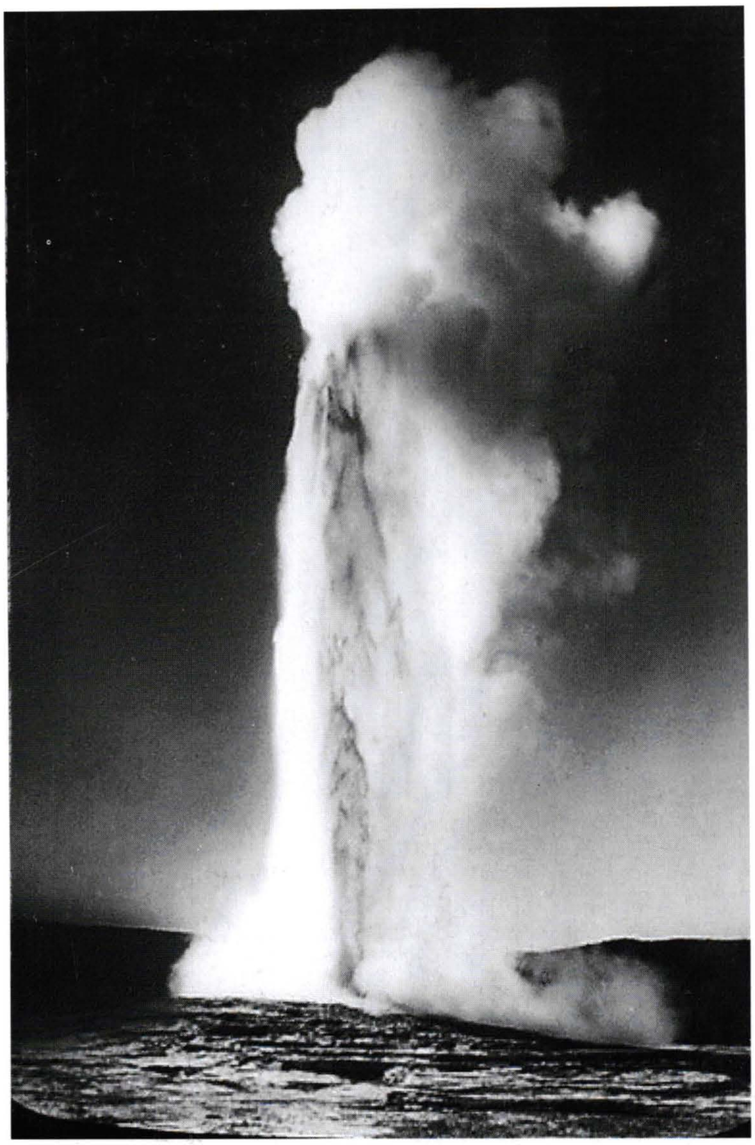
GOSA TRANSACTIONS



The Journal of
The Geyser Observation and Study Association

Volume VII
2002

The GOSA Transactions

The Journal of The Geyser Observation and Study Association

Volume VII
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All articles in this volume were reviewed for content and style by at least two people in addition to the editors. Their comments, returned to the authors, resulted in the final copy for publication.

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Old Faithful Geyser, photographed by Frank Jay Haynes sometime before 1910 (specific date unknown), Haynes #13040, courtesy of Montana Historical Society. See also above right and the note on page 2.

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The GOSA Transactions publishes articles, research notes, short notices, reviews and photographs of both general and technical interest on any aspect of the physics, chemistry, geology or behavioral aspects of geysers and related geothermal phenomena, as well as social and historical studies related to these phenomena.

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The Geyser Observation and Study Associations

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An Explanation of GOSA Measurement and Language Conventions

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

Distance and Height Measurements

The goal of this publication is for readers to understand the information contained in these articles without being bogged down or confused by unfamiliar measurement units. Therefore, GOSA publications prefer the use of the English system of measuring distances and heights (that is, units of feet, yards and miles) over the metric system. Although some feel that we should adopt the metric system, the simple fact is that the most Americans (the majority of our readers) do not readily understand metric units. Note that articles that do use the metric system will always be accepted.

To avoid possible confusion, punctuation–type abbreviations (such as ' for feet, " for inches and m for meters) should not be used.

Time Measurements and Their Abbreviations

Units of time are straightforward in nearly all cases (the use of inventions, such as the "famous" microdays and millihours, will not be accepted for publication). In general discussions, where specific data is not involved, it is preferred that time units be spelled in full ("hours" or "minutes," for example). Within specific data, however, the use of abbreviations is preferred. These units should be shown as follows: "d" = days; "h" = hours; "m" = minutes; "s" = seconds.

To avoid confusion, punctuation–type abbreviations (' for minutes and " for seconds) should not be used, and longer units of time, such as "years" and "months," should always be spelled in full.

Other Abbreviations

A number of additional, geyser–standard abbreviations may be used within articles, most commonly within data tables or in text where directly associated with specific data. These include:

"I" or "i" = interval; "IBE" = interval between eruptions; "D" or "d" = duration; "ie" = observed in eruption;
the tilde ("~") may be used to note an approximate time value.

In situations where there is only isolated usage of these terms, they should be spelled in full rather than abbreviated.

Past Tense versus Present Tense

Almost without exception, a discussion about geyser activity will be based on what was observed at some time in the past. Therefore, the use of past tense is strongly preferred.

More About the Cover Photo

The specific date on which the cover photograph of Old Faithful Geyser was taken is unknown. That it was taken by Frank Jay Haynes is certain, but the catalog number (#13040) tells only that original photograph negative was made sometime in or prior to 1910. The photo could date as early as the 1880s.

Historically, this image led sculptor Daniel Chester French to produce a marble statue with the long title of: "And the sons of God saw the daughters of men that they were fair." Compare this photo of the statue with the cover photo.

Trivia Question: What other famous statue was produced by Daniel Chester French?
Trivia Answer: The statue of Abraham Lincoln within the Lincoln Memorial in Washington, D.C.

Haynes Photo #32554

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Old Faithful Geyser, as photographed by Frank Jay Haynes in or before 1910. This photo is identified as #10161 per a numbering scheme devised by Jack Haynes, son of the photographer. This number cannot be related to any specific date and, in fact, the picture may have been taken as early as the 1880s.

Old Faithful Geyser's Lengthening Intervals

by Lynn Stephens

Abstract

As of December 31, 2001, Old Faithful's average interval has lengthened by 15 minutes, or almost 20%, since 1988.[1] This report reviews the record of Old Faithful's average interval through the 1988 edition of *The Story of Old Faithful* (which included data through 1987), updates the record to contain additional summary statistics through 2001, and discusses some of the changes in Old Faithful's intervals that have occurred in recent years.

Introduction

Old Faithful has been described as "the most perfect illustration of geyseric phenomena..." [Dumbell, 1920, p. 46]. It is considered THE symbol of Yellowstone National Park by many people. Perhaps this is why Old Faithful may also be the most studied geyser in Yellowstone. Although Old Faithful is not the largest of the predictable geysers and also is not the most regular geyser in the park, its performance has been remarkably consistent since the first recorded observations in 1870.[2] However, consistency does not necessarily mean "no change."

In the first edition of *The Story of Old Faithful Geyser*[3], George D. Marler, seasonal naturalist and park geologist, noted:

> There has been a long felt need for a written exposition that would briefly tell the story of Old Faithful Geyser...It is hoped that a written presentation of the facts will be a contribution toward the correcting of the false impressions that are held and circulated about this remarkable geyser, and further enhance the understanding and appreciation of Yellowstone's most unique wonder. [1953, p. 1.]

This report reviews the historical record of Old Faithful's average interval, updates the record for the period 1988 through 2001, and discusses selected changes in Old Faithful's average interval with the same hope that Marler had—that of increasing the understanding and appreciation of the complexity of Old Faithful.

Old Faithful's Interval Record — 1870–1987

Dr. P. P. Fix of the U.S. Geological Survey published a study on the regularity of Old Faithful Geyser in 1949. His review of the records of the interval between eruptions of Old Faithful (as reprinted in *The Story of Old Faithful Geyser*) is shown in Table 1. He concluded that the average interval for the period 1870 through 1947 was 65.12 minutes, and the range during that same period was 34 minutes to 91 minutes.

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[1] For example, the Yellowstone National Park website still shows (as of April 15, 2002) 76 minutes as the average interval. One handout used in the Old Faithful Visitor Center at least through the summer of 2001, "Facts and Theories About Old Faithful Geyser" (revised 3/91), gave the 1988 average of 76.17 minutes. The most recent version of the *Old Faithful Area Trail Guide* (revised June 1999), states the average interval is "about 80 minutes." An article "Old Faithful Still Faithful, But Slowing" in the April 2002 issue of *Yellowstone Discovery* stated the current average is 80 minutes. Another handout used in the Old Faithful Visitor Center through the summer of 2001, "Old Faithful: A Symbol of Yellowstone National Park" (revised 10/00), listed the 1999 interval as 80 minutes and indicated the 2000 interval was 85 minutes. An article "How Faithful is Old Faithful?" in the Spring 2002 issue of *Yellowstone Today* reported the current average interval (as of March 2002) at 92 minutes.

[2] Lee Whittlesey [1998, p. 1317] stated "...indeed it is the only geyser in Yellowstone for which there are records of each and every year since [1870]."

[3] *The Story of Old Faithful* has been revised several times (1957, 1961, 1969, 1974 and 1988). Only the first edition included the word "Geyser" in the title. In this article, the booklet will be referred to as *The Story of Old Faithful* unless the reference relates exclusively to the 1953 edition.

Table 1: Interval between Initiation of Eruptions, Old Faithful Geyser, 1870 – 1947

Year	Observer	Eruptions Seen	Minimum Interval	Maximum Interval	Average Interval
1870	Doane				50m
1870	Washburn				60m
1872	Peale	17	65m 00s	70m 34s	67m 54s
1873	Comstock	11	52m 05s	77m 35s	63m 48s
1875	Dana and Grinnell	24			65m 66s
1877	Sherman and Poe	7	62m	80m	67m
1878	Peale	97	54m 04s	78m 00s	65m 06s
1879	Mitchell				70m
1879	Seguin				45m
1883	Hallock				65m
1928	Allen and Day	6	57m 30s	74m	
1928-9	Baker	38	58m 20s	75m	
1932	Robertson	1,187	38m	81m	65.7m
1937	Fix (July 17)	2		84m	
1937	Fix (Aug. & Sept.)	23	42m 58s	79m 47s	67m 38s
1938	Woodward	771			66m 30s
1939	U.S.N.P.S.	500	40m	86m	66.1m
1940	"	1,075	39m	87m	67m
1941	"	1,577	38m	91m	66.3m
1942	"	1,452**	41m	90m	60.05m**
1943	"	376	39m	84.5m	63.45m
1945	"	940	39m	85m	63.77m
1946	"	1,495	34m	86m	63.2m
1947	"	1,500	39m	89m	63.3m
1870-1947		11,098*	34m	91m	65.12m

*11096 used to calculate average interval.

**During the 1942 season 1638 eruption intervals were recorded. The average interval for the season was 65.8 minutes. The discrepancy between the above figures for the 1942 season and those found in the table no doubt resulted from Fix's not having access to all of the records. It would seem that the seasonal average of 60.05m given by Fix is either a mathematical or typographical error. [Footnote added by Marler.]

Source: Fix, P.P., 1949, "Regularity of Old Faithful Geyser, Yellowstone National Park, Wyoming," *American Journal of Science*, v. 247, p. 250 as reproduced in Marler's *The Story of Old Faithful Geyser*, 1953, p. 19.

Average intervals cited in his table ranged from a minimum of 45 minutes (1879, Seguin) to a maximum of 70 minutes (1879, Mitchell). Assuming the 60.05m average listed in 1942 was an error (see the footnote in the table that was added by Marler), there were three averages of 60 minutes or less cited in Fix's table: (1) 45 minutes credited to Seguin 1879, (2) 50 minutes credited to Doane in 1870, and (3) 60 minutes credited to Washburn in 1870. In each of these cases no indication of the number of eruptions observed was provided, and the three numbers ended in either a "5" or a "0." The largest interval, 70 minutes credited to Mitchell in 1879, also was not accompanied by the number of observations, and was reported for the same year as the 45 minutes credited to Seguin. This lack of specificity may indicate that these four reports were estimates rather than measured amounts. The remaining averages were between 63 and 67 minutes.

For the first edition of *The Story of Old Faithful Geyser*, Marler compiled information for 1948 through 1952 (See Table 2). There were 9,340 total eruptions during that time period. The average interval was 63.6 minutes, with a minimum of 33 minutes and a maximum of 88 minutes. The minimum interval dropped by one minute from the 34 minute minimum for 1932 listed in Fix's table. Marler noted that the 33 minute minimum was first recorded in 1948. Marler's answer to the question

Table 2: Old Faithful Intervals—1948 – 1960

Year	Observer	Eruptions Seen	Minimum Interval	Maximum Interval	Average Interval
1948	U.S.N.P.S.	1,486	33m	85m	64.1m
1949	"	1,540	35m	88m	62.3m
Winter 49–50	Hart, N.P.S.	2,505	38m	88m	63.2m
1950	U.S.N.P.S.	1,215	33m	86m	63.8m
1951	"	1,305	33m	88m	63.1m
1952	"	1,289	35m	85m	64.9m
	Total 1948-1952	9,340	33m	88m	63.6m
1953	U.S.N.P.S.	1,210	35m	82m	64.3m
1954	"	1,084	35m	86m	64.5m
1955	"	1,357	37m	93m	64.5m
1956	"	1,326	34m	92m	64.5m
	Total 1948-1956	14,317	33m	93m	63.78m
1958	U.S.N.P.S.	1,354	35m	90m	62.8m
1959	"	1,619	33m	95m	61.8m
1960	"	4,381	35m	93m	66.3m
	Total 1948-1960	19,104	33m	95m	63.7m

Source: Compiled by Stephens from tables contained in the 1953, 1957, and 1961 editions of *The Story of Old Faithful.*

"How often does Old Faithful play?" was:

> The average interval has always been between 62 and 67 minutes. The average interval given is the determined average of the previous season. During the 1952 season the average for 1289 eruptions checked was 64.09 minutes. If the season is far enough advanced for data, it is the current average interval that is given. [1953, p. 34.]

He also noted that the averages for the past 10 years were consistently lower than the averages reported by Fix for years prior to 1943.

In the 1957 edition of *The Story of Old Faithful*, Marler added summary statistics for the years 1953 through 1956 (see Table 2). Summary statistics for the period 1948 through 1956 showed an average of 63.78 minutes, with a minimum of 33 minutes and a maximum of 93 minutes for the 14,317 eruptions seen during the years listed. The maximum of 93 minutes recorded in 1955 increased the previously recorded maximum of 90 minutes in 1940 by 3 minutes. He updated his answer to the question "How often does Old Faithful play?" to substitute the statement: "During the 1956 season the average for 1326 eruptions checked was 64.5 minutes." in place of statistics for the 1952 season. [1957, pp. 35-36.]

In the 1961 edition of *The Story of Old Faithful*, Marler added summary data for 1958, 1959, and 1960 (see Table 2). He deleted rows with data for 1953 and 1955. He did not include data for 1957. He computed summary statistics for the period 1948 through 1960. His table showed total eruptions seen of 19,104 for 1948–1960. Note however that the total 19,104 is the total for the years actually listed there and does not include eruptions seen in 1953 and 1955. He computed the average interval for the period 1948-1960 as 63.7 minutes. The minimum stayed at 33 minutes (first recorded in 1948), but the maximum increased from 93 minutes (recorded in 1955) to 95 minutes in 1959. He noted that the seasonal averages for 1943 up to the 1959 earthquake were still less than those prior to 1943. His answer to the question "How often does Old Faithful play?" was changed to read:

> The average interval has always been between 61 and 67 minutes. ...During 1960 season the average for 4381 eruptions checked was 66.3 minutes. Due to the [1959 Hebgen Lake] earthquake this was 5 minutes longer than the 1959 average. [pp. 35-36.]

Marler also added a section discussing the impact that the 1959 earthquake had on Old Faithful's average interval to the 1961 edition of *The Story of Old Faithful*. Prior to the earthquake, Old Faithful's intervals had averaged 60.8 minutes. By the end of 1959, the average interval had increased to 67.4 minutes. In 1960 the interval was 66.3 minutes. Thus, the Hebgen Lake earthquake has generally been credited with increasing Old Faithful's average interval by five to six minutes.

In the 1969 edition of *The Story of Old Faithful*, Marler kept Fix's table, but significantly changed the presentation of data in the table for years subsequent to 1947 (see Table 3). Individual rows for the years 1948 through 1960 were deleted. Instead, data was provided in summary form for the five-year periods of 1948–52, 1953–57, 1958–62, and 1963–67. Summary statistics for 1948 through 1967 showed an average interval of 64.7 minutes for the 35,118 eruption intervals with a minimum of 33 minutes and a maximum of 96 minutes. Marler did not note the year in which the 96 minute maximum was recorded, although he continued to note the seasons in which 33–minute intervals were recorded (1948, 1950, 1951, 1959, and 1968). The Questions/Answers section at the end of the booklet was removed with this edition, so Marler no longer provided statements about the average interval.

In the 1974 edition, Marler added two lines to the table summarizing Old Faithful intervals after 1947 — a line for the period 1968–72 and a line for 1973. (1973 was presented as a single line because the other lines — 1948–52, 1953–57, 1958–62, and 1968–72 — each covered a five year period.) Summary statistics for the period 1948 through 1973 resulted in an average interval of 64.8 minutes for the 46,999 eruption intervals, with a minimum of 33 minutes and a maximum of 148 minutes. The maximum was listed for 1973.

Table 3: Old Faithful Intervals—1948-1987

Year	Intervals	Minimum Interval	Maximum Interval	Average Interval
1969 Edition				
1948-52	9,340	33	88	63.3
1953-57	6,233	35	93	64.3
1958-62	10,958	33	95	65.3
1963-67	8,587	35	96	65.9
1948-67	35,118	33	96	64.7
1974 Edition				
1968-72	9,319	33	96	64.8
1973	2,562	35	148	66.3
1948-73	46,999	33	148	64.8
1988 Edition				
1973-77	15,105	35	120	67.6
1978-82	16,445	35	108	71.2
1983-87	25,111	34	110	72.1
1948-87	101,098	33	120	68.0

Source: Compiled by Stephens from tables contained in the 1969, 1974, and 1988 editions of *The Story of Old Faithful.*

Again, he noted all seasons for which minimum intervals of 33 minutes had been recorded (with no additional 33 minute intervals recorded since 1968), but made no comment on the maximum interval of 148 minutes listed for 1973. (Further discussion of the 148 minute interval is included in the section "Old Faithful's Maximum Interval.")

The most recent revision of *The Story of Old Faithful* was published in 1988. This revision was edited by Roderick A. Hutchinson, Yellowstone Research Geologist. Hutchinson added rows for 1973–77, 1978–82, and 1983–87. His summary statistics for the 101,098 intervals for 1948 through 1987 resulted in an average interval of 68.0 minutes with a minimum of 33 minutes and a maximum of 120 minutes. He updated the list of years in which the minimum interval of 33 minutes was recorded to include 1970, but made no comment on the maximum interval, even though the 148 maximum listed in the 1974 edition was removed and a maximum of 120 minutes was substituted in the line 1973–77.

A review of the data added for the period 1968 through 1987 shows that the average interval increased 7.3 minutes from the average of 64.8 minutes for 1968–72 to an average of 72.1 minutes for 1983–87. Lengthening intervals of Old Faithful have been attributed to the 1975 Yellowstone

Table 4: Old Faithful Intervals—1987-2001

Year	Number of Intervals	Minimum Interval	Maximum Interval	Average Interval	Median Interval	Standard Deviation
1987	3,021	34m	105m	71.1m		14m22s
1988	6,423	40	111	77.8	81	12m 54s
1989	6,723	40	119	78.2		
1990	6,656	41	114	76.2		15m 05s
1991	7,065	42	114	74.3		
1992	6,681	39	119	74.2	79	15m16s
1993	3,253	41	112	75.8	80	14m57s
1994	6,587	40	111	77.1	81	13m40s
1995	2,977	42	113	77.85	82	15m06s
1996	2,159	44	117	75.7	81	16m16s
1997	2,251	44	108	75.0	81	16m35s
1998	1,952	45	120	81.4	85	14m21s
1999	2,088	48	110	84.8	87	10m50s
2000	2,084	46	111	86.7	87	8m30s
2001	1,926	47	127	91.0	91	8m19s

Source: Data for 1988 and 1991-2001 compiled by Lynn Stephens from data contained in Old Faithful logbooks. Data for 1987 covers the period 2/10 – 6/30/87, was compiled by John Railey, and was reported in T.S. Bryan's *1987 Thermal Report.* Data for 1989 was compiled by R.A. Hutchinson and reported in the March-April 1990 issue of *The Geyser Gazer Sput.* Data for 1990 was compiled and published by R.A. Hutchinson in his annual report *Thermal and Seismic highlights of Yellowstone—1990-1991.*

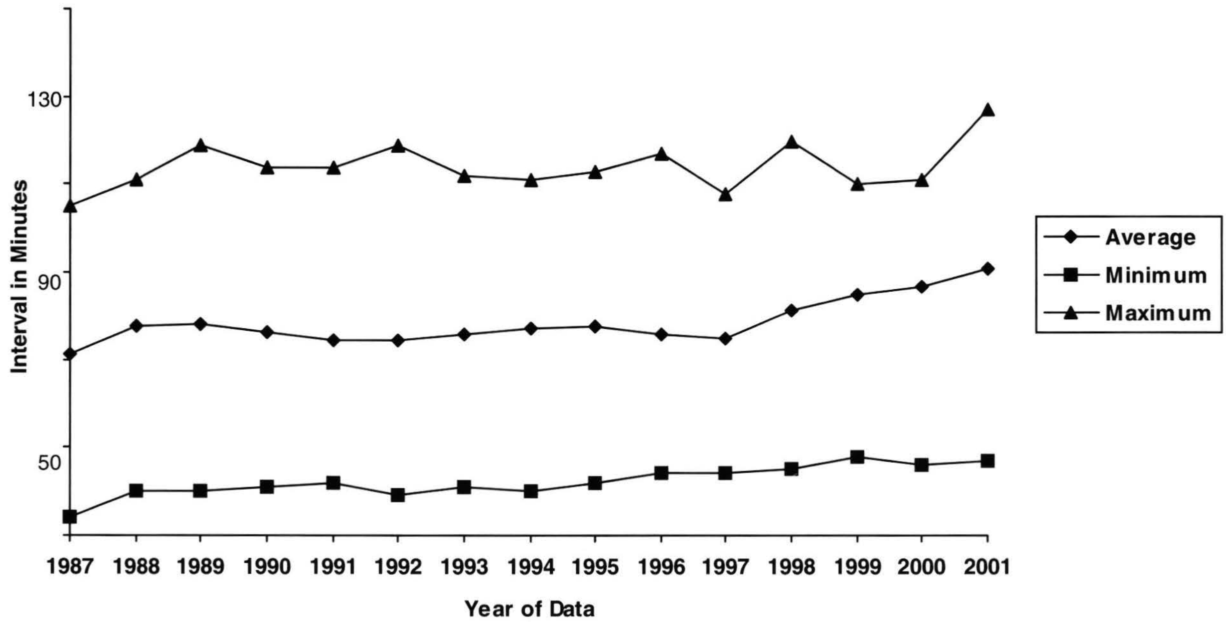
Plateau earthquake and the 1983 Borah Peak earthquake.[4] Interestingly, the only mention of the relationship between changes in Old Faithful's intervals and earthquakes in the 1988 edition of *The Story of Old Faithful* is a discussion of the 1959 earthquake.

Old Faithful's Interval Record — 1988 – 2001

A review of the average interval over the period 1988 through 2001 (see Table 4 and Figure 1) shows that the interval jumped almost 6 minutes between the average for the five year period 1983–87 (72.1 minutes) and 1988 (77.8 minutes). In his 1987 Report, T. Scott Bryan reported on statistics compiled by Thermal Volunteer John Railey for Old Faithful for February 1, 1987 through June 30, 1987. During that period, the average interval was 71.105 minutes. I extracted Old Faithful data for January 1, 1988 through December 31, 1988 from the logbooks. The monthly average for January was 77 minutes. This indicates that the interval increased almost 6 minutes between June 30, 1987 and December 31, 1987. *The Earthquake Catalog for the Yellowstone National Park Region: January 1, 1987 to December 31, 1987*, included a section by

[4] The 1991 NPS handout "Facts and Theories about Old Faithful Geyser" states: "After each of the last three major regional earthquakes (Hebgen Lake, 1959, magnitude 7.5; Yellowstone Plateau, 1975, magnitude 6.1; Borah Peak, 1983, magnitude 7.3) Old Faithful has had progressively longer average intervals due to shifts in circulation of hot water…" [p. 1].

Figure 1: Old Faithful's Intervals



Hutchinson on "Summary of felt earthquakes in Yellowstone National Park, 1987." In his abstract, Hutchinson [1997] noted that two small earthquakes had resulted in a 5+ minute increase in Old Faithful's interval.

Hutchinson [1991] noted in his 1990–1991 report that Old Faithful's average peaked in 1989, then declined slightly in 1990. In that report, he also reported an average for the Spring of 1991 of 74.5 minutes. Bryan [1991] reported that the mean of 174 mid–July intervals was 74.408 minutes. Other reports in *The Geyser Gazer Sput* for that year did not indicate any change in Old Faithful.

Old Faithful's average interval continued to decline in 1992, then reversed itself in 1993 and started a gradual climb in 1993, 1994, and 1995. The upward trend reversed in 1996 and 1997. Since the largest of these fluctuations was only 2.15 minutes (the decline from 1995 to 1996), these appeared to be random fluctuations rather than attributable to any specific event.

The next major increase in Old Faithful's interval occurred in January, 1998. The season average for 1997 was 75.0 minutes. The season average for January 18, 1998 through December 31, 1998 was 81.4 minutes. This increase has been attributed to the January 9, 1998, magnitude 2.2 earthquake centered about 1 mile north of Old Faithful, hereafter referred to as the 1998 "Biscuit Basin" earthquake.

Old Faithful's average interval has continued to lengthen in each of the years since 1998. The average interval increased by 3.4 minutes in 1999, 1.9 minutes in 2000, and 3.3 minutes in 2001. A review of monthly data (Table 5) showed that the increase in 1999 occurred during the "Spring Break" between mid–March and mid–April, when continuous data was not available from the Old Faithful Visitor Center (OFVC) logbook. The average for January through mid–March was 80m33s; the average for mid–April through December 31 was 85m59s — a jump of almost 5½ minutes over the January–March average. Beginning in April 1999, the monthly averages for 1999, 2000, and 2001 generally show a gradual upward trend interrupted occasionally by a slight downward dip in a monthly average. (There was a 3 minute decline in the December 1999 average, but it was not sustained.) The 1998 average of 81.4 minutes was the highest since the average had

Table 5: Old Faithful's Monthly Average Intervals—1999-2001

Month of Year	1999 Average (count)	2000 Average (count)	2001 Average (count)
January	80m24s (184)	84m04s (171)	89m19s (172)
February	80m26s (169)	84m51s (180)	89m41s (162)
March	80m44s (94)	86m21s (85)	88m53s (65)
Jan. – Mar.	80m33s (447)		
April	85m52s (100)	85m34s (68)	91m32s (61)
May	86m12s (193)	87m20s (219)	90m51s (202)
June	87m45s (257)	86m43s (287)	90m57s (269)
July	86m50s (249)	87m04s (286)	91m42s (245)
August	86m02s (264)	87m03s (266)	91m56s (262)
September	84m49s (241)	87m46s (224)	91m52s (224)
October	85m39s (177)	87m13s (181)	91m58s (166)
November	86m02s (39)	87m37s (31)	91m34s (21)
December	82m56s (121)	87m46s (87)	90m07s (86)
April – Dec.	85m59s (1641)		

Source: Compiled by Lynn Stephens using data from the Old Faithful logbooks.

peaked in 1989. In the next three years, the average climbed 9.6 minutes, increasing almost 12% over the 1998 average. This is the largest change identified in the 130 years that records have been available.

In summary, Old Faithful's interval remained relatively constant over the first 75 years (1870-1945) of recorded observations, averaging about 65 minutes. During the next 15 years, the average declined gradually until it was about 61 minutes just prior to the August 17, 1959, Hebgen Lake Earthquake. Following that earthquake, the average returned to the "historic" level of about 65 minutes, and essentially stayed close to the average for another 15 years. The combined effects of the 1975 Yellowstone Plateau and 1983 Borah Peak earthquakes increased the average by about seven minutes, to the 72 minute level. In 1987 "two small earthquakes" caused the average to increase another six or seven minutes to the 78 minute level. Over the next 10 years, the overall trend of the average was a gradual decline, until it reached 75 minutes in 1997. The January 9, 1998 "Biscuit Basin" earthquake caused an almost immediate increase in the average of about 6½ minutes, and the average continued to climb in the next three years, reaching its highest level ever of 91.0 minutes in 2001. In other words, after 105 years of relative stability, the average increased from 65 minutes to 91 minutes, or 40%, over the next 25 years.

Old Faithful's Minimum Interval

Old Faithful's minimum interval is listed as 33 minutes in a variety of publications, such as all editions of *The Story of Old Faithful*, the 1971 and 1978 reprints of Marler's *Studies of Geysers and Hot Springs along the Firehole River*, and Whittlesey's *Wonderland Nomenclature*. However, the minimum interval is listed as 30 minutes in the "Facts and Theories about Old Faithful Geyser" handout, revised 3/91. Bryan listed the minimum as 33 minutes in the 1979 and 1991 editions of *The Geysers of Yellowstone*. In the 1995 edition, he changed the known range to read a minimum of 30 minutes and noted there were "...two controversial but probable intervals of only 12 and 18 minutes." [p. 28.] His information for the minimum interval did not change in the 2001 edition.

The two "controversial but probable" short intervals that Bryan references were probably those witnessed by John Railey.[5]

In his *Thermal and Seismic Highlights of Yellowstone 1986–1987* report, Hutchinson included the following information:

> The last and possibly most significant eruptive event noted from Old Faithful is what must be classified as a minor eruption. On Wednesday, May 13, 1987, thermal Volunteer-in-Park John R. Railey observed and timed an eruption which lasted for 1 minute and 22 seconds at 1926 (MDT). From the tree reference scale at the Visitor Center front desk, he determined the maximum eruption height to be 140 feet (43 meters). With the empirical prediction table, he posted a new eruption time of 2010 for an expected interval of 44 minutes. Yet only 12 minutes later at 1938, Old Faithful erupted again to a height of 130 feet (40 meters) for more than 3 minutes. Fifty-nine minutes elapsed between the previous normal eruption at 1827 to the apparent minor eruption at 1926; thus the interval between the "normal" eruptions of 1827 and 1938 was 71 minutes. All three eruptions showed up as distinct peaks on the infrared chart record. "Preplay" has been interpreted and defined as splashing activity of less than 30 seconds in duration (typically less than 10 or 12 seconds) of low maximum height (less than 10 meters). While the May 13 event occurred before a long normal eruption in the manner of preplay, its duration and 43-meter-high water column suggest that it was a minor eruption. [pp. 4-5.]

Apparently because Hutchinson termed the eruption a "minor" eruption and he frequently used the phrase "minimum interval between *normal* eruptions of Old Faithful" [emphasis added] in his annual reports when citing minimum intervals for Old Faithful, the 12 minute interval has not been recognized as an "official" minimum.

This was not the first time that Railey had observed an eruption that Hutchinson labeled a "minor" eruption and the interval between the "minor" eruption and the next "regular" eruption was not reflected in the "official" statistics. Hutchinson's *Geologic and Thermal Highlights of Yellowstone 1980–1982* report contains the following information:

> On Thursday, May 14, 1981, Thermal Volunteer John R. Railey observed what could only be classified as a minor eruption – an event which is known to have only been recorded once before. At 18:56 MDT Old Faithful erupted and was timed with a 3 minute and 46 second eruption which, from the empirical table, predicted the next eruption should be at 20:08, give or take 5 minutes. Quoting Railey: '...At 20:11 hrs, an eruption or very high preplay occurred. This event lasted 1 minute 33 seconds and its height came about 2/3rds the height of the tree and held for approximately 45 seconds...I first recorded this as an eruption and made a 45 minute prediction. If I had not been watching some elk out by the cone, I would not have seen the 'second' eruption which took place at 20:28 hrs. This eruption had a duration of 4 minutes 27 seconds.' The interval thus produced between 18:56 and 20:28 MDT was 92 minutes. [p. 1.]

In this case, the interval between the two "normal" eruptions consisted of 75 minutes from the "regular" eruption to the "minor" and 17 minutes from the "minor" to the next "regular" eruption. This 17 minute interval has also not been reflected in the "official" statistics.

Another interesting part of this statement is the comment in the opening sentence that a minor eruption had been recorded before the May 14, 1981 observation by Railey. If there was one prior to the May 14, 1981 observation, then Railey's May 13, 1987 observation was at least the third minor eruption recognized by Hutchinson.

Rocco Paperiello has extensively researched the issue of minimum intervals for Old Faithful.

[5] The information contained in Hutchinson's annual reports reflect intervals of 12 and 17 minutes rather than 12 and 18, which is why I have included the word "probably."

He reviewed historical records such as monthly and annual Reports of the Superintendent, Reports of the Naturalist Division, newspaper and magazine articles, and reports from the 1871, 1872 and 1878 Hayden Surveys. He also searched the records for Old Faithful intervals contained in the Old Faithful Visitor Center logbooks. His research revealed a third sub–30 minute interval in the 1980s. Thermal Volunteer Mary Ann Moss recorded a 13 minute interval on October 16, 1985. This brings the number of sub–30 minute intervals to three — Railey's 12 minute interval in 1987, Moss's 13 minute interval in 1985 and Railey's 17 minute interval in 1981.

Paperiello identified three cases of 30 minute intervals. Either the June 20, 1936 or May 1951 interval might be the source for the minimum interval of 30 minutes used in the "Facts and Theories about Old Faithful Geyser" handout and Bryan's 1995 and 2001 editions.

The first 30 minute interval that Paperiello located occurred on June 20, 1936. Paperiello found three references to this interval: (1) A reference in the June 1936 "Report of the Naturalist Division" stating: "Old Faithful has set a new long and short interval record, the long interval being 92 minutes and the short interval 30 minutes. [Griswold, Report of the Naturalist Division, June 1936.] (2) A newspaper article identifying the date as June 20, 1936. (3) The OFVC logbook entry for June 20, 1936 [pp. 13-14] included details about the times, heights, and Ranger Naturalists who witnessed the eruption.

The second 30 minute interval that Paperiello located was a reference in the May 1951 Old Faithful Visitor Center logbook, which stated that 30 minutes was the shortest interval for the month.

The third 30 minute interval identified by Paperiello was a personal observation he made on July 6, 1994. The first eruption he observed "...reached only about 70 feet high and lasted only about 45 seconds, but it was a sustained eruption. The next eruption was exactly 30 minutes later (by my watch). It was a 'normal' eruption. Rick [Hutchinson] refused to allow this 'interval' to be recorded because he stated 'my watch was not accurate.'" [2002, Personal Communication.]

It certainly appears there is sufficient justification for changing the recognized minimum to 30 minutes and, depending upon whether one wants to recognize "minor" eruptions of Old Faithful in computing intervals, the "official" minimum could go as low as Railey's 12 minute interval in 1987.

Old Faithful's Maximum Interval

Old Faithful's maximum interval is listed as 120 minutes in the 1988 edition of *The Story of Old Faithful*, Whittlesey's *Wonderland Nomenclature*, the "Facts and Theories about Old Faithful Geyser" brochure, and Marler's *Studies of Geysers and Hot Springs along the Firehole River*.

The "currently accepted" maximum of 120 minutes evolved over the years as shown in Table 6. Early editions of *The Story of Old Faithful* reported increases in the maximum as they were identified, through the 1974 edition, which listed the maximum as 148 minutes. This was not a typographical error in the table since Marler also reports 148 minutes as the maximum in the text on pages 5 and 19, in addition to the chart entry on page 22. In the first edition of *The Geysers of Yellowstone*, Bryan also listed the maximum as 148 minutes.

The maximum listed in the 1978 edition of Marler's *Studies of Geysers and Hot Springs along the Firehole River* was 120 minutes. The maximum listed in the 1986 edition of Bryan's *The Geysers of Yellowstone* decreased to 120 minutes. Hutchinson also reduced the maximum listed from 148 to 120 minutes in the 1988 edition of *The Story of Old Faithful*. Bryan's maximum stayed at 120 minutes for the 1991 and 1995 editions.

Bryan's maximum for the "known range" was listed as 123 minutes in the 2001 edition and he added a reference to "another [controversial but probable interval] of 148 minutes." [p. 28.]

In the 1974 edition of *The Story of Old Faithful*, Marler identified the year in which the 148 minute interval occurred as 1973. Rocco Paperiello has stated "I believe that this [148 minute maximum] must be an error. I have carefully combed the entire 1973 log book and found no interval even close to this figure." [2002, Personal Communication.]

