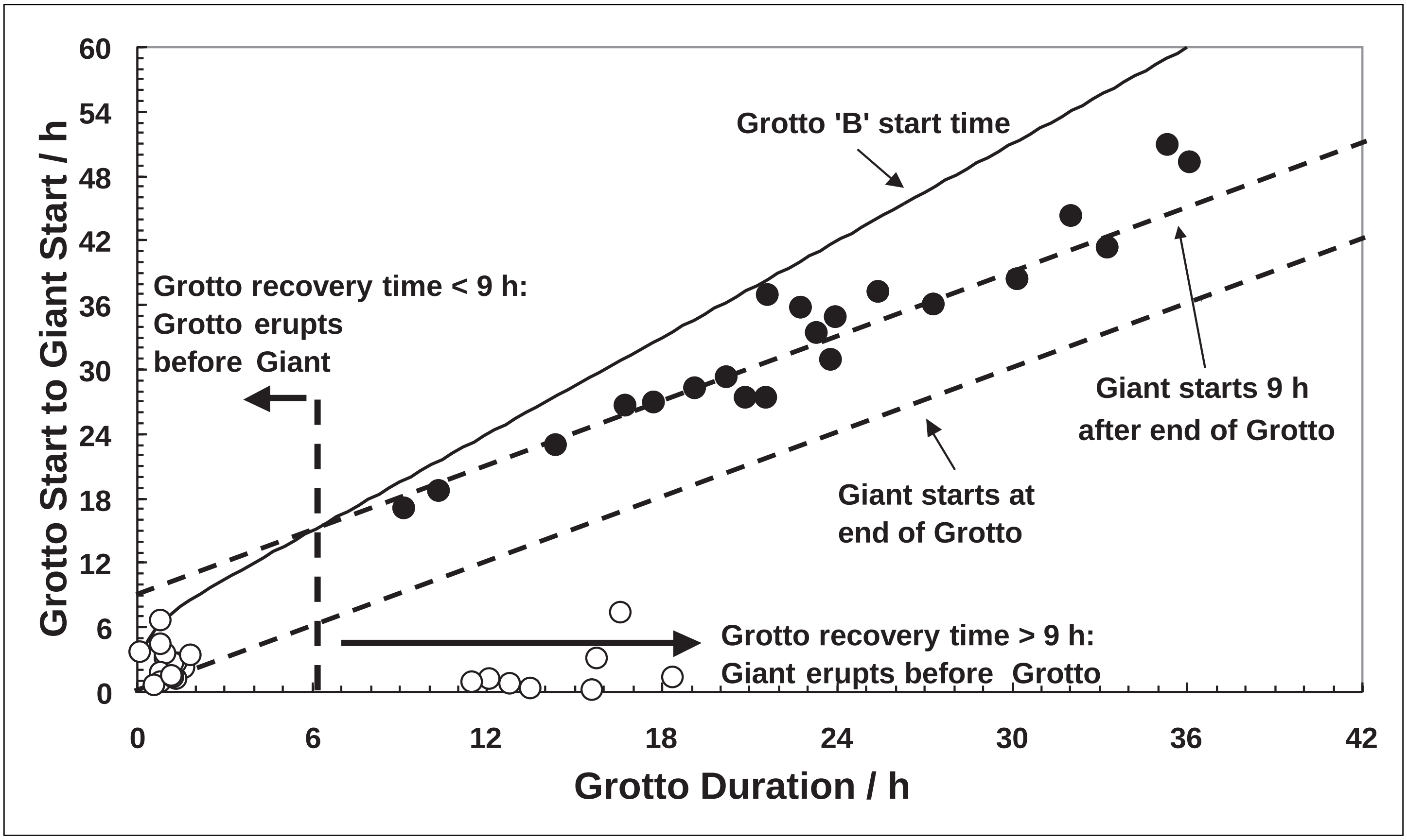

Figure 12. Grotto-to-Giant vs. Grotto duration: The curved solid line indicates where intervals would fall if they were coincident with the start of the next Grotto. The lower and upper dashed lines are for intervals coincident with the end of the current Grotto and the 9-hour mark after Grotto's end, respectively. The vertical dashed line shows the crossover point.

30 hours. There is no indication in this latter distribution that Giant erupts preferentially at multiples of the 9-hour 'recovery marathon' window. Evidently, once Grotto has an eruption after a marathon, Giant forgets when the last marathon ended.

DISCUSSION

Several of the preceding observations are worthy of brief discussion. First, the commonly used empirical rule that an eruption of Giant Geyser is unlikely after a 'short' marathon is demonstrated clearly by Figures 8 and 9. In Figure 12, a possible explanation for this rule is proposed in a separate plot of the 2006 data subset included in Figure 9. A fitted line that predicts Grotto type 'B' start times from Figure 1 has been added to the representation found in Figure 9 and is seen to cross the Giant 9-hour line at ~6 hours, where a vertical dotted line has also been drawn. As expected from the empirical rule, there are no *Group 2* Giants to the left of the vertical dotted line. The line that shows the expected start of the next Grotto Geyser stays below the 9-hour line until it crosses it at about 6 hours. This suggests that for durations less than 6 hours, the recovery time of Grotto will likely be less than 9 hours, which will not give Giant Geyser sufficient time to become active. The high probability of Grotto impeding Giant after a "short marathon" is demonstrated in the historical summary (Figure 9), where there was only one Giant following Grotto durations of 4 - 5 hours and one between 5 -7 hours. Evidently, then, a start of Grotto is a significant perturbation of the combined Grotto-Giant system and pushes the Giant complex back by an indeterminate extent from a major active phase.

A transformation in the Grotto-Giant system in September 2005 has weakened the strong regularity of Grotto's duty-cycle oscillation and lengthened Grotto's duration, and is concurrent with an upsurge in Giant's activity. The apparent constancy of the Grotto maximum average efficiency from 2000 to the present suggests that the post-2005 changes might be related to a mechanistic change in Grotto rather than a change in the net energy or water flows. The duty cycle and FM model analyses, given above, perhaps provide clues to what may have produced this change if the supposition is made that the long-period oscillation drives changes in Grotto's quenching mechanism. In the FM geyser model, if the modulation is in its positive phase, the quencher would be strong, making Grotto erupt with small t_0 reset times and causing an observer to record many short type 'A' Grotto eruptions. Alternatively, when the phase shifts negative, the quencher would be weakened and an observer would see many high t_0 type 'B' eruptions, which can be both short and extremely long.

Modeling a geyser as a frequency-modulated system has been demonstrated to be a useful way to quantify information about its long-term behavior in the form of a power spectrum of modulation frequencies. The source of Grotto's long-period modulation has not been identified, but the precise phase information of the modulation may help connect it to other systems or some basin-wide phenomenon as more systems are analyzed by this method. An examination of the phases of the Grotto's modulation frequencies reveals that there is no correlation between the phases of the long-period Grotto modulations and the start of Giant. This is not mean there is no connection between Grotto and Giant, but that whatever causes the long-period modulation in Grotto does not directly cause a Giant.

Acknowledgments

Thanks to the reviewers, Tara Cross; T. Scott Bryan; Georgia, Marc and Westerly Magnera; and Paul and Suzanne Strasser for error checking and helpful discussions.

Grotto Geyser, Sept. 7, 2007. Photo by Pat Snyder.

Changes in the Minor Activity of Geysers Prior to a Major Eruption

Jeff Cross

Abstract

Giant Geyser, Steamboat Geyser, Fan and Mortar Geysers, and Grand Geyser each erupt from complicated plumbing systems with two or more vents. The quiet interval between major eruptions of these geysers is punctuated by cycles of minor activity. During these cycles, the vents divide themselves into two groups which act antagonistically. Just prior to the major eruption, the antagonistic activity is replaced by concerted activity from all the vents. A hypothesis is presented to explain this observation.

OBSERVATIONS:

Many geysers undergo periodic cycles of minor activity in the quiet interval between major eruptions, during which one or several vents will overflow, erupt, and drain. These cycles are called by different names, depending on which geyser is being discussed. At Giant Geyser, they are called hot periods. At Fan and Mortar, they are called hot cycles, and at Steamboat Geyser, they are called minor eruptions. Grand Geyser does not erupt at all during its quiet interval, but its water level rises and falls periodically, being lowest when nearby Turban Geyser erupts. In each example, the vents divide themselves into two groups according to their activity. The groups are summarized below:

Table 1

Geyser Complex	Group A	Group B
Giant	Bijou Geyser	Mastiff Geyser Giant Geyser The hot period vents
Steamboat	North Vent	South Vent
Fan and Mortar	Main Vent East Vent Lower Mortar	River Vent High Vent Gold Vent
Grand	Turban Geyser	Grand Geyser Vent Geyser

In each of the above cases, the vent(s) in Group B are enervated whenever those in Group A are energized. At other times during the cycle, the situation reverses, and the vent(s) in Group A are energized while those in Group B are enervated. Just prior to the major eruption, this antagonistic activity is replaced by concerted activity. This process is discussed in more detail below.

Giant Geyser:

The Giant Geyser Complex includes Giant, Mastiff, Catfish and Bijou Geysers. In addition, many small vents (called the hot period vents) in front of Giant's cone can also erupt.

While watching Giant Geyser in 2006, I observed that these geysers naturally divide themselves into two groups. On the left (north) side of the platform is Bijou Geyser. On the right (south) side of the platform are Mastiff and Giant Geysers, and the hot period vents. When Bijou is erupting, the water levels on the right (south) side of the platform are low. However, when a hot period occurs, Bijou stops erupting. The water levels rise in Giant, Mastiff and the hot period vents. At the end of the hot period, the energy shifts back to the left side of the platform, and Bijou starts to erupt again.

Watching the progress of a hot period was like watching a giant seesaw tilt back and forth between Bijou and the Giant-Mastiff system. Catfish Geyser was the fulcrum of the seesaw, since its right (south) vent seemed to be more connected to Mastiff Geyser, while its left (north) vent was more connected to Bijou.

Notably, this seesaw-like behavior disappeared immediately prior to every eruption of Giant I saw during 2006 and 2007. One important sign that Giant might erupt was that Mastiff would remain full and overflowing (or erupting) after Bijou restarted. To see these formerly antagonistic vents erupting in concert was very unusual. Often, but not always, Giant attempted to erupt after this concerted play had gone on for a few minutes. If Giant erupted, the onset of its eruption increased, rather than decreased, the activity of Bijou, which would enter a very loud steam phase.

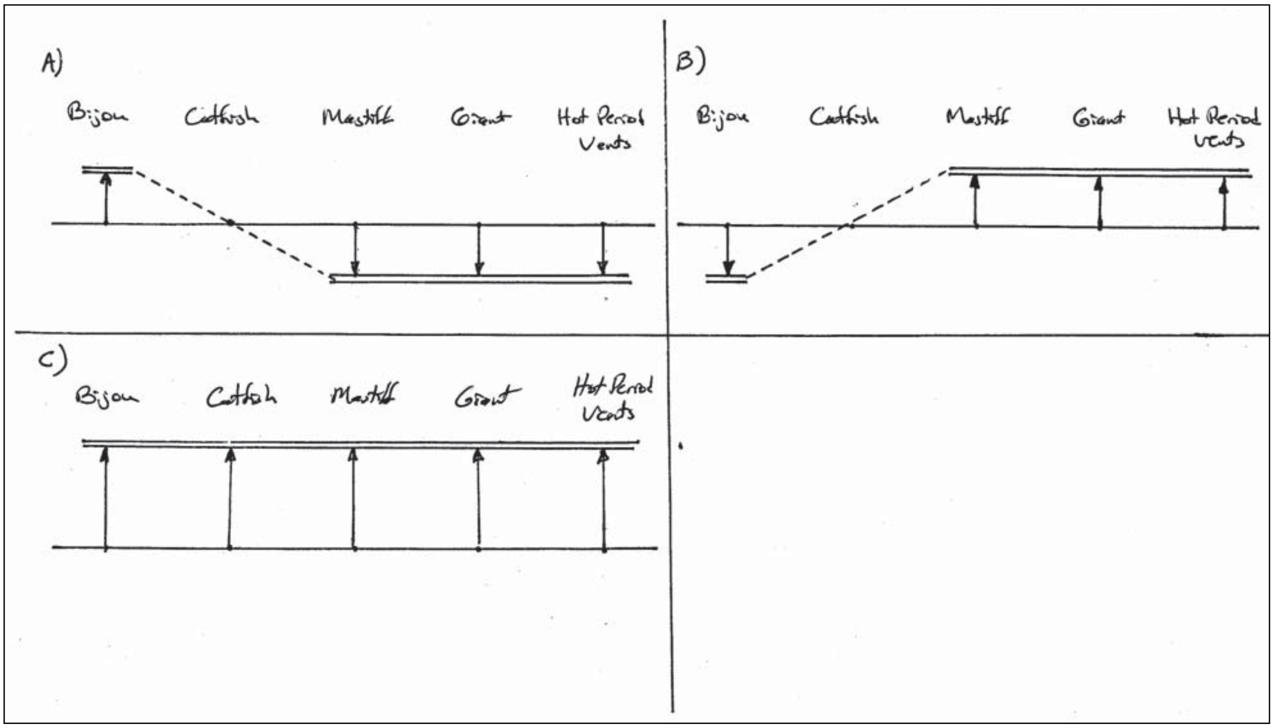

Figure 1. A diagram showing water levels in the vents of the Giant complex A) in between hot periods, B) during a hot period, and C) immediately before an eruption of Giant Geyser.

In summary, the following events occur in order:

1) Bijou erupts by itself.

2) Bijou stops erupting. While it is quiet, the water levels rise in Giant and Mastiff. The hot period vents erupt.

3) Just before Giant starts a major eruption, the hot period vents continue to erupt, and Mastiff may erupt. Bijou rejuvenates and erupts powerfully in concert with the other vents.

The interactions between Giant and Bijou have been discussed in more detail elsewhere (Keller, 2006).

Steamboat Geyser:

Strasser, Strasser and Pulliam (1990) studied Steamboat Geyser during the early 1980s. Their efforts to understand Steamboat's pre-eruptive activity showed that the geyser progressed through three phases of minor activity prior to an eruption. In order, these phases are:

1) The north vent erupts by itself. They called this activity "North Function."

2) The south vent erupts by itself. They called this activity "South Function."

3) Both vents erupt together. They called this activity "Simultaneous Function." Very strikingly, during simultaneous function, Strasser, Strasser and Pulliam observed that "both vents began their minor plays at nearly the exact same time—within one second."

It took several days (out of an interval of 4 to 12 days) for Steamboat to progress through this series of events. Notably, it was only after Steamboat had entered simultaneous function that it could have a major eruption. Also notable is that Steamboat could regress from simultaneous function to south function. It could also regress from south function to north function. However, except during a disturbance, it never regressed directly from simultaneous function to north function.

Fan and Mortar Geysers:

The impressive eruptions of Fan and Mortar Geysers issue from four major vents and five minor vents distributed over the east bank of the Firehole River. During major eruptions, the largest columns of water are thrown from Fan's Main and East vents, and Upper and Lower Mortar. Smaller columns are thrown from Fan's River, High, Gold and Angle vents, and Mortar's Bottom vent.

Based on their activity, the vents of Fan and Mortar naturally divide themselves into two groups. The minor vents include River, High, Gold and Angle.

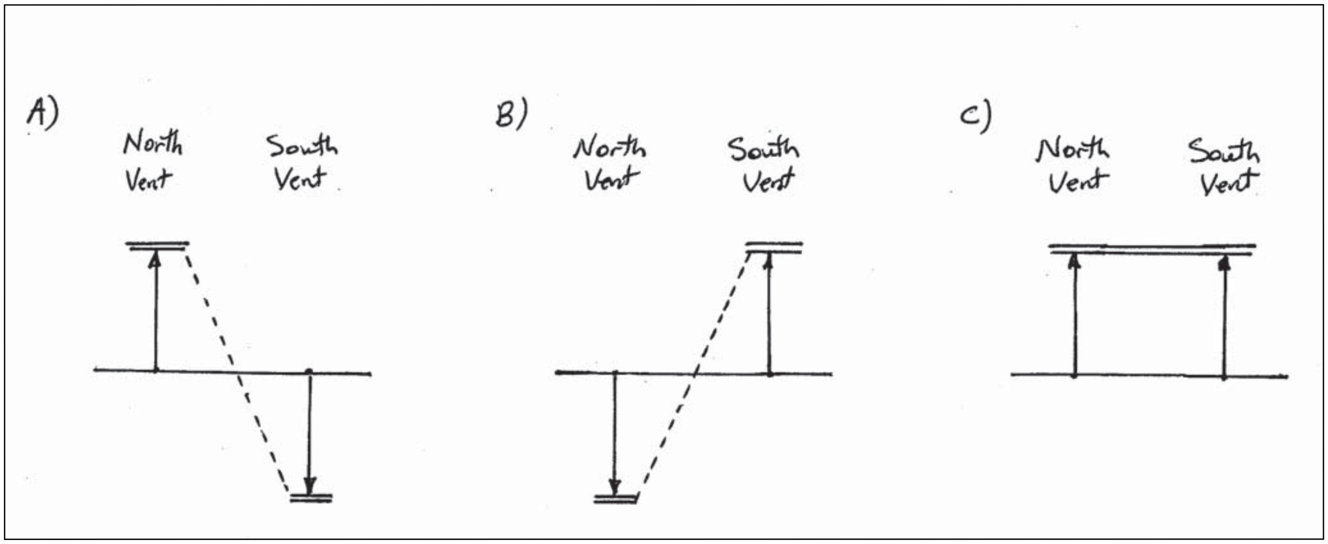

Figure 2. A diagram showing eruptive activity of Steamboat A) during North Function, B) during South Function, and C) during Simultaneous Function.

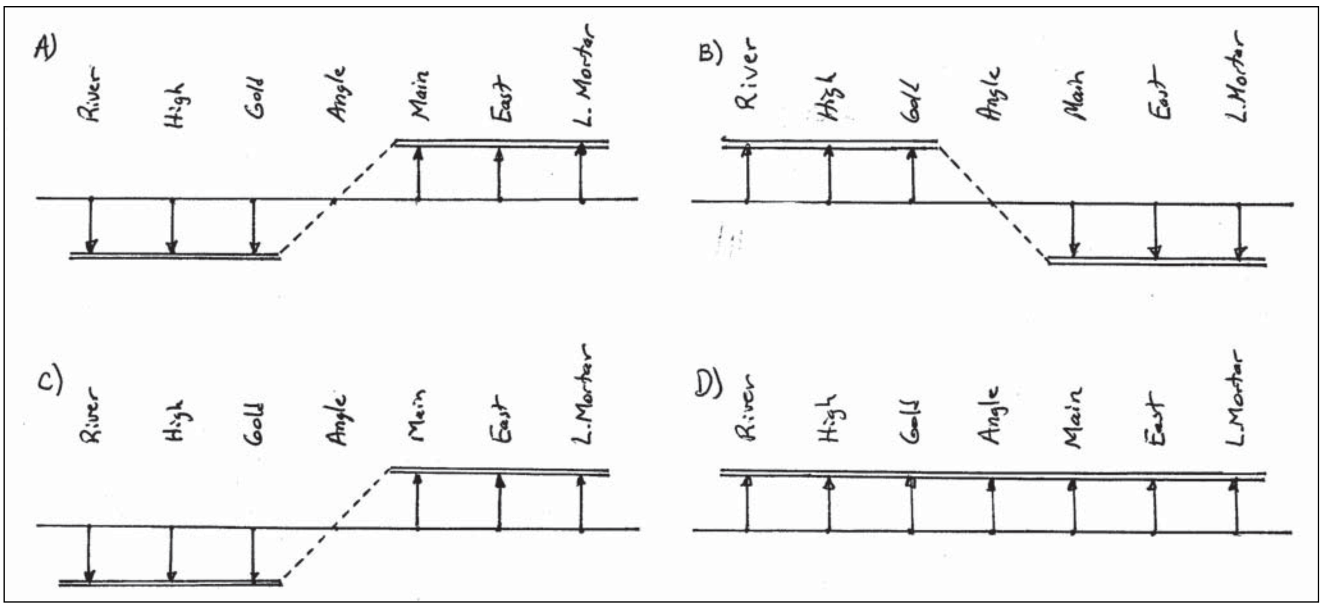

Figure 3. A diagram showing water levels in the vents of Fan and Mortar Geysers A) prior to the start of River vent, B) while River vent is in eruption, C) during a pause, D) after the pause, just prior to the major eruption.

The major vents include Fan's Main and East vents, as well as Lower Mortar. Mortar's Bottom Vent is very closely related to Lower Mortar. Upper Mortar is also a major vent, but during most years it is only weakly involved in the pre-eruptive activity.

Prior to a major eruption, Fan and Mortar undergo hot cycles. The nature of these hot cycles has changed considerably over the years, as outlined in Cross (2002, 2003, 2005). The classical hot cycle activity was first described by Strasser and Strasser (1989), who describe the progress of a hot cycle as follows:

1) Water rises in Lower Mortar.

2) Water erupts from Fan's River vent. This is the time when most observers record the start of the hot cycle, since the large, billowing steam clouds are very easy to see.

3) Fan's High vent begins to erupt, followed by Gold vent, and finally by Angle vent. Lower Mortar becomes weaker.

4) The minor vents cease to erupt, and the water levels fall in all vents.

Sometimes, a hot cycle is interrupted by a pause. During a pause, the normal progress of eruption from River through High and Gold is interrupted

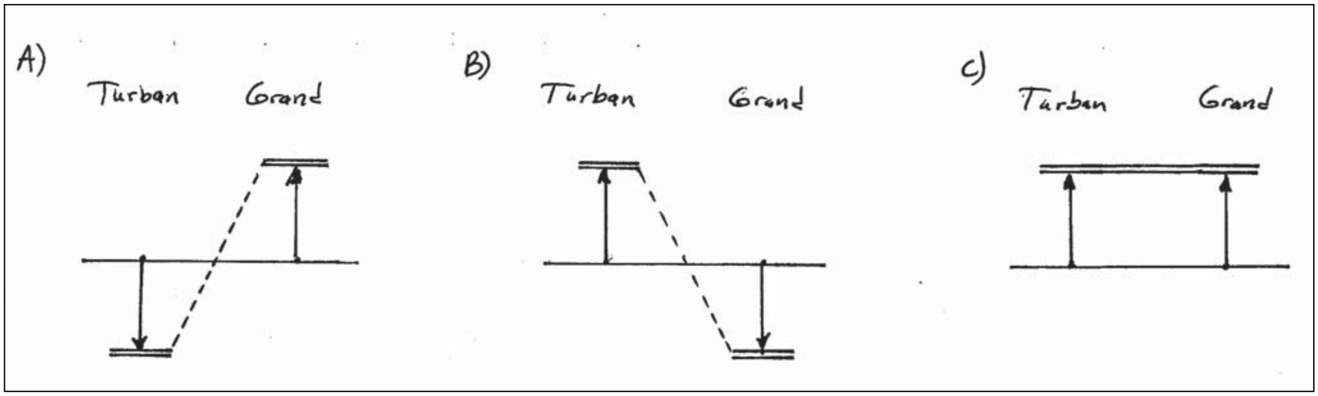

Figure 4. A diagram showing water levels in Grand and Turban Geysers A) while Turban is in between eruptions and Grand's water level is high, B) while Turban is erupting but Grand is ebbed, and C) immediately prior to Grand's eruption.

before Angle can erupt. If the progress is interrupted after Gold starts to erupt, the event is called a Gold Vent Pause. If the progress is interrupted before Gold starts to erupt, the event is called a River Vent Pause. More than one pause may occur during a hot cycle. Regardless of what type of pause occurs, or how many pauses occur in sequence, the effect of a pause on the complex is the same. All activity from Fan's minor vents ceases, but Lower Mortar and Main Vent are energized. If they retain their energy after River Vent restarts, an eruption is often imminent.

The last event to occur before a major eruption of Fan and Mortar is called the "lock." One way to identify the lock is to note that the normally random splashing of High, Gold and Angle vents begins to wax and wane in unison. As they grow stronger, water levels rise in Lower Mortar, and in Fan's Main and East vents. As the eruption begins, all of the vents burst into full eruption at nearly the same instant.

Note that in all of the above descriptions, the River-High-Gold system has acted antagonistically with the Main-East-Lower Mortar system. This occurs both during normal cycles and during pause cycles. Note, also, that just prior to the eruption, all of the vents act in concert.

Grand and Turban Geysers:

Perhaps the most classic case of geysers acting antagonistically during the quiet interval but acting in concert immediately before a major eruption is given in Bryan's (2001) description of Grand and Turban Geysers. The water level in Grand's pool typically falls at the time of Turban's eruption. However, "as Grand gets closer to the time of eruption, the water level drops less and more slowly, sometimes holding near full until only seconds before Turban erupts. Finally will come a cycle where the water level doesn't appear to drop at all. Now is the time to watch closely. Waves… begin to wash across the surface of the pool." Usually, these waves indicate that Grand is about to erupt. When Grand starts, Turban begins within a few seconds.

Whitledge and Taylor (2008) discuss the pre-eruptive cycles of Grand and Turban in more detail elsewhere in this volume.

DISCUSSION:

In my experiments with model geysers, I have had the opportunity to create two different configurations of geyser plumbing for systems with two vents. In the first case, a single standpipe divides at a point near the surface. This system gives a simultaneous eruption from two vents. In the second case, two separate standpipes are attached to the same reservoir. This system gives an eruption from only one standpipe. During the eruption, the non-eruptive pipe drains.

Clearly, the standpipes that diverge near the surface are just two different vents through which the same eruption will issue. It is not surprising that they should erupt in concert. However, when two different standpipes join the same reservoir in different places, the situation is different. Eruptive boiling will typically begin in only one of the two pipes. The sudden creation of steam bubbles will sweep the water in the eruptive pipe upward. At the same time, the water in the non-eruptive pipe is drawn downward by the falling pressure in the reservoir. The non-eruptive pipe drains.

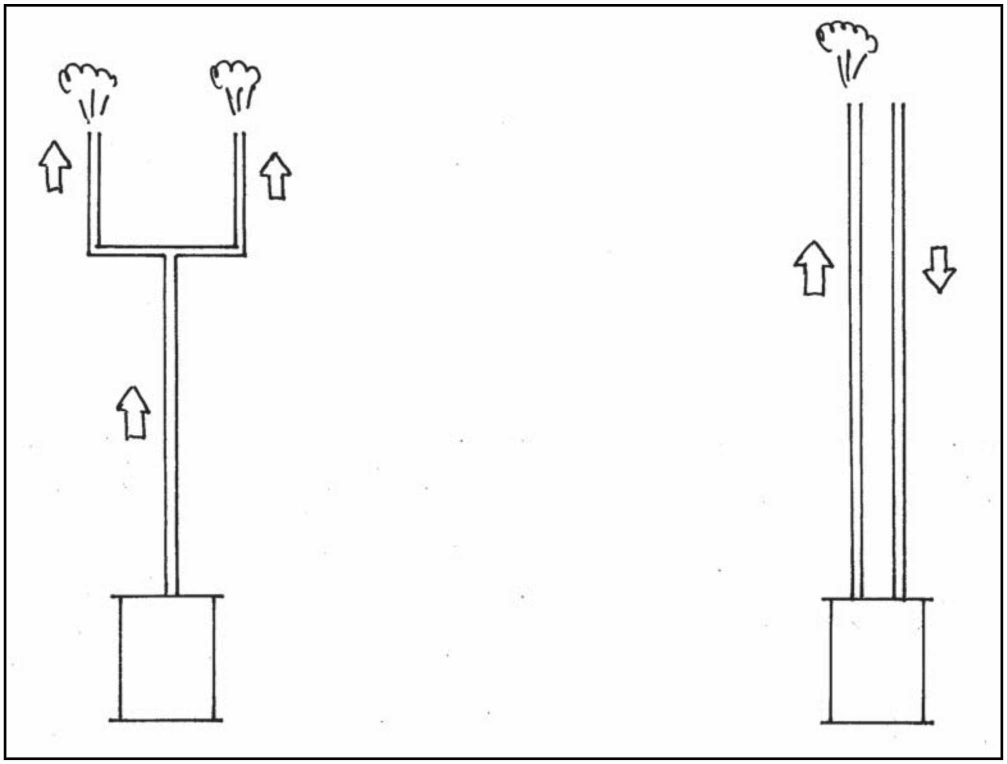

Figure 5. A diagram showing the difference in eruption pattern between A) two standpipes that join near the surface, and B) two standpipes join the geyser reservoir separately.

The examples described above represent two vents that erupt in concert (standpipes diverge near the surface), and two vents that are antagonistic (standpipes diverge at the point where the boiling occurs). One could envision that the boiling in a geyser system will cause antagonistic behavior between two vents if the boiling occurs above the point of connection. However, the vents will erupt in concert if the boiling occurs below the point of connection.

In the early stages of a geyser's quiet interval, boiling happens only very near the surface. If this is above the point where two different geyser pipes diverge, each vent will erupt solo and will have an antagonistic relationship with vents whose pipes connect with the erupting pipe below the point where the boiling occurs. When the geyser is very close to eruption, the point of boiling will have progressed downward, past the point of junction, and the pipes will erupt in concert. The downward progression of boiling is supported by temperature measurements in Old Faithful reported by Birch and Kennedy (1972). They found that Old Faithful's subsurface temperatures approached boiling most closely in the shallow parts of the system, while in the deeper parts of the system the temperatures were far below boiling for the hydrostatic pressure at those depths. As the eruption approached, the temperatures in the deep parts of the plumbing more closely approached the boiling temperature for the hydrostatic pressure at those depths.

PHYSICAL IMPLICATIONS:

Steamboat Geyser:

By assuming that the above hypothesis is true, we can draw some hypothetical diagrams of the vent systems described above. Steamboat Geyser forms the simplest system. Steamboat's north vent has been plumbed to a depth of 28 feet, while the south vent has been plumbed to a depth of 85 feet (White, Hutchinson and Keith, 1988). Notably, this is the greatest depth measured for any vent in Yellowstone. White, Hutchinson and Keith conjecture that the two vents are joined 20 feet below the surface.

As the system heats prior to an eruption, I hypothesize that boiling first occurs in the north vent (point A, Figure 6), above its junction with the south vent. At this time, the north vent has independent eruptions. Water in the south vent soon reaches boiling, too, and its eruptions begin to compete with those of the north vent. Eventually, the south vent takes over (boiling occurs at point B, Figure 6). When

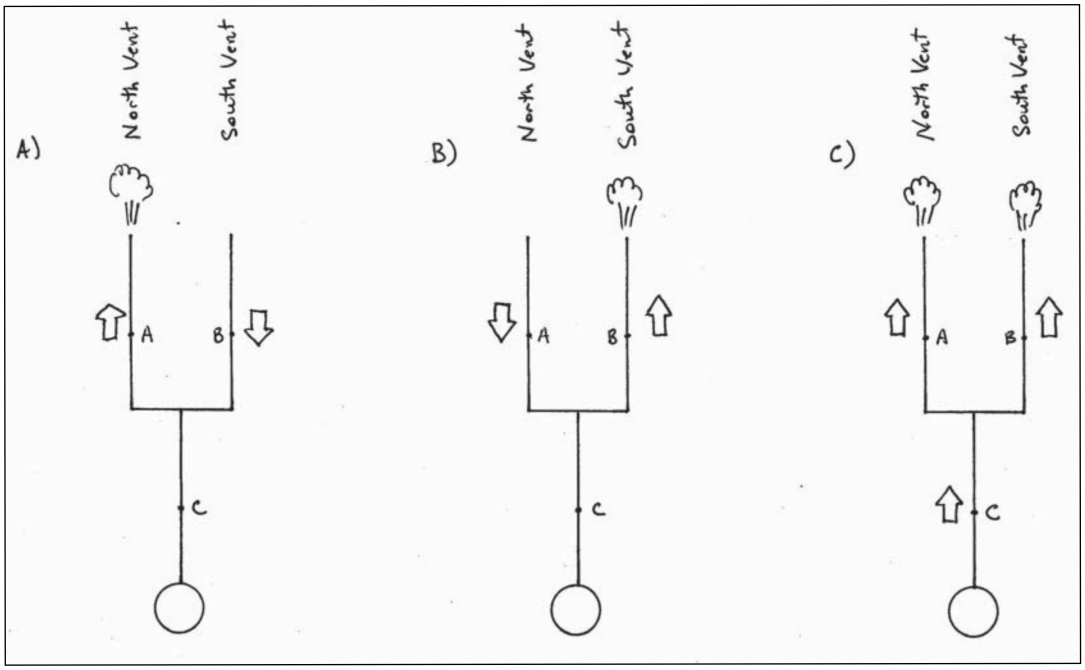

Figure 6. A diagram postulating the subsurface plumbing of Steamboat Geyser. The arrows indicate the direction of water movement.

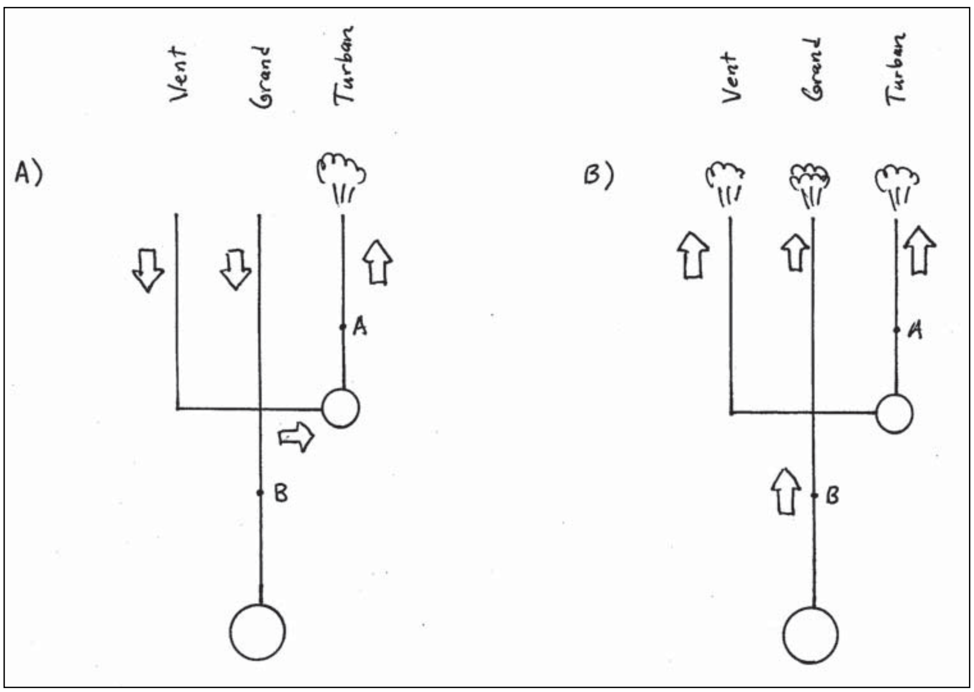

Figure 7. A diagram postulating the subsurface plumbing of Grand, Turban and Vent Geysers at times A) during an eruption of Turban, and B) immediately prior to an eruption of Grand.

water below the point at which the pipes diverge is hot enough to boil, both vents begin to act in concert (boiling occurs at point C, Figure 6).

Grand and Turban:

Grand and Turban form another simple system. Because Turban's eruptions are small, it is likely that it has a fairly shallow plumbing system. This system is interconnected with that of Grand. Boiling within Turban's system (point A, Figure 7) lifts the water in Turban and draws in water from Grand, causing Grand's pool to drain while Turban erupts. However, as Grand approaches its eruption, boiling below the point of connection (point B, Figure 7) allows both Grand and Turban to start erupting at the same time.

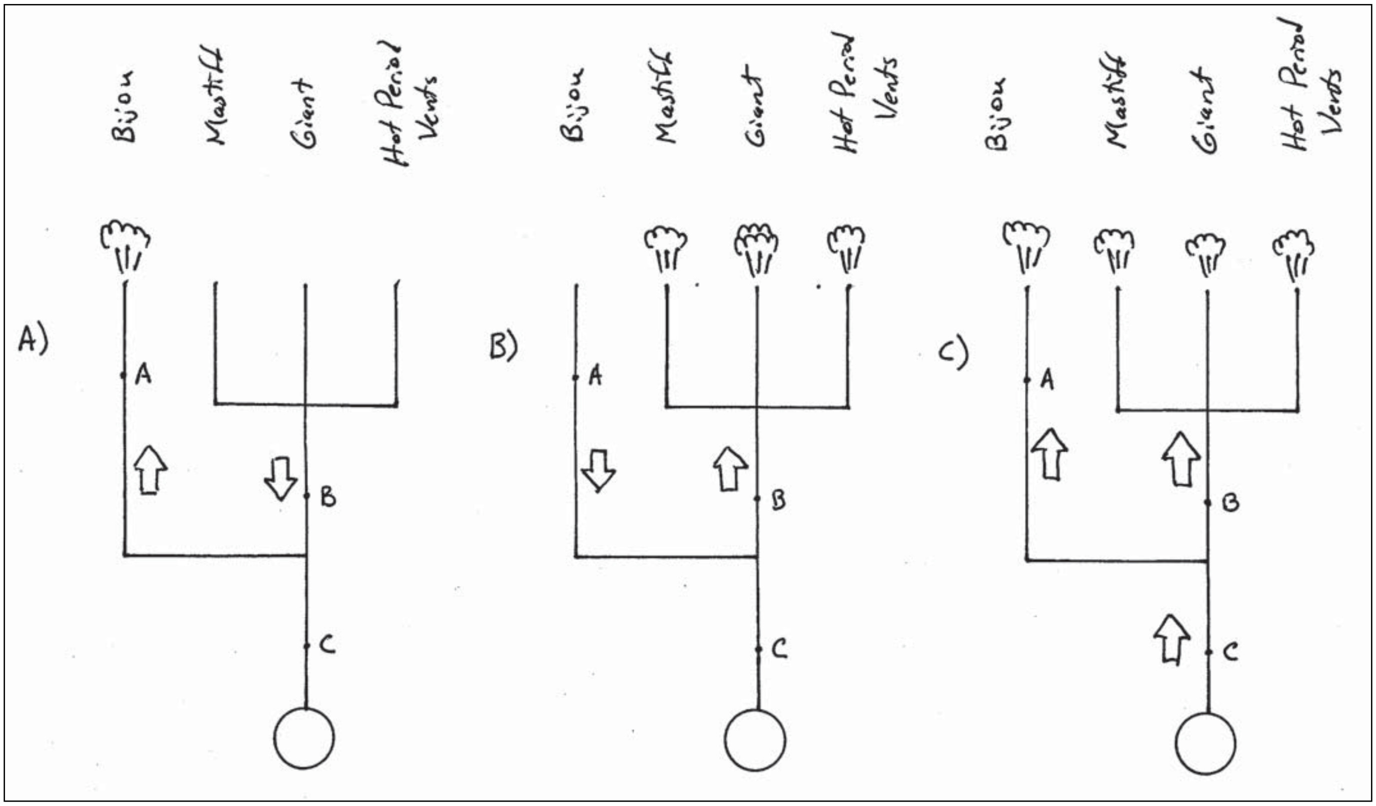

Figure 8. A diagram postulating the subsurface plumbing of the Giant Geyser complex at times A) while Bijou is erupting solo, B) during a hot period, and C) immediately prior to an eruption of Giant.

Vent Geyser usually begins to erupt soon after Grand and Turban start.

Giant:

Giant is no more complex. Typically, boiling occurs only under Bijou (point A, Figure 8). During hot periods, boiling occurs at point B (Figure 8), which is below the junction of Mastiff, Giant and the hot period vents, but above the junction between Giant and Bijou. However, in the few minutes prior to Giant's eruption, boiling has already begun to occur below the Giant-Bijou junction (point C, Figure 8), sending Bijou into a violent steam phase just as Giant starts.

Fan and Mortar:

Fan and Mortar are a little more complex. Since Fan's River, High and Gold vents all erupt together, it is reasonable to assume that they are different branches from a single standpipe. At the start of River Vent's eruption, boiling occurs at point A (Figure 9).

During a pause, water levels in the Main-East-Lower Mortar system rise and Fan's River vent stops erupting. If High and Gold vents are erupting, they, too, cease. This means that boiling is occurring in the Main-East-Lower Mortar system (at point B, Figure 9) and raising the water levels there. But because the boiling is occurring above the junction with the River-High-Gold system, the water levels fall in these vents.

As Fan and Mortar come out of a pause, water levels in all vents may be high at the same time. If the renewed activity in the River-High-Gold system does not drain the Main-East-Lower Mortar system, one may expect that an eruption is imminent. By inference, since water levels in all vents are high at once, the boiling has moved below the point where the Main-East-Lower Mortar system joins the River-High-Gold system (point C, Figure 9).

The point where Upper Mortar joins the system is in question. The nature of these hot cycles has changed considerably over the years, as outlined in Cross (2002, 2003, 2005). Cross (2003) notes that during Upper Mortar-initiated eruptions, heavy surging in the River-High-Gold system seemed to alternate with heavy surging from Upper Mortar. This would place the Upper Mortar junction below the junction joining River, High and Gold, but its placement regarding the junction of Fan's Main and East vents with Lower Mortar is uncertain.

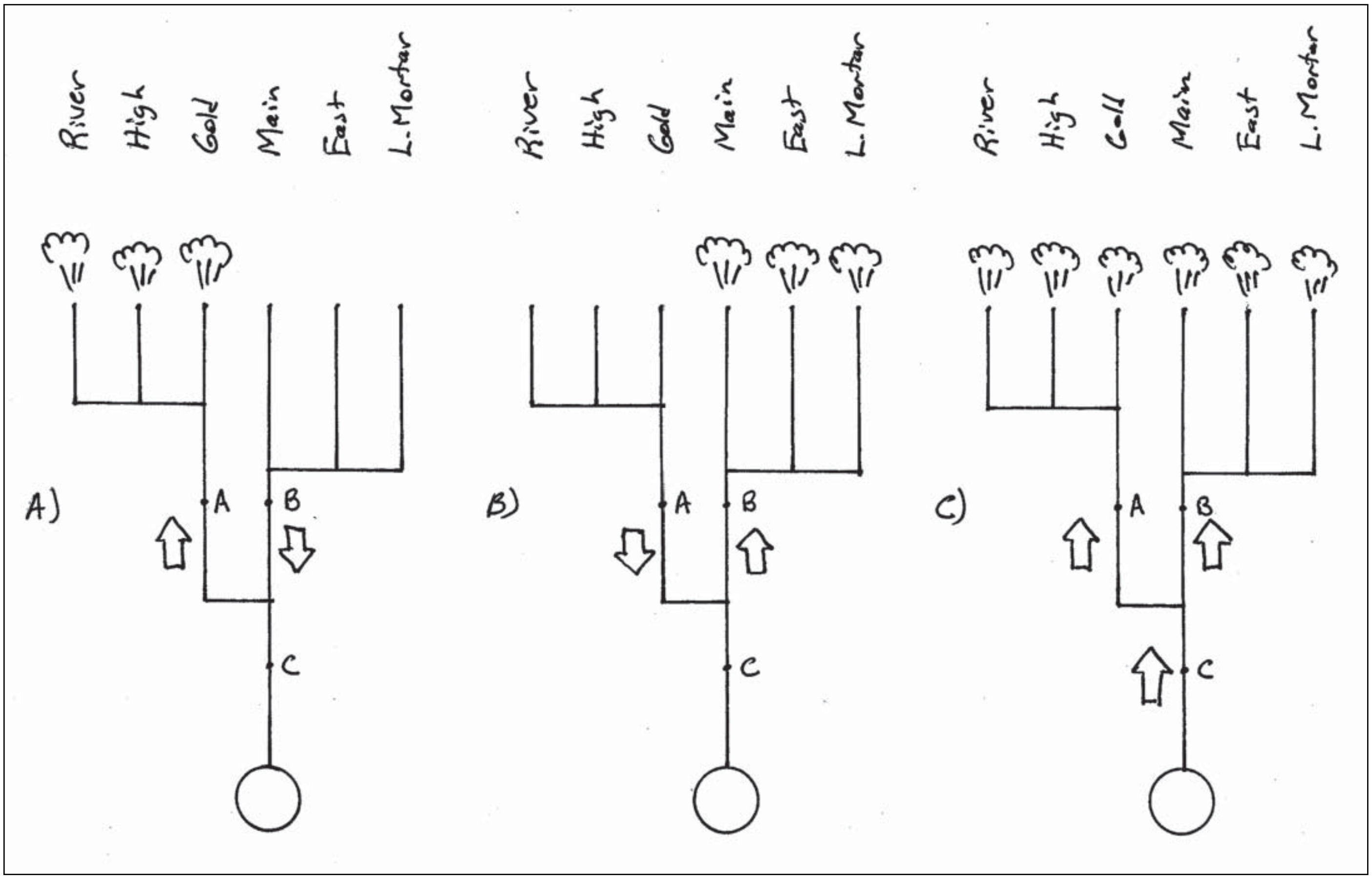

Figure 9. A diagram postulating the subsurface plumbing of Fan and Mortar Geysers during times A) at the start of the hot cycle, B) during a pause, and C) immediately prior to the major eruption.

CONCLUSIONS:

From direct observations, four systems of related geysers or geyser vents are shown to switch from antagonistic to concerted activity prior to the onset of a major eruption. This may be due to the progression of boiling from shallow parts of the system, which feed only one or a few vents, to deeper parts of the system, which are common to all of the vents in the system. Plumbing systems consistent with this hypothesis can be proposed for all of the geysers discussed in this article.

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I thank Paul Strasser and Ralph Taylor for reviewing this paper.

Baby Daisy Geyser Activity in 2003-2004

Ralph Taylor

Abstract

Baby Daisy Geyser is located in the Old Road Group of the Upper Geyser Basin. It has had only three known periods of activity: 1952, lasting less than one year; 1959, lasting less than one year, and 2003-4, lasting from February 2003 to December 2004. This paper discusses the 2003-4 activity as reported by observers between February and June of 2003 and as recorded electronically from June 2003 to the end of the active cycle in December 2004.

Introduction

The Old Road Group of the Upper Geyser Basin contains numerous hot springs but few geysers. The geysers that exist in this area, located east of the Grand Loop Road and south of Biscuit Basin, have often been active for relatively short periods only. One such geyser is Baby Daisy Geyser. This small geyser has had only three known periods of activity. The most recent active phase, which is the primary topic of this paper, began during the winter of 2002-3 and continued until December of 2004.

Location

Baby Daisy Geyser is located in a small group of features located between the footpath that follows the old Grand Loop Road and the Firehole River. Figure 1 is a section of the Old Faithful quadrangle topographic map showing the area. Baby Daisy Geyser is located below and to the left of the letter "B" in the "Biscuit Basin Geyser" caption. While it was active it was often seen from passing vehicles, especially those traveling from north to south. Baby Daisy's formation is located within sight of the trail from Morning Glory Pool to Biscuit Basin, but trees and undergrowth made it difficult to spot the low-lying crater when Baby Daisy was not erupting. When Baby Daisy was in an active phase and in eruption, it could easily be seen from the trail, as shown in Figure 2.

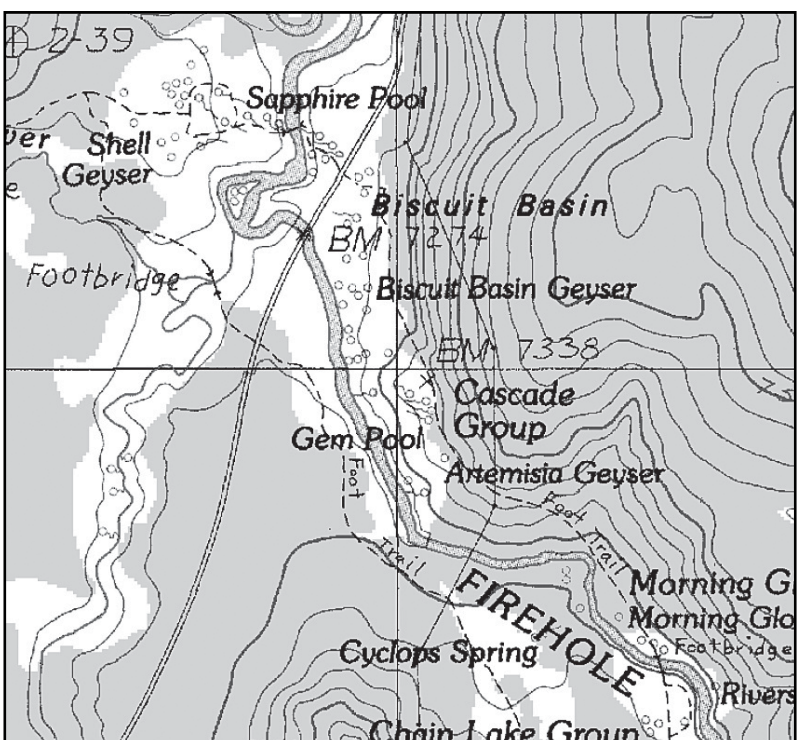


Figure 1. Section of the USGS topographic map showing the Cascade Group and Biscuit Basin. Baby Daisy Geyser is "B" in Biscuit Basin Geyser.

Historical Background

George Marler first noted eruptive activity at Baby Daisy in 1952. He wrote:

> During the 1952 season a plot of ground of about half an acre in extent suddenly became hot enough to result in 8 different springs taking on geyser proclivities. This occurred sometime between July 11 and 13. Previous to this I had never observed any geyser activity in this particular group of springs. Most had been quite inauspicious in appearance. These springs are located in the southeastern end of Biscuit Basin, on the east side of the Firehole River. The geyser farthest to the south was called Baby Daisy.[1]

He stated that activity continued for the rest of the 1952 season, but that no activity

[1] Marler, George D. *Inventory of Thermal Features of the Firehole River Geyser Basins and Other Selected Areas of Yellowstone National Park*, USGS GD73-018.

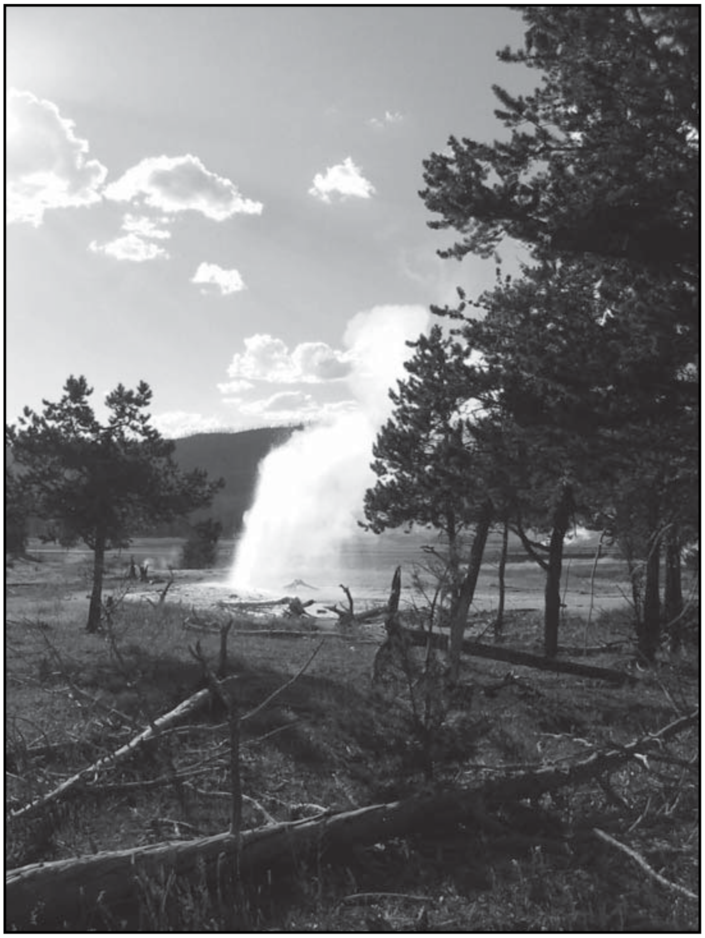


Figure 2. Baby Daisy Geyser in eruption, seen from the footpath along the old roadbed.

was observed from 1953 until the 1959 Hebgen Lake earthquake. Marler noted that the activity was the first in many years since a grove of lodgepole pine trees 9 meters (30 feet) from the geyser were killed by the spray, indicating that there had been no activity during the years that the trees had grown. Those trees were subsequently burned by the 1988 fires, and only scattered bits of wood remain.

The next activity was apparently initiated by the Hebgen Lake earthquake in 1959 and had ended by the 1960 season.

2003-4 Activity

The latest active period started during the winter of 2003. In an email to the geyser list, geyser gazer and NPS volunteer Mike Keller reported

> For the first time in many years Baby Daisy Geyser is active. NPS Rangers Dave Page and Tim Townsend both saw an angled geyser in the Cascade area erupting two days ago (2/20) around 1030ie. Over the past two days they kept seeing this geyser at least once a day. This evening (2/22) Tim and I went to see what feature was active and found it was Baby Daisy. While we were there it even erupted for us! The play lasted just over 3 minutes, was angled towards the old road, and reached from 20 to 25 feet. Based upon wash in the

Figure 3. Baby Daisy Geyser's formation from the location of the data logger. Note the large washed area around the crater.

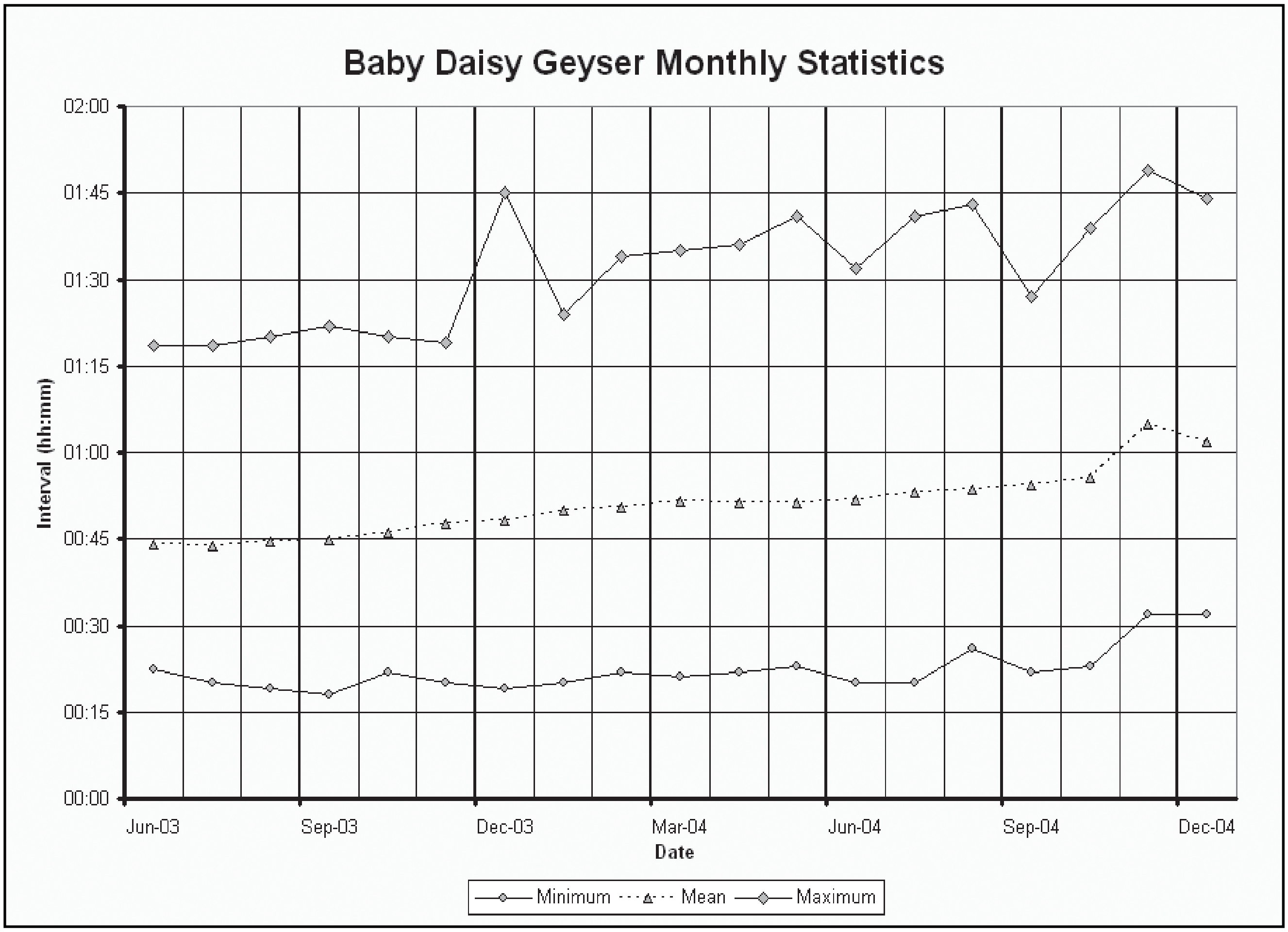


Figure 4. Baby Daisy Geyser eruption intervals (black) and 1-day moving median interval (gray).

> area it appears that Baby Daisy has been active for at least a week and possibly longer.[2]

The exact date of the reactivation was never determined due to the low number of visitors during the winter season. Activity reports continued through the winter and spring months with no reported periods of inactivity noted.

The author was a volunteer for the NPS during the active period. Upon my arrival at Old Faithful in June, I deployed an electronic data logger in Baby Daisy's runoff channel at the first opportunity. Electronic monitoring began at 1500 on 22 June 2003 and continued without a break until 25 June 2005. The last recorded eruption was at 0950 on 8 December 2004.

Description of Baby Daisy's Formation

Baby Daisy Geyser erupted from a roughly circular basin in a sinter mound covered by sinter gravel, as shown in Figure 3. The basin was approximately two meters (6.5 feet) in diameter and about 20cm (8 inches) deep. The vent was roughly circular, about 30cm (12 inches) in diameter, and located at the center of the basin. The sinter mound was washed clean of gravel for a meter or so uphill from the crater and for 8-10 meters (about 25-30 feet) to the north. There was a distinct berm of gravel around the washed area uphill from the vent. The basin from which Baby Daisy erupted was lined with ochre-colored sinter.

Eruption Characteristics

During the 2003-4 activity, eruptions of Baby Daisy Geyser occurred at intervals of between 18 minutes and 1 hour 50 minutes, averaging about 45 minutes in 2003 and 53 minutes between eruptions in 2004. Eruptions lasted between two and four minutes. As the start of an eruption approached, water rose in the vent until the inner basin was filled. The filling was accompanied by boiling that increased in vigor as the eruption neared. Once the eruption started, the water column rapidly reached its estimated maximum height of between 6 and 7.5 meters (20 to

[2] *"REPORT: Baby Daisy Geyser (Keller)"*, geyser report posted on the Geyser List Server, Mike Keller, 22 February 2003.