Table 6: Old Faithful's Maximum Interval

Source	Year	Maximum
Fix	1940	90
Marler, 1957	1955	93
Marler, 1961, 1971	1959	95
Marler, 1969	Not identified	96
Marler, 1974		
Bryan, 1979 and 2001	1973	148
Marler, 1978		
Marler/Hutchinson, 1988		
Bryan, 1986, 1991, 1995	Not identified	120
Stephens, 1998	1998	120
Stephens, 2001	June 14, 2001	127

Source: Various editions of *The Story of Old Faithful*, *Studies of Geysers and Hot Springs along the Firehole River*, *The Geysers of Yellowstone*, and *The Geyser Gazer Sput.*

Bryan's maximum for the "known range" of 123 minutes is supported by the following reference provided by Paperiello: "...on May 1, 1949 a 123 minute interval was recorded for Old Faithful. Eruptions occurred at 1:23 P.M. and 3:26 P.M. There were no intervening eruptions. The eruption at 3:26 was 'above the average height and lasted for six minutes'. The next eruption came at 4:10 P.M. This report was submitted by Dan S. Nelson, Park Ranger." [2002, Personal Communication.]

As Old Faithful's interval has lengthened over the past decade, several intervals near 120 minutes have been recorded. In 1989 Old Faithful had a 119 minute interval "the second longest ever". [Bryan, 1990, p. 90-9.] Presumably the 123 minute interval had not yet been "discovered" and 120 was being used as the standard for the longest interval. On October 17, 1998 there was a 120 minute interval.

Tim Thompson's analysis of Old Faithful intervals for the period May 1, 1997 through July 21, 1997 that was reprinted in the April 1998 issue of the *Geyser Gazer Sput* shows a maximum interval for Old Faithful of 126 minutes. This number is used in both the text and the legend accompanying the graph. The data source was "visually observed eruptions" from The Old Faithful Logbook for that time frame, not electronic data records. I have carefully reviewed the logbook data interval for that period. The maximum interval recorded during that period was 116 minutes on May 2. During that year, there were no comments by the naturalist staff about unusual Old Faithful behavior, which I believe would have been reported if Old Faithful had exceeded the "official" maximum by 6 minutes. (See for example a comment by Interpretive Ranger Ann Deutch reported in the April 1998 edition of the *Geyser Gazer Sput* about a 115 minute interval on February 13, 1998.) Therefore, I have concluded that the 126 minute maximum should have been 116 minutes.

On June 14, 2001 observers in the Old Faithful Visitor Center recorded an interval of 127 minutes. In preparing the electronic version of the OFVC logbook, I carefully checked the computations for the intervals both preceding and succeeding the 127 minute interval. There were no mathematical errors. Thermal Volunteer Ralph Taylor [2001] had reported a maximum of 121 minutes based on analysis of the data logger information for the period January 1, 2001 through September 13, 2001. This initially caused concern about the accuracy of the 127 minute interval until we learned that the Old Faithful data logger had lost data from June 1 through June 21 [Taylor, 2002]. Unless analysis of data logger information between September 13, 2001 and April 1, 2002 shows a longer interval, 127 minutes should, in my opinion, be considered the "official" maximum interval.[6]

TABLE 7: Frequency Distribution of Old Faithful Intervals for Winter 1949-50

36 through 40 minute intervals	0.8%
41 through 45 minute intervals	5.5%
46 through 50 minute intervals	6.2%
51 through 55 minute intervals	5.5%
56 through 60 minute intervals	11.1%
61 through 65 minute intervals	24.2%
66 through 70 minute intervals	24.6%
71 through 75 minute intervals	15.3%
76 through 80 minute intervals	5.7%
81 through 85 minute intervals	.9%
86 through 90 minute intervals	.8%

Source: Marler, 1953, *The Story of Old Faithful Geyser*, p. 7.

Shape of the Frequency Distributions of Old Faithful's Intervals

Old Faithful intervals have been used in a variety of statistics classes to demonstrate concepts associated with bimodality and construction of histograms. (See, for example Chatterjee, Handcock and Simonoff, *Casebook for a First Course in Statistics and Data Analysis*, 1995.)

Prior to the 1959 Hebgen Lake earthquake, Old Faithful intervals did not demonstrate bimodality. In the 1953, 1957 and 1961 editions of *The Story of Old Faithful*, Marler included a section "Statistical Study of Old Faithful's Eruptions." District Park Ranger Ruben Hart collected data for 2,605 intervals during the winter of 1949-50. Hart prepared a table showing the frequency distribution of intervals grouped in 5 minute categories, as shown in Table 7. A review of that data shows no bimodality in the distribution of Old Faithful intervals.

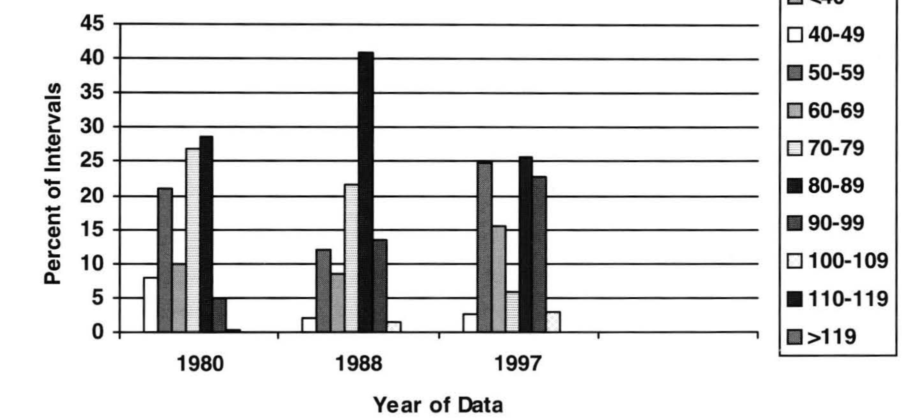
Beginning with the 1969 edition of *The Story of Old Faithful*, Marler/Hutchinson included information about a study of Old Faithful's intervals performed by Dr. John Rinehart. Rinehart plotted frequency distributions for Old Faithful intervals. Graphs for winter 1952–53 and the month of June 1967 are reproduced in *The Story of Old Faithful*. The graphs are captioned "Typical Behavior Before 1959 Quake" and "Typical Behavior After 1969 Quake." The graph for "Before 1959 Quake" shows an almost bell shaped curve; the graph for "After 1959 Quake" shows bimodality. Marler concluded: "...prior to the 1959 earthquake there were relatively few short intervals but these became more numerous following the disturbance. Thus the pattern of two types of eruption—long and short—became more pronounced after the earthquake." [p. 39.] Both the Hart study of intervals over the winter of 1949–50 and the Rinehart study, as well as Marler's use of the caption "Typical Behavior" indicate the one of the effects of the 1959 Hebgen Lake Earthquake was the introduction of bimodality into the frequency distribution of Old Faithful intervals.

As shown in Figure 2, following the 1959 Hebgen Lake earthquake, frequency distributions for Old Faithful intervals continued to demonstrate bimodality through 1997.[7] Although the shape of the distribution for each of the three selected years, 1980, 1988, and 1997 is not the same, each of the distributions shows bimodality, or a group of "short" intervals and a group of "long" intervals with fewer intervals in a "medium" category.

[6] Paperiello had communicated to me that the "second longest recorded" interval occurred on February 13, 2002, when Old Faithful had a 122 minute interval. However, he was unaware of the 127 minute interval at the time he provided that information. As of April 1, 2002, the February 13, 2002 122 minute interval should be considered the third longest interval behind the 127 minute June 14, 2001 interval and the 123 minute May 1, 1949 interval.

Specifically, the percentage of intervals in the 60–69 minute category is much smaller than the percent of intervals in the 50–59 minute and 70–79 minute categories for 1980 and 1988. The distribution had shifted to the right toward longer intervals in 1997 but still demonstrated bi-modality with the proportion of intervals in the 70–79 minute category much smaller than the proportion of intervals in the two surrounding categories of 60–69 and 80–89 minutes.

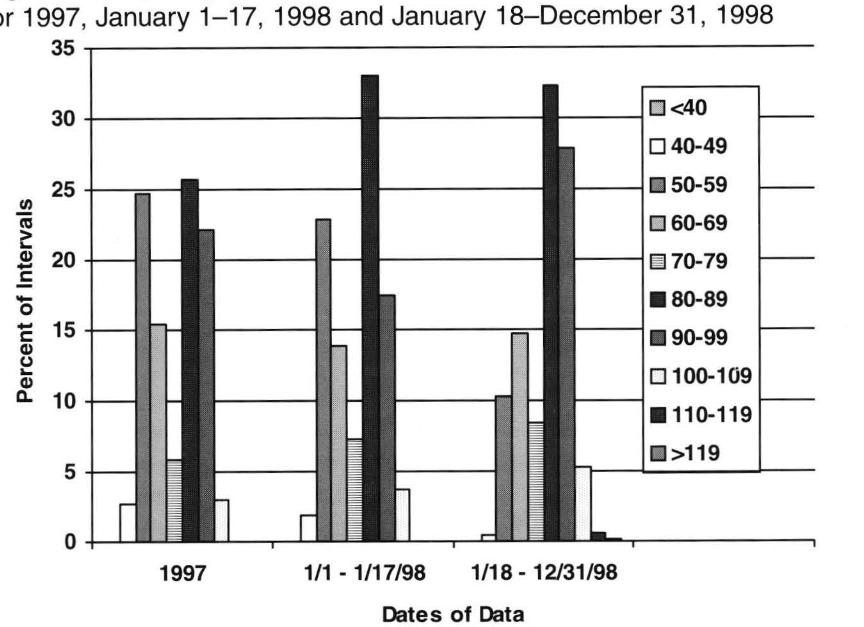
Figure 2: Frequency Distributions of Old Faithful's Intervals for 1980, 1988 and 1997



When I was first questioned about the impact of the 1998 "Biscuit Basin" earthquake on Old Faithful intervals, I indicated the increase in the average interval was attributable to a decrease in the proportion of shorter intervals and a movement toward longer intervals. [Milstein, 1998.] As shown in Figure 3, the percent of intervals in the 50-59 minute category declined by 14.4%, from 24.7% in 1997 to 10.3% for the period January 18, 1998 through December 31, 1998. The percent of intervals in the combined 80–89 and 90-99 minute categories increased by 11.9%, from 48.4% to 60.3%. The distribution did, however, still demonstrate bimodality, with the percent of intervals in the 70-79 minute category remaining much smaller than the percent of intervals in the two surrounding categories.

During the first three months of 1999, the frequency distribution appeared similar to the frequency distribution for January 18, 1998 through December 31, 1998. The shape of the distribution changed for the remaining nine months of 1999,

Figure 3: Frequency Distributions of Old Faithful's Intervals for 1997, January 1–17, 1998 and January 18–December 31, 1998



[7] One of the uses of the Old Faithful data sets from 1980 and 1990 was to demonstrate how choice of the boundaries on the categories impact the shape of the distribution. Bimodality may exist, but may not appear in the graph if the low proportions of intervals occur at the end points of the categories. For example, I had originally intended to use 1977 data as part of the frequency distributions. But because the low proportion of intervals occurred in the late 50 to early 60 minute range, use of the "0 – 9" minute categories showed no bimodality in the graph. Data for the years chosen for presentation here was visually examined to ascertain that use of the "0 – 9" minute categories did not misrepresent the data set.

as shown in Figure 4. There is no evidence of bimodality in the frequency distribution for intervals recorded from April through December, 1999. The percent of intervals in the 80–89 minute category increased by 16% for the period April through December 1999 compared to January through March 1999, and the percent of intervals in the 50–69 minute categories declined by 21.6% from the 28.2% level in January through March to a 6.6% level for April through December. The intervals that had been in the left tail moved to the center of the distribution, resulting in a distribution that looks very much like a normal curve.

The loss of bimodality is reflected in a decrease in the standard deviation of intervals. The standard deviation for 1997 was 16 minutes 35 seconds. In 1998 the standard deviation declined slightly, but was still 14 minutes 21 seconds for January 18 through December 31, 1998. For the first three months of 1999, the standard deviation was 14 minutes 41 seconds. During the remaining nine months, the standard deviation declined to 9 minutes 11 seconds.

The frequency distribution for 2000 looks very much like the distribution for April through December 1999, as shown in Figure 5. There was a shift of about 5% of the intervals away from the 60–79 minute categories to the 80–89 minute category. There was a continued decline in the standard deviation from 9 minutes 11 seconds in 1999 to 8 minutes 30 seconds in 2000.

Figure 4: Frequency Distributions of Old Faithful Intervals for January 18–December 31, 1998, January–March 1999 and April–December 1999

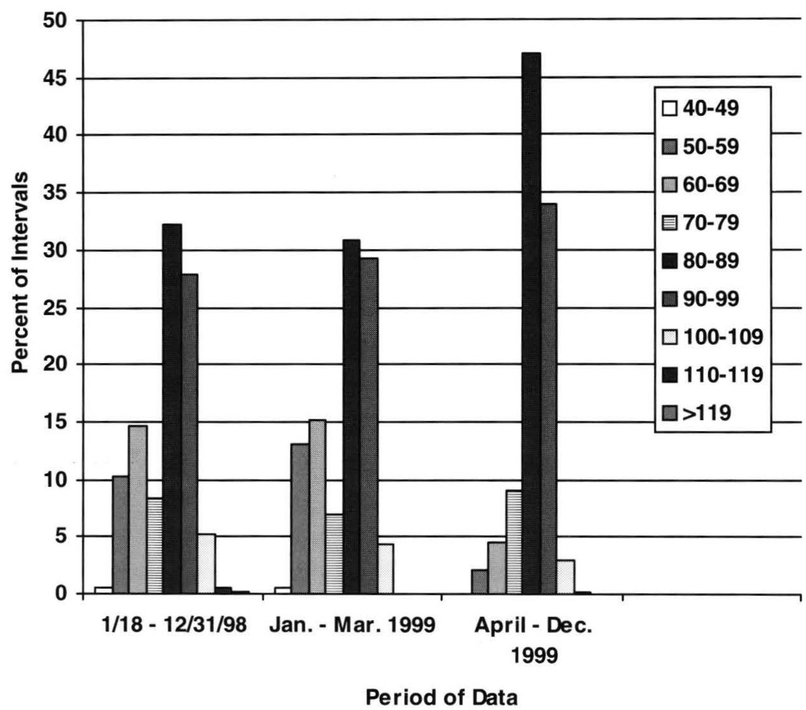
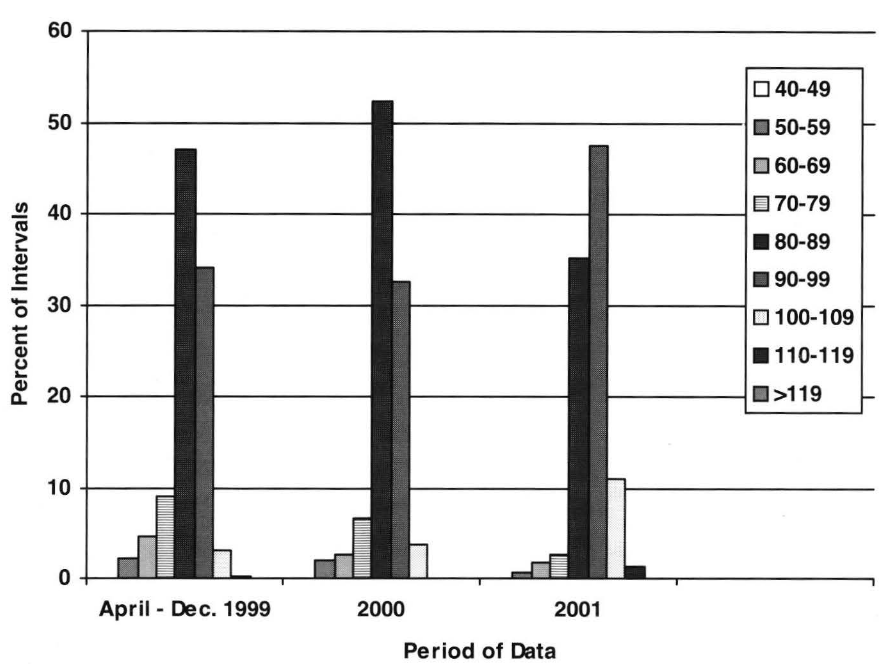


Figure 5: Frequency Distributions of Old Faithful Intervals for April–December 1999, 2000 and 2001



In 2001 there was an even larger shift away the shorter categories toward longer categories. The 70–89 minute categories lost 21% and the 90–109 minute categories gained 22.1%. The standard deviation for 2001 dropped only slightly, dropping to 8 minutes 19 seconds. Although the 1975, 1983, 1987, and 1998 earthquakes credited with lengthening Old Faithful's interval did not result in any major change in the shape of the frequency distribution of Old Faithful's intervals, the event(s) during the 1999 Yellowstone "Spring Break" apparently not only lengthened Old Faithful's average interval, but also significantly changed the shape of the distribution from one that demonstrated bimodality to a nearly "normal" curve.

In his annual reports, Hutchinson sometimes included comments about the number of times Old Faithful had two consecutive "short" intervals. For example, in his 1979–1980 [p. 1] report, he stated "On April 10th [Old Faithful] had two consecutive 'short' intervals (60, 43), which is an extremely rare occurrence." For 1991, Bryan reported "Rick Hutchinson has examined the full 1991 record and found that Old Faithful underwent 25 cases of consecutive short–short, short–medium, and medium–medium eruptions. That is, by far, its known record for such action." [1992, p. 92-30.] In the 1992 and 1993 issues of *The Geyser Gazer Sput*, there were scattered comments that Old Faithful had not had any consecutive short eruptions. With the exception of two or three isolated reports on Old Faithful, the only comments about Old Faithful in the 1994 through 1997 issues of *The Geyser Gazer Sput* were table entries showing summary statistics.

Following the 1998 "Biscuit Basin" earthquake, the proportion of short intervals declined such that people started reporting whether Old Faithful was even having any short intervals. For example, there were two such reports in *The Geyser Gazer Sput* in 1998. "On 8/7 Ann and Tom provided the following data: Old Faithful is beginning to have shorts every day." [Deutch 1998, p. 23.] And, "[O]n 8/17, P[aul] S[trasser] reported data covering 8/6 – 8/15...Old Faithful's intervals under an hour occur infrequently, sometimes less than two per day." [Dunn 1998b, p. 19.]

In 1999, there was one such report by Paul Strasser who reported that Old Faithful had two sub–60 minute intervals in one day. [Monteith 1999, p. 10.]

In 2000, I reported that during the entire month of August only 13 short intervals were observed based on data available in the OFVC logbook. Two of those occurred on August 1 and three occurred on August 4, but there were no consecutive short intervals. [Monteith 2000, p. 22.]

Finally, in December 2001, I reported that "[S]horts were uncommon throughout December. In fact, no sub–70 minute intervals were observed between December 17 and 21 [the first four days the Visitor Center was open and regular observations daylight observations of Old Faithful were being recorded.]" [Goldberg 2002, p. 16.]

I have not thoroughly examined the OFVC logbooks for 1992 through 2001, but based on the lack of reports, there may have been no consecutive short intervals during 1992 through 1997, and I am relatively certain that none have been observed for 1998 through 2001.

Hutchinson also commented on the number of intervals in excess of 99 minutes that were recorded each year. (Data on intervals in excess of 99 minutes is shown in Table 8.) For example, there were two intervals longer than 99 minutes in 1978, and seven intervals of 100 minutes or longer in each of 1979 and 1980. In 1982 there were four intervals of 100 minutes or longer, and three in 1983. In 1984 the number of intervals of 100 minutes or longer jumped to 22, reflecting the influence of the 1983 Borah Peak earthquake.

I do not currently have data available on the number of intervals that were greater than 99 minutes for 1985, 1986, and 1987. In 1988 there were 92 intervals of 100 – 109 minutes, and there were two intervals of 110 minutes or greater. I did not collect data for 1989-1991.

Because the frequency distribution of Old Faithful intervals had shifted to the right toward longer intervals, intervals between 100 and 109 minutes became more common during the 1990s. Intervals between 110 and 119 minutes became the "unusually long" intervals. In 1992 there were six such intervals. There was only one interval above 109

Table 8: Old Faithful's "Long" Intervals

Year (total intervals)	Number of Intervals 100 minutes or longer	Number of Intervals 110–119 minutes	Number of Intervals 120 minutes or more
1978 (NA)	2	0	
1979 (NA)	7	0	
1980 (3,321)	7	0	
1982 (3,023)	4	0	
1983 (3,245)	3	0	
1984 (3,222)	22	0	
1988 (6,423)	94	2	
1990 (6,656)	123	NA	
	Number of Intervals 100–109 minutes		
1992 (6,681)	75	6	
1993 (3,253)	56	1	
1994 (6,587)	90	5	
1995 (2,977)	101	6	
1996 (2,159)	68	6	
1997 (2,251)	68	0	
1998 (2,061)	107	11	1
1999 (2,088)	68	2	
2000 (2,084)	77	3	
2001 (1,926)	211	27	2

Source: Compiled by Lynn Stephens from Hutchinson's annual reports (using data for the years 1978, 1979, 1980, and 1990) and Old Faithful Visitor Center logbook data (remaining years).

minutes in 1993, but in 1994 there were five. There were six such intervals in 1995 and 1996. In 1997, the year prior to the next major increase in the length of Old Faithful's average interval, there were no intervals above 109 minutes.

In 1998 following the Biscuit Basin earthquake, another shift began. After the earthquake, there were 11 intervals between 110 and 119 minutes, and the first interval in the 120 minute and above category since 1977 appeared. In 1999 there were two intervals 110 minutes or longer, and in 2000 there were three intervals in that category. No intervals greater than 119 minutes were observed in those two years. In 2001 however, the number of intervals in the

110 to 119 minute category jumped to 27 and there were two intervals in the 120 and above category. Just as the 110 minute and above intervals became the "unusually long" category for the 1990s, perhaps the 120 minute and above intervals will become the "unusually long" category for the 2000s.

CONCLUSION

Old Faithful's interval lengthened as a result of the 1959 Hebgen Lake earthquake and the shape of the frequency distribution of intervals changed from one that did not demonstrate bimodality to one that did demonstrate bimodality. Subsequent earthquakes also resulted in lengthened intervals, but the shape of the distribution did not change until the 1999 "Spring Break" event(s).

Old Faithful's intervals do not immediately lengthen following earthquakes. Marler reported the following information about Old Faithful's response to the 1959 Hebgen Lake earthquake:

> During the first few days following the big tremors of the night of August 17, 1959, it was thought that Old Faithful had escaped wholly unscathed. The character and frequency of its eruptions were essentially the same. By the end of August the average interval had increased one minute over the pre-quake average. This was not of particular significance. Such short-time deviations in average time are not uncommon. However, during succeeding months there was a progressive increase in average time...From August 17 to the end of the year Old Faithful's average eruption time increased from 60.8 minutes to 67.4 minutes. [p. 37]

Similarly, examination of the daily average intervals for Old Faithful following the January 9, 1998 "Biscuit Basin" earthquake showed that Old Faithful's intervals did not begin to lengthen until January 18. The annual average interval for 1997 was 75 minutes. The average interval for January 9 through January 17 was also 75 minutes. On January 17 the daily mean was 73 minutes. On January 18 the daily mean interval increased to 84 minutes. The average stayed at this level for the last two weeks of January. The average gradually declined over the next few months, resulting in an average for January 18, 1998 through December 31, 1998 of 81.4 minutes.

Since the end of 1998, Old Faithful's average interval has lengthened another 10 minutes (as of December 31, 2001), and bimodality completely disappeared as the proportion of "short" intervals decreased dramatically until it was only slightly greater than the proportion of "really long" intervals. At least some of this increase has been attributed to "another swarm of earthquakes." [*Yellowstone Today*, Spring 2002, p. 5.] I am currently working on a paper for the next issue of the *Transactions* that will explore further the changes in Old Faithful's interval that occurred both before and after the various earthquakes that have been credited with lengthening Old Faithful's interval.

Although the "official" range for Old Faithful's intervals is either 30 or 33 minutes on the minimum side to 120 minutes (or possibly 148 minutes) on the maximum side, acceptance of the 30 minute minimum depends upon acceptance of minor eruptions of Old Faithful. If one does not recognize minor eruptions of Old Faithful, then the minimum should be reduced to Railey's 12 minute interval in 1987. Based on Rocco Paperiello's assertion that there is no 148 minute interval in the 1973 logbook, then, in my opinion, the maximum interval should be the 127 minute interval of June 2001, at least until a longer interval occurs subsequent to that date.

Prior to the 1959 Hebgen Lake earthquake, Marler [1953, p. 22] noted "It is doubtful if Old Faithful, or any geyser, has yet been observed long enough to say with any degree of finality just what its trend might be." While we may not be able to say what the trend will be in the future, as Tim Thompson [1998, p. 19] stated about changes in Old Faithful "...we are witnessing dramatic geologic changes in our lifetime."

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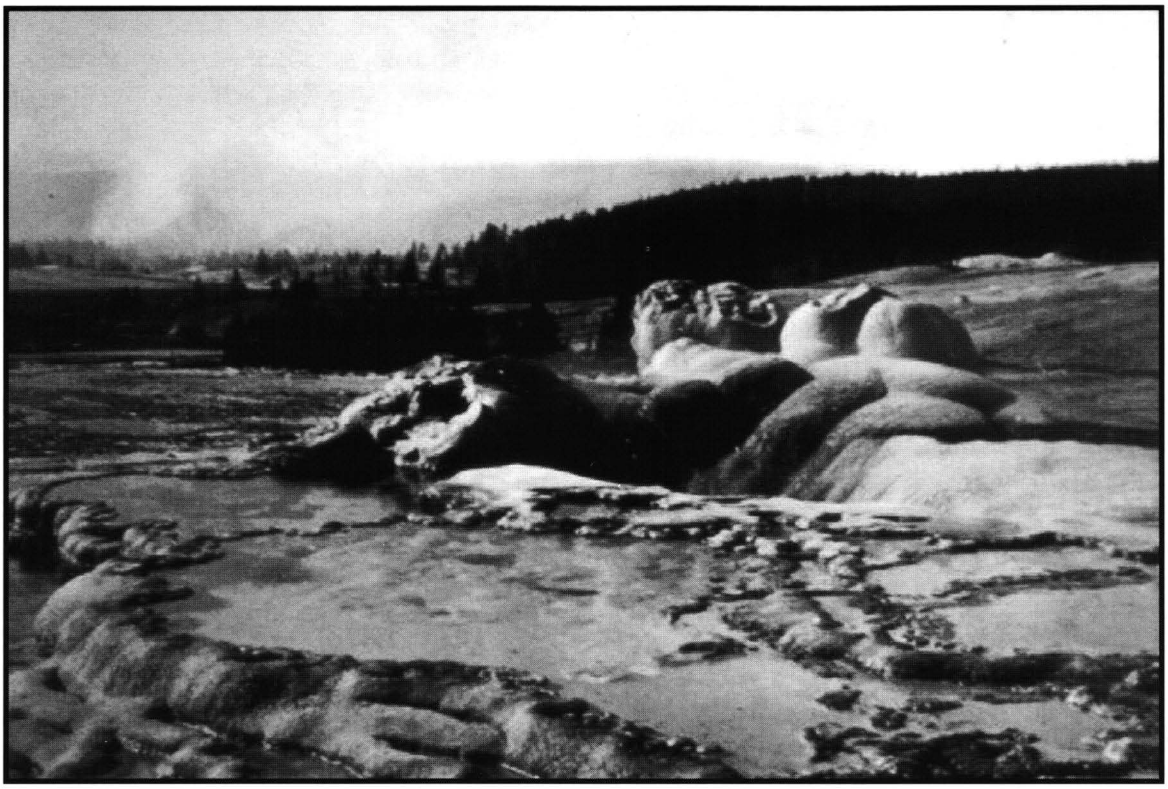
The thermal area of **Cisolok**, on the Cipanas River near the southwestern shore of the Indonesian island of Java, has long been reported by the Volcanological Survey of Indonesia as the site of a geyser or two. New Zealand's E.F. Lloyd recently obtained this photo, but his opinion is that this and another erupting spring there are *not* true geysers but instead are perpetual spouters or hot artesian springs. He observed no intermittency in the activity.



Readers might enjoy these comparison photographs with close–up views of Old Faithful Geyser's cone formation. It must have been a warm day when W. H. Jackson took the top photograph in 1871. It was cooler and early in the morning when T. S. Bryan (in uniform, on National Park Service duty) took the bottom photograph in 1984.

GOSA

The Geyser Hill Wave in May 2002

A cursory look

by T. Scott Bryan

Abstract

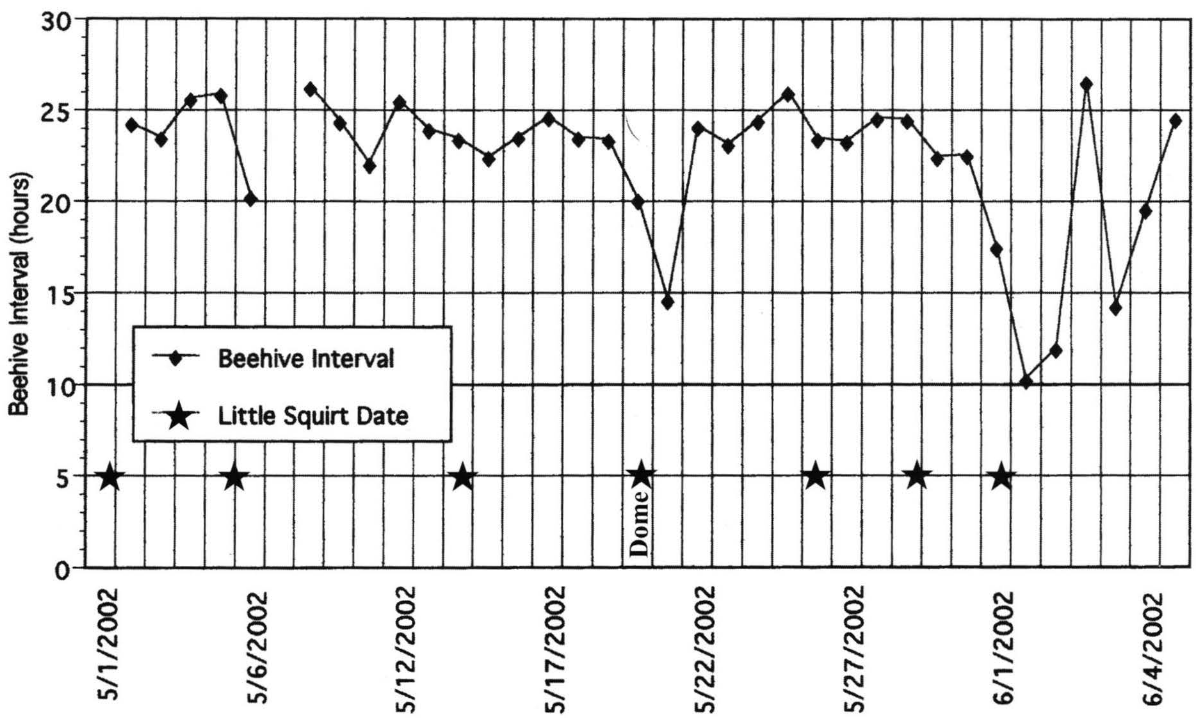
A cursory examination of eruption data for Beehive Geyser and Little Squirt Geyser indicates that the "Geyser Hill Wave" was operating in May 2002 much as it did in Summer 1992.

My article, short title *Cyclic Hot Spring Activity on Geyser Hill...* [GOSA Transactions, Vol. IV, 1993] contains details about the "Geyser Hill Wave" (GHW) and its culminating high water level, the "South Maximum" (SMax). In very brief summary, the GHW is a regularly cyclic event that affects virtually all thermal features on Geyser Hill. Although its cause is unknown, judging its progress is easy if the observer watches the water levels in Silver Spring and Bronze Spring, which are located in the extreme southernmost part of Geyser Hill. It is only at the time of SMax, when water levels are at their highest in those springs, that Little Squirt Geyser might erupt. Its activity, when seen, is taken as marking the time of SMax.

In 1992, I noted the following: "Beehive Geyser often has its shortest intervals ended by eruptions while Little Squirt is active" [p. 16]; "Beehive Geyser will have its shortest intervals at the time of or just after this peak [that is, SMax]" [p. 30]; and "...three of the four Dome [Geyser] initiations occurred at the time of Smax" [p. 18].

For the month of May, 2002, much of the eruption data for Beehive Geyser, most SMax dates as determined by Little Squirt activity and the single active episode of Dome Geyser were obtained from the Old Faithful Visitor Center logbook.

The situation seems abundantly clear when the data is plotted as a chart (below). On each of the seven recorded SMax dates, Beehive underwent a significant decrease in interval. The active episode by Dome occurred at the time of SMax. Indeed, that there was an unobserved SMax on about May 10 can easily be inferred. As brief as this examination is, it shows that simple observation goes far in understanding geyser activity on Geyser Hill.



The Twentieth Century History of Giant Geyser,

Upper Geyser Basin, Yellowstone National Park

by Mike Keller

Abstract

Research in the archives of Yellowstone National Park revealed numerous eruptions of Giant Geyser previously unknown to modern observers. In this paper, this activity is discussed on a yearly basis. The newly discovered eruptions change our perception of the pattern of Giant's activity during the 1900's. George Marler believed Giant to erupt on a "five year cycle" of activity. This does not appear to be the case. Also, there seem to have been fundamental changes in Giant's behavior three times this century (pre–1900 to 1947, 1949 to 1955, and 1978 to present).

Activity of 1900–1909

Early records of Yellowstone's geysers were thought to be non-existent or lost. However, these records do exist, just not in the form we are used to today. The primary reason for this stems from the Army placing a higher priority on reports of soldiers' duties versus reporting on the activity of the natural phenomena in early Yellowstone. Captain George Anderson, the Superintendent of Yellowstone from 1891 through 1897, appears to have been the first official who required logging geyser activity as standard procedure. It is because of his actions we have most of the data for major geysers in the 1890's.

Following Anderson's departure geyser recording was done only on the whim of any soldier who saw fit to report. However, we are fortunate to have had Sgt. Peter Christiansen stationed at Old Faithful from 1903 to 1908. He and fellow soldiers reported the activity of Beehive, Lion, Grand, Giant, and Giantess Geysers. Giant had at least 91 eruptions during this decade.

1900 – No records found

1901 – No records found

1902 – *Haynes Guide* table[1] (see endnotes), which changed in 1903 because of 1902 activity, states the interval is "6 to 12 days". The Guide for 1902 gave an interval of "2 to 4 days"[115].

1903 – Two eruptions listed in the Upper Basin Soldier Log[2]:

Nov 18
Dec 01

1904 – Ten eruptions are listed in the Soldier Log[3]. The *Haynes Guide* continues to show a "6 to 12 day"[116] interval for 1904.

June-07, 12(@0905)
July-03, 08, 13(@2030), 19, 26(@0500)
August-01, 11, 18(@0400)

1905 – Five eruptions are listed in the Soldier Log[4]. No change is noted in the *Haynes Guide* from 1904[117].

August-30(@1800)
October-13
November-02, 17
December-24

1906 – Nineteen eruptions listed in the Soldier Log[5]:

January-01, 06
April-28
May-18, 28
June-18, 29
July-21, 31
August-09, 16
September-09, 17, 27
October-09, 17, 25
November-13
December-10

1907 – Twenty-three eruptions listed for this year. Eighteen were in the Soldier Log[6] while another five were listed in the monthly payroll reports[7]:

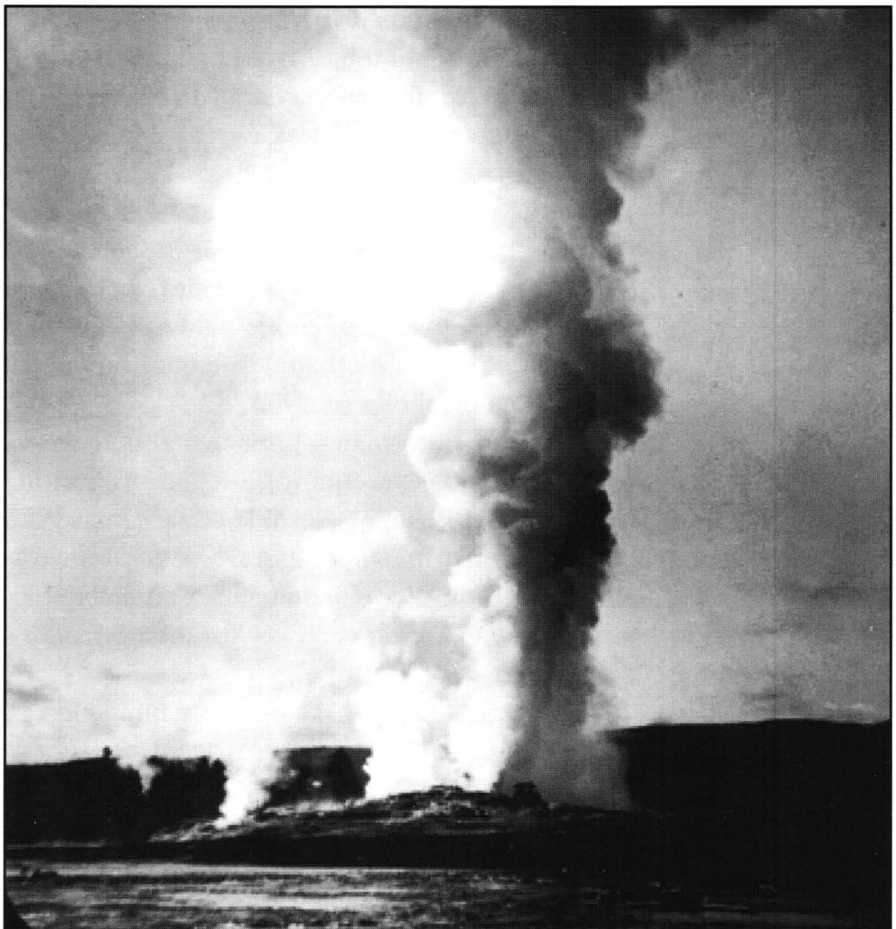


Figure 1. Giant Geyser (Haynes #13063), photographed sometime in or before 1910 by F. Jay Haynes. This is a curious view, as it looks toward Giant in the upstream direction from across the Firehole River. The prominent cone in front of the steam clouds is Bijou Geyser and the largest eruption might be rising from Catfish Geyser. The "lump" to the right of this steam cloud is actually four people, standing on the cone!