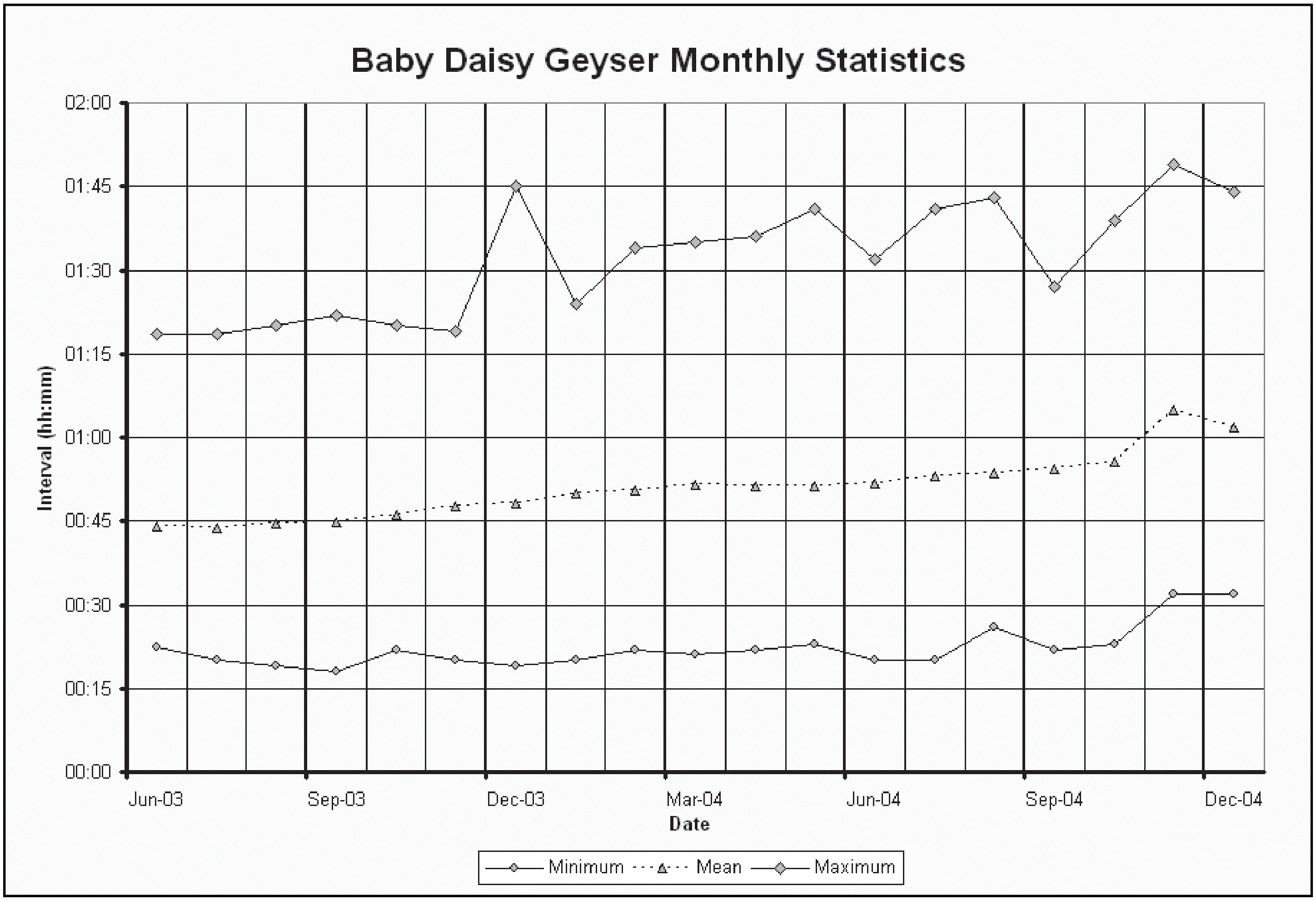


Figure 5. Baby Daisy Geyser monthly minimum, maximum, and mean intervals

25 feet). The water jet was angled at about 30° to the vertical toward the north. It was the similarity of this angled eruption from a round basin to the eruptions of Daisy Geyser that inspired the name "Baby Daisy."

Analysis of Eruptions

Reports of Baby Daisy Geyser eruptions before 22 June 2003 are sparse. Short sets of eruption intervals and durations were reported in March and April by geyser gazers.[3] Activity reports noted durations of two to three plus minutes. Paperiello reported intervals averaging 34 minutes on 15 March, 30 minutes on 19 March, 33 minutes on 29 March, 36 minutes on 6 April, 34 minutes on 12 April, and 40 minutes on 19 April.[4]

Once the electronic data logger was deployed, the temperature trace showed 15307 intervals ranging from 0h18m to 1h49m. Figure 4 is a plot of all intervals recorded by the data logger for Baby Daisy Geyser. The black band illustrates the erratic nature of the intervals, which varied by 60 to 80 minutes from minimum to maximum in any given month. There did not appear to be any pattern to the variation; that is, intervals did not alternate long-short but appeared to vary randomly from interval to interval.

Over the nearly 20 months for which there is a complete record of intervals, the general trend was a gradual increase shown by the white linear regression line in Figure 4. The wide variation in intervals makes trends difficult to see. To help illustrate trends in intervals, Figure 4 also includes a plot of daily moving median intervals, shown in gray.[5]

Closer examination of the moving median interval (the gray line in Figure 4) shows two events that changed intervals abruptly. The first occurred between 21 and 28 August 2003, when the daily median intervals dropped from 50 to 35 minutes,

[3] Posts to the geyser list server were made by Michael Lang on 3 March 2003, by David Goldberg on 14 March 2003, and by Rocco Paperiello (several reports in March and April 2003)

[4] Paperiello, Rocco; report posted to the Geyser List on 19 April 2003

[5] Actually, the moving median covers 29 intervals, which approximates the mean of 28.6 intervals per day.

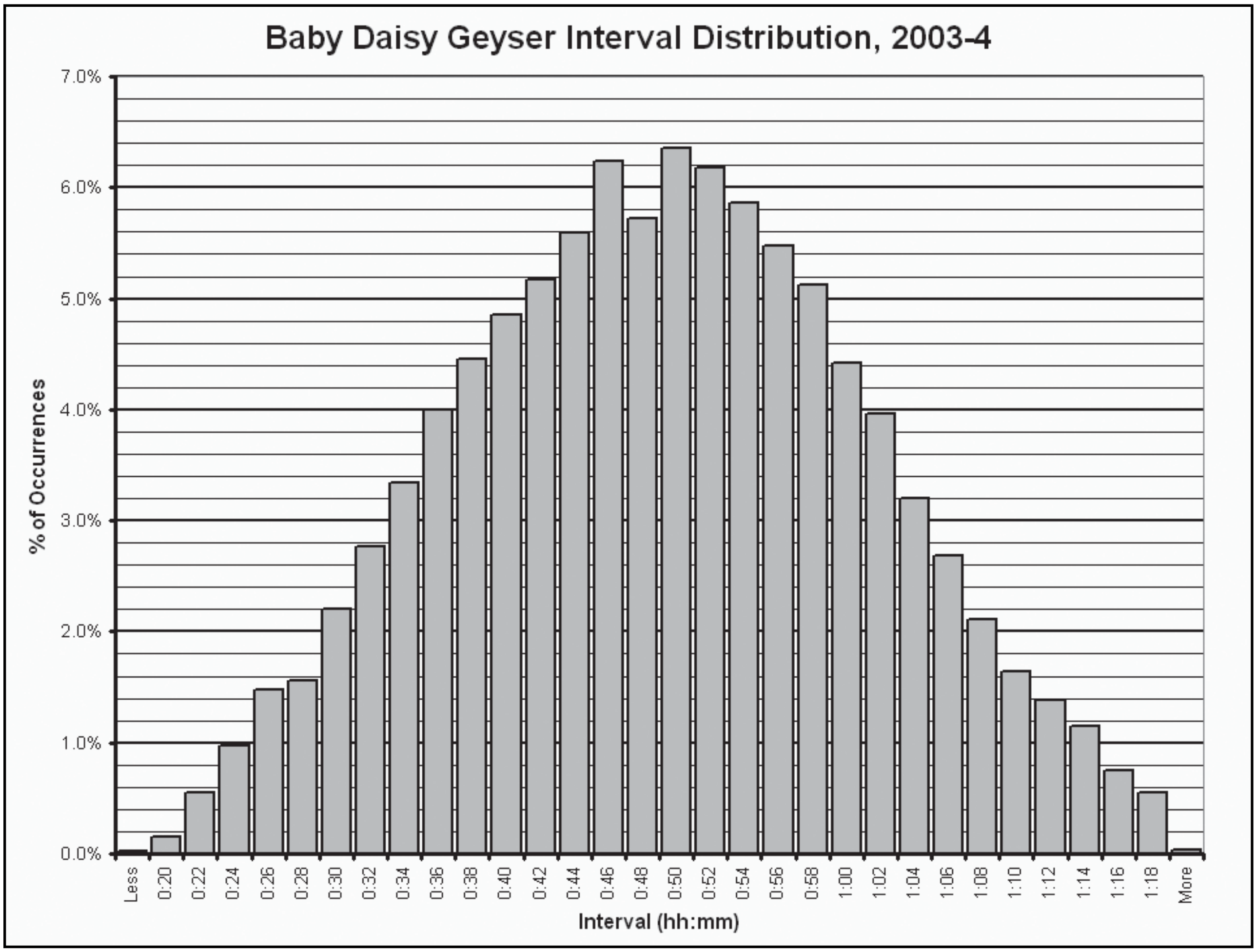


Figure 6. Baby Daisy Geyser interval distribution histogram

then recovered over the next three weeks to the long-term trend line. The second event occurred between 29 October and 2 November 2004, when the median intervals first dropped then jumped nearly 15 minutes in a three day period. After the latter change, intervals remained longer until the activity abruptly ceased on 8 December.

Figure 5 is a plot of the monthly minimum, mean, and maximum intervals, and provides a different look at the activity. The trend to longer intervals shows up on this plot also, as does the late October 2004 increase in intervals. The distance between the maximum and minimum curves clearly illustrates the variation.

Figure 6 is an interval distribution histogram for all of the Baby Daisy Geyser intervals recorded electronically. Bin labels are the center of the bucket; that is, the bin labeled "0:40" contains the percentage of intervals between 39m30s and 41m30s. The distribution is symmetrical about 0h50m with few extreme outliers. There does not appear to be a seasonal variation, and no other periodic fluctuations appear to be present.

Comparison with Historical Activity

Marler reports that during its initial observed activity in 1952 Baby Daisy's eruptions lasted "from about 2 to 2 ½ minutes"[6] and reported the eruption height as "about 30 feet"[7] and that "intervals ranged between about 90 and 120 minutes."[8] This activity is similar to what was seen in the 2003-4 activity but with rather longer intervals.

In the activity that followed the 1959 Hebgen Lake earthquake, Marler wrote:

> Again checked eruptions lasted from about 2 to 2 1/2 minutes; the height the same as during 1952. However, there was greater frequency of eruptions, the intervals ranging between about 60 and 96 minutes.[9]

This activity is more similar to the 2003-4 activity. The intervals fall within the range of intervals

[6] Marler, George D. *Inventory of Thermal Features of the Firehole River Geyser Basins and Other Selected Areas of Yellowstone National Park*, USGS GD73-018
[7] ibid.
[8] ibid.
[9] Marler, George D., ibid

from 2003-4, but apparently the sub-hour intervals seen in the latest activity were not observed in 1959. Overall, the latest activity is quite similar to the earlier activity, although there appears to have been more water or energy available in the most recent active period since longer durations and shorter intervals were observed.

Baby Daisy Geyser Returns to Dormancy

On 8 December 2004, with no premonitory signs, Baby Daisy Geyser simply stopped erupting. Aside from the abrupt increase in intervals in late October 2004 discussed above, there was no warning of waning power or declining activity. The last observed eruption intervals were no different from the preceding intervals. The final intervals are shown in Figure 7. At 0950 on 8 December Baby Daisy erupted for the final time in the 22-month-plus active period. The eruption was not observed, but the data logger trace shows nothing unusual about that eruption. There were no temperature variations following the last eruption that suggest any periodic overflows or other activity. When the logger was removed in June of 2005, the area was beginning to acquire a covering of dust and debris.

Eruption Time/Date	Interval
12/08/04 01:30:34,	0:32:00
12/08/04 02:37:34,	1:07:00
12/08/04 03:23:34,	0:46:00
12/08/04 03:57:34,	0:34:00
12/08/04 05:05:34,	1:08:00
12/08/04 06:05:34,	1:00:00
12/08/04 07:03:34,	0:58:00
12/08/04 08:02:34,	0:59:00
12/08/04 08:51:34,	0:49:00
12/08/04 09:50:34,	0:59:00

Figure 7. Baby Daisy Geyser's last ten eruptions.

Summary and Conclusions

Geysers in the northern part of the Old Road Group have tended to be episodic in activity. Examples other than Baby Daisy Geyser include Cauliflower Geyser and Biscuit Basin Geyser, both of which have had brief periods of activity but did not sustain their activity over long times. Although the exact start of the active period is not known, it is likely that the total span of the 2003-4 activity was just short of two years.

Intermittent reports for the first four months did not note any activity that differed markedly from the activity recorded during the 534 days of electronically recorded eruptions. Analysis of the electronically recorded eruptions indicates a gradual increase in interval, amounting to a change of about 15 minutes in daily moving median intervals from June 2003 to December 2004. Both the beginning and end of the series of eruptions were not associated with any known external events.

Baby Daisy Geyser, May 2003. Photo by Mike Newcomb.

Acknowledgements

The early activity of Baby Daisy Geyser during the active period described is known because of several observers who posted their observations on the Geyser List; thanks to all who provided this information. I would also like to thank the reviewers who made suggestions that improved the accuracy and readability of this paper. Finally, thanks to Editors Jeff and Tara Cross whose gentle prodding resulted in this paper.

New Activity at Biscuit Basin 2006-2007

Compiled by **Tara Cross**

Photos by **Kendall Madsen and Pat Snyder**

Descriptions by **Kendall Madsen, Mike Keller and Grover Schrayer**

During 2006 and 2007, new activity began to occur in the area of Biscuit Basin between Sapphire Pool and the Firehole River. Two new features were born, and a major geyser emerged from a spring that had been inactive for over 70 years.

In early 2006, tour guide Jim Holstein and park employee Mike Keller noted that a geyser had emerged near the Firehole River north of Black Opal Pool. The geyser had two vents, both of which participated in splashing eruptions from 3 to 5 feet high. Early observations indicated that it was expelling enough black gravel to create a dark berm around its eastern vent. Because of the dark water in the eastern vent and the milky water in the western vent, the informal name "Salt and Pepper" was suggested for the feature. During 2006, the eastern vent sometimes alternated between a milky and dark, but by 2007 its water was milky most of the time.

On July 13, 2006, Kendall Madsen and his family were across the Grand Loop Road watching Mercury Geyser when a large eruption of Black Diamond Pool caught their attention. Because it was dusk, the viewing conditions were not ideal; Madsen snapped the photo seen on page 103 before the brief, 40-second eruption ended. Although the eruption did not last long, it was powerful, reaching at least 40 to 50 feet and tossing out large rocks and debris. Visitors who had been closer to Black Diamond reported that they felt heavy ground thumps during the eruption.[1]

This eruption was significant because it was the first recorded activity of Black Diamond Pool since it was previously active in conjunction with Wall Pool in the 1930s. Eruptions continued to occur at erratic intervals ranging from 1 to 7 days during July and August 2006, with the shortest intervals occurring in the first two weeks of activity. Few eruptions were actually seen, though a small group of geyser gazers was on hand for an eruption on July 29. Mike Keller reported that the eruption started suddenly and threw dark-colored water 20 feet high and 20 feet wide for about 20 seconds, accompanied by "loud thumping and popping sounds."[2] Grover Schrayer

[1] Madsen, Kendall. 2006 Oct. A Black Diamond in the Rough. *The Geyser Gazer Sput* 20(4): 31-33.

[2] Keller, Mike. 2006 Jul 31. [Geysers] Black Diamond on 7/29. Report to geyser listserv, geysers@wallawalla.edu.

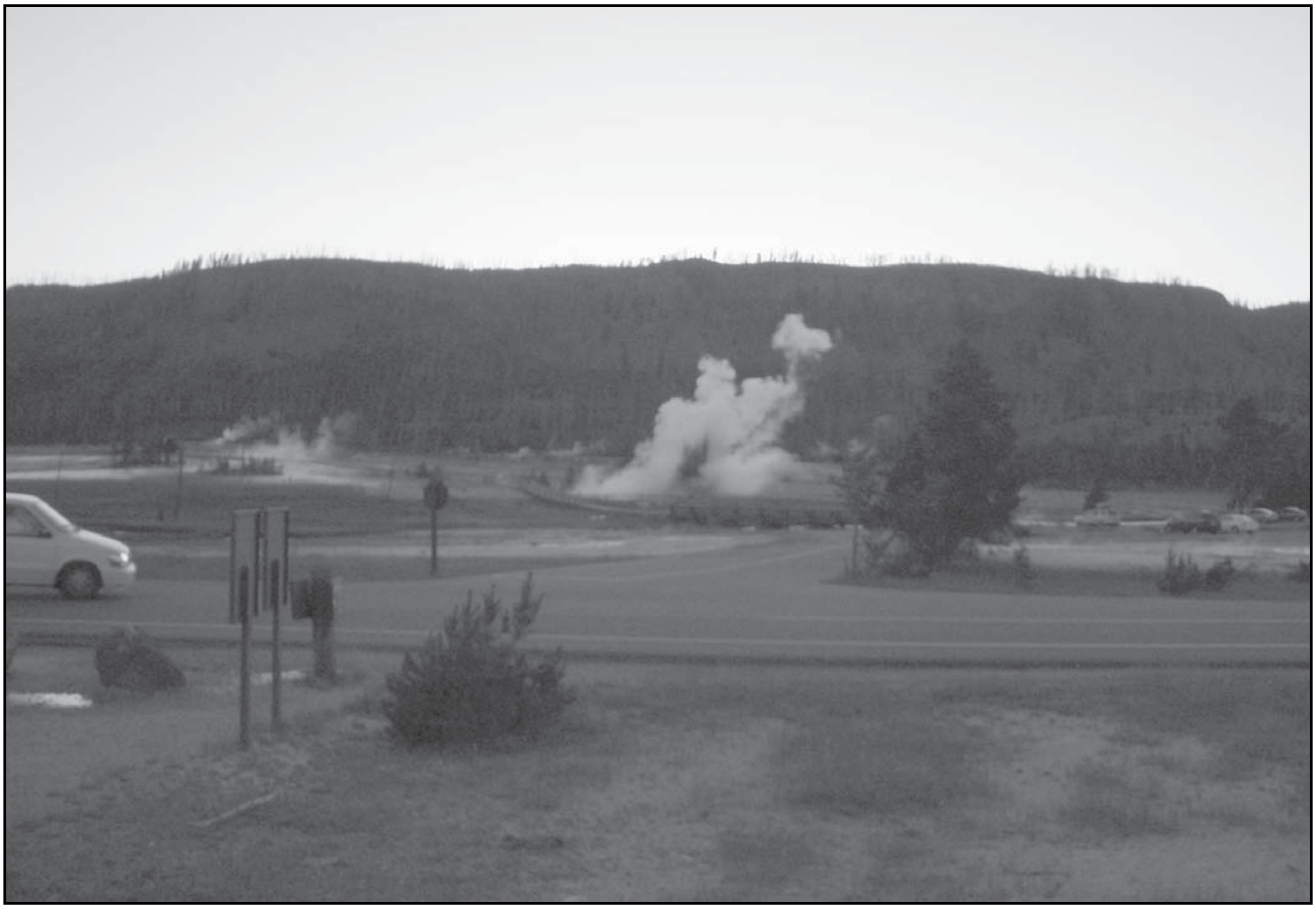
Figure 1: "Salt and Pepper" erupting on Sept. 7, 2007. The western vent is on the left and the eastern vent is on the right. Photo by Pat Snyder.

characterized the eruption as "more like a series of detonations than a geyser eruption."[3]

Observations throughout the rest of 2006 and 2007 revealed that Black Diamond continued to have sporadic eruptions that were sometimes months apart. Attempts to place an electronic monitor on Black Diamond were repeatedly thwarted when the explosive eruptions threw the monitoring device out of the pool.

Sometime during the winter of 2006-2007, a new vent developed near the boardwalk east of Back Opal Pool. The photo below showed the appearance of this feature on May 28, 2007.

[3] Schrayer, Grover. 2006 Jul 30. Personal communication.



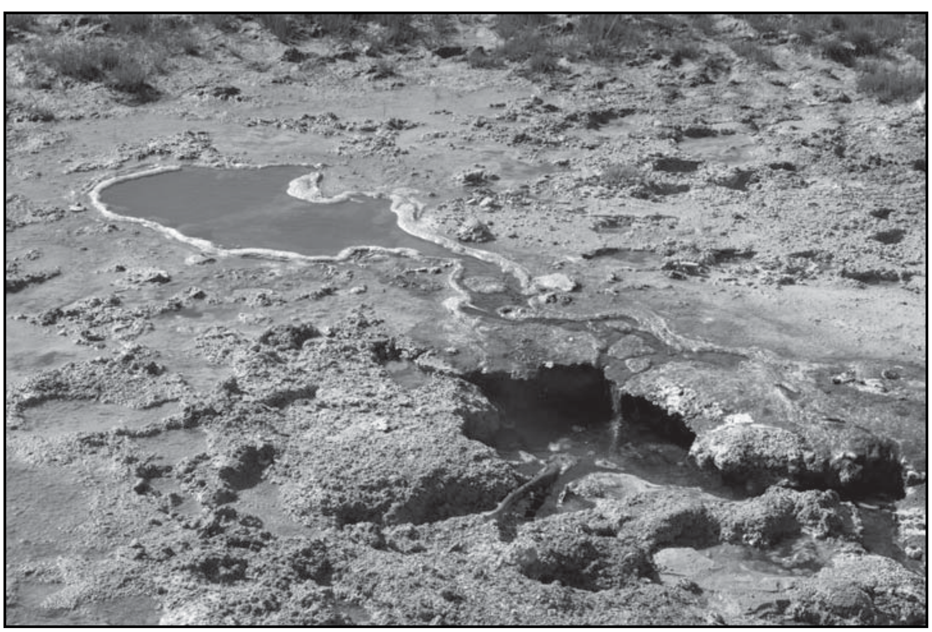


Figure 2, above: Black Diamond Pool erupting at 2108 on July 13, 2006. Photo by Kendall Madsen.

Figure 3, left: New thermal feature east of Black Opal Pool. Photo by Pat Snyder.

Flood Geyser – Patterns Over Time

Lynn Stephens

Abstract

This paper describes eruptive behavior patterns of Flood Geyser. It also presents evidence that Flood Geyser's longer and stronger eruptions are succeeded by longer intervals.

Introduction

Flood Geyser is located in Midway Geyser Basin about a half mile south of Excelsior Geyser. The road between Old Faithful and Madison Junction passes along a hilltop east of Flood Geyser. There is a pullout labeled "Flood Geyser" on the west side of the road. There is a viewing area from which Flood Geyser and Circle Pool can be seen. Flood Geyser perches on the east bank of the Firehole River at the base of the hill. Circle Pool is located just north of Flood Geyser.

Marler [1973] stated, "I know of no reference in available literature prior to 1970, which is descriptive of the nature of [Flood's] function." Marler reported that Flood Geyser's eruptive behavior pattern consisted of a series of short-duration eruptions followed by short intervals. The series of short-duration eruptions continued until a longer-duration eruption occurred. A quiet period followed the longer-duration eruption. This quiet period was longer than the intervals between the short eruptions. In the 35 years since 1970, Flood Geyser has exhibited variations from the pattern Marler observed. In some years Flood Geyser's eruptive pattern consists exclusively of longer-duration eruptions (major eruptions) with no short-duration eruptions punctuating the interval between major eruptions. In other years a single short-duration eruption occurs between major eruptions. In still other years, several short-duration eruptions may occur between major eruptions.

This paper has two main purposes. The paper discusses characteristics of Flood Geyser's pattern of eruptive behavior and variations the pattern has exhibited during the past 35 years. The paper also presents evidence that durations of Flood Geyser's eruptions determine length of the succeeding interval. This is the same relationship between durations and intervals that is exhibited by many other geysers such as Old Faithful and Great Fountain. This relationship is the most common relationship for geysers that exhibit some degree of relationship between duration and interval.[1]

ERUPTIVE PATTERNS OF FLOOD GEYSER

Historical References Prior to 1964

Lee Whittlesey [1988] provided the following historical record for Flood Geyser.

> Originally (1878) this spring of Dr. Peale's "Egeria Springs" was described as follows: "No. 38 is a geyser with a circular basin about 30 feet diameter. It is close to the trail and gives constant exhibitions, although the height to which the water is thrown is not great; 20 feet, perhaps, being the maximum." Peale observed seven eruptions, five of them in a row. He stated that they lasted 6-7 minutes to heights of about five feet. About the intervals he stated only that they "appear to occur with considerable regularity."
>
> Flood Geyser seems to have been given its name in 1884 by geologist Walter Weed, apparently from the "flood" of water that pours forth when it erupts. Weed described the crater and used the name but did not see the geyser erupt.
>
> Of Flood Geyser, geologist Arnold Hague stated: "The bowl, nearly circular, measures 22 inches [sic—feet] in diameter, enclosed by a raised rim of cemented obsidian fragments. When in eruption the Flood is said to throw

[1] One geyser that exhibits the opposite relationship—long duration followed by short interval and short duration followed by a longer interval—is Narcissus Geyser. See Rinehart and Rinehart [1990].

a jet 18 feet in height, but with what degree of regularity is not known."

Both Peale and Hague seem to have had trouble with the size of Flood's crater. George Marler gives it as 10 by 18 feet.

Little was really known about Flood Geyser's activity until 1970. A 1927 reference stated only that it was "extremely active." And for some reason the superintendent saw fit to mention in 1928 in a monthly report that Flood Geyser had erupted in both January and March to 10-15 feet high for about 45 minutes (these sudden mentions in the reports make one wonder if perhaps Flood Geyser had not been dormant for some time).

There is one mention in 1939 of Flood Geyser being seen in eruption twice, and after that the literature is pretty silent on this feature.

Flood Geyser was considered important enough to be included in the *Haynes Guide to Yellowstone National Park* beginning with the 1939 edition and continuing through the final edition in 1966. Clyde Max Bauer also included Flood Geyser in both editions of *The Story of Yellowstone's Geysers*. The mile-by-mile description in the *Haynes Guides* of the road between Madison Junction and Old Faithful noted that Flood Geyser was located 10.80 miles south of Madison Junction or 5.40 miles north of Old Faithful, on the near bank of Firehole River. Information about its eruptive patterns included in the table for "Geysers at Midway Geyser Basin" indicated the lack of knowledge about Flood Geyser's eruptive pattern. The table entry for Flood Geyser listed the height at a few feet and stated both duration and interval were "unrecorded." Bauer gave a location for Flood Geyser (one-half mile from Excelsior Geyser) and listed Flood Geyser's interval as "irregular."

1964 – 1973 George Marler's Observations

George Marler included only one reference to Flood Geyser in his 1964 booklet *Studies of Geysers and Hot Springs Along the Firehole River* (hereafter referred to as *Studies of Geysers*). The reference appeared in the "Table of Named Hot Springs in the Midway & Lower Geyser Basins Which Have Shown Geyser Activity." The table entry for Flood Geyser listed Flood Geyser's characteristics as:

Height	Duration	Interval
10–50 ft.	20-40 minutes	2–4 hr.

(Sometimes inactive for long periods)

In 1973 Marler summarized his observations about Flood Geyser. He provided the first information about the complexity of its eruptive behavior in his *Inventory of Thermal Features*.

> Two types of activity characterize Flood. There is a series of eruptions occurring about every 3 to 12 minutes. They last for less than a minute to about 3 minutes. Following each period of activity the water drops from 15 to 22 inches in the crater. These frequent eruptions, which increase in duration, lead up to the main eruption. The climax eruption lasts from 12 to 17 minutes. Following the longer periods of activity the water in the crater drops about 7 feet. Subsequent to the longer periods of activity, it is from about 100 to 105 minutes before the series of frequent eruptions is initiated.

In other words, a short-duration eruption (less than a minute to about 3 minutes) is ***succeeded*** by a short interval (3 to 12 minutes), and a long-duration eruption (12 to 17 minutes) is ***succeeded*** by a long interval (100 to 105 minutes).

With respect to height of the eruptions, Marler stated, "The eruptions are of the splashing type; most of the splashes reaching a height of from 5 to 6 feet, with occasional bursts near 10 to 12 feet. During the climax eruption I have seen bursts from 15 to 20 feet in height with a heavy discharge of water."

Marler did not indicate how many minor eruptions there were in the "series of eruptions" leading up to the major eruption. He stated only that they were "frequent" and that they increased in duration as the series of minor eruptions progressed. Total cycle time from one major eruption to the next major eruption appears to have been at least two hours—12 to 17 minutes of major eruption plus 100 to 105 minutes of quiet period plus the unknown period during which the minor activity occurred. The information in Marler's *Inventory* is consistent with the interval reported in his 1964 *Studies of Geysers*.

Marler updated the 1978 edition[2] of *Studies of Geysers* to include results from his observations in the 1970s. The table entry for Flood Geyser in the "Table of Named Hot Springs in the Midway and Lower Geyser Basins Which Have Shown Geyser Activity" showed both types of eruptions for Flood Geyser. Major eruption lasted 12 to 17 minutes. Intervals varied from 2 to 4 hours between the majors. Minor eruptions lasted ½ to 3 minutes. Intervals between the minors were 3 to 12 minutes. Marler did not state otherwise, so there is no reason to assume that the long quiet period switched from succeeding the major eruption to occurring after the last minor and prior to the major eruption.

1979 -- T.S. Bryan's The Geysers of Yellowstone

T.S. Bryan did not make a direct statement about the relationship between Flood Geyser's durations and intervals in the initial edition of *The Geysers of Yellowstone* [1979]. However, the information he provided about the nature of its eruptive behavior supports the assertion that Flood Geyser exhibits the most common relationship where duration controls the ***succeeding*** interval. Bryan's description stated:

> [Flood Geyser's] active period consists of a series of minor eruptions leading up to major action. The little eruptions last from 1 to 3 minutes and bulge masses of water up to about 10 feet. These recur every 5 to 10 minutes. The major splashing begins after about 2 hours of the minor play. It lasts upwards of 15 minutes and some large surges of water will jet to 25 feet. …After the major play, it will be from 1½ to 2 hours before the minor activity begins again.

In other words, he reported the cycle consisted of two hours of minor play with "little eruptions" lasting from 1 to 3 minutes and intervals between these eruptions of 5 to 10 minutes, followed by the major eruption jetting up to 25 feet lasting up to 15 minutes. The major eruption was followed by 1½ to 2 hours of no activity, i.e., the longer interval. Short-duration eruptions were succeeded by short intervals until one of the short intervals concluded with the long-duration eruption, which was succeeded by a long interval. Bryan also indicated the long-duration (major) eruption was higher than the short-duration (minor) eruption. Bryan's information was consistent with Marler's observations.

Bryan's table entry in the table "Geysers of the Midway Geyser Basin" showed durations of 1 to 15 minutes and intervals of minutes to 2 hours. These intervals represent intervals between eruptions rather than the interval from major to major, or total cycle time. Adding Bryan's "about 2 hours of minor play" to "upwards of 15 minutes" for the major eruption plus a quiet period of "1½ to 2 hours before the minor activity begins again" gives a total cycle time, or interval from one major eruption to the next eruption, of about 4 hours, which is also consistent with Marler's observations.

1983 and 1984 -- Observations by Heinrich Koenig and Tomas Vachuda

Koenig and Vachuda [1998] observed Flood Geyser on several dates in 1983 and 1984. Their observations with respect to intervals and heights are consistent with Marler's observations about the relationship between durations and intervals —longer, stronger eruptions are followed by longer intervals.

Koenig and Vachuda's data in Figures 1 and 2 of their paper grouped eruptions into three types—eruptions with durations less than 50 seconds, eruptions lasting about 2 to 4 minutes, and eruptions lasting approximately 6 to 8 minutes. Their observations (shown in Tables 1 and 2 in their paper) and the prediction equations they developed showed that longer-duration eruptions were ***succeeded*** by longer intervals.

Their prediction equations for the Interval After were as follows:

1983 -- Interval after = (5.595 * duration) + 1m24.84s, R-squared .973

1984 -- Interval after = (5.432 * duration) + 1m44.86s, R-squared .978

In other words, the longer the duration, the longer the interval after. For example, predictions obtained by applying the 1983 equation were that (1) a minor eruption with a duration of 10 seconds would be succeeded by an interval of 2m21s, (2) an intermediate eruption with a duration of 3 minutes would be succeeded by an interval of 17m02s, and (3) a major eruption with a duration of 8 minutes

[2] Apparently there was not time to incorporate Marler's 1970 observations into the 1971 reprint of *Studies of Geysers and Hot Springs along the Firehole River*.

would be succeeded by an interval of 45m10s. Table 1, located in the next section of this paper "1986 and 1991 Revisions of T.S. Bryan's Book," contains values resulting from application of their prediction formulas. These values were generally consistent with values reported by Bryan in 1986 (and in his subsequent editions), except that Koenig and Vachuda predicted the interval after the duration and Bryan stated these values applied to the interval preceding an eruption.

Koenig and Vachuda did not give an average value for total cycle time, or interval from major to major. I estimated a major to major time by using data from the figures contained in their paper and applying their prediction formulas. The approximation assumes that the relative proportion of minor eruptions, intermediate eruptions, and major eruptions reported in their data corresponds to the relative proportion of each type of eruption in the average cycle during each season.

In 1983 they reported 23 eruptions with durations less than 1 minute, ten eruptions with durations from 2 to 4 minutes, one eruption with a duration slightly less than 5 minutes, and four eruptions with durations from 6 to 8 minutes. Treating the eruption with a duration slightly less than 5 minutes as a major eruption gives an average of 4.6 short-duration eruptions and two intermediate duration eruptions per major eruption. Using an average duration of 30 seconds for the short-duration eruptions, an average of 3 minutes per intermediate eruption, and an average of 7 minutes for the major eruption, the 1983 prediction equation yields a total cycle time of approximately 85 minutes.

Treating the eruption with a duration slightly less than 5 minutes as an intermediate-duration eruption results in an average of 5.75 short-duration eruptions, 2.75 intermediate-duration eruptions for each of the four major eruptions. The 1983 prediction equation gives a total cycle time of approximately 100 minutes using the same average durations of 30 seconds per short-duration eruption, 3 minutes per intermediate-duration eruption, and 7 minutes for a major eruption.

The 1984 data consisted of 14 short-duration eruptions, ten intermediate-duration eruptions, and 12 major eruptions. Application of the 1984 prediction formula using 1.2 short-duration eruptions and .8 intermediate-duration eruptions per major eruption results in an estimated interval from major to major of about 55 minutes.

Although these are only approximations, it appears that the total interval from major to major had decreased from the 2- to 4-hour value of the 1960s and 1970s. There was also a decrease between 1983 and 1984.

Koenig and Vachuda also stated, "The longer eruptions seemed to have the larger bursts." The longer eruptions were succeeded by the longer intervals, so the larger eruptions were also succeeded by the longer intervals. Koenig and Vachuda's observations with respect to height of Flood Geyser's eruptions, as well as their observations about the relationship between duration and succeeding interval, were consistent with Marler's observations.

1986 and 1991 – Revisions of T.S. Bryan's Book

Bryan made several revisions to the information about Flood Geyser in the 1986 edition of *The Geysers of Yellowstone*. Bryan reported Flood Geyser

> …waited for 1985 to reveal the full extent of its complex behavior.
>
> The vigorous activity of Flood consists of minor, intermediate, and major eruptions. The duration of an eruption is directly related to the length of the interval preceding it. The minor eruptions have a duration of just 10 to 20 seconds following an interval of 1½ to 4 minutes. For the intermediates the durations are 2 to 5 minutes after 15- to 25-minute intervals. Majors last 6 to 8 minutes when the previous interval has been 33 to 45 minutes. Very few eruptions occur with values out of these ranges.
>
> Regardless of variety, all eruptions of Flood look about the same. …There is a tendency for the bigger splashes to occur during the major eruptions, but this is not an ironclad rule.

The table entry was changed to indicate an interval of 1½ to 45 minutes and duration of 10 seconds to 8 minutes.

Bryan stated that the "full extent of its complex behavior" was not revealed until 1985. Koenig and Vachuda noted three types of activity during their observations in 1983 and 1984. Their conclusion about the relationship between durations and intervals was opposite to the relationship stated by Bryan. Table 1 shows that the values generated by their prediction equations are generally consistent with limits stated by Bryan, except that their prediction equations are for the interval *following* the duration, rather than the length of the interval preceding it, as stated by Bryan.

Bryan's statement that duration is a function of the length of the interval preceding it is in direct conflict with Koenig/Vachuda's observations and all other observational data that has been reported. Bryan's statement was not merely a typographical error. Bryan's text repeats his belief that duration is related to the length of the interval preceding it three times in the following sentences:

> The minor eruptions have a duration of just 10 to 40 seconds following an interval of 1-1/2 to 4 minutes. For the intermediates the durations are 2 to 5 minutes after 15- to 25-minute intervals. Majors last 6 to 8 minutes when the previous interval has been 33 to 45 minutes.

In each case Bryan's relationship is the reverse of Koenig/Vachuda's observations. Bryan's minor eruptions "follow an interval of 1-1/2 to 4 minutes"; Koenig/Vachuda's minor eruptions are "followed by an interval of 1-1/2 to 4 minutes." Bryan's intermediate eruptions occur "after 15- to 25-minute intervals; Koenig/Vachuda's intermediate eruptions are "followed by an interval of 15- to 25-minutes." Bryan's major eruptions occur "when the previous interval has been 33 to 45 minutes"; Koenig/Vachuda's major eruptions are followed by an interval of 33 to 45 minutes before the cycle starts again with minor eruptions.[3]

Bryan did not make any statement about total cycle time, or time from one major eruption to the next major eruption.

1988 – 1991 Reports of Activity

The first five volumes of *The Geyser Gazer Sput*[4] (hereafter referred to as *The Sput*) contained only one reference to Flood Geyser. The June 1989 issue [3:3] stated, "Flood is also active." Bryan's [1989] list of geysers active in 1988 included Flood Geyser, but did not provide any details about the nature of its activity.

Bryan's information about Flood Geyser in the 1991 edition of *The Geysers of Yellowstone* was the same as the information contained in the 1986 edition, except that he changed the duration of the minors from "10 to 20 seconds" to "10 to 40 seconds."

1991 -- Stephens' Observations

I first started watching Flood Geyser in 1991 when I was taking a break between observations in the Fountain Complex. Rick Hutchinson indicated Tim Thompson was going to deploy an electronic

[3] Koenig and Vachuda made their observations and conclusions available to the Park Geologist and others in the 1980s and early 1990s. However, I do not know how widely the paper was disseminated prior to its publication in *The GOSA Transactions* in 1998.

[4] There was one issue of *The Geyser Gazer Sput* in December 1987. Since then *The Sput* has been published on a bi-monthly basis.

Table 1: Comparison of Bryan's Values with Koenig and Vachuda Predicted Values

Type of Eruption	Bryan's Values (1986 Edition)		Koenig and Vachuda 1983 Predictions		Koenig and Vachuda 1984 Predictions	
	Duration	Interval After	Duration	Interval After	Duration	Interval After
Minor	10-20 seconds	1½-4 minutes	10s	2m21s	10s	2m39s
			20s	3m17s	20s	3m34s
			40s	5m09s	40s	5m22s
Intermediate	2-5 minutes	15-25 minutes	2m	12m36s	2m	12m37s
			3m	18m12s	3m	18m03s
			4m	23m48s	4m	23m29s
			5m	29m23s	5m	28m55s
Major	6–8 minutes	33–45 minutes	6m	34m59s	6m	34m21s
			7m	40m35s	7m	39m46s
			8m	46m11s	8m	45m12s

Table 2: Descriptive Statistics Flood Geyser's Eruptive Cycle Summer 1991

Statistic	Durations			Interval After			Cycle Time
	Minors	"Inter-mediates"	Majors	Minors	"Inter-mediates"	Majors	
Count	10	30	7	10	26	4	1
Minimum	10s	1m18s	6m45s	1m10s	8m30s	31m39s	58m15s
Maximum	39s	2m49s	8m14s	3m32s	15m47s	33m57s	
Mean	23s	2m14s	7m09s	2m03s	12m40s	32m34s	
Median	24s	2m19s	7m05s	1m54s	12m40s	32m19s	
St. Dev.	8s	24s	30s	49s	2m01s	1m01s	

Table 3: Comparison of Bryan's 1991, Stephen's 1991, and Koenig/Vachuda's 1984 Duration and Intervals for Flood Geyser

Reporter [Year]	Type of Eruption		
	Minor	Intermediate	Major
Duration			
Koenig/Vachuda [1984]	10 to 40 seconds	2 to 4 minutes	6m to 8m09s
Bryan [1991]	10 to 40 seconds	2 to 5 minutes	6 to 8 minutes
Stephens [1991]	10 to 39 seconds	1m18s to 2m49s	6m45s to 8m14s
Interval			
Koenig/Vachuda [1984] Predicted/After	2m39s to 5m22s	12m37s to 23m29s	34m21s to 45m12s
Bryan [1991] Interval Before	1½ to 4 minutes	15 to 25 minutes	33 to 45 minutes
Stephens [1991] Interval After	1m10s to 3m32s	8m30s to 15m47s	31m39s to 33m57s

monitor on Flood Geyser. He requested that I provide Tim Thompson with some visual observations. After discussions with Tim Thompson, I decided to treat the eruptions with durations of less than 5 seconds, which generally consisted of one or two bursts, like Old Faithful Geyser's preplay. Koenig and Vachuda had also decided to exclude "one burst" eruptions from their 1984 analysis. Data for 1991 showed three types of eruptions—minor eruptions with durations of 10 to 40 seconds, intermediate eruptions with durations of 1¼ to 3 minutes, and major eruptions with durations exceeding 6 minutes. These categories were similar to those of Bryan and Koenig/Vachuda. The only difference was the length of the intermediate eruptions. Data was collected on six different days between July 27 and August 5, 1991. Total observation time was approximately ten hours, but since it was divided into eight different observation periods, the longest individual observation period was only about 1¾ hours.

Table 2 contains descriptive statistics for the durations and interval after each of the three types of eruptions for 1991. Duration of the minor eruptions varied from 10 to 39 seconds. Durations of the intermediate eruptions varied from 1m18s to 2m49s. Durations of the major eruptions varied from 6m45s to 8m14s. Intervals after the minor eruptions varied from 1m10s to 3m32s. Intervals after intermediate eruptions varied from 8m30s to 15m47s. Intervals after the major eruptions varied from 31m39s to 33m57s. The longer the duration, the longer the interval following that eruption is. The single observation of cycle time was 58m15s.

Table 3 displays a comparison of the 1991 observations with values given in Bryan's 1991 edition of *The Geysers of Yellowstone* and Koenig/

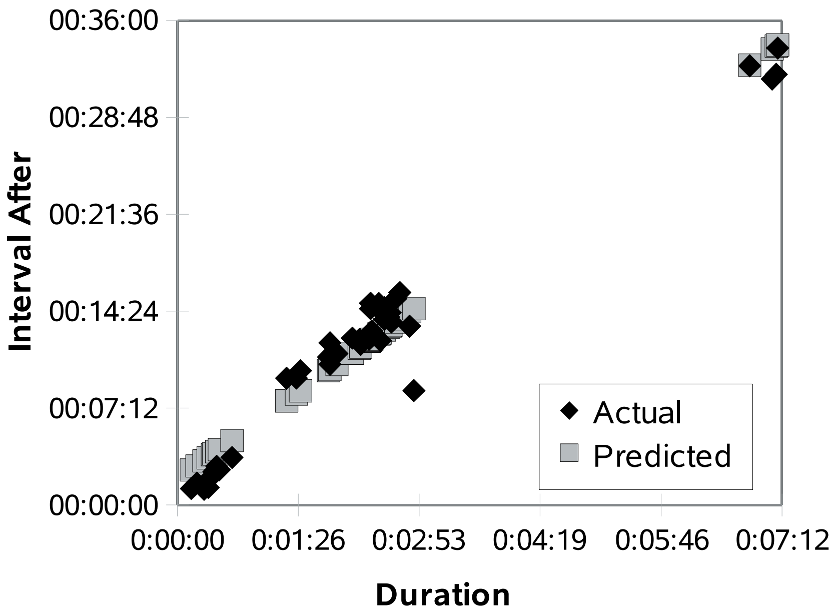


Figure 1: Flood Geyser 1991 Chart.

Vachuda's 1984 observations. The data for the minor durations was consistent across the years, but the interval had decreased for 1991 compared to 1984. Durations of the intermediate eruptions also decreased for the 1991 Stephens' observations compared to 1984 Koenig/Vachuda observations. A decrease in the interval after the intermediate eruptions accompanied the decrease in the duration of the intermediate eruptions. Duration of the majors was consistent across the years, but interval after the major eruptions decreased in 1991.

The regression equation based on 40 observations of duration and succeeding interval recorded in 1991 was as follows:

1991 Interval after = (4.523 * duration) + 1m51s, R squared .958

Intervals after each eruption were a function of the duration of the preceding eruption. Duration explained 95.8% of the variance in the intervals, slightly less than the 97.3% and 97.8% obtained by Koenig and Vachuda in 1983 and 1984, respectively, but still had a high level of explanatory power. Figure 1 shows the comparison between actual values and predicted values.

My observations were consistent with those of Marler, Bryan's 1979 edition of *The Geysers of Yellowstone*, and Koenig/Vachuda's 1983 and 1984 observations. Flood Geyser's durations controlled the interval *succeeding* the eruption rather than the preceding interval controlling the length of the subsequent duration. Short intervals followed short-duration eruptions; slightly longer intervals followed intermediate-duration eruptions; and the longest intervals followed major eruptions.

I recorded only one interval from major to major during the 1991 observation sessions. This interval was 58m15s. This value is consistent with the 55-minute major-to-major interval estimated using the Koenig/Vachuda regression formula for 1984.

I made all my observations from the pullout along the road on the hillside above Flood Geyser. I did not attempt to make any height estimates in 1991 or in any of the other years I have observed Flood Geyser.

1992 – 1995 Changes in Pattern of Activity

More frequent references to Flood Geyser's activity appeared in issues of *The Sput* published from 1992 through 1995 than had appeared during 1989 through 1991.

In 1992 both the January-February [6:1] and March-April [6:2] issues reported that Flood Geyser was active. The July-August issue [6:4] stated that Flood Geyser was "active and having rather few of the short, weak eruptions that have often punctuated the intervals in the past."

Three references to Flood Geyser appeared in the 1993 issues of *The Sput*. The January-February issue [7:1] stated that Flood Geyser was "active, no data." The May-June issue [7:3] stated that intervals for Flood Geyser were "very regular at 27 to 29 m. The usual duration was around 8m20s." Finally, the July-August [7:4] issue reported that Flood Geyser was "active as before."

These reports show a definite change in behavior pattern compared to the behavior pattern of earlier years. Although the 1992 reference indicated fewer minor eruptions were occurring, no information was provided about intervals between eruptions or total cycle time from one major to the next major, so it is not possible to determine how much of the change occurred in 1992.

In 1993, the duration of the majors at 8m20s was only slightly outside the upper boundary of the 6- to 8-minute limits that had been reported beginning in the early to mid-1980s. The statement that intervals were "very regular" indicates that the decrease in the number of minor eruptions that appeared in 1992 had continued until no minor eruptions were being recorded in 1993. The 27- to 29-minute intervals for major eruptions were the shortest ever reported. The shortest previously reported had been 33 to 45 minutes [Bryan 1986]. The 1993 maximum of 29 minutes was below the previously reported minimum of 33 minutes. The 1993 maximum was also well below the 45-minute interval succeeding 8-minute major eruptions in 1983 and 1984. The 27- to 29-minute interval from major to major was about half the 58-minute interval between major eruptions in 1991. The eruptive cycle exhibited by Flood Geyser in 1993 was much less complex and much shorter than the pattern shown during the 1970s and 1980s.

The only reference to Flood Geyser that appeared in the 1994 editions of *The Sput* was a report about a thermal burn that occurred in May [8:3]. The only reference in 1995 appeared in the June issue [9:3], which stated only that Flood was active.

Old Faithful Visitor Center (OFVC) logbook data for 1995 showed that Flood Geyser was having both major and minor eruptions in May and June 1995. The logbook data is sparse, but one piece of data shows a short-duration eruption followed by a short interval on June 4 (1m33s duration succeeded by an 11-minute interval). On July 3, I observed three consecutive durations ranging from 6m13s to 6m33s that yielded intervals of 50 and 51 minutes. This data indicates that Flood was demonstrating the relationship where duration controls the succeeding interval.

Consecutive eruptions on June 30, July 14, and August 5 had intervals ranging from 39 to 50 minutes. No durations were recorded for these eruptions, so it would appear that they were major eruptions. Cycle time from major to major had increased above the 1993 level, Flood Geyser was having minor eruptions, at least early in the season, and duration of major eruptions had decreased from 8+ minutes reported in 1993 to 6+ minutes, still within the 6- to 8-minute limits reported from 1983 through 1991. Available observational data indicated the duration of an eruption controlled the length of interval succeeding the eruption.

1995--Bryan's 1995 Revision of *The Geysers of Yellowstone*

Bryan's 1995 edition of *The Geysers of Yellowstone* described the same pattern of activity that he described in the 1986 and 1991 editions. He added a sentence about the nature of the relationship between durations and intervals, emphasizing his opinion that duration was controlled by the interval preceding the eruption rather than duration determining the interval succeeding the eruption. He expanded the values for intervals following the major eruption. He also added two sentences about the proportion of minors and majors in the eruptive cycle. His description is shown below, with changes from the 1986 edition shown in italics.

> …[Flood] waited for 1985 to reveal the full extent of its complex behavior.
>
> The vigorous activity of Flood consists of minor, intermediate, and major eruptions. The duration of an eruption is directly related to the length of the interval preceding it. *(This is the inverse of almost all geysers, in which the duration controls the following interval.)* The minor eruptions have a duration of just *20 to 40* seconds following an interval of 1½ to 4 minutes. The durations of the intermediates are 2 to 5 minutes after 15- to 25-minute intervals. And the majors last 6 to 8 minutes, the preceding interval having been *27* to 45 minutes. These values change little from year to year, and eruptions with statistics outside these ranges are rare. *The aspect that does vary is the relative proportions between the different kinds of eruption. Some years will have few minors, on other occasions it is the majors that are uncommon.*
>
> Regardless of variety, all eruptions of Flood look about the same. …There is a tendency for the bigger splashes to occur during the major eruptions, but this is not an ironclad rule.

Changing the lower boundary of the values for intervals following the major eruption from 33 to 27 minutes reflected values reported in June 1993. Inclusion of the two sentences about changes in the relative proportions of minors and majors across years incorporated data from 1992 and 1993 where "rather few of the short, weak eruptions" were reported in 1992 and none were reported in 1993.

Repetition of the statements that the values reported for intervals were for intervals *preceding* the duration seemed contrary to the observational data showing the reverse relationship—that durations controlled the interval *succeeding* the eruption. Observational data showed that Flood Geyser exhibited the same pattern as most other geysers rather than the inverse pattern as stated by Bryan.

1996—Another Change in Activity Pattern

Flood Geyser's behavior pattern underwent a change in 1996 compared with 1995 activity. Cycle time from major to major increased compared to cycle time in 1995. A report in the August [10:4] edition of *The Sput* stated, "Flood has been seen in eruption, …Mid-June report by Timothy Thompson puts the interval at 1.5–2h; in mid-July, this had decreased to 80–85m based on 40+ consecutive eruptions."

Thompson [1996] reported the results of electronic measuring equipment deployed at Flood Geyser for the period August 2 through August 17, 1996. His report drew no conclusions about any relationship between durations and intervals and did not report any data for durations. He did note that as the water level in the Firehole River decreased, mean and median intervals between eruptions decreased because short intervals started appearing. Frequency of the short intervals increased as the season progressed. His report stated:

> This year electronic monitoring equipment was deployed at Flood Geyser beginning 8/02/96. During the month of June, Flood Geyser IBE were extremely long. In all likelihood, the longer IBE were due to the high water level of the Firehole River. There is some evidence, that as the water levels are receding, IBE are beginning to decrease. Figure FL1 is a histogram of the distribution of IBE. The median of 73 minutes is still higher than observed during the past five years. The left skewing toward shorter IBE is due to the steady decrease of IBE from 8/2/96 to 8/17/96.
>
> Figure FL2 is the series of median daily IBE from 8/02/96 through 8/17/96. Monitoring began on 8/02/96 and it is probably inappropriate to assume the increased IBE are due to the high winds of early August. As mentioned earlier, Flood IBE was high in June and July. The series does exhibit a general decreasing trend of IBE.

Thompson's summary statistics included with Figure FL1 reported a mean of 71.63 minutes, for 328 intervals, with a standard deviation of 8.97 minutes, values from a minimum of 28 minutes to a maximum of 97 minutes, and median of 73 minutes. 90% of the intervals fell between 52 and 81 minutes.

Data in the OFVC logbook showed entries for one day in July and one day in August. Notations next to two of the three entries on July 12 state "minor." Each of the two intervals succeeding the eruptions noted as being a minor was a 12-minute interval. The third eruption, which was a major eruption, was *preceded* by a 12-minute interval.

The visual observations recorded in the logbook indicated that "minor" eruptions were once again occurring, but were not registering on the electronic monitoring device. Apparently these minor eruptions did not expel enough water to register as an eruption on the electronic monitoring device being used by Thompson. Thompson's data represented the cycle time or interval from major to major eruption. Flood Geyser's cycle time from major to major had once again increased, Flood Geyser was having minor eruptions, and there was observational data that the duration of an eruption controlled the length of the interval succeeding the eruption.

1997 Activity Pattern

The only report contained in *The Sput* appeared in the February [11:1] issue, which stated "Flood did nothing during a 24-minute period." This doesn't mean that Flood Geyser wasn't active. It simply means that particular interval exceeded 24 minutes.

Evidence that Flood Geyser was active during the 1997 spring and summer seasons is contained in entries in the OFVC logbook. Most entries were listed "ie" (in eruption). Few entries had notations about durations next to them. On September 4, 1997, the logbook entries showed a 45-minute interval ending with a "minor" followed by a 4-minute interval. Because there was no notation next to the eruption preceding the "minor" and also no notation next to the eruption succeeding the minor, it is reasonable to assume that these were both major eruptions. The

Table 4: Descriptive Statistics Flood Geyser's Eruptive Cycle June 18, 1998

Statistic	Durations		Interval After		Cycle Time
	"Inter-mediates"	Majors	"Inter-mediates"	Majors	
Count	5	5	5	4	4
Minimum	1m25s	9m8s	12m02	44m29s	56m50s
Maximum	2m03s	9m36s	15m04s	47m46s	62m56s
Mean	1m38s	9m20s	13m07s	45m54s	58m57s
Median	1m34s	9m12s	12m40s	45m40s	58m00s
St. Dev.	15s	13s	1m12s	1m23s	2m40s

minor eruption was preceded by a long interval and succeeded by a short interval.

1998 Pattern of Eruptive Behavior

Two reports of geyser activity appeared in the 1998 editions of *The Sput*. Each of the reports had appeared on the geyser listserv and was compiled in the "Geyser Activity" section of *The Sput*.

Randal Horobik's May 3 report on the listserv was printed in the June [12:3] issue. He reported that he "Timed a duration on Flood Geyser at 10min, 26sec, putting it well above the window given for an "average" major Flood eruption." At the time of Horobik's statement, Bryan's book listed 6 to 8 minutes as the duration for the majors. The most recent observational data shown in the OFVC logbooks that I located was 6 to 6½ minutes in 1995. The most recent observational data for durations of majors reported in *The Sput* had been in 1993 when the duration was reported as 8m20s. None of the publications I reviewed had listed a duration for majors up to 15 minutes since the 1979 edition of Bryan's book. Although the duration was within historical values for durations of major eruptions, it certainly was an increase over durations of major eruptions reported in the preceding 15 years.

My report sent to the listserv on June 21 (based on June 18 observations) was reprinted in the August [12:4] edition. "LS noted on 6/21, Flood—currently in the mode where it has a 1½ to 2 minute eruption, followed by a 12-13 minute interval; then a 9 minute eruption followed by a 45 minute interval, then repeats the cycle. I watched 5 consecutive cycles, all of which were identical within a minute or so."

As noted, I obtained data for five consecutive cycles. Each cycle consisted of one intermediate eruption and one major eruption. Table 4 shows statistics for the durations and intervals, reported by intermediate and major eruptions, and for cycle time. Total cycle time from one major eruption to the next major eruption was similar to both my observations in 1991 and those calculated by applying the Koenig/Vachuda 1984 prediction formula. Duration of majors had increased above the 6- to 8-minute values observed during the 1980s and 1990s. Intermediate eruptions were occurring, which probably corresponded to what many geyser gazers had been calling minors. Intervals after the intermediate eruptions had returned to 12 to 15 minutes, and intervals after the major eruptions had returned to about 45 minutes (44m29s minimum to 47m45 maximum actual observed values on June 18).

The nine pairs of observations yielded a regression equation as follows:

1998 Interval after = (4.288 * duration) + 6m07s, R squared .995

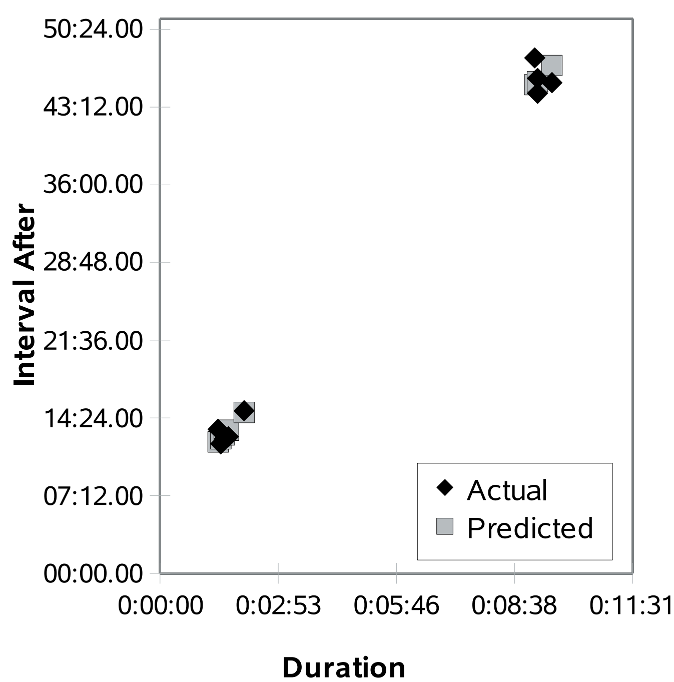


Figure 2: Flood Geyser 1998 Chart.

Table 5: Descriptive Statistics Flood Geyser's Eruptive Cycle August 28, 1999

Statistic	Duration			Interval After			Cycle Time
	Minors	Inter-mediates	Majors	Minors	Inter-mediates	Majors	
Count	7	1	4	7	1	4	3
Minimum	15s	1m55s	4m30s	3m52s	62m22s	1h47m12s	1h53m18s
Maximum	40s		5m25s	8m32s		2h13m0s	3h09m12s
Mean	27s		4m59s	6m14s		2h01m04s	2h19m55s
Median	25s		5m0s	6m06s		2h02m03s	1h57m15s
St. Dev.	9s		23s	1m43s		11m18s	42m44s

Figure 2 shows a comparison of the actual values with the predicted values.

Intervals after each eruption were still a function of the duration of the preceding eruption, as explicitly stated in my report originally posted to the listserv and reprinted in *The Sput*.

1999--Activity Changes As The Year Progresses

References to Flood Geyser's activity appeared in four of the six bi-monthly issues of *The Sput* in 1999.

The April [13:2], June [13:3], and December [13:26] issues each included a table of "Current Activity of Selected Geysers, 1999." This table appeared to be the same as the handout given to visitors by the Interpretive Staff at the OFVC. OFVC naturalist Tom Hougham prepared the tables contained in the April and June issues of *The Sput*. OFVC naturalists Ann Deutsch and Tom Hougham prepared the table contained in the December issue. All three tables reported the same data for Flood Geyser—interval 45 minutes, duration 7 minutes, and height of 10 feet.

Each table included a note at the bottom stating:

> All geyser activity changes with time; this list indicated typical activity as of Winter 1999 [for the table included in the April issue, Spring 1999 for the table included in the June issue, and Fall 1999 for the table included in the December issue]. Check with a park ranger, preferably at Old Faithful Visitor Center, for current information. For information on Echinus Geyser, ask at the Norris Geyser Basin Museum.

The note at the bottom of the table in the April issue also included an editor's note: "This chart includes, where available, electronic monitoring as well as logbook entries. The major predictable geysers would fall in this category. All other data comes from the logbook."

In updating the table to incorporate electronic data and data from the OFVC logbook, table entries for Flood Geyser for Spring and Fall activity were not updated to incorporate "current" data with respect to intervals. Observational data reported in the OFVC logbook for 1998 supported the interval of 45 minutes shown in the table included in the April 1999 issue. However, intervals recorded in the OFVC logbook and reported in *The Sput* beginning in June and continuing through early September ranged from 1 to 2¼ hours, much longer than the 45 minute interval stated in the Spring and Fall "Current Geyser Activity" tables.

A post by Mike Keller on the listserv stating, "Flood is having long intervals—in the range of 80–100 minutes" was reprinted in the June [13:3] issue of *The Sput*. The August [13:4] issue contained reprints of two posts that I had made on the listserv. The June 2 post, based on one observation period on May 30, stated Flood Geyser was "not having any minor eruptions. I timed only one interval between eruptions—2 hours 10 minutes 25 seconds. Durations ranged from 5½ to 6½ minutes." The posting on June 27 reported Flood Geyser was "still having intervals in excess of 2 hours." A review of the OFVC logbook data and discussion with other geyser gazers present in the Park indicated that no one had witnessed any minor or intermediate-duration eruptions from Flood Geyser.

I was not in the Park again until mid-August. I spent most of August 28 at Flood Geyser. During this observation period, which lasted about eight hours, I recorded durations and intervals for 12 consecutive eruptions, which had the following pattern: Minor, Minor, Minor, Minor, Minor, Minor, Major, Intermediate, Major, Minor, Major, Major. Table 5 shows de-

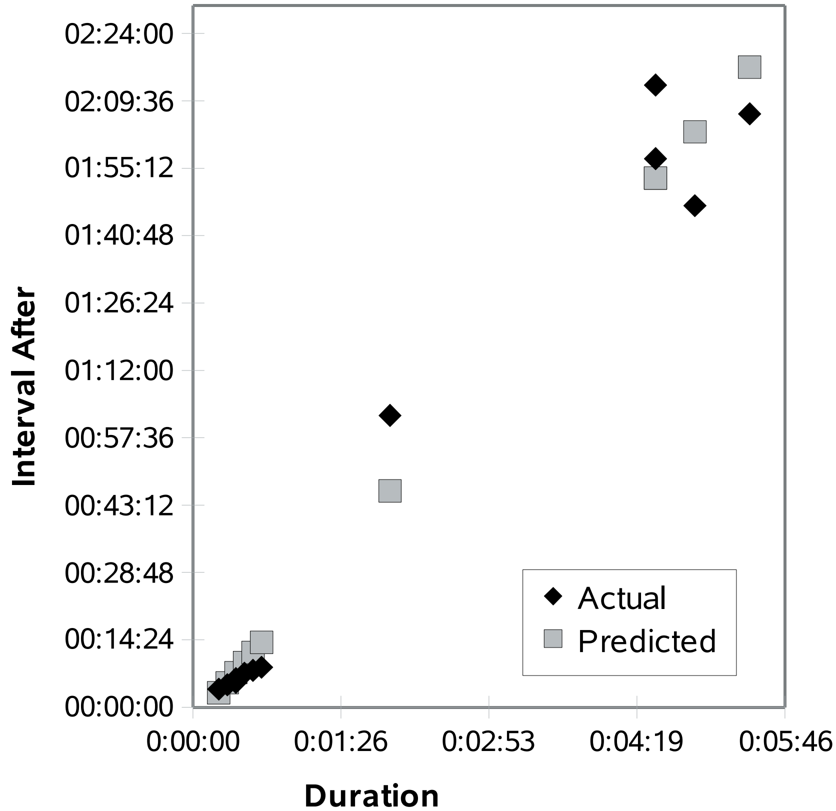


Figure 3: Flood Geyser 1999 Chart.

scriptive statistics for these durations and intervals.

Whereas early in the season (May and June), minor and intermediate-duration eruptions were not observed at Flood Geyser, minor and intermediate-duration eruptions had returned by late August. The regression equation for the 12 pairs of durations and succeeding interval for 1999 was as follows:

1999 Interval After = (25.883 * duration) – 3m24s, R squared .965.

Note that each minute of duration had a much greater effect on the succeeding interval in 1999 than it had in 1983, 1984, 1991, and 1998. The multiplier for duration was 5.595 in 1983, 5.432 in 1984, 4.523 in 1991, and 4.288 in 1998. The multiplier for duration in 1999 jumped to 25.883, reflecting the much longer cycle times recorded in 1999.

Figure 3 shows a comparison of the actual values with the predicted values. Intervals after each eruption were a function of the duration of the preceding eruption. The duration explained 96.5% of the variance in the succeeding interval.

The late season 1999 eruptive behavior pattern seemed most similar to the pattern reported during the 1970s by Marler and Bryan, although there were some differences. Durations of the eruptions consisted of three types—minor, intermediate, and major eruptions. Durations of the minors and intermediate eruptions were consistent with values reported in the 1970s. Duration of the majors with values from 4m30s to 5m25s was much shorter than the 12- to 17-minute durations of the 1970s (and 6- to 8-minute durations of the 1980s and most of the 1990s). Intervals succeeding the minors of 3m52s to 8m32s were within the 3- to 12-minute values reported by Marler for the 1970s (although the lower limit was below the 5- to 10-minute values published by Bryan in 1979). Reports of the 1970s had not included a distinction between minor and intermediate eruptions. The one interval succeeding the intermediate eruption of 62m22s was much longer than previously recorded intervals succeeding intermediate eruptions, which had been reported as 15 to 25 minutes by Bryan in 1986. However, intervals succeeding the majors varying from 1h47m12s to 2h13m0s were consistent with values reported in the Marler and Bryan publications of the 1970s. Overall, the late season 1999 eruptive behavior pattern was much closer to the eruptive behavior pattern of the 1970s than any pattern reported since the early 1980s.

Once again observational data showed that short-duration eruptions were succeeded by short intervals and long-duration eruptions were succeeded by long intervals.

2000 – A Year With No Short-Duration Eruptions Reported

References to Flood Geyser's activity appeared in five of the six bi-monthly issues of *The Sput* in 2000.

I noted that Flood Geyser had been in eruption on December 17, 1999, in my report on my December 2000 visit that appeared in the February issue [14:1].

In the April [14:2] issue I started including Flood Geyser in the "Summary of Geyser Activity" compiled from data reported in the OFVC logbook. The table in the April issue summarized Geyser Activity for January 1, 2000, through March 11, 2000. The entry for Flood Geyser in that table noted Flood Geyser was "active" during that period.

The August [14:4] issue included a "Summary

Table 6: Descriptive Statistics Flood Geyser's Eruptions Summer 2000

Statistic	Duration	Interval
Count	27	28
Minimum	6m0s	25m0s
Maximum	8m31s	32m0s
Mean	7m07s	28m01s
Median	7m0s	27m32s
Standard Deviation	26s	2m14s

of Geyser Activity" for each of three time periods—March 12, 2000, through April 30, 2000; May 1, 2000, through May 31, 2000; and June 1, 2000, through June 30, 2000. There were no reports of Flood Geyser in the OFVC logbook for March 12, 2000, through April 30, 2000, as noted in the "Summary of Geyser Activity" for that period. The table entry for May 1-31, 2000, noted that Flood Geyser was 'active.' The table entry for June 1-30, 2000, reported an average interval of 30 minutes, intervals varying from a minimum of 27 minutes to a maximum of 32 minutes, all durations were 6½ to 7½ minutes, and statistics were based on 12 reported intervals.

The October [14:5] issue included a "Summary of Geyser Activity" table for July 1-31, 2000, and one for August 1-31, 2000. The table entry for July stated that the mean interval was 25 minutes with intervals varying from a minimum of 25 minutes to a maximum of 29 minutes. Reported durations varied from 7 to 8 minutes. These statistics were based on 12 observed intervals. The entry for August was basically the same except that the maximum interval was only 27 minutes, and the statistics were based on four reported intervals.

The December [14:6] issue included two "Summary of Geyser Activity" tables—one for September 1–30, 2000, and one for October 1–November 1, 2000. Both table entries reported that Flood Geyser was "active," but no intervals had been reported.

Comments reported in the August and October issues and the OFVC logbook data showed that the eruptive behavior pattern in 2000 was a simple pattern. No minor or intermediate eruptions were reported. I had observed Flood Geyser on nine different days in June, July, and August, with two of these observation periods lasting four hours each, and had observed no minor (or intermediate) eruptions.

Table 6 shows descriptive statistics for durations and intervals. Durations of the majors averaged 7m07s, and varied from a minimum of 6m0s to a maximum of 8m31s. These values were similar to observations in the 1980s and early 1990s. Intervals between majors averaged 28m01s. The intervals varied from 25m0s to 32m0s. These limits were somewhat wider than the 27- to 29-minute values in 1993, but still fairly close. Flood Geyser exhibited basically the same activity pattern in 2000 that it had in 1993. Both were years when no minor eruptions were reported.

2001 – Short-Duration Eruptions Return

The first mention of Flood Geyser's activity appeared in the June [15:3] issue of *The Sput*. David Monteith reported on April 23 that "3 of the 6 times I passed it, Flood was in eruption" and on May 18 "All but twice when I drove past, Flood Geyser was in eruption."

I observed Flood Geyser on May 25, June 18, August 6, August 8, and August 26. The only day that I recorded data for the durations to the nearest second was June 18. Durations on other days were recorded to the nearest 15 seconds. Table 7 shows descriptive statistics for these observation periods.

The 2001 activity pattern exhibited by Flood Geyser was reminiscent of the 1998 pattern of activity. Every cycle except one consisted of one short-duration eruption followed by a major eruption. (The only exception was a cycle that consisted of two consecutive major eruptions.) No data in the OFVC logbook showed any indication of activity that was different from the activity I recorded.

In addition to repeating the pattern Minor, Major, Minor, Major that had been exhibited in 1998, there were other similarities. One of these was duration of major eruptions. Duration of major eruptions in 1998 varied from 9¼ to 10½ minutes. In 2001 the durations varied from 8½ to 11 minutes. In both years the limits were above the 6- to 8-minute values reported for most other years in the 1980s and 1990s. Intermediate-duration eruptions also showed some similarities. Intermediate-duration eruptions were recorded in both years. Durations of intermediate eruptions had about the same limits, 1½ to 2 minutes in 1998 and 1 to 2 minutes in 2001. Consistent

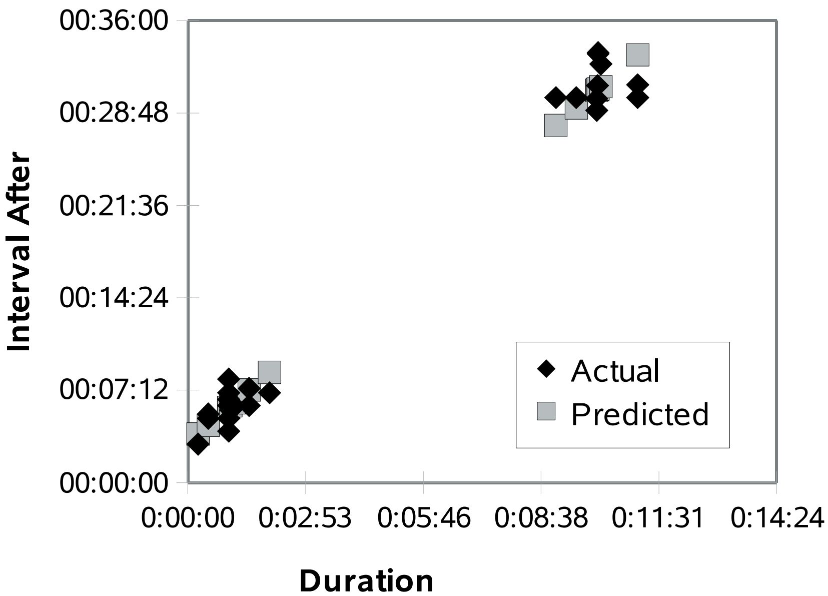


Figure 4: Flood Geyser 2001 Chart.

with observations in other years, shorter-duration eruptions were succeeded by shorter intervals and longer-duration eruptions were succeeded by longer intervals.

There were also some material differences related to intervals between eruptions. Intervals succeeding intermediate-duration eruptions in 1998 were 12 to 15 minutes; in 2001 these intervals dropped to 4 to 8 minutes. Intervals following major eruptions in 1998 were 44 to 48 minutes. In 2001 intervals following major eruptions dropped to 29 to 33½ minutes. Combination of the two decreases resulted in a 60% decrease from the 57 to 63 minute cycle times recorded in 1998 to 32 to 38¾ minute cycle times recorded in 2001.

Although the direction of the relationship stayed the same, with duration positively correlated with succeeding interval, the time required to recover from each eruption had materially decreased, as shown by the coefficient in the 2001 regression equation:

2001 Interval After = (2.749 * duration) + 3m06s, R squared .984

In 2001 each additional minute of duration increased the succeeding interval by only 2 minutes 45 seconds, while in 1998 each minute of increase in the duration increased the succeeding interval by 4 minutes 17 seconds. Figure 4 shows a comparison of the actual values with the values predicted by the regression formula.

Bryan's 2001 edition of *The Geysers of Yellowstone* presented the same information as the 1995 edition, and still contained the statement that Flood Geyser durations were related to the interval preceding the eruption.

2002 – Activity Pattern Similar to 2001 Pattern

Flood Geyser was mentioned in five of the six bimonthly issues of *The Sput* in 2002. The "Geyser Activity" reports compiled by David Goldberg for the February [16:1], June [16:3], October [16:5], and December [16:6] issues all stated Flood Geyser had been active.

I reported a summary of my observations of Flood Geyser for the period from Memorial Day through July 21 in the August [16:4] issue of *The Sput*:

> Memorial Day weekend I observed only 5 intervals, with a range of 28 to 32 minutes. Durations of all the eruptions I observed were 6 to 7 minutes.
>
> Starting in late June, I observed both intermediate (3.5 minute to 4 minute duration) eruptions and long (6 to 7 minute duration) eruption, in addition

Table 7: Descriptive Statistics Flood Geyser's Eruptive Cycles Summer 2001

Statistic	Duration			Interval After			Cycle Time
	Minors	Inter-mediates	Majors	Minors	Inter-mediates	Majors	
Count	3	11	17	3	11	11	10
Minimum	15s	1m0s	8m30s	3m0s	4m0s	29m0s	32m0s
Maximum	30s	2m0s	11m0s	5m20s	8m04s	33m30s	38m44s
Mean	25s	1m12s	10m05s	4m27s	5m0s	30m51s	36m10s
Median	30s	1m0s	10m02s	5m0s	10m02s	30m00s	36m27s
St. Dev.	9s	20s	41s	1m16s	1m08s	1m38s	2m16s

Table 8: Descriptive Statistics Flood Geyser's Eruptive Cycles Summer 2002

Statistic	Duration			Interval After			Cycle Time
	Minors	Inter-mediates	Majors	Minors	Inter-mediates	Majors	
Count	1	7	80	3m12s	7	59m	Bimodal
Minimum	20s	2m23s	5m20s		13m32s	26m44s	
Maximum		3m10s	7m14s		17m00s	32m30s	
Mean		2m44s	6m18s		14m48s	29m13s	
Median		2m41s	6m15s		14m20s	29m0s	
St. Dev.		19s	23s		1m18s	1m25s	

to the less than 10 second duration eruptions that I labeled "preplay." I recorded 36 intervals between long duration eruptions, ranging from 27 minutes to 33 minutes with a mean and median of 29 minutes, standard deviation of 1 minute 33 seconds, and a coefficient of variation of 5.9%. There were 5 intervals from intermediate to long eruptions ranging from 14 to 16 minutes. If these sample observations are representative of the actual activity, about 15% of the eruptions are intermediate eruptions.

I summarized my observations of Flood Geyser in conjunction with an analysis of OFVC logbook data for the "Summary of Geyser Activity" table for the period July 1 through September 30 in the December [16:6] issue of *The Sput*.

"As noted in the "Summary" chart, Flood's intervals (and durations) showed bimodality during the months of July through September. Durations were either about 3½ minutes or about 6½ minutes; intervals were either about 15 minutes or about 30 minutes. I recorded 51 closed intervals during the period—45 of the intervals (88%) were "long" intervals of about 30 minutes and 5 of the intervals (12%) were "short" intervals of about 15 minutes.

I collected data at Flood Geyser on 21 separate days during the summer 2001 season. Table 8 shows descriptive statistics for those observations.

Over the entire season I recorded durations for 88 eruptions. Only one (1%) of these eruptions was a minor; seven eruptions (8%) were intermediate-duration eruptions; and 80 eruptions (91%) were major eruptions. Length of the intermediate eruptions varied from 2m23s to 3m10s. Durations of major eruptions varied from 5m20s to 7m14s. Intervals following intermediate eruptions varied from 13m32s to 17m0s. Intervals following major eruptions varied from 26m44s to 32m30s.

Cycle time was 40 to 45 minutes when the cycle included an intermediate eruption between the two major eruptions. When there was no intervening intermediate eruption, the cycle time was 27 to 32½ minutes. None of the cycles I observed had more than one minor or intermediate eruption, which was the same as it had been in 2001.

The 2002 eruptive behavior pattern most closely resembled the 2001 eruptive behavior pattern when characteristics of eruptive patterns across the years were compared. However, there were also some differences. Intermediate eruptions were longer (2¼

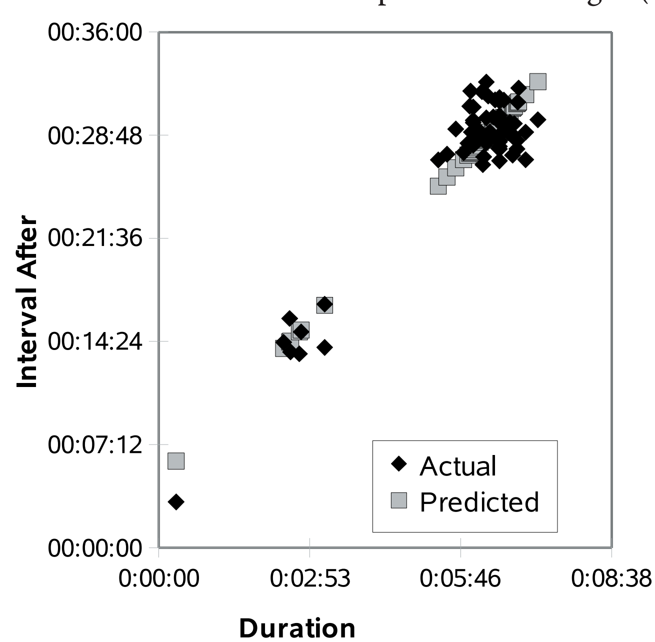


Figure 5: Flood Geyser 2002 Chart.

Table 9: References to Flood Geyser in "Summary of Geyser Activity" Tables in 2003 Issues of *The Sput*

Issue of *The Sput*	Time Frame Covered by The Table	Table Entry
February [17:1]	10/1/02 through 12/31/02	Active in October; No reports in December
August [17:4]	1/1/03 to 3/31/03	Active
August [17:4]	4/1/03 to 6/30/03	Average interval 28m; range 26m to 30m; n=13 intervals
October [17:5]	7/1/03 to 8/31/03	Average interval 27 m; range 26 to 32m; n=17 intervals; all durations 6 to 7 minutes
December [17:6]	9/1/03 to 11/2/03	Average interval 39 m; range 37m to 43m; n=7 intervals (includes intervals computed using consecutive i.e. reports}

to 3¼ minutes) in 2002 than they had been in 2001 (1 to 2 minutes). Consequently, the interval following the intermediate eruptions was also longer (13½ to 17 minutes) in 2002 than it had been in 2001 (4 to 8 minutes). On the other hand, major eruptions had longer durations in 2001 (8½ to 11 minutes) than they did in 2002 (5¼ to 7¼ minutes). Therefore, the interval following the major eruptions was longer in 2001 (29 to 33½ minutes) than it had been in 2002 (26¾ minutes to 29¼ minutes).

The regression formula for the 2002 data had the lowest explanatory power of any formula for prior years, with an R squared of .886. Knowing the duration could still be used to explain 88.5% of the variation in the succeeding interval. The regression formula for the 66 pairs of duration and succeeding interval was as follows:

2002 Interval After = (3.837 * duration) + 4m46s, R squared = .886

In 2002 each minute of duration added 3m50s to the succeeding interval, an increase over the 2001 multiplier of 2.749. Figure 5 is a graph of the actual values compared to the values predicted by the regression equation.

2003 – Another Year With No Short-Duration Eruptions Recorded

Flood Geyser appeared in four "Summary of Geyser Activity" tables printed in various issues of *The Sput* that were published in 2003. Table 9 shows the information contained in those tables. Note that the September-to-October statistics included intervals computed using "ie" reports. If the computations are based on the four closed intervals recorded in September, the upper boundary decreases from 43 minutes to 40 minutes and the average decreases from 39 minutes to 38 minutes. Regardless of which computation is used, the early September observations showed an interval well above the average interval from April through August.

In the August [17:4] issue of *The Sput* I reported "As far as I have been able to determine, the only type of eruption that Flood [Geyser] is having is the 6-to-7 minute duration eruption with intervals ranging from 26 to 30 minutes." I recorded observations on ten different days, one in May, two in June, four in July, and one each in August and September. I never saw a short-duration eruption. There were no reports of minor or intermediate eruptions of Flood Geyser in 2003 recorded in the OFVC logbook. Apparently the only type of activity exhibited by Flood Geyser in 2003 was major eruptions.

I recorded 38 durations between May 23 and September 3. The durations varied from a minimum of 5m50s to a maximum of 8m02s, with an average of 6m39s, median of 6m45s, and standard deviation of 34 seconds.

The only change in eruptive pattern that Flood Geyser demonstrated appeared in early September when four closed intervals between eruptions on September 3 varied from 37 to 40 minutes, up from the 25- to 32-minute intervals observed in earlier months. The average interval on September 3 was 38 minutes, up from the 27- to 28-minute average for April through August. The longest duration of 8m0s was succeeded by the longest interval of 40 minutes.

When the September 3 intervals are excluded, the 2003 behavior pattern is quite similar to the 2000 pattern, another year when no minors were reported. Durations of majors in 2000 were 6 to 8½ minutes; in 2003 they were 5¾ to 8 minutes. Intervals were 25 to 32 minutes in 2000; in 2003, excluding September, they were 26 to 32 minutes.

In 2003 closed intervals were 25 to 40 minutes when September was included. The September increase in intervals may have been an indication of the increase that was recorded during June and July of 2004. (Lack of observational data for Flood Geyser, and many other geysers, from mid-September to Memorial Day weekend is a phenomenon that occurs in most years, so changes in behavior patterns may not be recognized until months after they have occurred.)

2004 Return of Short-Duration Eruptions

David Goldberg reported that Flood Geyser was "active" in five of the six "Geyser Activity" reports that he compiled for *The Sput* in 2004. The only exception was the "Early Spring 2004 Geyser Activity" report that appeared in the April [18:2] issue, which did not contain any mention of geyser activity at Midway Geyser Basin.

My report on geyser activity at Midway that appeared in the August [18:4] issue stated:

> I've recorded 21 closed intervals for Flood Geyser, ranging from a minimum of four minutes to a maximum of 45 minutes, with an average of 30 minutes and a median of 32 minutes. As with Old Faithful, longer duration eruptions are followed by longer intervals and shorter duration eruptions are followed by shorter intervals.

I collected data at Flood Geyser on five days in June and July. Table 10 contains descriptive statistics for durations, intervals, and cycle times. Only one minor eruption was observed. That eruption represented 5% of the durations recorded in 2004. In 2002 only one minor eruption had been observed. That observation constituted 1% of the durations reported in 2002. The proportion of intermediate and major eruptions also changed when the two years were compared, consistent with Bryan's [1995 and 2001] statements that the relative proportion of the different types of eruptions varies from year to year. Intermediate eruptions constituted 30% of the 2004 eruptions compared with 8% of the 2002 eruptions. The proportion of majors decreased from 91% in 2002 to 65% in 2004.

In 2002, no cycle was observed that included more than one short-duration eruption. In 2004 some cycles had no short-duration eruptions, some cycles had only one short-duration eruption, and some cycles contained more than one short-duration eruption. As the number of short-duration eruptions increased, cycle time increased. Time from major to major without an intervening short-duration eruption varied from a minimum of 36m40s to a maximum of 46m10s. Cycle times that included at least one short-duration eruption varied from a minimum of 55m55s (one short-duration eruption with a duration of 1m35s) to a maximum of 1h28m50s (two short-duration eruptions, the first with a duration of 3m40s followed by an eruption with a duration of 2m55s.)

My observations resulted in 16 pairs of data where both duration and corresponding subsequent interval were recorded. The resulting regression equation was as follows:

2004 Interval After = (5.842 * duration) + 4m50s, R squared = .963

Figure 6 shows the actual values and the values predicted by the regression equation.

Table 10: Descriptive Statistics Flood Geyser's Eruptive Cycles Summer 2004

Statistic	Duration			Interval After			Cycle Time
	Minors	Inter-mediates	Majors	Minors	Inter-mediates	Majors	
Count	1	6	13m	1	6	8	8
Minimum	35 sec	1m35s	5m26s	3m40s	18m05s	36m45s	36m40s
Maximum		4m0s	6m50s		28m20s	46m10s	1h28m50s
Mean		3m05s	6m06s		23m43s	40m10s	51m28s
Median		3m10s	6m0s		23m57s	39m02s	47m18s
St. Dev.		50s	29s		3m29s	3m30s	17m31s

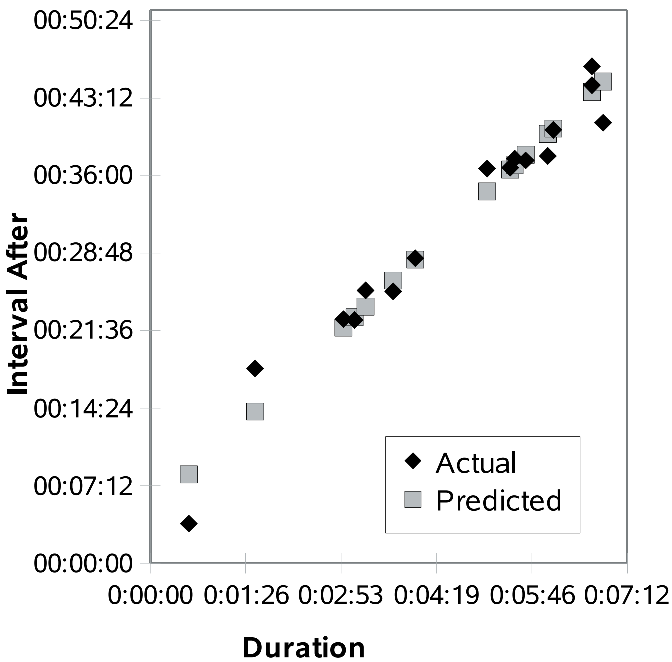


Figure 6: Flood Geyser 2004 Chart.

For 2004, the duration explained 96.3% of the variance in the interval succeeding the eruption. Each additional minute duration added 5m50s to the interval after that eruption. While the extent to which an increase in duration increased the subsequent interval varied across years between 1983 and 2004, the relationship was always positive and explained a large proportion of the variance in the interval following the eruption. Table 11 compares the regression results for the various years.

2005 Activity—Continuation of 2004 with Minor, Intermediate, and Major Eruptions

I collected data on Flood Geyser's intervals and durations on 13 days in June, July, August, September, and November 2005. During that time 115 durations and 101 intervals were recorded. (Descriptive statistics for 2005 durations and intervals are shown in Table 11.) Visual examination of the data for durations showed that most minor durations were between 5 and 31 seconds. There were two durations of 56 seconds. The next shortest duration was 1m53s. The two 56 second durations were included in the classification minor eruptions for 2005. Durations of the minor eruptions had a mean of 16s and a median of 14s. Durations of intermediate eruptions ranged from 1m53s to 3m32s, with a mean of 2m51s and a median of 2m57s. Durations of major eruptions ranged from 4m29s to 7m40s, with a mean of 6m21s and a median of 6m20s.

In 2004 the lower boundary for durations of major eruptions had been 5½ minutes. (See Table 12 for ranges of durations and intervals for selected years between 1991 and 2006.) In 2005 the lower boundary for durations of major eruptions continued to decrease. There was about a 1-minute decrease in the lower boundary in 2005. Even though the lower boundary of durations of major eruptions decreased, the mean and median durations both increased in 2005 (6m21s and 6m20s, respectively) compared to 2004 (6m06s and 6m0s, respectively).

Intervals after minor eruptions ranged from 33s to 7m01s, with a mean of 1m41s and a median of 1m45s. There was a gap of 5 minutes 23 seconds between the longest interval after a minor and the shortest interval after an intermediate eruption. The gap between the longest interval after an intermediate and the shortest interval after a major was much shorter—only 1m23s.

Table 11: Descriptive Statistics Flood Geyser's Eruptive Cycles Summer and Fall 2005

Statistic	Duration			Interval After			Cycle Time
	Minors	Inter-mediates	Majors	Minors	Inter-mediates	Majors	
Count	54	18	43	53	16	32	29
Minimum	5s	1m53s	4m29s	33s	13m03s	29m34s	31m56s
Maximum	55s	3m32s	7m40s	7m01s	28m11s	46m35s	1h11m16s
Mean	16s	2m51s	6m21s	1m41s	21m24s	37m59s	49m40s
Median	14s	2m57s	6m20s	1m45s	22m12s	38m11s	50m31s
St. Dev.	10s	35s	43s	1m13s	3m59s	4m15s	11m34s

Table 12: Range of Duration of Flood Geyser and Intervals After Each Type of Eruption

Type of Eruption	Duration	Interval After
Minor	30 seconds [1]	1 to 4 minutes [1]
1999		3½ to 8½
2001		3 to 5½
2005	5 to 56 seconds	½ to 7
2006	5s to 32s	37s to 8m59s
Intermediate	2 to 5 minutes [1]	15 to 25 minutes [1]
1991	1¼ to 3	8½ to 16
1998	1¼ to 2¼	
1999		62[2]
2001	1 to 2	4 to 8
2004	1½ to 4	18 to 28½
2005	1¾ to 3½	13 to 28
2006	2¼ to 4¼	15½ to 28¾
Major	6 to 8 minutes [1]	30 to 45 minutes [1]
1991	6¾ to 8¾	
1998	9 to 10	44 to 48
1999	4½ to 5½	107 to 133
2001	8½ to 11	29 to 33½
2002	5½ to 7¼	26½ to 32½
2003 (June – August)		25 to 32
2004		36¾ to 46¼
2005	4½ to 7¾	29 ½ to 46½
2006	5 to 7	25 to 29¾

[1] Values shown on Geyser Study and Observation Association website: http://www.geyserstudy.org, last accessed April 3, 2007.
[2] For 1999 there was only one observed interval after an intermediate eruption.

In 2004 only one interval (3m40s) was recorded following a minor eruption. (See Table 13 for a median values for durations and intervals for selected years from 1991 through 2006.) Intervals after minor eruptions in 2005 had a mean of 1m41s and a median of 1m45s. These values are similar to intervals after minor eruptions that were recorded in 1991 (2m14s and 2m19s, respectively).

Mean intervals of 21m24s and median intervals of 22m12s following intermediate eruptions were similar to those recorded in 2004 (23m43s and 23m57s, respectively). Mean intervals of 37m59s and median intervals of 38m11s following major eruptions were also fairly close to intervals recorded in 2004 (40m10s and 39m02s, respectively).

Cycle time (interval from one major to the next major) continued to vary depending upon the number of minor and/or intermediate eruptions between each major eruption. Cycle time in 2005 ranged from a minimum of 31m56s to a maximum of 1h11m16s, with a mean of 49m40s and a median of 50m31s. The mean and median are also similar to those recorded in 2004 (51m28s and 47m18s, respectively).

For 2005 there were 101 pairs of data where both the duration and corresponding subsequent interval were recorded. The resulting regression equation was as follows:

2005 Interval After =
(5.94 * duration) + 52s,
R squared = .968

Figure 7 shows the actual values and the values predicted by the regression equation. For 2005, the duration explained 96.8% of the variance in the interval succeeding the eruption. Each additional minute duration added 5m94s to the interval after that eruption. Minor eruptions had a clear impact on the regression equation for 2005 since the intercept was only 52 seconds.

2006 Activity—Continuation of 2005 (Minor, Intermediate, and Major Eruptions) with Twists

During 2006, I observed Flood Geyser on seven different days, with at least one observation period in each of May, June, July, August, and September. With the exception of the short observation period on May 25, minor, intermediate, and major eruptions were recorded on each day. Durations were recorded for 62 eruptions. The interval following an eruption was recorded for 55 eruptions. (See Table 4 for descriptive statistics related to eruptions of Flood Geyser for 2006.)

Several different types of cycles were observed. Sometimes a major eruption was followed by another major eruption, with no minor eruptions occurring between the two majors. In other cases a major was preceded by one or more minor eruptions. Sometimes a major eruption was followed by an intermediate eruption followed by another major eruption. Some, but not all, intermediate duration eruptions were preceded by a minor eruption. No case where an intermediate eruption was preceded by more than one minor eruption was observed. The different

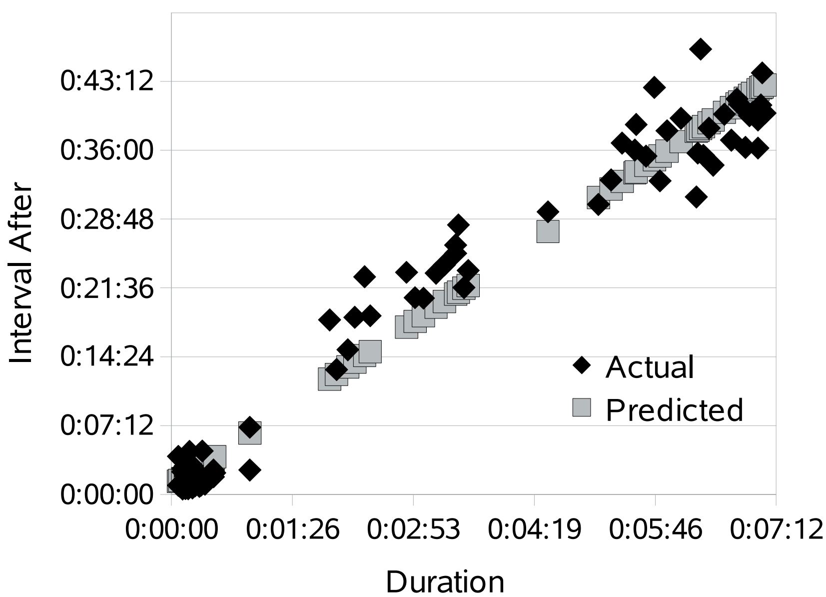


Figure 7: Flood Geysesr 2005 Chart.

types of cycles were dispersed across the observation periods.

Durations of the three types of eruptions had clearly distinguishable boundaries. Durations of minor eruptions ranged from a minimum of 5s to a maximum of 32s, with a mean of 16s and median of 15s. The minimum duration of an intermediate eruption was 2m15s and the maximum was 4m10s.

The mean and median durations of intermediate eruptions were 3m31s and 3m33s, respectively. The minimum duration of a major eruption was 5m05s, the maximum was 7m0s, and the mean and median durations were 6m07s and 6m04s, respectively. The gap between the longest intermediate duration (4m10s) and the shortest major duration (5m05s) was 55s, about the same as the gap (57s) had been in 2005.

Table 13: Durations and Intervals – Median Values

	Duration			Interval Succeeding		
Year	Minor	Inter-mediate	Major	Minor	Inter-mediate	Major
1991	24s	2m19s	7m05s	1m54s	12m40s	32m19s
1998		1m34s	9m12s		12m40s	45m40s
1999	25s	1m55s	5m0s	6m06s	62m22s	2h02m03s
2000			7m0s			27m32s
2001	30s	1m0s	10m02s	5m0s	10m02s	30m00s
2002	20s	2m41s	6m15s	3m12s	14m20s	29m0s
2003			6m45s			29m
2004	35s	3m10s	6m0s	3m40s	23m57s	39m02s
2005	14s	2m57s	6m20s	1m45s	22m12s	38m11s
2006	15s	3m33s	6m04s	2m30s	22m36s	28m34s

Table 14: Descriptive Statistics Flood Geyser's Eruptive Cycles Summer and Fall 2006

Statistic	Duration			Interval After			Cycle Time
	Minors	Inter-mediates	Majors	Minors	Inter-mediates	Majors	
Count	25	10	27	25	10	20	20
Minimum	5s	2m15s	5m05s	37s	15m35s	25m09s	17m25s
Maximum	32s	4m10s	7m0s	8m59s	28m41s	36m34s	56m40s
Mean	16s	3m31s	6m07s	4m07s	22m05s	29m48s	40m04s
Median	15s	3m33s	6m04s	2m30s	22m36s	28m34s	36m0s
St. Dev.	7s	34s	34s	3m06s	4m52s	3m22s	9m58s

Table 15: Data for Type A Minor Eruptions – Short Durations Followed by Interval Less Than 3 Minutes

Duration of Minor (m:s)	Succeeding Interval (m:s)	Succeeding Duration (m:s)
0:05	0:37	5:20
0:10	0:42	0:17
0:12	0:53	0:25
0:15	0:58	0:22
0:10	1:05	0:12
0:14	1:06	0:32
0:25	1:20	0:25
0:10	1:22	0:26
0:32	1:30	0:08
0:25	1:37	0:10
0:14	1:41	0:10
0:14	1:48	0:17
0:05	2:30	0:21

Table 16: Data for Type B Minor Eruptions – Short Durations Followed by Interval Greater Than 3 Minutes

Duration of Minor (m:s)	Succeeding Interval (m:s)	Succeeding Duration (m:s)
0:13	5:01	4:08
0:17	5:02	3:40
0:17	6:30	5:56
0:17	6:53	6:22
0:10	7:00	6:35
0:24	7:06	6:44
0:08	7:25	6:48
0:25	7:40	7:00
0:17	7:44	5:56
0:22	8:12	5:59
0:21	8:14	5:43
0:26	8:59	6:27

Intervals following minor eruptions ranged from a minimum of 37s to a maximum of 8m59s, with a mean and median of 4m07s and 2m30s, respectively. Intervals after minor eruptions clustered into two groups. One group of intervals varied from 37s to 2m30s, and the second group varied from 5m1s to 8m59s, as shown Tables 15 and 16. The interval between a minor and another minor eruption (Table 15, Type A, Sd/Si/Sd) was generally much shorter than the interval between a minor and either an intermediate or major eruption (Table 16, Type B, Sd/Li/MdorLd). There was only one short duration, short interval, long duration (Sd/Si/Ld) case.

This "twist" of two types of intervals following minor eruptions had not been recorded prior to 2006. The gap between intervals succeeding Type A minors (followed by another minor) and intervals succeeding Type B minors (followed by an intermediate or major eruption which concluded the cycle) was 2½ minutes. In 2006, once 2½ minutes had passed following a minor eruption, it was possible to predict with 100% accuracy that the next eruption would be either an intermediate or a major eruption, which would end that series of eruptions.

Intervals following intermediate eruptions varied from a minimum of 15m35s to a maximum of 28m41s, with a mean and median of 22m05s and 22m36s seconds, respectively. These values were comparable to descriptive statistics for intervals following intermediate eruptions in 2005.

Intervals following major eruptions varied from a minimum of 25m09s to a maximum of 36m34s, with a mean and median of 29m48s and 28m34s, respectively. The minimum was about 4½ minutes less than it was in 2005, and the maximum was about 10¼ minutes less than it was in 2005. The mean and median dropped by about 8 and 9¾ minutes, respectively.

The difference between the maximum interval following an intermediate eruption and the minimum interval following a major eruption has been declining in recent years. Prior to 2006 the maximum interval following an intermediate eruption had always been less than the minimum interval following a major eruption. Intermediate eruptions were characterized by both intermediate durations and intermediate succeeding intervals. In 2006 the upper limit of intervals following intermediate eruptions (28m41s) overlapped the lower limit of intervals following major eruptions (25m09s).

Despite the two newly observed characteristics (two types of intervals following minor eruptions and no longer a clear distinction between intervals following intermediate and major eruptions), intervals continued to show a positive correlation with the duration of the preceding eruption, i.e. the longer an eruption continued, the longer the interval following that eruption lasted. Figure 8 shows the actual values and the values predicted by the regression equation.

Observations in 2006 resulted in 55 pairs of data where both the duration and corresponding subsequent interval were recorded. The resulting regression equation was as follows:

2006 Interval After = (4.38 * duration) + 3m36s,

R squared = .911

For 2006, the duration explained 91.1% of the variance in the interval succeeding the eruption. This is the second lowest amount of variance explained in the 10 years for which regression results were determined, as shown in Table 17.

Web Based Information

In this era of electronic access to information, no review of available literature is complete unless it also explores information available through the Internet. In late April 2007, I located three web sites that offered information about Flood Geyser.

The Geyser Study and Observation website, http://www.geyserstudy.org/geyser.aspx?pGeyserNo=FLOOD, contained the most complete information about Flood Geyser:

> Flood Geyser is a fountain-type geyser. Erupting with bursts to 25 feet at

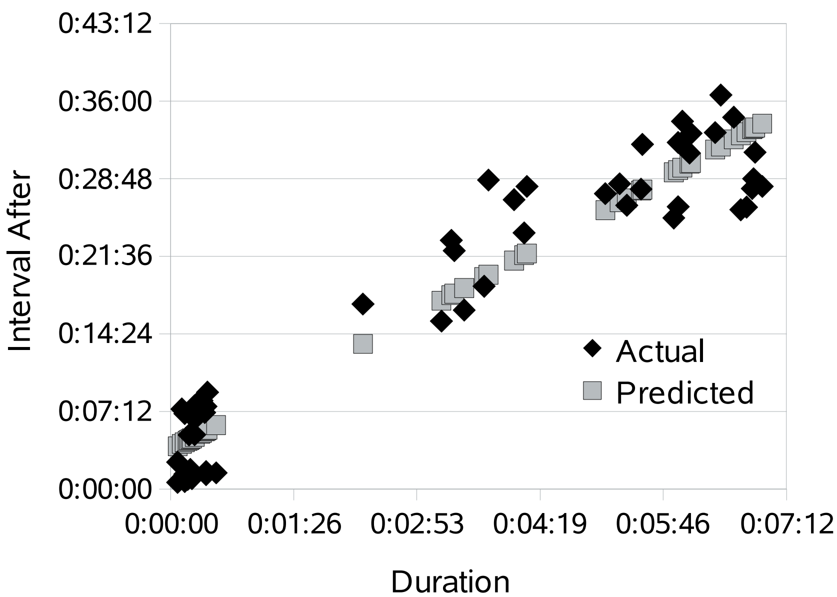


Figure 8: Flood Geyser 2006 Chart.

Table 17: Comparison of Regression Results for Relationship Between Duration and Interval Succeeding an Eruption of Flood Geyser

Year	Formula for Interval After	R squared	Observation s
1983	(5.595 * duration) + 1m25s	.973	38
1984	(5.432 * duration) + 1m45s	.978	36
1991	(4.523 * duration) + 1m51s	.958	39
1998	(4.288 * duration) + 6m07s	.995	9
1999	(25.883 * duration) – 3m24s	.965	12
2001	(2.749 * duration) + 3m06s	.984	25
2002	(3.837 * duration) + 4m46s	.886	66
2004	(5.842 * duration) + 4m50s	.963	16
2005	(5.940 * duration) + 0m54s	.968	101
2006	(4.384 * duration) + 3m36s	.909	55

> intervals of minutes to a few hours. Commonly, Flood plays frequently with one of three types of eruptions:
>
> **Minor** - every 1-4 minutes for 30 seconds
>
> **Intermediate** - every 15-25 minutes for 2 - 5 minutes
>
> **Major** - every 30-45 minutes for 6-8 minutes
>
> At times, though, Flood has been known to have intervals of 2-3 hours with durations of only about five minutes.

The website did not indicate whether the interval was the interval preceding or the interval succeeding the eruption type. Because "interval" is assumed to be the interval after, since this is the "most common relationship," the information is appropriate and covers the majority of the values Flood Geyser has exhibited over the past 35 years.

John Uhler's site, http://www.yellowstone-natl-park.com/geyser.htm, contained information about Flood Geyser in a table for Midway Geyser Basin. The table gave Flood's interval as 45 minutes, duration 7 minutes, height 10 feet. The information is the same as the information that was distributed by Old Faithful Visitor Center in 1999.

Michael Frazier's site, http://www.gigagraphica.com/geyser/flood/flood.html, stated, "Flood has intervals of 1 to 2 hours with a duration of 2 to 6 minutes. The interval after the eruption shown in the movie was 1 hour and 35 minutes." The movie was taken on May 25, 1999. While the information was appropriate for 1999, 1999 was not a typical year during most of the 1980s, 1990s, and first half of the 2000s.

I was unable to locate any information about Flood Geyser on the official Yellowstone National Park web pages at http://www.nps.gov/yell/.

SUMMARY OF ERUPTIVE ACTIVITY PATTERNS OF FLOOD GEYSER

Table 18 summarizes the characteristics of activity patterns exhibited by Flood Geyser reported or observed from 1973 through 2006.

Pattern A: Historical (1964)

As noted by Marler, not much was really known about Flood Geyser prior to 1970. His reported interval in the 1964 edition of *Studies of Geysers* was the same as his reports in the 1970s. However, the only other report of durations approaching 20 to 40 minutes was a report of a 45-minute duration in 1927. Due to the lack of available information, it is difficult to tell whether Flood Geyser's activity changed between 1964 and Marler's 1970 observations.

Pattern B: Major Eruptions Only (1993, 2000, 2003)

All reported eruptions were major eruptions in each of these years. In 1993 the duration was ~8m20s; in 2000 it was 6 to 8½ minutes; in 2003 it was 5¾ to 8 minutes. Reported intervals were 27 to 29 minutes in 1993; 25 to 32 minutes in 2000; and 26 to 32 minutes in 2003, through August. The maximum interval increased to 40 minutes in September 2003.

Table 18: Flood Geyser's Eruptiuve Behavior Patterns 1964 to 2006

Year/Reporter	Type of Eruption	Duration	Interval	Cycle Time
1964 Marler		20 to 40 min	2 to 4 hr	
1973 Marler	Minors	1 to 3 min	3 to 12 min	
	Majors	12 to 17 min	100 to 105 min	
1978 Marler	Minors	½ to 3 min	3 to 12 min	
	Majors	12 to 17 min	2 to 4 hrs	.
1979 Bryan	Minors	1 to 3 min	5 to 10 min	
	Majors	Up to 15 min	1½ - 2 hrs	3 ½ - 4 hrs
1983 Koenig	Minors	< 50 sec	2 to 5 min	
	Intermediates	2 to 4 min	12 to 24 min	Estimated
	Majors	6 to 8 min	35 to 46 min	85 – 100 min
1984 Koenig &	Minors	< 40 sec	2½ to 5½ min	
Vachuda	Intermediates	2 to 4 min	12 to 24 min	Estimated
	Majors	6 to 8 min	35 to 45 min	60 min
1986 Bryan	Minors	10 to 20 sec	1½ to 4	
Interval before	Intermediates	2 to 5 min	15 to 25 min	
	Majors	6 to 8 min	33 to 45 min	
1991 Bryan	Minors	10 – 40 s	1½ to 4 min	
Interval before	Intermediates	2 to 5	15 to 25 min	
	Majors	6 to 8	33 to 45 min	
1991 Stephens	Minors	10 to 40 sec	1 to 3½ min	
	Intermediates	1 to 3 min	8½ to 15¾ min	
	Majors	6¾ to 8¼ min	31½ to 34 min	58¼ min
1993 *The Sput*	Majors	~ 8m20s	27 to 29 min	27 to 29 min
	No minors reported during the season.			
1995	Minors/Inter.	1½ min	11 min	
OFVC logbook	Majors	6¼ to 6 ½ min	40 to 50 min	
	Limited data reported during the season			
1995	Minors	20 – 40 sec	1½ to 4 min	

Table 18: Flood Geyser's Eruptiuve Behavior Patterns 1964 to 2006

Year/Reporter	Type of Eruption	Duration	Interval	Cycle Time
Bryan	Intermediates	2 to 5 min	15 to 25 min	
Interval before	Majors	6 to 8 min	27 to 45	
1996	Minors	Yes	12 min	
OFVC logbook	Majors	Yes	No report	
	Extremely limited data in logbook			
Thompson electronic data			mid-June	1½ to 2 hrs
			mid–July	80 to 85 min
			August	28 to 97 min
1997	Minors	Yes	4 min	
	Majors	Yes	45 min	
	Extremely limited data in logbook			
1998	Intermediates	1½ to 2 min	12 to 15 min	
	Majors	9½ to 10½ min	44 to 48 min	57 to 63 min
1999	Minors	15 to 40 sec	4 to 8½	
	Intermediates	2 min	62	
	Majors	4½ to 5½ min	105 to 135	1¾ to 3¼ hrs
2000	Majors	6 – 8½ min	25 to 32 min	25 to 32 min
	No minors reported during the season			
2001	Minors	15 – 30 sec	3 to 5½ min	
	Intermediates	1 – 2 min	4 to 8 min	
	Majors	8 ½ - 11 min	29 to 33½ min	32 to 38¾
2002	Minor	20 sec	3m12s	Variable
	Intermediate	2¼ to 3¼ min	13½ to 17 min	
	Majors	5¼ to 7¼ min	26¾ to 29¼ min	
	Cycle to cycle with intermediate 41 to 45 minutes			
	Cycle to cycle with no intermediate 27 to 29 minutes			
2003	Majors	5¾ to 8 min	25 to 40¾ min	
	Intervals May–August 26 to 32 min			26 to 23 min
	Intervals September 37 to 40 min			37 to 40 min

Table 18: Flood Geyser's Eruptiuve Behavior Patterns 1964 to 2006

Year/Reporter	Type of Eruption	Duration	Interval	Cycle Time
2004	Minors	35 sec	3m40s	36 to 89 min
	Intermediates	1½ to 4 min	18 to 28 min	
	Majors	5½ to 7 min	36½ to 46¼	
2005	Minors	5 to 55 sec	½ to 7 min	32 to 71 min
	Intermediates	1¾ to 3½ min	13 to 28 min	
	Majors	4½ to 7¾ min	29½ to 46¾ min	
2006	Minor –Type A	5 to 32 sec	½ to 2 ½ min	17½ to 56¾ min
	Minor—Type B	8 to 26 sec	5 to 9 min	
	Intermediate	2¼ to 4¼ min	15½ to 28¾ min	
	Major	5 to 7 min	25 to 36 ¾ min	

Pattern C: Minor and Major Eruptions (1973, 1978, 1979, 1996, 1999)

Values shown by Marler [1973 and 1978] and Bryan [1979] were generally consistent, with only slight differences in upper and lower boundaries for durations and intervals of the types of eruptions (minors and majors) they described.

Lack of observational data makes it difficult to classify the behavior pattern of 1996. Minors were occurring, as evidenced by notations in the OFVC logbook, and the one interval following the "minor" was 12 minutes. Total cycle time for major to major recorded by electronic data varied from 1½ to 2 hours in mid-June, 80 to 85 minutes in mid-July, and 28 to 97 minutes during August. The longer intervals are also characteristic of the 1970s. However, the shorter intervals in August are not consistent with reports from the 1970s. Overall, 1996 has more characteristics in common with reports of the 1970s than reports in the 1980s and 1990s, so I have classified 1996 activity as Pattern C.

The pattern of activity exhibited in 1999 is more similar to the patterns described in the 1970s than to any other years I reviewed. Both short-duration and major eruptions occurred in 1999. Cycle time was 1¾ to 3¼ hours in 1999, shorter than, but still fairly comparable to Marler's cycle time of 2 to 4 hours in 1978. Intervals after major eruptions were 105 to 135 minutes in 1999, slightly longer than Marler's value of 100 to 105 minutes reported in 1973, and slightly less than Bryan's 1½ to 2 hours reported in 1979. However, the 1999 values for intervals after a major are more than double the values for intervals after the major reported in any other year during the 1980s, 1990s, and early 2000s, with the exception of 1996. If the one intermediate eruption is considered an outlier, the 1999 pattern of minors followed by 4-to 8-minute intervals and majors followed by 105- to 135-minute intervals fits very well with the pattern described in the 1970s. Classifying 1999 with the 1970s is also supported by results from the regression analysis. The multiplier for duration to estimate the following interval was 25.9, well above the multipliers of prior years, which had varied from 4.3 to 5.6, and also well above multipliers of subsequent years, which varied from 2.8 to 5.8.

Pattern D: Minor, Intermediate, and Major Eruptions (1983, 1984, 1991, 1995 1997, 1998, 2001, 2002, 2004, 2005, and 2006)

This pattern is a variation of Pattern C. Pattern C consists of a set of short-duration eruptions followed by short intervals until one of the short intervals concludes with a long-duration eruption.

The long-duration eruption is followed by a long interval before the cycle starts again with a set of short-duration eruptions. Pattern D has a similar cycle, but eruptions consist of three types—minor, intermediate-duration, and major eruptions. Minor eruptions are followed by short intervals until one of the short intervals concludes with an intermediate or long-duration eruption. Intermediate eruptions are followed by a mid-length interval after which the cycle starts again with short-duration eruptions. Major, or long-duration eruptions, are followed by longer intervals before the cycle starts again with short-duration eruptions.

Pattern D segregates the short-duration eruptions into two types of eruptions—minors with durations less than a minute, and intermediates with durations of 1 to 4¼ minutes. In most years majors had durations of 6 to 8 minutes, although durations were well above those values in 2001, when the values for the duration of major eruptions were 8½ to 11 minutes. Also, the lower boundary for duration of major eruptions dipped below the 6-minute mark to 5¼ minutes in 2002, 5½ minutes in 2004, 4½ minutes in 2005, and 5 minutes in 2006. Since the durations have been below 6 minutes for the past three years, it seems the accepted range for durations of major eruptions should be expanded to state "5 to 8 minutes."

In each of those years there was still a clear gap between the upper boundary of the duration of the intermediate eruptions and the lower boundary of the duration of major eruptions. However, the intervals for each type of eruption do overlap.

Table 19 shows a comparison of the ranges for intervals after each type of eruption and regression coefficients available for each of the years in Pattern D. As more years are added to the data set, the boundaries between the intervals succeeding each type of eruption start to overlap. Limits of 1 to 5½ minutes for the interval succeeding minor eruptions capture values across all the years except 2006, when the interval following the last minor before an intermediate or major eruption increased to 9 minutes. Limits from 4 to 28 minutes encompassed intervals observed after intermediate eruptions for all years until 2006, when the maximum interval following an intermediate eruption was almost 29 minutes. If 2001 is excluded as an outlier, the range of intervals following intermediate eruptions could be reduced to 8½ to 29 minutes, still rather broad limits

Flood Geyser in 2001, photo by Chris Dunn.

that will overlap with the lower boundary for intervals succeeding major eruptions. Values from 25 to 36¾ minutes for intervals succeeding major eruptions are required to encompass the limits observed across the years.

CONCLUSION

Flood Geyser does indeed exhibit a complex behavior pattern. The specifics of that pattern vary across the years. The specifics may even vary from month to month within some years. Boundaries for durations and intervals change. The proportion of different types of eruptions varies across years. The extent to which an increase in duration increases the subsequent interval varies from year to year, varying from a minimum multiplier of 2.75 to a maximum multiplier of 25.88, with 75% of the multipliers between 3.84 and 5.595. One constant across the years of observational data was that Flood Geyser exhibited the same relationship between duration and interval as Old Faithful Geyser exhibits—duration is related to or controls the succeeding interval. Short-duration eruptions were followed by short intervals and long-duration eruptions were followed by long intervals.

Tim Thompson noted two possible seasonal variations that could impact Flood Geyser's pattern of eruptive activity. Water level in the Firehole River could impact the intervals and/or proportions of each type of eruption. He also mentioned the possibility that Flood Geyser's intervals might be related to wind, although he decided it was "inappropriate" to assume that increased intervals were related to increased winds in August 1996. Conventional wisdom among gazer observers is that features that are isolated from other thermal features tend to have more regularity in their eruptive patterns than geysers that have connections with other thermal features. Flood Geyser is not located near any other major eruptive thermal feature. Environmental factors of wind and water level in the Firehole River offer potentially interesting directions for future research to explain why Flood Geyser's behavior pattern varies across the years.

ACKNOWLEDGEMENTS

Although I collected most of the data used in this analysis, analysis of Flood Geyser's pattern of activity for 1996 and 1997 would not have been possible without data from the OFVC logbook. Thank you to everyone who reported information about Flood Geyser to the OFVC for inclusion in the logbook.

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Flood Geyser on May 27, 2007. Photo by Pat Snyder.

Activity of Excelsior Geyser September 14 – 16, 1985

Mary Ann Moss

EDITOR'S NOTE: During its active episodes in the 1880s and 1890s, Excelsior Geyser was undoubtedly one of the tallest, most spectacular geysers the world has ever known. Historical accounts of Excelsior describe violent eruptions that were 300 feet tall and nearly as wide. However, the brief active phase in September 1985 remains the only known instance of major eruptions of Excelsior since it fell dormant in 1901. A few people were lucky enough to witness the 1985 activity, including Park Volunteer Mary Ann Moss, geyser gazer Mike Keller, and park employee Ed Wagner. What follows are their personal accounts and photographs documenting the unique activity of September 15 and 16, 1985. Mary Ann Moss was a volunteer for Park Geologist Rick Hutchinson, who asked her to take notes on the activity. She has shared her recollections here, along with the detailed notes she took, her photographs, and the original memorandum from Hutchinson. Supplementing this are additional photographs by Ed Wagner and a first-hand account by Mike Keller.

MY EXPERIENCE OF THE 1985 EXCELSIOR GEYSER'S ERUPTIONS

by Mary Ann Moss, Park Volunteer

On the evening of 14 September, 1985, I went to the Old Faithful Visitor Center and gave the "secret knock" to be let in by John Railey, volunteer for Rick Hutchinson. John was recording the nighttime eruptions of Old Faithful and would let volunteers in to record their eruption times in the logbook. I diligently recorded my times, then started down the list of eruptions, when what did I see in big bold letters at the bottom of the page: EXCELSIOR ERUPTED. Looking at John I said, "Is this a joke? This has to be a joke!" He chuckled and confirmed it was true. I had passed by Excelsior twice that day, around 11:30 a.m., and nothing had looked different. Just a little more steam, like it looks on a cool day. The amount was subtle.

Early morning 15 September, I arrived at Midway Geyser Basin, where Excelsior is located.

Figure 1: Excelsior Geyser's steam. Photo by Mary Ann Moss.

I began taking pictures of the runoff channel closest in direction to Flood Geyser. Water was rushing out of it! Normally that channel is dry. To this day I now look at that channel for signs of water every time I pass by. It would be wise for all to do the same.

Figure 2: Excelsior Geyser's runoff channel. Photo by Mary Ann Moss.

The next thing I noticed was the Firehole River color and the scouring of the river from the sinter.

As I started up the paved trail, there were water marks where the water ran out over it during the 14 September eruption.

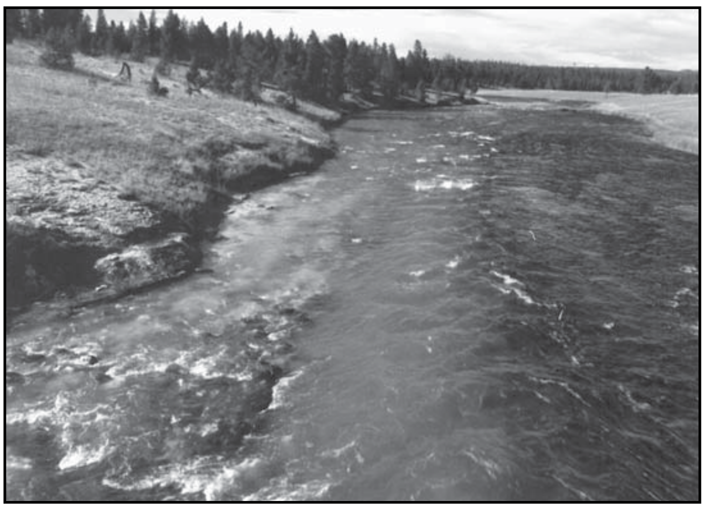
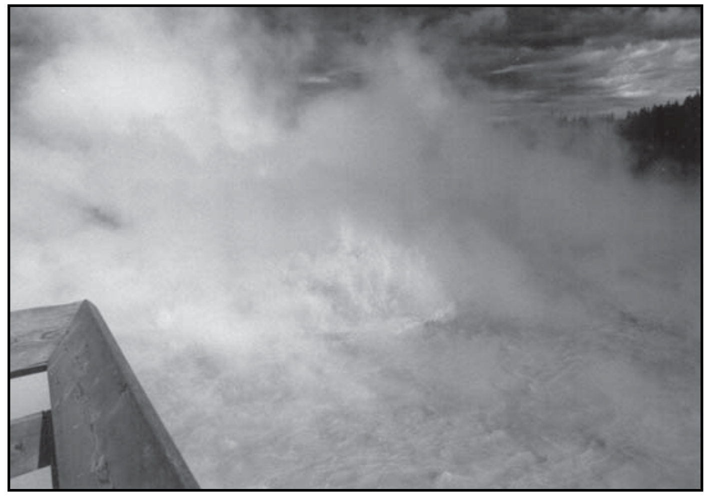
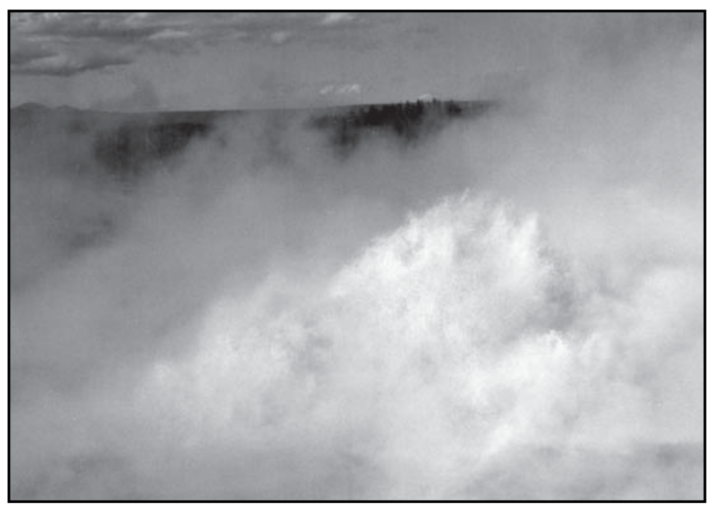


Figure 3 (top) and Figure 4 (bottom): The scoured Firehole River. Photos by Mary Ann Moss.