January-09
February-09, 17
March-09, 24
April-11, 19, 29
May-09, 16, 28
June-05, 19
July-03, 12, 22
November-05, 15, 23
December-03, 10, 18, 27

1908 – Thirty-three separate eruptions recorded in the Station Logs [8, 108], Payroll Reports[9], and GOSA Archives[10]:

January-05, 12, 19, 26
February-02, 10, 17, 24
March-04, 10, 19, 27
April-02, 09, 15, 22, 30
May-06, 09, 13, 29
June-12, 26
July-03, 09, 22
August-07, 23
September-01(@0730), 15
October-03, 13
November 16

1909 – The 1909 *Haynes Guide*, which changes from 1908, states the interval for Giant is "7 to 12 days"[118].

Activity of 1910–1919

Records of geyser activity for this decade are practically non–existent. Part of this is a result of the change from the Army to the newly established National Park Service (NPS) in 1916. It appears that some records were lost at this time. The only specific reports are found in the *Yellowstone News*, *Haynes Guides*, and local newspaper accounts. Beginning with the National Park Service in 1916 are the Monthly and Annual Reports of the Naturalist and Superintendent Divisions. These are where the first true geyser reports began to appear.

1910 – No records found

1911 – *Haynes Guide* table[11], which changes in 1912 because of 1911 activity, gives an interval of 7 to 12 days. This information is probably based upon a memorandum[113] sent to NPS headquarters in Mammoth from the Old Faithful Army Station. On the 2nd page of their "Table of Prominent Geysers and Springs" they state Giant's interval as "7–12 days" and its duration as "60 minutes." Dorothy Brown Pardo, who visited the park from July 11–16, wrote the following in her diary[12]:

> We were all interested in the Giant - that king of geysers that sends a flood of water heavenward

> 250 feet and holds it there for an hour and a half or two hours. This old fellow was doing a lot of growling in his subterranean abode, but was apparently on strike, for he had been very irregular in his appearances all season and was long overdue at this time.

1912 – No records found

1913 – No records found

1914 – Listed as "active" in the *Yellowstone News* with intervals of "6 to 14 days"[13].

1915 – Intervals reported by Skinner at 6 to 14 days[14]. A copy of the 1915 *Circular for Yellowstone National Park* can be found in Letter Box 20 in the Yellowstone Archives. This circular has a number of handwritten comments in it for revisions to the 1916 edition. While a number of other geysers had their existing comments crossed off and changed, the interval for Giant of "6 to 14 days" was not altered[119]. Along the margin of this document the statement "OK according to men, U Basin, and Sgt. Taylor, Jan 17, 1916" is also written in.

1916 – No records found

1917 – No records found

1918 – No records found

1919 – The Monthly Report of the Superintendent listed these seven eruptions[15]:

July-01(@1515), 13(@1425)
August-03(@0940), 14(@0730), 24(@2100), 27(@1345)
September-02(@1400)

Activity of 1920–1929

This is probably the first decade since the 1880's in which one can get a true feeling of what the geysers were up to by reading the literature. Numerous individual reports are known which discuss activity within the major geyser basins.

From 1920 through 1923 Milton Skinner provided accounts of geyser activity in the Upper Basin. However, Skinner retired in 1923, and as a result data on almost every major geyser is missing for 1924. Until the arrival of Charles Phillips and Wink Martindale in the fall of 1925 there is no known reference to Giant Geyser. Most of the Upper Geyser Basin activity from 1925 through 1927 was reported by Phillips and Martindale. While their monthly memoranda to the Superintendent's Office are on record, their actual field notes and reports were thought to be lost until I found them in an obscure reference box in the Yellowstone Archives in 1994.

Another important reference I found was a guide for the construction of a nature trail in the Upper Geyser Basin by Ansel Hall written in 1926 (see the article in *The GOSA Transactions*, Volume VI). From these documents a complete history of Giant Geyser's activity for the mid 1920's was constructed.

Unfortunately, two key events happened in the fall of 1927. Charles Phillips accidentally consumed water hemlock and died, and Ansel Hall left Yellowstone. With their departure most of the continuous observations and data collection for the 1920's came to an end. We must rely upon the Monthly Reports of the Superintendent for the remainder of this decade.

1920 – Six eruptions are known, but more are suspected. In a letter dated November 1, 1920 from Milton Skinner to Assistant Superintendent Lindsley Skinner (no relation), the following was said about Giant[16]:

> ...the Giant played on the 11th (Oct) and 18th (Oct) and probably at other times also.

These are the known eruptions for 1920:

June-02, 19, 26
July-27
October-11, 18

1921 – Giant was definitely active in 1921. George Marler stated there were 15 eruptions during this year[17], but I was only able to find five, on these dates:

June-02, 19
July-04, 15, 28
August-"...every 8 to 12 days..."

1922 – Giant's activity continued into 1922 with eruptions recorded on the following dates[18]:

June-11, 18
July-05(@1317), 12(@0950), 27(@0310)
August-09(@0850), 15(@0515), 24(@1810)
September-02(@1130)

1923 – Giant was still erupting frequently in the summer and fall of 1923. The following eruptions were listed in the Ranger Station Log[19]:

June-27(@0930)
July-03(@1935), 15(@0430), 23(@0745)
August-02(@0430), 17(@1925), 24(@1100), 29(@0700)
September-06(@1922), 12(@1250), 18(@1230)

1924 – With the retirement of Skinner there is practically no data for 1924. The few reports found make no mention of activity or dormancy in Giant. It is my belief that Giant was active in 1924, but its frequency is unknown.

1925 – Three eruptions are found in the Monthly Report of the Superintendent[20] and another is found in a memorandum from Sam Woodring to Superintendent Albright[111]. Charles Phillips corroborates the eruption of November 08. The following excerpts are from Phillips' notes[21]:

> Geyser Notes – October 1925
> Giant – no eruptions observed or reported. The log across the cone has been knocked off several times but this is apparently due to the wind or more active boiling, as it is difficult to fasten it securely in position.
>
> Geyser Notes – November 1925
> Giant – erupted Nov 8th at 11:00pm. I did not reach the geyser until the close of the eruption because it was very dark. Observations the following morning indicated that the eruption had washed away a large quantity of loose formation. The log replaced across the crater on the 9th has remained undisturbed the remainder of the month.
>
> Geyser Notes – December 1925
> Giant – no activity; the stick placed across the cone November 9th is still in position.

The known eruptions for 1925:

April-03(@1800)
June-20
July-05
November-08(@2300)

1926 – There was a marked increase in Giant's activity in the fall of 1926. In Ansel Hall's 1926 report for the construction of a nature trail, he made the following comments for the Giant[22]:

> Giant Geyser – Depth of crater 27 feet 7 inches. This is the largest active geyser in Yellowstone Park. The eruptions are 250 feet high and last for 1½ hours. The maximum height is kept up for 20 minutes at the beginning of the eruption. Eruptions usually occur every 8 to 14 days; in some years they are not so frequent. During 1926 it erupted about once every three months. The irregular cone of the Giant looks as if it has been blown off by an unusually violent eruption; if so, this has not happened since 1870. Several small openings around the Giant play at irregular intervals, thus probably causing some delay in the eruption of the Giant.

From Hall's statement of "three month" intervals, it would seem he wrote this before September. Prior to that month, the previous five eruptions all had had intervals of near three months. In September, however, Giant suddenly sped up for a few weeks[23]. The recorded 1926 eruptions:

February-12
May-24
August-29
September-07, 10(@1045), 18, 28(@1230/d=2h)
October-20

1927 – Another mid–season increase in Giant's activity occurred in 1927. The only winter or spring eruption was in February, about which Phillips wrote the following[24]:

> The only outstanding event of the month was an unusually vigorous eruption of the Giant on Feb. 4th. The last eruption was Oct 20th, an interval which is quite considerable with the three month period on which the geyser appears to be operating.

Starting in late June, Giant's intervals shortened from their three month average to 4 to 20 days[25]. It seems to have remained this frequent until about 1931.

The recorded 1927 activity:

February-04(@1245)
June-27 ("early morning")
July-09(@9845), 29
August-01, 05, 20
October-05, 20
November-20
December-08(time unknown/d=50m), 24

1928 – With the departure of Hall and Phillips the data for this year and 1929 is found primarily in the Superintendent's Monthly Reports[26].

January-19
March-03, 13, 30
April-19
May-31(@0000)
June-17
July-07
October-14
November-15(@1626/d=1h 19m), 26
December-04(@1430/d=1h 02m), 13

1929 – The following dates are a compilation from the Monthly Superintendent Reports[27], the Yellowstone Archives Card File[28], the GOSA Archives[29], Box K-41 in the Yellowstone Archives[30], and the Old Faithful Ranger Station Log[31]:

January-(between 12/22/28 and 1/5/29), 26
February-08
April-"...played three times..."
June-28 (between 1700 and 1800/d=1h 03m)
July-03(@1030), 09(@0530), 25(@1040)
August-01(@1530), 07(@2300), 19(@1515/d=1h 15m), 27(@1600)
September-"...played two times..."
December-"...played three times..."

Activity of 1930–1939

With the 1930's came some of the most important documents of geyser activity by some of the most important geyser gazers (George Marler, Clyde Max Bauer and Herbert Lystrup, just to name a few) in the history of Yellowstone Park. The growing amount of traffic to the Park and the need for geyser information to feed the increasing number of visitors required further studies of Yellowstone's natural wonders. Starting in 1938 George Marler began to write monthly and annual accounts of the geyser activity. In addition to these, there are other references to Giant found in local newspapers, guidebooks, Ranger Station Log Books (Green Log Books, YNP Archives, 1930-present), and personal accounts of various people in the park during this decade.

1930 –The activity of Giant during the late 1920's seems to have continued into 1930. While only 13 eruptions can be found, I believe others to have happened this year[32]:

February-"...played three times..."
May-"...played three times..." One of these was on the 29th(@1940)
June-01, 10, 19(@1430/d=1h 40m)
July-01(@1444), 21(@1452)
August-31(@1820/d=1h 30m)
September-28

1931 – Eight noted eruptions. It appears Giant started slowing down in 1931, a trend that continued until 1934. *The Livingston Enterprise* newspaper reported, on August 26th, the following about the August 22 eruption of Giant [33]:

> Inactive since May 22, Giant Geyser, the largest in Yellowstone National Park, thrilled thousands of tourists, park officials, and "savages" Saturday with a brilliant play that lasted for nearly an hour... The eruption sent a stream of water and steam to a height of 250 feet...

The first sentence above is incorrect, for Giant actually *did* play three times between May 22 and August 22, as well as on three other dates:

May-14, 22
July-13(@0500), 21
August-12, 22(@1550/d=2h 05m)
October-01(@2000), 31

1932 – Giant's decline apparently continued into 1932. The first eruption for the year was noted on June 04.

The eruption dates known for 1932[34]:

June-04(@1700/d=1h 42m)
July-21(@1703/d=1h 42m)[34]
August-12(@1350/d=2h 10m)
October-16

1933 – Giant is known to have erupted five times during 1933[35]:

June-02(@1405ie)
July-15, 25(@1300/d=1h 50m)
August-19(@1835)
September-07(@1655/d>1h)

1934 – Sometime in the late fall of 1933 or the early winter of 1934, Giant's intervals began to shorten once again. In fact, there was an apparent increase in geyser activity in much of the Upper Basin during late January of 1934. It is worth noting that no reference to any possibly–related seismic activity has been found. The following is from a *Helena Independent* newspaper article on February 14, 1934[36]:

> The Giant and Giantess Geysers are both very active. The Giant Geyser erupted three times in the month of January, Jan 8, 25, and noon on January 29. The Giantess began erupting at 2:40pm Jan 29 and the eruption continued for 2 hours.

Activity reported for 1934:

January-8, 25, 29(@1200)
February-(between 2/19 and 2/21)
March-(between 3/22 and 3/25)
April-15
May-06
August-02(@0819/d=2h 05m),
18(@2230/d=2h)
December-12(@1215/d=1h 45m),
15(@1345)

1935 – Herbert Lystrup and others filled out several index cards that are housed in the Yellowstone Archives in Box K-41. Data for Giant for the remainder of the 1930's can be found on them. Some of the information recorded was only a date and a time, but others had a couple of written or typescript paragraphs detailing activity[37]:

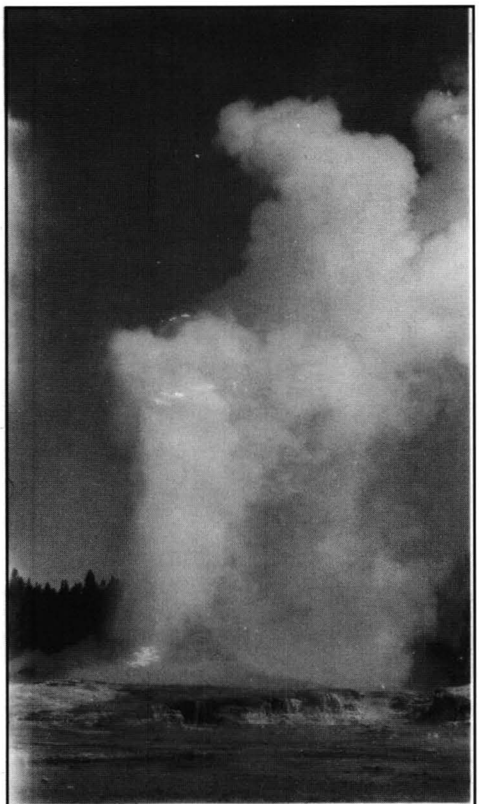


Figure 2. Although labeled as "Old Faithful in Eruption, 9–30–36, by Danecki," This clearly is the Giant Complex, and other pictures in the same album are in fact labeled as showing Giant. Who "Danecki" was is unknown. [Source: YNP Photo Archives, Album 3A, page 3.]

Giant Geyser June 18 1935
Ranger Wayne Replogle observed the start of play at 5:15pm. Duration of play– 1¾ hours. Max ht– 200-250 ft Great activity of Bijou and Catfish during play.

Giant Geyser July 25 1935
A very beautiful eruption of the Giant Geyser started without the slightest warning at 10:15am. The day was very bright and clear and the spurts for the first four minutes attained heights of well over 200'.

I was standing at the Daisy Geyser and just as the Daisy broke I turned in time to see the Giant lift the first spurt which was at once followed by the maximum spurt which I judge to have been very nearly 250'. There was a splendid opportunity to really appreciate the power and force of the Giant since there was not the usual amount of steam. After the first four minutes

> the spurts gradually became less in ht. tho [*sic*] a great amount of water was constantly being thrown out.
>
> The Giant was very nearly through at 11:45am. The last eruption occurred on June 29.

An overview of activity reported in 1935:

June-18(@1715/d=1h 45m), 29(@1315)
July-25(@1015)
August-10(@1645/d=1h 45m), 20(@2320)
September-12(@2350)
November-(between 11/4 and 11/6), 25
December-08, (between 12/22 and 12/25)

1936 – The interval of Giant decreased in the early part of the summer and maintained a 7 to 12 day average. This interval would remain fairly consistent until 1940. There was one interesting observation of Giant[38]:

> The Giant Geyser erupted June 12, 1936 at 3:45pm. The eruption was not of the normal duration and did not reach a height of over 150 ft. according to Leon Evans.

Eruptions reported for 1936:

April-09, 18
May-19, 31(@1015)
June-12(@1545)
July-02, 10, 19(@1215/d=1h), 30
August-06, 11, 24
September-03, 07(@0630), 30[112]
November-"...played twice..."

1937 – While the only eruption dates available for 1937 are in the summer, there is no indication of Giant being either dormant or having intervals longer than 7 to 12 days between November of 1936 and June of 1937. One of the index cards revealed this comment[39]:

> Erupted July 10, 1937 about 4:00pm... Eruption by 5pm practically ended except for steam rising with some water to heights of 50 to 75 feet. For many days before the eruption, the little geysers beside it had been spurting water, and Giant itself had frequently thrown water above the cone. [Phillip] Fix is inclined to believe the two activities just mentioned has [*sic*] been carried on without break since the time of the last eruption, though no detailed account was kept of them.

The recorded 1937 eruptions:

June-01, 10(@0900), 18(@2000)
July-10(@1600), 17(@2120), 27(@1300)
August-04(@2330), 17(@1745), 24(@2300)
September-02

1938 – Starting in 1938, George Marler became more and more the figurehead of thermal information. In the August Report of the Naturalist Division, Marler included one of the most thorough thermal reports for the decade, for geyser activity during 1938[40]. He eventually made this a monthly and annual tradition until the early 1970's. In addition to this report, there are the index cards[41], Old Faithful Ranger Station Log[42], newspaper clippings[43], and individual notes by a number of observers. Marler's comments about the August 17th eruption were as follows[44]:

> This eruption of the Giant began at 6:45pm, on August 17th. I was at the Grotto when the Giant began erupting. It could not have been more than 20 seconds following the initial eruption that I first beheld it. It was then playing to a height of about 50 feet. It was at least 20 seconds before the height of this eruption was doubled. At the end of about 3 minutes it was playing to a height not exceeding 150 feet. During the next 10 minutes this height (150 ft.) remained fairly steady. During the following hour the column slowly diminished in height. At 8:30, except for considerable issuance of steam, the eruption had ceased. During the eruption the Catfish, Mastiff, and Bijou remained relatively inactive.

Activity reported for 1938:

May-05, 15(@1100), 25(@1600)
June- 05(@1800/d=1h 15m),
  20(@1913/d=1h 15m)
July-04(@1600), 12(@0400), 24(@1255)
August-01(@1750/d=1h 45m), 17(@1845),
  21(@0845/d=1h 30m),
  29(@0955/d=1h 35m)
September-03 ("in the evening")
October-28[45]

1939 – Giant remained frequently active in 1939, with most intervals being from 2 to 8 days in the spring and early summer. During August the intervals began to lengthen. Sometime between the fall of 1939 and the spring of 1940 Giant changed its eruptive pattern. Not all of the eruptions during 1939 were spectacular[46]:

> Giant Geyser erupted at 2pm (07/02). It reached a height of 125 feet during the first 10 minutes. The eruption, which lasted one hour and forty minutes, was witnessed by several hundred persons.

A summary of the activity recorded in 1939:

April-21[114]
May-04, 17(@0830/d=1h 15m), 26(@1945/d=1h 30m)
June-03(@0845/d>50m), 11, 14(@0900), 23(@0600)
July-02(@1400/d=1h 40m), 10(@1220), 15(@1603), 23(@0610)
August-01, 03(@1545/d=1h 35m), 17(@1350/d=1h 40m), 31(@0100)
October-22 ("...played early in the morning...")

Activity of 1940–1949

Giant Geyser's eruptive pattern began to change in the 1940's. This is the first decade in which Giant is known to have had full years of complete dormancy (1947 and 1948). Giant also had three years where eruptive activity ended in the fall and did not resume until the following year in late summer or early fall, a pattern which is fairly consistent with today's activity. In fact, 34 of the 54 known eruptions of Giant in the 1940's were in the months of August, September, October, and November.

1940 – One of the most interesting accounts of Giant in its history was written by Herbert Lystrup for July 30, 1940[47]:

> On the afternoon of July 30, 1940 I was on my way to Biscuit Basin with ranger naturalist Beal. Driving past Giant we noticed unusual activity and we both commented about it. We drove directly to Daisy Geyser to chalk up the next play. We arrived at the junction of the Black Sand Basin Road and the Grand Loop Road near Grotto Geyser and again noted unusual activity at Giant Geyser. Ranger naturalist Beal went over to Giant Geyser and soon called me over. We noticed a heavy soapy scum on the surface of the shallow pools around Giant. I tasted the scum and it was distinctly soapy. I decided to return to the car to obtain a bottle to collect some of the soapy water. Just as I reached the car Giant Geyser played (2:03pm!).
>
> I left at once for the Museum and Ranger Station to notify all of the Giant play. Ranger Naturalist Beal stayed at the Giant to explain its activity. I also ran over to Beach Spring to notify Ranger Naturalist Douglass and the 1:30pm geyser party of the Giant eruption. I mentioned to Douglass that there was evidence of soaping!
>
> During the play of the Giant Geyser I gave no explanations of activity since my time was devoted to telling people that the Giant is in eruption.
>
> Ranger Naturalist Harry Bauer last evening (July 29th) said that someone came to him and said that Giant was unusually active. Dr. Bauer (Harry) suggested that since the man seemed to know what he was talking about it might be a good idea to drive out there. At 9:40pm we drove to Giant Geyser but noted no unusual activity.
>
> I personally feel that because of the excessive evidence of the soapy scum around the pools the Giant was soaped.

Prior to this, Giant had not had an eruption for 65 days, the longest known closed interval since 1927. Was there a missed eruption during this time? This seems highly unlikely. There were plenty of experienced personnel in the Upper Basin during 1940. The Old Faithful Log book does not record or imply any activity of Giant during June or July. Following this eruption, Giant had four more eruptions in the fall[48], giving it a total of nine known for the year:

January-21, 28
May-15, 26(@1150/d=1h 30m)
July-30(@1403)-PROBABLY SOAPED
August-19(@1628/d=1h 27m), 31
September-13, 18(@1355)

1941 – Sometime in the spring Giant stopped erupting. There was no known eruptive activity from March until September of 1941. Regarding the September 5 eruption, Ranger Bauman entered the following into the Old Faithful Ranger Station Log[49]:

> Another beautiful day with some little travel, about 7 cars watched the Giant Geyser play for 1 hour and 37 minutes from 2:30pm to 4:07pm

> and what a show it was. This was the first time that the geyser played since last March as far as we know.

There are two eruptions listed in the GOSA Archives for September[50], but their source of information is unknown. Even with them included, Giant only had these five known eruptions in 1941:

March-date unknown (see above)
April-22 [unknown to Bauman in the above]
September-05, 15
November-09(@1430/d=1h 37m)

1942 – The only records of activity for this year are found in the Chief Ranger Annual Reports[51]:

August-02(@0100), 12, 22(@1750)
September-03(@2130), 15(@1615)

1943 – Again it seems by early spring that Giant had stopped erupting and did not resume activity until mid summer. Harold Broderick's August 1943 report states the following[52]:

> Giant—Two eruptions this month... Small vents around Giant continued very active.

The reported 1943 activity:

July-08(@1650/d=1h 20m),
23(@1758/d=1h 15m)
August-03(@1755/d=1h 25m), 30(@1320)
September-09(@1819)
November-16(@1315)

1944 – Giant appears to have had a rejuvenation in 1944. From what was found in the Old Faithful Ranger Station Log[53] and from seasonal Ranger Bannan's Log[54], the intervals for most of the year were from 5 to 13 days long:

May-31(@1300)
June-08, 17, 26
August-16(@0831)
September-05, 11, 17, 24
October-02, 08, 14, 20, 27
November-06(@1315)

1945 – This was the last "good" year for Giant in this decade. It seems the high frequency of eruptions in 1944 continued in 1945[55]:

May-12(@1950), 28(@1145)
June-09(@1745), 24(@1030)
July-01(@1330), 11(@1648), 19, 26
August-02, 10, 18(@1545)

1946 – Whether or not Giant's activity continued beyond August 1945 and into the spring of 1946 is unknown. Records of only two eruptions for 1946 could be located. The Monthly Report of the Naturalist Division for June stated[56]:

> All major geysers were observed in eruption during the past month with the exception of the Giant Geyser, the latter erupted sometime during the week of May 13 to May 18, this was noted because of the marker which was placed near the geyser some few days before.

Activity known for 1946:

May- between 13 and 18
September-28(@1830)

1947 – Giant apparently did not erupt in 1947. This is the first confirmed year of dormancy of Giant in this decade. What makes this especially interesting is that 1947 was a banner year for most of the geysers in the park. Giant seems to be the only major geyser that was not active.

1948 – Giant's dormancy seems to have continued through all of 1948.

1949 – Giant was dormant until September, when it erupted twice. The Old Faithful Ranger Station Log for September 4 states[57]:

> 11:45am (Ranger) Chaffee en route from basins to Ranger Station observed Giant Geyser playing.

The other eruption of Giant for 1949, on September 17, was reported by George Marler[58].

The recorded 1949 eruptions:

September-04(@1145ie), 17

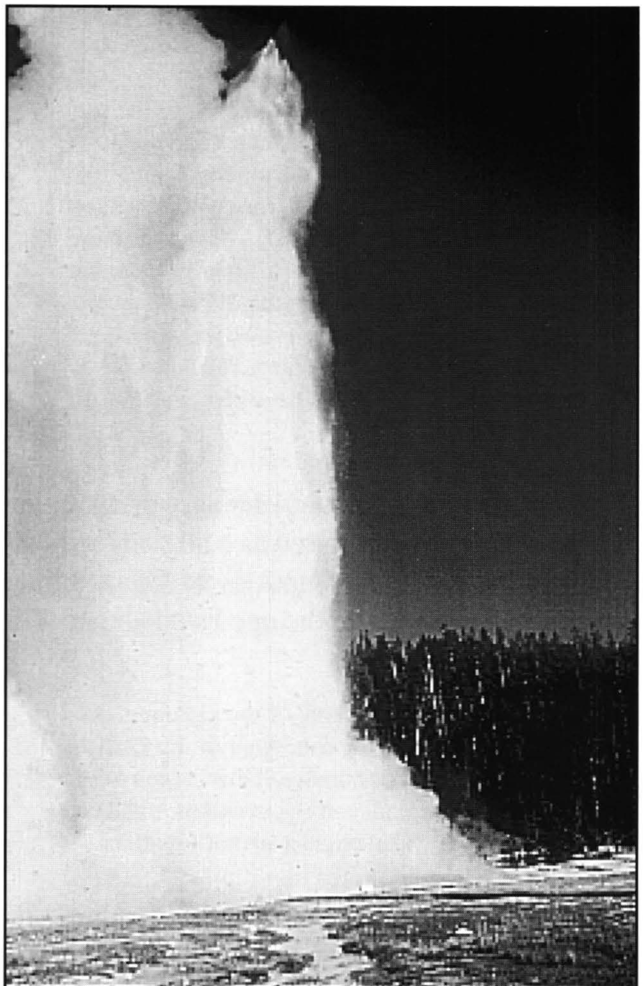


Figure 3. Giant Geyser, photographed from the road by George Marler in July 1951. [Marler Collection, Brigham Young University Archives, with one–time use permission.]

Activity of 1950–1959

The early 1950's were Giant's glory years. George Marler spent numerous hours at Giant during these years and provided us with most of what is known about Giant until the early 1990's. Giant was "discovered" by Marler to have hot periods in May of 1951, a discovery which would eventually help end the old question of "when will the Giant erupt?" The Mastiff Function activity of 1951 was new for the 1900's. Marler also came up with the theory of "five year cycles" of activity in the Giant Complex. He believed that another cycle of eruptive activity was about to begin in the fall of 1959 but was stopped by the Hebgen Lake earthquake. Marler's general belief was that this earthquake was the cause of Giant's near–dormancy until the late 1980's. Note that this idea is no longer accepted.

1950 – Giant had its first eruption for the year on June 30. Little did people know that this eruption initiated an active cycle that would include *at least* 465 eruptions in the next five years. It was not until September that Giant settled into a predictable pattern of activity. While there is no data for the winter of 1950–1951, there also is no evidence to indicate that Giant was not active.

The eruptions known for 1950[59]:

June-30(@1900)
August-26(@0545)
September-06(@1950), 15, 23, 29
October-07
November-24(@1230)

1951 – Marler returned to the Upper Geyser Basin in May of 1951, finding Giant to be "...still erupting with the same frequency as in September of 1950"[60]. This was the first year in which he also observed a major eruption of Mastiff prior to Giant[61]:

> On May 11 of this season I observed an eruption of the Mastiff... Following a few heavy surges it suddenly and massively lifted to a height of not less than 30 feet from its south vent. The Catfish at the same time began playing vigorously. Within a matter of seconds the Giant started playing with a simultaneous cessation of play of both Mastiff and Catfish. The behavior of the Mastiff was wholly unheralded to me and occasioned considerable surprise, not being aware at the time of any such behavior.
>
> Following the May 11 display of the Giant and until July 18, I was at the cone of the Giant two different times when it began playing... In neither case did Mastiff so more than surge up 3 or 4 feet prior to the Giant's activity.

On July 18th, Marler and Ranger Naturalist Sam Beal witnessed an even more spectacular eruption from both Mastiff and Catfish[62]:

> On July 18 while I was taking Ranger Naturalist Beal to Madison Junction I observed the Giant to be in a critical stage of heat and stopped the car. The critical stages recur about hourly. It is only at one of them that the Giant plays. Following about two minutes of observation both the Mastiff and Catfish began playing more vigorously than normal. The critical situation resulted in our moving expeditiously in the di-

rection of the scene. Before we had covered more than 100 feet the Mastiff suddenly lifted; not to a height of '20 to 30 feet', it massively rocketed skyward to a height comparable to Old Faithful's! At the same time the Catfish, which even in its most violent stages reaches 30 feet, fully doubled its height, with a pressure display very much like that of the Beehive. The Bijou went into a violent steam phase which equaled the Black Growler at its best. The hydrotechnic display lasted for 10 minutes with an inactivated Giant. Then suddenly the Giant began surging heavily for a few seconds when it explosively rose in a spectacular display that the adjective 'Giant' alone would describe. During any previous eruption of the Giant which I have witnessed I have never seen it rise higher than what I would judge as about 180 feet – the eruption varying between about 150 and 180 feet. Not so with this mighty uprising of superheated water. I am confident that had triangulation been made of the top of the water column would have been considerably over 200 feet.

Instead of the Mastiff bowing out of the picture when the Giant entered the stage, for fully 5 minutes following Giant's mighty display, the Mastiff played on equal terms with its Giant companion. Of the two the Mastiff was the more impressive due to the fact it lifted not one but two columns of water into the celestial sphere. The water from the north vent played at an angle of about 15 degrees from the vertical, and away from the south vent whose water reached for the zenith.

Figure 4. The twin columns of Giant Geyser and Mastiff Geyser, photographed by George Marler on August 06, 1951. [Marler Collection, Brigham Young University Archives, with one–time use permission.]

From July 18, 1951 until January of 1952, the Giant Complex was reported as being on the Mastiff Function. Not all eruptions of Giant during this time were similar to the one listed above. For example[63]:

> On July 23 Catfish alone, of the big three, preceded Giant. During this eruption of Catfish, which lasted for 10 minutes, it discharged a volume of water equal to, if not in excess, to that of Old Faithful. The height was not less than 75 feet.

Not every eruption in 1951 had either Mastiff or Catfish erupt. For those that did, Marler gave the following definition of what he termed the Mastiff Function[64]:

> When the pressure was on the north side of the platform I considered the Giant to be on the Mastiff Function. While on the Mastiff Function the Giant would erupt more powerfully than when the energy was on the southern side of the platform.

An even more detailed account of the Mastiff Function is found in the *Yellowstone Nature Notes*[65]:

> ...Following the eruption of July 5 the pressure suddenly shifted from the right to the left side of the sinter platform, from south to north, in the direction of Mastiff, Catfish, and Bijou. The sloshing in Giant between its hot periods completely ceased. Neither the small vents to the right (southwest) of Giant nor the Tortoise any longer played at the time of one of the hot periods. Two small vents in front of the Giant would erupt during most of the hot periods. It was only during the hot periods that the water in Giant would surge high enough to be seen above its

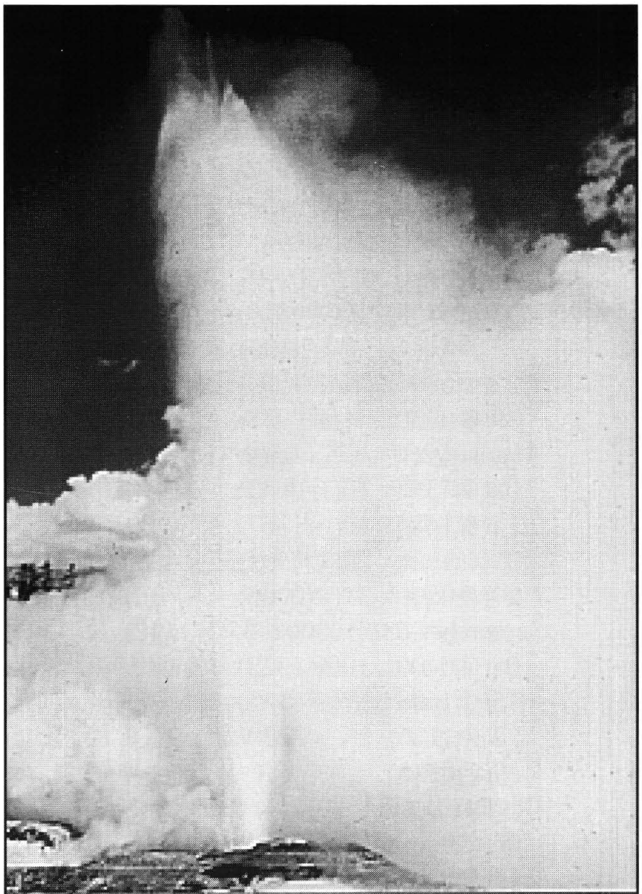


Figure 5. Catfish Geyser, photographed by George Marler on July 23, 1951. Note that this was a "Catfish Function" (no Mastiff) eruption of Giant. [Marler Collection, Brigham Young University Archives, with one–time use permission.]

> rim. Even the ebolution [*sic*] was feeble compared to its function prior to the shift of pressure. During these hot periods the water in Mastiff would rise to a greater degree than previously, with occasional heavy discharge welling over the rim of its crater. At the beginning of the hot periods the activity in both Bijou and Catfish would cease as before, but one or both would start playing before the critical period ended. A sudden change from a water to a steam phase in the Bijou indicated the end of the hot period.

As the year progressed the strength of Mastiff's eruptions, when they occurred, lessened. By the fall most of Mastiff's eruptions were from 30 to 50 feet in height, rarely being taller than 70 feet. During most of these smaller eruptions Mastiff's north vent did not erupt[66].

The recorded 1951 eruptions [MF-Mastiff eruption before Giant; CF-Catfish eruption before Giant]:

March-"...played at least once..."
April-"...played at least once..."
May-03(@0825), 05(@1303), 11(@1600MF), 16(@1349/d=1h 31m) 22(@0700/d=1h 30m), 27(@2200)
June-02(@1730), 08(@0330), 13(@000), 19(@0530), 25(@0130), 30(@1027)
July-05(@1125), 11(@1725), 18(@2010MF,CF), 23(@1132CF), 31(@0400MF)
August-06(@1220MF), 13(@0125MF), 18(@1720), 24(@1201MF), 31(@1358MF,CF)
September-06(@1045), 12(@1529), 18(@400MF), 23(@2210), 29(@1005)
October-05(@2225MF), 10(@1531), 14(@1610), 28(@0430)
November-04(@0630), 10(@0200), 16(@830), 22(@1720MF), 28(@0430)
December-05(@2200), 11(@1433MF), 16(@1305), 22(@0834), 28(@0530)

1952 – The Mastiff Function activity continued into 1952. In Marler's *Inventory...*, he stated the Mastiff Function ended in January[67], but in his personal notebooks at Brigham Young University he documented eruptions of Mastiff in February, March, and September[68]. Given the specific definition of *general* platform activity that Marler considered to represent the Mastiff Function, it seems that Mastiff can erupt when the energy is at the southern side of the platform (that is, when the system is *not* on the Mastiff Function).

With the transfer of energy back to the southern side of Giant's platform in January, Giant's interval between eruptions suddenly dropped to about 60 hours! This interval was to be the 'norm' for the next three years. During 1952 Giant had its second shortest interval ever known, only 34 hours. This was also the first year in which a compete January–to–December record on Giant was made, with no eruptions missed. This was because Marler remained at Old Faithful for the winter season. The total number of eruptions for Giant in this year was 137.

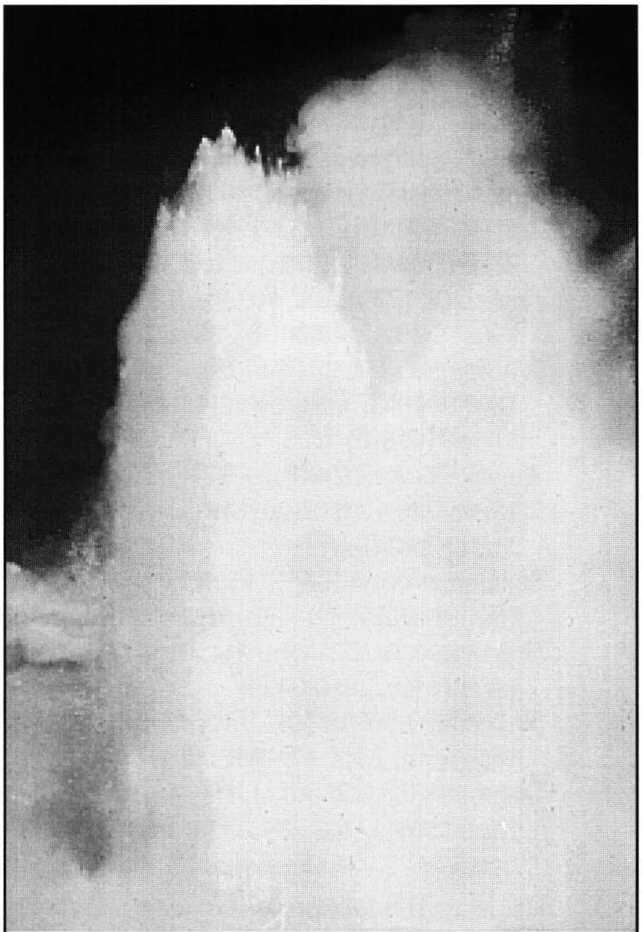


Figure 6. Giant Geyser and Mastiff Geyser, photographed by George Marler in July 1951. Note that the original photo fails to show the base of the eruption. [Marler Collection, Brigham Young University Archives, with one–time use permission.]

The complete record of activity for 1952[69] [MF-Mastiff eruption before Giant]:

January-04(@0230), 09(@0832MF), 14(@1210), 17(@1342MF), 21(@0905), 25(@0935), 27(@1527), 30(@1128)
February-02(@0330), 04(@1701), 07(@1414), 10(@1518), 14(@1637), 18(@0710), 21(@1416), 24(@0300MF), 27(@1515MF)
March-01(@0100MF), 03(@1455), 06(@0730), 08(@1346), 11(@0000), 15(@0200), 19(@1642), 22(@1835), 24(@1732), 27(@2030), 31(@0430)
April-03(@1822), 06(@0545), 10(@0445), 14(@0844), 18(@0200), 21(@1727), 24(@2130), 27(@0430), 29(@0630)
May-01(@0600), 03(@0602), 06(@0615), 07(@1610), 10(@0905), 12(@0755), 14(@1938), 17(@0445), 19(@0755), 23(@1011), 25(@1832), 28(@1107), 31(@0455)
June-02(@1432), 04(@2041), 07(@1130), 09(@1230), 12(@1634), 14(@2145), 16(@1946), 19(@2138), 22(@070), 25(@1850), 28(@0545)
July-01(@0400), 03(@1422), 05(@0905), 07(@2150), 10(@0819), 12(@1843), 15(@1114), 18(@0100), 19(@1200), 22(@0300), 24(@1352), 26(@1855), 29(@0330), 31(@0958)
August-02(@1425), 05(@1153), 08(@1355), 10(@0645), 12(@1010), 14(@1449), 16(@1857), 19(@0925), 21(@1745), 24(@0701), 26(@1129), 29(@0200), 31(@0000)
September-03(@0300), 05(@1442), 08(@0400), 10(@1323), 13(@0500), 15(@1608), 17(@1755), 20(@0500), 22(@1126), 24(@2230MF), 26(@1200), 29(@0545)
October-01(@1630), 04(@0400), 06(@0200), 08(@1025), 10(@1520), 13(@0900), 15(@0000), 18(@1205), 20(@2200), 22(@0000), 25(@1100), 28(@0400)
November-01(@0705), 04(@0200), 06(@0300), 08(@1252), 11(@0748), 13(@2140), 16(@0745), 19(@200), 21(@1222), 23(@1454), 26(@0400), 28(@1558)
December-01(@0300), 03(@2200), 06(@0600), 09(@1715), 12(@1553), 15(@400), 17(@0600), 19(@1255), 21(@1018), 23(@1235), 25(@0600), 27(@1532), 30(@0530)

1953 – Marler best summarized the 1953 activity in his *Inventory*[70]:

> During May to October 1953, Giant erupted 60 times. The shortest interval was 39 hours and 45 minutes, the longest 93 hours and 30 minutes. The time of the average interval was 60 hours. While the season average was slightly longer than for 1952 (54.4 hours), the monthly average for June and July was the shortest on record-52.4 hours. The 14 eruptions which occurred in July were the greatest recorded number of times Giant has played during any one month.

Despite the fact there is no known data for January, February, March, October, November, and December, it is highly unlikely Giant stopped erupting or changed its activity in these months. There was at least one eruption of Mastiff as well, this occurring on July 24[71].

A review of the recorded 1953 activity[72] [MF-Mastiff eruption before Giant]:

April-30(@1030)
May-03(@0000), 06(@1930), 10(@1601), 13(@0800), 16(@0500), 18(@1215), 21(@0500), 23(@1330), 26(@0000), 28(@1210), 31(@0850)
June-02(@0755), 04(@0000), 06(@0630), 08(@2358), 11(@1826), 14(@0000), 16(@0814), 18(@1256), 21(@1330), 23(@0300), 24(@2230), 27(@0005), 28(@2000)
July-01(@0645), 03(@1109), 06(@0330), 08(@0643), 09(@2202), 12(@0515), 14(@1656), 17(@0000), 19(@1317), 22(@0200), 24(@1626MF), 26(@2059), 29(@0658), 31(@1422)
August-02(@1703), 05(@1137), 08(@0230), 10(@2219), 12(@2200), 15(@0759), 18(@1015), 20(@1426), 23(@0818), 27(@0320), 29(@1138), 31(@1627)
September-03(@2120), 06(@2009), 09(@1605), 12(@0822), 15(@0653), 18(@0420), 21(@1844), 24(@0200), 26(@2220), 29(@0222)
October-23(@1300)

1954 – The first possible sign of Giant's changing its eruptive activity began in the fall[73]:

> On September 19 at 2:00pm the Giant Geyser was reported to have reached its average August eruption interval of 64 hours. At this time a number of people were waiting, expecting an eruption to occur. At about 4:00pm the Grotto Geyser and Grotto Drain Geyser [now, Grotto Fountain] went into eruption and played vigorously for several minutes. Some people waited well into the night for Giant. It did not erupt until the middle of the night of September 20th. The eruption interval approached 98 hours. The next eruption of the Giant occurred near the August interval average for it was reported to have played on the 23rd at about 7:00pm. Its activity was watched following the eruption of the 23rd and it erupted at 12:10am on the morning of the 26th with an interval of about 77 hours. The geyser was watched closely day and night beginning the 28th and although the Mastiff, Catfish, and Bijou played fiercely during the hot phases and the Oblong erupted frequently, playing five times during the night of the 29th, the Giant did not play until late in the night of October 01. Its exact play was not known, but it was after 10:00pm. The interval on this eruption approached 120 hours.

While there were hints of some sort of exchange of function between Giant and Grotto all through 1954, Giant did not "let go of the reins." In June the shortest interval ever observed for Giant was recorded, just 28 hours! Again, although some months in 1954 have no recorded data for Giant, it is believed there were no radical changes in its activity[74]:

June-01(@0600), 04(@0745), 06(@1900), 08(@1514), 10(@1621), 13(@1805), 15(@1725), 20(@0000), 21(@0400), 23(@1135), 25(@0640), 27(@1750), 29(@1705)
July-01(@0500), 03(@0630), 06(@1043), 08(@1221), 10(@1044), 12(@1822), 15(@1125), 17(@1310), 19(@1215), 21(@1523), 23(@1720), 26(@0815), 28(@0400), 30(@1828)
August-02(@0445), 04(@1825), 07(@0145), 09(@1531), 12(@1450), 14(@1805), 17(@0255), 19(@1443), 23(@0400), 25(@1612), 27(@2315), 30(@1109)
September-02(@1058), 04(@2109), 07(@2320), 10(@1219), 14(@0200), 17(@0400), 20(@1755), 23(@1900), 26(@0010)
October-01(@0000)

1955 – The end of the best cycle ever known for Giant Geyser came in the fall of 1955. Early in the year Giant's intervals were still averaging near 64 hours, but this rapidly began to increase in the latter part of the summer[75]:

> From July 1 and for the remainder of the season, the length of the intervals steadily increased. Seven eruptions occurred during July as against 11 for June. The number decreased to 4 for August. From August 29 to October 25

> there were but three additional eruptions. The October 25 eruption was the last recorded one. If any occurred during the ensuring winter they are unknown. All evidence is to the effect that since October 25, 1955 Giant has been dormant.

With no observer present in the Upper Basin during the winter of 1955–1956 the last eruption in this active cycle is unknown. Given some activity that was observed in April of 1956, it is possible there may have been a few more eruptions from Giant during the winter.

The known 1955 activity[76]:

May-28(@1000), 30(@0720)
June-01(@1145), 04(@0000), 06(@1030), 08(@2340), 11(@2040), 14(@1040), 16(@1200), 19(@2130), 22(@1306), 25(@0200), 29(@1519)
July-01(@1700), 05(@1200), 08(@1540), 14(@1500), 17(@1110), 22(@1220), 27(@0810)
August-10(@0000), 14(@1235), 18(@0130), 29(@1635)
September-13(@0000)
October-01(@1325), 25(@1530)

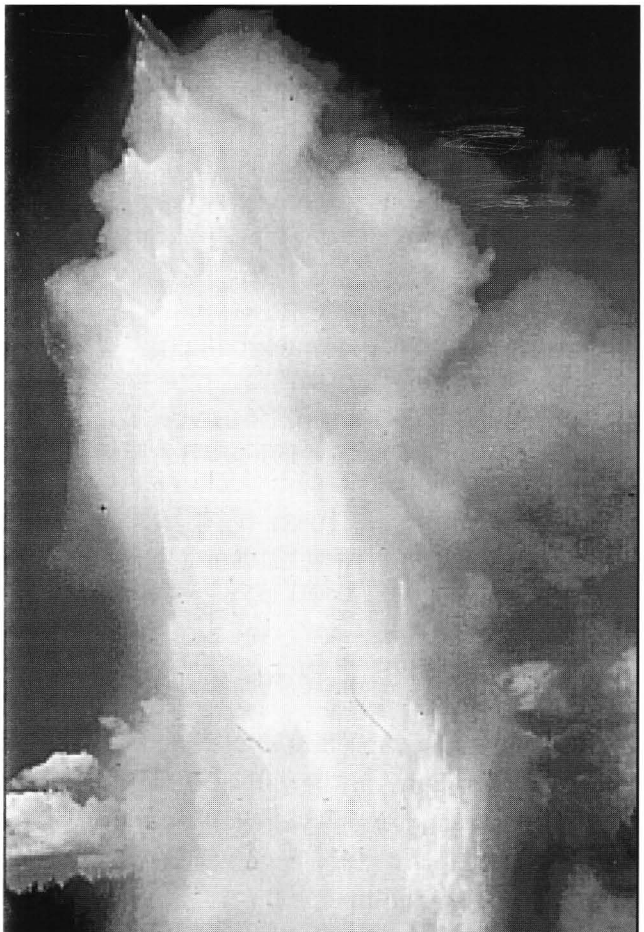


Figure 7. One of the last eruptions of Giant Geyser's protracted 1950's action, photographed by George Marler on July 05, 1955. [Marler Collection, Brigham Young University Archives, with one–time use permission.]

1956 – While no eruptions are reported for 1956, the following was reported by Park Naturalists' Condon, Beal, and Elliott in April's Monthly Report of the Chief Ranger[77]:

> On April 18 a trip was made to Old Faithful... The Giant Geyser was functioning in one of its hot phase patterns and an unusual hot phase was observed at about 5:30pm. On this occasion there was a pronounced activity on the part of all of the small vents in front of the giant cone, with the Christmas Tree [the modern "Feather Vent"] erupting to heights of 15 ft. The Turtle which is to the south of Giant normally only overflows without violence. On this occasion, the Turtle erupted to heights in excess of 20 feet for about four minutes.

This is the only mention of hot period activity for 1956. Marler states in his 1956 reports that there was no hot period activity during his time in the park. Given this, the activity seen by Condon, Beal, and Elliott must have been one of the last hot periods. Was Giant still active earlier in this year? In my opinion, probably "Yes."

1957 – The activity of the vents on Giant's platform had all but quit in 1957. The Bijou, which was perpetually active in 1956, was so inactive that the cyanobacteria mats dried up and fell off its cone[78].

1958 – There was a marked increase in the activity in Bijou, Catfish, and Mastiff during 1958. By the time October arrived, Marler felt Giant might have been approaching another cycle of activity[79].

1959 –The Sub-District Naturalist's Report for January stated the following[80]:

> Grotto Fountain Geyser has not been observed in eruption during this month and the slow shift of energy back to Giant Geyser continues. On

> January 29th, Catfish Geyser was erupting 5 to 6 feet high every few minutes indicating an increase in thermal activity and energy in the Giant Group.

Despite the seemingly imminent prospect of an eruption from Giant, there was no activity from it or the Platform Geysers before or after the Hebgen Lake Earthquake, as summarized by Marler in his monthly report for August[81]:

> For the first time since 1955 the sloshing in Giant was forceful enough in the crater for water to splash over the back of the cone. During this increased animation the indicator vents in front of the Giant never became activated…"

Activity of 1960–1969

Activity by Giant during the 1960's was minimal. Its only eruption was on September 18, 1963. Marler wrote the following[82]:

> Sometime during the early evening of September 18 Giant erupted. In view of the fact that at no times previous to the eruption there were symptoms of eruptive activity it is assumed that the eruption was induced. The eruption did serve to increase in the manifestation of thermal energy within the group, but in succeeding days this energy gradually declined.

Activity of 1970–1979

The longest known quiet interval for Giant was that between September 18, 1963 and September 9, 1978, almost 15 years. Apart from increased platform activity in 1973[83], there was no real indication from Giant in the 1970's that it was ready to erupt. Observers were quite surprised, then, when Giant did erupt in 1978. In a memo from Rick Hutchinson to the Chief Park Naturalist was the following[84]:

> At approximately 4:00pm MDT on Saturday September 9, 1978 Giant Geyser had its first known major eruption in almost 23 years... [Editorial note: the 1963 eruption was not known to Hutchinson at the writing of this report.]
>
> Visitor reports indicated that the only noticeable warning was '…considerable ground shaking and rumbling prior to the eruption'. Maximum height was described as well above the surrounding trees and estimated to be in excess of 45 meters. A steady stream of water was discharged up into the air for approximately 45 minutes with a small amount of rocks, coins, branches, two log signs, and other assorted items of trash carried out by the eruption.

Marie Wolf, who witnessed the eruption from a distance, said the water was a murky brownish color. For several days after the eruption, the area smelled of cooked grass and cyanobacteria mats.

Activity of 1980–1989

The first real taste of a reactivation of Giant began in the late 1980's. Solo eruptions are known for several years of the 1980's. Along with those eruptions was the resumption of hot period activity, something that had not occurred since 1956.

1980 – No eruptions

1981 – No eruptions

1982 – Giant erupted in a snow storm on September 27 (@1215)[85]. Rick Hutchinson stated the following in his 1982 Annual Report:

> Based upon a visitor report, Giant began a major eruption at 1215 on September 27. This was its first and only display since September 9, 1978 (a 1479 day interval), and second known eruption since October 25, 1955. Estimated maximum height from the few visitors on hand range from at least 30 to 75 meters. When Old Faithful Rangers Jennifer Hutchinson and Robert Carnes arrived at 1255, the geyser was still playing around 10 meters high.
>
> Interviewing the visitors by J. Hutchinson revealed that two other features in the Giant Group (probably Mastiff and Catfish Geysers), started prior to Giant.

1983 – No eruptions known.

1984 – One eruption was witnessed on October 12 (@0111ie)[86].

1985 – No eruptions known.

1986 – Several people witnessed a spectacular eruption on August 20 (@1136)[87].

1987 – Another late season eruption occurred on September 12 (@1358), with a duration of 67 minutes[88]. Following this eruption hot period activity independent from Giant eruptions resumed. These were the first known hot periods (apart from the ones assumed to have happened with Giant's eruptions) since 1956. Along with this eruption, major eruptive activity was seen in all of the Purple Pools, which lie a short distance upstream and across the Firehole River from Giant. Although long known as members of the Giant Group because of their corresponding drop in water levels following Giant's eruptions, this was the first time in their history that these vents were seen to erupt.

1988 – The increase in activity at Giant continued through the winter and lasted throughout the year. Giant had its first eruption on June 28 (@2155)[89]. This eruption was at the end of twilight and was not witnessed by any geyser gazer until about two minutes into the eruption. I was at Grotto about 25 minutes before Giant erupted. There had been a hot period earlier in the day and since the interval between hot periods at the time was 2 to 9 days, I left the area. Hot periods resumed nine days after this eruption. Their frequency was 24 to 120 hours and they eventually led to another eruption in September[90]. This eruption was witnessed by Lynn Stephens in its entirety. Mastiff preceded Giant and played to at least 100 feet. Once again hot period activity resumed and Giant erupted for the third time in 1988, on December 18[91]. I was at Giant for this eruption. At no time did Mastiff erupt. Within a week, hot period activity similar to that of the summer once again resumed.

The reported 1988 activity [MF-Mastiff eruption before Giant]:

June-28(@2155/d=1h 12m)
September-12(@1846MF/d=1h 07m)
December-18(@0036/d=1h 19m)

1989 – The year started with great promise for Giant. There was an eruption on April 17 (@0818ie)[92], which was followed by more hot period activity. The hot periods in 1989 were happening with a greater frequency than those of 1987 or 1988, sometimes being as little as 4 hours apart. There also seemed to be a general weakening of the Grotto Geyser Complex following Giant's April eruption[93]. Unfortunately, there were no more known eruptions of Giant in 1989.

Activity of 1990–1999

Through the 1990's, Giant Geyser seemed to continue to slowly awaken from its long dormancy. Eruptions are known for each year in this decade. Hot period activity has also continued, although not in all years. In almost all cases, hot period activity resumed following an eruption from Giant but gradually weakened or stopped by the following spring.

An interesting trend that Giant has displayed in the 1990's is its tendency to be dormant in the spring and early summer months, only to erupt during the months of August or September. While Giant was watched closely during throughout this decade, there was never any indication that the relatively intense action from late–1996 through 1998 was imminent.

1990 – There were four eruptions of Giant in 1990, two in January and two in September. Preceding the January eruptions, there were several known hot periods. Some of them saw heavy periods of overflow and surging in Mastiff Geyser[94]. The hot period activity ended by early spring. There were no hot periods prior to the September eruptions.

The activity recorded in 1990[95]:

January-between 1/6 and 1/8,
between 1/22 and 1/27
September-23(@1035), 30(@1525)

1991 – In what became typical of the 1990's, Giant did not erupt until early in the fall. Prior to the first eruption, there were occasional intervals between hot periods of one every 10 to 17 days. The first eruption took place late in the evening on August 20[96]. Heinrich Koenig arrived at Grand Geyser at about 2:00 am and observed a lot of steam coming from the northern end of the basin. Because it was cold and raining, he did not investigate the source. The following morning it was very evident Giant had erupted. Within ten days the hot periods resumed, the intervals between them being a few hours to about 5.5 days long. In late October, Rocco Paperiello and I were present for Giant's second eruption of the year, on October 21[97]:

> When Bijou entered another pause at 170656, there were several items which began to happen... The first time I noticed Mastiff in eruption was at 171351. In the past a strong eruption from Mastiff was boiling from either vent reaching from 2 to 3 feet in height. To my delightful surprise Mastiff was erupting from the front (west) vent in a steady boiling/surging column between 8 and 15 feet high... During Mastiff's eruption, no surging was visible in Giant. When Bijou entered its steam phase , the surging in Giant suddenly became very violent. The sloshing in the crater at first was angled from left to right and filled only the lower third of the cone, but gradually increased in strength until it was vertical, filled half the cone, filled all of the cone, surged over the top of the cone, surged 10 feet over the top of the cone, then majestically launched skyward. The initial surge of water was estimated to be between 200 and 230 feet.

The reported eruptions for 1991[MF-Mastiff erupted before Giant]:

August-20
October-21(@1722MF/ d=1h 22m)

1992 – Only one eruption, again in the fall, is known for 1992. This eruption was preceded by an eruption of Mastiff to about 4 feet. The eruption was on September 24 (@1345)[98].

1993 – There was no known eruption of Giant in 1993 until early December. At no time prior to this was there any hot period activity. The eruption occurred sometime between December 02 and December 07[99].

1994 – Giant continued its autumnal ways with a single eruption on September 29 (@1252)[100].

1995 – The following was reported in *The Geyser Gazer Sput* by Tom Hougham[101]:

> **Giant Geyser:** on January 12, two of the 5 NPS signs ("Giant" and "Stay on Walk") were discovered washed all the way to and pinned under the boardwalk. There was evidence of fairly recent gravel movement and matted grass to the west of Bijou, and more extensively to the north of Giant's cone... and to the south towards the boardwalk... Behind Giant's cone a 20cm [8in] diameter chunk of bacterial mat had been displaced and was quite dead. ...there was no evidence of fresh sediment in the river.

Figure 9. The eruption of Giant Geyser on September 25, 1995. [Photo by David Monteith]

> Fresh snow depths on the two displaced signs were 7.5cm-10cm [3-4 in] which would indicate that if an eruption had occurred it would have been in the previous two days...

It is unknown if there was eruption of Giant in early January. While I believe this to have been an eruption, I will leave that for you to decide. Another eruption of Giant was witnessed on September 25 (@1520). Mastiff Geyser erupted to about 50 feet prior to the start of Giant[102].

Figure 8. A hot period, on July 03, 1997. Note "Feather Vent" and others playing in front of the cone of Giant, small but visible boiling in Mastiff Geyser, and jetting by Catfish Geyser (left). [Photo by T. Scott Bryan]

The activity reported in 1995 [MF-Mastiff erupted before Giant]:

January-10–12(?)
September 25(@1520MF)

1996 – During the spring and summer of 1996 there was an increase in the amount of activity in Bijou Geyser. At no time was Bijou known to slow down or cease its activity. In late July, Giant had its first known eruption of 1996. This was followed by five additional eruptions[103]

The activity recorded in 1996 [MF-Mastiff erupted before Giant; CF-Catfish erupted before Giant]:

July-31(@1743MF/CF)
October-09(@1827), 18(@1111/d=1h 07m), 24(@1307ie)
November-09(@0111), 18(@1055)

1997 – Giant's best period of activity for the 1990's began in 1997. In the spring and summer, Giant continued to have semi-frequent eruptions with intervals of 6 to 45 days. On September 12, Giant's intervals suddenly shortened to 3.5 to 5 days, and they remained this way until early April of 1998. Several eruptions were preceded by eruptions of Catfish and/or Mastiff. Turtle Geyser, which had not been observed in eruption since 1956, was seen several times in October and December during Giant's eruptions. Its play was never more than about 2 feet high.

The reported 1997 activity[104, 105] [MF-Mastiff erupted before Giant]:

January-(...between 1/01 and 1/03...), 19
February-06 (@1700), 24(@1107)
March-04(@1357), 13(@2257), 23(@0745), 30(@1929)
April-06(@1932), 13(@1402), 23(between 2300 4/22 and 0300 4/23),
May-24(@1121MF)
June 7(@1429)
July-10(@0606ns), 16, 22
August-01(@0634MF), 10(@0842MF), 24(@1224)
September-08(@1629), 12(@2216), 16(@0630ns), 19(@2210MF), 23(@2040), 27(@1138MF)
October-01(@0230), 06(@1533), 10(@0315), 14(@0721MF), 17(@1644MF), 21(@1833), 25(@2127), 30(@0415)
November-03(@0300), 07(@1715), 12(@1415), 16(@0200), 20(@1930), 24(@1330), 30(@1100)
December-03(@2345), 08(@0330), 12(@0630), 16(@0801), 20(@0602), 24(@1558), 29(@1743)

1998 – Giant started the year the same way it ended 1997, with frequent eruptions every 3.5 to 5 days[106]. This activity was short lived, however, and by late March Giant's intervals quickly lengthened. It was dormant by late April. Hot period activity continued until early July, but even it stopped on July 03. It appeared as if Giant was lapsing back into another dormant cycle. On July 31, however, hot periods once again started, giving hope of more eruptions. It was much to everybody's surprise when South Purple Pool and the small unnamed geyser next to it began erupting in September. The overflow from South Purple Pool was greater than at any time I had ever witnessed, and many geyser gazers believed the energy in the group had shifted from Giant to the Purple Pools. On the morning of October 11, all three of the Purple Pools were seen to erupt from 50 to over 125 feet high. This period of activity was the largest witnessed from them.

Giant did have one additional eruption in 1998[107]. It was seen late in its eruption by Tom Hougham on October 15.

The activity recorded for 1998 [MF-Mastiff erupted before Giant]:

January-02(@1743), 06(@1151),
10(@1158), 14(@0908), 17(@1951),
21(@1217), 25(@1330), 29(@0638),
February-02(@0358), 06(@0023),
10(@0606), 14(@1328), 18(@2330),
22(@0802), 26(@1000)
March-02(@1448), 07(@0558), 12(@1337)
17(@1619/d=64m), 23(@1615MF/d=62m)
April-15(@0040), 30(early am)
October-15(@0826ie)

1999 – Giant closed the decade with another six eruptions. Throughout the winter and early spring, South Purple Pool continued to overflow, and there were no hot periods from Giant. On April 30 South Purple Pool was found not to be in overflow, and on May 02 Giant had its first hot period of the year. On May 09, Giant had its first eruption of the summer, at 0727. This eruption was preceded by a very unusual eruption of Mastiff Geyser[109]:

> A few seconds before Bijou paused, the water level in Mastiff was high enough to begin overflowing. A minute into the pause Mastiff was erupting from its north vent to about 45 feet. This lasted for a full three minutes. During this time all the vents on Giant's platform were in eruption. There was little to no activity from Giant itself. Suddenly the activity in Mastiff and the Platform Vents quit! At this time Bijou, which had been in a loud steam phase, changed back into a water phase. Normally this behavior meant the conclusion of a hot period with no eruption from Giant. In all the literature I had read, and in my own personal observations, I had never heard of a hot period in which Mastiff erupted and Giant did not. During this entire two minute pause, the water level in Mastiff stayed within a few inches of overflow. As if a valve were turned at a depth, Bijou went back into steam phase and Mastiff began to erupt once again. This time the play was from both vents, and was closer to 55 feet in height. With this restart in Mastiff, Giant began to have voluminous surges from its cone. Giant started erupting about 90 seconds after the restart of Mastiff.

Following this eruption, hot periods once again resumed, and Giant erupted again overnight on June 19–20. A third eruption of Giant was witnessed on July 29[110], seen in eruption by NPS employee Bronco Grigg at 0600. Hot period activity resumed once again. Unfortunately, there were no further eruptions until early November. By the end of the year, the activity in Giant held great promise for 2000.

The reported eruptions for 1999 [MF-Mastiff erupted before Giant]:

May-09(@0727MF)
June-between 2200, 6/19 and 0300, 6/20
July-29(@0600ie)
November-02(@0615), 08(@0134),
28(@1529)
December-09(@1258)

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* In reviewing this paper, Yellowstone Historian Lee Whittlesey noted that the Year 2000 was a part of the 20th Century. So for completeness, let it be noted that Giant Geyser had at least 17 eruptions during that year (with most of November unobserved).

Closing Discussion

A quick review of Giant Geyser's eruptive activity on a decade-by-decade basis shows us:

1900-1909	92 reported eruptions
1910-1919	7 reported eruptions
1920-1929	87 reported eruptions
1930-1939	107 reported eruptions
1940-1949	55 reported eruptions
1950-1959	465 reported eruptions
1960-1969	1 reported eruption
1970-1979	1 reported eruption
1980-1989	8 reported eruptions
1990-1999*	94 reported eruptions

Remember, this list is compiled from known eruptions; many others no doubt took place. The total reported eruptions in the above list is 917.

As can be seen, the activity of Giant this century has varied greatly from year to year. While data is not available for some of the years between 1900 and 1918, I am very confident in stating that Giant did not have a complete Twentieth Century year of inactivity until 1947. Why this was the case is unknown, especially when 1947 was one of the best ever for geyser activity in Yellowstone. My belief is that there was some degree of seismic activity in the Park. Giant is one of the few geysers in Yellowstone that seems to show no or even a negative response to seismic activity. One needs only to look at its reaction to the 1959 Hebgen Lake earthquake to see this.

Something changed fundamentally in the Giant system in the early 1940's. Geyser observers in the 1990's have commented on how Giant "likes to wait" until the fall months to erupt. We thought this was a recent trend for Giant. Looking at the 1940's activity, we can see that this pattern of behavior is not new. When looking at Giant's eruptions from 1940 through 1999, excluding the 1950-1955 activity, 81 of 137 eruptions (59%) occurred during the months of August, September, October or November. This number is even more surprising when one looks at the same months for activity from 1900 through 1939, when Giant erupted only 102 times (36%) in those same months (which, of course, are 33% of the full year).

The activity of Giant in the 1950's seems to have been an aberration. Yes, there were periods of frequent activity in Giant between 1906 and 1908, and again in 1997–1998, but as a whole this five year period was far and away the best period of activity for Giant. There are a number of theories as to why. My thoughts are as follows. Several factors "came together" in 1951 and 1952. First, I think Giant was recovering from whatever happened in 1947. Second, I believe Giant and the Daisy Group are very closely related. Splendid Geyser awoke from a long dormancy in 1952, and I think Giant was a benefactor of the increased energy along the fault that Daisy lies on. Third, for the first time in the history of the Park, Giant appears to have been able to completely "tap" the energy in the Grotto Group to the point that Grotto was essentially dormant.

Mastiff Geyser's activity in the 1950's and again from the late 1980's to date is another oddity in Giant. From October of 1896 until May of 1951 there were no documented eruptions of Mastiff. Was it inactive these 55 years? It seems hard to believe that an eruption of the Mastiff prior to Giant would not have evoked some sort of comment by a visitor, soldier or Ranger. I cannot offer a suggestion as to why it was inactive in the early years of the 1900's, or why it decided to awaken when it did later in the century.

Since the fall of 1998, Giant has behaved much as it did in the 1930's, with intervals of 6 to 60 days. As Giant's history has shown us, however, it is unlikely that this type of activity will continue. Between the large number of earthquakes, seasonal water variations, and its connections to the Grotto and Daisy Groups, anything is possible in the future, from long–term dormancy to record–setting activity.

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[45] Photo album 3, YNP Photo Archives. This photo is unnumbered and unlabeled but clearly shows Giant in eruption with date "10-28-38" written on back.

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Historic Eruptive Activity in the Purple Pools Complex

By Mike Keller, with T. Scott Bryan

Abstract

Eruptive activity by any of the Purple Pools is rare, having been seen only in 1987, 1998 and 2000. South Purple Pool was active on each of those occasions. In 1997 and 1998 it was accompanied by East and North Purple Pools as they underwent their only known eruptions. In 1998 and 2000, South Purple was also joined by UNNG–GNT–1. This historic action is summarized in this paper.

Introduction

The Purple Pools occupy a sinter flat a short distance upstream and across the Firehole River from the Giant Complex of geysers (see map Figure 1 and photo Figure 2). Long known as members of the Giant Group because of their reaction (primarily, lowered water levels) to eruptions by Giant Geyser, eruptive activity of their own has been extremely rare.

On August 18, 2000, South Purple Pool had its first eruption since October 1998. This was only its third period of activity in Yellowstone's history.

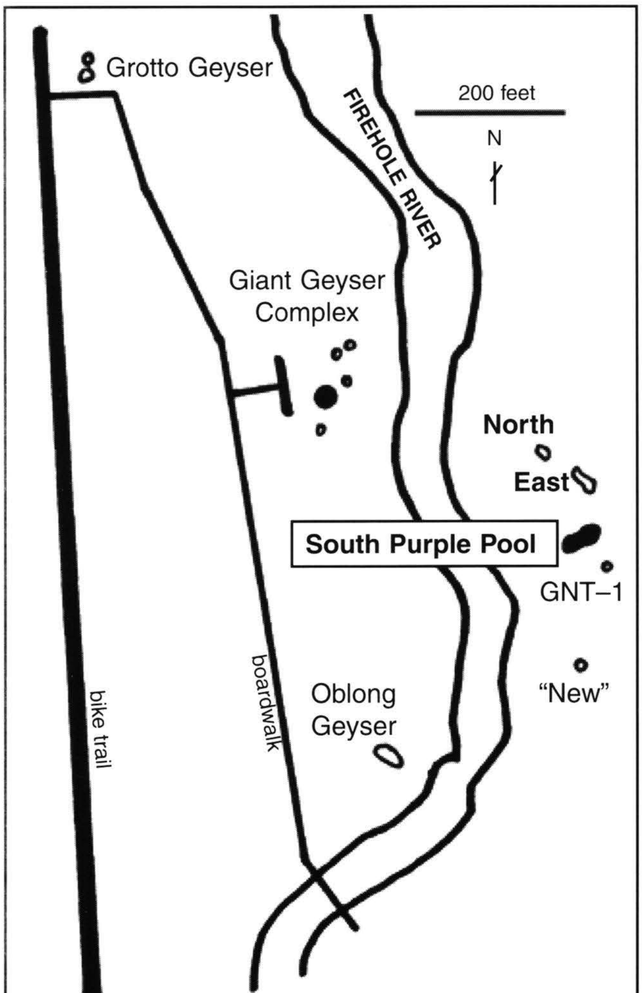

Figure 1. Sketch map of the Giant Geyser Group and vicinity. [Drafted by Scott Bryan, based on USGS "Thermal Map V–B, Giant," 1974]

Behavior before August 18, 2000

The first eruptions ever observed in any of the Purple Pools took place on October 18, 1987. Given the known connction with the Giant Complex, it is believed that this was a delayed response to the September 12, 1987 eruption of Giant Geyser.

First (apparently) were eruptions by East and North Purple Pools. It is likely that they were accompanied by South Purple Pool), but the activity took place at night and was not directly witnessed. However, during the following day, South Purple Pool alone had several additional eruptions, one of which was estimated by observer Phil Landis as "over 35 feet high" [Landis, 1987].

No further eruptions in the Purple Pool Complex were seen until late summer 1998. The first eruption, on September 21, 1998, was by South Purple Pool. It was also seen erupting alone on October 8, 9 and 10, but the best was to come the next day.

For this group of springs, October 11, 1998 was the record–setting day. That morning's sequence of events, starting at 07:56, was detailed by Zavodni [1998]. In summary, two eruptions by South Purple Pool (both 35 to 40 feet high) were followed (at 08:15) by simultaneous eruptions by South Purple Pool (70 to 90 feet high), East Purple Pool (20 to 35 feet) and North Purple Pool (110 to 130 feet). The total duration of this concerted ac-

Figure 2. A panorama view of the Giant Geyser Complex (left–center foreground including the prominent cone of Giant Geyser) and the Purple Pools Complex (right–center background). [Photo by Ralph Taylor]

tion was about 6 minutes. This spectacle was followed by an additional 13 eruptions by East Purple Pool, one of which was accompanied by the South pool.

South Purple Pool underwent a few additional, solo eruptions in the succeeding days. The last known in the series was seen on October 29, 1998.

Throughout this time span of South Purple Pool activity, the unnamed geyser a few feet to its south [designated as "UNNG–GNT–1" in Bryan, 1995, 2001] was also active. Eruptions were frequent at times, with intervals as short as 5 minutes. The bursting height was quite variable, ranging up to 20 feet [Dunn, 1998].

From October 29, 1998 until August 18, 2000, no additional eruptive activity was observed from any of these features. The overflow from South Purple through the winter of 1998–1999 was greater than at any time I had ever previously observed.

In late April of 1999 the overflow diminished, and almost immediately Giant Geyser began having hot periods. Within 12 days, on May 9, Giant erupted. Giant Geyser continued to have hot periods and occasional eruptions during the summer and fall of 1999. No change in South Purple's water level was observed.

Sometime in the late spring of 2000 South Purple's water level began to rise. In late July of 2000, some geyser observers began to comment on "occasional surges" of water in South Purple. While no eruptions were seen, large sheets of water would flood down the runoff channel and into the Firehole River.

The active cycle of August 18–19, 2000

Around 1725, while lying on a bench waiting for Grand Geyser, Heinrich Koenig commented: "There goes Riverside." However, Riverside was seen in eruption less than two hours earlier, at 1547. When I sat up and looked down basin, it was very evident that South Purple Pool was in eruption. This started a series that lasted 8 hours and 05 minutes, and included a total of 28 eruptions by South Purple Pool and 11 by UNNG–GNT–1. The complete activity cycle is listed as Table 1.

The water of South Purple looked greenish early in the series. As it continued to erupt, enough mud, sand, and gravel had washed into it to change the water to a dark brown color. Large logs and mats of grass were thrown up to 20 feet in the air during South Purple's eruptions. The later eruptions of South Purple were much larger than those early in the cycle. With permission from the National Park Service, I was allowed to spend the final five hours of the active cycle in the trees near South Purple Pool. None of the eruptions during daylight reached more than about 50 feet in height. However, I conservatively estimate that the last third of the eruptions were from 80 to 100 feet high, and 40 to 90 feet wide.

Table 1
Eruptive Activity of South Purple Pool and UNNG–GNT–1
August 18–19, 2000

Time	Duration*	Interval*	Height (feet)	UNNG
1727, 8/18	1:30		25	no
1739	1:30	12	30	no
1749	1:50	10	35	no
1757	0:47	8	35	no
1804	2:03	7	30	yes
1814	1:33	10	30	yes
1829	0:43	15	30	yes
1842	2:17	13	35	yes
1859	4:58	17	30	yes
1935	1:56	36	50	yes
1955	0:43	20	40	no
2014	2:18	19	50	yes
2033**	2:40	19		yes
2057**	2:27	24		yes
2128	1:38	31	40	yes
2148	1:36	20		no
2210	1:42	22		yes
2223	1:42	13		no
2236	1:46	13		no
2257	1:47	21		no
2317	1:11	20		no
2328	1:21	11		no
2347	1:51	19		no
0007, 8/19	1:46	20		no
0028	2:01	21		no
0049	1:38	21		no
0111	1:44	22		no
0132	1:18	21		no

* — Duration is shown as minutes:seconds; Interval is minutes
** — data provided by Marie Wolf and Rocco Paperiello

During several of the early eruptions by South Purple Pool, UNNG–GNT–1 had several small "minor" eruptions of its own. Each started a few seconds after South Purple began to play. They lasted from 15 to 105 seconds and reached not more than 8 feet high. UNNG–GNT–1's concert with South Purple Pool at 22:10 on August 18 was the last of its series.