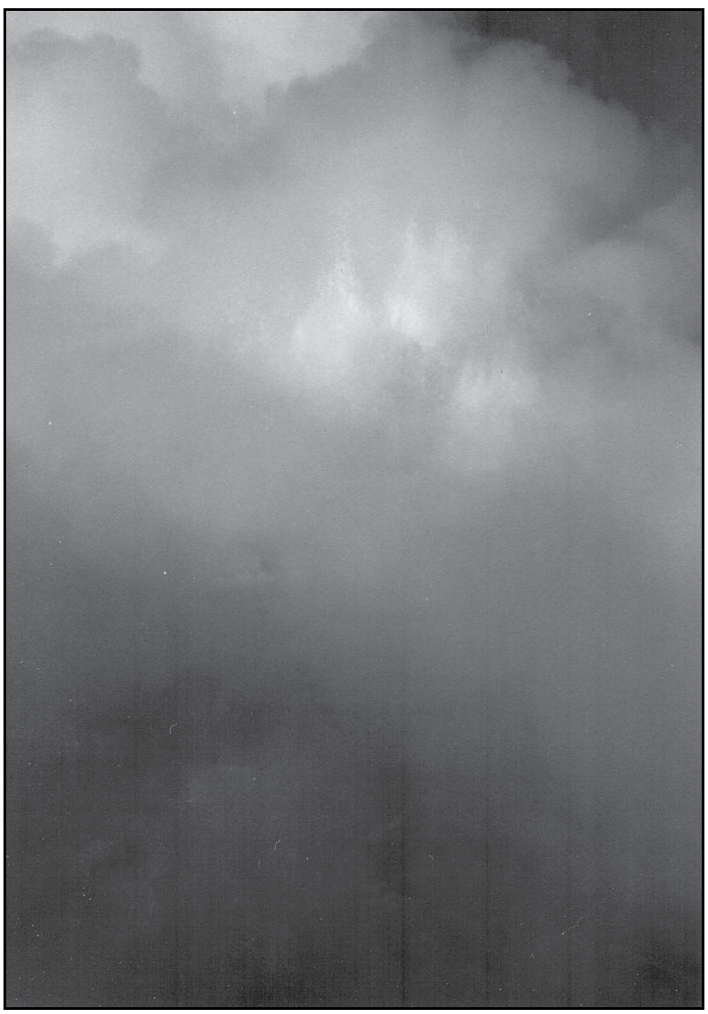
Figures 5, 6 and 7: Excelsior viewed from the boardwalk. Photos by Mary Ann Moss.

Daryl Lafferty, the geyser gazer who reported the eruption of 14 September, told about a woman visitor who was very indignant about the water on the trail and complained that "the park service should do something about that!" Steam was very heavy that second day. Marie Wolf and Rocco Paperiello stopped by for a while. Marie was ill and went to sit in the truck while Rocco watched some more eruptions until he had to leave for work.

Rick Hutchinson, park geologist, asked me to take notes on Excelsior that day. I was so afraid I'd miss recording something of great importance. After all, Excelsior doesn't erupt every day, but I said yes to taking notes. Rick gave me instructions about guessing height: it is 35 feet from pool to platform viewing area, anything above that adds to it. The eruptions were very difficult to see because of the steam, and I had to strain my eyes to see the smaller eruptions. Time and time again I recorded eruptions and ripples of water coming across the pool. I wasn't taking pictures; there wasn't time because the eruptions' durations weren't long enough. To be a good note taker, I couldn't do both!

The larger eruptions all came from the five or six vents in the center of the pool. Finally as the day went on, at 9h 30m, I thought "The next eruption, I am taking pictures." Lucky for me it was the largest at 1754, duration 5m, height 25 meters. "Time for pictures on this one."

Figure 8, above: Another boardwalk view. ***Figure 9, below:*** In full eruption. Photos by Mary Ann Moss.



Jen Hutchinson and Janine Wagner arrived. Park workers lined the rail! The boiling was getting stronger! It was eerie quiet except for the boiling. No one was making a sound. The boiling seemed to last five minutes or longer, but it probably wasn't, when a huge burst of water shot skyward and completely across the pool. People gasped and screamed! This burst had the finger tip points of water going from north to south across the pool, the same as the early Haynes photos. Three- and four-foot waves climbed the walls of the alcove area near where I was standing. I remember thinking, "Is this point going to hold?" I had to back up to get my photos because the eruptions were too huge to get them in the frame.

As it turned out, the photos are not as good as what is in my mind, but at least I have the photos. The eruption was gray in color and seemed very violent to me.

Another eruption of almost the same size came 1h 54m later at 1948 d = 4m, H = 15 meters. No one

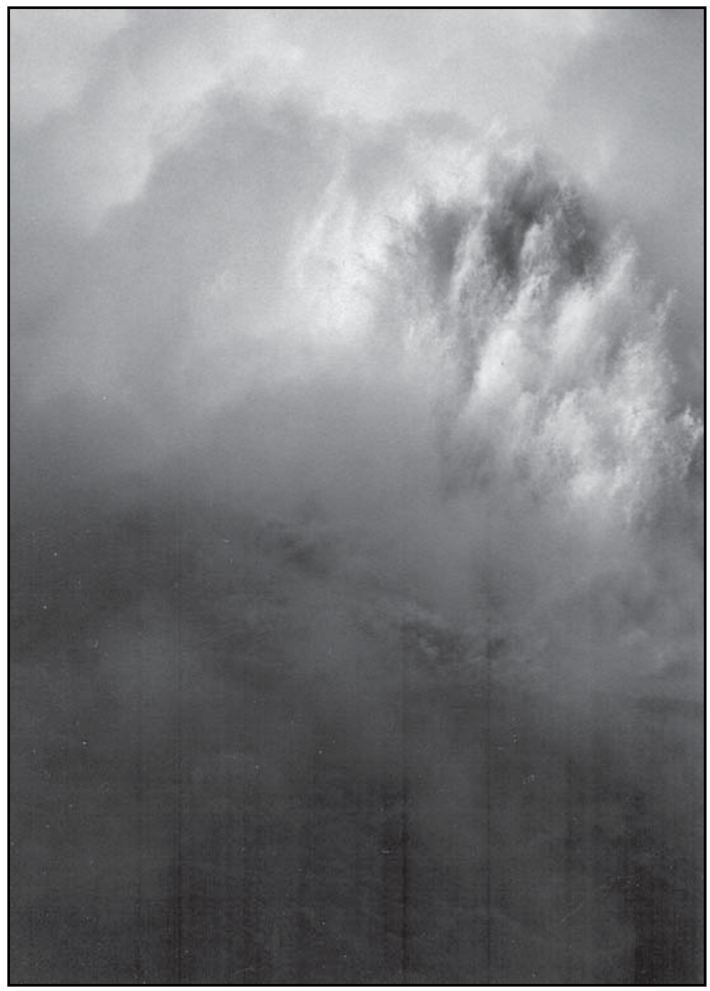


Figure 10: The large bursts. Photo by Mary Ann Moss.

was there with me to see this one. It was nearly dark, and note taking had to stop. After nearly twelve hours I was ready for a break! I asked Rick if he wanted me to stay in my van in the parking lot that night. He said no. I always wonder if there were more eruptions that night.

The next morning, 16 September, I was there taking notes again. There were a few small minor eruptions with the last at 1016, then continuous boil as it does today. By 1300 the water was clearing to a slight greenish hue. Note taking stopped around 1600.

Seeing eruptions of Excelsior Geyser leaves a person stunned and in awe! It's hard to take in seeing an eruption with that kind of force behind it. All in all it was a wonderful experience but would have been more so if other gazers had been there to share it with me. I decided to check Turquoise and Opal pools. They were still high, as was Grand Prismatic.

Rick and Johann put out markers on Excelsior Geyser after the eruptions quit on 16 September. Who would have thought there would come a day markers had to be put on Excelsior Geyser . . . but that's a geyser for you. Anything can happen!

I continued to monitor Excelsior Geyser. *See tables on the following pages.*

Figures 10 and 11: Another large burst, top, and doming action, above. Photos by Mary Ann Moss.

Figure 12: Water in a normally dry alcove. Photo by Mary Ann Moss.

Figure 13: Rick Hutchinson, right, and assistant place markers on Excelsior. Photo by Mary Ann Moss.

Eruptions of Excelsior Geyser
September 14–16, 1985

Time	Interval (minutes)	Duration (minutes)	Maximum Height (meters)	Comments
Saturday, September 14, 1985				
1251	—	—	—	
1256	5	—	6	
1302	6	2	3	
1308	6	2	—	Obscured by steam
1315	7	2	3	
1322	7	2	6	
1328	6	2	—	Obscured by steam
1335	7	2	4	
1344	9	1½	6	
1352	8	2	5	
1402	10	2	—	Obscured by steam
1410	8	2	4	
1418	8	2	3	
1424	6	2	4	
1438	14	2	3+	
1449	11	2	7	
1459	10	2	4	
1510	11	2	6	
1521	11	2	7	From this time on, minor
1530	9	2	5	0.5 – 1.5 boils were inter-
1540	10	2	6	spersed with eruptions on
1550	10	2	2	an increasingly frequent
1601	11	2m08	4	basis.
1612	11	seconds	1	Broad, minor eruption, no waves.
1621	9 (20)	2	3	
1636	15	seconds	—	Minor eruption with small waves.
1637	16	2	3+	Minor boils became more frequent,
1645	—	seconds	2	to almost continuous except for a
1651	14	2	7	brief period after each "regular" eruption.
1659	—	seconds	2	Minor eruption.
1703	12	2	5	
1710	—	seconds	2	Minor eruption.
1712	9	2½	4	
1720	—	seconds	1.5	Minor eruption.
1722	10	2	7+ (?)	Very steamy.
1731	9	2	8–9	
1739	—	seconds	—	Minor boil.

Time	Interval (minutes)	Duration (minutes)	Maximum Height (meters)	Comments
1742	—	seconds	2?	Wave produced, very low.
1746	15	2	—	Obscured by steam
1755	9	2	—	Obscured by steam
1802	—	seconds	—	Minor eruption
1806	11	2	3	
1816	10	2	5	
1836	20	2	5	
Sunday, September 15, 1985				
0732	—	—	—	Very large eruption with mist landing on patrol car in parking lot reported by M. Divine.
0824	—			Obscured by steam.
0848	24	2	—	Obscured by steam.
0904	16	2	—	Obscured by steam.
0918	14	2	—	Obscured by steam.
0931	13	3½	—	Obscured by steam.
0944	13	2	—	Obscured by steam.
0948	—	<½	—	Obscured by steam, minor eruption.
1002	18	2m55	5+	
1011	—	—	—	Minors, with frequent heavy surging 1 – 2 m.
1016	14	4	9	Major eruption like reported at 0732 (i.e.). Water level in crater dropped 15 cm at end of eruption; overflow resumed after 17 minutes, first boil resumed at 1036 after 20 minutes.
1055	39	2½	8	
1105	—	—	—	Minor, with large noisy boil.
1112	17	1m58	—	Obscured by steam.
1124	12	1m56	7	
1131	—	<1	—	Minor, with 2 m boils
1136	12	1m53	—	Obscured by steam.
1147	11	3m13	6	
1155	—	—	—	Minor, big noisy boil.
1200	13	2m47	6	
1214	14	1m33	4	
1223	9	2	10	Water level dropped 5 cm after eruption.
1233	—	—	—	Minor, no established waves.
1241	18	1m47	3	
1253	12	1m53	4	
1307	14	2	4	
1315	—	—	—	Minor eruption.
1317	10	2m04	—	Obscured by steam.
1328	—	1	—	Minor, waves only.

Time	Interval (minutes)	Duration (minutes)	Maximum Height (meters)	Comments
1332	15	4m06	16 – 17	Third major eruption observed; water level in crater dropped 22 cm, exposing numerous animal bones (mainly dogs) near outlet. Overflow resumed after 31 minutes.
1431	59	~1	~2	Weak “regular” eruption.
1452	21	1½	5	
1510	18	2	3	
1527	17	1	4	
1545	18	1m57	9	
1555	—	—	—	Minor with waves.
1559	—	—	—	Minor with waves.
1605	20	2	6	
1619	14	1m50	6	
1637	18	2	2 – 3	
1649	12	2m52	8	
1704	—	—	—	Minor, steamy with waves.
1710	—	~1	—	Obscured by steam.
1724	35	1m34	—	Obscured by steam.
1732	—	—	—	Minor, steamy.
1738	14	2	2	
1747	9	4	2	
1753	—	—	—	Minor.
1754	7	5	25	Fourth and largest observed major eruption of entire series. Lateral spread of bursts could not be taken in with a 28 mm wide angle lens from the boardwalk viewing area south of the crater; thus the bursts are estimated to be at least 30 m wide. First boil resumed at 1828 after 34 minutes. From then until 1920 there was essentially continuous heavy boiling and minor surging on the surface with only slight pauses.
1853	59	2	—	Obscured by steam.
1902	9	2	6	
1925	23	2	6	
1934	9	3	—	Obscured by steam.
1943	—	3	1?	Minor, obscured by steam.
1948	14	4	15	Fifth and last observed major eruption. Intervals between major eruptions were 2h44, 3h16, 4h22, and 1h54. Surveillance ended at 2000 due to darkness.

Time	Interval (minutes)	Duration (minutes)	Maximum Height (meters)	Comments
Monday, September 16, 1985				
0752	—	2	3	
0757	5	2	4	
0818	21	2m09	—	Obscured by steam.
0837	19	4m47	4?	Obscured by steam.
0943	66	2m50	3	Last regular eruption.
1016	33	—	—	Last minor eruption, then continuous boil until approximately 1600. Pool in crater was clearing to slight greenish hue by 1300.
[end of active episode]				

SUBSEQUENT OBSERVATIONS

18 September 1985	1400, Color of pool blue-green but not completely clear
19 September 1985	0830 to 1005, Markers in place- heavy boiling that almost never stops
20 September 1985	1045, Markers in place 1730, Pool now clear
21-30 September 1985	No change in markers or color
1 October 1985	1700, Markers in place and pool clear. Some algae starting to grow in channel close to trail.
2 October 1985	Pool clear, markers in place
3 October 1985	1019 - 1356, Excessive amount of overflow in all runoff channels, especially the channel nearest Flood Geyser. Pool clear and markers in place.
4 October 1985	Having 5 foot boils (this is normal since the eruption)
5 October 1985	Could not see markers in overflow channel but marker of most importance still in place. Excelsior very quiet today.
6 October 1985	No change
11 October 1985	Pool clear and markers in place (snowed)
15 October 1985	Pool clear and markers in place
18 October 1985	Pool clear - markers in place. Algae has increased. It is greenish brown in color.

Additional Excelsior Accounts

SEPT. 18, 1985 NEWS RELEASE: EXCELSIOR GEYSER ERUPTIONS (Sept. 14, 15, 16)

Last eruption 0943 Sept. 16 Monday. By 1300 the murky color was beginning to change to green. September 17, 1800—the pool was darker green. At the start of the day [Sept. 15] 0730 the boiling seemed heavier than it was Monday afternoon. Intervals of the eruptions were from (10) minutes to (1) hour. Durations for major eruptions [were] from 2 minutes to 5 minutes. Rick Hutchinson, park geologist, said the 25 meter eruption was 3 x 30 [meters] if Jen Hutchinson couldn't get it in her wide-angle lens, Sept 15 – time 1754. Bursts were from north to south across the pool same as early photos. The vents the eruptions were coming from were about 80 feet from main viewing corner of boardwalk.

EXCELSIOR IN 1985 by Mike Keller

I was fortunate enough to be at Excelsior the last day it was active. The tallest eruption I saw was about 20 feet high. Here is what I recall:

It was a typical mid-September day with gray skies, snow squalls, steady wind, can't-see-a-thing-from-a-large-body-of-thermal-water kind of weather. I had heard a rumor that Excelsior was active and convinced my mom that we should run into the Park to see it. After many hours of coaxing I was finally able to persuade her to drive down from Livingston and let me skip school (I was in 11th grade at the time).

First thing I remembered seeing was when we got to Fountain Flats drive, and the Firehole River was milky white, not truly murky but definitely cloudy. The carnage at Excelsior's crater was fantastic. The entire runoff area as you know it today was excavated (no other word to describe it). It looked like a fleet of bulldozers had leveled the ground from Excelsior towards the river. A large sandbar of mud, silt, rocks, and geyserite was deposited almost 75% of the way across the bridge. When we first arrived, Excelsior was not in overflow, something in itself that was pretty cool to see.

Walking up the trail, Excelsior was about a foot below overflow and completely chalky in color. As I was standing there, it suddenly had a period of bursting to about 15-20 feet (I say about because you couldn't really see too much with the steam) that lasted about 30 seconds. These bursts sent waves at least 6 inches high across the entire pool surface to the northeast. After the activity stopped I walked up to the crater and found Mary Ann Moss on the southern side of the crater.

While I talked with her, Excelsior had 2 more periods of bursting similar to what I mentioned above. From the south side you could see the water better as the wind was blowing the steam towards the north. One burst easily hit 20 feet (about 10 feet over our heads) and was easily two to three times as wide. At the time I had never seen that much water in the air at a single time from one geyser. It was like the entire middle of the crater suddenly lifted as a whole into the air. As Excelsior calmed down, the same waves I saw on the other side could easily be seen and heard rushing into the walls beneath us.

The entire inside of Excelsior's crater was torn up. It was obvious the larger eruptions had created much larger waves than the ones I saw that day. No portion within the crater was untouched by wash/wave action.

For whatever reason, Excelsior decided to stop the day I got there. Once the geyser started to overflow, the activity in its basin quickly subsided. I would estimate that the last good period of bursting I saw was around 1145. When I left it around 1500, it was having occasional superheated boils to a few feet but no true bursting.

Figures 14 and 15: Top, the dry runoff channel. Above, another view of Excelsior erupting in September 1985. Photos by Ed Wagner.

Observations of "Underhill Geyser" in the Lower Geyser Basin

Stephen Michael Gryc

Abstract

"Underhill Geyser" (known earlier as "Dragonfly Geyser") has a brief recorded history of eruptive activity, and this article is the first published description of the feature. The author observed 32 eruptions over a period of two successive days in July of 2006. A typical eruption is described and a table of timed activity is provided.

Location

Unofficially-named "Underhill Geyser" (also known as "Dragonfly Geyser") lies between the Pink Cone Group and the Fountain Group in the Lower Geyser Basin, about a third of a mile to the northwest of Narcissus Geyser. It is an isolated spring. The closest thermal feature is an old sinter mound about three hundred feet to the southeast. The old mound has a small hole that emits a little steam. Though infrequently observed, the geyser is close enough to the Yellowstone's Grand Loop Road that a visitor to the geyser can hear and see traffic through the trees to the west. Hoof marks impressed in the sinter surrounding the geyser and scattered scat and bones indicate that the area is frequented by Yellowstone's larger animals.

An Incomplete History

The earliest known reports of the geyser date to 1998 or 1999. Despite the relatively recent discovery of this feature, the author has been unable to positively identify the first observer or the people who initially applied the names Dragonfly and Underhill. Early observers of geyser activity at the site include T. Scott Bryan, Jeff Cross, James Evrard, Michael Frazier, Will Moats, Rocco Paperiello, and KC Thomson. Michael Frazier recorded video of the geyser in eruption in June of 2001.

Photo 1: "Underhill Geyser" in eruption, looking east toward Narcissus Geyser and the Pink Cone Group. Photo by Stephen Gryc.

Photo 2: Crater of Underhill Geyser. Photo by Michael Frazier.

The first name applied to the geyser seems to be that of Dragonfly. Scott Bryan suggests that it was because the observer saw dragonflies in the area.[1] Underhill Spring is a name that appears on Walter Weed's map of the area in the Hague Atlas of 1904, but no other reference to Underhill Spring is known.[2] The name Underhill was applied to an entire group of mostly dormant springs by the United States Geological Survey in their map of the area from the 1960s. Some unknown observer apparently adopted the name Underhill for the presently erupting spring in reference to the USGS map. By comparing the present geyser's location to the location on Weed's map, it appears that Weed's Underhill Spring is not the same feature as the geyser under discussion.

The dragonflies observed in the area around the geyser were red-orange, a color similar to that of the outer edge and run-off channels of the geyser. There is a small ridge, the sloping end of a larger hill, that hides the site of the geyser from view from Firehole Lake Drive. Both Dragonfly and Underhill are names with some modestly descriptive relevance to the geyser.

1. T. Scott Bryan, personal email message, June 16, 2007
2. Lee Whittlesey, personal email message, July 13, 2007

As it appears that most observers now refer to the geyser as Underhill rather than Dragonfly, the author will henceforth refer to the feature as Underhill Geyser.

Description of the Crater

Underhill Geyser's crater is roughly circular with a diameter of about six feet. There is an inner rim about three and a half feet in diameter surrounding a slightly deeper inner crater. The geyser's vent is close to nine inches in diameter. The crater features small beads of geyserite. The inner crater is pink while the outer crater is grey. The crater's outer edge is orange and ornamented with geyserite deposits that resemble eggs and mushrooms in size and shape. The main run-off channel extends to the southeast and is colored red-orange. When the geyser is not in eruption, its crater is striking and attractive in itself.

Description of Eruptions in July 2006

The following description pertains the author's observations in early July of 2006. Underhill Geyser's eruption began before overflow started, even before water reached the crater's inner rim. After the eruption commenced, the crater continued to fill, and water began to overflow the crater's rim after about a minute. The pulsing eruption sent waves out to the edge of the pool. Pulses occurred at the rate of about two per second. Most bursts were between one and three feet, but there were some in every eruption that reached four or five feet with an exceptional six- or seven-foot burst on occasion. The action was often most vigorous in the fourth minute of the eruption, but larger bursts also occurred late in the eruption. Around the sixth minute the eruption periodically waned and sometimes paused, only to reinvigorate with more bursting action. In most eruptions the author noted three such pauses and as many as five pauses in the longer eruptions. The indication that the eruption was over was a clear drop in the level of the pool. The complete drain took about fifty seconds. The water receded to no more than a foot down the vent, and then the vent and crater immediately started to refill as small bubbles rose with the water level. One subtle aspect of the eruption was a soft sound that was distinct from the pulsing and bursting of the water. It was a quiet but rapidly percussive sound akin to that of a very small motor, almost a purr. The sound stopped only when the drain was completed.

Eruption Observations

July 7, 2006

Start Time	End Time	Duration	Interval	Quiet Period
13:02:25	13:12:19	9:54		
13:17:19	13:23:21	6:02	14:52	5:00
13:28:05	13:38:44	10:39	10:46	4:44
13:43:33	13:55:08	11:39	15:28	4:49
13:59:54	14:09:42	9:48	16:21	4:46
14:14:59	14:27:43	12:44	15:05	5:17
14:32:39	14:46:01	13:22	17:32	4:56
14:50:19	14:57:36	7:17	17:39	4:18
15:02:47	15:12:45	9:58	12:28	5:11
15:18:26	15:29:53	11:27	15:39	5:41
15:34:19	15:43:41	9:22	15:53	4:26
15:48:35	15:58:09	9:34	14:16	4:54
16:04:05			15:30	5:56

July 8, 2006

Start Time	End Time	Duration	Interval	Quiet Period
9:19:17 i.e.	9:24:15			
9:29:34	9:37:25	7:51		5:19
9:42:22	9:52:08	9:46	12:48	4:57
9:56:48	10:03:53	7:05	14:26	4:40
10:08:46	10:19:11	10:25	11:58	4:53
10:24:00	10:30:30	6:30	15:14	4:49
10:35:30	10:43:53	8:23	11:30	5:00
10:49:05	11:00:20	11:15	13:35	5:12
11:04:45	11:14:38	9:53	15:40	4:25
11:19:52	11:27:52	8:00	15:07	5:14
11:33:04	11:42:30	9:26	13:12	5:12
11:47:07	11:58:40	11:33	14:03	4:37
12:03:07	12:17:30	14:23	16:00	4:27
12:21:40	12:31:21	9:41	18:33	4:10
12:35:23	12:44:30	9:07	13:43	4:02
12:49:06	13:00:56	11:50	13:43	4:36
13:05:23	13:17:50	12:27	16:17	4:27
13:22:15	13:30:35	8:20	16:52	4:25
13:36:00	13:47:20	11:20	13:45	5:25
13:52:50	14:02:20	9:30	16:50	5:30

The durations of the 31 observed eruptions varied between a minimum of 6m02s and a maximum of 14m23s. The mean duration was 9m57s, the median duration was 9m50s, and 11 of the 31 durations were between 9 and 10 minutes. There was a second cluster of 6 durations between 11 and 12 minutes.

Intervals between start times of successive eruptions varied from 10m40s up to 18m33s with a mean interval of 14m50s. The median interval was 15m06s with 9 of the 30 observed intervals in the range of 15 to 16 minutes. With its relatively short quiet periods between starts, the geyser was in eruption about two thirds of the time when observed.

Earlier Data

Jeff Cross[3], Michael Frazier[4], and Will Moats[5] recorded data for Underhill Geyser during the past few years. A summary of their data is shown below along with a summary of this paper's data for comparison. The data suggest that the geyser's eruptive pattern has not changed much over the years that it has been observed. There aren't enough data to state with certainty that either durations or intervals have lengthened significantly from 2000 to 2006.

Durations

Year	No. Recorded	Min./Max	Mean	Observer
2000	8	3:06/11:30	8:41	Cross
2001	2	7/9	8	Frazier (1) Moats (1)
2002	2	7/9	8	Frazier
2003	2	8:23/8:40	8:31	Frazier
2004	5	7:06/10:09	8:20	Cross (4) Frazier (1)
2006	4	9:18/10:48	10:01	Cross
2006	31	6:02/14:23	9:57	Gryc

Intervals

Year	No. Recorded	Min./Max	Mean	Observer
2000	7	6:48/16:30	12:54	Cross
2001	2	12/15	13:30	Frazier (1) Moats (1)
2002	2	10/15	12:30	Frazier
2003	1	14:14	14:14	Frazier
2004	5	12:36/16:06	14:18	Cross (4) Frazier (1)
2006	4	9:18/10:48	14:51	Cross
2006	30	6:02/14:23	14:50	Gryc

Photo 3: A larger burst (about 5 feet) from an eruption of Underhill Geyser. Photo by Stephen Gryc.

3. Jeff Cross, personal email message, September 23, 2007
4. Michael Frazier, personal email message, September 14, 2007
5. William Moats, personal email message, September 29, 2007

Narcissus Geyser Eruption Patterns June 27 – July 31, 2005

T. Scott Bryan

Abstract

Narcissus Geyser's pattern of alternating long and short intervals has been written about since at least the early 1980s. Electronic monitoring has made further analysis possible. This article examines the interval and duration data in July 2005, concluding that Narcissus' unusual alternating pattern of long duration-short interval, short duration-long interval eruptions existed over 96% of the time.

Introduction and History

In his overview paper about the electronic monitoring of geysers during 2005, Ralph Taylor [*The Geyser Gazer Sput*, December 2005] noted that the eruption pattern of Narcissus Geyser (Lower Geyser Basin) appeared to be the same as previously observed. However, Taylor also noted that he had not performed any actual analyses of the data, which were collected using a monitor maintained by Taylor as a volunteer for the Yellowstone Center for Resources. As I have long been intrigued by Narcissus' activity, I was granted permission to produce this report using the electronic data, which was provided by Taylor as a Microsoft Excel file.

Years ago — probably in the early 1980s — Dr. John Rinehart wrote a paper (unpublished) about the eruption pattern of Narcissus Geyser. He postulated that the eruption intervals alternated between longer and shorter modes. Without further rigorous observational evidence, this suggestion has generally been taken as a "fact without proof," but also has often been questioned by some observers.

In fact, Rinehart's conjecture is correct with very few exceptions, as outlined in the following.

The Data

The data used here was extracted from three text files that present the date and time of each data point and its temperature recorded in both Fahrenheit and Celsius degrees. The recorder — a thermocouple located in the western runoff channel a few feet from the geyser's crater — obtained the temperature one time per minute. Therefore, 49,495 data points were examined for this report (limited to June 27 at 16:50 to August 1 at 01:45, 2005), a volume that precludes including the data file with this paper. A small part of the data plot is shown in Figure 1, which is more fully explained later.

Because I do not have a computer program capable of extracting preferential data from a text file, I instead copied the files into Microsoft Word and reformatted the temperature columns to right–justification. I then visually scanned the values while scrolling. Because of the justification, temperatures greater than 100°F "jumped out" and were taken as showing the onset of and duration of an eruption. This temperature cutoff is arbitrary, to be sure, but it was easy and is likely to be more reliable than any lower temperature value. Out of 257 eruptions, there were six occasions when the maximum temperature failed to reach 100°F, but in each of these cases it was clear from examining the abrupt change of the temperature curve that an eruption did take place. (Presumably, a surging runoff without eruption could accomplish this, but since such an event has never been observed, I discarded that possibility. Instead, I believe the cause to have been strong wind that can push the majority of the runoff water to the east and away from the monitor.)

I believe the values of interval used here are accurate for the purpose of this paper. There certainly is a time lag between the actual start of an eruption and when it is detected by the monitor. This difference is apt to be most significant when judging the start time of the short mode eruptions. Those eruptions start when the geyser's pool is well below overflow and therefore require a short time before the runoff reaches the detector. By contrast, the long mode eruptions begin after a protracted period of overflow. "Ground truthing" — that is, comparisons between visual observations and the recorded times of the

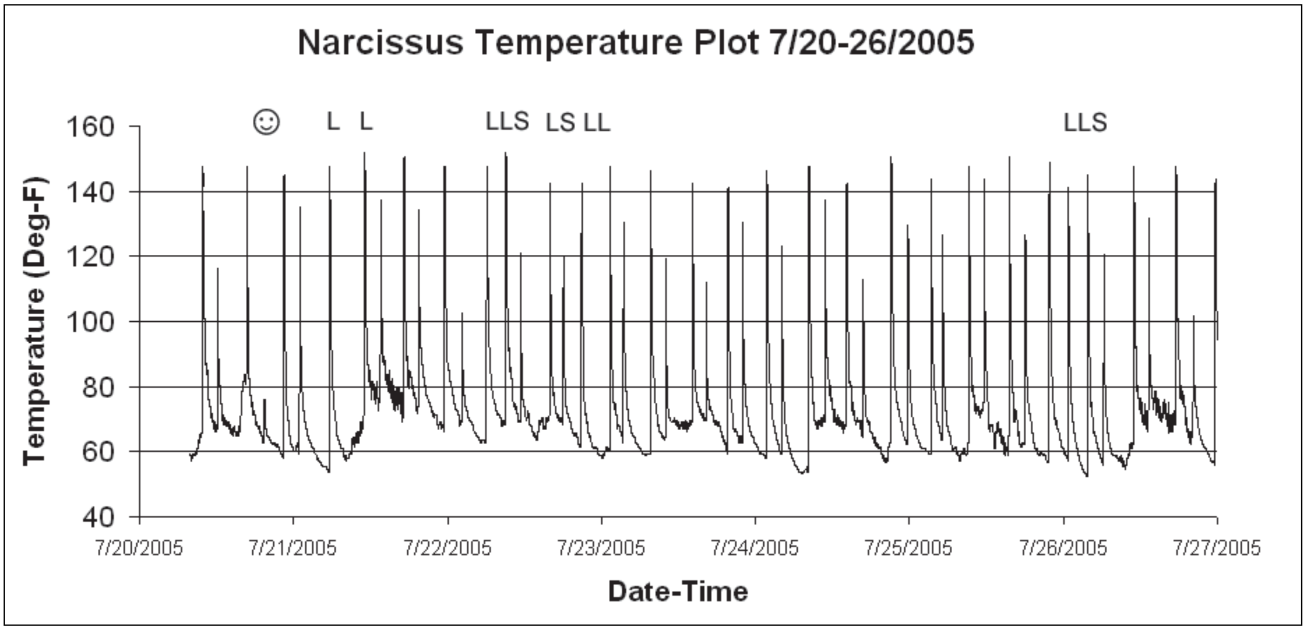


Figure 1.

same eruptions — shows that the time difference between the actual eruption and recorder times is not more and usually much less than three minutes. Therefore, I have taken the monitor times as being accurate.

There is undoubtedly a greater error when judging the eruption durations, since the cooling rate of lingering runoff water will be affected by air temperature and/or wind chill. Therefore, the analysis of the eruption durations should be taken as somewhat less accurate.

The Statistics

During the time of this study, Narcissus' net average interval was 3h 13m. That value is essentially meaningless, however, given the geyser's strongly bimodal nature.

Narcissus operates with two modes of both interval and duration — short mode intervals produce short mode durations, long mode intervals yield long mode durations. Unfortunately, there is a slight overlap of the interval modes, as shown on Figure 2, and it was an analysis of the durations that proved this. During this study, there were 123 cases of short mode and 134 of long mode.

The short mode intervals ranged between 1h 49m and 2h 57m. Their average was 2h 23m; the modal value was 2h 22m (8 cases).

The long mode intervals ranged between 2h 39m and 5h 54m. Their average was 3h 57m; the modal value was 3h 24m (4 cases; there were several values of 3 cases each).

The Pattern of Eruptions

As noted, the long–standing conjecture has stated that a long interval and duration is followed by a short interval and duration. By and large, this is entirely true. During this study, there were only 10 of 257 (3.9%) occasions when the pattern failed. In each of these ten cases, a long mode interval and duration was followed by another long mode interval and duration. There were no cases of consecutive short mode eruptions; what initially appeared to be consecutive short mode eruptions proved otherwise when their durations were considered.[1]

An example of the eruption pattern is shown in Figure 1. The alternating long–short interval pattern is clear with few exceptions. The exceptions are indicated by the lettering along the top of the temperature curve, where "S" indicates a short mode interval and "L" a long mode interval. (The "smiley face" symbol indicates a case where a short mode eruption presumably occurred with a minimal temperature increase at the monitor.[2])

When I began this study, I first examined only the intervals. In doing so, there seemed to be a small but clear distinction between the short and long interval

[1] Another interesting plot might be a graph of Duration on the X–axis versus Interval on the Y–axis (either the interval preceding or following the eruption), plotting minimum, mean, and maximum intervals for a given eruption duration. However, to do this realistically would, I feel, require that the length of the durations be more accurate than can be obtained from the electronic data.

[2] Observers have sometimes reported eruption intervals longer than 6 hours and have equated these to "minor" or "aborted" eruptions. Perhaps this "smiley face" occurrence is an example of this possibility.

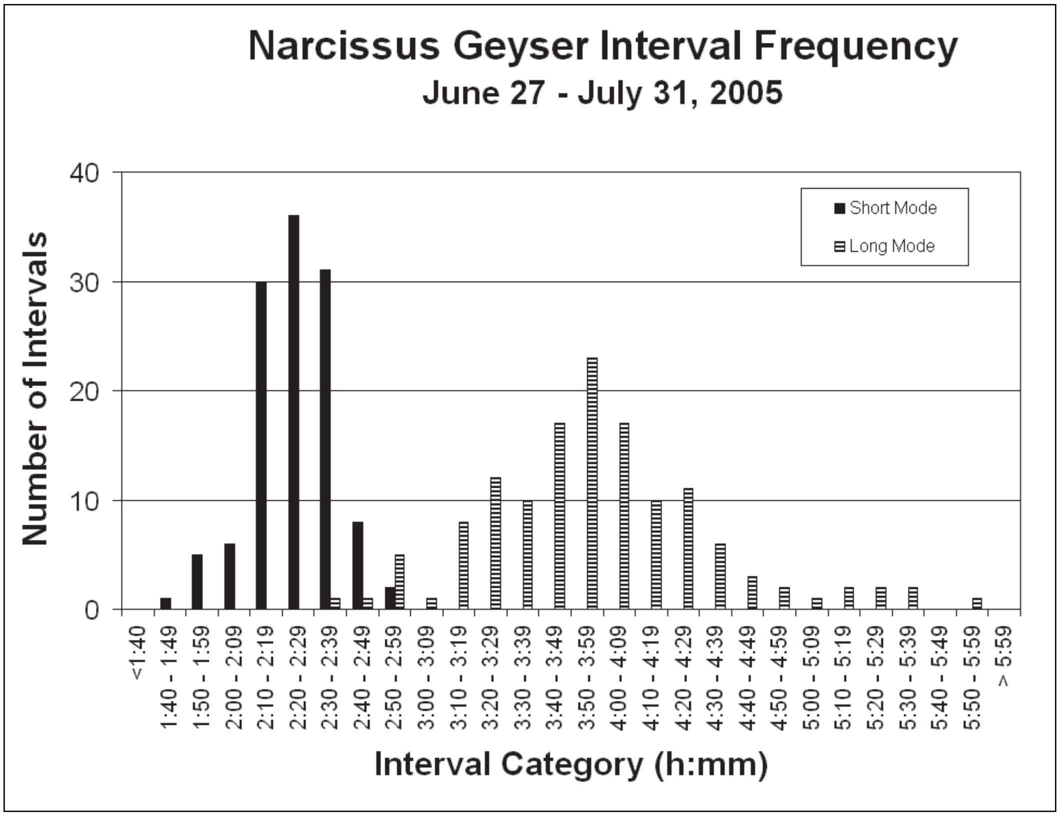


Figure 2.

populations, namely a time gap of 11 minutes between the longest short mode and the shortest long mode. It was later, when I began to consider the differences in duration, that I realized my initial conclusion was incorrect and that there is a slight overlap in the data. Several intervals appeared to represent the short mode, but those eruptions showed distinctly long mode durations. In a fashion similar to judging the intervals, I judged the durations as the time from first to last temperature value greater than 100°F (the six eruptions in which the temperature failed to reach 100°F still exhibited eruption–style temperature changes).

I extracted approximate durations from only the first week of the data (June 27 through July 3), with the following result. Durations of the short mode varied between 1 and 9 minutes, and gave an average of 5.38 minutes. Durations of the long mode varied between 9 and 17 minutes, and gave an average of 14.52 minutes. These values are actually in good keeping with observational data, where the short mode durations are typically between 5 and 8 minutes and long mode durations between 13 and 16 minutes. Although this covers only a short time span, the result is entirely in keeping with the observations of previous years and is believed to reflect the long-term behavior of Narcissus Geyser.

Conclusion

With few exceptions, Narcissus Geyser does indeed alternate between short mode and long mode eruptions. This pattern failed only 3.9% of the time, when there were consecutive long mode intervals and durations. There is little or nothing that might "predict" the consecutive long mode behavior — in data not rigorously analyzed, it appears that the first of the consecutive long mode eruptions had an exceptionally long duration, but this applies to only some of the data.

In final summary, then, if Narcissus Geyser has an eruption duration greater than 9 minutes, then that represents the long mode, which will be followed by a short mode interval of (roughly) 2 to 3 hours. If the duration is less than 9 minutes, then that represents the short mode which will be followed by a long-mode interval almost always longer than 3 hours and usually near 4 hours. (Should the duration be 9 minutes, then "take your pick.")

In most geysers, a short duration eruption is typically followed by a short interval to the next eruption. Narcissus is different, and perhaps unique, in that its short duration is *always* followed by a long interval, and a long duration is almost (but not quite) always followed by a short interval.

"Music, Song and Laughter": Paradise at Yellowstone's Fountain Hotel 1881-1916

Lee H. Whittlesey

It must have been paradisiacally idyllic. Life at the Fountain Hotel in Yellowstone National Park during the halcyon days of stagecoaches "on the grand tour" probably bordered on Shangri-La, at least at times. The hotel's location in the Lower Geyser Basin, the long summer days, the bears that seemed always visible at its garbage dump, the exquisite nearby geysers and hot springs, and even "Lover's Leap" whose charms beckoned to hotel employees---all of those things must have combined to produce a place of heavenly Yellowstone bliss.[1] Indeed, a 1905 brochure aptly called the hotel "prettily located withal!"[2] Although we so far know little about either its interior "look" (only one interior image seems to have survived) or about day-to-day activities there between 1891 and 1916, the picture that emerges of the Fountain Hotel from letters, archival documents, and visitor accounts remains one of exultant happiness.

The Fountain Hotel was open for twenty-six summers, all of them occurring during Yellowstone's stagecoach days. One of Webster's definitions of *paradise* is "a pleasure garden with parks, animal sanctuaries, and so forth." That fit both Yellowstone and its Fountain Hotel precisely. The hotel sat on the east side of Fountain Flats, a beautiful meadow in the nation's first and most famous park where most animals had been protected from hunting since 1883.[3]

At the time of the hotel's construction in 1890, Yellowstone already had several small and two large hostelries in operation: the National Hotel at Mammoth that opened in 1883 and a barn-like but relatively comfortable structure at Canyon that also opened for business in 1890. Hence, real comfort for the genteel stagecoach tourist was a full day away to the north or east from Fountain. While Old Faithful's small "Shack Hotel" to the south bulged and labored

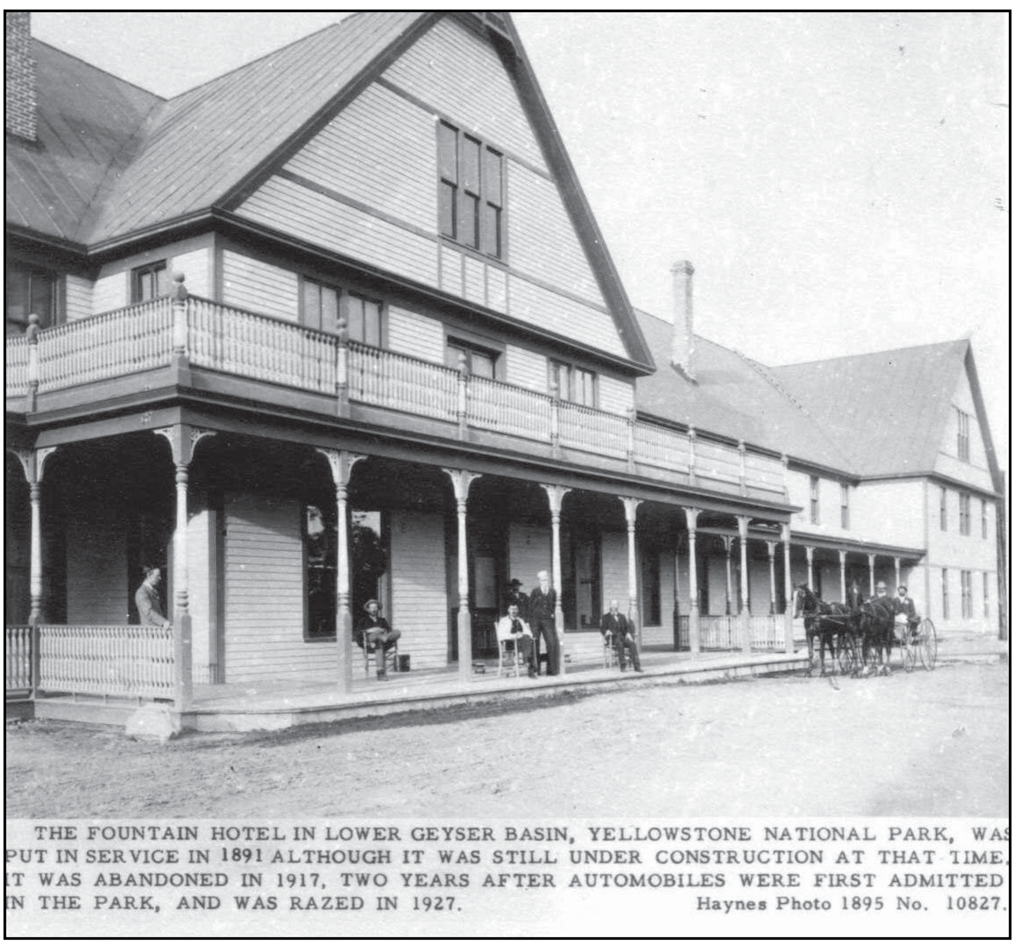


Figure 1: The Fountain Hotel. F.J. Haynes photo ca 1895 from Jack Haynes Christmas Card. M.A. Bellingham collection.

under an increasing visitor load, the even more primitive Firehole Hotel (formerly Marshall's Hotel) to the west was in its last full season as a hostelry. Plans for two more "grand" hotels, those slated for Lake and Fountain, had been in the minds of Yellowstone Park Association officials (financially backed by the Northern Pacific Railroad) for several years, so now they pressed ahead with those plans.[4]

Park superintendent F.A. Boutelle thought time was "very important" that summer because of the lack of proper visitor accommodations. He authorized YPA to "commence cutting timber at once" for the building of the new hotel.[5]

Secretary of the Interior John Noble was also sympathetic to the plans of YPA. "Having been through [the Park] myself," he wrote, "when I was compelled... to stay either in a tent or the smallest of cabins, poorly constructed, and with no accommodations that were at all comfortable, I have thought that if a series of hotels could be established under reasonable restraints..., a great advance would be made [at Yellowstone]."[6] While warning that workmen should not be allowed to mar the beauty of the park by cutting timber or quarrying too close to park roads, Noble approved "plans and specifications" for the hotel on August 18, 1890, and construction began shortly afterward.[7]

Secretary Noble was influenced to grant this lease following his receipt of a number of letters of complaint about conditions in the park involving crowding at Firehole Hotel and stage drivers refusing to travel farther than the hotel. He thus wanted "to abundantly provide for the public comfort and prevent any recurrence of the jam [of visitors] that had taken place at [the tiny Firehole Hotel]." A letter from attorney John G.H. Meyers gave the details:

> We reached [Firehole Hotel] and there were nearly one hundred people to crowd into thirty-seven rooms and a few tents, and the manager...assigned my wife and child to a room to be occupied by two other married couples and a young lady, and when I protested against it [I] was informed that was all that could be done, so I occupied the room with them. Here were eight persons, married and single, huddled together in one small room, with my child and self sleeping on a mattress on the floor. The toilet accommodations are simply abominable. If you wish to wash, you can go off to the brook and obtain the water, or go without. Eleven miles farther on [at Old Faithful] there is another hotel, and that night only twelve people occupied it, and it could have accommodated sixty. But the drivers of the stages had their instructions to stop...and would not go farther.[8]

Location of the site from which employees cut timber for the new Fountain Hotel remains unknown, but some cutting apparently occurred at a site on Hicks Lake, located three miles to the southwest, and cutting was probably moved later to a site between Fairy Falls and Twin Buttes.[9] The extensive metal remnants of an old sawmill operation along with many cut stumps, a small food-storage cabin, and what appears to be a larger residential cabin all remain at Hicks Lake today. Likewise, traces of an old road can be followed northwest from that sawmill site across an open meadow to the Firehole River. Archival documents from August 2, 1890, along with archeological remnants at the Hicks site suggest that employees floated logs down the river from the Fairy Falls area to the sawmill at Hicks Lake where they were worked before being transported by wagon to the hotel site.[10]

Noble's office laid out the requirements for Fountain Hotel's construction in a detailed fourteen-page document.[11] A comparison of it with similar specifications for the park's Lake Hotel,[12] then also under construction, makes it clear that the two buildings were being designed almost identically, so it is small wonder that pictures of them look so similar. It is probable that N.L. Haller of Washington, D.C., listed in these documents as architect for Lake Hotel, was also the architect of the Fountain Hotel. The specifications left the outside color of the buildings to be decided upon by the Association, and yellow was eventually selected for both buildings.[13] Charles Gibson (President of the Yellowstone Park Association) and his associates had difficulty getting funds for the new hotel during the financial crunches of that year and so had to advance $30,000 of the money out of their own pockets.[14]

The idyllic scene that would eventually characterize the Fountain Hotel was not initially present. Instead, the construction of the new hotel was at first a mess, at least if one believes geologist Walter Harvey Weed. Weed, long associated with the U.S. Geological Survey and with Dr. Arnold Hague in studying Yellowstone's hot springs, was assigned to keep the absent Hague informed about conditions in the Park that summer, and Weed was not happy about what he found at the hotel site in the autumn of 1890. Whether he objected to the location of the hotel itself or the messiness of its construction (or both) is not known, but he lamented the scene greatly. The location, on a timbered hill north of the park's famous "Mammoth paint-pots," had been chosen by superintendent F.A. Boutelle, and Weed griped about that, objecting to both the forest being thinned there and to the fact that the Thud Group of hot springs was located "but a hundred yards or so from the northwest corner of the building." He did not like the stacks of lumber on the sinter flat southwest of the hotel, the large log mess-hall just north of the hotel built to feed construction crews, numerous haystacks in the area used to feed stock, or the other scattered log buildings and tents nearby that were being used for necessary housing. He was openly angry about hotel washing being done at Thud Spring and the wagons that hauled hot water from it every few minutes. He even groused about "several dirty half-clad children" playing near an empty washtub and a "dirty old woman" who worked nearby amongst "cans and refuse" in the road. All in all, Weed thought the site of the rising edifice to be an "exhibition of squalor that is most disgusting."[15]

What Weed saw were really the last "gasps" of YPA's much-maligned Superintendent of Construction, R.R. Cummins, who was building the Fountain Hotel, along with what was essentially its twin, the park's new Lake Hotel. Cummins, who would soon get into trouble with his superiors, was probably stretched thin that summer as he rode back and forth between Fountain and Lake and watched both of his new hotels grow.

The Yellowstone Park Association should have known better than to trust Cummins when his recent work on the new, barn-like Canyon Hotel proved far from satisfactory. Indeed, Secretary of Interior Noble and park superintendent F.A. Boutelle had already exchanged words about Cummins's potential for causing trouble.[16] But the company thought the problems stemmed from the meddling of the General Manager of YPA, E.C. Waters, and so it let Cummins proceed. After Waters's removal, nothing improved with Cummins's operations and, moreover, work on the two new hotels became so expensive that the railroad had to advance an additional $60,000 to YPA.[17] In May of 1891, W.G. Johnson, Comptroller of YPA, following an inspection of the Fountain and Canyon Hotels, wrote that the workmanship seemed very poor and that he believed "it would be to the interests of the Association to experiment no longer with Cummins." That summer a strike by hotel workmen caused by Cummins's inability to get along with them made it certain that he would be fired.[18]

The hotel that Cummins erected, at least according to the original plans[19] and a recent archeological study of the site[20], was an F-shaped building whose front porch and longest side faced south. It contained 133 (rentable) rooms, 141 beds (at least in 1903), space enough to house 250 guests, and it cost $100,000. Included in the furnishings list was a fifteen-gallon coffee urn manufactured by Walterstorff, Martz, and Company of St. Paul.[21] The Fountain Hotel took around a year to build. According to the park superintendent, YPA completed and opened it except for one wing "about the middle of June," 1891. The Company immediately abandoned the small and inadequate Firehole Hotel, a mile to the northwest, and in November the old buildings there were burned except for two newer cottages and a barn to their west.[22]

Plans from 1896 show that the Fountain Hotel boasted 135 numbered rooms with a central office on the first floor, along with a wine room, bar, dining room, kitchen, pantry, and a couple of other partitioned-off rooms related to the kitchen.[23] By contrast, the second floor was composed completely of guest bedrooms. The laundry (along with the hotel's engine room) was a separate two-story building located east of the hotel's "west wing," that is, between the hotel's two long wings that extended north from its south-facing side. The second floor of the laundry was devoted to employee housing, with seven rooms located there. Employees added a barn, a root-house (for storage of perishable goods), an ice house, cold storage, and charcoal bin in 1897, and the building appears also to have been re-roofed and painted that year. Locations of the numerous outhouses that undoubtedly served the hotel's outbuildings are as yet unknown.[24]

Figure 2: The Fountain Hotel with Leather Pool in the foreground. Haynes 100 Series postcard, ca 1908, M.A. Bellingham collection.

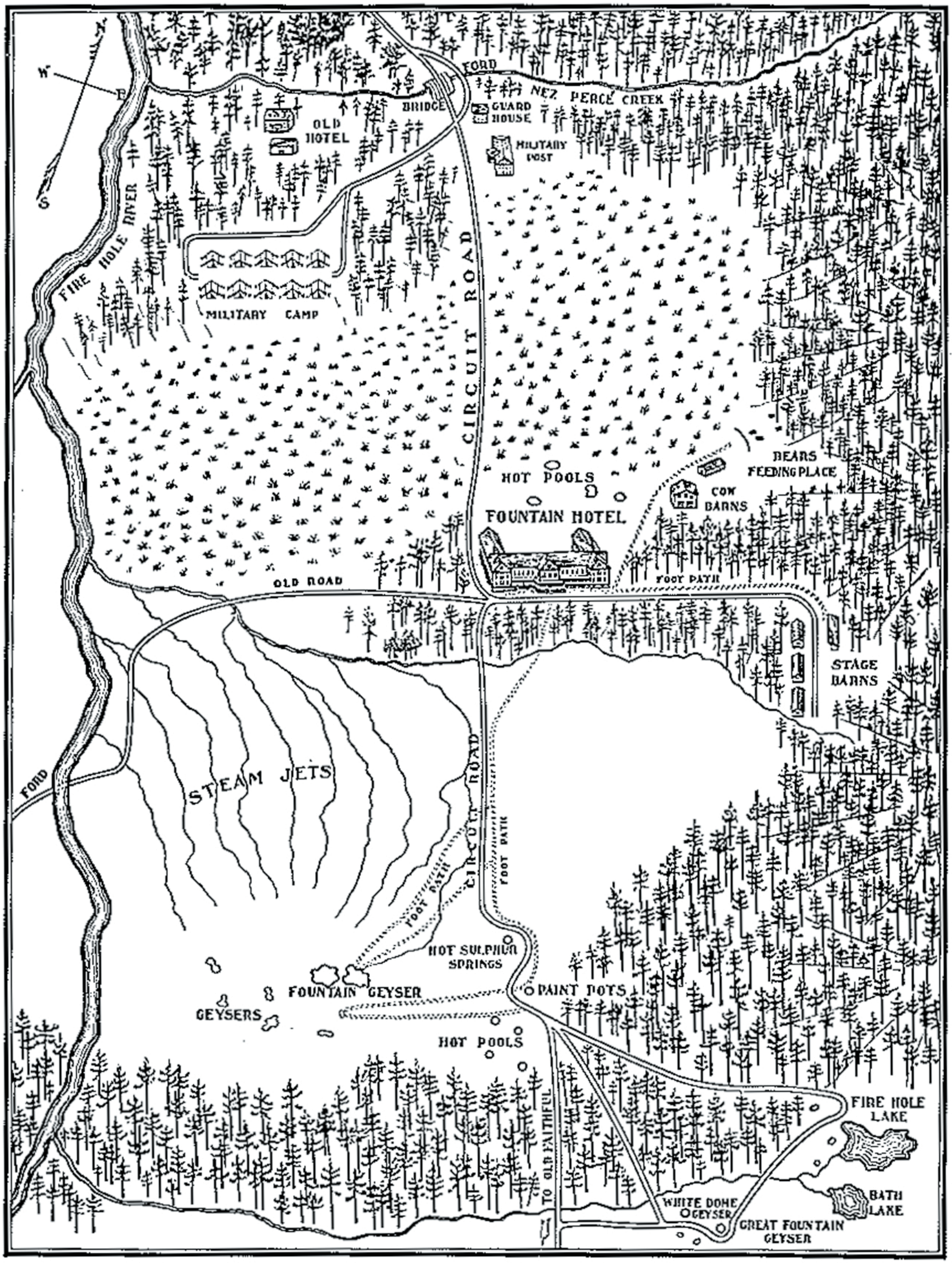
Both the 1890 plan and the "First Floor" plan (no date) indicate that the entryway at Fountain Hotel was a tall, rectangular, "rotunda" room (about 42x52 feet) that opened all the way up through the second floor to a high ceiling.[25] The large fireplace (mentioned below by visitor Patty Selmes) was located immediately at one's left, while the hotel's front office (registration desk) was at the upper left and the main stairs were located at the upper right of the rotunda room. A "gent's parlor" was placed off the rotunda room to the left and a "ladies' parlor" was off it to the right. Just past the office, the strolling visitor entered the large dining room (about 58 by 42 feet), and this room was probably the site of the hotel's dances once its tables and chairs were moved out. Behind (north of) the dining room was positioned the hotel's large kitchen (only slightly smaller than the dining room) with its requisite steam tables, counters, ovens, sinks, and pantry. Behind (north of) it was another large square room divided into "store room" at west and "help's hall" at east.[26]

Interestingly, a large, gray rock outcropping near the hotel's southeast corner became long allied with the place. Not only was the hotel's location platted from this rock outcropping, but visitors had their pictures taken on and around it for the hotel's entire life. An Acmegraph Company postcard of the hotel, one of many Yellowstone collectibles today, showed this "Fountain Rock" near the southeast corner of Fountain Hotel. [27]

The hotel itself faced south so that visitors could have a view of the Fountain Geyser area from the hotel's long porch. (A shorter veranda decorated the second story, so that visitors could lounge on it at a higher elevation.) Stagecoaches that unloaded visitors at the porch could then proceed east and south on a (dirt) road that led to the transportation company's barns and coach sheds. A road that forked north from this eastbound road led to the cow barns (and later a corral), the hotel garbage dump, and what appears to have been an employee dormitory.

Even before workers finished the Fountain Hotel, the Yellowstone Park Association began plans to staff it. Mr. Benton Hatch, hired to manage the new hostelry, passed through Livingston on his way to the park in April of 1891, telling locals that the new hotel would soon be finished and would contain "all modern improvements, including an electric light and complete water service."[28]

And indeed these innovations helped give the Fountain Hotel charm during its first season. Visitor Patty Selmes arrived that summer and stated that "there had been great improvements [in the park] since my former trip [in 1888]." She called the hotel



LOWER GEYSER BASIN.

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Figure 3: Lower Geyser Basin map from 1914 Campbell Guide.

Figure 4: The Fountain Hotel. Haynes Black and White Single-Margin Italic Set postcard, ca 1905, M.A. Bellingham collection.

"a most imposing lodge for so vast a wilderness," and her poetic description tells us a bit about the inside of it:

> Our entrance was through a large hall, where a regiment of big rocking-chairs, formed into a hollow square around the fireplace, gave silent promise of comfort. As it was getting late and we wanted to catch a glimpse of the Fountain [Geyser] and the Paint-Pots before dark, we went to tea immediately and had nearly finished when a boy, stationed to watch, came in breathlessly and announced that 'She would go off in four minutes!' A golden-haired vision had just set our sauce---which means canned peaches---before us, but, leaving it untasted, we rushed after the boy, past the rocking-chairs, across the porch and down to the brink of a deep, hot, troubled pool of dark-blue water...Only the promise of a natural hot-springs bath lured us back to the house.[29]

The baths at Fountain Hotel were indeed being supplied with natural hot spring water from nearby Leather Pool, then called "White Sulphur Spring." Indeed, park and company officials of that day were more interested in the comfort of visitors than in protection of park resources. An 1897 visitor explained that "the heat in the soil keeps up the temperature."[30] What he meant was that the water pipe from "White Sulphur Spring" ran through thermal ground which kept it warm so that the piped water did not lose heat on its way to the hotel. A 1909 guidebook stated that "the fine sulphur baths of the Fountain are in grateful remembrance of all who have had the good fortune to enjoy them; the water comes from one of the hot springs near the Paint Pots at an elevation sufficient to send the water to the bathrooms on the second floor of the hotel."[31] YPA President Charles Gibson claimed the hotel's baths were "not equaled [anywhere] in the United States," and indeed a 1908 visitor called the ablution the most delightful bath he had ever taken. "I do not know why," he opined, "but there is some subtle quality in the water that leaves the skin like a baby's--some of nature's alchemy, one of her mysterious compounds that the chemists cannot duplicate nor even imitate."[32]

The Yellowstone hot springs and geysers seemed magical indeed. The ladies in Patty Selmes's party watched Fountain Geyser, for which the hotel and the valley were both named, erupting sixty feet into the air. And Selmes's reference to the "golden-haired vision" makes it clear that the Association had already begun hiring women waitresses at the Fountain Hotel, just as park scrapbooks tell us the company was simultaneously doing at Lake and Canyon Hotels.

Visitor F.B. Nash found the hotel similarly charming in July of that year, calling it "a great hostelry, the largest and...best in the park." Nash especially liked "genial" manager Hatch, whom he found "made life very pleasant in this fine house." Nash noted "that large lobby with its great fire place, filled with all classes and conditions of men taking their ease in mutual sufferance with content is a pleasant spot to remember."[33]

The idyllic times at Fountain Hotel had begun, but toward the end of the 1891 season manager Hatch found his employers not so charming. Differences of opinion over how the place was to be managed resulted in Hatch's resignation in September. Unfortunately for YPA, about twenty of Hatch's employees agreed with him and quit the company as well. A Mr. Z.E. Bloomburg was then engaged to finish the season at Fountain.[34] Nevertheless, Lake Hotel employee Clara Green, who visited there September 27, opined that the "Fountain is a beautiful hotel and has a good business."[35]

The hotel's history is sketchy for the seasons of 1892 and 1893. In one of only two known 1892 accounts, traveler Eliza Upham praised the Fountain as a step up from the horrible shack hotel at Upper Basin. She noted that "this hotel the Fountain House is the nicest in the Park and quite a contrast to the past 'paper' hotel." Upham painted this pleasing picture for us:

> The rooms are pleasant and the dining-room looks pretty and attractive, with the tables set diagonally, and lots of silver, and the napkins standing like open fans.[36]

Similarly the Reverend J.H. Potter was delighted by what he found "at the end of an eight hours' stage ride" when his driver reined them up to the hotel, which he called a "very extensive and comfortable lodging place." He wrote:

> It is supplied with the modern conveniences—electric lights and steam-heaters, a spacious dining room, large sleeping apartments with heaters in them, and tables with a good bill of fare, all of which were prized by weary, hungry, chilly tourists. An extensive fire-place, all aglow with blazing fir five feet in length, gave us a welcome appreciated by our company. As soon as we had been assigned our rooms and thoroughly warmed and had eaten our dinner, we started for the geysers…[37]

A reference for 1893 called Fountain "one of the best [hotels] in the park" but noted only that "the fire on [its] great hearth is most welcome."[38] The railroad's *Wonderland Junior* pamphlet for that year noted that the hotel had steam heat, electric lights, accommodations for 250 people, and "hot mineral baths, the medical properties of which are, as stated by eminent medical and scientific men, to be found in but one other hot spring in the world."[39] A discerning reader intuitively doubts this last assertion.

Like the other hotels in Yellowstone, the Fountain Hotel was given a winter-keeper to watch over it through the long, cold park winters when it was closed, and there exist rare but occasional accounts of these park men. During the winter of 1893-94, the winter-keeper was John Schmidt, described by national writer Emerson Hough as "an efficient hand at getting up good and frequent meals" in the hotel's kitchen. Hough and some soldiers from Fort Yellowstone stayed at the Fountain Hotel during the extended cross-country ski trip for which Hough later became famous for writing about the capture of notorious buffalo killer Ed Howell. Hough spent quite a few sentences discussing how many western men were "cranks" or half insane due to their solitary lives in wilderness settings, but then noted that he found Schmidt "quite the opposite of this." Hough averred that Schmidt talked on and on to them in a monotone, "no doubt the reflex voice of his monotonous, solitary life," and entertained the visitors with his attentions to his two cats and one dog. "For the dog," wrote Hough, "we visitors had no affection...[for he]had a habit of sitting up all night and barking at the wolves and foxes which every night came in about the hotel kitchen where we made our abode."[40]

References like these to animals appeared often in accounts about the Fountain Hotel, bears being mentioned most frequently. The hotel's garbage dump became well known in the park for the number and size of the bears that frequented it. Hotel porters soon learned that tips could easily be made by offering to take visitors there to see bears.[41]

The garbage dump was located on a low hillside about two hundred yards northeast of the hotel and just west of Lone Spring, a spring whose rusting pipes today indicate that it was used to provide hot water for a nearby employee bunkhouse that seems to have been located at a creek near the foot of the hill below the dump. Nearby were signs telling visitors not to get too close to bears feeding on garbage and at least one small wooden cabin where garbage cans were kept.[42] In the meadow farther west, the hotel's cattle grazed near a couple of cow barns. Twelve cows in 1900 grew to over one hundred in several corrals in 1907, so at least the later cows probably had no problems with marauding bears.[43]

Presbyterian minister Henry M. Field stayed at the Fountain Hotel in 1894 and was told about the bear show where there was "always a quorum in session... about sundown."[44] Eager to see a bear, Field shouted, "Show me one!" to one of the men there, and he was taken to the site, whereupon a huge cinnamon bear could be seen nosing among the cans and bottles.[45]

The Fountain Hotel abounded in bears. Even today the vast wilderness area to its east is closed to hiking each spring in order to prevent disturbance of cub production and of carcass utilization by bears emerging from hibernation. In the early 1890s, bears routinely stole swill from the hotel's "cow-house" located northwest of the building and from a garbage barrel at the hotel's back door. It was probably in 1894 when a group of "roguish" young men thought it would be funny to see a bear actually inside the building. They used a "loaf" of sugar to lure one to the rear door, and from there the bear walked into the lobby. One lady immediately fainted, one or two more guests screamed, and the hotel clerk called out, "Keep still, everybody, and the bear won't harm you." The bear proceeded rather deliberately to nose the hotel's telegraph key before walking out the front door into the night, and only then did complete pandemonium reign in the guests' reactions.[46]

The bear show at the hotel became well known. Superintendent H.B.M. Young was told about it as soon as he arrived in the park and routinely told visitors to "go over to the Fountain Hotel and there you will see as many bears as you wish." Dan Beard, who started the Boy Scouts of America, noted that bears began to appear merely at the sound of the Fountain garbage wagon as it rumbled to the dump.[47] And one of the most famous naturalists of the day, Ernest Thompson Seton, used the Fountain Hotel garbage dump to observe enough bear behavior for a lengthy piece in his book *Wild Animals at Home* (1913). Seton sketched and photographed bears there, once seeing thirteen of the bruins, and describing in detail one old sow's determined spanking of her two cubs for misbehaving. According to one writer,[48] Seton, while at the hotel, met the bear Wahb at the hotel about whom he later wrote his celebrated book *Biography of a Grizzly* (1903), and he returned to the park in 1912 to add more information to his notes.[49] Journalist Henry Finck found the scene at the hotel a "most interesting illustration of the rapidity with which wild animals can be tamed," although one doubts that any of the bears he saw there were tame. Finck visited the hotel in 1897 and noted the parade of bears from half a dozen to sixteen that came to the garbage dump each evening around six. Finck noted:

> There they are, black bears, a few cinnamons, occasionally even a grizzly, quietly munching the bones and fruit peelings, while a dozen or two of the hotel guests look on ten yards away. One soon gets used to the scene; some men feed the bears apples out of the hand, and we ourselves adapted our habits so soon to the situation that when we met a bear in the woods afterward we paid no more attention to him than if he had been a dog.[50]

One of these Fountain Hotel bears became the most famous bear in Yellowstone history. That bear was photographed at the hotel dump sometime 1893-1899, and ultimately it became the symbol of the Yellowstone Park Company. The story of this bear was recorded for us by the park hotel company in a rare 1905 brochure:

> the bear who looks at you so quizzically from the cover of this booklet was a 'Fountain bear,' and this excellent picture was made by the young son of a former manager of the Fountain Hotel...it has been adopted as an emblem to represent Yellowstone Park...[51]

After the picture's first publication,[52] photographer F. Jay Haynes reproduced it as number 118 of his "one-hundred" postcard series published in 1908. By that time, company president Harry Child had placed the bear in the center of three red, white, and blue circles

Figure 5: The pools of Fountain and Morning Geysers with the Fountain Hotel in the background. Acmegraph postcard, ca 1908, M.A. Bellingham collection.

and thus created the logo for both his Yellowstone Park Association and his Yellowstone Park Transportation Company. When several such companies merged in 1936 into the Yellowstone Park Company, the bear continued as the company's emblem, and through 2001 it remained the symbol of Yellowstone's AmFac Parks and Resorts concessionaire.[53]

Naturalist Seton also wrote about Fountain Hotel bears in his book *Lives of the Hunted* (1901). In his fifty-page story of "Johnny Bear," Seton attributed existence of the hotel's garbage dump to orders given by the "steward of the Hotel" to dump garbage "in an open glade of the surrounding forest" near the hotel. Despite this comment, one has to believe that the park superintendent played some role in approving the site of the dump. Regardless, Seton's book delightfully presented the adventures of Johnny, Grumpy, Slim Jim, and other bears as a normal part of the Fountain Hotel scene—or at least so it was in 1897, the year Seton was there.[54]

If bears were one attraction at Fountain Hotel, geysers were certainly another.[55] The nearby Fountain Geyser had become famous by 1891, giving its name to the hotel and later to the nearby mud-pots (Fountain Paint Pot) and to the valley containing the hotel (Fountain Flats). Fountain Geyser's sixty-foot-high water bursts that were thirty feet in diameter occurred every 2-8 hours (1881-1898) and lasted 15 minutes to an hour. Because Fountain Geyser "displayed its charms with vigorous regularity,"[56] it became immensely popular with hotel visitors who could watch it from the building's front porch or travel one-quarter mile over to it. But on Monday morning, June 26, 1899, at 9:20 a.m., everything changed when an unnamed pool to the north began suddenly to erupt 200 to 250 feet high. A newspaper writer called the eruption "the grandest I have ever witnessed in the park."[57]

These huge, new eruptions electrified visitors and employees at the Fountain Hotel. A stagecoach traveler named Mrs. James Morris was asleep in her hotel room in August when about midnight gongs sounded, bells rang and porters went running about pounding on the doors and crying, what seemed to our sleepy imagination, 'Fire,' but presently we heard distinctly the words, 'The new geyser is playing,' echoing down the corridor. In ten minutes every tourist was out, in all sorts of costumes from blanket to full dress, either shivering on the long veranda or hurrying down to the basin to see the new geyser play, and right royally he did it, too. Upward into the black night shot a stupendous column of water three hundred feet high.

The hotel porters arrived at the geyser first and, playing their red calcium lights on the massive body

Figure 6: Morning Geyser, July 4, 1991. Photo by Tom Dunn.

of falling water (unthinkable today), gave the visitors a display of "fire and water" that took everyone's breath away. Mrs. Morris stated again that the water column was "three hundred" feet high, its delicate, rose-colored steam rising much higher and floating away into the black night. The hotel's cat hurried to the geyser and stood transfixed by the magic scene, geyser water falling all around him until someone picked him up and carried him out of danger.[58]

In honor of Admiral Dewey, who was then a national presidential hopeful involved in the U.S. war with Spain and in the Philippines, the new geyser was named "Dewey Geyser,"[59] but it was also quickly referred to as "New Fountain Geyser."[60]

The new geyser provided a show for Fountain Hotel visitors several times that summer. It played twice on June 11 and then put on a night show on August 6. Hotel employees built a fire near it at 9 p.m. in order to light it up for tourists, but army Corporal M.J. Whalen made them put it out. Hotel manager E.J. Westlake telegraphed his boss James Dean asking him why, for Westlake claimed fires there had not been "heretofore" illegal. Westlake then asked the army for "permission as to [the] fire as [the geyser] is a great attraction to tourists when it plays at night."[61] But the new geyser quit erupting before the year was out in the manner so typical of Yellowstone's constantly-changing geothermal springs, and Fountain Geyser resumed its former activity.

However the hotel's winter-keeper saw "Dewey Geyser" erupt again in early 1901, for it made the local newspaper. A reporter stated that the geyser broke out

> last week near the Fountain Hotel, in what is known as the lower basin. Mr. King, who is in charge of the hotel for the winter, was aroused from his slumbers on the morning of February nineteenth by the shaking of the building, the rattling of dishes, etc., and upon investigation found a new geyser throwing a large volume of water over two hundred feet high and continuing at its play for one hour and a half, the thermometer at the time being ten degrees below zero.[62]

Neither of the names stuck for the new geyser, and today it is officially known as Morning Geyser.[63]

The great number of geysers and hot springs near Fountain Hotel were fabulous attractions that made a stay there magical and idyllic, akin to nineteenth-century theater presentations of "Aladdin's Cave," as one early Yellowstone visitor noted.[64] In addition to Fountain and "Dewey" geysers, tourists could take a side road by surrey to see the huge Great Fountain Geyser, Firehole Pool, which exhibited "blue fire" flashing gas bubbles, and Surprise Pool, which burst into a surprise boil whenever a handful of sand was thrown into it (an illegal activity today).[65] Or they could walk a short distance north to the "Hotel Group" (today called the Thud Group) of hot springs where tour guides would show them "Barbara Fritchie's Well," the "Star Spangled Banner," "Hiawatha," "Thanatopsis," and other hot springs romantically named from great literature, although all of their names are different today.[66] Here a visitor might also see "Evangeline Geyser," named because nineteenth-century tour guides used it to tell the story of that romantic poem by Henry Wadsworth Longfellow. The spring's heart-shape, its red and white color, and its escaping steam, which created a thumping noise, reminded visitors of a beating heart and inspired tour guides into relating the story of Evangeline and her lover who were long separated and finally reunited at the ends of their lives. "This is the forest primeval," would intone the tour guide, taking his cue from Longfellow, and then he continued:

> As you stand on the outer margin [of the spring] or on one of the islets in [its] outer heart you become aware of a tremulous motion, terminating in a slight concussion. These increase in frequency and force until you become convinced that beneath your feet there is a throbbing heart. There are deep drawn sighs, terminating in a convulsive sob. Is it Evangeline agonizing over her lost lover? Are you actually treading on a bleeding heart? Looking to the south side of the crater: there is a crimson current oozing away...The illusion is complete. It is the bleeding heart of Evangeline![67]

Also nearby were the "Mammoth Paint Pots," known by 1914 as Fountain Paint Pot. They were the park's most famous bubbling mud-pots, and no visitor wanted to miss them. Tourists of the 1870s had called them "paint pots" because of their mud's resemblance to paint; indeed Lt. G.C. Doane had noted in 1870 that "a plasterer would go into ecstasies over this mortar" because it had been "worked" for perhaps ten thousand years.[68] This opportunity involving the mud was not lost on managers at Fountain Hotel. Company records at Minnesota Historical Society make it clear that sometime before 1903, maintenance personnel used the pinkish mud at the paint pots to "paint" (calcimine) many interior walls in the Fountain Hotel.[69]

This story sounded so fantastic that some park tour guides told it to visitors as a joke, apparently thinking it had never happened![70] But indeed it had. Naturalist John Burroughs, who accompanied President Theodore Roosevelt to Fountain Hotel before it opened in April of 1903, confirmed that he (Burroughs)

> was pleased to be told at one of the hotels that they had kalsomined some of the rooms with materials from one of the devil's paint-pots. It imparted a soft, delicate, pinkish tint, not at all suggestive of things satanic.[71]

Burroughs and President Roosevelt were taken to the not-yet-open Fountain Hotel, where the president hoped to see some of the bears for which the hotel was famous, but they were "not yet out of their dens." The country was covered with snow, even in the third week of April that year, and President Roosevelt, while riding in a sleigh near the hotel, captured a mouse that he saw running across the ground. He sent it to Dr. Hart Merriam who told him later that it was *Nacrotus nanus*, a species not theretofore identified in Yellowstone.[72]

If Roosevelt stayed in the Fountain Hotel as he did at some other park hotels that year, it is not recorded. Regardless, by that time numerous improvements and repairs had made the hotel into a place that was more than simply comfortable and that firmly ensconced it in its idyllic Yellowstone surroundings. That set the stage for Knights Templar member Edmund Erk to write the most complete known account of a trip to the Fountain Hotel.

It occurred on August 27, 1904, and Mr. Erk loved his stay at the hotel. He found the rooms large and spacious, the bed linen "faultlessly white," the furniture modern and comfortable, and the service "throughout the house" excellent. He extolled the large drawing room on the first floor as "one of those rooms which are the chief features of all summer resorts." (This room was the entryway "rotunda" room if the hotel's plans are any indication.) He was pleased with everything about the hotel except its piano ("a small, clattery, wheezy, asthmatic thing"), and this failing got worse when a bad pianist (a tourist) sat down at it. Even the hotel's engineer and fireman were service-minded, said Erk, as they volunteered to give shaves to two party members when a search of the hotel "failed to reveal a barbershop."[73]

Erk's description of a luncheon provides one of only a few known pictures of a meal at the Fountain Hotel. Several writers have furnished brief passages involving food served from cans, but Erk's is the only one with pretenses of real description. One hopes that what he encountered was typical Fountain fare:

> The table was snowy white in the array of linen and the service was equal to that of any first class metropolitan hotel. To find such conditions in the very wilds of the west was a surprising and most agreeable fact. Imagine how [we] poor, weary and hungry pilgrims devoured those appetizing viands; we felt that some good angel had suddenly swept down from out of a better land and set before us a mighty porterhouse steak, an inch and one-half thick, hot and spluttering from the griddle; dusted with fragrant peppers; enriched with little melting bits of butter of unimpeachable freshness and genuineness; the precious juices of the meat trickling out and joining the gravy, archipeligoed with mushrooms; a strip or two of tender, yellowish [fat?], gracing an outlying district of this ample county of beefsteak; and the long white bone which divides the sirloin from the tenderloin still in place. That good, imaginary angel, also added a great cup of home-made coffee, with cream 'a-froth' on top; some real butter, firm, yellow and fresh; some smoking hot biscuits; a plate of hot buckwheat cakes with transparent syrup. Could words describe the sumptuousness of this layout...?[74]

After lunch, Erk and his party withstood the horrible piano player and then watched Fountain Geyser erupt, before heading to the garbage dump to look at bears. They spent the evening in conviviality. "The hours that followed, about the spacious verandas and drawing room," gushed Erk, "were among the most pleasant in our memories of the entire trip. Music, song and laughter was [sic] general and ever present, and all shared therein, in full accord."[75] The party watched dancers in the "drawing room" who bobbed and swirled until late.

If Mr. Erk delectably described a 1904 meal, journalist Jane MacMillan wrote a less poetic account when she merely listed items from a 1914 menu at Fountain Hotel. Included at that time were mangoes, sweet pickles, and radishes for appetizers, followed by beef barley soup, Columbia River salmon with hollandaise sauce, "duchesse" potatoes, chicken pot pie, mashed potatoes, green peas, lettuce and tomato with mayonnaise, "macedoine" fruit salad, coconut cream pie, vanilla ice cream, assorted cake, cheese and crackers, coffee, tea, milk, and iced tea.[76] And of course dancing generally followed the food.

Indeed dancing became an ever-present activity at Fountain Hotel. Historian Aubrey Haines has noted that the hotel featured frequent balls and was, prior to the turn of the century, "the only place beyond Mammoth Hot Springs where a lady might need a silk dress, or a gentleman something better than his traveling clothes."[77] There is no information on what years dances were held or how frequently, but probably they were oft-held affairs of most summers, for a squad of U.S. Army, encamped just to the north on Nez Perce Creek, was always available to supply ladies traveling alone with dancing partners. Private Herbert Angelo was stationed there in 1902 and noted in his diary that he and fellow soldiers danced at the Fountain Hotel during many August nights that summer.[78]

We do not know what bands graced the "drawing" room at Fountain Hotel, but presumably on some occasions YPA hired the same band that played at the Mammoth and Canyon Hotels, namely Chicago's Nuernberger Orchestra. Regardless of who provided it, music, accompanied by song and laughter, seems ever to have been a part of the scene at the Fountain Hotel.

After the dancing, or sometimes during it, hotel employees could sneak off to their favorite nearby romantic spot. Located about three-quarters of a mile to the northeast and reached by a trail that ran north from the garbage dump, it was a high, rock pinnacle known as "Lover's Leap."[79] From it, sweethearts could watch beautiful Yellowstone sunsets across Fountain

Flats, look at bears in the woods, or walk idly hand in hand through a group of interesting hot springs.

Other activities at Fountain Hotel included occasional church services, for there is at least one account of such an occurrence. The Reverend J.H. Potter, traveling through Yellowstone in 1892, found to his chagrin that "there was no arrangement for stopping over" on Sundays. The master of transportation at Fountain Hotel told Potter that there was no recognized Sabbath in Yellowstone but that if the Reverend could convince an entire stage-load of people to be interested in the prospect, "our stage could stop over the Sabbath." The minister says he convinced "quite a number" of folks to stop over for church services and that they asked him to do the preaching in the parlor of Fountain Hotel. According to Potter, army soldiers and hotel employees joined the group to make "a very interesting congregation" that was "an unusual occurrence in that place." The pastor proceeded to rail against, in his later account if not in the sermon itself, Satan and his missionaries in Yellowstone. "Intoxicating liquor," wrote Potter, is "secretly taken into the park, and other evil influences are there [as well]." "Some who observe the Lord's day at home," he lamented, "seem to think the Fourth Commandment is not binding when they are on a journey…There is a growing tendency to desecrate the hallowed hours of God's precious day even among good people." Perhaps the Reverend should not have been surprised that in such a tourist place as Yellowstone pocketbook issues would prevail over preaching.[80]

Employees, at least those who drove park stagecoaches or handled park horses, had their own (today somewhat puzzling) area in the woods several hundred yards southeast of the hotel, indicated on the map (p. 153) as "stage barns," and southeast of a large pond that no longer exists. At least four buildings are thought to have been at this site, but there are no known close-up maps or detailed descriptions of it.[81] Field checks by the author in 2001 revealed remnants of buildings, corrals, the remains of a metal spring-box sunken in the ground, and other vestiges of what must have been a large support operation for the hotel. 1904 visitor Edmund Erk's mention is the only known one that gives us any information on this place with its stage barns. His account, complete with an interesting employee who did not speak English, was necessitated when several of his party members were accidentally left behind by their stage-drivers the following morning. Thus one of those visitors

> sought the company's barn in the rear of the hotel in hopes of securing a rig to carry the forsaken [ones] to their friends. Beating his way through underbrush and far into the woods in the dangerous vicinity in which we saw the unscrupulous bears the night previous, [this man] eventually came upon a hostler pitching hay in what appeared to be a barn. Approaching the man with all possible grace, [he] made an eloquent plea for a horse...[the stranger] replied in a mixed and unintelligent jargon, which appealed to the ear as a mixture of Slavonish [Slavonic?], Chinese and Greek...After a disappointing search of the shed to find that there was not a horse in sight, [our man] wended his way back through the woods, dodging shadows for bears.[82]

In 2001, the author experienced the same eerie feelings of watching for grizzly bears in these deep woods while walking the old road southeast from the hotel to the "barns." We must wait for archeology and/or the discovery of further documents in order to solve the mysteries of this little-known site of a fair amount of Yellowstone history that might, if we knew more about it, speak to class relations at the turn of the nineteenth century.

The Fountain Hotel was also the site of a mystery. On the evening of July 30, 1900, a visitor named LeRoy R. Piper—a bank cashier from St. Marys, Ohio who was fancily dressed—purchased a cigar from the cigar stand, stepped out onto the porch of the hotel, and was never seen again. U.S. Cavalry troopers searched for a month for him, his brother-in-law came to the park to look for him, a reward of $1,000 was posted for his return, but it was all for naught. He had disappeared without a trace, perhaps falling into one of the many hot springs that dot the area. One hundred years later to the night, on July 30, 2000, chief park tour guide Leslie Quinn led his fellow Yellowstone guides to the old hotel site and lit cigars in commemoration of that strange event.[83]

By 1927, when the hotel was razed, the Piper incident had spawned a legend that an entire family had disappeared at Fountain Hotel.[84] Old, creaky buildings seem often to have been the sites of such legends in Yellowstone. Another story in the 1920s had it that the building had been haunted, the winter-keeper at some point having been aroused on several nights at the same time "by the ringing of the service bells connected to one of the rooms." Checking the room several times, he was unable to find anyone there. "An investigation undertaken a few months later showed that a mouse had built a nest within the walls of the room, as it were, and in so doing had stepped on the annunciator wire, closing the circuit and causing the bell to ring."[85]

And, of course, the usual strange little events happened at the Fountain Hotel just as they happened anywhere. In 1903, Manager H. E. Fletcher fired cook Frank McCormick for striking kitchen girl Anna McClain with an iron spoon.[86] In 1906, Manager Harry Lewis reported that two drunken park soldiers created a scene at the front desk by using vile language in front of tourists. When one of the soldiers drew and leveled his gun at Lewis, the hotel's telegraph operator took it away from him, and the two hotel men eventually kicked the drunks out.[87] In 1908, winter-keeper Sam Eagle was dismissed for selling liquor to soldiers, tried, and fined fifty dollars plus costs by the park judge, but he was back working as winter-keeper at Fountain Hotel the following year.[88] In 1915, Sergeant Dalton and Private Winn were on duty overnight at the hotel "in case of necessity" when a tourist became "partly insane" there and required escort by guard to Mammoth the next morning.[89] These kinds of law enforcement incidents, handled today by park rangers, were handled in those days by U.S. Army soldiers.

The soldiers no doubt had their hands full one day in 1897 when a lady tourist waved a coat or something in front of a team of horses hitched to a stagecoach being loaded in front of the hotel. The frightened team ran away with its driver and charged into another coach load of tourists from Pennsylvania, thus "upsetting both outfits." The wife of Rev. B.D. Albright sustained a broken shoulder joint, Miss Lucy Diehl got a broken wrist, Mrs. Annie Hart received bruises, and the driver of the runaways was "seriously hurt." Runaway teams were all too common in horse-drawn America, and Yellowstone was certainly not exempt from that scene.[90]

A lightning strike in 1908 seems to have injured a stagecoach driver and affected the Fountain Hotel's communications. Traveler Thomas B. Hill noted:

> A very severe storm came up while we were at this hotel [with] rain, hail, thunder and lightning. The lightning struck the hotel, burning out the telephone system. We also very nearly lost our driver here. He was fixing the curtains on the coach, standing on a wheel, when there was a flash of lightning [and] his feet were knocked out from under him and he fell into the coach. It was still raining when we left the hotel…[91]

From records found by historian Aubrey Haines at Minnesota Historical Society, we know something about the numbers of visitors who stayed at the hotel during the first years of the twentieth century. Haines listed the numbers at 6118 for 1902, 5955 for 1903, 8488 for 1904, and 14,814 for 1905. A more thorough study of visitor numbers is needed to illuminate the hotel's fluctuating business, but it is worthy of note that in those days park hotels tended to lose money while the stagecoach companies that transported visitors were always profitable. That situation is exactly reversed today, as current park hotels make money and park transportation in the form of busses and other vehicles tends to lose money.[92]

Indeed, YPA managers worried for years that the upcoming erection of a new hotel at Upper Geyser Basin, eight miles to the south, would destroy business at the Fountain. Their report to stockholders in 1897 emphasized that the Fountain Hotel was "the best planned and the best built hotel owned by the Association, but it is at the wrong place, and will become almost valueless when a new hotel shall [sic] have been constructed at the Upper Geyser Basin, either by the Association or [by] other parties." Manager of all park hotels James H. Dean lamented to his superiors in 1900 that he had no power to stop tourists from staying with the hated Wylie Company (a tent-top competitor) at Old Faithful instead of returning for a second night at Fountain. The lack of a real hotel there and visitors' desires to see those geysers combined to hurt YPA's business at Fountain. Park photographer Frank Haynes's establishment of the Monida-Yellowstone Stage Company in 1898 no doubt aided Fountain Hotel, and it was probably that additional business that helped keep Fountain alive after the Old Faithful Inn opened in 1904.[93]

By 1910, the company had erected a number of additional buildings behind (north of) the Fountain Hotel. An unusual photo in a tourist scrapbook from 1909 or 1910 shows the hotel from the north so that all of those rear buildings can clearly be seen in addition to the two prominent north wings. The laundry/engine room/housing building was located between the hotel's two wings, a third story having been added to it at some point. A small, one-story building of unknown function was located between the laundry and the west wing.

The scrapbook photo clearly depicts the hotel's layout at that time. A large, underground root-cellar is shown as built into a hill just north of the icehouse. Firewood is stacked in at least three massive tiers along the back (north) side of the hotel in great amounts. Finally, the hotel's icehouse is shown east of the east wing just as 1911 plans would later show it, a one-story building resembling a warehouse.[94]

Seventy-one years later, John Egger still remembered that icehouse where ice cut in winter was stored in sawdust for summer use. Egger, who spent his life in Yellowstone working for the Company, ran the hotel's power plant in 1916. "I was the engineer the last year they ran it, 1916," he told the author in a 1981 interview. "I used to shut [the] electric generators down about nine in the morning and start them up about four in the afternoon. That was to save energy and personnel. Two of us ran the power plant. Homer Carper was the other guy [engineer]."[95] Historian Doris Whithorn's contacts with Yellowstone old-timers in the 1960s turned up a photo of employees like these on the steam engine at Fountain Hotel about 1900 which she says was "used to run the laundry facilities, saw wood or do any other jobs where power machinery was desirable."[96]

Strangely, from 1910 to 1916 extended references to the hotel, except for the small incidents already mentioned, remain few. The usual sources—from magazine articles to diaries to archival documents—do not reveal much about events at the hotel or the ongoing employee lives that were spent there. Even a newspaper search of the several Livingston (Montana) newspapers 1891-1917 turns up almost nothing additional. Only Arthur North's mention of meeting the hotel's winter-keeper, his wife, and their three little girls in May of 1911, and the newspaper notice of a grand masquerade in September illuminate that period.[97] Presumably Fountain Hotel's idyllic times continued during these years, but sadly we do not have those stories.

In 1916 someone installed what appears to have been a new water system in the woods several hundred feet east of the hotel at the top of a small hill. We have no idea who installed the water system or exactly how it worked. Today there are sixteen concrete pillars deep in the forest, arranged in a square and each about two feet high. The notation "A Phr[i?]ddocks/1916/A.D." is etched into the concrete of the most southwesterly pillar, possibly memorializing the name of one of the laborers who built the pillars. In 1993 archeologists found a cold water line buried below a trench leading westward from the pillars toward the hotel site, indicating that this was a foundation for a large water cistern of some type installed at the very end of the hotel's life, perhaps before the Yellowstone Park Hotel Company realized that the end of stagecoaches would spell doom for the place. The concrete piers that once supported the water tank stand alone in the forest today, a puzzling monument to last-minute planning and changing times in Yellowstone.

Fountain Hotel's last summer of operation was 1916. We know that the hostelry was open that summer because park visitor David M. Steele says he made an overnight stop there.[98]Automobiles had been officially admitted to Yellowstone on August 1, 1915, where they confusedly coexisted with stagecoaches. Accordingly, the summer of 1916 was a disorderly one, with both motor and horse-drawn vehicles plying park roads. The simultaneous operation of both of these transportation types caused chaos: car engines frightened horses, and park roads were not engineered properly for cars. Cars could get farther in a day than could stagecoaches. Hence, two hotels and twelve lunch stations were no longer needed, and so they were all shut down following the summer of 1916.[99] The Fountain Hotel was abruptly closed.

One visitor saw the boarded up edifice as a stark symbol of the new popularity of car travel to the national parks and the West. He suspected that its closure was "a result of the camp kits slung on the running boards of the endless stream of private cars on the road." He was essentially right. More and more park visitors were camping, rather than staying in hotels, and motorization was the reason.[100]

The building stood empty for eleven more years and was finally torn down in June, 1927. Assistant Chief Ranger Joe Douglas then burned its ruins.[101] Its windows, doors, and oak staircase were pressed into service to build the new women's housing near Old Faithful Inn, today known as "Laurel Dormitory."[102]

Figure 7: Clepsydra Geyser with the Fountain Hotel in the background. Lantern slide, date unknown, M.A. Bellingham collection.

For the Fountain Hotel, the music, song, and laughter were over. Some of that gaiety could and did easily move to other places in Yellowstone National Park, all of which had their share of it anyway. But the idyllic little piece of Wonderland paradise that existed for twenty-six summers at Yellowstone's Fountain Hotel was gone forever. Today most of the thousands of visitors that throng the nearby walkways leading to Fountain and Clepsydra geysers and the famous paint-pots have no idea that such music, song, and laughter were celebrated for so long and so near to those fabulous Yellowstone thermal attractions.[103]

[**Editor's Note:** The historical images in this article were graciously provided from the collection of M.A. Bellingham.]

FOOTNOTES:

[1] The history of Yellowstone stagecoach days is in Aubrey L. Haines, *The Yellowstone Story: A History of Our First National Park* (Boulder: Colorado Associated University Press, 1977; revised 1996), II, chapter 15; Richard A. Bartlett, "Those Infernal Machines in Yellowstone Park," *Montana the Magazine of Western History* 20(July, 1970):16-29; and Lee H. Whittlesey, *Storytelling in Yellowstone: Horse and Buggy Tour Guides* (Albuquerque: University of New Mexico Press, 2007), chapters 10-11. Older with some mistakes and omissions but with information that is otherwise hard to find is Merrill D. Beal, *The Story of Man in Yellowstone* (Yellowstone Park: Yellowstone Library and Museum Association, revised 1960), chapter twelve.

[2] YPA Hotels, *Yellowstone Park* (No place: no date, probably 1905), p. 17, copy at YNP Library.

[3] *Webster's New International Dictionary...*(Springfield, Massachusetts: G and C. Merriam Company, 1951). The history of animals in Yellowstone is Paul Schullery and Lee Whittlesey, "The Documentary Record of Wolves and Related Wildlife Species in the Yellowstone National Park Area Prior to 1882," in John Varley and Wayne Brewster, eds., *Wolves for Yellowstone? A Report to the United States Congress*

(Yellowstone National Park: National Park Service, July, 1992), vol. IV, pp. 1-4 through 1-173; and in Lee H. Whittlesey, "A History of Large Animals in Yellowstone National Park before 1882," unpublished draft ms. written for National Park Service, January, 1992, YNP Library.

[4] Histories of the early concessions operations in Yellowstone including YPA are Mark Daniel Barringer, "Private Empire, Public Land: The Rise and Fall of the Yellowstone Park Company," unpublished PhD. dissertation, Texas Christian University, 1997; Patrick J. Curran, "Yellowstone Park Association, 1886-1896," unpublished manuscript, August 23, 1968, YNP Library; and Richard A. Bartlett, *Yellowstone: A Wilderness Besieged* (Tucson: University of Arizona, 1985). The history of Firehole (Marshall's) Hotel is in Lee H. Whittlesey, "Marshall's Hotel in the National Park," *Montana the Magazine of Western History* 30(Autumn, 1980):42-51.

[5] Archive Document 360, July 19, 1890, YNP Archives.

[6] "Disgruntled Tourists," *Livingston* (Montana) *Enterprise*, August 23, 1890.

[7] Archive document (hereafter AD) 358, August 18, 1890; 359, August 18, 1890; 615, November 29, 1890; and John Noble and I.B. Casey, "Agreement for Lease of Site at Fountain Geyser...," August 18, 1890, in Box C-16, file "Yell. Park Assoc.," YNP Archives. This last is also reproduced in the McRae document, cited below, pp. 62-63. See also AD 362 through 364, all 1890, YNP Archives.

[8] Thomas C. McRae, "Yellowstone National Park.", 52nd Congress, 1st Session, House Report No. 1956, July 20, 1892, pp. VI, 4, 29-30, 102. See also Anonymous, "Badly Treated in the National Park," undated newspaper clipping [August 9, 1891] in Scrapbook 4209, p. 4, YNP Library. A last-minute withdrawing of this lease for the new Fountain Hotel, due to politics and involving President Benjamin Harrison's son Russell, was resolved in favor of YPA and the details are in the 300-page McRae document, pp. XII, 61.

[9] Telegram, AD 783, Craighill to Boutelle, August 2, 1890, YNP Archives. This telegram states that Cummins found the timber on Nez Perce Creek to be poor and wanted to cut at a site near Twin Buttes. See also AD 615, November 29, 1890, YNP Archives.

[10] Field investigations at Hicks Lake (one mile northwest of Lower Basin Lake) conducted by author and Paul Rubinstein in summers 1999 and 2001. The name Hicks Lake seems to have been applied to this otherwise unnamed lake by Northern Pacific Railroad surveyors in 1882 at the time the main park road ran just to the west of it. See the 1882 map by Carl Hals included in George Wingate, *Through the Yellowstone Park on Horseback* (New York: O. Judd Company, 1886), book-pocket; and the foldout map included in A.B. Guptill, *Practical Guide to Yellowstone National Park* (St. Paul: F. Jay Haynes, 1890). Hicks was apparently a Northern Pacific Railroad official whose first name is as yet unknown.

[11] I.B. Casey, as approved by John Noble, "Specifications: of labor and material...of the Frame Hotel...at Fountain Geyser," n.d., in Box C-16, folder "Yell. Park Assoc.," YNP Archives. See also Boutelle to Noble, May 9, 1890 and May 28, 1890 in Letters Sent, vol. 3, pp. 91, 93, YNP Archives. Some of the equipment used for the building's construction which was then (1889-1892) located at Fountain Hotel and at the sawmill site is listed in [Yellowstone Park Association], "Saw Mill Machinery," in "Hotels and Machinery Record," p. 97, Fall, 1892, box YPC-151, YNP Archives.

[12] Item in box C-16, folder "Yell. Park Assoc.," YNP Archives.

[13] Exactly when yellow was selected as the exterior color for Fountain Hotel is not known, but probably it was at the very beginning. Regardless, an 1899 company memo makes it clear that 180 gallons of yellow paint were being ordered that summer specifically for the hotel's exterior. "Memorandum for Mr. Relf. For a Requisition.," August 15, 1899, file 619 "Yellowstone National Park General," Box 134. F.5.11B, Northern Pacific Railway Records, Chief Engineer's Files, Minnesota Historical Society, St. Paul, Minnesota. This same memo gives the *other* colors selected for the hotel: white, black, French gray, and cream for the exterior, and "Ohio Stone," yellow-brown, French gray, and lavender for the interior.

[14] Gibson in McRae, "Yellowstone National Park.", 1892, p. 181.

[15] Weed to Hague, October 1, 1890, in Record Group 57, Arnold Hague Papers, box 6, National Archives.

[16] AD 361, July 22, 1890, YNP Archives; see also AD 352, November 7, 1890, and 353, August 1, 1890, YNP Archives.

[17] Haines, *Yellowstone Story*, II, p. 47.

[18] Curran, "Yellowstone Park Association, 1886-1896," August 23, 1968, p. 8.

[19] Anonymous, "Fountain Hotel Approval Plan," scale one-eighth inch equals one foot, Department of the Interior, August 18, 1890, in folder six, Haynes Collection, Montana Historical Society, Helena, Montana; "First Floor," plan of Fountain Hotel (apparently a working original drawing), no date, one inch equals ten feet, in folder six, Haynes Collection, Montana Historical Society. See also Anonymous, "Outline Plan, Fountain Hotel, Yellowstone Park, Yellowstone Park Hotel Company," n.d., about 1911, in drawer 14, folder H, YNP Library; and "W.B.," "Fountain Geyser Basin Hotel," 1896, plans in drawer 37, folder 16.0124, YNP Library. Missing from the Helena files (folder 3) is "Fountain Hotel Plans, 1896," four sheets, so I was not able to examine them.

[20] William J. Hunt, Jr., Ralph J. Hartley, Bruce A. Jones and Melissa Connor, "1992 and 1993 Archeological Inventories and Evaluations of Cultural Resources, Madison Junction-Biscuit Basin Road Reconstruction (Pkg. 254D), Yellowstone National Park," unpublished National Park Service report, Midwest Archeological Center, Lincoln, Nebraska, March, 1994, pp. 36-38 and Figures 38-41.

[21] Newell F. Joyner, "History of Improvements in Yellowstone National Park," unpublished manuscript, 1929, p. 12, YNP Library; Haines, *Yellowstone Story*, II, p. 116. YPA's original "Hotels and Machinery Record," dated Fall, 1892, gives the complete list of boilers, heaters, pumps, and other interior furnishings for the Fountain Hotel's engine room, kitchen, and laundry. It is in box YPC-151, YNP Archives. See also [Yellowstone Park Association], "Capacity of Hotels," 1903, in folder 11, file 210A, Minnesota Historical Society, St. Paul, Minnesota.

[22] Whittlesey, "Marshall's Hotel in the National Park," p. 51; Charles Gibson and George S. Anderson in McRae, "Yellowstone National Park.", pp. 194, 199-200, 218-219. A cardboard poster, 16"x22", found in the hotel's "cornerstone" during its 1927 demolition and dated September 22, 1890, 9 a.m., reads as follows: "This the Fountain Hotel…under

auspices of the Yellowstone Park Assn…to be dedicated for the reception of tourists and the general public in this the year of our Lord [1890]. The architect and Superintendent of Construction being R.R. Cummins of the State of Pennsylvania. W.D. Clark, Forman [sic]. Joseph Stulb, Jr. of Pennsy.[,] Clerk. The men at work on same building this day are as follows [thirty-three names listed]." The poster bears the business cards of W.G. Pearce (General Purchasing Agent, Northern Pacific Railroad), Mr. and Mrs. William S. Mellen (of NPRR) and a Mr. and Mrs. Colver (apparently a Minneapolis lawyer and his wife). Poster in Map Drawer 14, YNP Library.

[23] "Fountain Geyser Basin Hotel," 1896, plans in drawer 37, folder 16.0124, YNP Library.

[24] Yellowstone Park Association, "Report on Hotels," year ending October 31, 1897, in President's File 209-[1], folder 2, Minnesota Historical Society. Letters dated June 26, July 3, and September 2, 1897, in President's File 210A, folder 14, Minnesota Historical Society, St. Paul, Minnesota.

[25] The only known interior drawing shows this room with a lower ceiling (including a chandelier) than the "rotunda" plans of the hotel seem to indicate.

[26] There are slight variations among the several sets of floor plans, and we do not know which one was the exact building erected because no interior photographs are known to exist. For example, one plan shows "writing room" in the place of "gent's parlor," and there are variations from plan to plan as to where stairs are located and to the configuration of the hotel's front porch. Additionally, one plan shows the locations of the ice house and laundry/engine room reversed from that given above in my main text.

[27] "Lease No. 2. Lease to Yellowstone Park Association.," November 10, 1905, p. 3, in Box C-16, folder "Yell. Park Assoc.," YNP Archives. The wording for this lease states that "Site No. 5…Begin[s] at a cross cut in north east side of jutting rocks about 20 feet in diameter." The postcard is "Fountain Hotel, Yellowstone Park", Number 6514, Acmegraph Company, Chicago, n.d. [about 1912], copies in Ruth Quinn collection, Gardiner, Montana, and Susan Davis collection, Yellowstone National Park.

[28] "Local Layout," *Livingston Enterprise*, April 25, 1891.

[29] Patty M.F. Selmes, untitled newspaper clipping in Scrapbook 4209, 1891, p. 146, YNP Library.

[30] T.S. Kenderdine, *California Revisited. 1858-1897.*(Newtown, Pennsylvania, no publisher, 1898), p. 283.

[31] Reau Campbell, *Campbell's New Revised Complete Guide and Descriptive Book of the Yellowstone Park* (Chicago: Rogers and Smith Company, 1909), p. 155. Presumably the first-floor bathrooms also received this hot water, but we do not know it for sure.

[32] Charles Gibson in McRae, "Yellowstone National Park.", p. 193; F. Dumont Smith, *Book of a Hundred Bears* (Chicago, Rand McNally and Company, 1909), p. 109. The 1993 archeological project uncovered the remnants of a "wooden hot water line" that the archeologists believed had once connected the Fountain Hotel to nearby Gentian Pool, a separate hot spring in the area from Leather Pool. What the pipe was actually used for and where it actually connected to the hotel are presently unknown. Hunt, et al., "1992 and 1993 Archeological Inventories…," Figure 40. Author's telephone conversation with archeologist Bill Hunt, Midwest Archeological Center, Lincoln, Nebraska, April 30, 2002.

[33] F.B. Nash, "Vacation Notes," undated magazine article [1891] in Scrapbook 4208, p. 22, YNP Library.

[34] "Local Layout," in *Livingston Enterprise*, September 5, 12, 1891.

[35] Clara Green, "Clara Green's Comments on Working in Yellowstone National Park 1891 & 1892," descendants' transcription of original diary, p. 10, YNP Library.

[36] Eliza A. Upham, "Eliza A. and E. Annie Upham's Excursion with the Raymond Party to the Yellowstone National Park In September 1892," photocopy of handwritten diary-account, YNP Library, p. 50. Original owned by M.A. Bellingham, Emigrant, Montana.

[37] Rev. J.H. Potter, *Across the Continent and Back Again* (Cincinnati: Elm Street Printing Company), 1893, pp. 44-45.

[38] Anonymous, "The Yellowstone National Park.," *Harper's Weekly* 37 (July, 1893):722.

[39] Northern Pacific Railroad, *Wonderland Junior* (St. Paul, NPRR, 1893), p. 13.

[40] Emerson Hough, "Forest and Stream's Yellowstone Park Game Exploration. No. 9.," *Forest and Stream*, July 21, 1894, p. 47. For another winter adventure at Fountain Hotel, see Lewis R. Freeman, *Down the Yellowstone* (New York: Dodd, Mead, and Company, 1922), pp. 37-40. While the red fox (*Vulpes vulpes*) has been a continuous resident of Yellowstone National Park, the gray wolf (*Canis lupus*) was exterminated from the area by the 1930s but reintroduced to the park in 1995. In 1894, both species were residents and thus could have been noticeable to Fountain Hotel dogs. See Schullery and Whittlesey, "Documentary Record of Wolves," pp. 1-142 to 1-147, 1-152; and Lee H. Whittlesey, "A History of Large Animals in Yellowstone National Park Before 1882," unpublished draft report, January, 1992, pp. 161-162, 175-176, YNP Library.

[41] Anonymous, "In the Playground," undated newspaper clipping [1895] in Scrapbook 4209, p. 135, YNP Library.

[42] 1898 photo in Gardner Stilson Turrill, *A Tale of the Yellowstone; or In a Wagon Through Western Wyoming and Wonderland* (Jefferson, Iowa: G.S. Turrill, 1901), p. 93.

[43] Campbell, *Campbell's...Guide*, 1909, p. 106 and map on p. 107. For cows at Fountain Hotel, see Lee H. Whittlesey, "Cows All Over the Place: The Historic Setting for the Transmission of Brucellosis to Yellowstone Bison by Domestic Cattle," *Wyoming Annals* 66(Winter, 1994-1995):50.

[44] Campbell, *Campbell's...Guide*, p. 106; see also anonymous, "Yellowstone Park Brief Notes of a Trip to This Famous Wonder," n.d. [1895] in Scrapbook 4209, pp. 61-62, YNP Library. 1894 was also the year that traveler August Straus recorded one of the few negatives on record against the hotel. Straus called all of the hotels in the park and the men that ran them "first class" with the exception of "Mr. Miller" at Fountain: "He seems to be cold-blooded in his accommodations to his guests, and it is not in him to make things pleasant. He is simply one of that kind who do not care a continental whether the guests enjoy themselves or not." Aug. Straus, untitled undated newspaper clipping [1894] in Scrapbook 4208, p. 89, YNP Library.

[45] Henry M. Field, *Our Western Archipelago* (New York: Charles Scribner's Sons, 1895), pp. 220-222.

[46] Anonymous, "An Unwelcome Caller," undated newspaper clipping [1895] in Scrapbook 4209, p. 109, YNP Library.

[47] The superintendent is quoted in Dan Beard, "In a Wild Animal Republic," *Recreation* 15(December, 1901):423.
[48] Wilbur F. Gordy, "A Trip to Yellowstone Park," *Perry Magazine*, November, 1901, p. 86.
[49] Ernest Thompson Seton, *Wild Animals at Home* (Garden City: Doubleday, Page, and Co., 1922), pp. 204-213. The 1913 edition has superior photos to the 1922 one. See also H. Allen Anderson, "Ernest Thompson Seton in Yellowstone Country," *Montana the Magazine of Western History* 34(Spring, 1984):46-59.
[50] H.T. Finck, "Yellowstone Park in 1897," *The Nation* 65 (October 7, 1897): 277. For other bear stories at Fountain Hotel, see Katherine Louise Smith, "The Animals of Yellowstone Park," *American Homes and Gardens*, June, 1906, pp. 392, 394-395; and Anonymous, "Yellowstone Park from a Car Window," *Forest and Stream* 59(August 2, 1902):82-83.
[51] YPA Hotels, *Yellowstone Park*, n.d., [1905], p. 20. Unfortunately neither this manager's name nor his son's name are so far known.
[52] The photo was published in Olin Wheeler, *Wonderland 1900* (St. Paul: NPRR, 1900), p. 117, and in William Tod Helmuth, *Yellowstone Park and How It Was Named* (Helena: C.B. Lebkicher, n.d. [1893-1899]), in Rare Box 15, YNP Library.
[53] As of 2008, Xanterra Company, descendant of AmFac, has decided to allow its historic transportation department to retain this company symbol. A visitor of 1909 or 1910 had another story about this bear, one that seems less likely to be true, but for history's sake, I report it here. On F. Jay Haynes's postcard #118, this visitor, probably a park employee, recorded the following story: "This is 'Old Joe,' I think, one of the tamest bears in the park. He is thought to have been killed this spring by falling into a hot pool near Thumb Station. As a cub, he was captured and kept with his brother at the Wylie Camp and [they] were fed by tourists. Then the other bear got tangled up in the chain and was hung. After that they let this fellow loose, but he always kept near the hotels and camps and was familiar with everyone." Handwritten notation on F. Jay Haynes, "A Park Bear," postcard 118, in Susan and Jack Davis collection, Bozeman, Montana. Postcards in this collection became part of the YNP museum collection in 2002.
[54] London: Hodder and Stoughton; New York: Charles Scribner's Sons, 1901, pp. 141-191.
[55] Visitors seem to have been so taken with these two scenic attractions at Fountain that they wrote about them rather than about the hotel itself, leaving us with a dearth of information on the hostelry and an abundance of material on bears and geysers there.
[56] Nash, "Vacation Notes," n.d. [1891], in Scrapbook 4208, p. 22, YNP Library. Statistics and history of Fountain Geyser are in Lee H. Whittlesey, *Wonderland Nomenclature: A History of the Place Names of Yellowstone...*(Helena: Montana Historical Society microfiche, 1988), p. 596, entry for Fountain Geyser.
[57] Anonymous, "New Geyser in the Yellowstone.", June 27 [1899], in Scrapbook 4210, p. 34, YNP Library. See also *Livingston Enterprise*, July 1, 1899.
[58] Mrs. James Morris, *A Pacific Coast Vacation* (New York: Abbey Press, 1901), pp. 246-248.
[59] E.H. Barbour, "The Rapid Decline of Geyser Activity...," *Science*, n.s., 10 (October 6, 1899):490-491. George Dewey is discussed in Laura Wexler, *Tender Violence: Domestic Visions in an Age of U.S. Imperialism* (Chapel Hill: University of North Carolina, 2000).
[60] Wheeler, *Wonderland 1900*, pp. 104, 111.
[61] AD 4911, J.H. Dean to Capt. Brown, July 12 [1899]; AD 5011, E. J. W[estlake] to Dean, referred to Superintendent O.J. Brown, August 6-7, 1899, YNP Archives.
[62] Anonymous, undated, untitled newspaper clipping, about February 25, 1901, in Hester Ferguson Henshall, "Trip Through Yellowstone National Park," scrapbook and trip log, August, 1903, p. 35, Montana Historical Society.
[63] Morning Geyser has continued to occasionally erupt over the years to heights of 200 feet or so but with long periods of dormancy.
[64] G.C. Doane in *Battle Drums and Geysers*, Orrin and Lorraine Bonney, eds. (Chicago: Swallow Press, 1970), p. 344.
[65] Campbell, *Campbell's...Guide*, 1909, p. 108.
[66] G.L. Henderson, *Yellowstone Park: Past, Present, and Future* (Washington, D.C.: Gibson Brothers, 1891), p. 7. See generally Lee H. Whittlesey, *Yellowstone Place Names* (Bozeman: Wonderland Publishing Company, 2006).
[67] G.L. Henderson in Whittlesey, *Wonderland Nomenclature*, 1988, p. 596, entry for Fungoid Spring.
[68] Doane in *Battle Drums and Geysers*, 1970, p. 289.
[69] For two visitors who had this story related as fact to them by park tour guides, see Rube Shuffle, *Yellowstone Letters* (New York: Neale Publishing Company, 1906), p. 51, and Nicolas Senn, *Our National Recreation Parks* (Chicago: W.B. Conkey, 1904), p. 35. For mentions of the mud calcimining as fact, see Campbell, *Campbell's...Guide*, 1909, p. 108; Hiram M. Chittenden, *The Yellowstone National Park* (Cincinnati: Robert Clarke Company, 1903), p. 216; John Burroughs in Paul Schullery, ed., *Old Yellowstone Days* (Boulder: Colorado Associated University Press, 1979), p. 225; and "To Yellowstone Park Over the Lines of the Salt Lake Route," p. 13, n.d. [1911], in Scrapbook #2, Accession 3151, Howard Hays Collection, University of Wyoming, American Heritage Center, Laramie, Wyoming. This last pamphlet states: "The rooms of the Fountain Hotel were calcimined with this [mudpot] material."
[70] For this joke version, see John Atwood, *Yellowstone Park in 1898* (Kansas City: Smith-Grieves, 1918), pp. 15-16, who noted that he thought the story true until he saw "the twinkle in my informant's eye."
[71] John Burroughs, *Camping and Tramping with Roosevelt* (Boston and New York: Houghton Mifflin Company, 1907), pp. 67-68.
[72] *Ibid*., pp. 65-67. Roosevelt's own account of this is in his book *Outdoor Pastimes of an American Hunter* (New York: Charles Scribner's Sons, 1923), p. 343, wherein he identified the mouse spot as "upper basin."
[73] Edmund Frederick Erk, *A Merry Crusade to the Golden Gate* (Akron, Ohio: Werner Company, 1906), pp. 81-82, 84-86.
[74] *Ibid*., pp. 80-81.
[75] *Ibid*., p. 86. A briefer 1904 account of visitors at Fountain Hotel "singing rag-time songs" in the hotel's large reception room is Clifford Paynter Allen, "Pilgrimage of Mary Commandery No. 36, Knights Templar of Pennsylvania to the Twenty-Ninth Triennial Conclave of the Grand Encampment U.S. at San Francisco, California, August 22 to September 21 (Yellowstone is August 26-31, pp. 19-69), 1904, pp. 33-34, Library

of Congress, American Memory Collection, website: http://memory.loc.gov.

[76] Jane MacMillan, "Hotels of Wonderland Restore Broken Appetites," *Helena* (Montana) *Daily Independent*, July 26, 1914, p. 15.

[77] Haines, *Yellowstone Story*, II, p. 116.

[78] Herbert L. Angelo, facsimile of handwritten diary, n.d. [August, 1902], p. 70, YNP Library. For mention of a dance held in 1900, see Charles M. Taylor, Jr., *Touring Alaska and the Yellowstone* (Philadelphia: G.W. Jacobs and Company, 1901), p. 330.

[79] The name of the place is mentioned in George D. Marler, *Inventory of Thermal Features of the Firehole River Geyser Basins...* (Springfield, Virginia: National Technical Information Service, 1973), p. 605.

[80] Potter, *Across the Continent and Back Again*, 1893, pp. 53-55.

[81] "Fountain Barn" (probably the relevant site) is mentioned in "Hotel Company Sites," n.d. [probably 1906-1912], in Item 59 (box 28), file "Leases Reissued[,] Yellowstone Park Hotel Company," YNP Archives, as being an area of more than 21,000 square feet that was leased to YPA at that time. But there is no further information on it in this file.

[82] Erk, *A Merry Crusade*, p. 90.

[83] Haines, *Yellowstone Story*, II, pp. 118-119; Lee H. Whittlesey, *Death in Yellowstone: Accidents and Foolhardiness in the First National Park* (Boulder: Roberts Rinehart, 1995), p. 180 and cited accounts; Leslie J. Quinn to Lee Whittlesey, 2001 communication.

[84] "Park Charges Stories Being Sent Out...Hurt Name," *Livingston Enterprise*, September 9, 1928.

[85] Joyner, "History of Improvements," p. 13.

[86] AD 4241, Anna McLain to superintendent, September 4, 1903, with four endorsements about the incident, YNP Archives.

[87] AD 6502, Harry Lewis to John Pitcher, September 6, 1906; AD 6503, O.O. Twiss to John Pitcher, September 6, 1906, YNP Archives.

[88] AD 8588, S.B.M. Young to Commanding Officer, October 27, 1908; S.B.M. Young to T.E. Farrow, October 26, 1908 in Letters Sent, vol. XIX, p. 338; John Meldrum to Solicitor, November 19, 1908, in bound volume 242, p. 91; and AD 7172, Major Fifth Cavalry to Riverside Station, April 5, 1909, YNP Archives. For the Eagle family as winter-keepers at Fountain Hotel, see generally Sam and Ed Eagle, *West Yellowstone's 70th Anniversary 1908 to 1978* (West Yellowstone, Montana: Eagle Company, Inc.), 1978.

[89] "Remarks," Weekly Outpost Report, Fountain Station, June 20-26, 1915, in Item 117 (box 78), YNP Archives.

[90] *Livingston* (Montana) *Herald*, August 5, 1897. For more on runaways in Yellowstone, see Whittlesey, *Death in Yellowstone*, pp. 141-150.

[91] Thomas B. Hill, "Wonders of Yellowstone," *Winona* (Minnesota) *Daily Republican*, August 27, 1908, p. 8.

[92] From annual reports of Yellowstone Park Association at Minnesota Historical Society as read by Aubrey Haines onto audiotape 63-5, side 1, track 3, YNP Library oral history collection.

[93] Yellowstone Park Association, report on hotels and profits to "Stockholder, Y.P.A.," January 2, 1897, in President's Subject Files, file 209-B, folder 11, Minnesota Historical Society; James H. Dean to C.S. Mellen, July 25, 1900, in President's Subject Files, file 210-C, folder 2, Minnesota Historical Society, St. Paul, Minnesota. For an angry discussion of the problem of Fountain Hotel being in the wrong place, see Finck, "Yellowstone Park in 1897," p. 276.

[94] This photo is one of the unattached ones in H.B. and Isabel L. Weatherwax scrapbook, n.d., about 1910, unpaginated, museum accession number YELL-1998, photo number YELL-129827-1, YNP photo archives.

[95] John Egger to Lee Whittlesey, January 17, 1981, at Gardiner, Montana. According to the 1911 plans, the engine room and laundry were located between the two north-running wings of the hotel.

[96] Bill and Doris Whithorn, *Photo History from Yellowstone Park* (Livingston, Montana: Livingston Enterprise, n.d. [1970]), p. (18).

[97] Arthur W. North, "Alone in the Yellowstone: Riding in the Path of the Pioneers, Before the Season Opens in the Park," Sunset 27(August, 1911):136. The masquerade ball occurred in September of 1911 and was reported in "Grand Masquerade at Fountain Hotel," *Livingston Enterprise*, September 28, 1911, p. 3: "Joe DeBar was in charge of arrangements" and "every partici[pant]" enjoyed "a most entertaining evening." The program included the awarding of prizes for best costumes and orchestral renditions of waltzes, two-steps, and schottisches for dancing, including "Geyser the Geysers," "Fountain Dreams," and "Old Faithful Bunch."

[98] David M. Steele, *Going Abroad Overland: Studies of Places and People in the Far West* (New York and London: G.P. Putnam's Sons, 1917), p. 107.

[99] The story of the motorization of Yellowstone is in Bartlett, "Those Infernal Machines." Details on the confused summer of 1917 with its new busses and coalescing of park concessioners is in [Chester A. Lindsley], *Annual Report of the Superintendent of Yellowstone National Park*, 1917, unpublished report, YNP Library, pp. 1-11. See also Haines, *Yellowstone Story*, II, pp. 256-275; and "Auto Tourism Conquers Yellowstone," in Bartlett, *Wilderness Besieged* , pp. 73-102.

[100] Quoted in Anne Farrar Hyde, *An American Vision: Far Western Landscape and National Culture, 1820-1920* (New York and London: New York University Press, 1990), p. 298.