Behavior since August 18, 2000

As of early September 2002, there have been no further eruptions from any of the Purple Pools or UNNG–GNT–1 to the south of South Purple Pool. As Giant Geyser began having frequent eruptions in late October of 2000, the volume of overflow from South Purple lessened. The current overflow is about one–third to one–half the volume it was in August of 2000.

"New" Geyser, which had not been active since 1971, began showing signs of life in November of 2000. I had never observed or heard water in this geyser. On cold mornings in late October and early November, the steam coming from its crater was heavier than I had ever seen in past years. This change in activity was enough to have me tell other geyser gazers to keep an eye on "New." Finally, in late December of 2000, eruptive activity was seen in "New." The activity only lasted a few days, but consisted short and frequent eruptions reaching from one to ten feet high. The activity had stopped by December 27th.

Editorial Note: This paper is based on a draft written by and reference information provided by Mike Keller. The text was extensively rewritten by Scott Bryan, Editor of this journal, at Mr. Keller's request. Additional substantial revisions were provided by Ralph Taylor, Lynn Stephens and Mary Beth Schwarz.

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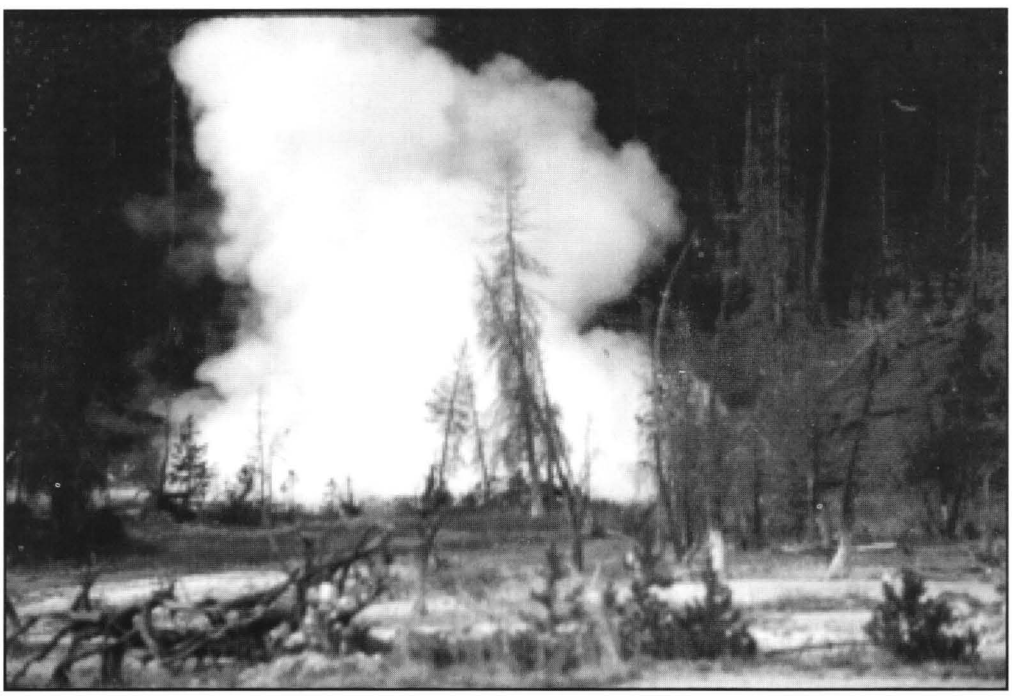
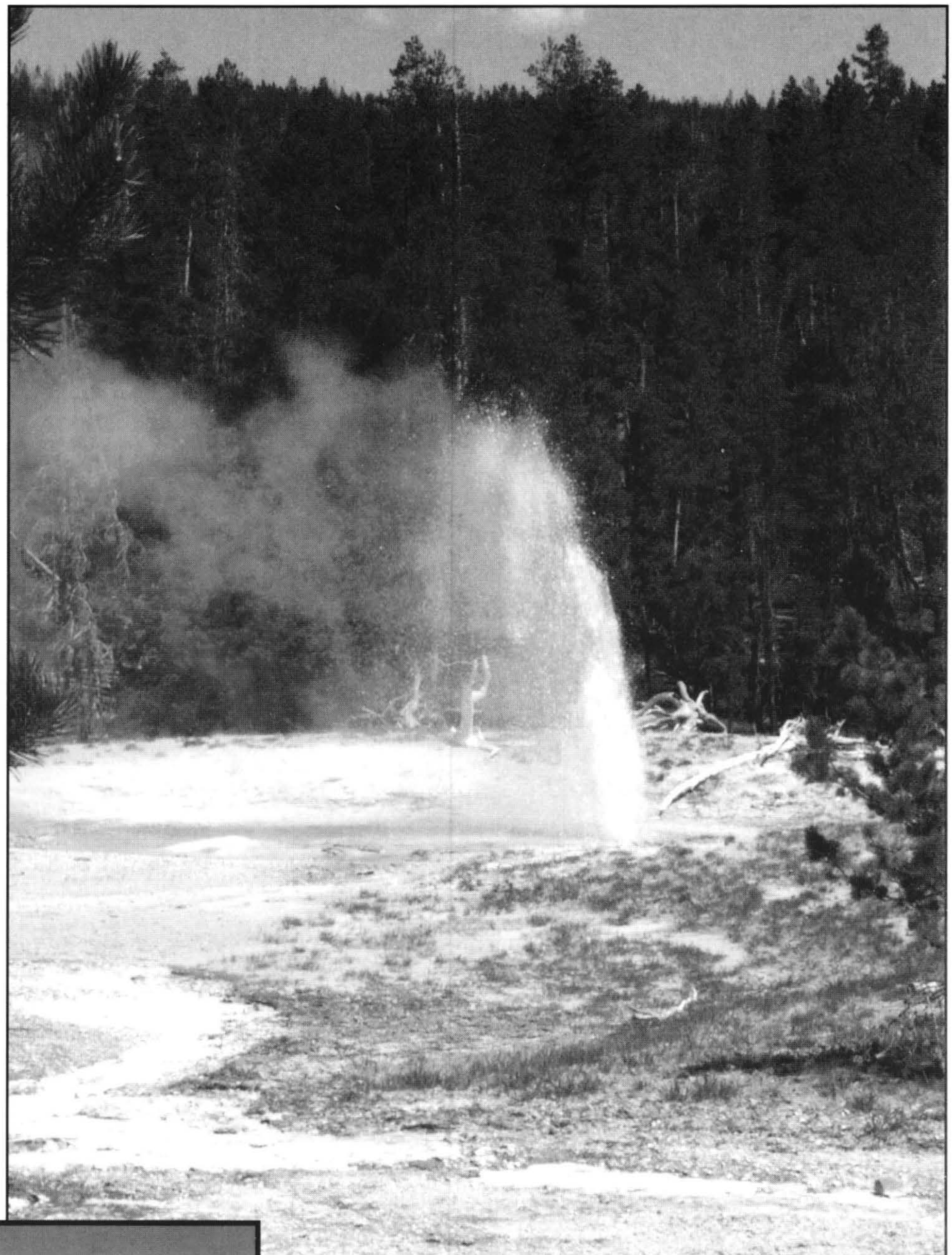
Two photographs showing South Purple Pool in eruption on August 18, 2000. These views are from the boardwalk across the Firehole River from Oblong Geyser. Note in the photo above the jet of water nearly as high as the treetops on the ridgeline. [Photos by Ralph Taylor]



Startling Geyser — May 31, 2002



Startling Geyser (also known as "South South Grotto Fountain") is rarely seen, often going through entire seasons without being reported. However, on May 31, 2002, several geyser gazers had the good fortune to see an eruption. It began after Grotto Fountain Geyser had undergone several aborted attempts to begin its eruption.

Startling's play lasted several minutes, during which its steady cone–type jetting reached at least 15 feet high.

The photo to the left shows Startling (right) joined by Grotto Fountain, which had begun erupting only seconds after Startling reached its full height.

Both photos by Scott Bryan.

Fan and Mortar Geysers in the Summer of 2001,
May 24 to November 4

By Tara Cross

Abstract

During 2001, Fan and Mortar Geysers erupted with relative frequency. Observations of the cyclical activity between major eruptions revealed consistent patterns of behavior. This article details the patterns that were observed in 2001 and discusses how this activity differed from that seen in previous years.

Introduction

Fan and Mortar Geysers have intrigued geyser enthusiasts for decades. They represent one of the most complex geyser systems in Yellowstone and are widely regarded as one of the best shows among the geysers. Over the years hopeful observers have collected a wealth of information about the geysers' minor activity and how it relates to their major eruptions.

During the 1980s and 1990s Fan and Mortar were relatively frequent. Dormant periods usually lasted a year or less and occurred every few years. However, in May of 1998 Fan and Mortar began their longest dormancy in twenty years, remaining completely quiet until a few isolated eruptions in early 2000. To the excitement of geyser gazers, Fan and Mortar began to have more frequent eruptions in June of 2000. Erratic at first, Fan and Mortar gradually became more regular during the late fall and winter months. Even so, only a few eruptions were seen before June of 2001.

Observers spent great deal of time waiting for Fan and Mortar during the summer of 2001. Study of the minor activity between eruptions revealed that Fan and Mortar settled into a consistent pattern for most of the summer and fall, exhibiting some behaviors that were unusual in previous years. Between May 24 and November 4, Fan and Mortar erupted 34 times. Of these, 21 eruptions were observed from the start. This article discusses the behavior patterns and activity seen during 2001 (see Table 1).

The Vents of the Fan and Mortar Geyser Complex[1]

Fan Geyser lies along a fracture that runs roughly perpendicular to the Firehole River. Fan consists of six significant vents that are active during major and minor activity.[2] In order south to north, they are River, High, Gold, Angle, Main, and East. Mortar sits on the edge of the river just upstream from Fan. Mortar has four vents—Upper and Lower Mortar, Bottom, and Frying Pan.

River, High, Gold, and Angle Vents comprise what are called "the minor vents." Main Vent, East Vent, and Lower Mortar (and Bottom Vent) comprise the "main system." Upper Mortar and Frying Pan are connected to but not grouped with these systems.

The locations of the vents are shown on the map of Figure 1.

The Vents of Fan:

River Vent actually consists of a numerous vents that erupt horizontally out of the steep riverbank into the Firehole River (hence it is also sometimes referred to as "the River Vents"). During minor cycles, River sputters to a few inches. In major eruptions, River shoots water horizontally 5 to 10 feet into the Firehole.

High Vent sits atop a mound of brownish sinter immediately above the River Vents and the Firehole River. It normally splashes a few times

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[1] Fan Geyser and Mortar Geyser were known to have independent eruptions in the past. While they may still be considered as two separate geysers by some definitions, their activity is so interrelated that they are discussed here as a single geyser system.

[2] A description of Fan and Mortar's minor activity is included later in this article.

Table 1
List of Major Eruptions
Fan and Mortar Geysers
May 24 to November 4, 2001

Date	Time	Interval
June 1-2	overnight	I~16¼d
June 7	0942ns	I~5¼d
June 16	1606	I~9d6h24m
June 25	0730ie	I~8d15h24m
June 28-29	overnight	I~3¾d
July 3	2358	I~4¾d
July 11	1228	I=7d12h30m
July 16	1624	I=5d3h56m
July 20	0600ie	I~3d13h36m
July 24	early a.m.	I~3¾d
July 29	0651	I~5¼d
August 5	0516	I=6d22h25m
August 7	1159	I=2d6h43m
August 10	1400	I=3d2h01m
August 13-14	overnight	I~3½d
August 20-21	overnight	I~7d
August 25	1510	I~4½d
August 28	2252	I=3d7h42m
September 2	1530	I=4d16h38m
September 6	1625	I=4d0h55m
September 9	1635	I=3d0h10m
September 16	0440	I=6d12h05m
September 19	1314	I=3d8h34m
September 23	0901	I=3d19h47m
September 25-26	~0245	I~2d17h44m
September 29	1632	I~3d13h47m
October 2	1757	I=3d1h25m
October 6	1241	I=3d18h44m
October 8-9	overnight	I~2 2/3d
October 14	1131	I~5¼d
October 18	2205E	I~4d10h34m
October 26	1826	I~7d20h21m
October 30	2007E	I~4d2h34m
November 4	1402	I~4d17h55m

E – time determined from electronic temperature recording device, courtesy Jens Day and the National Park Service. Electronic times approximate, with 8-minute sample spacing.

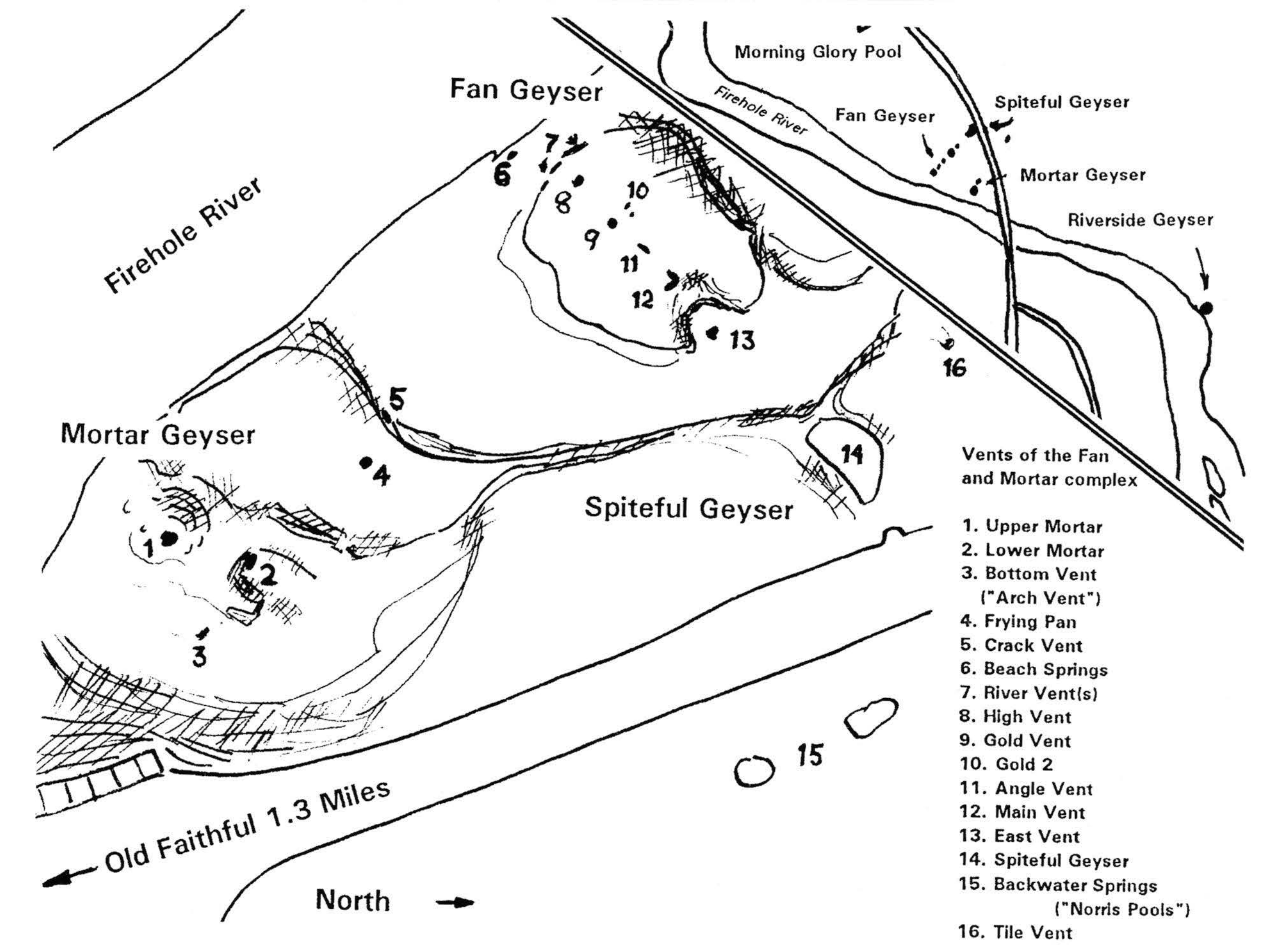

Figure 1. Sketch map showing the vents of the Fan and Mortar geyser complex. [reproduced from Strasser, 1993]

in the minutes after River Vent starts, getting stronger with the start of Gold Vent. Its minor activity consists of punctuated splashing to 1 to 3 feet. During a major eruption, High Vent usually reaches 15 to 20 feet high and erupts with great force, angled slightly away from the river.

Gold Vent lies a few feet from High Vent along the fracture and is surrounded by gold–stained geyserite. During minor activity Gold splashes to 3 to 5 feet. In a major eruption, it erupts to about 20 feet at a slight angle toward the Firehole River. Gold is usually the best measure of water levels in the minor vents. When there is visible pooling of water within Gold's vent, the water levels are high. It is quite obvious when the water in Gold has dropped below the rim. As the vents are losing energy and beginning to shut off, Gold reverts to heavy steam with a few water droplets mixed in.

On the north side of Gold Vent (away from Mortar) is a small crack not visible from the trail. Along this crack are three small vents that can sometimes be seen sputtering to a few inches when water levels are high in Gold Vent. These have been called "Gold 2" by observers.

Angle Vent is next along the fracture and closest to Main Vent. Its opening cannot be seen from the trail, but its location is marked by orange-brown sinter around the vent. It is usually obvious when Angle is erupting — after the first few minutes of stronger activity, steam mixes in with the splashing eruption resulting in a noisy hissing sound. Angle Vent's minor eruptions consist of small 1– to 3–foot splashes angled away from Gold Vent. During major eruptions, Angle becomes more forceful, but its punctuated jetting is usually obscured by neighboring Main Vent.

Main Vent occupies a cavernous L–shaped opening on the south side of a mound of eroding sinter. During major eruptions, Main Vent is the dominant vent of Fan, with several large water jets. The principal vertical column reaches 60 to 80 feet high; a larger column erupts at an angle to 90 to 140 feet and sometimes crosses the dirt path past Spiteful Geyser. Main Vent's strongest activity is in the first 5 to 6 minutes of the major eruption. During 2001, Main Vent could sometimes be silent for many hours during intervals between major eruptions. However, during stronger cycles, the water level rose in Main Vent. As it rose, the water within Main Vent also became agitated, leading to episodes of heavy steaming, roaring, and sometimes visible spitting and splashing. Activity by Main Vent was almost always present during eruption cycles in 2001. While this activity could be as spare as steaming and roaring, some eruption cycles included near–constant splashing from Main Vent and occasionally large splashes that filled its vent. This type of strong activity was normally seen during River and Gold Vent pauses in conjunction with high energy and water levels in Lower Mortar and Bottom Vent.

East Vent lies within a small gorge on the other side of the mound of sinter from Main Vent. In 2001, East Vent was not active during minor cycles beyond gentle steaming. However, it was often the first vent of Fan to begin a major eruption. During major eruptions, East erupted to 50 to 60 feet in a broad column angled slightly away from the trail.

The Vents of Mortar:

Upper Mortar is the large cone situated on the bank of the Firehole River near the old road bridge. Like the rest of the complex, Upper Mortar has suffered greatly from erosion since the 1970s and its opening has widened. Major eruptions can vary from 60 to 90 feet high, but in 2001 nearly always reached 80 feet. While in major eruption Upper Mortar emits water and roaring steam that can be heard a half mile away.

During 2001, Upper Mortar did not always participate in a minor cycle. When it did, the activity consisted of periodic steaming, splashing, and/or surging near the time that Fan's minor vents were shutting off. During weak cycles Upper Mortar did not do anything beyond its normal gentle steaming. In a stronger cycle, there could be Upper Mortar Puffing and Huffing ('UMPH')[3] just as River Vent was shutting off. During very strong cycles, this activity could begin anywhere from 10 to 20 minutes after the start of River Vent and often progressed from rushes of steam with a few water droplets to large surges that filled the cone and spilled water over the sides. These surges sometimes triggered major eruptions.

Lower Mortar's vent occupies a depression on the north side of Upper Mortar. A few minutes before the start of River vent, water levels rise in Lower Mortar and splashing is visible within its vent. When water levels are especially high, minor splashing becomes thicker and more persistent; this activity has been referred to as "fuzzballs." During 2001 this strong splashing was sometimes followed by Lower Mortar minors, explained later in this article.

At the beginning of a major eruption, Lower Mortar bursts to 20 to 40 feet and overflows copiously from a full pool. Within a minute or two, it drains and ceases activity for a few minutes. When its eruption resumes, it has a jetting eruption without any pool. In 2001 this part of the eruption could vary greatly in size, from 30 feet to over 60 feet, with one part of its column nearly vertical and the other angled slightly towards the bridge embankment. During more powerful eruptions, Lower Mortar's column was known to douse the embankment and even the trail above it.

Bottom Vent (also called "Arch Vent") has changed dramatically since it was first seen and named in 1983. At that time, it was covered by several layers of sinter deposit and had several openings (hence the original name, "Bottom Vents"). The first activity was limited to gentle steaming. In 1987 two small vents began to emerge [Strasser, 1989]. Increased activity over the years eventually eroded the layers until a single vent

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[3] Though vernacular, the acronym 'UMPH' also fittingly describes the sound made by Upper Mortar as steam is forced upward from depth.

developed below a slab of sinter that resembled an arch—resulting in the later name, "Arch Vent." Both of these names have been in common usage over the years.[4]

Since Bottom Vent became frequently active in 1996, it has completely eroded the overlying sinter and undercut the "arm" of Lower Mortar. By 2001, eruptions came from a jagged vent in a deep ravine between Lower Mortar and the old road embankment. Eruptions have also increased in size, from less than a foot high when it was first seen to nearly 10 feet high during major eruptions in 2001.

Frying Pan consists of several vents on the slope of Mortar towards Fan. Frying Pan is not always active during a cycle. When it is, it usually begins after Angle and quits after River has shut off. At times it can be active continuously for several cycles of River Vent. In 2001, it also occasionally joined Lower Mortar during Lower Mortar minors. Even during major eruptions, however, Frying Pan erupts to only a few inches high.[5]

Related features:

Tile Vent, when active, flows out of an old tile culvert near Spiteful Geyser. The culvert was presumably intended to allow an old thermal feature that had been covered when the road was constructed to have an outlet. Although it was observed to have voluminous discharge during major eruptions of Fan and Mortar in the 1980s and early 1990's, Tile Vent was not known to emit anything beyond gentle steam in 2001.

Beach Springs are a group of small vents located along the base of Fan Geyser's mound below River Vent. These vents do nothing but overflow gently and are sometimes submerged by high water in the Firehole River.

Crack Spring is located below Frying Pan next to Mortar's formation. In 2001 its activity consisted of gentle overflow beginning a few minutes before Frying Pan and ending immediately afterwards. Crack Spring was sometimes active even when Frying Pan was not, overflowing 20 to 30 minutes after River Vent started.

Spiteful Geyser has an elongated pool a few yards from the trail directly in the path of Main Vent. Spiteful is on the same fissure as Fan Geyser and is connected to the Fan and Mortar complex. During the 1980s and 1990s, the water level in Spiteful would drop an inch or two during major eruptions of Fan and Mortar. This behavior continued in 2001. When active, Spiteful has violent eruptions to 10 to 40 feet. It reactivated after 20 years of dormancy in 1996 and was active sporadically for the next 4 years until it fell dormant again in 2000. Spiteful has small vents in cracks at the east end of its crater that sputter perpetually to a few feet in height.

Across the trail from Spiteful Geyser are two features that usually go unnoticed but are known to be connected to Fan, Mortar, and Spiteful. "**Norris Pool**,"[6] the southern spring, was a scummy, shallow pool until 1995, when it became a superheated mudpot. Then in 1998 it began having true eruptions that expelled a great deal of mud and gravel, eventually revealing an old, sinter–lined crater. By 2001, it was filled with clear, bluish water that bubbled constantly. On at least four occasions in 2000, Norris Pool erupted along with major eruptions of Fan and Mortar. There were no observed eruptions of Norris Pool in 2001, but it continued to show its connection to Fan and Mortar by rising a few inches and boiling vigorously during major eruptions. Water level and strength of boiling varied.

"Backwater Spring," the northern spring, showed connections to Spiteful Geyser in the 1970s, but in the following years was reduced to a tepid muddy depression. In 2001 Backwater Spring often served as a drain for some of the wash from Main Vent during major eruptions of Fan and Mortar.

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[4] The name "Bottom Vents" was given by H. Koenig and predates the name "Arch Vent" by several years.

[5] During 1999, a feature apparently related to Frying Pan began to emerge along a crack on the back of Lower Mortar's formation. By 2001, this group of vents had developed a small pool and sputtered to a few inches high along with Frying Pan.

[6] The name "Norris Pool" was given to this feature in 1983 because it smelled like the acidic features at Norris Geyser Basin. Though commonly used by geyser gazers, the name remains informal.

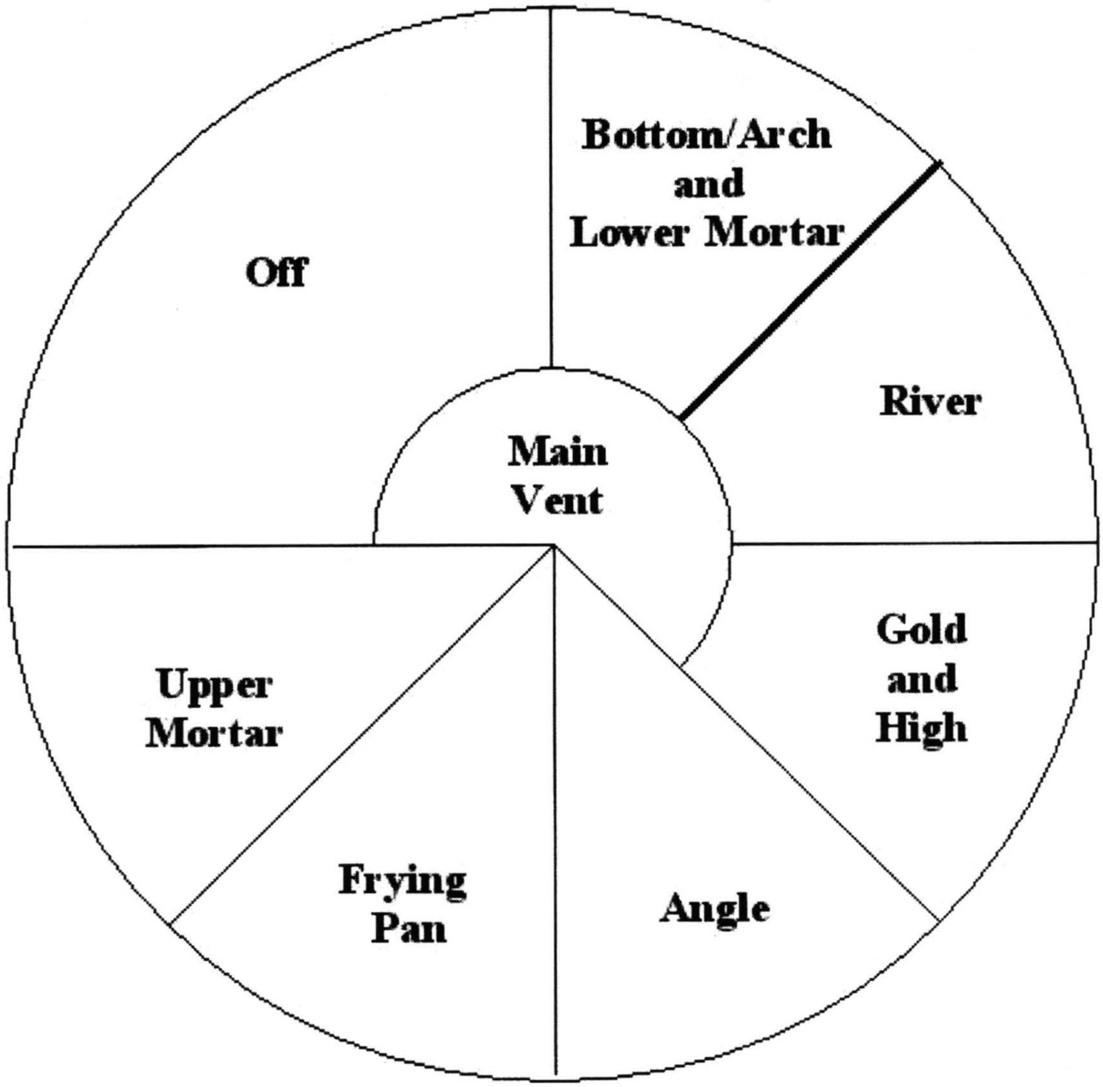

Figure 2. The Cycle Diagram (see text for explanation).

Minor Cycles

As in previous years, Fan and Mortar had cyclic minor activity between major eruptions. The basic pattern of this activity is shown in the cycle diagram (Figure 2). The time taken for each stage of the cycle varies greatly from cycle to cycle and is not proportional to that shown on the diagram. The diagram simply acts as a guide to the order in which events occur.

River Vent is most frequently used to distinguish the "beginning" of a minor cycle because its steam is easy to see. Thus in this article a "minor cycle" refers to the time elapsed between one River Vent start and the next. During a minor cycle, River is normally followed by Gold and High together, and then Angle. After the start of Angle, Frying Pan is next to come on (though Frying Pan does not always participate in the cycle). If Upper Mortar steaming, splashing, or surging occurs, it is at the time when the minor vents are starting to shut off. Angle and Frying Pan usually remain active for a few minutes after River has shut off. This is followed by a period of time when all of the vents are quiet. Then, before River starts again, water levels rise in Lower Mortar and Bottom Vent. The best indication of this is a growling and gurgling sound within Lower Mortar's vent, sometimes accompanied by gurgling and splashing from Bottom

Vent. In 2001, Bottom Vent would sometimes have a short-duration eruption (5 to 20 seconds) just before or just after River came on.

Even though there have been variations to the basic cycle, the cycle structure has remained unchanged since it was first described in the 1980s. In 2001, there were two common variations to the basic cycle. One was "garbage cycles," weak, disorganized, and generally lousy–looking cycles. Indications of a lousy cycle ("garbage mode") were:

1. Low water levels in all vents, especially evident Gold and Lower Mortar.
2. Short periods of time, ranging from 1 to 15 minutes, between when River shut off and when it started again.
3. Continuous activity by Angle and Frying Pan between cycles of River Vent.
4. Cycle lengths ranging from 2 to 25 minutes.
5. No "events" (pauses, Bottom Vent eruptions, and Lower Mortar minors).

The other variation was longer, stronger cycles. Signs of a strong cycle were:

1. Long periods of time (over 20 minutes) when all vents, including Angle and Frying Pan, were quiet.
2. Lack of continuous activity by Angle Vent.
3. River and Gold Vent pauses.
4. Splashing/roaring in Main Vent.
5. Bottom Vent eruptions.
6. High water levels in Lower Mortar.
7. Lower Mortar minors.

Strong Cycle Events

Three types of "events" occurred during stronger cycles of Fan and Mortar: pauses (explained below), Bottom Vent eruptions, and Lower Mortar minors. No known eruption between May 24 and November 4 occurred without some sort of "event." Every observed eruption cycle included at least one Bottom Vent eruption, and most included Lower Mortar minors. Only two known eruption cycles did not include pauses; however, the necessary shift of energy to the "Main system" of Lower Mortar, Main Vent, and East Vent always occurred, with or without a true pause.

Pauses:

A pause occurs when the minor vents shut off at a point in the cycle *before* Angle Vent has turned on. If only River Vent comes on, it is a "River pause." If Gold and High come on after River and then all three vents quit, it is a "Gold pause." In both kinds of pauses, Main Vent is usually seen steaming and roaring even before River Vent shuts off.

In 2001, both River and Gold pauses frequently resulted in an energy shift to the "Main system" and often led to Bottom Vent eruptions and Lower Mortar minors. Pauses without other events usually lasted 3 to 12 minutes. Pauses that included other events could be anywhere from 10 to 70 minutes in length.

Variations on pauses:

When two pauses happen consecutively without a full cycle being completed, this activity is called a "double pause." Double pauses were commonly seen in the early 1990s, but only three were observed in 2001, and all three led to a major eruption. In these cycles, the length of the pauses varied from 10 to 47 minutes.

Occasionally River Vent sputters briefly and then shuts off again within 2 to 3 minutes. These short spits have been colloquially referred to as "coughs." Sometimes Gold and High also splash with River during a cough. Either way, these were clearly not true cycles or pauses. Coughs were common in 2001, and it appeared that they were usually nothing more than aborted attempts to begin a cycle. However, on some occasions coughs appeared to be precursors to rising water levels in Main Vent. In these cases, coughs could have the same results as pauses: steaming, roaring, and splashing in Main Vent, Bottom Vent eruptions, and Lower Mortar minors.

Sometimes, as in the mid-1990s, Angle Vent splashed at unexpected times in the cycle. Unless Angle did not actually shut off from cycle to cycle but splashed continuously, these minor spits from Angle did not appear to be significant. Pauses could still occur even if Angle had a small splash.

Bottom Vent eruptions:

In 2001, Bottom Vent eruptions could occur at three different times during a cycle: after River Vent had shut off and water levels had risen in Main Vent; within a few minutes either before or after River started; and during River and Gold pauses. It was not uncommon for Bottom Vent to have small splashes at these times without having a full eruption. When Bottom did erupt, the water level rose to overflow and it began thicker splashing to anywhere from 1 to 5 feet. Eruptions were angled slightly away from Lower Mortar and usually created at least a small amount of runoff in the channel it shares with Lower Mortar. Eruptions lasted anywhere from 5 seconds to 6 minutes. Longer eruptions of Bottom Vent were frequently accompanied by heavy splashing in Lower Mortar and Lower Mortar minors. Typically, Bottom Vent eruptions that occurred within a few minutes of River had short durations (5 to 20 seconds) and did not have the same significance as the longer duration eruptions that occurred during off periods or pauses.

Lower Mortar minors:

Lower Mortar minors were almost never seen before Fan and Mortar came out of dormancy in 1996. By 2001, however, Lower Mortar minors had become common occurrences. They happened during times of high water levels in Lower Mortar and Bottom Vent, either between River Vent cycles or during pauses. They usually began with rising water levels and "fuzzballs" within Lower Mortar's vent and frequently occurred while an eruption of Bottom Vent was in progress (most that did not were of short duration). Water levels would pool up in Lower Mortar periodically accompanied by splashes to 1 to 3 feet. This activity could build into a true minor eruption of Lower Mortar. In 2001, these eruptions lasted anywhere from 15 seconds to over 3 minutes and were 5 to 20 feet high. Strong Lower Mortar minors resembled Lower Mortar's activity in the first several minutes of a major eruption. Bottom Vent usually persisted for most of the duration of the minor and occasionally until the conclusion, but was sometimes drowned by overflow from Lower Mortar.

Figure 3. A *Lower Mortar minor*, photographed on September 2, 2001. Bottom Vent, in eruption, can barely be seen to the left of Lower Mortar. [Photo by Kitt Barger]

Eruption Cycles

In 2001, eruptive cycles were distinctive because nearly every aspect of the cycle was stronger than normal cycles. Many of the eruptive cycles observed in 2001 included splashing from Main Vent. Main Vent had near–constant splashing and large surges in nearly all eruptive cycles seen in September, October and November. Main Vent splashing most often occurs during pauses, but a shift to Main Vent can occur without a pause. Fan and Mortar erupted after a "cough" on October 2 and with no pause at all on October 14.

Eruptive cycles also included "events." Those cycles that were well–enough observed to note the sequence of events are detailed in Table 2. As noted,

Table 2
Fan and Mortar Eruption Cycle Chart
May 24-November 4, 2001*

Date	Time	Pause? (time on-off)	Bottom Vent?	Lower Mortar minor?	Start Type**	River to start	Observer
6/16	1606	Gold (8-24), River (8-11)	yes (d=2m30s)	no	UM	23m	Mary Kennedy
7/3	2358	River (10-13), River (11-10)	yes - 3	yes (d=40s)	UM	22m	Andrew Bunning
7/11	1228	Gold (9-28)	yes (d=5m05s)	yes (d=3m10s)	LMM	-	David Schwarz
7/16	1624	Gold (8-43)	yes - 2	yes (d=3m)	UM	22m	David Schwarz
7/29	0651	River (10-17)	yes (d=30s)	no	UM	24m	Mary Kennedy
8/5	0516	River	yes - at least 2	yes (d=2m40s)	UM	21m	Tara Cross
8/7	1159	?	?	?	UM	?	Bill Laird
8/10	1400	River (8-20), River (8-47)	yes - 4	yes (d=15s, 2m35s, 2m27s)	UM	25m	Paul Strasser
8/25	1510	?	yes - 2	yes (d=2m30s)	UM	24m	Lynn Stephens
8/28	2252	?	yes - 5	yes (d=3m)	LMM	-	David Leeking
9/2	1530	River (8-18)	yes - 3	yes (d=1m49s, 3m10s)	LMM	-	Tara Cross
9/6	1625	River (11-34)	yes (d=5m)	yes (d=3m13s)	UM	29m	Lynn Stephens
9/9	1635	River (11-41)	yes - 3	yes (d=2m18s)	UM	24m	Tara Cross
9/16	0440	?	?	?	UM	?	Lynn Stephens
9/23	0901	Gold (11-61)	yes - 4	yes (d=1m41s, 2m32s)	UM	24m	Lynn Stephens
9/29	1632	Gold (8-70)	yes - 5	yes (d=1m42s, 2m17s)	UM	22m	Tara Cross
10/2	1757	River cough (off 47)	yes - 3	yes (d=20s, 2m10s)	UM	30m	Tara Cross
10/6	1241	Gold (8-39)	yes - 2	yes (d=1m53s)	UM	32m	Tara Cross
10/14	1131	none	yes - 2	yes (d=3m)	UM	26m	Mary Kennedy
10/26	1826	River	yes - 2	yes	lock	?	James B. Grigg
11/4	1402	?	yes - 3	yes (d=2m10s)	UM	24m	Tara Cross

*Chart includes only eruptions where information about the eruption cycle was available. Thank you to Mary Kennedy, Andrew Bunning, David Schwarz, Bill Laird, Paul Strasser, Lynn Stephens, David Leeking, and James B. Grigg for providing information for this chart.