[101] [Horace Albright], Monthly Report of Superintendent, June, 1927, p. 12; [Horace Albright], Annual Report of Superintendent, 1927, unpublished, YNP Library, p. 9; Joyner, "History of Improvements," p. 12.

[102] John Egger to Lee Whittlesey, January 17, 1981, interview at Gardiner, Montana.

[103] The Fountain Hotel site is probably one of those places the National Park Service refers to as a "cultural landscape," a place where culture and nature come together in a noteworthy way, and it may also be eligible for nomination to the National Register as a National Historic Site or a National Historic District.

Geyser Activity in the Upper, Midway, Lower, Gibbon and Lone Star Geyser Basins, and Other Thermal Areas, Yellowstone National Park, 1988 - 2006

Jeff Cross

Abstract

The recent history of over 60 geysers in Yellowstone's backcountry and undeveloped frontcountry thermal areas from 1988 through 2006 is presented. My observations are compared with other observations during and immediately prior to the years covered by this study.

The object of this paper is to present my observations of geysers in backcountry and undeveloped frontcountry thermal areas in Yellowstone National Park between 1988 and 2006. Some small, forgotten geysers in the main geyser basins have been included as well. Shoshone Geyser Basin and Heart Lake Geyser Basin are not included because they have been described previously (Cross, 2003; Cross, 2005). Likewise, Phoenix Geyser, in the Gibbon Geyser Basin, has been described previously (Cross, 2003) and is not included here.

Unnamed hot springs and geysers are often identified with numbers assigned by Paperiello and Wolf (1986). Names known to be informal have been placed in quotation marks. Data logger records were obtained through a National Park Service permit, which is gratefully acknowledged.

In the following report, I have occasionally reported findings based on very sparse data. I have included this information because the geysers in question are often completely ignored, and the data I present therefore forms a significant part of the historical record.

Readers are referred to the maps in Bryan (2001) and Paperiello and Wolf (1986) for the location of the thermal features discussed in this report. I have added a few maps of my own for the River Group and Lone Star Geyser Basin.

UPPER GEYSER BASIN

Castle Group

Deleted Teakettle has major and minor eruptions. In 2005 and 2006, major eruptions occurred every 21-72 minutes. Major eruptions lasted up to 4 minutes, reached 3 feet high, and created a heavy overflow stream that cascaded down the steep bank of the Firehole River. Minor eruptions began to occur 15 to 20 minutes following a major eruption. They occurred every 4 to 8 minutes, lasted up to 1 minute and threw water to 1 to 2 feet. Minor eruptions produced very little runoff. No relationship between the cycles of Deleted Teakettle and the water level in South Scalloped Spring was obvious in 2005 or 2006.

Daisy Group

Bank Geyser erupted every 33 to 207 seconds for durations of 5 to 20 seconds in 2006. Though frequent, Bank Geyser was quite irregular and sometimes lapsed into brief periods where it produced only waves and periodic overflows, as reported in Bryan (2001). Full eruptions splashed water up to 4 feet.

Cascade Group

In 2006, "**Slide Geyser**" rupted every 20.2 to 21.0 minutes. The average of 10 intervals recorded by me was 20.5 minutes. Slide is a very regular geyser. Its intervals typically vary by only a few percent from the average value. In 2006, 8 timed durations ranged from 38 to 47 seconds, with an average of 42 seconds. The eruptions throw water to 3 feet outward from the steep bank of the Firehole River.

Slide's activity from 1983 through 2000 is thoroughly analyzed by Stephens (2002). Average intervals increased steadily from 13.9 minutes in September, 1983 (Paperiello and Wolf, 1986) to 18.1 minutes in 2002 (Bryan's data cited by Stephens). Taken together with my data from 2006, this implies an average increase of 17 seconds per year over the 23 seasons from 1983 through 2006. Over the same time period, average durations remained constant. Bryan's four durations recorded in 2002 give the same 50-second

Slide Geyser

Year	Minimum (minutes)	Maximum (minutes)	Average (minutes)	Count	
1983	11.2	15.2	13.9	5	Paperiello and Wolf (1986)
1988	14.5	15.3	14.9	10	Stephens (2002)
1990	15.3	15.8	15.5	6	Stephens (2002)
1992	15.8	16.0	15.9	3	Stephens (2002)
1993	15.4	15.6	15.5	4	Stephens (2002)
1994	18.1	18.5	18.2	8	Stephens (2002)
1995	17.4	17.6	17.5	4	Stephens (2002)
1996	18.4	18.7	18.5	3	Stephens (2002)
1998	17.1	17.7	17.3	8	
2000	18.4	18.6	18.5	4	Stephens (2002)
2001	17.4	17.7	17.6	5	
2002	17.7	18.6	18.1	3	Bryan, in Stephens (2002)
2004	19.3	20.5	20.1	5	
2005	20.0	21.0	20.6	4	Stephens (2005a)
2006	20.2	21.0	20.5	10	

average as that reported by Paperiello and Wolf 19 years earlier, during September, 1983.

Data reported by Paperiello and Wolf for May, 1983, show anomalously short intervals averaging 11.3 minutes and anomalously long durations averaging 81 seconds.

Biscuit Basin

Rusty Geyser erupts every 17 to 135 seconds for durations of 6 to 33 seconds and throws water 6 to 8 feet high. These statistics are summarized from data collected by me in July and September, 2006.

Jewel Geyser erupts every 3.8 to 15 minutes. Average intervals collected during 1989 through 2005 by me, and during 1989 through 1992 by Taylor and Taylor (1990, 1992, 1993), range from 5.7 to 9.0 minutes. Durations were recorded in 1990 by Taylor and Taylor (1992) and in 1996 by me. During those years, eruptions lasted from 3 to 76 seconds with averages of 38 seconds (1990) and 62 seconds (1996). The height of the eruptions is 10 to 20 feet.

Jewel was studied by Taylor and Taylor from 1989 through 1992. The data reported in their 1993 article show average intervals of just over 8 minutes during 1989 through 1991. In 1992, however, the average rose to 11 minutes. They suggest that this sudden increase may have had something to do with the subsequent blowout of research drill hole Y-8, which is located approximately 1150 feet to the east, next to the Biscuit Basin parking lot. It was at this time, too, that Jewel Geyser stopped overflowing. Eruptions now come from a low water level. My data show that

Jewel Geyser in 1985, erupting from a full crater. Photo by Carlton Cross.

by 1994 the intervals had shortened to pre-1992 values. Data collected by Ken Reeves in 2005 showed that Jewel was erupting every 5.7 minutes, on average (Reeves, 2005a). This is substantially shorter than the average intervals recorded by me from 1994 through 2004.

Before introducing the members of the **Silver Globe Complex,** it is necessary to point out that the original Silver Globe Spring is immediately south of Avoca Spring (Paperiello and Wolf, 1986). It is recognizable by the large silvery steam bubbles that rise in the pool when the spring is erupting, and also by the sinter overhang that arches over the spring. The name Silver Globe has been applied to all of the other vents located to the south, with various suffixes such as pool, geyser, drain, pair, cave, slit, etc. Only two of these names, Silver Globe Cave and Silver Globe Slit,

Rusty Geyser, intervals

Year	Minimum (seconds)	Maximum (seconds)	Average (seconds)	Count
July, 2006	79	135	95	10
September, 2006	17	113	65	44

Rusty Geyser, durations

Year	Minimum (seconds)	Maximum (seconds)	Average (seconds)	Count
July, 2006	6	33	17	11
September, 2006	7	31	16	38

Jewel Geyser, Intervals

Year	Minimum (minutes)	Maximum (minutes)	Average (minutes)	Count	
1989	3.8	12.5	8.4	130	Taylor and Taylor (1992)
1990	3.8	14.5	8.2	85	Taylor and Taylor (1992)
1991	6.5	10.9	8	9	Taylor and Taylor (1992)
1992			11		Taylor and Taylor (1993)
1994	7	10	8.3	10	
1996	7.0	8.6	7.8	17	
1996	7.0	11.3	8.8	27	
1998	6.9	11.1	9.0	9	
2004	6	9	7.2	10	
2005			5.7	6	Reeves (2005a)

Jewel Geyser, Durations

Year	Minimum (seconds)	Maximum (seconds)	Average (seconds)	Count	
1990	3	74	38	66	Taylor and Taylor (1992)
1991	16	70	35	10	Taylor and Taylor (1992)
1996	51	76	62	11	

have become entrenched. Since no two sources use the same names for the other vents, I have chosen to use letters to describe the vents to avoid confusion. My lettering scheme follows that of Paperiello and Wolf (1986).

The **Silver Globe Complex** consists of 6 geysers. Five of these are related to each other. Starting at the northeast corner and moving southwest, the vents are identified as follows.

Vent A is also known as Silver Globe Cave. Its eruptions jet out at an angle to 15 feet vertically and 30 feet laterally.

Vents B and C are both found in the same small, pretty blue pool. Vent B erupts only when Vent A (Cave) erupts, and can reach 3 to 6 feet high.

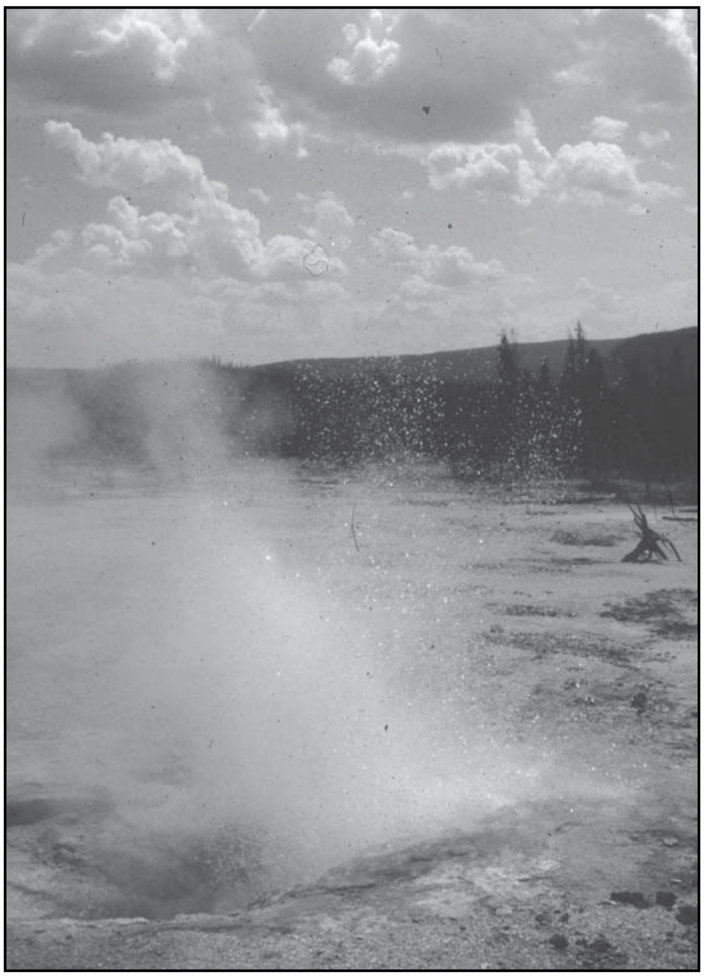
Vent C has been inactive since 1991. During 1990 and 1991, it had large eruptions to 20 feet.

Vent D is a double vent. The eastern vent is the more active of the two. It can erupt as high as 10 feet, surging a massive flood of water over the sinter. The western vent is closely related, but less eruptive.

"**Silver Globe Slit Geyser**" (vent E) lies just beyond vent D. It erupts from a narrow crack next to a shallow collecting basin. It is completely unrelated to the other geysers and tends to erupt at consistent intervals.

The Silver Globes were observed closely in 1990, 1994, 1996 and 2002. In 1990, vent C was highly active. Spectacular major eruptions reached 20 feet high. They occurred every 12 to 31 minutes with an average interval of 19 minutes, measured over 8 intervals. Each major eruption of vent C was followed

"Silver Globe Cave" (Vent A), erupting in 1990. Photo by Carlton Cross.



"Silver Globe Cave" (Vent C), erupting in 1990. Photo by Carlton Cross.

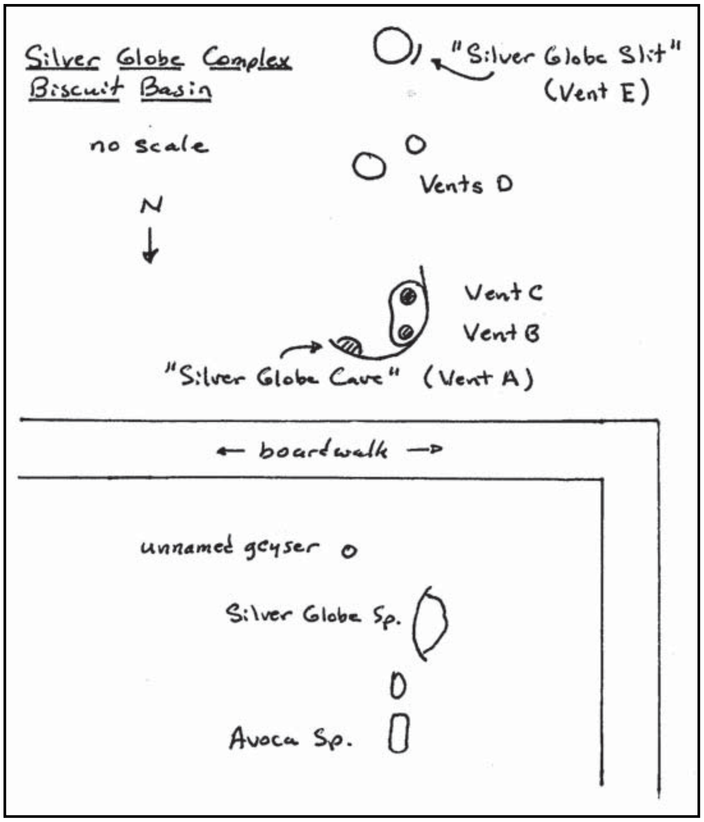
closely by a major eruption of vents A and B, excepting once when vents A and B erupted first, followed by vent C.

In 1994, vents A, B and D were highly active. Major eruptions of vent D were followed closely by vents A and B. Intervals ranged from 29 to 36 minutes. Similar activity in 1996 occurred every 13 to 60 minutes. The eruptions were brief, lasting for 18 to 35 seconds. In 2002, vents A and B were erupting every 12 to 28 minutes. Vent D followed some but not all of the eruptions of vents A and B.

Every time I have watched the Silver Globes, three trends have been obvious. First, an eruption of vents C or D will often cause vents A and B to erupt, although sometimes the order is reversed and vents A and B erupt first. Second, vents A and B always erupt together. Third, the interval between major eruptions of any of the vents is often irregular, but the intervals tend to be around 15 to 30 minutes. Frequent minor activity from all of the vents punctuates the intervals between major eruptions. Similar activity that occurred during the 1980s is reported in Paperiello and Wolf (1986) and Scheel and Schrayer (1989).

Activity in the Silver Globes seems to have decreased in the last few years. The washed margins in front of vents A and B and the large washed margin that was present around vent D are all badly weathered. When these vents are highly active, large puddles are usually found around the craters. Recently, these puddles have been absent.

"**Silver Globe Slit Geyser**" is a very regular geyser. Data collected in 1990, 1994 and 1996 gave 13



closed intervals ranging from 22 to 37 minutes with an average of 30 minutes. The durations ranged from 71 to 106 seconds and gave an average of 87 seconds for 17 timed durations. The eruptions jetted water to 12 feet. More recently, Silver Globe Slit has been less active. Intervals reported by Graham Meech in 2001 and 2002 were 48 to 59 minutes (Meech, 2001, 2002).

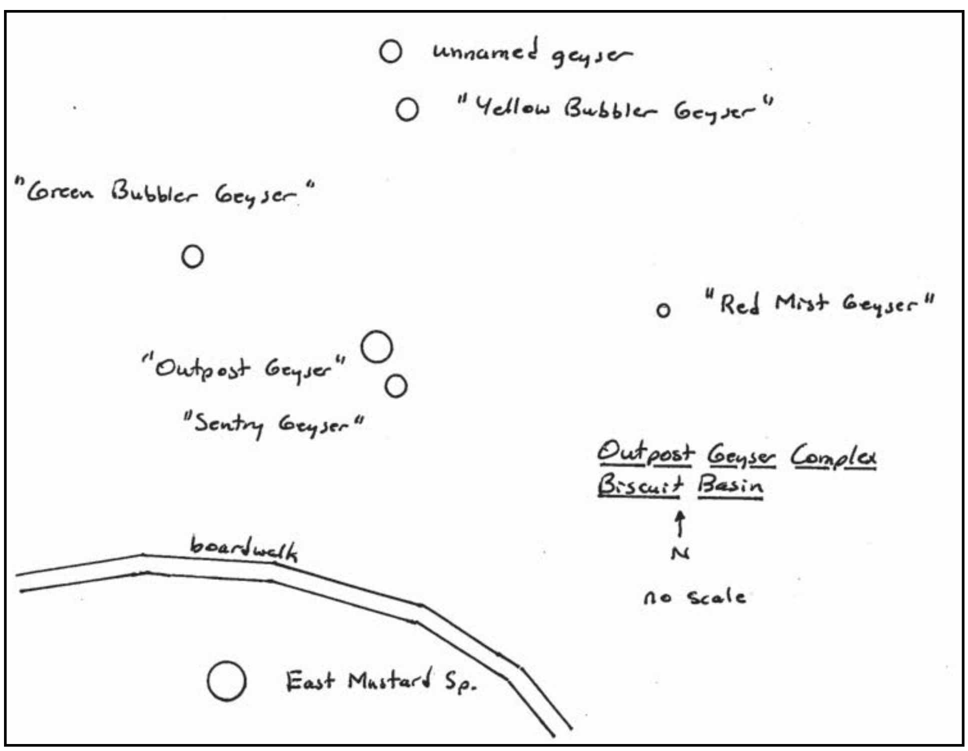
An **unnamed geyser** on the opposite (north) side of the boardwalk from the Silver Globe Complex erupts at highly irregular intervals. In 1996, the range of intervals was 4 to 7 minutes with durations of 90 to 172 seconds. In 2002 the range of intervals was 3 to 17 minutes and the range of durations was 2.5 to 16 minutes. The eruptions were 2 feet high.

"Outpost Geyser" and **"Sentry Geyser"** are described by Gryc (2002) and Bower (2002). All of the names for geysers in this small complex were applied by Gryc. In 2001 and 2002, Gryc and Bower describe Outpost as erupting every 4 to 12 minutes for durations of 1 to 6 minutes. Eruptions of Sentry, occurring at intervals of 6 to 28 minutes and lasting 31 to 259 seconds, occurred at about the time of some, but not all, of Outpost's eruptions. Their data were collected in 2001 and 2002. My data from 2002, 2004 and 2006 are summarized below.

"Outpost Geyser" erupts every 4.5 to 11.8 minutes for durations of 1.1 to 5.5 minutes. The eruptions throw water 5 to 10 feet high. Although the intervals and durations are highly variable, a strong relationship between them exists whereby the length of each eruption strongly influences the length of the next interval.

"**Sentry Geyser**" erupts every 7 to 37 minutes for durations of 19 to 285 seconds and throws water to 3 feet. It is strongly related to Outpost Geyser, immediately to the north. Of the 15 eruptions of Sentry recorded in 2002, 14 were in concert with Outpost. Of the 8 eruptions recorded in 2004 and 2006, 7 were in concert with Outpost. If Sentry Geyser was to erupt, it usually started close, but slightly prior, to the start of Outpost Geyser.

The interval and duration data for 2002 were strongly bimodal. The average short mode interval was 9.6 minutes, while the average long mode interval was 21.7 minutes. Likewise, the durations were bimodal. The average short mode duration was 38 seconds, while the average long mode duration was 201 seconds. This bimodal behavior was less prominent in 2006. The three data points obtained in 2004 are insufficient for analysis.



Outpost Geyser, intervals

Year	Minimum (minutes)	Maximum (minutes)	Average (minutes)	Count	
2001	4.4	12.4	9	43	Gryc (2002)
2002	4	10	7.3	14	Bower (2002)
2002	4.5	10.7	8	25	
2004	5.8	11.8	9.1	11	
2006	4.8	9.1	7.3	7	

Outpost Geyser, durations

Year	Minimum (minutes)	Maximum (minutes)	Average (minutes)	Count	
2001	1.8	6.0	3.7	46	Gryc (2002)
2002	1	5	2.8	16	Bower (2002)
2002	1.1	5.5	3.0	26	
2004	1.2	4.8	3.1	9	
2006	1.4	3.7	2.5	8	

Sentry Geyser, intervals

Year		Minimum (minutes)	Maximum (minutes)	Average (minutes)	Count	
2001		7.3	28.2	18.6	20	Gryc (2002)
2002		6	27	18	5	Bower (2002)
2002	(short)	7.3	12.9	9.6	8	
	(long)	19.2	26.7	21.7	6	
2004		26.6	36.7	30.1	3	
2006		8.3	11.8	9.9	3	

Sentry Geyser, durations

Year		Minimum (seconds)	Maximum (seconds)	Average (seconds)	Count	
2001		31	259	137	23	Gryc (2002)
2002		60	240	2.9	7	Bower (2002)
2002	(short)	19	59	38	5	
	(long)	121	285	201	6	
2004		110	167	152	4	
2006		38	248	96	4	

The bimodal behavior of Sentry occurs because Sentry must erupt in concert with Outpost, but Outpost often erupts without Sentry. In this way, Outpost acts like a pacemaker for Sentry, so that its intervals can only be integer multiples of N, where N is the length of Outpost's interval.

Although Gryc (2002) describes "**Green Bubbler Geyser**" as erupting at intervals of 5 to 9 minutes for durations of 4 to 7 minutes, I have never found a pattern to the eruptions. The maximum height is 4 feet.

"**Yellow Bubbler Geyser**" in 2002 had two intervals of 68 and 41 minutes. The three timed durations were all between 9 and 10 minutes and the maximum height was 1 foot.

Beyond Yellow Bubbler is a second **unnamed geyser** that in 2002 gave two intervals of 127 and 53 minutes, with durations of 4 and 5 minutes and a height of 1 foot. This geyser did not seem to be related to Yellow Bubbler.

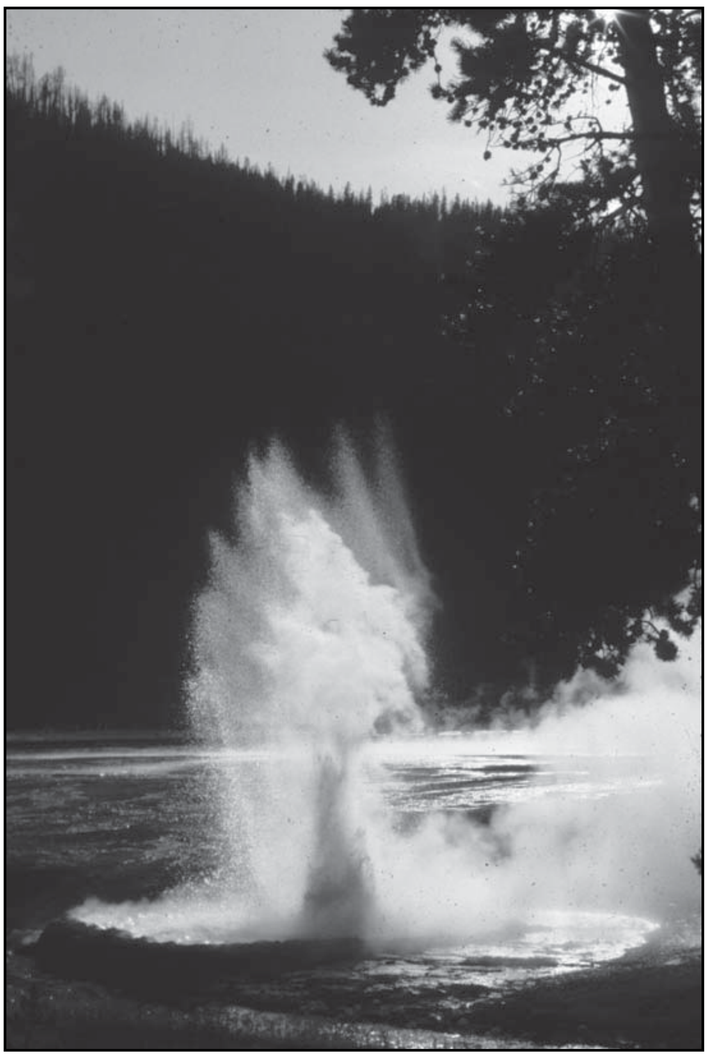
"**Red Mist Geyser**" cycles very rapidly. The intervals in 2002 were 19 to 57 seconds, durations were

East Mustard, Intervals

Year	Minimum (minutes)	Maximum (minutes)	Average (minutes)	Count	
1996	5.8	6.9	6.4	26	
2001	6.1	7.2	6.9	17	Gryc (2001)
2002	5.6	6.6	6.0	27	
2004	7.5	8.2	7.9	10	
2006	6.6	7.1	6.8	7	

East Mustard, Durations

Year	Minimum (seconds)	Maximum (seconds)	Average (seconds)	Count	
1996	150	222	180	23	
2001	156	199	175	18	Gryc (2001)
2002	137	180	156	28	
2004	165	199	180	9	
2006	113	173	157	8	



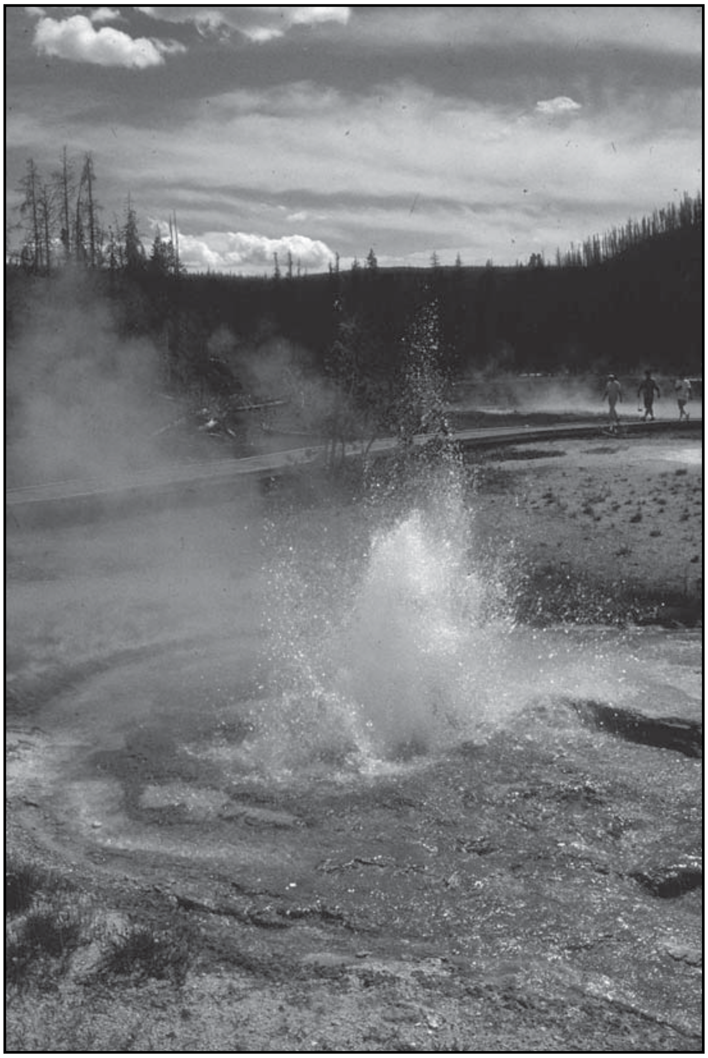
Cliff Geyser, erupting in 1991.

7 to 14 seconds and the eruptions sprayed thin jets and mist to 2 to 5 feet. It was active in 2004 and 2006 also.

East Mustard Spring erupts every 5.6 to 8.2 minutes, with average intervals ranging from 6.0 to 7.9 minutes. Eruptions last from 113 to 222 seconds, with average durations ranging from 156 to 180 seconds. The eruptions throw water to 6 feet. This activity has remained constant from 1996 through 2006. Careful observation of West Mustard Spring shows that its water level lowers by about an inch while East Mustard is erupting.

Black Sand Basin

Cliff Geyser has a major eruption every 24 to 74 minutes. Twice, exceptionally long intervals of 128 minutes have been noted (Stephens, 2007b). For 19 intervals obtained between 1995 and 2006 by me, the range is 28 to 74 minutes, and the average is 44 minutes. For 23 major eruption durations, the range is 7 to 19 minutes with an average of 12 minutes. During a major eruption the pool fills to overflowing and remains at overflow until the eruption ends. Then, following a brief period of quiet, minor eruptions begin to occur. These occur frequently until the next major begins. Major eruptions throw water 20 to 40 feet into the air. The explosion of steam bubbles through the pool is sometimes loud enough to be heard from Black Sand Pool, which is one-third of a mile distant.



"Ragged Spring's Annex," erupting in 1995.

Reports by Bower (1997) and Stephens (2005b, 2006, 2007a, 2007b) show similar data. Bower reported intervals of 24 to 34 minutes and durations of 6 to 13 minutes in 1997. Stephens reported intervals of 47 to 72 minutes in 2005, and intervals of 30 to 128 minutes in 2007. The 128-minute interval was noted as being unusually long. Average intervals during that time period ranged from 49 to 58 minutes. Durations during the same period ranged from 3 to 15 minutes, with averages ranging from 8.3 to 10.3 minutes. Stephens (2007a) also found reports of Cliff erupting at similar intervals and durations in 1986. Bryan (2001) notes that the intervals were hours long during the 1960s, but became gradually shorter during the 1970s.

Ragged Spring is one of the most erratic geysers in Yellowstone. Intervals recorded between 1995 and 2006 range from 3 to 71 minutes without any clear pattern. A relationship with nearby Cliff Geyser is unlikely. The eruptions are brief, typically lasting around 30 seconds. Thin spikes from the main crater reach 10 to 30 feet high, while a second, round vent (called "Ragged Spring's Annex") located towards Iron Spring Creek erupts to 10 feet with a heavy column which, at its best, is reminiscent of Aurum Geyser.

Pine Springs

An **unnamed subterranean geyser** is located at the southern end of the Pine Springs Group. The activity is cyclic, with violent eruptions that reach up to 6 feet above pool level occurring in series. In 2004, four complete series of 2 to 5 eruptions were observed. Two intervals between series were 20 and 56 minutes. Frequent minor eruptions occurred in between the series. Paperiello and Wolf (1986) report similar observations in 1981. The only significant difference is that in 2004, individual major eruptions within each series came only a few minutes apart, but in 1981 they were separated by 9 to 18 minutes.

Pipeline Meadows

"**Dilapidated Geyser**" was quite active in 2006. Alan Glennon and I were fortunate to see an eruption on 15 September. The interval from the previous eruption was 28.5 hours. No eruption had occurred for at least a week prior to that eruption. Scott Bryan reported a steam cloud roughly 15 days previous.

The observed eruption lasted for 5 minutes, reached 15 feet high and poured out a flood of water, easily filling the runoff channel. Despite this, the column was not steady and seemed weaker than other observed eruptions, one of which erupted a steady water column to 40 feet and had a total duration of 20 minutes (see below). It is possible that the eruption seen on 15 September was a follow-up to the eruption seen the day before, since Dilapidated is known to have series of eruptions of diminishing power.

Prior to the eruption, the pressure pool had been overflowing every 7 to 9 minutes. Some of these overflows were heavy and flooded the pool's outlet. The water in Dilapidated rose and fell in parallel with that of the pool, and spilled out of the vent just before the eruption started. During the eruption the pool boiled and overflowed heavily for the first minute and then drained. It is important to note that frequent overflows from the pressure pool do not indicate that Dilapidated will erupt any time soon, since identical overflows are known to occur for weeks on end in between eruptions of Dilapidated.

In the 3 hours following the eruption, the water level rose to within 18 inches of overflow. Frequent periods of violent boiling occurred during the filling. Although follow-up eruptions of Dilapidated have been known to occur as few as 2 hours after the major (Bryan, 2001), it was clear that none occurred in this case, since markers were found unwashed two days later.

Following its eruption on September 15, Dilapidated did not erupt again until some time after 08 October, an interval of at least 23 days. It washed markers twice in October. All together, the data suggest that Dilapidated was having a few eruptions each month during the late summer and fall of 2006.

Dilapidated reactivated in 2002, after being dormant since 1991 (Goldberg, 2002). An interval between two eruptions that occurred in series on May, 24, 2002, was approximately 3.5 hours. Dilapidated was also active in 2003 (Goldberg, 2003), and again in 2005, when an eruption lasting 20 minutes and reaching 40 feet high was observed by Bronco Grigg (Goldberg, 2005a). Notably, this eruption was much larger and longer than the one I witnessed in 2006 (see above). It is also larger than those noted in Bryan (2001), who cites a maximum height of 30 feet and durations of 2 to 5 minutes. Throughout the summer of 2005, Dilapidated continued to erupt infrequently. One interval was as short as a week, although most were longer. Eruptions seemed to have stopped occurring by October (Goldberg, 2005b).

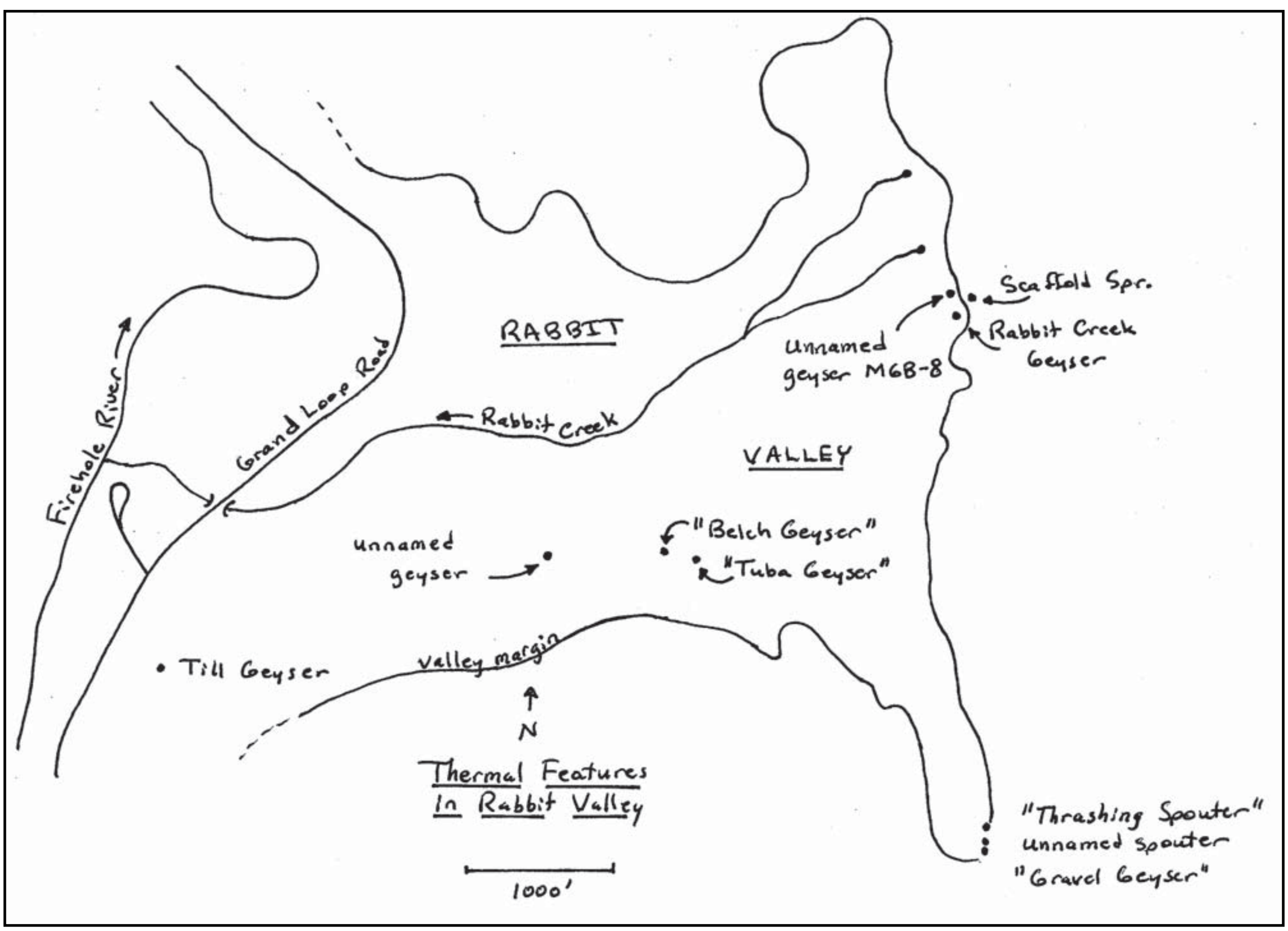
Dilapidated resumed its activity in early 2006. In March of that year, an eruption lasting 4 minutes and reaching 20 feet high was seen by Mike Keller (Goldberg, 2006a). Another eruption was witnessed during April (Goldberg, 2006b), and eruptions continued throughout the early summer. Typical intervals were shorter than a week. The shortest interval was 3 days (Goldberg, 2006c). By August, it had fallen dormant, but was seen again in September (see above), and was active through October.

Two **tiny vents** in the runoff channel from Dilapidated's pressure pool were active as geysers in 2005 and 2006. The eruptions occurred every minute or so and were a few inches high.

MIDWAY GEYSER BASIN

Rabbit Valley

Geysers in Rabbit Valley are found in three separate locations. Rabbit Creek Geyser is located at the



east side of the Rabbit Valley, directly at the base of the slope. Thrashing Spouter and Gravel Geyser are found in a narrow, steep-sided valley at the southeast corner of Rabbit Valley. Tuba, Piccolo and Belch Geysers are found in the upper portion of the south margin of Rabbit Valley, immediately west of a small hill that protrudes into the valley.

Rabbit Creek Geyser has been a consistent performer over the last 23 years. The intervals range from 18 to 25 minutes, with the average of 25 intervals obtained between 1994-1996 and 2001-2006 being 21 minutes. This excludes two outliers of 15 and 11 minutes that were recorded in 1994. The durations range from 94 to 240 seconds, with the average of 32 durations being 176 seconds. Intervals obtained in 1983 and 1984 by Paperiello and Wolf (1986) show a range of 18 to 22 minutes and an average of 20 minutes over 8 intervals. Durations they timed ranged from 142 to 218 seconds with an average of 180 seconds.

Eruptions of Rabbit Creek Geyser are violent. Seething masses of superheated water are tossed a few feet above the pool's surface, while large steam bubbles, as big as 6 feet in diameter, burst above the foam, rising as many as 6 feet above pool level. The jagged crater enhances the violent appearance of the eruptions. Ground vibrations caused by subterranean steam concussions during the eruptions are often felt.

Rabbit Creek Geyser was dormant from 1997 through 2000. During these years, it boiled every few minutes. These small boiling episodes also occur between major eruptions when Rabbit Creek Geyser is active, sometimes leading observers who see only the minor activity to report, errantly, that the geyser is dormant.

An **unnamed geyser** 100 feet north of Rabbit Creek Geyser has been consistently active from 1990 through 2006. The frequent eruptions come from either one or both of the vents in the pool and splash water about 3 feet high. In 1994, we walked up on an exceptionally large eruption that reached around 12 feet high. Wash from eruptions of comparable size has been noted several times, but we have never seen another large eruption.

Directly above Rabbit Creek Geyser is a deep, blue pool. It is known as "**Scaffold Spring**" because of all the fallen lodgepole pines contained within the crater. Scaffold Spring's crater opens halfway up the steep slope above Rabbit Creek Geyser. It is the only thermal vent in the area to occupy such a location. All the other thermal vents along the east side of Rabbit Valley open either on the valley floor or on top of the bench high above Rabbit Creek Geyser. Scaffold's runoff stream passes directly between Rabbit Creek Geyser and the unnamed geyser just north of it.

"**Thrashing Spouter**" is a large perpetual spouter located within a narrow canyon at the southeast corner of Rabbit Valley. The large bursts reach 5 to 10 feet high. Two other spouters are nearby. Just downslope from Thrashing Spouter is a large pit containing numerous fumaroles and spouting vents. On the other side of Thrashing Spouter is a second perpetual spouter. It erupts from beneath a boulder, spraying water outward for a distance of 6 feet. Gravel Geyser breaks out immediately to the south of this spouter.

Thrashing Spouter. Photograph by Carlton Cross.

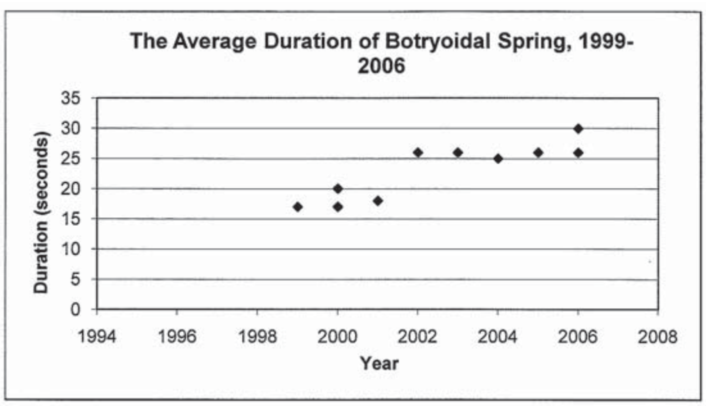
"**Gravel Geyser**" was active only during the summer of 1999. It erupted to 2 feet every 80 to 105 seconds for durations of 50 to 70 seconds. The eruptions rose through a gravel-filled basin, hence the name. Gravel has been dormant every year since then, and wildflowers now grow in its basin.

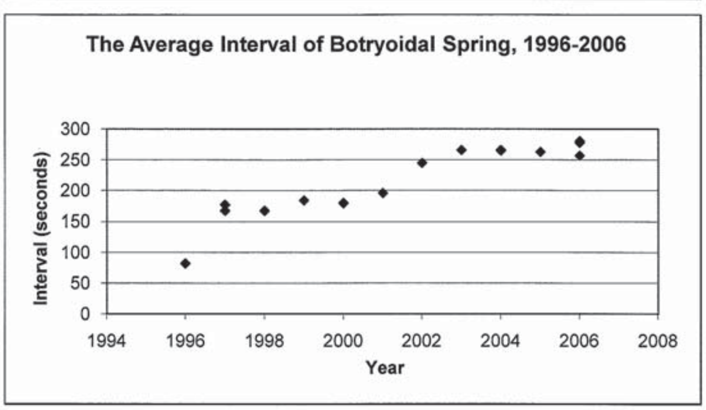
"**Tuba Geyser**" was active in 1997 (Dunn, 1997) and again in 1999. Eruption intervals and durations were both hours long. Rocco Paperiello reported that over 5 closed intervals obtained in 1999, Tuba was erupting every 22 to 27+ hours (Paperiello, 1999). Eruptions threw water to 10 feet vertically and 20 feet laterally. Within Tuba's basin is a second vent that sometimes erupts, dubbed **Piccolo Geyser.**

For the last several years, Tuba has been completely dormant. In 2004, a large rainstorm washed sand and silt into the vent, making the site difficult to find. In 2007, the crater was open again. It was unclear whether Tuba was having eruptions at that time.

"**Belch Geyser**" was active only in 1999. The vent was located in the middle of the runoff stream that drains the southern part of Rabbit Valley. Presently it is covered with mud and is impossible to locate. The minute eruptions recorded in 1999 came every 57 to 75 minutes. Lasting less than 1 minute, they seldom produced any true bursting. However, at the end of the eruption, the entire stream would be sucked down the vent, accompanied by a loud and protracted slurping sound. Following this, the geyser would noisily burp out the air it had sucked in with the water, hence the name. The belching sounds lasted for 90 to 105 seconds after the drain ended.

An isolated, **unnamed vent** between Tuba Geyser and Till Geyser was active as a geyser in 2002. It was also active in 1999 (Murray, 2008) and in 2001, when Barger (2001) obtained a closed interval of 4 hours, 37 minutes, a duration of 16 minutes, and a height of several feet. In 2002, wash extended up to 12 feet from the crater's south edge, implying that large eruptions occurred that year.





LOWER GEYSER BASIN

White Creek

During early August, 1996, the White Creek Group experienced a remarkable surge in thermal activity. The surge was probably triggered by a series of small earthquakes that occurred directly beneath the group that year (SPUT, 1996). The energy surge affected Botryoidal Spring, A-2 Geyser and several vents next to A-2 that began erupting as geysers or increased their activity. It also created a new geyser that erupted from the bed of White Creek at or near the site of Verdant Spring. This geyser threw muddy bursts of water to 10 feet, accompanied by loud popping sounds that were clearly audible from the parking lot, which is 500 feet away. Todd Singleton reported the first observed eruptions of this feature. Most of the new activity died out within a year. The most significant permanent changes in the White Creek Group are the persistently large eruptions of Botryoidal Spring, and the dormancy of A-2 Geyser.

"**A-0 Geyser**" erupts every 20 to 35 minutes. Of 20 intervals obtained by me at various times from 1989 through 2006, the average is 26 minutes and the range is 20 to 35 minutes. Durations ranged from 29 to 99 seconds, the average of 22 durations obtained during 1989 through 2006 being 44 seconds. The pretty eruptions reach 10 feet.

Notably, two other studies discovered similar patterns. Intervals obtained by Paperiello and Wolf (1986) in 1984 had a range of 25 to 30 minutes and averaged 29 minutes over 12 intervals. Of 8 durations obtained, the average was 37 seconds.

A substantial study was undertaken by Ken Reeves during 2003, 2004 and 2006 (Reeves, 2005, 2006). He reports 15 intervals ranging from 24 to 31 minutes, with an average of 27 minutes and durations of 27 to 44 seconds with an average of 39 seconds. These studies all show very uniform activity for A-0 Geyser over the 23 seasons from 1984 through 2006.

Paperiello and Wolf #6 is a depressed basin containing several vents that can erupt as geysers. In 2000 and 2001, a pair of vents here erupted every 9 to 11 minutes, briefly spraying water to 3 feet.

"**A-2 Geyser**" has been dormant since 1996. In 1984, Paperiello and Wolf (1986) reported intervals of 71 to 74 minutes and durations of 7 minutes. Its eruptions drained numerous small vents around the crater, including that of the long-inactive A-1 Geyser, showing that all of these vents were connected

Botryoidal Spring Intervals

Year	Minimum (seconds)	Maximum (seconds)	Average (seconds)	Count	
1996	73	98	82	18	
1997	156	177	167	5	
1997			177	15	Gryc (1997)
1998	153	185	167	21	
1999	163	202	184	15	
2000	168	195	179	14	
2000	171	189	180	9	
2001	171	210	196	10	
2002	227	259	245	6	
2003	228	326	266	32	Reeves (2005a)
2004	243	291	265	8	
2004	232	310	266	35	Reeves (2005a)
2005	258	275	263	8	Reeves (2005a)
2006	232	279	257	7	
2006	244	326	281	32	Reeves (2006)
2006	230	320	278	46	Bower (2006)

Botryoidal Spring Durations

Year	Minimum (seconds)	Maximum (seconds)	Average (seconds)	Count	
1996					
1997					
1998					
1999	11	21	17	16	
2000	16	23	20	14	
2000	12	21	17	9	
2001	12	23	18	11	
2002	25	28	26	7	
2003	15	35	26	33	Reeves (2005a)
2004	23	27	25	8	
2005	21	31	26	27	Reeves (2005a)
2006	23	28	26	9	Reeves (2005a)
2006	21	34	30	33	Reeves (2006)

with A-2. The vents would then refill during A-2's quiet interval. It is clear that the energy that used to power A-2's eruptions is now issue from nearby Botryoidal Spring, although during 1996 both features were briefly active at the same time. We recorded an interval of 65 minutes and a duration of 8.5 minutes for A-2 Geyser in 1996, while Botryoidal was active.

Botryoidal Spring erupts every 153 to 326 seconds for durations of 11 to 35 seconds. Prior to 1996, Botryoidal was nearly a perpetual spouter, reaching 5 feet high. The earthquake swarm of 1996 transformed it into the most impressive geyser in the White Creek Group. Eruptions begin suddenly with an explosive burst that can reach 15 feet high. This initial burst is followed by smaller bursts of steadily decreasing size. Both intervals and durations have increased since 1996. The largest increases occurred between 1996 and 1997, and between 2001 and 2002.

Ken Reeves made a study of Botryoidal Spring during 2003 through 2006 (Reeves, 2005b, 2006). Averages and ranges for his data sets support the conclusion that Botryoidal's intervals and durations were stable from 2002 through 2005. However, his data show that the average interval increased by 18 seconds over the average interval that he obtained in 2005. Data reported by Bower (2006) are similar.

Verdant Spring does not seem to exist any more. Marler (1973) describes its location as being next to a sharp bend in White Creek upstream from Botryoidal Spring, and describes its size as being 21.5 by 45.5 feet. No spring of these dimensions presently exists at the site. It is possible that the old Verdant

Spindle Geyser Intervals

Year	Minimum (seconds)	Maximum (seconds)	Average (seconds)	Count
1990	168	185	177	10
1995	170	185	179	7
2002	178	195	186	10
2003	156	215	191	10
2004	185	193	189	6
2006	178	198	187	9

Spindle Geyser Durations

Year	Minimum (seconds)	Maximum (seconds)	Average (seconds)	Count
1990	69	84	75	9
1995	56	70	61	8
2002				
2003	46	91	57	9
2004	38	55	48	7
2006	41	65	55	10

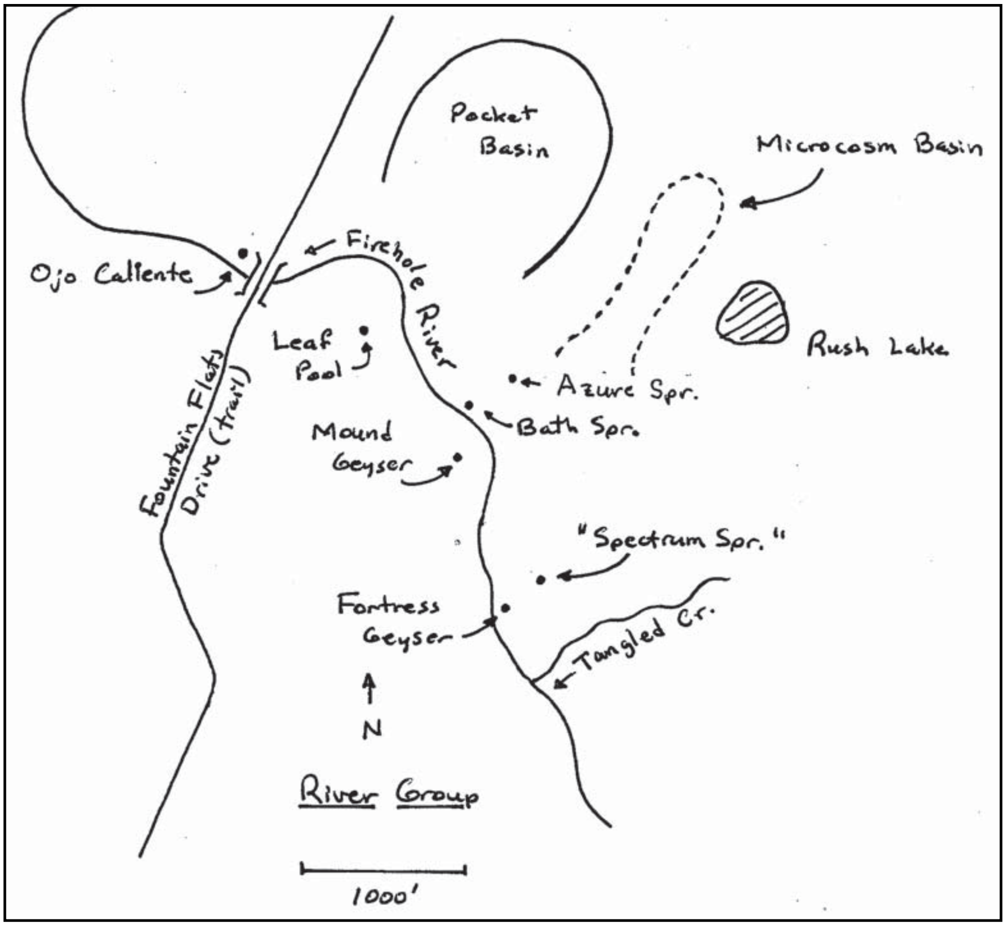
"Growl Geyser," erupting in 1999.

Spring is entirely buried by sand and gravel washed in by White Creek. It is also very likely that the energy that used to come out through Verdant Spring was responsible for the more recent feature known as Black Cat Geyser.

"**Black Cat Geyser**" was active only briefly during the 1996 surge in thermal energy that affected A-2 Geyser and Botryoidal Spring. Four intervals obtained by us on 07 August 1996 were 24, 20, 8 and 17 minutes. Since the vent of this geyser was within White Creek, the cold water collapsed nearly every steam bubble that the geyser produced during its eruptions. The resulting concussions created loud, rapid popping sounds, resembling the noise made by an exploding pack of firecrackers, hence the name. The eruptions burst muddy water to 10 feet.

"**Tuft Geyser**" erupts every 31 to 38 minutes for 7 to 12 minutes. The eruptions are 3 to 5 feet high. The average of 8 intervals gathered between 1991 and 2002 is 34 minutes, and the average of 12 durations gathered during the same time is 9 minutes. This data is remarkably similar to that reported by Paperiello and Wolf (1986), who in 1983 recorded 8 intervals of 28 to 37 minutes with an average of 34 minutes. The 10 durations they recorded ranged from 11 to 17 minutes with an average of 13 minutes. Intervals of 20 minutes were reported by Todd Singleton in 1996 during the increase in thermal activity that affected A-2 Geyser and Botryoidal Spring (Singleton, 1996).

Spindle Geyser is exceptionally consistent. Intervals obtained between 1990 and 2006 have ranged from 156 to 215 seconds, with yearly averages of 177



minutes. The data obtained in 2000, 2004 and 2006 are consistent. Eruptions throw water 3 to 6 feet high. See Gryc (2008) for a more detailed description of this feature.

A short distance east from Underhill Springs Geyser is an **unnamed steam vent**. In September, 2006, it was periodic, venting steam every 15 to 19 minutes for durations of 8 to 13 minutes. Water could be heard splashing deep underground during steaming periods.

Quagmire Group

"**Growl Geyser**" (Paperiello and Wolf #7, Bryan (2001) #105 QAG-1) is the only dependable geyser in the Quagmire Group. It erupts from a low cone at the south margin of the thermal area. Six timed intervals obtained in 1998, 1999 and 2004 ranged from 55 to 63 minutes, with durations of 9 to 13 minutes. The eruptions threw water to 2 feet. It is interesting to note that the activity is the same as that reported by Paperiello and Wolf (1986). While the crater drains following an eruption, the geyser suddenly emits a loud growling sound, hence the suggested name, Growl Geyser.

to 191 seconds. Durations have ranged from 38 to 91 seconds, with averages of 48 to 75 seconds. Durations were recorded from the appearance of flashing steam bubbles in the crater. Most eruptions fail to burst water into the air, but occasionally a splash may rise 1 to 3 feet above the water.

Tangled Creek

An **unnamed geyser** near Tangled Creek west of White Dome Geyser erupted every 2 to 5 minutes in 2004 and 2006. Eruptions were brief, lasting around 10 seconds, and reached heights of 10 to 15 feet.

Firehole Lake

Artesia Spring was active as a geyser in September, 2002. Its brief eruptions came in series and reached 6 to 10 feet high. Durations were 14 to 20 seconds. Series recurred every 5 to 10 minutes. Within each series, eruptions were spaced at intervals of 55 to 67 seconds.

Underhill Springs

"**Underhill Springs Geyser**" erupts every 7 to 16 minutes. Most intervals are between 12 and 16

River Group (west bank of the Firehole River)

Leaf Pool is an intermittent spring. Intermittent overflow was noted in 1995 and again in 2004. This is notable because Marler (1973) states very clearly that Leaf Pool does not overflow at all.

Mound Geyser's intervals are bimodal. Of 42 intervals obtained by me between 1995 and 2006, 14 (33%) are short-mode, with a range from 13 to 19 minutes and an average of 16 minutes. The remaining 24 intervals (67%) are long-mode, with a range from 21 to 29 minutes and an average of 25 minutes. All recorded durations are 3 to 6 minutes. Similar data were reported by Graham Meech (2001) and Todd Singleton (2001). The eruption height is variable. Most eruptions lift water as a seething mass to at least 3 feet, although heights of 6 feet are frequently

"Dark Pool," photographed during a rare period of frequent activity in 2006.

attained. Puddles of water surrounding the vent attest to occasional eruptions that are probably 10 to 15 feet high.

An **unnamed geyser** (Paperiello and Wolf #35b) lies immediately north of Mound Geyser. It cycles every 3 to 5 minutes, forming a heavy discharge stream that courses down to the Firehole River via a deeply eroded runoff channel. Occasionally, the overflow is punctuated by small, bursting eruptions. Although the vent is close to Mound Geyser, I have not found any direct correlation between the activity of this geyser and the cycles of Mound.

Of interest is the geyser's heavily eroded runoff channel. Clearly, the current discharge is inadequate to carve such a large channel into the river bank. Marler (1973) conjectured on its origin, citing Mound as the probable source of the huge floods of water required to erode such a large, deep channel. Close examination, however, suggests that it was large eruptions from this unnamed geyser that eroded the channel.

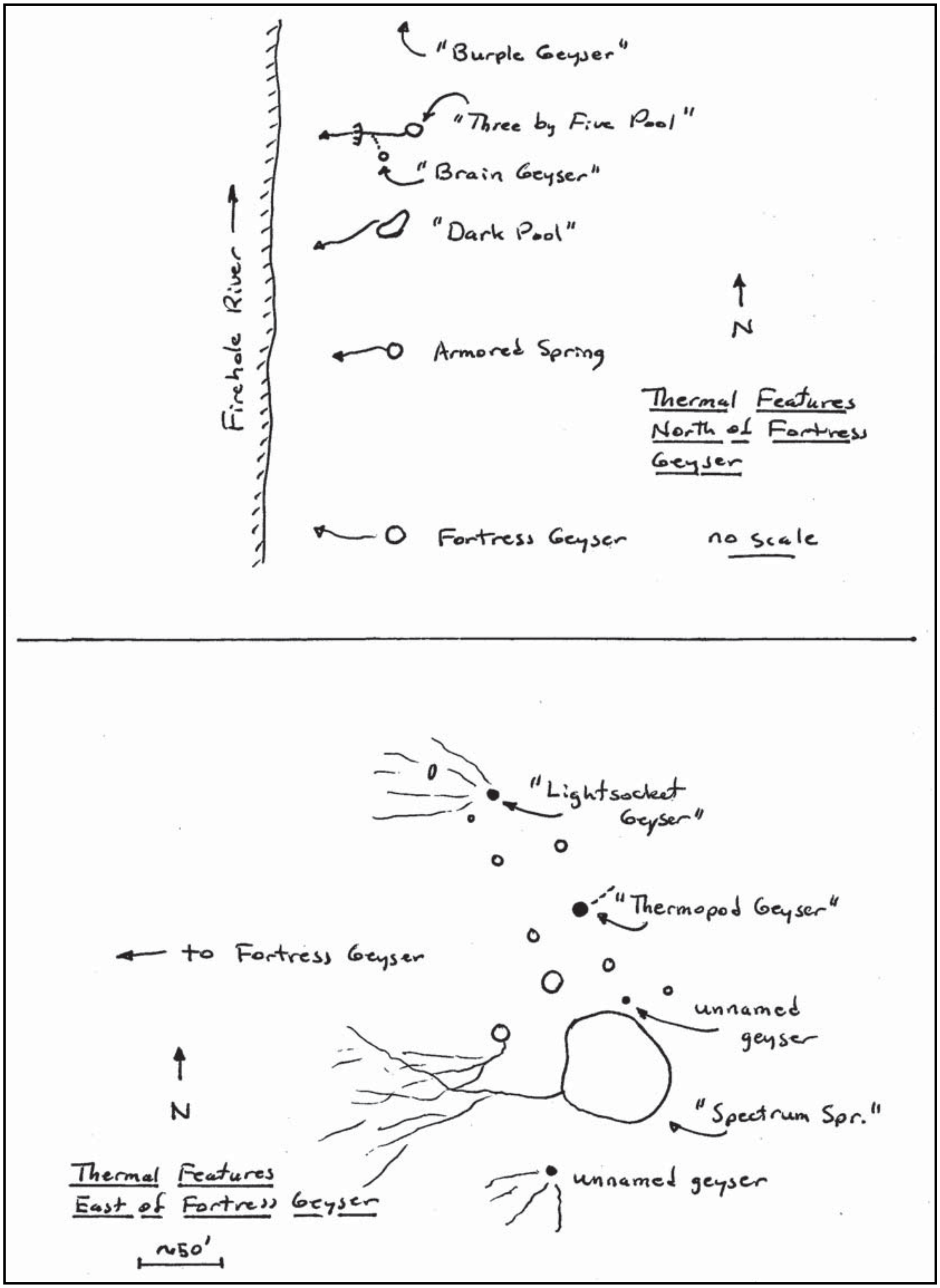
One piece of evidence supporting this idea is that the channel heads directly at the unnamed geyser. The channel does not continue into Mound's basin. Furthermore, at the head of the channel the eroded area becomes quite wide, as if washed by a heavy, fan-shaped jet emanating from the unnamed geyser. Examination of the geyser's vent suggests that if it were to erupt powerfully, the stream would be split into a large fan with the dimensions necessary to account for the erosion patterns.