** Start Type:

UM – Upper Mortar

LMM – Lower Mortar Minor

d - duration

all but one (for certain) included pauses. Eruption cycles usually included one to three Lower Mortar minors also. Eruptions could occur without a Lower Mortar minor, but none were seen without at least one Bottom Vent eruption. When there was a Lower Mortar minor in an eruption cycle, the time from the last Lower Mortar minor to the start of the eruption was usually 36 to 39 minutes, with a range of 26 to 50 minutes (excluding eruptions that started during Lower Mortar minors).

Figure 4. Upper Mortar surging. This initiated the eruption of September 23, 2001. The dark hole to the lower right of Upper Mortar is the vent of Lower Mortar. [Photo by Kitt Barger]

Once the minor vents came on in an eruptive cycle, they usually stayed strong for a full 15 minutes before showing any significant drop in water levels. If water levels dropped within 10 minutes of River, it was unlikely that an eruption would occur. After about 15 minutes the water levels could wax and wane; even if they did not stay strong after 20 minutes, an eruption could still be initiated by Upper Mortar.

Observers in the 1980s and 1990s noted that a late start of Gold Vent usually indicated a strong cycle and sometimes led to eruptions [Day, 1989; Schwarz, 1993]. In 2001, however, it was very unusual for Gold to start more than 5 minutes after River. When this did occur, it was normally associated with high water levels in Main Vent and a possible attempt at a River pause. As long as there had been pauses and/or events in a cycle, the time elapsed between the start of River Vent and the start of Gold Vent appeared to be irrelevant.

Types of starts

By far the most common type of start seen in 2001 was the *Upper Mortar start*, seen in 17 of 21 eruptions. This was a major departure from observations in previous years. Upper Mortar starts occurred anywhere from 21 to 32 minutes after River started, with the most common time being 24 minutes. The critical time in the cycle for Upper Mortar starts came when the minor vents were beginning to shut off. Anywhere from 10 to 20 minutes after River Vent began, Upper Mortar would begin to have periodic surges 30 to 90 seconds apart. These usually began with UMPHs and gradually built in size to cone-filling surges. The surge that triggered the eruption would be anywhere from 5 to 20 feet high, last 10 to 60 seconds, and inundate the entire cone with water. These surges tended to be smaller earlier in the summer; by fall, Upper Mortar was practically in full eruption during the initiating surge. East Vent was the first vent of Fan to signal the start of a major eruption, and would begin either during this surge or a few seconds after.

Before 2001, Upper Mortar starts were extremely rare. Fan and Mortar nearly always erupted from what came to be called a *lock*, or "classic lock." This term was originally used because when observers saw this activity, they knew Fan and Mortar were a "lock" to erupt. Paul Strasser described "lock" in the following way:

> Gold and High Vents are splashing steadily and continuously, their height and power slowly increasing, accompanied by heavy surging from

> Angle Vent. As the Angle Vent gets stronger its water column slowly changes to vertical. When they are all going full tilt, erupting to a height of 4 to 8 feet, the eruption is imminent [Strasser, 1989].

This type of start was seen only once in 2001, on October 26. Water levels were high in the minor vents after River came on, and High, Gold, and Angle built to a "lock" about 16 to 18 minutes later. The eruption began with Main Vent, immediately followed by East Vent [Grigg, pers. comm.]. (These eruptions can also start with East Vent first.)

On three occasions in 2001, a surprising new type of start was observed. On July 11, August 28, and September 2, a major eruption began *during* a Lower Mortar minor. In the two instances when complete data was taken, *Lower Mortar minor starts* occurred during pauses, a time in the cycle when it was previously unknown for Fan and Mortar to erupt. One eruption occurred 28 minutes into a Gold pause, the other 18 minutes into a River pause.

When an eruption began during a Lower Mortar minor, all the vents were quiet except for Lower Mortar and Bottom Vent. Then East Vent suddenly shot out of its vent with almost no warning, quickly followed by the rest of the vents. Each time a major eruption began during a Lower Mortar minor, the minor had reached or passed 3 minutes in length when East Vent started. Instead of losing energy after 2 minutes, Lower Mortar gained in strength. In 2001, only one known Lower Mortar minor over 3 minutes in duration failed to trigger an eruption — but Upper Mortar triggered a major eruption later on in the same cycle.

Eruptions

Every major eruption of Fan and Mortar in 2001 was unique. Some eruptions were dominated by Fan, others by Mortar, and, on several occasions, both geysers were superlative. Upper Mortar was most commonly the dominant vent, regularly erupting to 80 to 90 feet and roaring energetically. Fan had several eruptions reaching well beyond the edge of the path near Backwater Spring. If Lower Mortar was the dominant vent, it was often a special treat for onlookers. It had several eruptions reaching at least 50 to 60 feet high, with part of its column arching over the embankment near the bridge and onto the path. No matter which vent was dominant, the eruptions were always spectacular.

Intervals

Recovery cycles:

Comparatively little data was collected on the minor activity of Fan and Mortar in the days immediately following major eruptions. However, from observations throughout the summer, it is known that Fan and Mortar had what is referred to as a "recovery" mode that lasted for about 8 to 30 hours after each eruption. During this recovery mode, there were often frequent "events" and the activity in general looked strong, except for low water levels in the minor vents. It was not uncommon to see strong cycles with pauses, long–duration Bottom Vent eruptions, and multiple Lower Mortar

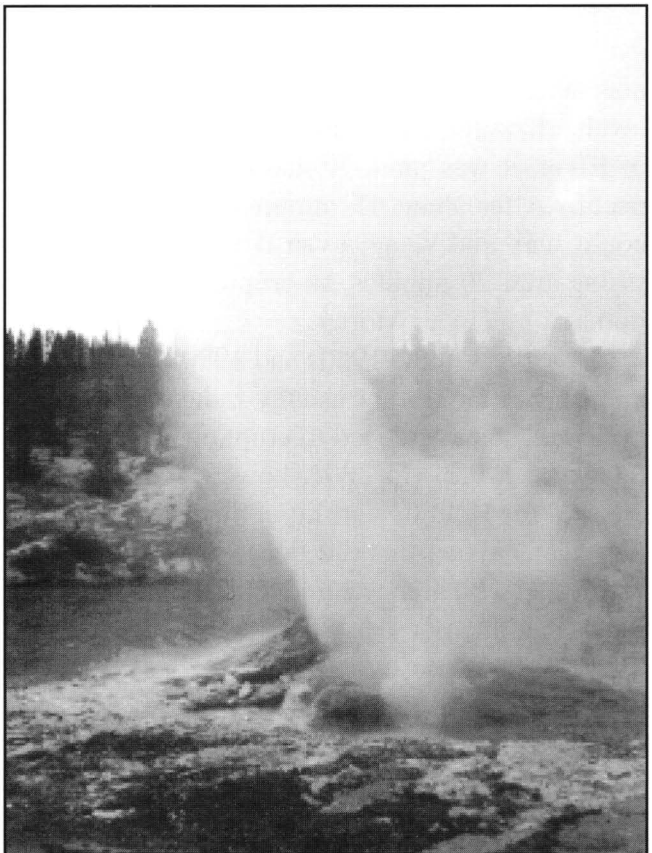

Figure 5. Strongly jetting Upper Mortar behind bursting Lower Mortar, moments after the start of the eruption of June 1, 2002. [Photo by Scott Bryan]

Figure 6. The initial burst from Fan's East Vent on September 23, 2001. This eruption, whose trigger was Upper Mortar, is shown in Figure 4. (Upper Mortar lies to the left, out of the picture.) [Photo by Kitt Barger]

minors. In fact, some observers were encouraged by this strong activity, only to discover later that Fan and Mortar had already erupted hours earlier. It was speculated that there might be a connection between the strength of this recovery activity and the length of the next interval. However, there were not enough observations to prove or disprove this theory.

Long mode and Short mode:

In 2001 there was a distinct difference between intervals in the 2 to 5 day range ("short mode") and intervals longer than 5 days ("long mode"). These differences could be seen in the minor activity between eruptions. Short mode intervals usually had many normal and strong cycles with occasional "garbage" cycles. Main Vent was quite active during short mode intervals, often steaming even during weaker cycles. Long mode intervals consisted predominantly of "garbage" cycles interspersed at random by stronger cycles. During long mode, there could be days between Lower Mortar minors, with the activity consisting of short, weak cycles. Activity from Main Vent, when it did occur, was anemic. When Fan and Mortar had an exceptionally strong cycle in long mode, it very often led to an eruption.

Fan and Mortar had mostly long mode intervals until August, with a range from 3½ days to 9¼ days. Throughout August and September, Fan and Mortar settled into short mode, having only 2 intervals longer than 4¾ days. During this time, the minor activity of Fan and Mortar was remarkably consistent, with frequent "event" cycles and extremely strong eruption cycles. In October and into November there were two long mode intervals, and minor activity was less consistent.

Energy surges:

In the 1980s and 1990s, Jens Day noted that Fan and Mortar cycles appeared to follow a pattern in which there was a "energy surge" about every 16 to 20 hours [Day, 1988]. Such a pattern was not detected in 2001. It was, however, not uncommon for stronger cycles to come in clusters. Very strong cycles usually required at least several cycles between them, but there could be "events" in two successive cycles, and the system could maintain high water levels for several hours.

As with Day's "energy surges," it appeared that stronger cycles were more frequent during shorter intervals; "event" cycles and high water levels were not common during longer intervals.

East Vent Solo eruption

The most unusual event witnessed at Fan and Mortar in 2001 was an East Vent solo eruption on May 31, seen by Matthew McLean. The events occurred as follows:

River Vent had been off for 36 minutes in a normal quiet period when a Lower Mortar minor began. This eruption began normally but after 45 seconds abruptly lost force and stopped. As if taking over the energy, East Vent suddenly began to erupt by itself to 30 to 35 feet. This solo eruption lasted one minute and then quit as suddenly as it started without any activity from any other vents.

The East Vent solo eruption was followed by an exceptionally strong cycle that included a 30–minute Gold pause, another colossal Lower Mortar minor lasting 3 minutes, and strong Upper Mortar surging 22 minutes after River Vent started. However, none of this led to a major eruption. It was almost as if East Vent jumped the gun and started before the rest of the system was ready—then couldn't get it going at the appropriate time in the cycle [McLean, pers. comm.].

This activity was unusual not only because East Vent had never been known to erupt before without being accompanied by a major eruption, but also because it occurred at a time when it was virtually unheard of for a major eruption to begin (during the quiet period between minor eruptions of River Vent). It is a mystery as to why this occurred or what it meant — though Lower Mortar and East Vent are closely connected as part of the "main system" which also includes Main Vent.

Conclusion

Due to their relative frequency and the consistent behavior patterns seen before eruptions, Fan and Mortar were comparatively easy to see in 2001. However, many of the behaviors seen were significantly different from those observed in the 1980s and 1990s. It will certainly be interesting to see what changes may happen in the future.

Acknowledgements

This article by no means covers all of the available information about Fan and Mortar Geysers. The focus was specific to the geysers' behavior in the summer of 2001, May 24 to November 4. For a thorough background of Fan and Mortar's behavior prior to 1988, Paul Strasser's article in the *GOSA Transactions,* Volume I is an exceptional source. Other GOSA Transactions articles include "Fan and Mortar Geysers in 1988" by Jens Day (Volume I) and "Fan and Mortar Geysers in the summers of 1991 and 1992" by David Schwarz (Volume IV). For a complete historical overview of the Fan and Mortar complex, see "Why Mortar is Fan," by Paul Strasser (Volume IV).

A great deal of time was spent watching Fan and Mortar by other geyser gazers while I was unable to be present. I relied heavily on the reports, data, and observations of others to keep track of Fan and Mortar throughout the summer. Of particular help were Paul Strasser, David Schwarz, Lynn

Fan Geyser's Main Vent accompanied by Lower Mortar (bottom left) a minute or so after the "classic lock" – East Vent & Upper Mortar start on June 1, 2002. [Photo by Scott Bryan]

Stephens, David Goldberg, Mary Kennedy, Andrew Bunning, Bronco Grigg, and Matthew McLean. Without their help, this article would have been impossible.

Numerous others also contributed to the wealth of data collected in 2001, too many to mention here. Thank you to all who shared their observations and insights, and who provided good company in the long hours at Fan and Mortar. Thank you also to the National Park Service, and especially to Jens Day for providing electronic data–logger information for eruptions that were not seen first–hand.

Special thanks go to Kitt Barger, who provided three of the photographs used in this article.

Finally, thank you to all who read this article, especially Lynn Stephens, Paul Strasser, Nancy Cross, Steven Miller, and David Schwarz. Their insight and suggestions were invaluable.

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Two more views of Fan and Mortar, the eruption of June 1, 2002. Both photos by Scott Bryan.

Above. At the far left is the steady jet of Upper Mortar; lower and to its right is Lower Mortar. Arching above and behind their steam is the sharply angled jet of Fan's Main Vent.

Right. Taken at nearly the same angle as the photo above, this shows the surge by Upper Mortar that triggered the eruption. Lower Mortar can be seen steaming to the right of Upper Mortar; the "classic lock" jetting by Fan's minor vents is barely visible in the background.

Slide Geyser, Upper Geyser Basin, 1974 – 2001

By Lynn Stephens

Abstract

This paper summarizes Slide Geyser's activity from the inception of its known activity in 1974 through 2001. In general, during this history the geyser has shown gradually increasing intervals and slightly decreasing durations.

Introduction

Slide Geyser is located in the Cascade Group of the Upper Geyser Basin, on the hillside west of Atomizer Geyser. The best viewing place for Slide Geyser is from the meadow looking east across the Firehole River toward the hillside on which Slide Geyser is perched (see Figures 1 and 2). Slide Geyser was named in 1974 by thermal researcher Marie Wolf because of the sliding of its runoff water down a channel. [Whittlesey, 1988.]

Figure 1. The vent of Slide Geyser (arrow) is high on the steep sinter enbankment above the Firehole River. In the ravine to the right are other hot springs, including the spouter called Restless Geyser (a.k.a., "Owl's Mask Spring"). [Photo by Scott Bryan, May 30, 2002]

This report reviews information about Slide from its first reported activity in 1974 through the end of 2001 Summer season. The report summarizes information published about Slide and information available from the Old Faithful Visitor Center (OFVC) logbooks from 1989 through 2001.

Description of Slide Geyser

Slide Geyser is not visible from the trail near Artemisia Geyser and Atomizer Geyser because it is located a few feet over the brow of the hill (looking west toward the Firehole River). The crater is located at the top of a long sinter 'slide' that leads down to the river. The crater is somewhat L–shaped, with the long axis located horizontally on the hillside. The short axis is at the south end of the opening, reaching down toward the river. There are two small holes on the hillside above the main axis of the crater. The water from an eruption appears to be forced from the crater, and slides down the 'slide' to the river. There is no cyanobacteria on the slide. About one–third of the way down on the north side and five–eights of the way down on the south side of the slide, brown algae appears along the extreme edges. The lower quarter of the slide has a hoof–shaped pattern, and the south part of the hoof has orange cyanobacteria on it.

When viewed from the west, across the river, the eruption begins and ends with small splashes that barely reach the lip of the crater. In the middle of the eruption, several large splashes eject water outward from the crater and hillside.

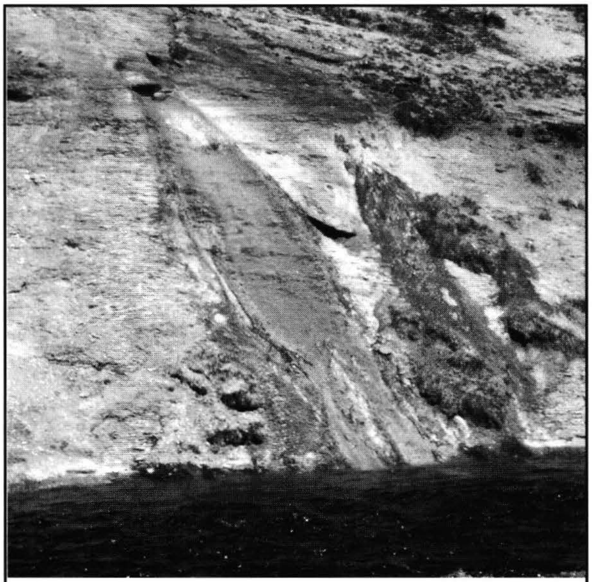


Figure 2. A close view of Slide Geyser's vent. Note the apron of fresh sinter formed by the gushes of water that appear to 'slide' down the embankment. One such gush can be seen just below the vent's opening. [Photo by Scott Bryan, May 30, 2002]

Slide's Eruptive Record

Slide was not known to be active before 1974, according to T.S. Bryan [1986]. George Marler did not include any discussion about Slide Geyser in the 1971 edition of *Studies of Geysers and Hot Springs along the Firehole River*, and also did not include anything in his *Inventory of Thermal Features* [1973]. The first published reference I found to Slide was in the 1978 edition of Marler's *Studies of Geysers and Hot Springs along the Firehole River*. Marler included Slide as a line entry in his "Table of Named Hot Springs in the Upper Geyser Basin," listing its interval as 10 to 30 minutes cyclic, durations as 2 to 3 minutes, and height as 3 feet.

Slide Geyser is Number 109 (an unnamed geyser) in the first edition of T.S. Bryan's *The Geysers of Yellowstone* [1979, p. 68]. The first known detailed observation of this spouter was made in 1974. At that time the intervals were about 5 minutes long and the duration was much less than 1 minute. The water was thrown out horizontally, reaching out perhaps 10 feet. The name "Slide" was incorporated into the 1982 edition of the book [Bryan, 2002].

Marie Wolf collected data about Slide's eruptions on May 25, 1983 and September 13,1983. Data for the four intervals she obtained on the afternoon of May 25, 1983 ranged from a minimum interval of 10 minutes 41 seconds to a maximum interval of 12 minutes 29 seconds, with a mean of 11 minutes 19 seconds and a median of 11 minutes 4 seconds. Durations for the five eruptions ranged from a minimum of 57 seconds to a maximum of 2 minutes 3 seconds. [Wolf and Paperiello, 1986.] See Table 1 for data logs for Wolf, Stephens and Cross, and "season" average intervals and durations. Average intervals are shown in Figure 3 and average durations are shown in Figure 4.

On the evening of September 13, 1983, Wolf observed six consecutive eruptions. Intervals ranged from a minimum of 11 minutes 12 seconds to a maximum of 15 minutes 11 seconds. The median was 14 minutes 29 seconds, and the average was 13 minutes 55 seconds. Durations ranged from a minimum of 44 seconds to a maximum of 56 seconds.

Wolf also published information about Slide's activity in 1984:

> This geyser was still erupting regularly during the Summer of '84, with intervals of about 10 to 14 minutes and durations of less than 1 minute to almost 2 minutes. Its eruptions, a series of splashes pushed out of its vent on the steep side of an old sinter cone, were only reaching, at best, 1 to 3 feet out from the vent. [1986, p. 246.]

T.S. Bryan included the following information about Slide in the 1986 edition of *The Geysers of Yellowstone*:

> SLIDE GEYSER is located on the high bank of the Firehole River below Atomizer Geyser. There is no record of activity from this vent prior to 1974. The crater opens directly onto the precipitous slope. Slide is quite regular in its performance. Intervals range from 5 to 12 minutes, with little variation at any given time. The water bursts out of the cavernous vent so that the play is mostly horizontal, sometimes reaching out as far as 10 feet. [p. 87.]

Bryan's table entry [p. 89] adds information that the duration is one minute. Bryan's range of intervals (5 to 12 minutes) is significantly less than

Marler's range (10 to 30 minutes) and Wolf's range of 10 to 14 minutes. Because Slide's opening is basically parallel to the hillside, water from the eruption is splashed out horizontally, not purshed upward vertically. Thus, Slide's "height" is generally measured in terms of the horizontal distance from the opening rather than the vertical distance above the vent, as is the case with most geysers. Bryan's "horizontal, sometimes reaching out as far as 10 feet" is much larger than Wolf's "reaching at best, 1 to 3 feet out from the cone." Marler's height of "3 feet" doesn't specify whether this is vertical height above the top of the opening or horizontal throw outward from the opening.

In an article in *The GOSA Transactions,* Volume I [1989], I reported intervals for September 3, 4, 5, and 6, 1988. Ten intervals were obtained, ranging from a minimum of 14 minutes 27 seconds to a maximum of 15 minutes 17 seconds, with a mean of 14 minutes 54 seconds and a standard deviation of 15 seconds. These intervals were in the middle of Marler's range, slightly above the upper limit of Bryan's range, and slightly longer than Wolf's 1983 and 1984 intervals.Durations ranged from a minimum of 41 seconds to a maximum of 66 seconds, with an average of 53 seconds.

During the decade of the 1990s there was little published information about Slide's activity. There were two brief references to Slide in *The Geyser Gazer Sput*, and Bryan modified the information about Slide contained in the 1995 edition of *The Geysers of Yellowstone*. I reviewed the data contained in the Old Faithful Visitor Center logbooks and did not find any data other than observations that I had reported.

I collected data on six intervals for Slide on three different days in 1990. The average interval was 15 minutes 31 seconds with a standard deviation of 22 seconds. The minimum interval was 15 minutes 19 seconds and the maximum interval was 16 minutes. Only three durations were recorded, ranging from 37 seconds to 54 seconds. The average interval had increased by 37 seconds during the previous two years. Given the small sample sizes, at the time it was difficult to know whether this could have been attributed to random fluctuations.

Figure 3: Slide Geyser's Average Interval — 1983–2001

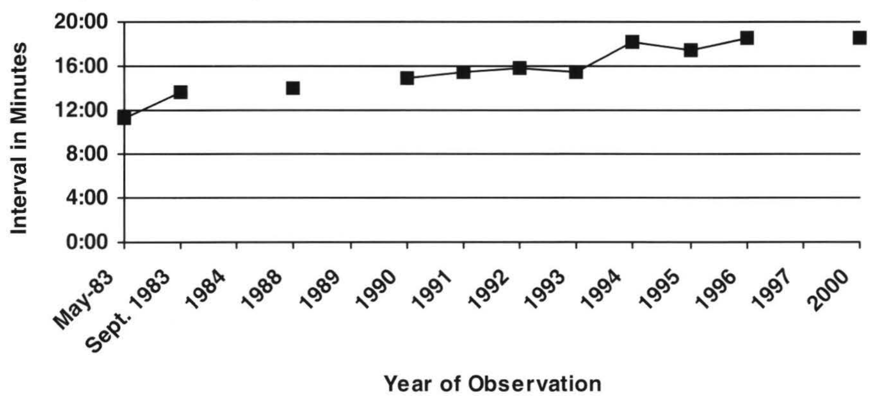
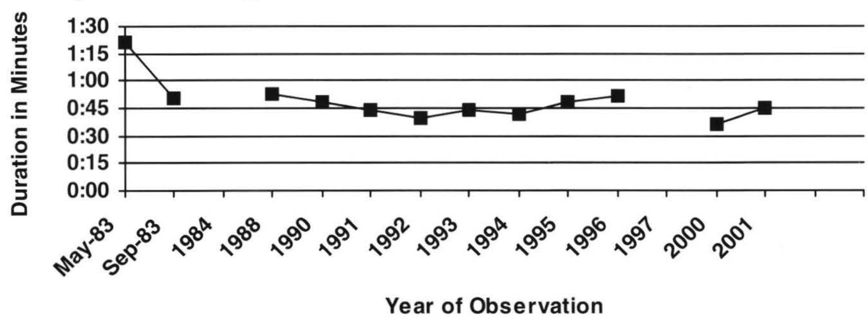


Figure 4: Slide Geyser's Average Duration— 1983–2001



Bryan's information about Slide did not change in the 1991 edition of *The Geysers of Yellowstone*. In the 1995 edition, he widened the range of intervals from 5 to 12 minutes to 5 to 20 minutes, and added the information:

> "Slide was dormant for part of 1991, and its intervals have generally been getting longer with each passing season. It can be viewed from the edge of the forest across the river, near the trail between Daisy Geyser and Biscuit Basin." [p. 129.]

Slide was reported dormant in the May – June, 1991 issue of *The Geyser Gazer Sput*:

> "Mike Keller reports that Slide is dead. No water is visible in either it or any of the nearby pits, and only slight steam wafts from the vents on chilly days." [p. 91-19.]

Slide had recovered by the time the information was printed. On May 25, 1991, I observed an eruption of Slide at 14:06, which lasted 44 seconds. Unfortunately, I did not stay to record a second eruption to get an interval and did not collect any additional data that year.

In 1992 I observed five intervals in July with an average interval of 15 minutes 53 seconds and a standard deviation of 3 seconds. The average duration was 39 seconds. Sample sizes is again small, but the average duration appeared to be decreasing while the average interval was increasing.

I observed one interval of 15 minutes 3 seconds in December that year. This is the only record of a winter interval that has been reported in the OFVC logbook and, being an isolated value, it is not included in the data calculations of this paper.

In 1993 I collected data for five durations and four intervals in August. The average for the four intervals was 15 minutes 31 seconds, a slight decline from the 1992 average, with a standard deviation of six seconds. The average duration was 44 seconds.

Data were collected on June 19 and August 31 in 1994. The average for the eight intervals was 18 minutes 13 seconds with a standard deviation of 7 seconds. The average for the ten durations was 42 seconds. Since 1992, the average had increased another 2 minutes 20 seconds.

In the August 1995 issue of *The Geyser Gazer Sput*, it was reported that:

> David Leeking recorded an interval of 17 minutes between two eruptions lasting about 45 seconds. [p. 1.]

I recorded four intervals on September 2 with an average of 17 minutes 28 seconds, and a standard deviation of 4 seconds. Durations averaged 48 seconds.

On September 2, 1996, I observed four eruptions. The three intervals averaged 18 minutes 31 seconds, an increase of slightly more than 1 minute over the 1995 average.

For the next three years I did not collect any data on Slide, and there are no observations recorded in the OFVC logbook.

In 2000 I watched five eruptions with an average interval of 18 minutes 31 seconds and a standard deviation of four seconds. The average had stayed the same as the 1996 average. I was quoted in *The Geyser Gazer Sput* as saying:

> Although Slide intervals have increased slightly over the past decade, I still believe this geyser is one of the most regular in Yellowstone. [*in* Monteith, 2000, p. 21.]

Although the sample sizes are extremely small, on each day over the past dozen years that I have collected data, the standard deviation has been very small—ranging from a minimum of three seconds to a maximum of 22 seconds.

The final report on Slide included here came from Jeff Cross who reported that he timed five intervals on September 15, 2001. These intervals were "highly regular" within a range of 17 to 18 minutes; the corresponding durations were of 45 to 50 seconds and the height was 3 feet. [Monteith, 2001, p. 24.]

Conclusion

Slide Geyser has shown remarkable consistency in its eruptive behavior on any particular day for which observations were available over the last 20 years.

Average durations range from a minimum of 36 seconds to a maximum of 1 minute 21 seconds. Length of durations appeared to decline significantly between May 1983 and September 1983, with durations in years subsequent to September 1983 staying about the same as those of September 1983.

The records show that between May 1983 and 2001, Slide's average interval increased from 11 minutes 19 seconds to 18 minutes 31 seconds. Five minutes of the seven minute increase occurred in two separate 2½ minute increases—one between May 1983 and September 1983, and another between 1993 and 1994.

Although data were not collected for 1997, 1998, and 1999, the average interval for the observations in 1996 was the same as the average interval for the observations in 2000. It does not appear that the January 9, 1998 "Biscuit Basin earthquake" that resulted in changes in the geyser activity in the Upper Geyser Basin (such as lengthening Old Faithful's intervals and reactivating Cascade Geyser for a few months) had any impact on Slide Geyser.

Finally, although only one short period of dormancy for Slide is known, considering the relatively few observations that are available, it is very possible that other periods of dormancy have occurred between 1974 and 2001 without being recognized or reported.

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Table 1: Log of Slide Geyser Data

Researcher	Date	Time (h:m:s)	Interval (m:s)	Duration (m:s)
Wolf	5/25/83	16:07:13		2:03
		16:19:42	12:29	0:57
		16:30:46	11:04	1:03
		16:41:50	11:04	1:27
		16:52:31	10:41	1:15
		5/1983 Average	11:19	1:21
Wolf	9/13/83	19:21:44		0:44
		19:36:14	14:30	0:55
		19:50:43	14:29	0:55
		20:05:00	14:17	0:51
		20:16:12	11:12	0:44
		20:31:23	15:11	0:56
		9/1983 Average	13:55	0:50
Wolf	1984		10 – 14 minutes	Less than 1 minute to just under 2 minutes
Stephens	9/3/88	09:40:30		0:48
		09:55:20	14:40	0:42
		10:10:37	15:17	0:41
		10:25:40	15:03	0:41
		12:56:12		0:43
		13:10:53	14:41	0:49
		13:26:05	15:12	0:50
		13:41:15	15:10	0:47
	9/4/88	18:13:54		1:06
		18:28:52	14:58	1:03
	9/5/88	18:54:50		1:05
		19:09:48	14:58	0:57
		19:24:28	14:40	0:56
	9/6/88	10:39:57		1:03
		10:54:00	14:27	1:05
		1988 Average	14:54	0:53

Stephens	6/19/90	13:56		
		14:11	15:xx	
		14:27	16:xx	
	8/11/90	10:30:05		
		10:45:26	15:21	
	9/1/90	12:22:20		
		12:38:05	15:45	0:37
		12:53:24	15:19	0:52
		13:09:05	15:41	0:54
		1990 Average	15:31	0:48
Stephens	5/25/91	14:06:24		0:44
Stephens	7/30/92	09:06:27		0:29
		09:22:17	15:50	0:41
		09:38:08	15:51	0:41
		09:54:03	15:55	0:38
		10:09:56	15:53	0:37
		10:25:52	15:57	0:49
		1992 Average	15:53	0:39
Stephens	8/8/93	13:56:45		0:42
		14:12:07	15:22	0:50
		14:27:39	15:32	0:32
		14:43:13	15:34	0:44
		14:58:50	15:37	0:53
		1993 Average	15:31	0:44
Stephens	6/19/94	08:28:55		0:39
		08:47:10	18:15	0:33
		09:05:25	18:15	0:40
		09:23:36	18:11	0:51
		09:41:49	18:13	0:39
	8/31/94	10:27:12		0:44
		10:45:24	18:12	0:41
		11:03:31	18:07	0:52
		11:21:37	18:06	0:42
		11:40:05	18:28	0:43
		1994 Average	18:13	0:42

Stephens	9/2/95	11:07:10		0:46
		11:24:38	17:28	0:46
		11:42:02	17:24	0:50
		11:59:27	17:25	0:52
		12:17:00	17:33	0:48
		1995 Average	17:28	0:48
Stephens	9/2/96	14:20:22		0:48
		14:38:43	18:21	1:00
		14:57:13	18:30	0:51
		15:15:56	18:43	0:48
		1996 Average	18:31	0:52
Stephens	7/3/00	11:27:24		0:40
		11:45:57	18:33	0:38
		12:04:30	18:33	0:37
		12:22:56	18:26	0:32
		12:41:31	18:34	0:31
		2000 Average	18:31	0:36
Cross	9/15/01		17-18 minutes	45-50 seconds

----

the following data is not included in the analyses in this paper
but is shown here for comparative purposes

Bryan	5/30/02	12:44:18		0:49
		13:02:02	17:44	0:51
		13:20:35	18:33	0:52
		13:38:37	18:02	0:47

A geyser at **Tagajia**, Xizang (Tibet), People's Republic of China. This picture was taken in 1993. The photographer was apparently an employee of the Wood's Hole Oceanographic Institution, but who he was, why he was in Tibet and how this photo reached the Yellowstone Archives are unknown. (The handwriting on the original 35mm slide frame appears to be Germanic in style.)

Geyser Activity North of East Mustard Spring in Biscuit Basin, June–July, 2001

by Steve Gryc

Abstract

Five small hot springs located to the north of East Mustard Spring in Biscuit Basin were active as periodic geysers during June and July of 2001. This report describes the activity of the five springs and gives data related to their eruption times, durations and intervals.

Introduction

In his *Inventory of Thermal Features...*, George Marler begins his discussion of North Geyser in Biscuit Basin with the following:

> The stretch of sinter lying to the north of Mustard Springs has many small springs. I have observed geyser activity in three of them. [Marler 1973, p. 24]

Marler identifies the northernmost spring as North Geyser but gives no information about the other two geysers.

In the encyclopedic *The Geysers of Yellow-stone*, T. Scott Bryan gives the group of sometimes–geysering springs that lie between East Mustard Spring and North Geyser a single designation as UNNG-BBG-2 and describes the group as follows:

> In the area north of the boardwalk but on the front side of the rise that hides the site of North Geyser are several erupting springs. None has been named, and the activity [in] them all changes frequently. They usually play as perpetual spouters, but they have histories as intermittent geysers as well. [Bryan 1995, pp. 148–149]

Bryan shows three dots on his map of Biscuit Basin to represent the springs of UNNG-BBG-2.

In late June and early July of 2001, I observed five small but active geysers in the area north of East Mustard Spring in Biscuit Basin. All of these springs acted as periodic geysers rather than perpetual spouters. Occasionally all of these springs could be seen erupting concurrently and, occasionally, all would be quiet. The geysers seemed to act independently of one another except for the pair that lies closest to the boardwalk. This paper will describe the activity of these five springs with emphasis on the related pair of geysers closest to East Mustard Spring and the boardwalk. I saw no evidence that North Geyser, which lies to the north of the group of five, was active, and it will not be discussed.

Location Of The Five Springs

The largest geyser of the five to be discussed lies approximately 75 feet northeast of East Mustard Spring. I refer to this spring as "Outpost Geyser" for its position on the northern edge of Biscuit Basin and for its prominence within the group of five springs. Adjacent to the southeastern portion of Outpost's crater lies a smaller spring which I refer to as "Sentry Geyser" because of its proximity to and close eruptive relationship with Outpost Geyser. The spring that Bryan describes as "emitting steamy jets of spray" [Bryan 1995] lies about 75 feet northeast of Outpost Geyser. Because of its spraying eruptions and the red tinge to its sinter platform, I refer to this spring as "Red Mist Geyser." About 75 feet north of Outpost Geyser lies another small erupting spring which I refer to as "Yellow Bubbler Geyser" because of the nature of its eruption and for the yellow flowers (stonecrop) that grow several feet southwest of the geyser. A very similar spring lies about 60 feet to the northwest of Outpost Geyser, and I refer to it as "Green Bubbler Geyser" because of the grassy ridge that lies to the spring's south and partially obscures it from view from the boardwalk.

A crude map (Figure 1) shows the relative positions of the five springs. All of the observations of these geysers were made from the boardwalk, so the distances and positions shown on the map

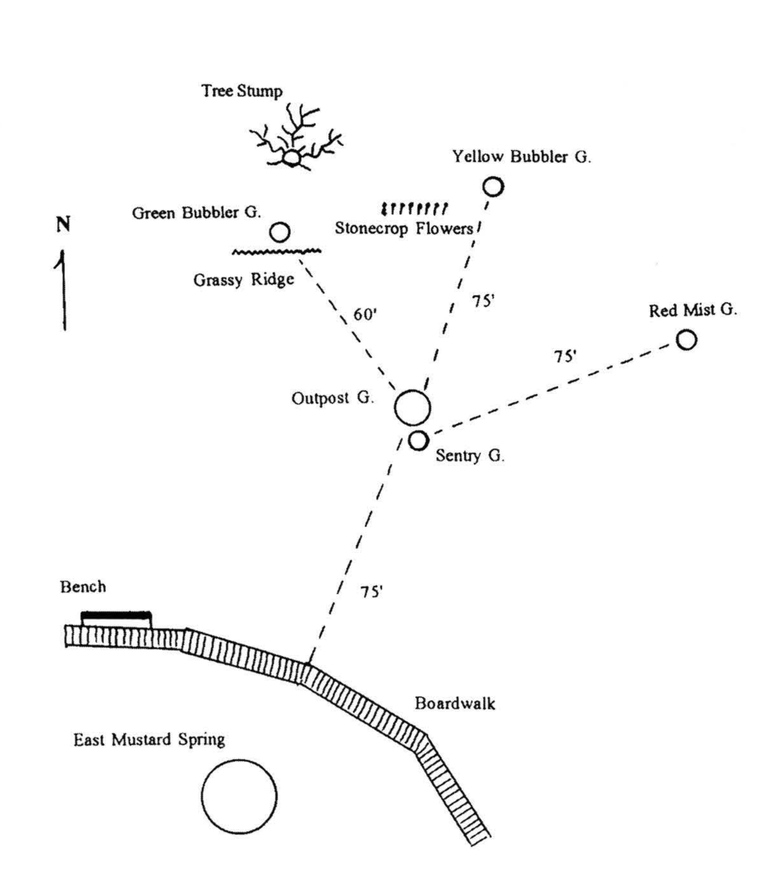

Figure 1: Map showing relative positions of the erupting springs north of East Mustard Spring. Distances are approximate and given in feet.

represent approximations rather than actual measurements.