A small **unnamed geyser** (Paperiello and Wolf #50) south of Mound Geyser was active in 2002. It erupted every 21 to 338 seconds for durations of 10 to 124 seconds to 1 foot. The data show that this geyser was extremely irregular. Its cycles were not related to those of Mound.

River Group (east bank of the Firehole River)

The following geysers break out on the east bank of the Firehole River. Fortress Geyser is the most prominent feature in the area. It is also the southernmost of the significant features. Moving north takes one past Armored Spring, an unnamed geyser (sometimes called Dark Pool despite the fact that the pool is not dark at all), Brain Geyser, Three by Five Pool, and Burple Geyser. They are described below in order.

"**Dark Pool**" erupts from a long, blue pool south of Brain Geyser and north of Armored Spring. Its activity is extremely variable. In 2006, we saw it erupt 6 times at intervals of 19 to 21 minutes to heights of 5 to 8 feet for durations of 31 to 32 seconds. However, later that year it failed to erupt during a wait of over an hour. Likewise, in 2004 I saw this pool erupt, but failed to see any activity from it at all during a wait



of over an hour the next day. Puddles around the crater in 2002 indicated that it was active that year, although I saw no eruptions. In 1997, one interval was ~60 minutes.

An **unnamed geyser** immediately to the south of Spectrum Spring erupts to 3 feet every 9.1 to 18.7 minutes for durations of 2.1 to 7.2 minutes. The average interval has consistently ranged from 10 to 12 minutes, while the average duration has ranged from 2.6 to 4.6 minutes. The geyser was not active prior to 1997. From 1997 through 2006, no dormant period has been recorded by me. I did not visit the area in 2003 or 2005. This geyser would seem to be a relatively dependable feature.

"**Brain Geyser**," when active, erupts every 11 to 21 minutes for durations of 30 to 62 seconds. The height is often merely a boil, although occasional splashes may reach a few inches high. Brain's activity from year to year is inconstant. It was active in 2004 and 1999-2001. It was confirmed dormant in 2002 and 2006. Paperiello and Wolf (1986) report intervals of 7.9 to 11.7 minutes with averages of 9 to 10

Unnamed geyser south of Spectrum Spring, Intervals

Year		Minimum (minutes)	Maximum (minutes)	Average (minutes)	Count
1997		13.8	18.7	15.3	4
1998	active				
1999	active				
2000		9.8	10.8	10.4	4
2001		9.3	14.3	11.5	15
2002	active				
2004		9.1	10	9.5	5
2006				16	3

Unnamed geyser south of Spectrum Spring, Durations

Year	Minimum (minutes)	Maximum (minutes)	Average (minutes)	Count
1997	3.6	7.2	4.6	4
2000	2.1	3.4	2.6	5
2001	2.9	6.8	4.1	18
2004	2.3	3.3	2.9	5
2006			4	3

An unnamed geyser south of Spectrum Spring, erupting in 1997.

minutes during 1984 and 1985, showing that Brain's intervals have lengthened slightly since the 1980s.

In 2000, Rocco Paperiello reported that Brain was dormant (Keller, 2000). However, when Michael Goldberg and I arrived on 02 July 2000 (following the report), we found that Brain was active. Its water was murky, a condition I had never seen before. The water cleared over the next two hours while Brain erupted every 17 to 21 minutes. These intervals were longer than the 10 to 14 minute intervals seen at other times. Brain's sudden rejuvenation, murky water, and oddly long intervals suggest that some sort of localized hydrothermal disturbance was occurring. Another fact to support this idea is the unusual activity of Three by Five Pool, which is immediately north of Brain (see below).

"**Three by Five Pool**" is roughly 3 feet wide and 5 feet long, hence the name. The sides of the pool are very dark, giving the pool a nearly black appearance. Despite a lack of obvious runoff channels, washed areas, or splash basins, this pool is listed by Bryan as a geyser that has rare eruptions reaching heights of 6 feet.

The eruption that Michael Goldberg and I saw in 2000 came with no warning. We were standing at nearby Burple Geyser when we saw the water in Three by Five Pool suddenly rise, flooding the platform and cascading down the steep bank of the Firehole River. Jets of sand exploded into the pool, tearing up biological mats. The water rapidly became brown and murky. Although no bursts actually broke the surface, the activity was impressive. The eruption lasted for about 1 minute.

Following the eruption, the water receded to about 1 foot below the rim and began rising slowly, reaching overflow 27 minutes later. I have never seen

A small eruption of "Thermopod Geyser," photographed in 2002.

this pool erupt at any other time.

"**Burple Geyser**" was noted active in 2000 and in 2006. The year 2000 was the first time I had seen activity from it. Although it does cycle, I have never accurately determined the interval or duration. Its eruptions are a few inches high.

The following geysers are found on the flat above Fortress Geyser.

"**Spectrum Spring**" is by far the largest of the many hot pools and geysers that are found on the flat above Fortress Geyser. The brilliant and varied colors present in the pool inspired the name. In 2001, a vent in the northwest corner of its basin was active as a geyser, with intervals of 9 to 11 minutes and durations of 85 to 130 seconds. The eruptions threw water to 3 feet. It was also active in 2004.

An **unnamed geyser** immediately to the south of Spectrum Spring erupts to 3 feet every 9 to 18 minutes for durations of 2 to 7 minutes. The average interval has ranged from 9.5 to 16 minutes, while the average duration has ranged from 2.6 to 4.6 minutes. The geyser was not active prior to 1997. From 1997 through 2006, no dormant period has been recorded by me. I did not visit the area in 2003 or 2005. This geyser would seem to be a relatively dependable feature.

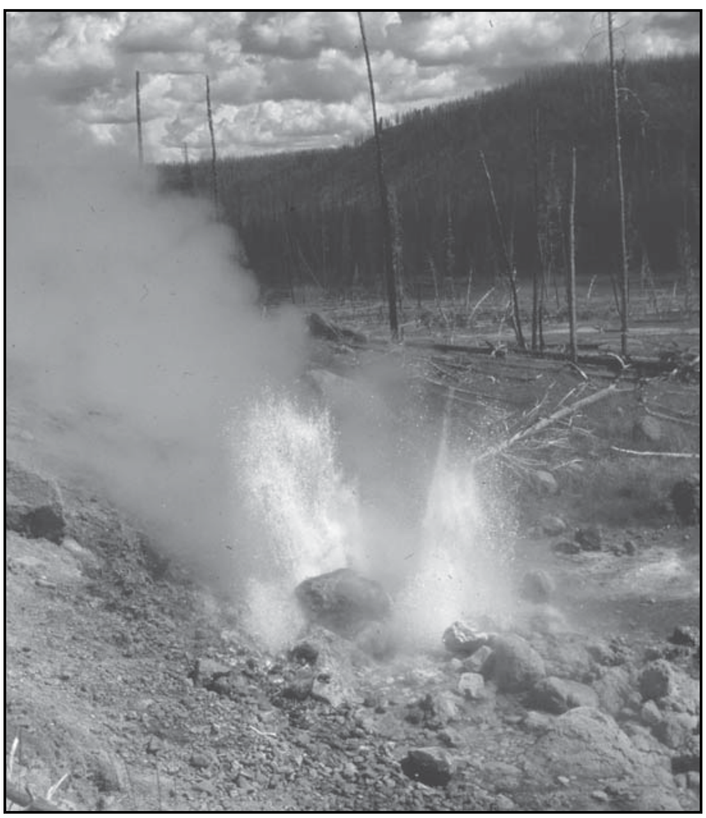
An **unnamed geyser** lies immediately to the north of Spectrum Spring. Sinter chips and sand scattered around the vent during 2004, its only recent year of activity, suggest that it blew out after being sintered over for many years. A single interval of 58 minutes was obtained that year. Frequent minor eruptions and false starts punctuated the time between the two major eruptions. These eruptions were both brief, lasting 1 to 2 minutes, and threw water 3 feet high.

"**Thermopod Geyser**" was named in 2002 by Matthew McLean and David Goldberg. Geyser activity has been noted by us in 1994, 2002 and 2004. In 2002, the eruptions came every 10 to 20 minutes, lasted for 69 to 108 seconds, and threw water to 3 feet. In 2004 the geyser was active, but the eruptions were weak. In 1994, we recorded 4 intervals of 9 minutes, durations of 26 to 38 seconds, and heights of 2 feet. The geyser had blown out earlier in 1994, and had had much larger eruptions earlier that year. At that time, it was obvious that it was an old vent that blew out after being filled in with sinter deposits for many years.

"**Lightsocket Geyser**" erupts from a small round vent and a slightly larger rectangular vent within the same small pool. Together, the vents have the shape of a household light socket, hence the

Spray Geyser, Average Intervals and Durations

Year	Mode	Average Interval	Average Duration
1995	Front	127	67
1997	Front	112	61
1997	Front	113	63
1997	Middle	137	87
2000	Middle	125	63
2001	Front	136	58
2002	Middle	76	41
2004	Front	131	56
2006	Front	109	54



1) Top left: Spray Geyser, erupting from its middle vents in 1997. These are the historically active vents of Spray Geyser.
2) Above, Spray Geyser, erupting from its lower vent in 1997. Note the heavy wash on the hillside above and to the left of the vent.
3) Bottom left, Spray Geyser, erupting simultaneously from its middle and upper vents in 1997.

name. Although I have recorded very little data for this geyser, it has frequently been active. Its best year was perhaps 2001. The eruptions are 1 to 2 feet high.

Microcosm Basin

A large **mud geyser** has erupted from the northernmost crater in Microcosm Basin, an area also known informally as Pocket Basin Mudpots. Two different vents within the large crater have erupted as mud geysers. The vent on the east end of the boomerang-shaped crater was active in 2000, throwing mud 10 to 20 feet high every 13 to 16 minutes for durations of 40 to 82 seconds. Mud splatter surrounding the crater indicated that much larger eruptions

Oblique Geyser Intervals

Year		Minimum (minutes)	Maximum (minutes)	Average (minutes)	Count	
	1928			6		Allen and Day (1935)
	1961	8	10			Frisbee (1961)
	1984	9.6	10.7	10	9	Milada Vachuda, in Paperiello and Wolf (1986)
	1985	8.4	11.2	10.3	8	Milada Vachuda, in Paperiello and Wolf (1986)
	1989	9.5	9.9	9.8	6	
	1990			9.6	9	Bryan (1990)
	1990	9	11	9.5	4	T. Cross
1990-92		9	11	9.7	39	Dunn, Dunn and Dunn (1993)
	1992	9	10	9.7	10	T. Cross
	1993	8	10	9.3	8	T. Cross
	1995	8.8	9.7	9.3	5	
	1996	8.9	10.4	9.5	5	T. Cross
	1997	9.0	9.3	9.1	6	
	1997	9	10	9.1	9	T. Cross
	1998	8.4	9.3	8.9	9	
	1998	9	9.6	9.3	4	T. Cross
	1999	8.4	9.0	8.7	7	
	2000	8.8	9.3	9.1	5	
	2001	8.9	9.8	9.3	8	
	2001	8.5	9.6	9.2	7	T. Cross
	2002	8.8	10.4	9.3	7	
	2002	8.3	9.7	9.3	6	T. Cross
	2003	8.3	9.5	9.0	5	
	2003	8	9	8.6	9	T. Cross
	2004	8.3	9.0	8.6	6	
	2004	8.4	9.8	8.9	6	T. Cross
	2005	7.6	10.0	8.7	4	
	2006	9.0	10.5	9.6	12	

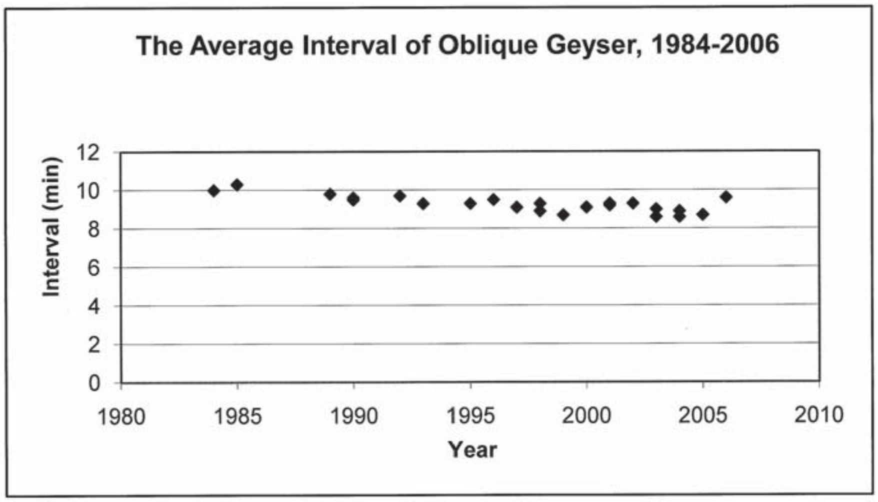
Oblique Geyser Durations

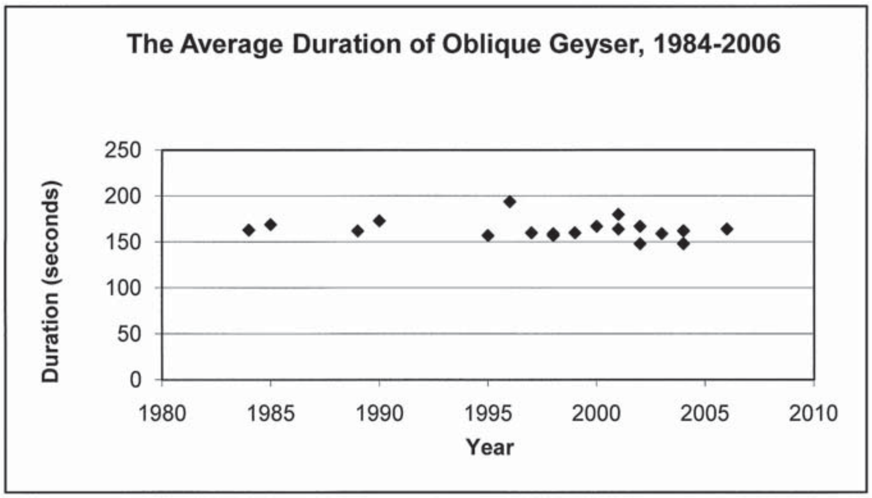
Year		Minimum (seconds)	Maximum (seconds)	Average (seconds)	Count	
	1984	135	186	163	11	Milada Vachuda, in Paperiello and Wolf (1986)
	1985	159	174	169	4	same
	1989	131	190	162	5	
	1990			173		Bryan (1990)
1990-92		140	188	167	30	Dunn, Dunn and Dunn (1993)
	1995	132	193	157	6	
	1996	165	240	194	4	T. Cross
	1997	131	177	160	9	
	1998	130	170	157	10	
	1998	135	185	159	5	T. Cross
	1999	155	175	160	8	
	2000	155	185	167	6	
	2001	135	190	164	8	
	2001	153	211	180	5	T. Cross
	2002	130	160	148	6	
	2002	148	188	167	6	T. Cross
	2003	120	210	159	7	
	2004	140	155	148	7	
	2004	140	189	162	7	T. Cross
	2006	135	215	164	8	

had occurred unseen. A vent at the west end of the same crater was active in 1992, throwing mud 10 to 15 feet high every 10 to 16 minutes for durations of less than 1 minute. Clark Murray also saw this feature active as a geyser in 1998 and 2001.

Imperial Group

Imperial Geyser reactivated in 1997, having been dormant since 1985 (Bryan, 2001). The erupting vent is on the east side of the crater. The vent active during the original activity between 1927 and 1929





was probably the one located centrally in the main pool. Imperial's eruption is nearly continuous. Brief pauses lasting a few seconds occur every few minutes. The 50-foot eruptions are spectacular, resembling a half-size version of Grand.

Spray Geyser presently erupts from three vent complexes, which I will call the upper (east), middle and lower (west) complexes. The upper complex consists of two vents located behind the main formation. The middle complex consists of two vents centered within the formation itself. These are the historically active vents of Spray Geyser. The lower complex consists of one main vent and several minor vents immediately in front of the formation. The lower vents acted as drains for water erupted from the middle vents until some time during the middle 1990s (probably in early 1995, see below), when the main activity shifted to the lower vents and the middle vents stopped erupting.

Spray Geyser is bi-functional. Lower vent function eruptions come exclusively from the eastern of the lower vents. Middle vent function eruptions begin with an eruption of the middle vents, sometimes followed immediately by a brief eruption of the upper vents. The upper vents often start to play just before the middle vents stop, so that Spray Geyser briefly projects four columns of water into the air. The exquisite symmetry of these four columns is unmatched anywhere. In either function, the intervals and durations are 1 to 2 minutes long.

It is unclear how long Spray Geyser has been bi-functional. In 1988, when I first visited Spray Geyser, the eruption came entirely from the central vents. The lower vents were inactive and functioned as drains for runoff from the middle vents. By 1995, the activity had switched to the lower vents, which had produced some tremendous eruptions that scoured the hillside above, washing soil and gravel into the runoff channel and excavating a steep bank in front of the geyser. To account for the heavy erosion, these eruptions would have to have been far larger than any eruptions reported during the late 1990s. The scour from this unseen activity was very fresh in the summer of 1995, suggesting that it occurred earlier that year. The scour is still visible, although grass is presently growing on the scoured areas.

Spray Geyser's intervals and durations are remarkably consistent. The average intervals have ranged from 109 to 137 seconds (excepting 2002) and the average durations have ranged from 54 to 87 seconds (excepting 2002). Notably, the intervals and durations do not vary when Spray shifts from front vent function to middle vent function. The 2002 intervals and durations are shortened relative to the other data. The reasons for this are unclear. The eruptions are 10 to 20 feet high.

GIBBON GEYSER BASIN

Geyser Springs

Three geysers at Geyser Creek have shown consistent activity between 1988 and 2006. They are Oblique Geyser, Subterranean Blue Mud Geyser, and

Eruption	Oblique Geyser start time	Unnamed Steam Vent start time	Offset (minutes)
1	1807	1802	-5
2	1817	1813	-4
3	1826	1926	0
4	1836	1837	1
5	1846	1848	2
6	1856	1859	3
7	1906	1910	4
Average Intervals (min):	9.8	11.3	

Oblique Geyser. Photo by Carlton Cross.

an unnamed intermittent steam vent under a large boulder next to Oblique Geyser. The impressive Big Bowl Geyser has also been consistently active, but it is a perpetual spouter.

Oblique Geyser erupts every 7.6 to 11.2 minutes. The average interval is very stable. From 1984 through 2005, only a slight decrease in the average interval is obvious. Over the 23 years from 1984 through 2006, the average interval has varied from 8.1 to 10.3 minutes. Likewise, the durations are stable and have ranged from 120 to 240 seconds with averages of 148 to 194 seconds. Data given by Frisbee (1961) in an unpublished report gives intervals of 8 to 10 minutes. Allen and Day (1935) note intervals of 6 minutes. From 1961 to 2006, only a slight decrease in the average duration is obvious. The noisy eruptions throw jets of water 25 feet high.

Oblique Geyser is probably not related to an **unnamed periodic steam vent** that is located under a large boulder to the west (first reported by Bryan, 1990). The strongest evidence to support this comes from a data set obtained in 2006 on the steam vent and Oblique simultaneously. Note two facts:

1) The average interval for Oblique is 9.8 minutes, while that of the steam vent is 11.3 minutes.

2) A comparison of the time of each eruption of Oblique with the steam vent shows that the times when the steam vent is active vary throughout Oblique's cycle. In the data table shown below, the steam vent precedes the first eruption of Oblique by 5 minutes. However, it precedes the second eruption by 4 minutes, occurs in concert with the third Oblique eruption, and lags the fourth through the seventh eruptions by 1, 2, 3 and then 4 minutes. Clearly, the steam vent can erupt at many different times during Oblique's cycle. It is notable that no eruptions of the steam vent preceded Oblique by less than 4 minutes. More data will be required to determine if this happens consistently.

"**Subterranean Blue Mud Geyser's**" activity varies greatly from year to year. Recorded intervals have ranged from 5 to 23 minutes. Durations are typically less than 1 minute. As the name suggests, the eruption is entirely subterranean. The water is heavy with an intriguingly blue mud that coats the walls of the underground chamber with elaborate grooved patterns. Subterranean Blue Mud has been active on roughly half the visits I have made to the area.

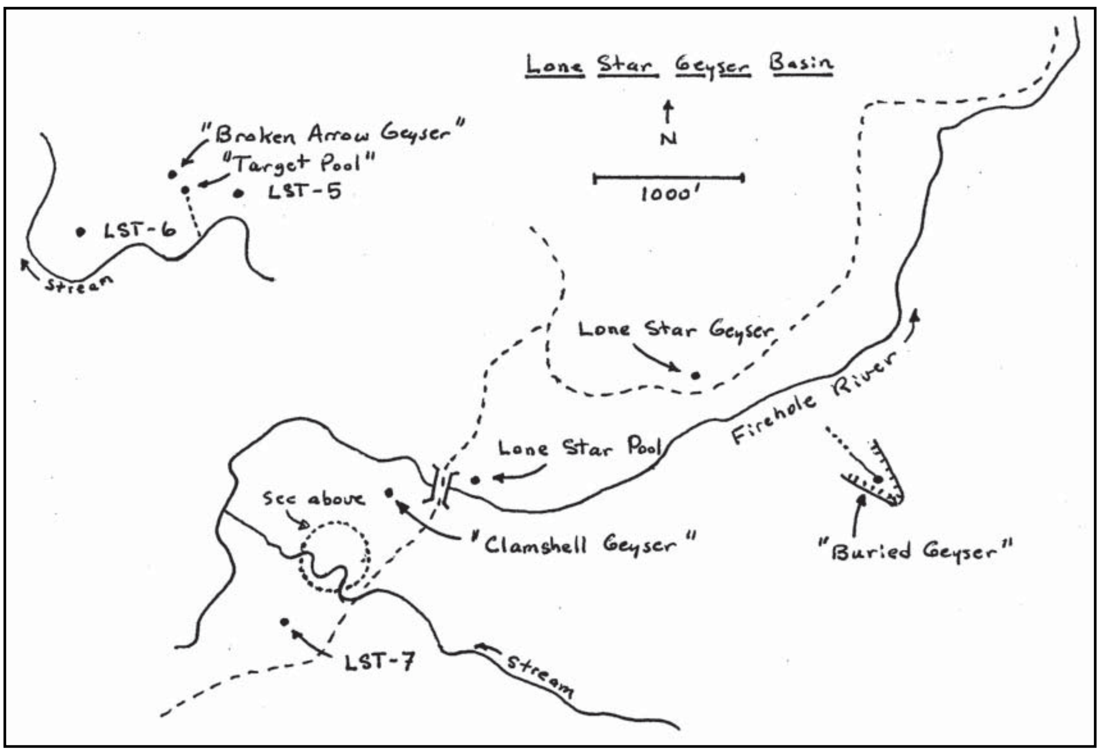
Other geysers at Geyser Creek have been far less dependable. **"Anthill Geyser"** has never had full eruptions at any time we were in the area, from 1988 through 2006. It apparently had a brief episode of activity that was reported in the SPUT (1992). Likewise, we have never seen **"Tiny Geyser"** have full eruptions. A set of three pools in the upper group of hot springs **(Paperiello and Wolf #50)** used to maintain a sand berm around its margin. In 1998, two intervals of 41 and ~30 minutes were obtained by Michael

Goldberg. The activity was simply a heavy overflow without any bursting. More recently, the sand berm has been weathered, implying dormancy.

A large pool on the east side of Geyser Creek near the lower end of the area (Paperiello and Wolf #18) was reported active in 1985 by Milada Vachuda (Paperiello and Wolf, 1986) and was seen erupting by Clark Murray in June, 1991 (Murray, 1991, 2008). Murray observed that the eruptions, which consisted of a single, muddy burst of water, came 5 to 30 minutes apart. Intervals were irregular. The maximum height was 8 feet. In September of 1991, Murray again saw the geyser active. This time, the eruptions lasted over a minute, and the intervals were long and erratic. The Dunns also reported it active in 1996 (Dunn, 1996). Since this pool has a large sand pile next to it, I propose that it should be named **"Sand Pile Geyser."**

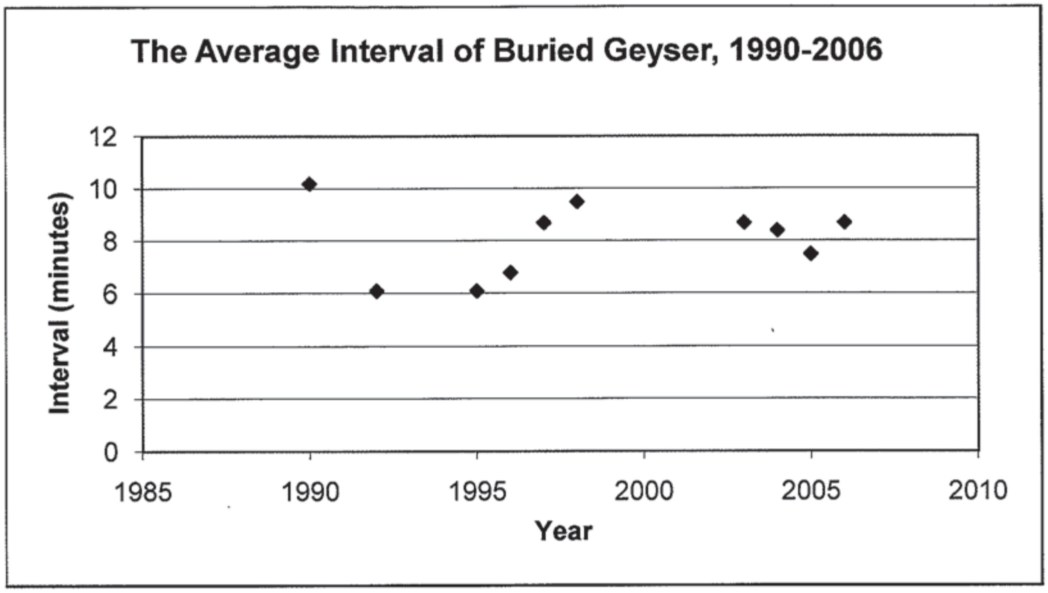
Several of the vents within the gully and on the steep slopes above the upper Geyser Springs have erupted. The largest eruption came from a mudpot near Geyser Creek (Paperiello and Wolf #78). In 2001, we noted mud spattered on nearby plants and rocks for a distance of 21 feet to the north, 21 feet to the east and to heights 10 feet above the elevation of the vent. A small mudflow extended from the crater towards Geyser Creek. The eruption was probably quite brief, since most of the spattered foliage was not burned, and the mud layer was very thin.

The large blue pool (Paperiello and Wolf #26) on the opposite side of Geyser Creek from Oblique



Buried Geyser Intervals

Year	Minimum (minutes)	Maximum (minutes)	Average (minutes)	Count	
1990	8.5	12.6	10.2	14	Bower (1992)
1992	4.2	9.0	6.1	22	
1995	5.3	6.8	6.1	6	
1996	4.9	8.2	6.8	8	
1997	8.1	9.7	8.7	5	
1998	8.3	11.4	9.5	5	
2003	6.2	11.3	8.7	13	
2004	6	11	8.4	5	
2005	5.3	9.4	7.5	10	
2006	8	10	8.7	5	



Geyser is known as **Bone Pool.** It overflowed continuously until 2002, when it ebbed to 10 inches below overflow. Since then, water levels have risen a little each year, reaching 4.5 inches below overflow in 2006.

LONE STAR GEYSER BASIN

"**Buried Geyser**" erupts every 4 to 13 minutes. The eruption is nearly continuous, except for a brief pause during the time of lowest water. Splashing begins while the geyser is well below overflow. The bursts gradually increase in strength as overflow is reached, and abruptly decline when overflow ceases. The strongest eruptions burst water to 15 feet. The onset and cessation of overflow are the only well-defined parts of the cycle.

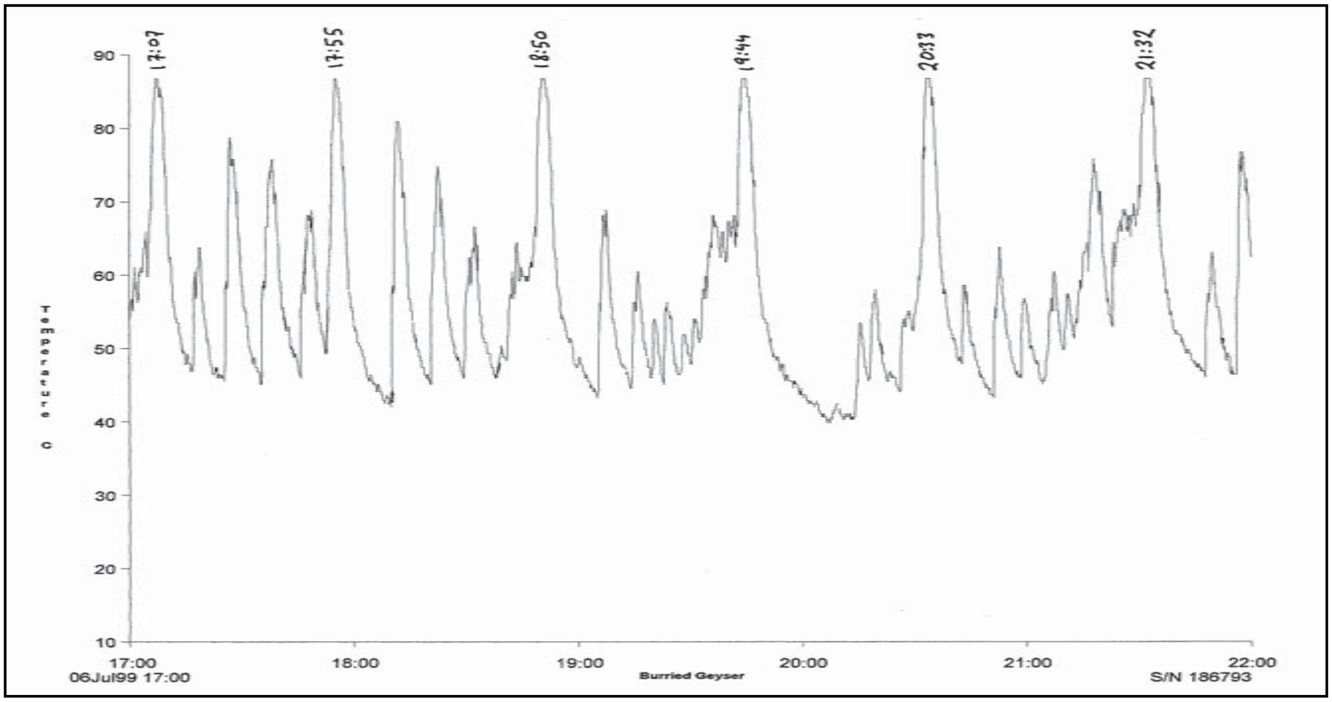
Evidence for a change to more powerful eruptions was discovered in 2002, when an 18-inch deep moat was found in front of the crater. The moat was not present in 2000 and thus formed between 2000 and 2002. Since 2002, a few of the largest observed eruptions have spilled water into the moat. However, the flow from these eruptions has never been strong enough to account for the amount of erosion that occurred between 2000 and 2002, so the unseen activity must have been even larger.

Buried Geyser. Photo by Carlton Cross.

Data collected by me between 1992 and 2006 show that Buried Geyser's average interval varies from 6.1 to 9.5 minutes. A sudden jump of nearly 2 minutes occurred between 1997 and 1998. Data collected by Gordon Bower in 1990 and reported in Bower (1992) give an average duration of 10.2 minutes.

The present Buried Geyser formed in the summer of 1983. Its history is recorded in Paperiello and Wolf (1986). Prior to 1983, a small perpetual spouter existed at the site. It erupted to 6 feet from under a ledge. In July of 1983, the activity abruptly changed. At that time, Buried began having powerful eruptions that threw water to 35 feet vertically and 45 feet laterally. These large eruptions occurred at intervals of just over 2 hours and had durations of 4 minutes. The erosive power of the eruptions was tremendous. It excavated the steep hillside around the crater, removed entire boulders, and obliterated all traces of the small spouter—the original Buried Geyser—that had previously occupied the site.

In between the major eruptions, the water level in Buried Geyser rose and fell every 5 to 7 minutes. After the major eruptions ceased between August and September of 1983, Buried Geyser erupted on inter-



Buried Geyser temperature record from 1999. Temperature peaks represent eruptions. The large peaks occur roughly once an hour and may correspond to unusually powerful eruptions.

Clamshell Geyser erupting. Photo by Clark Murray.

vals of 4 to 6 minutes. These eruptions were generally smaller than the eruptions noted in July and August. Data collected by Paperiello and Wolf in September of 1984 and August of 1985 closely resemble the present activity. At that time, eruptions occurred every 8 to 13 minutes and were 6 to 18 feet high. The water appeared milky white with suspended silt. It was still cloudy when we first visited the site in 1989, but it was clear when we visited in 1992.

Does Buried Geyser have major and minor eruptions, as described by Bryan (2001) and Bower (1992)? I suggest that Buried Geyser generally does not have clearly defined major eruptions. Buried Geyser produces large eruptions, small eruptions, and every size in between. The only consistent pattern is that small eruptions seem to follow large eruptions. This may cause observers to classify the large eruption as a major, and those that follow as minors.

At times, however, large eruptions have occurred according to a set pattern. During July 1999 and again during July 2000, the data logger record shows that strong temperature spikes, presumably indicating large eruptions, occurred roughly once an hour. Of 137 such eruptions detected by the logger,

Target Pool (left) and Broken Arrow Geyser (right), erupting in 2005. Photo by Clark Murray.

Bombshell Geyser, erupting in 2004.

over the Firehole River. I have checked it on many occasions between 1995 and 2006. When Clamshell is active, the sand is freshly washed and any pine needles that have blown into the crater are arranged in a neat circle at the high water mark. Data collected between 1996 and 2006 suggest that Clamshell has been active roughly 1 day out of every 3, on average. The eruptions are brief and reach 6 feet high.

Clamshell seems to be strongly influenced by groundwater. Early in the season it is typically full of tepid water, and at these times it does not erupt. Late in the season, or during periods when no rain has fallen, it typically splashes a few inches high from a water level several inches below the top of the vent. It will not erupt at these times, either. It seems to be active only when it is between the extremes of high water and low water.

In 1999, we placed a data logger on Clamshell. Over a span of 2 days, it had 14 eruptions. Of the 13 intervals, 10 ranged from 45 to 101 minutes, while the remaining 3 intervals ranged from 4 to 6 hours. This suggests series-type behavior.

In September of 2005, Clark Murray and Rocco Paperiello found Clamshell to be highly active (Murray, 2008). Over the course of a single day, it erupted to 8 feet every 40 to 50 minutes. Notably, this occurred while unusual activity was occurring in two other thermal features located 850 feet to the southwest (see below).

"**Broken Arrow Geyser**" and "**Target Pool**" (Paperiello and Wolf #1a and 1b) are found in the northeast corner of the Campsite Group. Broken Arrow Geyser erupts from a tiny vent in a long crack that points directly at Target Pool. Broken Arrow Geyser was active in 1995. Its tiny eruptions threw water a few inches high and recurred every few minutes. This is the only time I have seen Broken Arrow Geyser active.

Broken Arrow Geyser and Target Pool had a series of significant eruptions in September of 2005. As observed by Murray (2008), the eruptions occurred every 100 minutes. At these times, Broken Arrow Geyser would fill with water and erupt to 1 foot, while Target Pool would erupt to 2 to 3 feet. Eruptions generated moderate overflow, although heavier

the average interval was 59 minutes with a range of 36 to 96 minutes. Long periods of time passed where the large eruptions occurred regularly, but long periods of time also passed where the large eruptions did not occur at all. The pattern of hourly large eruptions was completely absent from a data logger record obtained in August of 1999, and was also absent from data collected in 2001 and 2006.

I suggest that two reservoirs exist beneath Buried Geyser. The shallow reservoir is responsible for nearly all of the modern eruptions. I also believe that this reservoir was already functioning during the major activity in July and August of 1983, and that it was responsible for the 5-to-7 minute rise-and-fall cycles recorded by Paperiello and Wolf at that time.

I suggest that a second, deeper reservoir was responsible for the 40-foot eruptions that occurred during July and August of 1983. When Buried Geyser is having small eruptions, it is the shallow reservoir alone that is functioning. However, when exceptionally large eruptions occur, as they did in July of 1999 and July of 2000, the deep reservoir also participates.

A sinkhole opened in Buried Geyser's runoff channel in 2000. It swallows the entire runoff stream, which re-emerges a short distance downslope. The sinkhole is 62 inches long, 32 inches wide and 26 inches deep. It has maintained a constant size since it formed.

"**Clamshell Geyser**" (listed as LST-8 in Bryan, 2001) erupts from a small crack vent in a shallow, saucer-shaped crater in the woods west of the bridge flow and larger eruptions were inferred from more extensive wash around the vents. This active phase was apparently very brief, since geyser eruptions did not recur in 2006.

GLEN AFRICA BASIN

"**The Black Torch**" (Paperiello and Wolf #26a) is the only known true geyser in Glen Africa Basin. In 2004, it cycled every 191 to 208 seconds. The 6 intervals I obtained gave an average of 200 seconds. The intensely black crater would fill, overflow, and then begin churning as silvery steam bubbles shot into the pool. This produced a striking flame-like effect, which inspired Paperiello and Wolf to apply the name. Perhaps every third eruption would involve a distinct burst of water to 1 foot, making this hot spring a true geyser. The waving periods lasted for 32 to 38 seconds with an average value of 34 seconds. This is another feature that has remained unchanged in the 19 years since Paperiello and Wolf (1986) observed it in 1985.

In 2004, nearby Bombshell Geyser (also known as Pseudo Geyser) and Red Jacket Spring were both active as perpetual spouters. Bombshell Geyser was especially impressive, bursting violently to 10 feet and flowing a heavy runoff stream. Red Jacket Spring erupted to 5 feet.

Along the stream above the main active area was a vent that produced sounds like a revving motorcycle engine. I suggest the name "Motorcycle Spring" for this intriguing feature.

The Flutter Wheel was also active. It is one of the oddest thermal features anywhere. Submerged in the waters of Alum Creek, it is a fumarole that shoots out a powerful column of steam bubbles. As these bubbles condense rapidly in the cold water, they produce a metallic purring sound.

NORTH BOG CREEK HOT SPRINGS

Thermal activity at North Bog Creek Hot Springs is divided between two groups of thermal features. The Southeast Group lies along the north fork of Bog Creek and is the site of the most intense activity. The Northwest Group lies at a higher elevation, near a wet meadow and a small, non-thermal tributary of Sour Creek. We visited the area once, in 1999.

In the Northwest Group, "**Enigma Geyser**" was found active. Its vent is located on a low sinter mound in the lower (western) margin of a gas barren, and it is difficult to locate the geyser unless it happens to be in eruption. In 1999, the vent was dry and the sinter formation around it was in a slight state of decay. The noisy puffing eruptions began suddenly. They lasted for around 40 seconds and occurred on intervals of 7 to 11 minutes. None of the eruptions discharged any water, although the sounds of boiling could be heard deep underground. These intervals were longer than those reported by Paperiello and Wolf (1986), which in 1985 ranged from 3 to 7 minutes, although the durations, of 25 to 44 seconds, were similar. Paperiello and Wolf cite data gathered by Rick Hutchinson, who in 1976 found intervals

Names proposed for thermal features:

Name	Proposed by
Scaffold Spring	Jack Hobart
Thrashing Spouter	Jeff Cross
Gravel Geyser	Jeff Cross
Tuba Geyser	Jeff Cross
Piccolo Geyser	Rocco Paperiello
Belch Geyser	Jeff Cross
Black Cat Geyser	Rocco Paperiello
Growl Geyser	Jeff Cross
Three by Five Pool	Michael Goldberg
Spectrum Spring	Jeff Cross
Thermopod Geyser	David Goldberg and Matthew McLean
Lightsocket Geyser	Rocco Paperiello
Sand Pile Geyser	Jeff Cross
Clamshell Geyser	Marie Wolf
Broken Arrow Geyser	Rocco Paperiello and Clark Murray
Target Pool	Rocco Paperiello and Clark Murray
Motorcycle Spring	Jeff Cross

of 5 to 8 minutes and durations of 30 to 60 seconds. Overall, it would seem that Enigma Geyser could be fairly consistent over long periods of time.

The main focus of activity in the Southwest Group occurs in a steep-sided amphitheater. Its floor and walls are alive with fumaroles, spouters, and churning pools. The hillsides are covered liberally with sulfur. An intensely acidic thermal stream drains the amphitheater. Despite the acidic conditions, most of the water in the pools was quite clear. In this unlikely location, Paperiello and Wolf (1986) report the existence of two geysers. Neither **Vitriol Geyser** (#7a) nor a nearby **unnamed geyser** (#8) were seen in eruption, however.

UNNAMED THERMAL AREA 2 MILES NW OF NORRIS GEYSER BASIN

Large steam clouds from this thermal area were visible from the vicinity of Norris Geyser Basin in 2004. To determine the source of these clouds, we visited the thermal area in September of that year. The two largest steam clouds came from a large acidic hot spring (Paperiello and Wolf #30) at the northeast corner of the thermal area (a small deposit of hollow sulphur spheres was found around the margin of this spring), and from a powerful fumarole (Paperiello and Wolf #5) in the central part of the thermal area, just downstream from the pair of explosion craters that opened in January and May of 1987 (Hobart, 1989; Hutchinson, 1987). The fumarole roared loudly enough to impede conversation. It was obvious that the fumarole had not erupted at any time in 2004. It is also unlikely that the acidic hot spring had erupted.

We also visited this thermal area in 1997 and 1989, but did not see any geysers active. Bryan (2001) lists three geysers at the site.

Names:

Because many of the thermal features described in this article are poorly known, or are known only by identification numbers that indicate nothing about the feature's activity, I (and several other people), have proposed thermal names that may be original with this paper. A list of these names is included.

Acknowledgments:

I thank Carlton Cross and Tara Cross for accompanying me on trips to backcountry thermal areas and placing and collecting data loggers. Clark Murray supplied personal observations and photographs, which are gratefully acknowledged. I thank David Schwarz for reviewing this paper. The National Park Service research permit under which the data logger studies were performed is also gratefully acknowledged.

Data Summary Geyser	Interval	Duration	Height (feet)
UPPER GEYSER BASIN			
Deleted Teakettle	4-8 minutes (minor)	1 minute (minor)	2 (minor)
	21-72 minutes (major)	up to 4 minutes (major)	3 (major)
Bank Geyser	33-207 seconds	5-20 seconds	4
"Slide Geyser"	20-21 minutes	38-47 seconds	3
Rusty Geyser	17-135 seconds	6-33 seconds	8
Jewel Geyser	4-13 minutes	3-76 seconds	20
Silver Globes A-D	12-60 minutes	18-35 seconds	20
"Silver Globe Slit"	22-59 minutes	71-106 seconds	12
UNNG E of Silver Globe	4-17 minutes	2-16 minutes	2
"Outpost Geyser"	5-12 minutes	2-6 minutes	10
"Sentry Geyser"	7-37 minutes	19-285 seconds	3
"Green Bubbler"	5-9 minutes	4-7 minutes	4
"Yellow Bubbler"	41 and 68 minutes	9-10 minutes	1
UNNG north of Yellow Bubbler	53 and 127 minutes	4-5 minutes	1
"Red Mist Geyser"	19-57 seconds	7-14 seconds	5
East Mustard Spring	5-8 minutes	156-180 seconds	6
Cliff Geyser	24-74 minutes	7-19 minutes	40
Ragged Spring	3-71 minutes	seconds	30
"Pit Geyser" (Pine Springs)	20 and 56 minutes (major series)		6
	minutes (in major series)	1 minute	
"Dilapidated Geyser"	hours to weeks	minutes	40
MIDWAY GEYSER BASIN			
Rabbit Creek Geyser	18-25 minutes	94-240 seconds	6
UNNG N of Rabbit Creek Geyser	Frequent (minor)	seconds	3 (minor)
	rare (major)	seconds	12 (major)
"Gravel Geyser" *	80-105 seconds	50-70 seconds	2
"Tuba Geyser" *	hours	hours	10
"Belch Geyser" *	57-75 minutes	seconds	boil
UNNG between Tuba and Till *	4h37min	16 minutes	feet
LOWER GEYSER BASIN			
"A-0 Geyser"	20-35 minutes	29-99 seconds	10
Paperiello and Wolf #6	9-11 minutes	seconds	3
"A-2 Geyser"	dormant		
Botryoidal Spring	153-326 seconds	11-35 seconds	15
"Black Cat Geyser" *	8-24 minutes	seconds	10
"Tuft Geyser"	31-38 minutes	7-12 minutes	5
Spindle Geyser	156-215 seconds	38-91 seconds	3
UNNG near Tangled Creek	2-5 minutes	seconds	15
Artesia Spring	5-10 minutes (series)		
	55-67 seconds (single eruptions)	14-20 seconds	10
"Underhill Springs Geyser"	7-16 minutes	12-16 minutes	6

Continued on next page.

Geyser	Interval	Duration	Height (feet)
UNNG steam vent	15-19 minutes	8-13 minutes	steam
"Growl Geyser"	55-63 minutes	9-13 minutes	2
Mound Geyser	13-19 minutes (short)		
	21-29 minutes (long)	3-6 minutes	6
UNNG N of Mound	3-5 minutes	brief	2
UNNG S of Mound	21-338 seconds	10-124 seconds	1
"Dark Pool" *	19-21 minutes	31-32 seconds	8
UNNG under rock near Dark Pool	10-17 minutes	seconds	subterranean
"Brain Geyser"	11-21 minutes	30-62 seconds	boil
"Three by Five Pool"	rare	seconds	boil
"Burple Geyser"	minutes	minutes	inches
UNNG in Spectrum Spring	9-11 minutes	85-130 seconds	3
UNNG S of Spectrum Spring	9-18 minutes	2-7 minutes	3
UNNG N of Spectrum Spring	58 minutes	minutes	3
"Thermopod Geyser" *	9-20 minutes	26-108 seconds	3
"Lightsocket Geyser"	unrecorded	unrecorded	2
UNNG mud geyser, east *	13-16 minutes	40-82 seconds	20
UNNG mud geyser, west *	10-16 minutes	brief	15
Imperial Geyser	nearly continuous	nearly continuous	50
Spray Geyser	76-137 seconds (average)	41-87 seconds (average)	20
GIBBON GEYSER BASIN			
Oblique Geyser	8-11 minutes	120-240 seconds	25
UNNG steam vent	11 minutes (average)	brief	steam
"Subterranean Blue Mud Geyser"	5-23 minutes	brief	subterranean
LONE STAR GEYSER BASIN			
"Buried Geyser"	4-13 minutes	indefinite	15
"Clamshell Geyser" *	minutes to hours	brief	6
"Broken Arrow Geyser" *	100 minutes	unrecorded	1
"Target Pool" *	100 minutes	unrecorded	3
GLEN AFRICA BASIN			
"The Black Torch"	191-208 seconds	32-38 seconds	1
NORTH BOG CREEK HOT SPRINGS			
"Enigma Geyser"	7-11 minutes	40 seconds	steam

Note: UNNG is an abbreviation for unnamed geyser.
Geysers marked with an asterisk (*) are typically less active. The tabulated data represents the best activity.

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The Number of Geysers in Backcountry and Undeveloped Frontcountry Thermal Areas in Yellowstone National Park

Jeff Cross

The object of this paper is to present a list of geysers that exist in the backcountry and undeveloped frontcountry thermal areas in Yellowstone National Park. Although many of these geysers are listed in Bryan (2001), reference to additional sources shows that a total of 529 known geysers have erupted in backcountry and undeveloped frontcountry thermal areas. Certainly, not all of these geysers could be expected to be active in any given year. However, all of these geysers have been active at some time since the Park's creation in 1872, and, with few exceptions, all of these geysers can be expected to be active at some time during the next century.

I have confined this list to include only backcountry and undeveloped frontcountry thermal areas because these are my primary areas of interest, and also because the geysers here are far less likely to appear in reports and articles. These geysers get neglected because they are remote, and because roads, trails, and boardwalks built near or through the listed thermal areas do not provide access to all of the thermal features. A good example of this is Heart Lake Geyser Basin, where the trail passes through only the Middle Group, which contains no geysers at present. Rustic Geyser, the best performer at Heart Lake, is 1150 feet from the nearest trail. Glade Geyser, the largest geyser at Heart Lake, is 750 feet from the nearest trail. Practically speaking, not one geyser at Heart Lake is accessible via a trail.

At Shoshone Geyser Basin, all of the geysers on the west side of Shoshone Creek, as well as a number of geysers on the east side of the creek, are inaccessible via trail. A careful count of the accessible geysers reveals that 22 percent of the geysers are accessible via trail at Shoshone Geyser Basin. Statistics are similar at Lone Star Geyser Basin (19% accessible), Gibbon Geyser Basin (4% accessible), and the undeveloped portions of the Lower Geyser Basin (6% accessible). Other backcountry thermal areas, like those in the Hayden Valley, at Lewis Lake, and at Bog Creek Hot Springs, are a mile or more from the nearest trail. In fact, a count of the backcountry and undeveloped frontcountry geysers shows that only 12 percent (66 out of 529) of these geysers are trail-accessible. Clearly, the Park's trail system does not conduct the visitor to even half of these geysers, and it is obvious why reports on their activity are few and far between.

A review of the literature shows that Yellowstone's backcountry and undeveloped frontcountry thermal areas include many more geysers than one would expect. The total number of geysers at Shoshone, previously estimated at 74 by Paperiello (1989), now adds up to 100 geysers. At Heart Lake, the total, previously estimated at 48 by Paperiello (1989) now adds up to 63 geysers. In both cases, the increase amounts to about 30 percent over the previously known totals. Because most of the geysers not already listed by Bryan (2001) were first reported in GOSA publications like the Transactions, these new statistics show that GOSA is having a substantial impact on the knowledge of geyser activity in Yellowstone National Park.

If multiple sources cite geysers of ambiguous identity—a common situation with obscure, unnamed geysers—I have used the single source which identifies the greatest number. This avoids duplication. For example, both Keller (2003) and Bryan (2001) list numerous unnamed geysers in the Myriad Group. So that none of the unnamed geysers are counted twice, I have included the total from Keller as the sole source in the official count.

Readers should consult the references for maps of the thermal areas. Because large perpetual spouters are impressive but are not technically geysers (the eruption never stops) they have not been included in the list. Official thermal feature names are used where known. In numerous cases, informal names have been used. These names have been placed in quotation marks. Where no informal names are present, an identification number from the relevant literature source is used.

Visitors to backcountry thermal areas should be aware that, in the absence of clear pathways, it is always necessary to guard one's safety by not approaching any hot spring, geyser, fumarole or mudpot too closely. Also, it is of the utmost importance that visitors avoid damaging any of the mineral formations or algae mats that form around the thermal features. Geyserite, which forms right next to a geyser's vent or pool, is especially fragile. Geyserite takes longer to recover from damage than any other formation found in the geyser basins. Please enjoy the beauty of the geyserite formations and algae mats, but do not damage them by walking across them or climbing on the geyser cones.

Following each entry in the list, I have noted whether (Y = yes, N = no) the geyser is visible from a trail, boardwalk, or roadway. I have used my own discretion in making these judgments. In my opinion, a 150-foot tall eruption of Round Geyser in the Upper Geyser Basin's Myriad Group, when viewed from the nearest road (500 feet away), would impress a majority of the viewers. Thus, I have listed Round as being accessible. By contrast, a 3-foot tall eruption from a small geyser would hardly be appreciated by someone standing off at any distance greater than 30 feet. To refer to an earlier example, Heart Lake Geyser Basin's Rustic Geyser, which erupts to 35 feet, is impressive when viewed at a distance of 30 to 100 feet. However, it fails to impress at all when viewed from the trail, which is 1150 feet away. Even Old Faithful would look small at that distance.

The definition of "geyser," given by White (1967) and used by the authors cited in the references section, is as follows: "Geyser—a hot spring characterized by intermittent discharge of water ejected turbulently and accompanied by a vapor phase."

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Geysers in the Backcountry and Undeveloped Frontcountry Thermal Areas in Yellowstone National Park

	Reference	*Is the geyser visible from a trail, road or boardwalk?*
UPPER GEYSER BASIN		
Pipeline Meadows		
"Dilapidated Geyser" (PMG-1)	Bryan (2001)	N
PMG-2	Bryan (2001)	N
Midas Spring (PMG-3)	Bryan (2001)	N
"Secluded Geyser" (PMG-4)	Bryan (2001)	N
Bend Cone	Bryan (2001)	N
Pipeline Creek		
PIP-1	Bryan (2001)	N
unnamed geysers (2)	Bryan (2001)	N(2)
Upriver Group		
UPG-1	Bryan (2001)	N
unnamed geyser	Bryan (2001)	N
Pine Springs		
Mud Geyser	Bryan (2001)	N
PIN-1	Bryan (2001)	N
unnamed geysers (3)	Bryan (2001)	N(3)
Hillside Springs		
unnamed geyser	Bryan (2001)	N
Subtotal **16**		
Myriad Group		
Basin Spring	Bryan (2001)	Y
Three Crater Spring	Bryan (2001)	Y
Mugwump Geyser	Bryan (2001)	Y
MYR-1	Bryan (2001)	Y
"Middle Sister"	Bryan (2001)	Y
"South Sister"	Bryan (2001)	Y
Little Brother Geyser	Bryan (2001)	Y
"Cousin Geyser"	Bryan (2001)	Y
Trail Geyser	Bryan (2001)	N
West Trail Geyser	Bryan (2001)	N
Myriad Geyser	Bryan (2001)	Y
Round Geyser	Bryan (2001)	Y
Abuse Spring	Bryan (2001)	Y
Spectacle Geyser	Bryan (2001)	Y
White Geyser	Bryan (2001)	Y
Unnamed geyser next to White	Bryan (2001)	N
Lactose Pool	Bryan (2001)	N
Bell Geyser	Bryan (2001)	N
Pit Geyser	Bryan (2001)	N
Strata Geyser	Bryan (2001)	N
Blue Lemon Spring	Bryan (2001)	N

	Reference	Is the geyser visible from a trail, road or boardwalk?
unnamed geyser near Basin Spring	Bryan (1989)	Y
unnamed geysers beyond Three Sisters (2)	Bryan (1990)	Y(2)
unnamed geysers near Bell, Pit, Strata (4)	Bryan (1990)	N(4)
unnamed geyser near Myriad	Bryan (1990)	N
unnamed geysers near Station Spring (3)	Bryan (1990)	N(3)

Note: A total of 49 geysers are listed by Keller (2003).

Subtotal **49**

UPPER GEYSER BASIN TOTAL	**65**	**16 visible (25%)**

MIDWAY GEYSER BASIN

Rabbit Creek Group		
Till Geyser	Bryan (2001)	Y
MGB-1 through MGB-5 (5 geysers)	Bryan (2001)	Y(4), N(1)
River Spouter	Bryan (2001)	N
Pebble Spring	Bryan (2001)	N
Silent Pool	Bryan (2001)	Y
unnamed geyser N of MGB-3	Bryan (1990)	N
unnamed geyser 100 yards NE of Till	Bryan (1990)	N
Flood Group		
Catfish Geyser	Bryan (2001)	N
Flood Geyser	Bryan (2001)	Y
West Flood Geyser	Bryan (2001)	Y
"Tangent Geyser" (MGB-6)	Bryan (2001)	Y
MGB-7	Bryan (2001)	Y
Rabbit Creek		
Rabbit Creek Geyser	Bryan (2001)	N
MGB-8	Bryan (2001)	N
"Tuba Geyser"	Dunn (1997)	N
"Belch Geyser"	SPUT (2001)	N
unnamed geyser in pit	Barger (2001)	N
"Gravel Geyser"	SPUT (2001)	N
Paperiello #11	Bryan (1992)	N
UNNG N end Highlands	Bryan (1993)	N

MIDWAY GEYSER BASIN TOTAL	**24**	**10 visible (40%)**

LOWER GEYSER BASIN

White Creek Group		
"A-0 Geyser"	Bryan (2001)	Y
"A-1 Geyser"	Bryan (2001)	Y
"A-2 Geyser"	Bryan (2001)	Y
Paperiello #6	Paperiello and Wolf (1986)	Y
Botryoidal Spring	Bryan (2001)	Y
"Logbridge Geyser"	Bryan (2001)	Y

		Reference	Is the geyser visible from a trail, road or boardwalk?
	Diamond Spring	Bryan (2001)	N
	WCG-4	Bryan (2001)	N
	"Tuft Geyser" (WCG-3)	Bryan (2001)	N
	"Eclipse Geyser"	Bryan (2001)	N
	Spindle Geyser	Bryan (2001)	N
	unnamed geyser near Spindle	Bryan (1992)	N
	unnamed geyser near A-2	Bryan (1993)	N
	unnamed geyser near Five Sisters	Bryan (1990)	N
Subtotal	**14**		
Serendipity Meadows			
	unnamed geysers (2)	Bryan (1993)	N(2)
Subtotal	**2**		
Pink Cone Group			
	Narcissus Geyser	Bryan (2001)	N
	"Underhill Springs Geyser"	Gryc (2008)	N
Subtotal	**2**		
Kaleidoscope Group			
	Kaleidoscope Geyser (#1a)	Keller (2005)	N
	#1b	Keller (2005)	N
	#1c	Keller (2005)	N
	#1d	Keller (2005)	N
	#2	Keller (2005)	N
	#3	Keller (2005)	N
	"Three Crater Geyser" (3 geysers, #4)	Keller (2005)	N(3)
	#5a	Keller (2005)	N
	"Collapse Geyser" (#5b)	Keller (2005)	N
	#5c	Keller (2005)	N
	"Blowout Geyser" (#6)	Keller (2005)	N
	Drain Geyser (#7)	Keller (2005)	N
	Deep Blue Geyser (#8)	Keller (2005)	N
	#9	Keller (2005)	N
	#10	Keller (2005)	N
	#11	Keller (2005)	N
	#12	Keller (2005)	N
	#13	Keller (2005)	N
	"The Firehose" (#14)	Keller (2005)	N
	"Honeycomb Geyser" (#15)	Keller (2005)	N
	#15a	Keller (2005)	N
	Honey's Vent (#16)	Keller (2005)	N
	Old Surprise Spring (#17)	Keller (2005)	N
	#18	Keller (2005)	N
	#19	Keller (2005)	N
	#20	Keller (2005)	N
	"Coral Spring" (#22)	Keller (2005)	N
	#23	Keller (2005)	N
	#24	Keller (2005)	N

		Reference	Is the geyser visible from a trail, road or boardwalk?
	#25	Keller (2005)	N
	#29	Keller (2005)	N
	#30	Keller (2005)	N
	#31	Keller (2005)	N
	#32	Keller (2005)	N
	#34	Keller (2005)	N
	#35	Keller (2005)	N
Subtotal	**38**		
Fissure Group			
	Ferric Geyser	Bryan (2001)	N
	Bridge Geyser	Bryan (2001)	N
	Sprinkler Geyser	Bryan (2001)	N
	West Sprinkler Geyser	Bryan (2001)	N
	Earthquake Geyser	Bryan (2001)	N
	"Vertical Geyser"	Bryan (1990)	N
	unnamed geysers (15)	Bryan (1990)	N(15)
	Angle Geyser	Bryan (2001)	N
	"Impatient Miser Geyser"	Bryan (2001)	N
Subtotal	**23**		
Quagmire Group			
	"Growl Geyser" (QAG-1)	Bryan (2001)	N
	unnamed geysers (2)	Bryan (1992)	N(2)
Subtotal	**3**		
Camp Group			
	Snort Geyser	Bryan (2001)	N
Subtotal	**1**		
Porcupine Hill Group			
	Porcupine Hill Geyser	Bryan (2001)	N
Subtotal	**1**		
Morning Mist Springs			
	Morning Mist Geyser	Bryan (2001)	N
	Geyserlet	Bryan (2001)	N
	Paperiello and Wolf #10	Bryan (1989)	N
	Paperiello and Wolf #17	Bryan (1989)	N
	Paperiello and Wolf #35	Bryan (1989)	N
Subtotal	**5**		
Culex Basin			
	Paperiello and Wolf #19	Bryan (1989)	N
	Paperiello and Wolf #26	Bryan (1989)	N
	Paperiello and Wolf #32	Bryan (1989)	N

		Reference	*Is the geyser visible from a trail, road or boardwalk?*
	Paperiello and Wolf #34	Bryan (1989)	N
	Paperiello and Wolf #38	Bryan (1989)	N
	Paperiello and Wolf #42	Bryan (1989)	N
Subtotal	**6**		
River Group			
	Mound Geyser	Bryan (2001)	N
	unnamed geysers N of Mound (2)	Bryan (2001)	N(2)
	unnamed geyser S of Mound	Cross (2008)	N
	RVG-1	Bryan (2001)	N
	RVG-2 (3 geysers)	Bryan (2001)	N(3)
	RVG-3	Bryan (2001)	N
	"M-190B Geyser"	Bryan (2001)	N
	RVG-4	Bryan (2001)	N
	Azure Spring	Bryan (2001)	N
	Paperiello #7 (5 geysers)	Paperiello and Wolf (1986)	N(5)
	"Pocket Basin Geyser"	Bryan (2001)	N
	"Burple Geyser" (Paperiello and Wolf #26)	Paperiello and Wolf (1986)	N
	RVG-5 "Three by Five Spring"	Bryan (2001), Cross (2008)	N
	"Brain Geyser" (Paperiello and Wolf #27)	Paperiello and Wolf (1986)	N
	RVG-5a "Dark Pool"	Cross (2008)	N
	Fortress Geyser	Bryan (2001)	N
	unnamed geyser S of "Spectrum Spring"	Cross (2008)	N
	unnamed geyser NW of "Spectrum Spring"	Cross (2008)	N
	unnamed geyser to N of "Spectrum Spring"	Cross (2008)	N
	"Thermopod Geyser"	Cross (2008)	N
	"Lightsocket Geyser" (Paperiello #15)	Paperiello and Wolf (1986)	N
	Bath Spring	Bryan (1989)	N
	unnamed geyser 1/4 mile S of Fortress	Bryan (1990)	N
	unnamed geyser near Skeleton Pool	Bryan (1993)	N
Subtotal	**31**		
Sentinel Meadows			
	"Convoluted Geyser" (SMG-2)	Bryan (2001)	N
	Flat Cone	Bryan (2001)	N
	Iron Pot	Bryan (2001)	N
	unnamed geyser near Boulder Spring	Bryan (2001)	N
	SMG-1	Bryan (2001)	N
	The Bulgers	Bryan (2001)	N
	SMG-3	Bryan (2001)	N
	Rosette	Bryan (2001)	N
	Paperiello #6	Paperiello (1990)	N
	Paperiello #8a	Paperiello (1990)	N
Subtotal	**10**		
Fairy Meadows			
	Locomotive Spring	Bryan (2001)	N
	Column Spouter	Bryan (2001)	Y
	Paperiello and Wolf #18	Bryan (1989)	N

	Reference	*Is the geyser visible from a trail, road or boardwalk?*
Paperiello and Wolf #19	Bryan (1989)	N
Paperiello and Wolf #27	Bryan (1989)	N
Paperiello and Wolf #29	Bryan (1989)	N
Paperiello and Wolf #47	Bryan (1990)	N
Paperiello and Wolf #50	Bryan (1990)	N
Paperiello and Wolf #70	Bryan (1990)	N
Paperiello and Wolf #71	Bryan (1990)	N
Paperiello and Wolf #73a	Bryan (1990)	N
Subtotal 11		
Spray and Imperial		
Spray Geyser	Bryan (2001)	Y
Imperial Geyser	Bryan (2001)	Y
Subtotal 2		
Marshall's Hotel Group		
"Twilight Geyser"	Bryan (2001)	N
Subtotal 1		
LOWER GEYSER BASIN TOTAL	**150**	**9 visible (6%)**
LONE STAR GEYSER BASIN		
Halfway Group		
"Halfway Spring"	Bryan (2001)	N
unnamed geyser in woods	Cross, personal observation	N
Lone Star Group		
Lone Star Geyser	Bryan (2001)	Y
"Black Hole Geyser"	Bryan (2001)	Y
"Perforated Cone Geyser"	Bryan (2001)	Y
Bassett Group		
"Buried Geyser"	Bryan (2001)	N
Channel and Bridge Groups		
"Meadow Cones" (LST-3)	Bryan (2001)	N
"Meadow Pool" (LST-3)	Bryan (2001)	N
LST-5	Bryan (2001)	N
"Clamshell Geyser" (LST-8)	Bryan (2001)	N
Campsite Group		
"Broken Arrow Geyser" Paperiello and Wolf #1a	Paperiello and Murray (2005)	N
"Target Pool" Paperiello and Wolf #1b	Paperiello and Murray (2005)	N
LST-5	Bryan (2001)	N
LST-6	Bryan (2001)	N
LST-7	Bryan (2001)	N

	Reference	Is the geyser visible from a trail, road or boardwalk?
Divide Group		
"Divide Geyser"	Cross, personal observation	N
LONE STAR GEYSER BASIN TOTAL	**16**	**3 visible (19%)**
SHOSHONE GEYSER BASIN		
Little Giant Group		
"Trailside Geyser"	Bryan (2001)	Y
Little Giant Geyser	Bryan (2001)	Y
"Double Geyser"	Bryan (2001)	Y
"Meander Geyser"	Bryan (2001)	N
Locomotive Geyser	Bryan (2001)	Y
unnamed geyser below Trailside	Bryan (2001)	Y
"Horse Trail Spring"	Bryan (2001)	Y
unnamed geyser near Little Giant	Paperiello (1989)	N
2nd unnamed geyser below Trailside	Cross (2003)	Y
"Trio Geyser"	Cross (2003)	N
Subtotal 10		
Minute Man Group		
"Skylight Geyser" (SHO-10)	Bryan (2001)	Y
Soap Kettle	Bryan (2001)	Y
Little Bulger Geyser	Bryan (2001)	Y
"Little Bulger's East Vent"	Bryan (2001)	Y
SHO-11 upper	Bryan (2001)	N
SHO-11 lower	Bryan (2001)	N
Gourd Spring	Bryan (2001)	Y
Shield Geyser	Bryan (2001)	Y
Minute Man Geyser	Bryan (2001)	Y
Minute Man's Pool	Bryan (2001)	Y
SHO-12	Bryan (2001)	N
Five Crater Spring	Bryan (2001)	N
Square Spring	Paperiello (1989)	N
Scout Spring	Paperiello (1989)	N
Subtotal 14		
Orion Group		
Taurus Spring	Bryan (2001)	Y
Union Geyser	Bryan (2001)	Y
Sea Green Pool	Bryan (2001)	Y
White Hot Spring	Bryan (2001)	Y
"Fifty Geyser" (SHO-2)	Bryan (2001)	Y
SHO-3	Bryan (2001)	Y
SHO-4	Bryan (2001)	N
SHO-13 (USGS #86a)	Bryan (2001)	N
Kitchen Spring	Paperiello (1992)	Y

		Reference	Is the geyser visible from a trail, road or boardwalk?
	Yellow Boiler	Paperiello (1992)	N
	Paperiello #22	Paperiello (1992)	N
	Paperiello #20	Paperiello (1992)	N
	Paperiello #38	Paperiello (1992)	N
	Paperiello #53	Paperiello (1992)	N
	Paperiello #25	Paperiello (1992)	N
Subtotal	**15**		
Camp Group			
	Geyser Cone	Bryan (2001)	N
	SHO-14	Bryan (2001)	N
	Paperiello #7a	Paperiello (1992)	N
	Paperiello #16	Paperiello (1992)	N
Subtotal	**4**		
North Group			
	Mangled Crater Spring	Bryan (2001)	N
	Frill Spring	Bryan (2001)	N
	Pearl Spring	Bryan (2001)	N
	unnamed geyser near Pearl	Cross (2003)	N
	Glen Spring	Bryan (2001)	N
	Brown Sponge Spring	Bryan (2001)	N
	Yellow Sponge Spring	Bryan (2001)	N
	Small Geyser	Bryan (2001)	N
	Knobby Geyser	Bryan (2001)	N
	Bead Geyser	Bryan (2001)	N
	Velvet Spring	Bryan (2001)	N
	Fissure Spring	Bryan (2001)	N
	Lion Geyser	Bryan (2001)	N
	Bronze Geyser	Bryan (2001)	N
	Iron Conch Geyser	Bryan (2001)	N
	"Yellow Sponge Crack" (Paperiello #7a)	Paperiello (1989)	N
	"Chocolate Pool" (Paperiello #13)	Paperiello (1989)	N
	"Troll Geyser" (Paperiello #18)	Paperiello (1989)	N
	"Terracette Spring" (Paperiello #20)	Paperiello (1989)	N
	Paperiello #23	Paperiello (1989)	N
	Paperiello #27	Paperiello (1989)	N
	Paperiello #42	Paperiello (1989)	N
	"Old Lion Geyser" (Paperiello #43)	Paperiello (1992)	N
	Paperiello #45	Paperiello (1989)	N
	Paperiello #61	Paperiello (1989)	N
	"Snail Geyser" (Paperiello #4)	Cross (2003)	N
	"Slosh Geyser" (Paperiello #25)	Cross (2003)	N
	"Yellow Sponge Cone" (Paperiello #7b)	Cross (2003)	N
	"Snout Geyser" (Paperiello #63)	Cross (2003)	N
	"The Hydra" (Paperiello #9)	Cross (2002)	N
	unnamed geyser in triangular pool	Cross (2003)	N
	unnamed geyser by Blowout Pool	Cross, personal observation	N
Subtotal	**32**		

		Reference	Is the geyser visible from a trail, road or boardwalk?
South Group			
	SHO-7	Bryan (2001)	N
	"Outbreak Geyser" (SHO-8)	Bryan (2001)	N
	Three Crater Spring	Bryan (2001)	N
	Coral Pool	Paperiello (1989)	N
	Wave Spring	Paperiello (1989)	N
	Flake Spring	Paperiello (1989)	N
	Paperiello #12	Paperiello (1989)	N
	Paperiello #13	Paperiello (1989)	N
	Blue Glass Spring	Paperiello (1989)	N
	"1994 blowout"	Cross (2003)	N
	unnamed geyser N of 1994 blowout	Cross (2003)	N
	"Diverted Geyser" (Paperiello #4)	Cross (2003)	N
	"Rototiller Geyser"	Cross, personal observation	N
Subtotal	**13**		
Western Group			
	"Pectin Geyser" (Paperiello #14)	Bryan (2001)	N
	"Not Pectin Geyser" (SHO-15)	Bryan (2001)	N
	Paperiello #10	Cross (2003)	N
	Paperiello #16	Paperiello (1992)	N
	"Tunnel Geyser" (Paperiello #54)	Paperiello (1992)	N
	Paperiello #2	Cross (2003)	N
	"Double Crater Spring" (Paperiello #26)	Cross (2003)	N
Subtotal	**7**		
"Horse Camp Group"			
	Paperiello #15	Paperiello (1992)	N
	Paperiello #2	Paperiello (1992)	N
Yellow Crater Group			
	unnamed geyser	Bryan (2001)	N
Lake and Shore Groups			
	unnamed geyser (Lake Group)	Cross (2003)	N
	"Burning Eyes Geyser"	Cross (2003)	N
Subtotal	**5**		
SHOSHONE GEYSER BASIN TOTAL		**100**	**22 visible (22%)**
HEART LAKE GEYSER BASIN			
Rustic Group			
	Rustic	Bryan (2001)	N
	HRG-P7	Bryan (2001)	N
	"Composite Geyser" (HRG-P6)	Bryan (2001)	N
	HRG-P3	Bryan (2001)	N

		Reference	*Is the geyser visible from a trail, road or boardwalk?*
	Prometheus Spring	Bryan (2001)	N
	HRG-P12	Bryan (2001)	N
	"Threaded Geyser" (HRG-P15)	Bryan (2001)	N
	Paperiello #17	Paperiello (1989)	N
Subtotal	**8**		
Lower Group (eastern subgroup)			
	"Turbine Geyser" (HLG-P1)	Bryan (2001)	N
	"Calix Geyser" (HLG-P19)	Bryan (2001)	N
	HLG-P32	Bryan (2001)	N
	HLG-P34	Bryan (2001)	N
	"Ivory Geyser" (HLG-P43)	Bryan (2001)	N
	HLG-P53	Bryan (2001)	N
	HLG-P54	Bryan (2001)	N
	HLG-P8	Bryan (2001)	N
	HLG-P7	Bryan (2001)	N
	Paperiello #21	Paperiello (1989)	N
	Paperiello #24	Paperiello (1989)	N
	Paperiello #41	Paperiello (1989)	N
	Paperiello #1 (western subgroup)	Paperiello (1989)	N
Subtotal	**13**		
Middle Group			
	HMG-P42	Bryan (2001)	N
	HMG-P56	Bryan (2001)	N
Subtotal	**2**		
Fissure Group			
	HFG-P5	Bryan (2001)	N
	HFG-P7	Bryan (2001)	N
	"Pit Geyser" (HFG-P35)	Bryan (2001)	N
	HFG-P36	Bryan (2001)	N
	"Glade Geyser"	Bryan (2001)	N
	"Wisp Geyser" (HFG-P138)	Bryan (2001)	N
	HFG-P116	Bryan (2001)	N
	Splurger Geyser	Bryan (2001)	N
	Puffing Spring	Cross (2005)	N
	"Shell Geyser"	Bryan (2001)	N
	Hooded Spring	Bryan (2001)	N
	"Siphon Geyser" (HFG-P52)	Bryan (2001)	N
	HFG-P91	Bryan (2001)	N
	HFG-P70	Bryan (2001)	N
	HFG-P69	Bryan (2001)	N
	HFG-P68	Bryan (2001)	N
	HFG-P67	Bryan (2001)	N
	Paperiello #65	Bryan (1990)	N
	"Fissure Springs Geyser" (Paperiello #57)	Bryan (2001)	N
	Paperiello #56	Paperiello (1989)	N
	Paperiello #80	Paperiello (1989)	N

		Reference	Is the geyser visible from a trail, road or boardwalk?
	Paperiello #99	Paperiello (1989)	N
	"Porthole Geyser" (Paperiello #101)	Paperiello (1989)	N
	Paperiello #103	Paperiello (1989)	N
	Paperiello #106	Bryan (1990)	N
	Paperiello #140	Paperiello (1989)	N
	Paperiello #143	Paperiello (1989)	N
	Paperiello #159	Paperiello (1989)	N
	Paperiello #166	Bryan (1990)	N
	Paperiello #173	Paperiello (1989)	N
	unnumbered geyser, by Paperiello #69	Cross, personal observation	N
	Paperiello #78	Cross (2005)	N
	Paperiello #74	Cross, personal observation	N
Subtotal	**33**		
Upper Group			
	Deluge Geyser	Bryan (2001)	N
	Paperiello #14	Cross, personal observation	N
	HUG-P16	Bryan (2001)	N
	HUG-P11	Bryan (2001)	N
	Yellow Funnel Spring	Bryan (2001)	N
	HUG-P51 (2 geysers)	Bryan (2001)	N(2)
Subtotal	**7**		
HEART LAKE GEYSER BASIN TOTAL		**63**	**0 visible (0%)**
GIBBON GEYSER BASIN			
Artist's Paint Pots			
	GIB-2	Bryan (2001)	Y
Subtotal	**1**		
Geyser Springs			
	"Bull's Eye Spring" (GIB-7)	Bryan (2001)	N
	"Anthill Geyser" (GIB-3)	Bryan (2001)	N
	GIB-8 "Sand Pile Geyser"	Bryan (2001)	N
	GIB-4	Bryan (2001)	N
	"Subterranean Blue Mud Geyser"	Bryan (2001)	N
	Oblique Geyser	Bryan (2001)	N
	"Big Bowl Geyser"	Bryan (2001)	N
	GIB-9	Bryan (2001)	N
	"Bat Pool" (GIB-6)	Bryan (2001)	N
	"Tiny Geyser" (GIB-5)	Bryan (2001)	N
	"Entry Pool"	Bryan (1989)	N
	5 unnamed geysers	Bryan (1989)	N(5)
Subtotal	**16**		

		Reference	*Is the geyser visible from a trail, road or boardwalk?*
Gibbon Hill Group			
"Phoenix Geyser"		Bryan (2001)	N
Gibbon Hill Geyser		Bryan (2001)	N
Subtotal	**2**		
Sylvan Springs			
GIB-13		Bryan (2001)	N
Paperiello and Wolf #2		Paperiello and Wolf (1986)	N
Paperiello and Wolf #3		Paperiello and Wolf (1986)	N
Subtotal	**3**		
Gibbon Canyon			
unnamed geyser		Bryan (2001)	N
Subtotal	**1**		
GIBBON GEYSER BASIN TOTAL	**23**		**1 visible (4%)**
NORRIS GEYSER BASIN			
100-Spring Plain			
"Tantalus Geyser"		Bryan (2002)	N
"Breach Geyser"		Bryan (2002)	N
The Gap			
"Elk Geyser"		Wolf and Paperiello (1999)	N
unnamed geysers (6)		Wolf and Paperiello (1999)	N(6)
Unnamed area 2 km west of Norris			
unnamed geysers (3)		Bryan (2001)	N(3)
NORRIS GEYSER BASIN TOTAL	**12**		**0 visible (0%)**
WEST THUMB GEYSER BASIN			
Lake Shore Group			
Overhanging Geyser		Bryan 2001	N
Blowhole Spring		Bryan 2001	Y
Subtotal	**2**		
WEST THUMB GEYSER BASIN TOTAL	**2**		**1 visible (50%)**

	Reference	Is the geyser visible from a trail, road or boardwalk?
POTTS HOT SPRING BASIN		
Upper Mercurial Group		
Geyser 51	Taylor & Grigg (1999)	N
Geyser 1a "Pince-Nez Geyser"	Taylor & Grigg (1999)	N
Geyser 1b	Taylor & Grigg (1999)	N
Geyser 41	Taylor & Grigg (1999)	N
Geyser 21	Taylor & Grigg (1999)	N
Geyser 42	Taylor & Grigg (1999)	N
Geyser 48	Taylor & Grigg (1999)	N
Geyser 49	Taylor & Grigg (1999)	N
Geyser 22	Taylor & Grigg (1999)	N
Geyser 23	Taylor & Grigg (1999)	N
Geyser 15b	Taylor & Grigg (1999)	N
Spring 173	Seen summer 2006	N
Spring 176	Seen summer 2006	N
Geyser 174	Taylor & Grigg (1999)	N
Subtotal 14		
Lower Mercurial Group		
Geyser 3	Taylor & Grigg (1999)	N
Geyser 3a	Taylor & Grigg (1999)	N
Geyser 2a	Taylor & Grigg (1999)	N
Geyser 2b	Taylor & Grigg (1999)	N
Geyser 2c	Taylor & Grigg (1999)	N
Spring 4	Taylor & Grigg (1999)	N
Geyser 5	Taylor & Grigg (1999)	N
Geyser 6 "Mercurial Geyser"	Taylor & Grigg (1999)	N
Geyser 7 "Tadpole Geyser"	Taylor & Grigg (1999)	N
Geyser 8 "Generic Geyser"	Taylor & Grigg (1999)	N
Geyser 9 "Quinque Geyser"	Taylor & Grigg (1999)	N
Geyser 14	Taylor & Grigg (1999)	N
Geyser 10	Taylor & Grigg (1999)	N
Geyser 11	Taylor & Grigg (1999)	N
Geyser 12 "Corner Pocket Geyser"	Taylor & Grigg (1999)	N
Geyser 333	Taylor & Grigg (1999)	N
Geyser 343 "Berm Geyser"	Taylor & Grigg (1999)	N
Geyser 30	Taylor & Grigg (1999)	N
Geyser 38 "Pear Pool"	Taylor & Grigg (1999)	N
Geyser 32	Taylor & Grigg (1999)	N
Geyser 31	Taylor & Grigg (1999)	N
Geyser 33 "Spate Geyser"	Taylor & Grigg (1999)	N
Geyser 34	Taylor & Grigg (1999)	N
Geyser 35 "Cuirass Geyser"	Taylor & Grigg (1999)	N
Subtotal 24		

	Reference	*Is the geyser visible from a trail, road or boardwalk?*
North Beach Group		
60 North	Taylor & Grigg (1999)	N
60 South	Taylor & Grigg (1999)	N
Spring 17	Seen summer 2007	Y
Subtotal 3		
South Beach Group		
Geyser 70	Taylor & Grigg (1999)	N
Geyser 71 "Ramshackle Geyser"	Taylor & Grigg (1999)	N
Spring 72	Taylor & Grigg (1999)	N
Subtotal 3		
Empty Hole Group		
11EH	Taylor & Grigg (1999)	N
Geyser 5EH	Taylor & Grigg (1999)	N
Geyser 6EH	Taylor & Grigg (1999)	N
Geyser 7EH	Taylor & Grigg (1999)	N
Geyser 8EH	Taylor & Grigg (1999)	N
Geyser 9EH "Resurgent Geyser"	Taylor & Grigg (1999)	N
Subtotal 6		
POTTS HOT SPRING BASIN TOTAL	**50**	**1 visible (2%)**
ADDITIONAL GEYSER AREAS		
Lewis Lake Hot Springs		
"Reverse Geyser"	Cross (1998)	N
Ferris Fork of the Bechler River		
unnamed geysers (3)	Bryan (2001)	N(3)
Boundary Creek		
unnamed geysers (2)	Bryan (2001)	N(2)
Joseph's Coat Hot Springs		
"Broadside Geyser"	Bryan (2001)	N
Bog Creek Hot Springs		
"Enigma Geyser"	Bryan (2001)	N
"Vitriol Geyser"	Paperiello and Wolf (1986)	N
Paperiello and Wolf #8	Paperiello and Wolf (1986)	N
Sulphur Hills Hot Springs		
Crater Hills Geyser	Bryan (2001)	N
Alabaster Springs		
unnamed geyser	Paperiello and Wolf (1986)	N

	Reference	*Is the geyser visible from a trail, road or boardwalk?*
Glen Africa Basin		
"The Black Torch" (Paperiello #26)	Cross, personal observation	N
Highland Hot Springs		
Miniature Geyser	Bryan (2001)	N
Sedge Bay		
unnamed geyser	Bryan (2001)	N
Seven Mile Hole		
Halfway Spring	Bryan (2001)	Y
Safety Valve Geyser	Bryan (2001)	Y
unnamed geyser	Bryan (2001)	Y
Grand Canyon of the Yellowstone		
Fairy Geyser	Bryan (2001)	N
Watermelon Geyser	Bryan (2001)	N
Tom Thumb Geyser	Bryan (2001)	N
"Red Rock Geyser"	Bryan (2001)	N
"Phantom Bridge Geyser"	Bryan (2001)	N
Paperiello and Wolf #5	Paperiello and Wolf (1986)	N
ADDITIONAL AREAS TOTAL	**24**	**3 visible (13%)**
GRAND TOTAL	**529**	**66 visible (12%)**

New Geyser Activity at Black Sand Basin

In early May 2007, several observers noticed a new geyser beyond Opalescent Pool in Black Sand Basin. Stephen Eide, who took eruption photos *(above and immediate right)* on May 3, 2007, reported, "Most of the eruption was in the 10-15 foot range with the higher bursts 20 feet high, as best I could estimate….The eruption was relatively steady while I watched it at that height. It occasionally weakened, or thinned out for a second or so, but that is all."

Eide suggested the name "Sunlight Geyser" for this feature, in reference to Sunlight Basin, an early name for Black Sand Basin.

The lower right photo, taken by Pat Snyder on July 31, 2007, illustrates the activity seen during the months following the geyser's emergence. In more than 45 minutes of observation that day, Snyder saw "Sunlight Geyser" having bursts reaching no higher than 3 feet.

About the Authors

T. Scott Bryan (M.S., Geological Sciences, University of Montana) has been in Yellowstone in 1949, 1951, 1952, and during every summer starting with 1970. He worked in the park as a summer seasonal employee from 1970 to 1977 and 1980 to 1986, and served as a volunteer in the summers of 1987 to 1993. He has also visited the geysers in California, Nevada, Oregon, Mexico, Russia, Fiji, and New Zealand. One of the founding Directors and the first President of GOSA, Scott began the publication of *The Geyser Gazer Sput*, served as the editor of several volumes of these *GOSA Transactions*, and is the author of *The Geysers of Yellowstone* (University Press of Colorado, new 4th Edition was published in July 2008) and *Geysers: What They Are and How They Work* (Mountain Press, 2nd Edition). With his wife, Betty, as co-author, he is also the author of *The Explorer's Guide to Death Valley National Park* (University Press of Colorado, new 2nd Edition due in 2009). Professor Emeritus from Victor Valley College in California, his permanent residence is now in Oro Valley, Arizona.

Jeff Cross 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 spent the last year teaching chemistry at Walla Walla University.

Tara Cross (Master's 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 Fan and Mortar Geysers, Link Geyser, and Shoshone Geyser Basin in that publication. She has also contributed articles to *The Geyser Gazer Sput* on Fan and Mortar Geysers, Giant Geyser, and the geysers of New Zealand.

John Ego is a senior geologist for the National Oil Corporation of Kenya. He is actively involved in the search for petroleum, both in modern and ancient rift basins in Kenya and in sedimentary basins offshore.

Stephen J. Eide holds a Bachelors degree in Pharmacy from Idaho State University 1980. He works as a consulting pharmacist in nursing homes and assisted living facilities in western Idaho. He began visiting Yellowstone in 1994 and has returned several times a year since then. He is interested in any thermal feature, with some special emphasis on geysers. He makes a point of visiting some of Yellowstone's backcountry features at least yearly. He does enjoy the Fountain group; however, he is interested in any geyser.

Dr. Stephen Michael Gryc is a classical composer whose music is heard throughout the world in live performance and in recordings. He earned four degrees in music from the University of Michigan and is currently Professor of Music Composition and Theory at the Hartt School of the University of Hartford in Connecticut. His interest in both sound and geysers led him to make digital audio recordings of Yellowstone's thermal features and other environmental sounds. His Yellowstone recordings have been used in the soundtrack of the educational film *Yellowstone: A Symphony of Fire and Water* and in an exhibit at Yellowstone's Canyon Museum. Dr. Gryc has been visiting Yellowstone National Park since 1963 and has contributed articles to *The Geyser Gazer Sput* and the *GOSA Transactions*, Volumes VII and IX.

Thomas Magnera first visited the Upper Geyser Basin in 1973 and has been plagued with geyser syndrome and the owner of a wide-brimmed hat ever since. Closely timed radio calls announcing "Fan and Mortar is in a lock" and "Giant is surging above the cone" would mostly likely force him to dash to Fan and Mortar. When recovering from trips to Yellowstone, he is a research scientist at the University of Colorado.

Mary Ann Moss Mary Ann Moss was a volunteer for park geologist Rick Hutchinson in the 1980s and early 1990s, conducting various research projects for the National Park Service. Though she could often be found studying Giant and Grotto Geysers, she also documented the activity of Excelsior Geyser and many others.

R. Bernhart Owen is Professor in the Department of Geography at Hong Kong Baptist University. His research interests include sedimentation in African Rift lakes, where he commonly using fossil diatoms (algae with siliceous skeletons) to reconstruct environmental history, and the geology of Hong Kong. Recent work has included studies of diatoms that live in and around hot springs and geysers. He is also author of two books on the geology and landscapes of Hong Kong.

Robin Renaut is a Professor in the Department of Geological Sciences at the University of Saskatchewan. His research interests include the origin of geothermal deposits (sinter, travertines) and sedimentation in East African lakes. He has undertaken research in many geothermal locations including New Zealand, Iceland, Kenya, Bolivia and Chile. One recent study has been on the history of activity at Geysir in Iceland, using volcanic ash layers in the sinter as a dating tool (published in Journal of the Geological Society, London, v. 164: 1241-1252 [2007]).

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) recently retired from Eastern Washington University where she was a Professor of Accounting and taught courses in accounting, business statistics and decision making. She stared volunteering as a thermal observer in Yellowstone in 1988. In recent years she has volunteered for both the Park Geologist and the Old Faithful Visitor Center. Her duties include collection and analysis of geothermal data, preparation of the electronic version of the Old Faithful Visitor Center logbook, and assistance with Great Fountain predictions. Lynn has contributed several articles in previous volumes of The GOSA Transactions, including pieces about Old Faithful, Giant, Atomizer, Slide, Till, and a series of articles on the Fountain Complex. She is a frequent contributor to The Geyser Gazer Sput, where her articles range from technical analysis of geyser behavior patterns to reports on current geyser behavior (with particular emphasis on geysers in the north end of the Upper Geyser Basin, Midway, Firehole Lake Drive, and the Fountain Complex in the Lower Geyser Basin) to human interest articles about geyser gazers to whimsical articles such as geyser quotes and doggerel. She is currently writing a 20-year review of Beehive's Behavior Patterns for Transactions XI and a series of articles about the 1959 Hebgen Lake Earthquake that will appear in The Geyser Gazer Sput between August 2008 and August 2009. Lynn currently serves as the 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 has served as a Director of GOSA for many years, and has been President since May of 1994. Ralph has been a Volunteer for the National Park Service since 1987, and since his retirement in 1997 has spent 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 and writes a regular column in The Geyser Gazer SPUT.

Vicki M. Whitledge holds a Bachelor of Science degree in Marine Biology from Long Island University-Southhampton, New York, and Master and Doctorate Degrees in Applied Mathematics from the University of New York-Stony Brook. She is an Associate 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.

Lee Whittlesey's thirty-five-year studies in the history of the Yellowstone region have made him an expert on Yellowstone's vast literature and have resulted in numerous publications. He is the author, co-author, or editor of eight books and more than twenty-five journal articles, including: *A Yellowstone Album: A Photographic Celebration of the First National Park; Death in Yellowstone*; *Lost in the Yellowstone (with Truman Everts)*; *Yellowstone Place Names* (revised edition in 2006), and the voluminous *Wonderland Nomenclature* (2,123 pages). Dr. Paul Schullery joins him as co-author of *Myth and History in the Creation of Yellowstone National Park,* and their next book, *A History of Large Mammals of the Yellowstone Region, 1806-1883*, is forthcoming in 2009. His most recent book is *Storytelling in Yellowstone: Horse and Buggy Tour* Guides, and his next book, *Images of America: Yellowstone*, will appear in May of 2008. In *The Guide to Yellowstone Waterfalls and Their Discovery* (2000), Whittlesey and two co-authors revealed the existence of more than 225 previously unknown waterfalls in Yellowstone National Park. For this accomplishment, he was featured on ABC News, NBC News, the Discovery Channel, the Travel Channel, and *People* magazine, and he is often seen on regional and local television talking about Yellowstone's history. Whittlesey has an M.A. in history from Montana State University and a law degree (J.D.) from the University of Oklahoma. Because of his extensive writings and long contributions to Yellowstone National Park, Idaho State University conferred upon him an Honorary Doctorate of Science and Humane Letters in 2001. Since 1996, he has been an adjunct professor of history at Montana State University.

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Baby Daisy Geyser Activity in 2003-2004

Ralph Taylor

Abstract

Baby Daisy Geyser is located in the Old Road Group of the Upper Geyser Basin. It has had only three known periods of activity: 1952, lasting less than one year; 1959, lasting less than one year, and 2003-4, lasting from February 2003 to December 2004. This paper discusses the 2003-4 activity as reported by observers between February and June of 2003 and as recorded electronically from June 2003 to the end of the active cycle in December 2004.

Introduction

The Old Road Group of the Upper Geyser Basin contains numerous hot springs but few geysers. The geysers that exist in this area, located east of the Grand Loop Road and south of Biscuit Basin, have often been active for relatively short periods only. One such geyser is Baby Daisy Geyser. This small geyser has had only three known periods of activity. The most recent active phase, which is the primary topic of this paper, began during the winter of 2002-3 and continued until December of 2004.

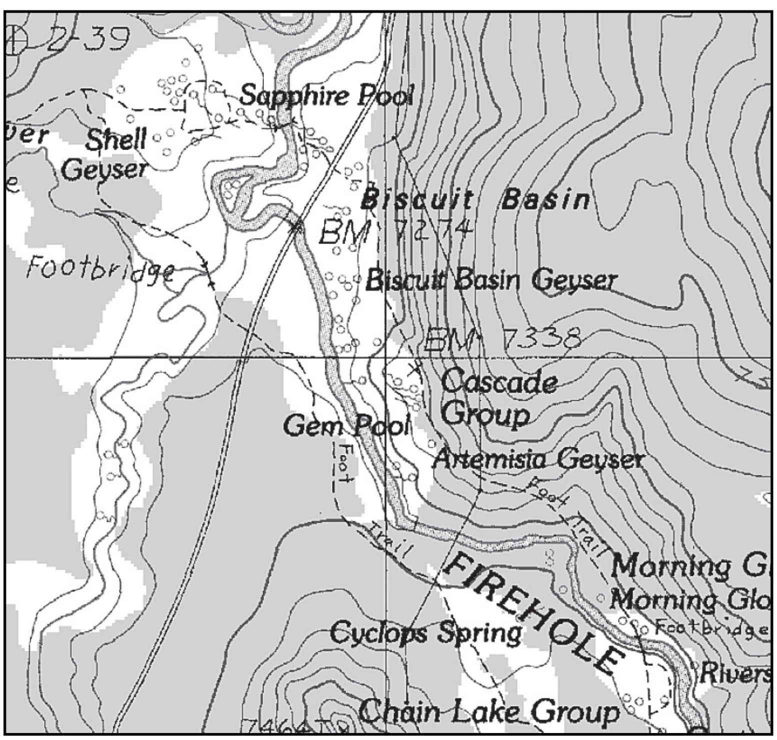


Figure 1. Section of the USGS topographic map showing the Cascade Group and Biscuit Basin. Baby Daisy Geyser is "B" in Biscuit Basin Geyser.

Location

Baby Daisy Geyser is located in a small group of features located between the footpath that follows the old Grand Loop Road and the Firehole River. Figure 1 is a section of the Old Faithful quadrangle topographic map showing the area. Baby Daisy Geyser is located below and to the left of the letter "B" in the "Biscuit Basin Geyser" caption. While it was active it was often seen from passing vehicles, especially those traveling from north to south. Baby Daisy's formation is located within sight of the trail from Morning Glory Pool to Biscuit Basin, but trees and undergrowth made it difficult to spot the low-lying crater when Baby Daisy was not erupting.

When Baby Daisy was in an active phase and in eruption, it could easily be seen from the trail, as shown in Figure 2.

Historical Background

George Marler first noted eruptive activity at Baby Daisy in 1952. He wrote:

> During the 1952 season a plot of ground of about half an acre in extent suddenly became hot enough to result in 8 different springs taking on geyser proclivities. This occurred sometime between July 11 and 13. Previous to this I had never observed any geyser activity in this particular group of springs. Most had been quite inauspicious in appearance. These springs are located in the southeastern end of Biscuit Basin, on the east side of the Firehole River. The geyser farthest to the south was called Baby Daisy.[1]

He stated that activity continued for the rest of the 1952 season, but that no activity

[1] Marler, George D. *Inventory of Thermal Features of the Firehole River Geyser Basins and Other Selected Areas of Yellowstone National Park*, USGS GD73-018.

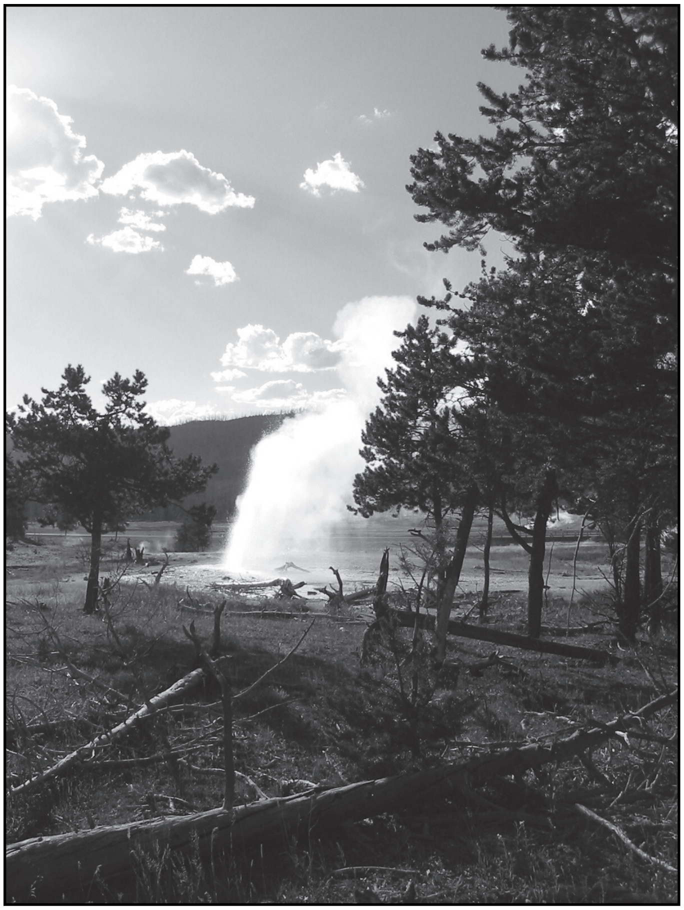


Figure 2. Baby Daisy Geyser in eruption, seen from the footpath along the old roadbed.

was observed from 1953 until the 1959 Hebgen Lake earthquake. Marler noted that the activity was the first in many years since a grove of lodgepole pine trees 9 meters (30 feet) from the geyser were killed by the spray, indicating that there had been no activity during the years that the trees had grown. Those trees were subsequently burned by the 1988 fires, and only scattered bits of wood remain.

The next activity was apparently initiated by the Hebgen Lake earthquake in 1959 and had ended by the 1960 season.

2003-4 Activity

The latest active period started during the winter of 2003. In an email to the geyser list, geyser gazer and NPS volunteer Mike Keller reported

> For the first time in many years Baby Daisy Geyser is active. NPS Rangers Dave Page and Tim Townsend both saw an angled geyser in the Cascade area erupting two days ago (2/20) around 1030ie. Over the past two days they kept seeing this geyser at least once a day. This evening (2/22) Tim and I went to see what feature was active and found it was Baby Daisy. While we were there it even erupted for us! The play lasted just over 3 minutes, was angled towards the old road, and reached from 20 to 25 feet. Based upon wash in the

Figure 3. Baby Daisy Geyser's formation from the location of the data logger. Note the large washed area around the crater.

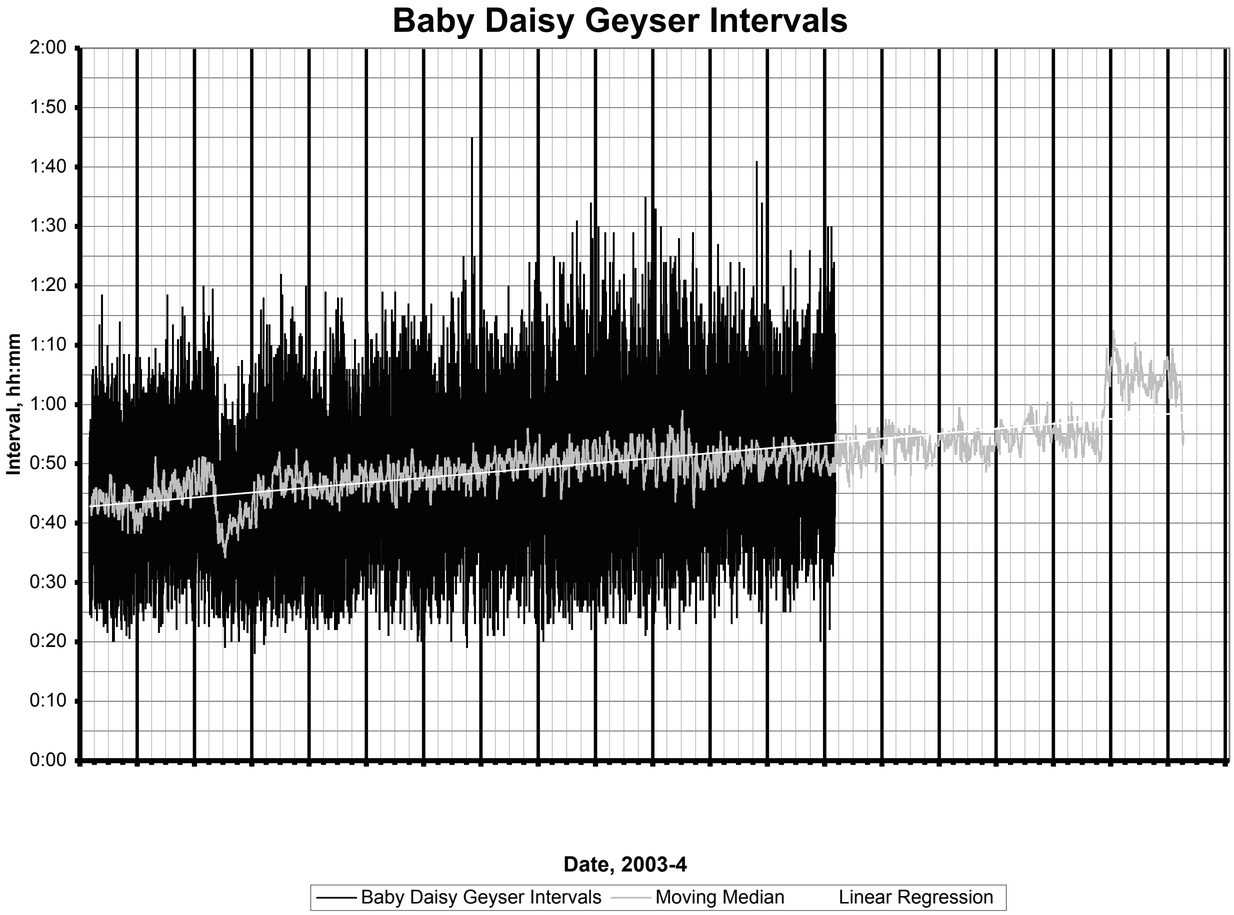


Figure 4. Baby Daisy Geyser eruption intervals (black) and 1-day moving median interval (gray).

> area it appears that Baby Daisy has been active for at least a week and possibly longer.[2]

The exact date of the reactivation was never determined due to the low number of visitors during the winter season. Activity reports continued through the winter and spring months with no reported periods of inactivity noted.

The author was a volunteer for the NPS during the active period. Upon my arrival at Old Faithful in June, I deployed an electronic data logger in Baby Daisy's runoff channel at the first opportunity. Electronic monitoring began at 1500 on 22 June 2003 and continued without a break until 25 June 2005. The last recorded eruption was at 0950 on 8 December 2004.

Description of Baby Daisy's Formation

Baby Daisy Geyser erupted from a roughly circular basin in a sinter mound covered by sinter gravel, as shown in Figure 3. The basin was approximately two meters (6.5 feet) in diameter and about 20cm (8 inches) deep. The vent was roughly circular, about 30cm (12 inches) in diameter, and located at the center of the basin. The sinter mound was washed clean of gravel for a meter or so uphill from the crater and for 8-10 meters (about 25-30 feet) to the north. There was a distinct berm of gravel around the washed area uphill from the vent. The basin from which Baby Daisy erupted was lined with ochre-colored sinter.

Eruption Characteristics

During the 2003-4 activity, eruptions of Baby Daisy Geyser occurred at intervals of between 18 minutes and 1 hour 50 minutes, averaging about 45 minutes in 2003 and 53 minutes between eruptions in 2004. Eruptions lasted between two and four minutes. As the start of an eruption approached, water rose in the vent until the inner basin was filled. The filling was accompanied by boiling that increased in vigor as the eruption neared. Once the eruption started, the water column rapidly reached its estimated maximum height of between 6 and 7.5

[2] "*REPORT: Baby Daisy Geyser (Keller)*", geyser report posted on the Geyser List Server, Mike Keller, 22 February 2003.

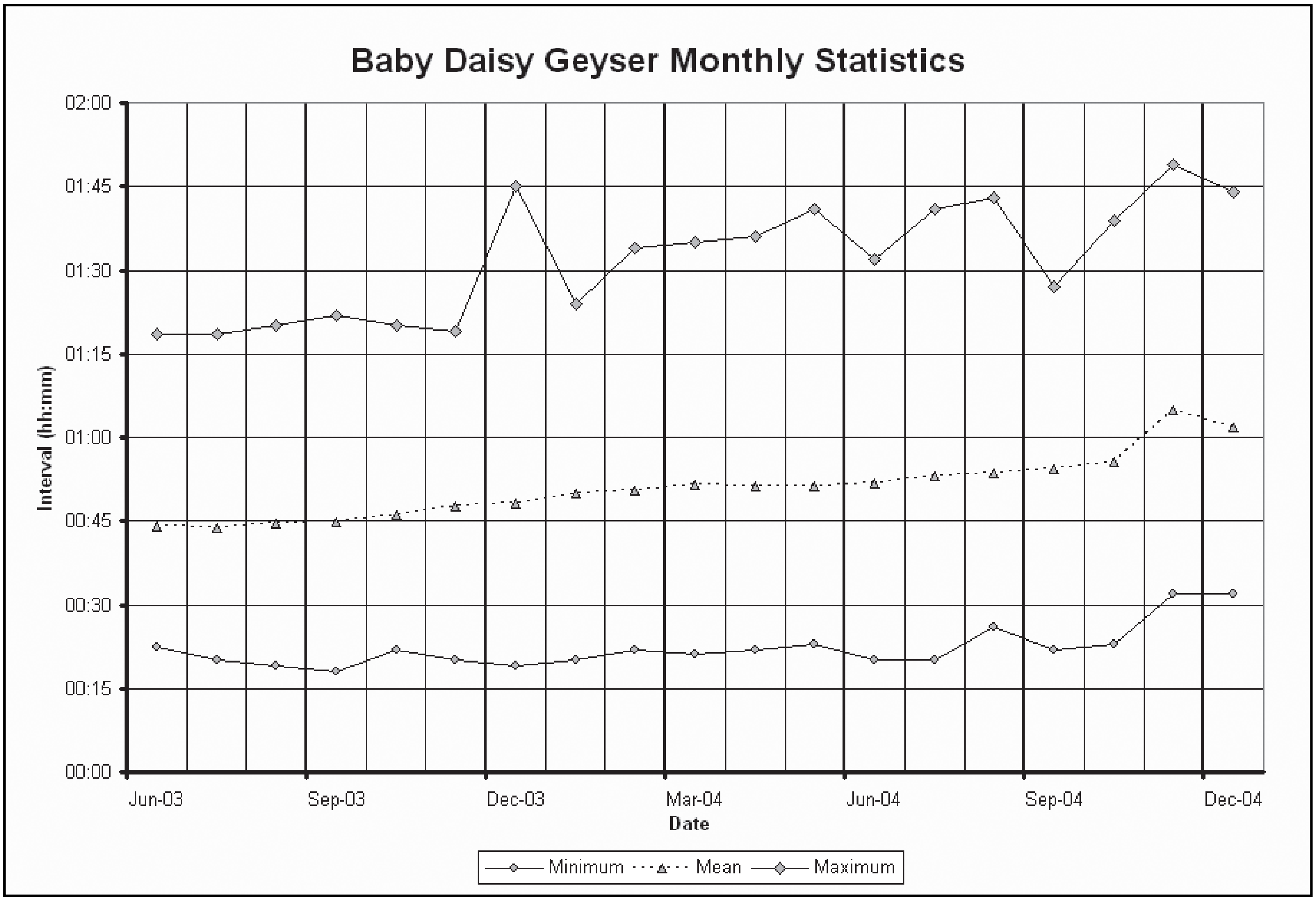


Figure 5. Baby Daisy Geyser monthly minimum, maximum, and mean intervals

meters (20 to 25 feet). The water jet was angled at about 30° to the vertical toward the north. It was the similarity of this angled eruption from a round basin to the eruptions of Daisy Geyser that inspired the name "Baby Daisy."

Analysis of Eruptions

Reports of Baby Daisy Geyser eruptions before 22 June 2003 are sparse. Short sets of eruption intervals and durations were reported in March and April by geyser gazers.[3] Activity reports noted durations of two to three plus minutes. Paperiello reported intervals averaging 34 minutes on 15 March, 30 minutes on 19 March, 33 minutes on 29 March, 36 minutes on 6 April, 34 minutes on 12 April, and 40 minutes on 19 April.[4]

Once the electronic data logger was deployed, the temperature trace showed 15307 intervals ranging from 0h18m to 1h49m. Figure 4 is a plot of all intervals recorded by the data logger for Baby Daisy Geyser. The black band illustrates the erratic nature of the intervals, which varied by 60 to 80 minutes from minimum to maximum in any given month. There did not appear to be any pattern to the variation; that is, intervals did not alternate long-short but appeared to vary randomly from interval to interval.

Over the nearly 20 months for which there is a complete record of intervals, the general trend was a gradual increase shown by the white linear regression line in Figure 4. The wide variation in intervals makes trends difficult to see. To help illustrate trends in intervals, Figure 4 also includes a plot of daily moving median intervals, shown in gray.[5]

Closer examination of the moving median interval (the gray line in Figure 4) shows two events that changed intervals abruptly. The first occurred between 21 and 28 August 2003, when the daily median intervals dropped from 50 to 35 minutes,

[3] Posts to the geyser list server were made by Michael Lang on 3 March 2003, by David Goldberg on 14 March 2003, and by Rocco Paperiello (several reports in March and April 2003)

[4] Paperiello, Rocco; report posted to the Geyser List on 19 April 2003

[5] Actually, the moving median covers 29 intervals, which approximates the mean of 28.6 intervals per day.

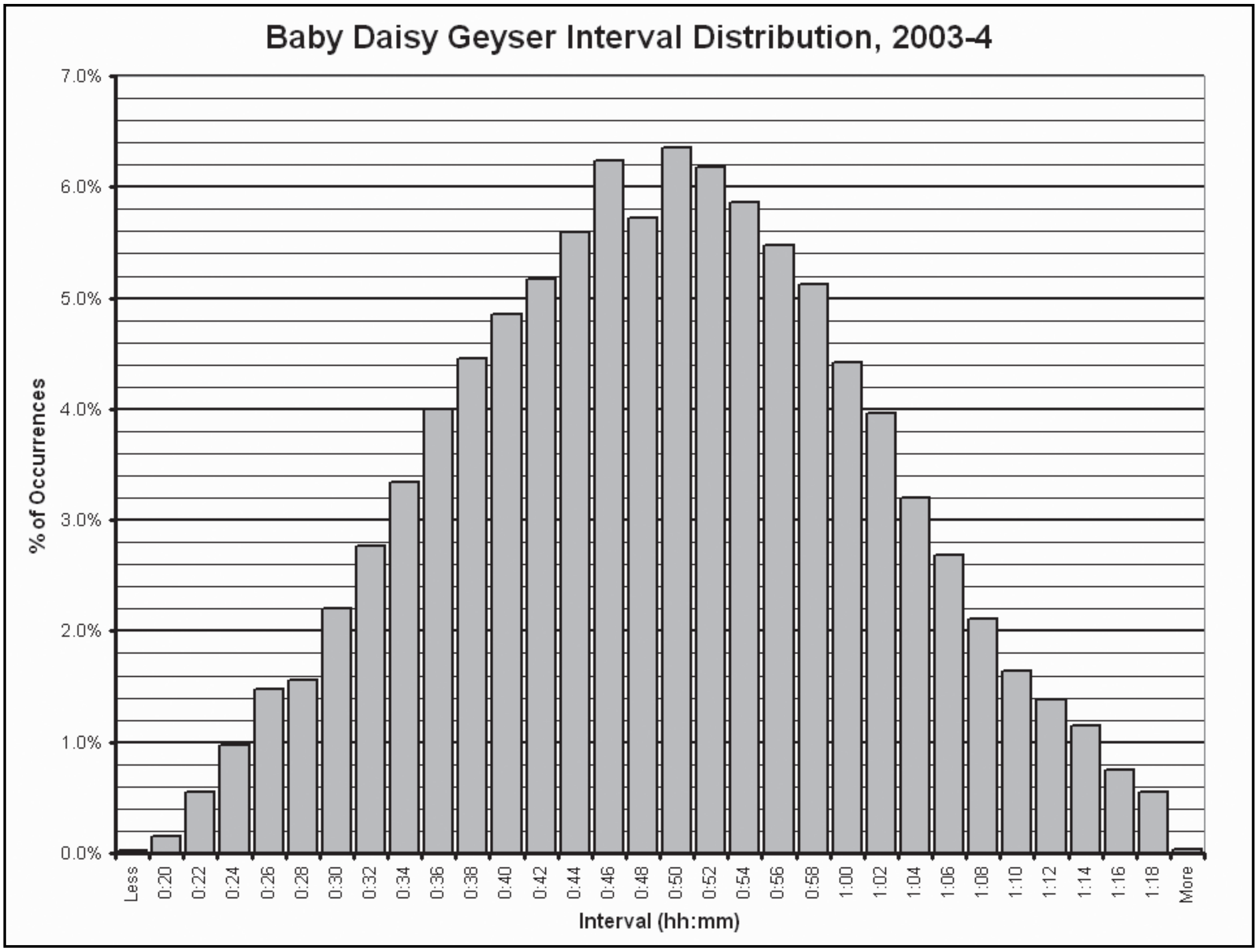


Figure 6. Baby Daisy Geyser interval distribution histogram

then recovered over the next three weeks to the long-term trend line. The second event occurred between 29 October and 2 November 2004, when the median intervals first dropped then jumped nearly 15 minutes in a three day period. After the latter change, intervals remained longer until the activity abruptly ceased on 8 December.

Figure 5 is a plot of the monthly minimum, mean, and maximum intervals, and provides a different look at the activity. The trend to longer intervals shows up on this plot also, as does the late October 2004 increase in intervals. The distance between the maximum and minimum curves clearly illustrates the variation.

Figure 6 is an interval distribution histogram for all of the Baby Daisy Geyser intervals recorded electronically. Bin labels are the center of the bucket; that is, the bin labeled "0:40" contains the percentage of intervals between 39m30s and 41m30s. The distribution is symmetrical about 0h50m with few extreme outliers. There does not appear to be a seasonal variation, and no other periodic fluctuations appear to be present.

Comparison with Historical Activity

Marler reports that during its initial observed activity in 1952 Baby Daisy's eruptions lasted "from about 2 to 2 ½ minutes"[6] and reported the eruption height as "about 30 feet"[7] and that "intervals ranged between about 90 and 120 minutes."[8] This activity is similar to what was seen in the 2003-4 activity but with rather longer intervals.

In the activity that followed the 1959 Hebgen Lake earthquake, Marler wrote:

> Again checked eruptions lasted from about 2 to 2 1/2 minutes; the height the same as during 1952. However, there was greater frequency of eruptions, the intervals ranging between about 60 and 96 minutes.[9]

This activity is more similar to the 2003-4 activity. The intervals fall within the range of intervals

[6] Marler, George D. *Inventory of Thermal Features of the Firehole River Geyser Basins and Other Selected Areas of Yellowstone National Park*, USGS GD73-018

[7] ibid.

[8] ibid.

[9] Marler, George D., ibid

from 2003-4, but apparently the sub-hour intervals seen in the latest activity were not observed in 1959. Overall, the latest activity is quite similar to the earlier activity, although there appears to have been more water or energy available in the most recent active period since longer durations and shorter intervals were observed.

Baby Daisy Geyser Returns to Dormancy

On 8 December 2004, with no premonitory signs, Baby Daisy Geyser simply stopped erupting. Aside from the abrupt increase in intervals in late October 2004 discussed above, there was no warning of waning power or declining activity. The last observed eruption intervals were no different from the preceding intervals. The final intervals are shown in Figure 7. At 0950 on 8 December Baby Daisy erupted for the final time in the 22-month-plus active period. The eruption was not observed, but the data logger trace shows nothing unusual about that eruption. There were no temperature variations following the last eruption that suggest any periodic overflows or other activity. When the logger was removed in June of 2005, the area was beginning to acquire a covering of dust and debris.

Eruption Time/Date	Interval
12/08/04 01:30:34,	0:32:00
12/08/04 02:37:34,	1:07:00
12/08/04 03:23:34,	0:46:00
12/08/04 03:57:34,	0:34:00
12/08/04 05:05:34,	1:08:00
12/08/04 06:05:34,	1:00:00
12/08/04 07:03:34,	0:58:00
12/08/04 08:02:34,	0:59:00
12/08/04 08:51:34,	0:49:00
12/08/04 09:50:34,	0:59:00

Figure 7. Baby Daisy Geyser's last ten eruptions.

Summary and Conclusions

Geysers in the northern part of the Old Road Group have tended to be episodic in activity. Examples other than Baby Daisy Geyser include Cauliflower Geyser and Biscuit Basin Geyser, both of which have had brief periods of activity but did not sustain their activity over long times. Although the exact start of the active period is not known, it is likely that the total span of the 2003-4 activity was just short of two years.

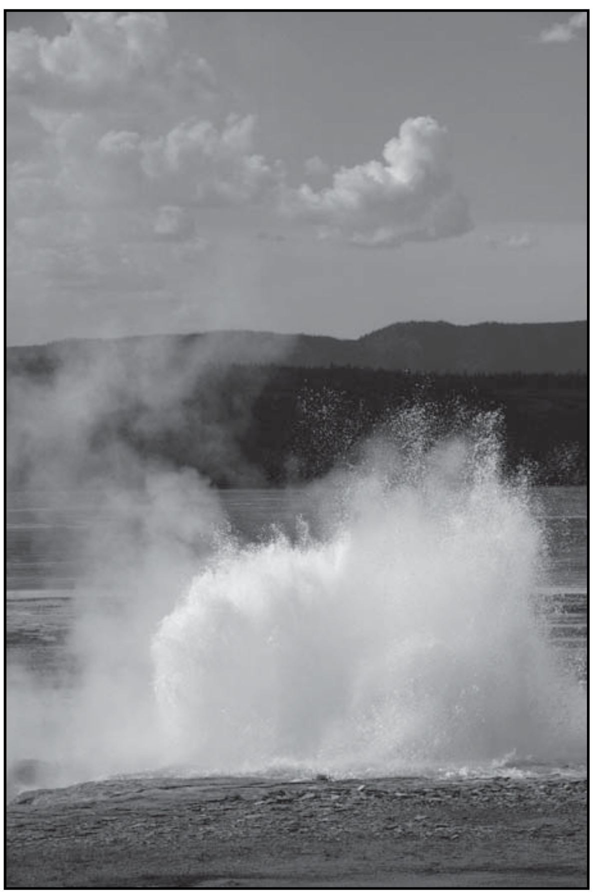
Intermittent reports for the first four months did not note any activity that differed markedly from the activity recorded during the 534 days of electronically recorded eruptions. Analysis of the electronically recorded eruptions indicates a gradual increase in interval, amounting to a change of about 15 minutes in daily moving median intervals from June 2003 to December 2004. Both the beginning and end of the series of eruptions were not associated with any known external events.

Baby Daisy Geyser, May 2003. Photo by Mike Newcomb.

Acknowledgements

The early activity of Baby Daisy Geyser during the active period described is known because of several observers who posted their observations on the Geyser List; thanks to all who provided this information. I would also like to thank the reviewers who made suggestions that improved the accuracy and readability of this paper. Finally, thanks to Editors Jeff and Tara Cross whose gentle prodding resulted in this paper.

Morning's Thief Geyser Activity in 2007



Though it had been active in prior years, Morning's Thief Geyser began to have much larger eruptions in 2006 and 2007. Bursts could reach 50 feet or more, and Morning's Thief was sometimes mistaken for nearby Morning Geyser, which was dormant. Most eruptions occurred immediately prior to or during eruptions of Fountain Geyser.

Photos: Morning's Thief in May 2007, top and left, by Graham Meech. Below, Morning's Thief (on the right) in concert with Fountain (left) in July 2007, by Pat Snyder.