"Red Mist Geyser"

In his discussion of UNNG-BBG-2, Bryan [1995] describes the action in one of the erupting springs:

> "In 1993 the vent farthest to the right (east) sent noisy, steamy jets of spray 10 feet high at intervals of 25 to 40 seconds for durations of 5 to 10 seconds."

This is undoubtedly the spring I refer to as Red Mist Geyser. The play of Red Mist Geyser comes in a series of pulsed ejections of water and steam. The water is dispersed in a spray rather than in a column or globular burst. The eruption of water is preceded by several puffs of steam.

During the period of my observations, Red Mist sent up spray to heights varying from about 2 to 6 feet for about 5 to 8 seconds with pauses of about 10 to 25 seconds. The geyser still steamed between these short pauses. Every 2 to 5 minutes there would be a longer period of quiet with no steam being emitted; then a few puffs of steam would appear, and another series of pulsing eruptions would commence. The longer steamless pauses varied rather narrowly between 1m 40s and just over 2 minutes. This geyser's puffing/pulsing action with spraying eruptions accompanied by its own unique sound would make this feature an object of interest among visitors if it were closer to the boardwalk.

"Yellow Bubbler Geyser"

The play of Yellow Bubbler Geyser is a constant bubbling and bursting from a small pool that forms prior to the eruption. The maximum height of the ejected water is around 18 inches. A tiny vent on the western edge of the crater plays along with the main vent. The largest and most vigorous action occurs at the beginning of an eruption with play very gradually diminishing to nothing over the course of the eruption. I timed three eruptions on June 27 and one on July 2 and obtained the following durations: 20m 20s, 22m 09s, 26m 00s and 26m 40s. The average (mean) duration was 23m 47s. The only closed interval I obtained was 2h 08m 20s on the morning of June 27. This interval may be close to this geyser's norm; in observing this group of five geysers during several sessions of a little over two hours each, I saw Yellow Bubbler erupt at least once during each observation period.

"Green Bubbler Geyser"

Green Bubbler Geyser lies in a depression between the uprooted stump of a dead tree (to its north) and a small ridge with a line of grass growing on it (to its south). The geyser is partially obscured from view from the boardwalk, making it

Table 1
"Green Bubbler Geyser," June 27, 2001

Begin-End Times	Duration	Interval
19:17:30-19:24:48	7m 18s	
19:26:45-19:32:00	5m 15s	9m 15s
19:33:22-19:39:00	5m 38s	6m 37s
19:39:57-19:44:03	4m 06s	6m 35s
19:45:55-19:52:01	6m 06s	5m 58s
19:52:52-19:57:35	4m 43s	6m 57s
19:58:36-20:04:24	5m 48s	5m 44s
20:05:21-20:10:40	5m 19s	6m 45s
20:11:12-20:17:15	6m 03s	5m 51s
20:18:40-20:24:03	5m 23s	7m 28s
20:25:17-20:30:09	4m 52s	6m 37s
20:30:14-20:36:58	6m 44s	5m 57s
20:37:33-20:43:18	5m 45s	7m 19s
20:44:47-20:49:49	5m 02s	7m 14s
20:50:11-20:55:59	5m 48s	5m 24s
20:58:01-		7m 50s

difficult to discern the beginnings and ends of eruptions. I had to stand on the bench near the Mustard Springs and intently stare at this feature in an attempt to get accurate timings of its eruptions. The geyser appears to form a pool in its crater before an eruption, but this too is difficult to see. Over the course of the bubbling, bursting eruption, the action grows very gradually to its full height of about one foot. The eruption then declines in a similar, very gradual manner. The timings for the eruptions commenced with the first sight of water bursting, even if only to a very low height. On the evening of June 27, I witnessed 16 consecutive eruptions of Green Bubbler, obtaining 15 durations and 15 intervals. The timings along with the duration of each eruption and its interval as calculated measured from the previous start are shown in Table 1.

The average (mean) duration obtained from this sequence of observations is 5m 37s, with times ranging between the shortest at 4m 06s to the longest at 7m 18s, this being the only duration of over 7 minutes.

The average interval is 6m 46s, so this geyser was in eruption much (more than 43%) of the time. The shortest recorded interval was 5m 24s, and the longest was 9m 15s, the only interval over 8 minutes.

"Outpost" and "Sentry" Geysers

Outpost and Sentry Geysers will be discussed together because of their proximity and closely related eruptive behavior. Outpost Geyser is the largest geyser in the group of five geysers and can be easily seen and studied from the boardwalk. Its eruption is large enough that it can be noticed from most other places along the loop route through Biscuit Basin. The crater is roughly circular and about five and a half feet at its greatest width. The interior of the crater is irregular, featuring several smooth and rounded geyserite "cobbles." A smaller geyser lies on the south-southeast edge of Outpost Geyser's crater, the craters of the two geysers being only a few inches apart. Sentry Geyser's circular crater is about three feet in diameter and its interior is shallower with a more regular funnel shape than Outpost's crater. The vents of both geysers appear to be near the center of their craters.

Figure 2. "Outpost Geyser" [Photo by Will Moats, 2001]

Before an eruption of Outpost Geyser occurs, its crater fills with water and forms a pool. Since the crater fills with a bubbling action, deciding when an eruption had commenced was problematic but important for the uniformity of timings. I decided that the first burst of water to exceed the rim of the vent would be designated as the beginning of an eruption. I found some amount of variability in the time that Outpost took to fill its crater and start an eruption, from a quick fill of only 9 seconds up to 46 seconds, though most fills took between 23 and 33 seconds.

Outpost's play is typical of fountain–type eruptions with a series of closely spaced bursts. Most bursts are from 2 to 4 feet, but there are a few 5 to 6 foot bursts with every eruption. Occasionally an exceptional burst of up to 7 or 8 feet will occur. Each burst sends out a wave to the edge of the crater. During the eruption a small vent on the southeast edge of Outpost's crater rhythmically sends up a small bubble of water, and it continues to play as long as the pool continues to cover it before draining away, even if the main eruption has ceased.

After an eruption, Outpost's pool drains more slowly than it fills, usually taking 60 to 70 seconds before water can no longer be seen. When Sentry starts a dual eruption with Outpost, Outpost tends to fill and drain more quickly. The quick fill in my data list of only 9 seconds came after Sentry had already started its eruption. Similarly, Sentry would sometimes fill, erupt briefly, and drain more quickly than normal after Outpost had started its eruption. The two geysers seldom start their eruptions at the same time (though I did see this happen once); most times they will both begin to fill before either has commenced an eruption.

There is very little runoff from these two geysers. The relatively small amount of runoff forms small puddles around the combined circumference of the two craters.

Sentry Geyser's eruption, like its crater, is significantly smaller than Outpost's. Sentry will burst as high as two feet, though most bursts are smaller. Sentry fills its crater and forms a pool with a bubbling action similar to Outpost's. Sentry's fill and drain times are comparable to those of Outpost, though some fills I noticed were longer than any I saw for Outpost (over 70 seconds). Occasionally Sentry would start to fill after Outpost had filled and started its eruption; in such cases Sentry would often have a very quick fill, brief eruption, and a quick drain.

From the data I collected from 46 eruptions, I found that the average (mean) duration for an eruption of Outpost Geyser was 3m 43s, which was very close to the median duration of 3m 22s. The extremes I recorded were 1m 45s for the shortest duration and 6m 00s for the longest.

The 43 intervals I timed for Outpost averaged out to 8m 20s, which again was very close to the median interval of 8m 21s. Intervals were measured from the start of one eruption to the start of the next eruption. The intervals varied from the shortest of 4m 26s to the longest of 12m 24s.

The 23 observed eruptions of Sentry Geyser showed a mean duration of 2m 15s with the median being 2m 37s. The shortest duration was 0m 31s and the longest was 4m 19s.

Twenty intervals were observed for Sentry, with the mean being 18m 23s, again close to the median of 18m 35s. Intervals varied between 7m 26s (the shortest) and 28m 14s (the longest).

Short durations (those around a minute or less) were often followed by a short interval (around 10 minutes or less). Here are some duration/interval pairs from eruptions of Sentry Geyser to illustrate this point: 31s/8m 55s, 37s/10m 14s, 44s/7m 20s, 50s/10m 03s,1m02s/9m 50s. It must be noted, however, that on June 26 I observed a 57–second eruption that was followed by a longer than normal interval of 19m 16s. So the general duration–interval relationship is a weak one, as shown by the scatter plot (Figure 3, next page).

There is a close relationship between Outpost Geyser and Sentry Geyser. Eruptions from the less frequent Sentry Geyser almost always overlap with the more active Outpost Geyser. However, I observed one instance in which Sentry filled and then began to erupt as Outpost was filling; after only 37 seconds of play, and one second before Outpost started its eruption, Sentry abruptly stopped and quickly drained. Outpost continued with an eruption of normal duration.

Outpost's durations were not generally affected by dual eruptions with Sentry. The data do show, however, that a longer than average duration of one of the geysers in a dual eruption (over 4 minutes for Outpost or over 3 minutes for Sentry) often corresponded to a shorter than average duration in the other.

Of the 46 eruptions of Outpost Geyser that I timed, exactly half of them were dual eruptions with Sentry Geyser. Either geyser may begin to fill, erupt, and/or drain before the other in a dual eruption, and I observed only one instance where the two geysers commenced an eruption during the same second. Whether Outpost or Sentry starts a dual eruption seems not to make any difference in the durations of the eruptions. In at least one case, Outpost started filling first, although Sentry started its eruption before Outpost. When I observed the two geysers on June 26, Sentry would join Outpost in a dual eruption after one or two solo eruptions by Outpost. On June 27 and again on July 2, I observed several pairs of consecutive dual eruptions. In all 5 such cases of consecutive duals, the first duration of Sentry Geyser was short (from 31 to 62 seconds) while the next duration was significantly longer (1 minute, 51 seconds to 4 minutes, 19 seconds). Also, the interval of Sentry's first eruption was significantly longer than the interval of the second eruption in the pair of dual eruptions. These pairs of consecutive duals were separated by one or two solo eruptions of Outpost. I never witnessed a series of three or more consecutive dual eruptions of Outpost and Sentry.

The data for Outpost and Sentry Geysers are presented next to each other in Tables 2, 3 and 4 (following pages) to show the relationships between the two. Dual eruptions are shown on the same line, with the instance of the Sentry eruption followed by Outpost one second later shown as a dual eruption but indicated with an asterisk. The eruption times have been coordinated with the clock at the Old Faithful Visitor Center. In addition to listing start and stop times for each eruption, I have listed each eruption's duration and its interval as measured from the start of the previous eruption.

References

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Marler, George D., 1973, *Inventory of Thermal Features of the Firehole River Geyser Basins and Other Selected Areas of Yellowstone National Park,* Menlo Park, CA: U.S. Geological Survey and National Park Service, National Technical Information Service PB-221289.

Figure 3.

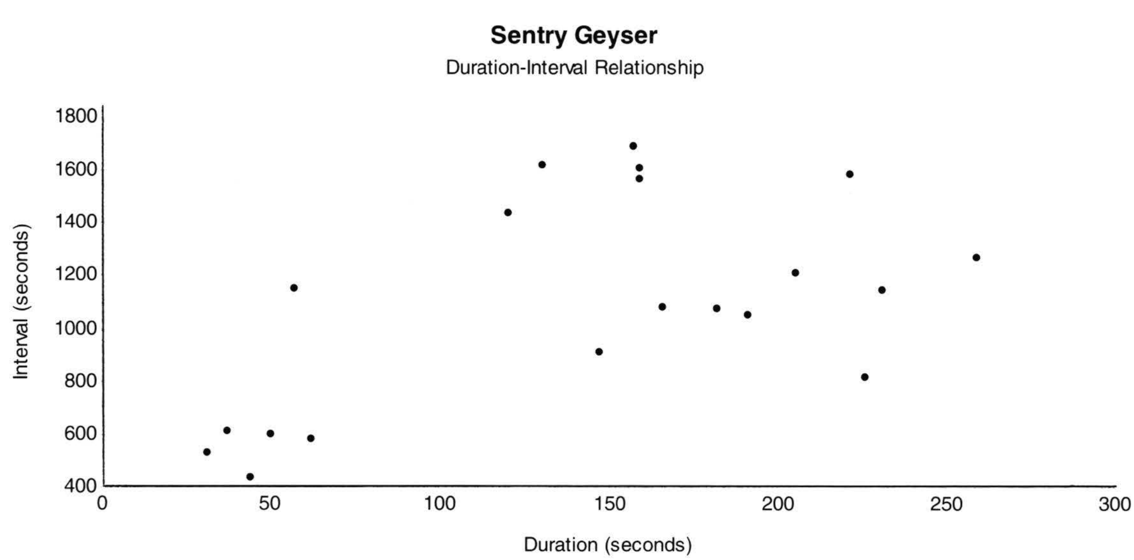


Table 2 — June 26, 2001

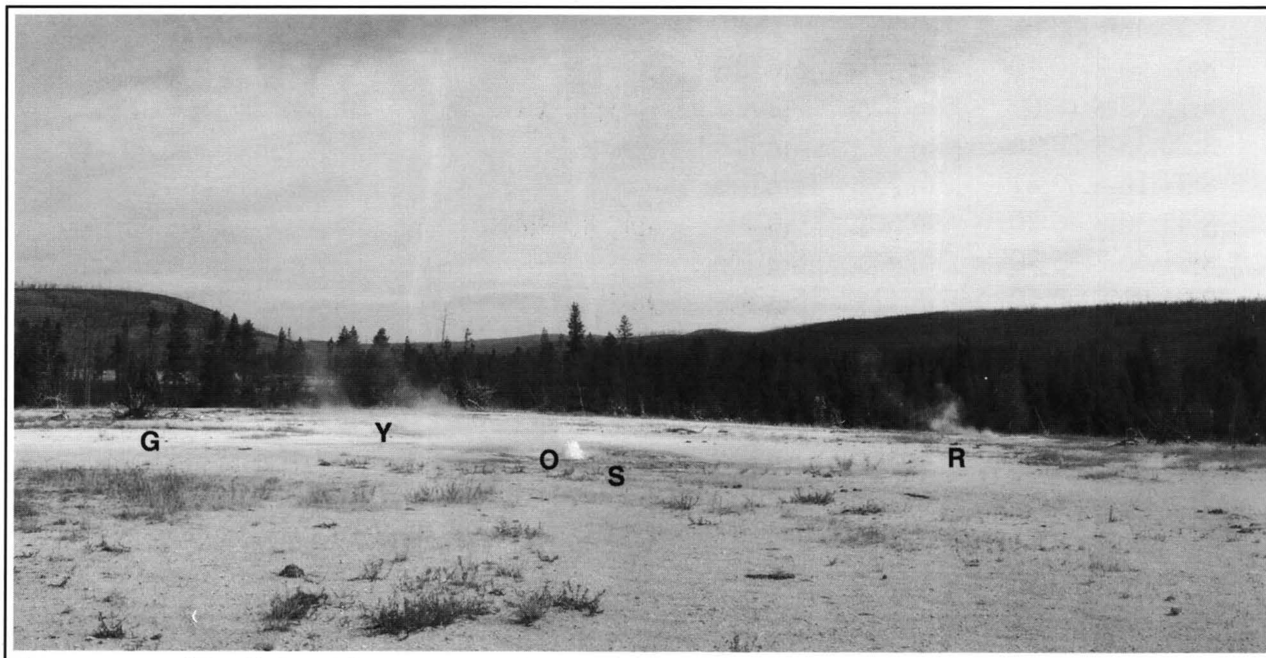
"Outpost G" Times	Duration	Interval	"Sentry G" Times	Duration	Interval
7:23:40-7:25:25	1m 45s		7:23:40-7:25:40	2m 00s	
7:29:18-7:34:53	5m 45s	5m 38s			
7:40:37-7:43:13	2m 36s	11m 19s			
7:48:32-7:54:11	5m 39s	7m 55s	7:47:43-7:48:40	0m 57s	24m 03s
7:59:56-8:02:53	2m 57s	11m 14s			
8:08:02-8:10:35	2m 33s	8m 06s	8:06:59-8:10:40	3m 41s	19m 16s
8:14:59-8:20:00	5m 01s	6m 57s			
8:25:30-8:28:45	3m 15s	10m 31s			
8:33:52-8:39:30	5m 38s	8m 22s	8:33:30-8:36:55	3m 25s	26m 31s
8:45:16-8:48:10	2m 54s	12m 24s			
8:53:35-8:56:38	3m 03s	8m 19s	8:53:45-8:56:22	2m 37s	20m 15s
9:02:00-9:07:40	5m 40s	8m 25s			
9:13:42-9:17:18	3m 36s	11m 42s			
9:23:04-9:25:00	1m 56s	9m 22s	9:21:59-9:25:10	3m 11s	28m 14s
9:29:08-9:32:54	3m 46s	6m 04s			
9:38:28-9:41:38	3m 10s	9m 20s	9:39:35-9:40:20	0m 45s	17m 36s

Table 3 — June 27, 2001

"Outpost G" Times	Duration	Interval	"Sentry G" Times	Duration	Interval
7:55:48-8:00:08	4m 20s				
8:05:56-8:10:10	4m 14s	5m 48s			
8:15:52-8:18:09	2m 17s	5m 42s	8:15:50-8:18:29	2m 39s	
8:22:35-8:28:35	6m	4m 26s			
8:34:16-8:37:41	3m 25s	11m 41s			
8:43:30-8:46:20	2m 50s	9m 14s	8:42:40-8:46:31	3m 51s	26m 50s
8:51:46-8:55:30	3m 44s	8m 16s			
9:01:09-9:03:50	2m 41s	5m 39s	9:01:48-9:04:15	2m 27s	19m 08s
9:08:50-9:11:54	3m 04s	5m			
*9:17:41-9:21:42	4m 01s	5m 47s	*9:17:03-9:17:40	0m 37s	15m 15s
9:28:19-9:30:40	2m 21s	10m 38s	9:27:17-9:31:03	3m 46s	10m 14s
9:35:23-9:38:01	2m 38s	7m 04s			
9:43:33-9:48:25	4m 52s	5m 32s	9:44:45-9:45:16	0m 31s	13m 42s
9:54:34-9:58:07	3m 33s	11m 01s	9:54:11-9:58:30	4m 19s	8m 55s
10:03:52-10:07:50	3m 58s	9m 18s			
10:13:57-10:16:03	2m 06s	10m 05s	10:15:25-10:16:27	1m 02s	21m 14s
10:20:47-10:26:41	5m 54s	4m 44s	10:25:15-10:27:06	1m 51s	9m 50s

Table 4 — July 2, 2001

"Outpost G" Times	Duration	Interval	"Sentry G" Times	Duration	Interval
18:33:40-18:38:48	5m 08s		18:35:40-18:36:30	0m 50s	
18:44:43-18:47:32	2m 49s	11m 03s	18:45:43-18:47:53	2m 10s	10m 03s
18:52:29-18:58:13	5m 44s	7m 46s			
19:03:52-18:08:07	4m 15s	5m 39s			
19:14:04-19:17:04	3m 00s	10m 12s	19:12:50-19:15:52	3m 02s	27m 07s
19:22:25-19:25:44	3m 19s	8m 21s			
19:31:05-19:33:52	2m 47s	8m 40s	19:30:50-19:33:36	2m 46s	18m 00s
(Note: Outpost started filling before Sentry though Sentry erupted first.)					
19:38:48-19:42:28	3m 40s	7m 43s			
19:47:43-19:50:57	3m 14s	8m 55s	19:48:53-19:49:37	0m 44s	18m 03s
19:56:11-19:58:28	2m 17s	8m 28s	19:56:13-19:58:52	2m 39s	7m 20s
20:02:40-20:08:22	5m 42s	6m 29s			
20:13:58-20:17:11	3m 13s	11m 18s			
20:22:19-20:26:55	4m 36s	8m 21s	20:22:24-20:24:18	1m 54s	26m 11s



A panorama of the Outpost Geyser area, showing (left to right) "Green Bubbler" ('G'), "Yellow Bubbler" ('Y'), "Outpost" ('O') in eruption, "Sentry" ('S') and "Red Mist" ('R'). [Photo by Scott Bryan, August 31, 2002]

Geyser Activity North of East Mustard Spring in Biscuit Basin, May and August, 2002

by Nancy Bower

Abstract

Observations on small geysers in the northern portion of Biscuit Basin were conducted in 2002, prior to realizing that Steve Gryc had made similar observations during mid–summer 2001. A comparison of the two data sets indicates some significant changes in eruptive behavior.

Introduction

This report describes the activity of six geysers north of East Mustard Spring that caught my attention on a walk around Biscuit Basin on May 14, 2002. They were again observed on August 3, 2002. This report makes use of Steve Gryc's map , names and descriptions as a baseline for comparisons [see Gryc, 2002, this volume]. Gryc's map is a good indicator of locations and distances.

All photos in this report were taken from the bench on the boardwalk by East Mustard Spring.

"Red Mist Geyser"

Both Bryan [2001] and Gryc [2002] describe this feature as a spray of water mixed with noisy steam with pauses of one or two minutes. "Red Mist" was active both in May and August, but eruptions were not mist– or spray–like. As its vent is in a depression, some of its activity is not visible above ground level and would sometimes appear as water droplets and steam. Most eruptions, though, were splashy bursts of one to three feet high (see Figure 1). The pauses between activity were always less than one minute long and the geyser was active all the time the area was observed.

Given the high frequency of eruptions, specific data on this activity was not recorded.

"Yellow Bubbler Geyser"

I saw two geysers in the area of Gryc's single "Yellow Bubbler." I designate them "Yellow Bubbler" 'A' and 'B'. "Yellow Bubbler" 'A' erupts from a pool to a maximum height of two feet. 'B' lies just south and a bit east of 'A'. It also erupts from a pool, but has two vents and erupts only a foot high. Both of 'B's observed eruptions were in concert with 'A' (see Table 1 and Figure 2, next page).

Note that the one observed interval, 43 minutes, was very much shorter than those recorded by Gryc in 2001.

Figure 1. "Red Mist Geyser." [Photo by Robert Bower]

Table 1. "Yellow Bubbler Geysers"

	"Yellow Bubbler 'A' " times	"Yellow Bubbler 'B' " times
May 14, 2002	1045-1051 d = 6 min.	
	1128-1139 d = 11 min. i = 43 min	1128-1138 d = 10 min.
August 3, 2002	1155-1159 d = 4 min.	1154-1204 d = 10 min.

Figure 2. "Yellow Bubbler" 'A' left, "Yellow Bubbler" 'B' right. [Photo by Robert Bower]

"Green Bubbler Geyser"

As Gryc [2002] describes, this geyser is obscured somewhat from view, making it more difficult to obtain start and stop times. In May all of the eruptions I observed were very small eruptions of only six to eight inches. It reminded me of "Dilemma Geyser" in the Pink Cone area. I was therefore quite surprised in August to see its last two eruptions going as much as three feet high (see Table 2 and Figure 3).

Table 2. "Green Bubbler Geyser"

Start time	Stop	Duration	Interval
May 14, 2002			
1049	1051	2 min.	
1056	1058	2 min.	7 min.
1106	1117	11 min.	10 min.
1121	1124	3 min.	15 min.
1130	1133	3 min.	9 min.
1141	1144	3 min.	9 min.
1147	1151	4 min.	6 min.
1154	1156	2 min.	7 min.
August 3, 2002			
1129	1131	2 min.	
1137	1139	2 min.	8 min.
1151	1152	1 min.	14 min.
1206	1207	1 min.	15 min

"Outpost" and "Sentry" Geysers

The character of "Outpost" and "Sentry" Geysers' eruptions were very much like that described by Gryc. I did note that the small bubbler on the southeast edge of "Outpost's" crater started at about one

Figure 3. "Green Bubbler Geyser." [Photo by Robert Bower]

minute into each eruption. I also noted that each of "Sentry's" eruptions overlapped eruptions of "Outpost" (see Table 3 and Figure 4). "Sentry'"usually started first, or followed within seconds of "Outpost's" starts.

References

Bryan, T. Scott, 2001, *The Geysers of Yellowstone*, 3rd Edition (revised); University Press of Colorado.

Gryc, Stephen, 2002, "Geyser Activity North of East Mustard Spring in Biscuit Basin, June–July, 2001;" in *The GOSA Transactions*, Volume VII [this volume].

Figure 4. "Outpost Geyser" (left), "Sentry Geyser" (right). [Photo by Robert Bower]

Table 3. "Outpost" and "Sentry" Geysers

"Outpost" times	duration	interval	"Sentry" times	duration	interval
May 14, 2002					
1047-1050	3.min				
1055-1059	4 min.	8 min.	1053-1056	3 min.	
1104-1108	4 min.	9 min.			
1114-1116	2 min.	10 min.			
1120-1124	4 min.	6 min.	1120-1122	2 min.	27 min.
1131-1134	3 min	9 min.			
1139-1140	1 min.	8 min.	1137-1141	4 min.	17 min.
August 3, 2002					
1127-1130	3 min.		1127-1129	2 min.	
1134-1139	5 min.	7 min.			
1144-1146	2 min.	10 min.	1141-1146	5 min.	14 min.
1151-1151	3 min.	4 min.			
1159-1159	2 min.	9 min.			
1204-1204	2 min.	5 min.			
1208-1210	2 min.	6 min.	1207-1208	1 min.	26 min.
1214-1216	2 min.	6 min.	1213-1216	3 min.	6 min.
1219-1222	3 min.	5 min.			

Rusty Geyser (foreground) and rarely–active "Dusty Geyser" are next to the entrance road to the parking lot at Biscuit Basin. [Photo by T. Scott Bryan, October 1978]

Fountain Geyser:
Electronic Monitor Results from 2000 and 2001

by Ralph C. Taylor

Abstract

An electronic temperature recorder, or data logger, was deployed on Fountain Geyser beginning in August 2000. This paper discusses the data collection methods and analyzes trends in Fountain Geyser's eruptive behavior as deduced from the temperature record from August 2000 to December 2001. A significant shift in eruption frequency and duration occurred following a period of "wild phase" activity in November 2000.

Introduction

Fountain Geyser is a large geyser that erupts from a deep pool in a thick sinter shield in the Fountain Paint Pot area. Fountain Geyser is typical of "fountain-type geysers," that is, those geysers that erupt from a full pool of water, with bursts rocketing through the water. Beginning in August of 2000 an electronic data logger was deployed in Fountain Geyser's runoff channel to monitor the activity of the geyser. The data logger was deployed and monitored during the course of the author's duties as a volunteer for the National Park Service. Note that any deployment of instruments requires a research permit and permission from the National Park Service.

Data Logger Placement

For the period from 19 August 2000 to 31 December 2001, a data logger belonging to the National Park Service was deployed near Fountain Geyser to determine the eruption patterns. The logger, a Hobo Pro® made by Onset Computer Corporation, was located in the sinter sand at the edge of the runoff channel a few meters from the boardwalk. Some plates of sinter and a covering of sinter sand hid it from view. The thermistor was located in the edge of the scoured sinter runoff channel in a location that was well inundated by the copious overflow during summer eruptions. In the winter (which the author has not experienced first–hand), it appears from the temperature graphs that ice dams can form and block the flow of water to the sensor. In most cases, it was possible to discern the approximate start and end of eruptions, even in the icy conditions. A piece of sinter placed over the thermistor anchored the thermistor and prevented direct sunlight from giving false high temperature readings.

During the summer months of 2000, from the initial deployment in August to the first week in October, the logger was set to record temperatures at intervals of 30 seconds. The data from 21 May 2001 to 4 October 2001 was also recorded at 30 second intervals. This data point interval allowed measurement of eruption durations to a precision of about ±1 minute with a similar precision for intervals. Since the mean interval during this time was approximately six hours and the mean eruption duration was about 28 minutes, this represents a maximum error of about 0.5% on interval and about 3.5% on the durations.

The deployment from 6 October 2000 to 21 May 2001 used a sampling interval of five minutes, which represents a maximum error of about 1.4% on intervals and about 25% on intervals. The winter deployment in 2001, from 4 October to 31 December, recorded temperatures every three minutes, resulting in a maximum error of about 0.8% on intervals of six hours and 12% on intervals of 25 minutes.

Method of Detecting Eruptions

The data logger records the temperature at the thermistor at programmed intervals. With a programmed interval of 30 seconds, one week of data results in over 20,000 temperature readings. During the quiet part of Fountain Geyser's cycle, no overflow is present and the temperature approaches the ambient temperature of the ground. When an eruption occurs, the water overflows the crater shortly following the start, and the hot water reaches the thermistor shortly after overflow begins. For most eruptions the initial temperature rise is large and sudden, making it relatively easy to detect the start of the eruption. At the end of the eruption, Fountain shuts off rapidly and the water flow stops quickly. From the point at which overflow of hot water ceases, the temperature at the thermistor begins to decline exponentially as the rocks around the thermistor cool.

The overflow of water during the eruption is not constant. During some eruptions the flow of water at the thermistor was interrupted for a time, and then resumed. Factors such as wind and air temperature also affect the temperature record. During the winter months the signature of eruptions was more difficult to detect reliably. There were times when only the slightest temperature rise was detected. Since the author was not present to observe the thermistor site, the exact cause is unknown. A possible cause for the small temperature rise is ice dams formed along the side of the runoff channel isolating the thermistor from the freely flowing hot water.

The process of analyzing the data files was automated by software created for the purpose. The software looks for either a rise in excess of 12°C in one sample or a rise of at least 1.8°C followed by a rise of at least 1.1°C on the next samples, or a rise of 7°C in three samples, providing a temperature rise of at least 15°C occurred within 30 minutes. This method of detection worked very well in the summertime, but occasionally missed eruptions in the winter when the total temperature rise sometimes was only two or three degrees. In these cases, visual examination of the temperature graph and data set was used to determine the start and end times for the eruptions.

Finding the end of the eruption was complicated by the occasional pauses during the eruptions. The software determines the duration of an eruption by starting at a point 40 minutes after the eruption start time and scanning backward to find the point at which the temperature begins to fall. On some eruptions this gave a time that was short, apparently because the eruption declined in force as it progressed, with a corresponding gradual decrease of runoff water temperature. Examination of a number of these eruptions led to a change in the algorithm to look for an inflection in the curve marking the start of the exponential decline of the water temperature that signaled the end of the re–supply of hot water from the eruption. This method appeared to give consistent results, but eventually a tedious examination of all of the eruptions was necessary.

Validating the Data Logger Results

The start and end time detection algorithm has not been rigorously "ground truthed" by comparing detailed visual observation with the temperature graph. However, a comparison of electronically determined times with times from the Old Faithful Visitor Center logbook suggests that the electronic start times are three to four minutes later than visual times, which is reasonable considering the time required for water to overflow the crater after the first visible bursts and distance the runoff water must flow to reach the sensor.

For example, there were 23 Old Faithful Visitor Center logbook entries for eruptions in August and September of 2000 for which there are corresponding data logger times. This comparison excludes all logbook times marked "ie" [in eruption], "ns" [near start] or "vr" [visitor report]. The range of lag times, or time from the visual sighting to the logger–detected start time, was two minutes two seconds to six minutes two seconds. The mean time was three minutes 53 seconds and the median was four minutes two seconds. The standard deviation was just under one minute, at 59 seconds. Note that the resolution of logbook times is one minute and the resolution of the logger for this time was 30 seconds for intervals up to 4 October and five minutes after that date.[1]

[1] Logbook eruption start times record the minute in which the eruption started. Logbook durations are typically recorded to the second. Data logger times are recorded to the second for each temperature measurement, but since temperature was sampled every 30 seconds the start time can be determined to the 30 second interval during which the event occurred.

In 2001, there were 94 eruptions for which comparable visual and data logger times were available between 20 June and 30 October. The mean lag from the observed start time to the electronically determined start time for these 94 eruptions was three minutes 39 seconds and the median lag was three minutes 24 seconds. The range of lag times was 24 seconds to 11 minutes 24 seconds with a standard deviation of one minute 56 seconds. This sample includes numerous eruptions for which the data logger resolution was five minutes (those after 4 October), so the larger variation between logbook and data logger times is expected.

Durations computed from the electronic data appear to be about three minutes shorter than visual times, based on just 17 data points. For the period from mid–August 2000 to the end of September 2000 there were only 17 eruptions for which both visual and electronic durations were available. The difference between electronically determined and visually determined durations ranged from one minute to 14 minutes 30 seconds. The 14 minute difference was a single event; the next larger difference was just five minutes. The mean difference between the logbook duration (which was recorded to the nearest minute) and the electronically determined duration was three minutes 16 seconds and the median difference was two minutes 30 seconds. The electronically determined duration was always shorter. The difference may be due to the end of the eruption being less likely to provide runoff water to the sensor, causing the early electronic detection of an end time. The electronically determined durations, although consistently shorter than the logbook times still provide a good indication of changes in the activity of the geyser.

In 2001, there were 55 comparable visual duration and electronic duration data points between 20 June and 2 October. The range of duration difference was one minute to 10 minutes 30 seconds with both the mean and median difference of three minutes 30 seconds. The standard deviation was just one minute 36 seconds, indicating that the electronically determined times were in good agreement with the visually observed times.

More careful ground truthing may lead to a better placement of the sensor and start times and durations more closely in line with visual observations. Intervals between eruptions from the existing database are valid within the resolution of the measurements. Durations computed from the logger data appear to be consistently 3 minutes 30 seconds shorter than visually measured durations.

Wild Phase Activity

Fountain Geyser has wild phase activity from time to time. In this mode, a long period of low intensity eruptive behavior with little overflow occurs. The author did not witness any wild phase activity, but correlation of reported instances of wild phase activity with the electronic monitor data showed that the wild phase activity is characterized by a number of eruptions at shorter than normal intervals (as short as one hour) followed by an apparent pause of activity, ending with more short interval short duration eruptions. The pause in activity, that is, the lack of detectable eruptions, shows on the interval graph as a very long interval, often off the scale. The longest interval between detected eruptions in 2000 occurred between 02:46 on 19 December and 21:31 on 24 December, an interval of over 138 hours. In 2001 there were several long intervals that were preceded and followed by short intervals and were probably wild phase activity (48 hours ending at 11:11 on 26 January, 19 hours ending at 8:51 on 24 March, and 127 hours 45 minutes ending at 16:06 on 21 April, among others). Ice dams in the runoff channel may have caused other long recorded intervals without the short interval activity. Many, but not all, of the instances of wild phase activity ended with one or more short interval eruptions. Apparently the gap in recorded activity (i.e., the apparent long interval) results from activity of too low an intensity to eject enough water into the runoff channel to reach the sensor. Some of the reported periods of wild phase activity showed on the electronic record as periods of short intervals with no evident pause in activity.

Fountain Geyser's Behavior

Fountain Geyser's overall behavior for the study period is shown in the graph in Figure 1. One immediate item of note is the appearance of numerous short (less than four hour) and long (more than seven hour) intervals. The short intervals were verified with the logbook and represent a recurring pattern of eruptive behavior. The electronic logger record does not show what else was happening in the Fountain group, and the significance of the periodic episodes of short intervals is not clear. Since the wild phase activity was preceded and followed by episodes of short interval activity, the episodes of short interval activity may represent a shift of energy or water that is related to the cause of wild phase activity.

The long intervals shown in Figure 1 resulted from a mixture of two or three phenomena. First, there are some genuine long intervals, which may be related to wild phase activity. Reports of wild phase activity in the logbook corresponded to activity characterized by decreasing intervals, then a long period (12 to more than 100 hours) with no eruptions recorded, and then short interval eruptions with gradually increasing intervals. Second, there are probable double intervals in the winter months where it seems likely that an eruption was not detected, probably because of ice dams in the runoff channel near the thermistor. Finally, there are a few unexplained long intervals that could simply be long intervals occurring as a result of some characteristic of Fountain Geyser that is currently unexplained. Some of the long intervals may be influenced by wind cooling of the pool.

A second phenomenon shown by the graph in Figure 1 is the sudden change in interval following the period of inactivity in November 2000. During the gap in the eruption sequence, Fountain Geyser was in wild phase, a continuous boiling eruption that does not cause the overflow channel to fill. Before the wild phase in early November, Fountain had intervals with a mean of 7h21m and a median of 7h25m45s. Following the wild phase, the mean interval dropped to a mean of 4h59m12s and a median of 5h00m. This drop clearly represents a major change in the activity of this geyser. The new, shorter intervals remained stable through 2001.

The most significant event in the sixteen month data run is the discontinuity in activity in late October of 2000. Figure 2 shows the Fountain Geyser intervals between 18 August and 31 December 2000. Until about 3 November we see a pattern of eruption intervals between seven and eight hours. There is a saw tooth pattern of increasing intervals for

Figure 1. Fountain Geyser Intervals, 2000-2001

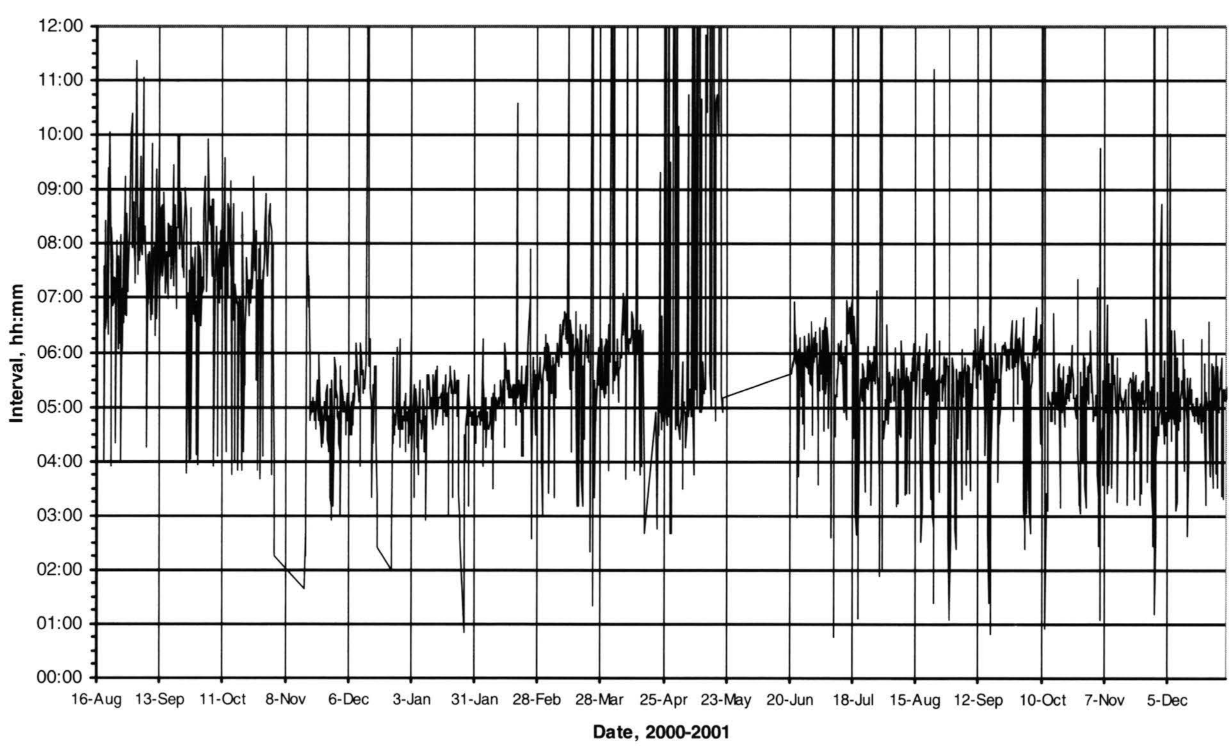
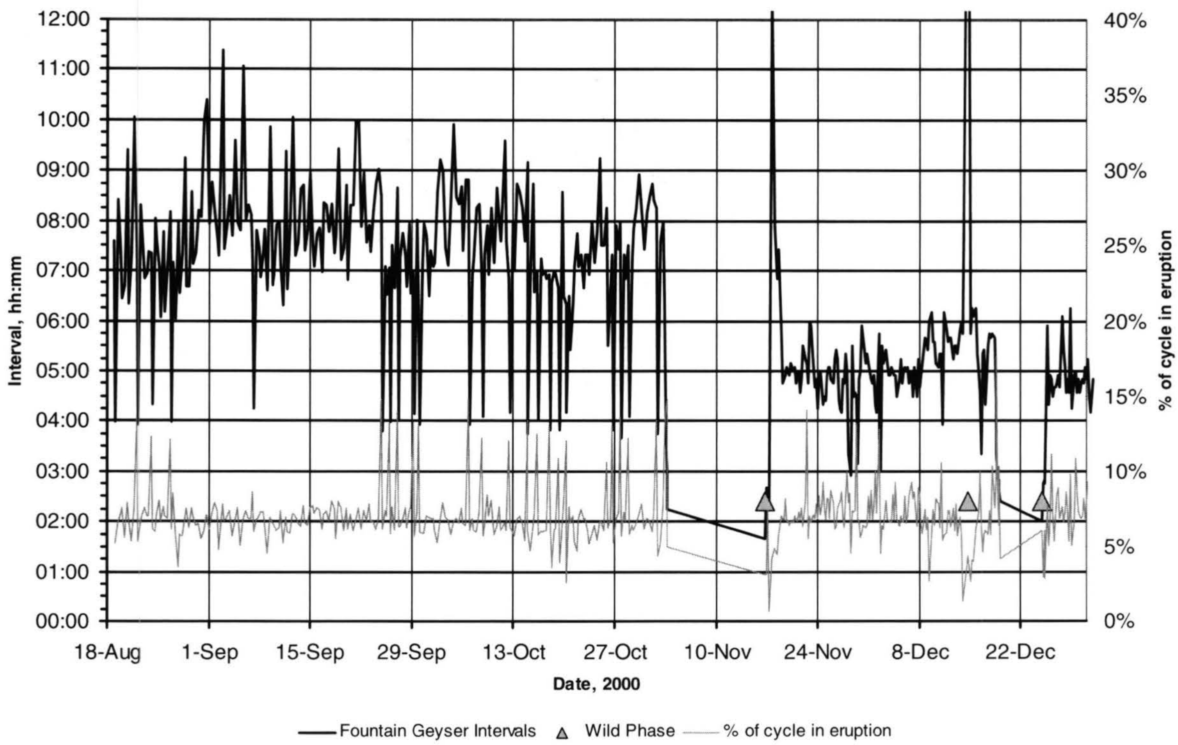


Figure 2. Fountain Geyser Intervals, 2000

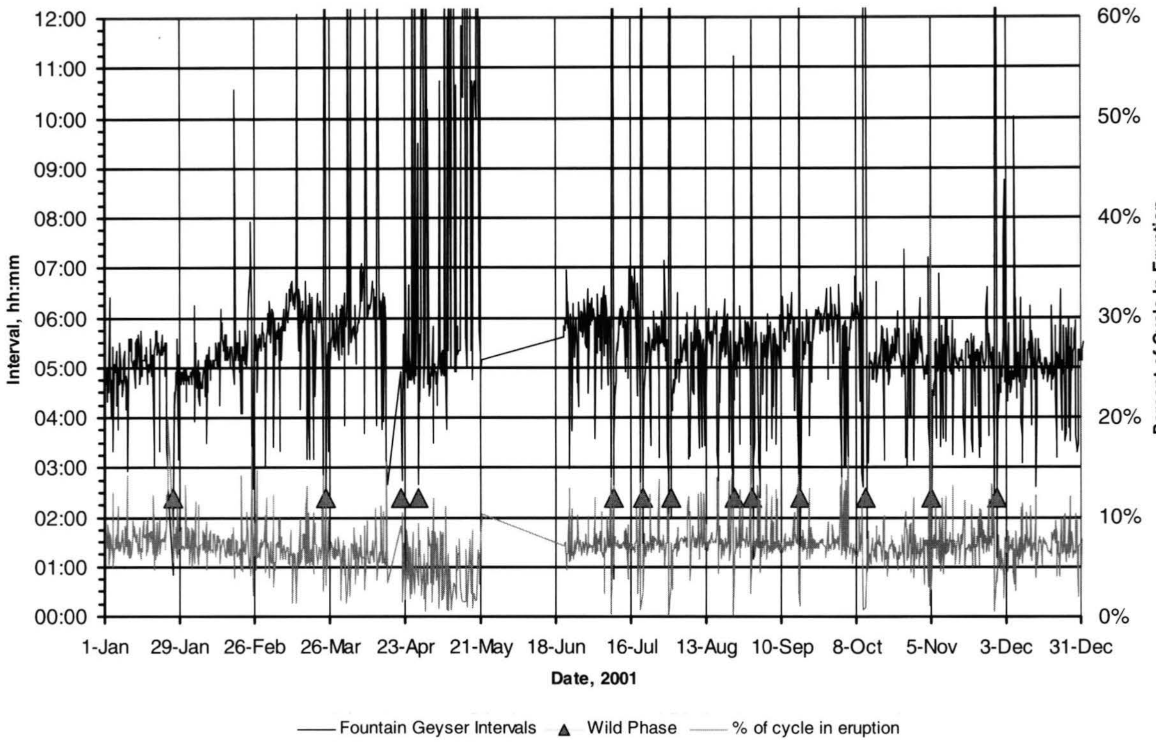


about two weeks followed by one or more short (about four hour) intervals that are coincident with a decrease of most intervals from around eight hours to around seven hours. In late September the short intervals were occurring almost daily. For all of October the short intervals continued, most at intervals of one to two days. During this entire period intervals of up to eleven hours occur, but none that appear to be double intervals, indicating missed eruptions.

On 3 November three eruptions occurred with decreasing intervals and durations, and then Fountain entered a period of "wild phase" activity. The author has not witnessed wild phase activity, but evidently there is continuous boiling and low level activity with no true eruptions during this time. Judging from the runoff temperature, there is no runoff either, or only a small amount that does not contact the thermistor. The wild phase activity in November 2000 marked a significant and long–lasting change in activity for Fountain Geyser. When normal activity resumed on 16 November, the pattern of eruptions was different from before the wild phase. The mean interval had dropped to about five hours, and the saw tooth variation in intervals was no longer evident. Two further episodes of wild phase activity occurred, one short one around 14 December and a longer episode ending on 24 December. Wild phase episodes continued throughout 2001, as did short, four hour intervals. The typical pattern for wild phase activity in 2001 was a few short interval, short duration eruptions followed by the wild phase activity, terminating with one to three short interval, short duration eruptions.

The change in behavior following the November wild phase activity was a long-term change. The new pattern of continued throughout 2001, as shown in Figure 3. Fountain's median interval prior to the November 2000 wild phase activity was 7 hours 25 minutes, with a median duration of just over 30 minutes. Following the wild phase in 2000 the median interval was 4 hours 55 minutes with corresponding median duration of 20 minutes. The median interval for all of 2001 was 5 hours 15 minutes and the median duration was 22 minutes 24 seconds.

Figure 3. Fountain Geyser Intervals, 2001



The second obvious gap, from 21 May 2001 to 21 June 2001 was caused by the data logger memory filling and the consequent suspension of data recording. The prominent gap in data from 21 May to 20 June was caused by the data logger filling its memory and stopping. The long intervals in the four weeks prior to the data gap are of unknown origin, but may be instances of missed eruptions because of ice or the sensor being moved from its intended spot by current or animal activity. When I downloaded the data in June, the sensor was out of place, but had no tooth marks or other evidence of animal intervention.

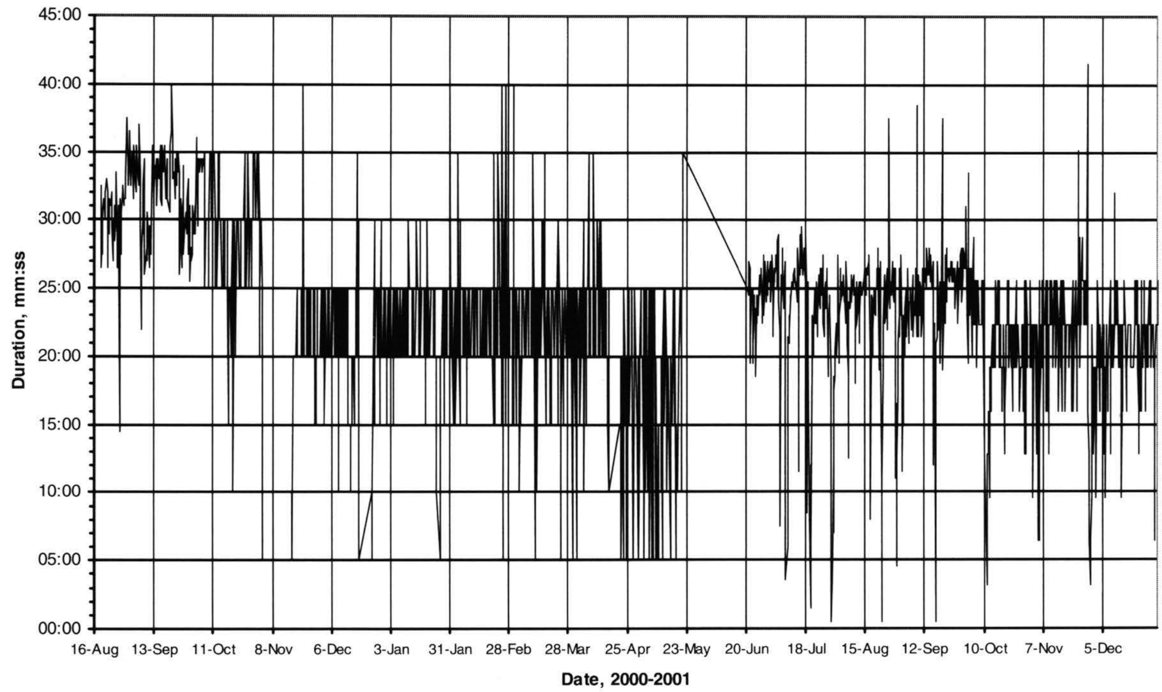
By July of 2001 a pattern of cyclic variation in interval became evident. Wild phase activity recurred every 10 to 20 days, and periods of short intervals, sometimes accompanied by a wild phase, sometimes not, recurred every four or five days. It is not clear what the mechanism driving the change was. No notable seismic events were noted at the time of the shift.

Analysis of Durations

Analysis of the durations of Fountain Geyser's eruptions is complicated by the difficulties encountered in determining the durations accurately. There was a definite drop in duration following the wild phase activity in November 2000 as shown in Figure 4. During the winter months (October to June) the duration computation has a resolution of five minutes, but in the summer months has a resolution of 30 seconds. The very short durations indicated are probably more an artifact of the instrumentation and the method for determining the end of the eruption than a true indication of short eruptions. The exception to this statement is the short duration eruptions that are known to occur just before and just after wild phase activity. The eruption durations remained consistently in the 20 to 27 minute range for most intervals following the November 2000 wild phase.

The data loggers have a memory capacity sufficient to record just over 65,000 data points. The time between temperature readings is programmable

Figure 4. Fountain Geyser Durations, 2000-2001



over a wide range (0.5 seconds to many hours) allowing a trade–off between resolution of events and the total time before the logger memory fills up. During the winter months, the data logger was deployed with a sample interval of five minutes to enable the whole winter season to be monitored. This resulted in a relatively imprecise determination of durations for the winter months. There were several periods during the winter months where the temperature trace showed little or no sign of the eruptions. In performing the analysis described below, careful visual examination of the temperature curve considering the characteristic shape of eruptive episodes in warmer temperatures revealed faint traces of the eruptions. A likely cause of the poor recording is ice formation in the pauses between eruptions with a sufficient thickness to prevent complete melting by the runoff water when an eruption did eventually occur.

The percent of the interval during which a geyser is actually in eruption is a measure of the total energy and water escaping from the system. For Fountain Geyser, the average percent of the interval spent in eruption was 7.14% for 2000 and 7.27% for 2001. The percent of time in eruption is plotted along with the intervals in Figure 2 and Figure 3. The apparent reduction of time spent in eruption in April and May of 2001 is probably due to the short durations derived from the logger data during that time. The low recorded water temperature and great difficulty in determining eruption start and stop times during this period make the durations and percent of time active suspect for these months.

Duration-Interval Relationship

It is the case with many geysers that there is a strong relationship between the duration of an eruption and the following interval. For the short time for which data is available before the November 2000 wild phase activity, there did appear to be such a correlation. After eruptions resumed in late November, and for all of 2001, there appeared to be no correlation (R^2 = 0.0006). Examination of the data sets showed that the data following the wild phase in November 2000 was skewed by two factors: (1) durations computed from the winter data (sampled at 5 minutes) did not allow sufficiently accurate determination of intervals, and (2) the durations and intervals surrounding instances of wild phase activity represent a separate population of events. Excluding the data with 5 minute sample rate and the eruptions around the wild phases, there was a similar relationship between the duration of an eruption and the following interval. The slope of both regression lines, that is, the amount of interval for each minute of duration, was similar (9.36 before the change, and 8.22 after). The interesting difference was that the intercept, that is, the interval increment, was just over 45 minutes.

Change in Activity after Wild Phase

A summary of the eruption statistics before and after the wild phase activity in October–November 2000 is shown in the chart to the right. The decrease in both intervals and durations is clear from all of the statistics. The maxima reflect the wild phase long intervals. Because of the frequent episodes of short interval activity following the long wild phase in 2000, the coefficient of variation increased by 10% for 2001 compared to 2000.

The summary excludes the winter durations when the sampling interval was 5 minutes, and excludes some of the events around wild phases. This is shown by the difference in the numbers of durations and intervals. The summary shows that the intervals dropped substantially after the change at the time of the extended wild phase activity in October and November of 2000. The mean interval decreased by 2:06:02 and the median interval by 2:13:27. The durations also decreased by about nine minutes.

Summary

The use of electronic data loggers allows a complete record of geyser activity, not subject to observer availability. The record from August of 2000 to the end of 2001 was broken by several weeks when the data logger memory filled, but otherwise represents a complete record of eruption starts. The durations cannot be determined accurately from the winter data sampled at 5 minute intervals, but there does not appear to be a discernable difference in durations during the winter based on the less-precise determinations.

The record clearly shows a marked change in both interval and duration following an extended wild phase in October–November 2000. During 2001 a pattern of short intervals (in the three hour range) every few days emerged. Occasional wild phase activity occurred throughout the monitoring period, but only the extended wild phase in 2000 resulted in (or was coincident with) a large change in geyser behavior.

Intervals	Before Change	After Change
Eruptions	245	1620
Minimum	3:40:00	0:50:00
Mean	7:24:14	5:18:12
Median	7:27:30	5:14:03
Maximum	11:22:30	29:04:00
Std. Dev.	1:25:08	1:50:49
Coef. Of Var.	19.2%	34.8%
Durations		
Eruptions	152	868
Minimum	0:22:00	0:03:12
Mean	0:31:26	0:22:32
Median	0:31:30	0:22:24
Maximum	0:40:00	0:41:36
% in eruption	7.13%	7.30%

Norris Geyser Basin in 1974

A Summary of Geyser and Disturbance Activity

by T. Scott Bryan

all photographs by the author

Abstract

The summer season of 1974 was among the most remarkable ever experienced at the Norris Geyser Basin. Most features with any record of previous activity played that year, often with great frequency, and a few features never previously known as geysers also underwent eruptive activity. Many details about this action were recorded by the naturalist staff in the handwritten logbook that was maintained at the Norris Museum. In fact, so intense was the geyser activity that many things that would be taken as extremely remarkable in later years were *not* recorded in 1974, because then it was ordinary. It is highly unfortunate that the Norris logbook of 1974 was misplaced for more than two decades before being located and made available during 1998. Here, then, is information about a special year that, until now, has gone largely unrecognized.

Introduction

The photograph above shows a scene that was quite common during the 1974 summer season at the Norris Geyser Basin. Ledge Geyser is in full eruption in the center foreground; behind it are Africa Geyser (center) and Little Whirligig Geyser (left). On other occasions it might have been possible to take a similar picture showing these geysers playing in concert with Whirligig Geyser, Constant Geyser, Fireball Geyser and Arsenic Geyser (and perhaps many more). Geyser action was fully as vigorous and unusual in the Back Basin as it was in the Porcelain Basin, and a few unprecedented eruptions were recorded in the 100 Springs Plain area as well.

The naturalist staff that season consisted of George Algard (area supervisor), Butch Bach, Scott Bryan, Duane Cape and Jim Jones. Cleanliness and maintenance— and much "unofficial" interpretation— was performed by Fred Longino. At that time, Norris was administered as part of Yellowstone's West District, whose District Naturalist was John Stockert. Interpretive Specialist Bill Lewis and Chief Naturalist Al Mebane made frequent visits. All of the above people (plus a few "unknowns") made entries in or contributed to the Norris Museum logbook.

In the following pages, the thermal activity of 1974 is treated in three sections: 1) individual hot springs, taken in alphabetical order by sub–basin; 2) disturbance events; and 3) other points of interest. As long as this report is, it is not all–inclusive.

Hot Spring Descriptions, Back Basin

Arch Steam Vent — Although prominent runoff channels prove a rather vigorous prehistory, eruptive activity by Arch Steam Vent has been rare at best during recorded times. Note that Whittlesey [1988] describes this only as "a steamvent." The four eruptions recorded during 1974 probably represent its historic best. The eruptions took place on June 7, June 18, between June 30 and July 2, and on August 15. The use of markers made certain that no eruptions were missed between June 7 and September 24.

Of these eruptions, only that at about 1615 on June 7 was witnessed— barely. I was walking toward Echinus Geyser on interpretive duties when I saw a billowing steam cloud to the south across the Back Basin. However, only after the 1633 eruption by Echinus was I able to investigate and see that Arch had in fact been in eruption. The runoff channel was wet and still warm at 1650, and weak puffs of steam emanated from Arch's hillside vent.

The evidence is that these eruptions sprayed fairly large volumes of water at about a 20° angle away from the hillside. The spray was hot enough to kill the foliage in the top parts of nearby trees within the aim of the eruptions (this can still be seen), and the volume was sufficient to wash the sign log into the trees several tens of feet away from where it was placed at the base of the hill.

I guess I can 'sort–of' claim to have seen an eruption, but since my view was impeded by trees and apparently no other known reporter has ever seen Arch erupt, it is impossible to say how far these eruptions reached up and out from the hillside, or what their durations were.

Cistern Spring — Cistern was adversely affected by the basinwide disturbance of August 14. On August 19, Bach wrote: "Either Cistern is overflowing less H_2O, or the structure of the terraces is directing it in a different manner, as many of the terraces are now dry." By the next day it was clear that the flow volume had indeed decreased, and this condition persisted for several days. Interestingly, though, there is no mention of Cistern in the logbook after August 21.

Emerald Spring — As has been the case in more recent years, Emerald Spring was affected by the disturbances of 1974, including the minor "Emerald-Steamboat-Echinus 'Zap'" of July 14. On that date over the course of a few minutes when Bach recorded "odd behavior" by Echinus Geyser (exceptionally long overflow, abrupt start and short duration), the water of Emerald Spring turned murky gray as it vigorously boiled up to 5 feet high. A short while later the surface water temperature was found to be 199°F, and the fact that it was superheated was recorded in the logbook. A

Boiling in Emerald Spring following the disturbance of August 14, 1974.

similar change in appearance took place with the basinwide disturbance of August 14. On both occasions, Emerald required several days to return to more–or–less normal activity. Because of the September development of "Emerald's Springs" (below), Emerald Spring's water did not fully clear until after the geyser basin closed for the season.

"Emerald's Springs" — If any one event of the 1974 season stands out in my mind, it was the development of "Emerald's Springs" starting on September 14, by which date Algard and myself were the only remaining staff members. I noted temperature measurements and prepared a map of these springs in a report. Unfortunately, that report is not part of the logbook, and its present location (if it still exists) is unknown. Therefore, brief logbook notes and my memory must suffice.

At 1100, Emerald was clear and appeared as usual (slight bubbling). However, an hour later as I returned from Echinus Geyser I noted the water to be murky. By 1230 it was described as "filthy brown" and at 1340 came the first notice of the new springs: "and new springs have broken out on slopes NE, N and NW of Emerald. Total flow several gallons per minute." And finally at 1740, "Emerald Spring area going crazy. Will write it up."

Previously active in the 1930s and briefly in 1971 (and never again since early 1975), these springs created the shallow depressions located on the slopes leading toward Emerald Spring's crater. These are now difficult to discern, and some even contain young pine trees. But at their peak development, these springs numbered as many as 15 and discharged as much as 50 gallons of *clear* water per minute. Several played as geysers. The eruptions reached as much as 10 feet high from some vents. This activity persisted for several days before it began to decline very gradually. At least two of the springs were still active in 1975.

Muddy Sneaker Complex — The Muddy Sneaker Complex was named by Park Geologist Rick Hutchinson in about 1971 when a new mud pot formed in the middle of the trail below Blue Mud Spring. In short order, several additional muddy springs made their debuts. In 1974, a number of new mud pots of significant size developed in this complex. Two were given informal names.

"Duane's Delight" in a less active mood, following the spectacular activity of late August, 1974.

"Duane's Delight" (after naturalist Duane Cape, who first reported its development) was the larger of the two. In time, it formed a crater fully 10 feet in diameter and, late in the season, threw clots of viscous mud as far as 20 feet into the air.

The other, "Fearless Fred's Muddy Sneaker" (also known as "Freddie's M.S.," after maintenance worker Fred Longino) was a creation of the August 14 disturbance. When first seen it was described by Algard as "...~3 ft. across, throwing rocks and putting out large amounts of water laden with gray clay." It gradually grew larger and more violent, peaking around August 23 when I wrote: "Fred's M.S. — very thick mud, thrown to 20' up and ~50" out!! All go see." Activity then decreased so that by September 4

"Fearless Fred's Muddy Sneaker," shown on September 3, 1974 after its major activity.

Cape wrote: "not too active today or yesterday. No mud being thrown above surface."

"Butch Geyser" — This small geyser, more recently called "Orby," was named not after Butch Bach but after another Butch who had worked at Norris in previous years. The geyser was active throughout the 1974 season, but was a very small, near–perpetual spouter until the August 14 disturbance. On August 15, Algard wrote: "...is now comprised of a pool ~8' in diameter, instead of the old uncovered spouter. Now erupts through the pool." The logbook gives no statistics, but I recall that the intervals were much shorter than the durations, which were several minutes long, and that the height reached perhaps 6 feet.

"Butch Geyser" (more recently known as "Orby" or "Orbicular Geyser") following the August 14 disturbance.

Palpitator Spring — It was during 1974 that Palpitator was first recognized to undergo true geyser eruptions. The first tentative suggestion of this was on June 27, when Bach wrote: "dried up @1730. From the appearance around the feature—wet rocks, damp, etc.— it may have erupted???" Subsequent observations, usually days apart, found the crater damp but drained on many occasions. Interestingly, though, apparently no eruption was ever actually witnessed during 1974.

"Rubble Geyser" — The crater of Rubble Geyser developed during 1972, when it initially was referred to as "Centennial Geyser." It was active to some extent throughout the 1974 season but was at its best following the August 14 disturbance. On the morning of August 16 it was observed to play about 10 feet high with discharge great enough to flood the trail leading toward Palpitator Spring.

Steamboat Geyser — Steamboat did not play during 1974; indeed, its minor activity was very weak at best and often essentially nonexistent. Dr. Donald E. White, of the USGS, visited Norris on June 18. I accompanied him around the basin as he used a weighted thermocouple to measure temperatures and depths in several features. Among these was Steamboat, whose southeast vent was probed to a depth of 85 feet; the highest temperature, 234°F, was recorded at just 70 feet. I clearly recall standing next to that amazingly huge opening with nary a concern about being sprayed.

Hot Spring Descriptions, Porcelain Basin

Africa Geyser — Africa Geyser was first known to play during 1971, when eruptions as much as 45 feet high rose from a previously inactive crater. The activity persisted with a high degree of regularity into 1973, when the geyser began occasional regressions into steady steam phase action.

In early 1974, Africa was essentially in perpetual steam phase, and the logbook notes that it began taking "complete siestas" on June 16. Note that it

Africa Geyser in steam phase, accompanied by Fireball Geyser (left, at the end of the rainbow), in August 1974.

was on that same day that eruptions were first recorded for Constant, no doubt indicating a rather direct subsurface relationship between those features.

Africa did have occasional water phase eruptions, but they tended to be weak and brief interruptions of steam phases. At times, such as August 14, the steam emission was so violent that the roaring could easily be heard from the Back Basin in the vicinity of Echinus. I also recall that we could hear Africa from the Norris housing area, through the forest well east of the main highway.

An eruption by Basin Geyser's secondary vent, lower left. The pool of Basin itself is to the right while steam rises from Ledge Geyser in the upper background.

Basin Geyser — Basin Geyser occupies a large, oval crater heavily lined with sinter, immediately over the knoll from Jetsam Pool and Ledge Geyser. Basin has had episodes of eruptions, including 1974 when there were occasional splashes from the pool.

However, the more significant action of 1974 was, perhaps, not really from Basin itself but from a secondary vent at the southeast edge of the crater. This vent was frequently active, sometimes playing for many hours (even days?) without pause. Although I do not recall for sure, I believe this activity ceased at the time of the August 14 disturbance.

Bear Den Geyser — Bear Den was never a very reliable performer during 1974. Its activity was often cyclic, several eruptions being observed in the course of a few hours but then no more for a day or so. Even when in–series, the eruptions were never predictable. Notable, perhaps, is the logbook notation of an interval of only 40 minutes on July 19. Nearly all recorded eruptions were seen from the Museum, and I never obtained a single photograph showing Bear Den in eruption.

"Christmas Geyser" — This small geyser jetted water at a sharp angle to the northeast out of a crack–like vent along the edge of one of Porcelain Basin's main runoff channels, not far from Africa and Constant Geysers. The informal name was given because of the color combination of green runoff water algae and orange–red iron oxide mineralization surrounding the vent. Christmas (later, Paperiello's "1V Geyser") certainly existed prior to the August 14 disturbance, and in fact it probably had some small eruptions before that dramatic day. However, with the disturbance, Christmas entered a period of violent steam eruptions. Some of the spray reached several feet high and landed at least 10 feet outward from the vent. On August 16, my hand–held thermometer registered 197°F within the vent.

"Christmas Geyser," August 15, 1974.

Congress Pool — Congress Pool provided some of the most dramatic changes of 1974. It began the season as a blue pool of semi–clear water that stood nearly to the rim of its large crater. The first time a change was noted was on July 14— a date for which there is other evidence of a minor disturbance—

Congress Pool erupting on September 6, 1974.

when my personal note (not in the logbook) stated that the pool was murky gray and "boiling." Four days later, Duane Cape wrote in the logbook: "Heavy boiling; murky–gray; Slight overflow. Ave[rage] temperature 203.5°F."

No further notes about Congress Pool entered the logbook until the time of the August 14 disturbance. It serves well, I believe, to give a series of "daily" logbook quotations:

August 14: "Boiling vigorously, dark gray, slight overflow."

August 15: "violent surging, H_2O down ~6", no o'flow."

August 23: "water level now down ~18", heavy surging"

August 24: "H_2O now down ~2' "

And so it went. The farther the water level dropped, the more violent became the surging and splashing of the muddy water in the pool. Gradually, Congress Pool grew hotter and became a truly periodic geyser.

August 29: "H_2O level down about 3 vertical feet."

August 30: "now 201°F"

September 1: "down ~3 1/2 feet, some heavy boiling."

September 5: "Has dropped another foot— down therefore about 4 1/2 feet— boiling vigorously up to 3 ft. every few seconds."

By September 6, Congress Pool had become a significant geyser. I spent one hour that afternoon making time observations. The average of 24 intervals was 41.3 seconds; the average of 21 durations was 135.6 seconds. Individual eruptions ranged between 4 and 10 feet high above the pool level (so to about eye level when standing on the trail).

The water level continued to drop until September 9, by which time the eruptions were described as "sudden and massive." I recall that washed areas surrounding the crater implied that still stronger eruptions took place on the night of September 9–10. Then the water level began to recover. As it rose, in an inverse of the previous weeks, the eruptive activity declined. Congress was "back to normal", full and quiet by September 21.

Constant Geyser, Little Whirligig Geyser and Whirligig Geyser — It is well to consider these three geysers at once, since they and their activity are closely tied to one another.

The season opened with Little Whirligig being the active member of this complex. As had been the case in previous years, it played as a near–per-

Little Whirligig Geyser in July 1974.

petual spouter, pauses in its action being infrequent and brief.

The 1974 logbook contains no mention of any of these geysers until late on June 16, a few hours later on the same date when Africa Geyser was noted as taking "a complete siesta." The logbook entry I wrote late on the 16th reads as follows:

"1800 Closing up shop — visitors reported Constant Geyser erupted at ~3:15 and 4:25. I saw an eruption at 5:50 – intervals of 70 and 85 minutes" [Note: emphasis in the original; at that time, Algard and therefore all of us often recorded times using a 12–hour clock.]

By the following day (June 17), the logbook began to contain frequent records of eruptions by Constant, some up to 30 feet high and some in short–interval series of eruptions. Then on June 18, Butch Bach wrote the following, which is the first record of (Big) Whirligig in 1974 and, I believe, the first in several years:

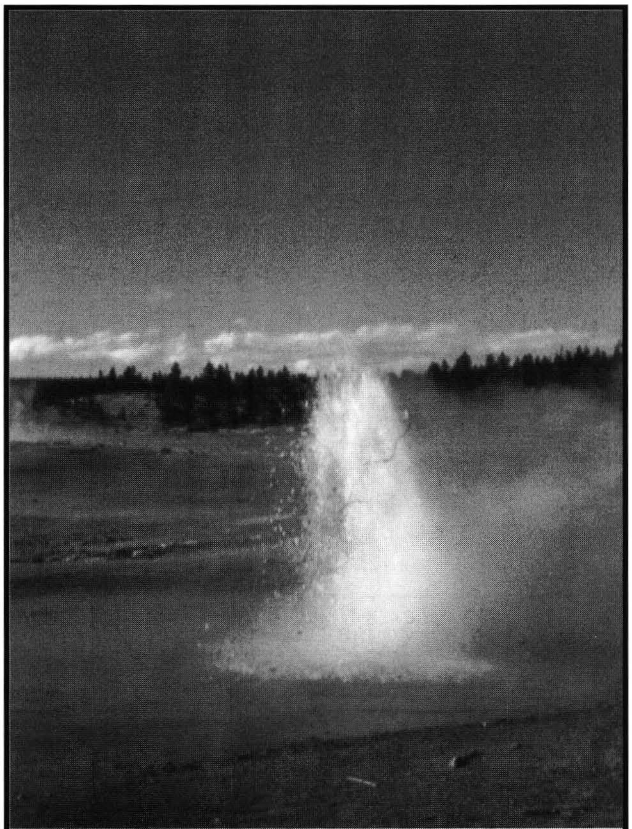
"1800 — Just before leaving I noticed weird happenings down @ L & B Whirligig. Both were in eruption simultaneously & Little had drained quite a bit so that the red–orange colors were really vivid due to the iron oxides being bared. Big's eruption consisted of a grayish–milky water while Little's was still clear. Both continued in eruption together for about 30 minutes until I left. A mean thunderstorm caught about 20 people out there. Will be interesting to see what transpires @ B & L Whirligig tomorrow![...] Just as I'm leaving I realize that L & B Whirligig are both 'dead' and drained and Constant is erupting to about 5'."

"2100 — Strolled over this evening for a curiosity visit — L & B was [*sic*] quiet — then @ 2130 Big erupted and has been going at it for 15 min. Little W still quiet. Africa is not overflowing like it was before — the outline of the vent can be clearly seen." (Note that I can find no earlier logbook comment about Africa's overflow.)

Somewhat later on the 18th, I visited the basin and recorded:

"2230 — Big Whirligig in eruption, ended at 2241. L Whirligig erupting throughout. Constant quiet."

It quickly became apparent that an exchange of function was in progress here. Whereas Little



Little Whirligig Geyser as it appeared in 1970, when its activity was nearly perpetual.

Whirligig had been active nearly without pause, irregularity kicked in when Constant rejuvenated on the 16th. Then, with eruptions by Whirligig beginning on the 18th, Little Whirligig began having complete cessations, falling quiet during and shortly after eruptions by Whirligig. It then played on short intervals until about the time of Whirligig's next eruption. Some of these eruptions had explosive starts, jets of water reaching as much as 40 feet high and arching outward to and across the boardwalk (positioned then about where it is today). By June 21 we recognized that this cyclic action repeated on intervals of approximately 2 hours. The recorded start times for Whirligig on June 23 supported this: 0903, 1118, 1302, 1459 and 1644.

On July 6, I wrote:

"Whirligigs — Neat things continue — Big has just (at 1640) completed a third 5–minute eruption w/out any intervening eruptions of Constant or Little W. Intervals about 18 & 22 min between Big's eruptions. Water level in Little rises till

(Big) Whirligig Geyser, July 1974. Note the angled "rooster–tail" vent jetting to the right of the bursting main vent. It produced a chugging sound easily heard from the Museum building.

eruption seems inevitable, then is sucked back as Big starts..."

With this, the observed activity consisted only of Whirligig and Constant on most days. When Little Whirligig did erupt, the play was uniformly brief and weak, and most of its attempts at play were failures.

This activity continued until the time of the August 14 disturbance. On that morning we found the crater of Little Whirligig to be dry but coated with gray clay. Whirligig was erupting muddy water and, as noted in the logbook, "became muddier as the day progressed..." Constant played frequently, and in the late afternoon Algard wrote:

"Constant — Late P.M. Began having eruptions every minute— some 30–40 ft. (counted 17 in a row) Was very, very muddy — was bone dry at 5:50 pm (completely drained)"

Little Whirligig was not seen on that day. Indeed, on the 16th I wrote:

"Little W — cold & dry. New channel from Constant leads into LW."

Constant continued having series of eruptions at intervals of about 1 minute (as many as 20 recorded on August 19). The activity then began to gradually decline until the following was recorded on August 25:

"Constant — 1053, single weak eruption, brought up murky light–gray water/ 1 burst @1330."

"Whirligigs — Little and Big had simultaneous eruptions, both started and stopped at virtually the same instant ~1425–1433. First eruption of Little in about 12 days."

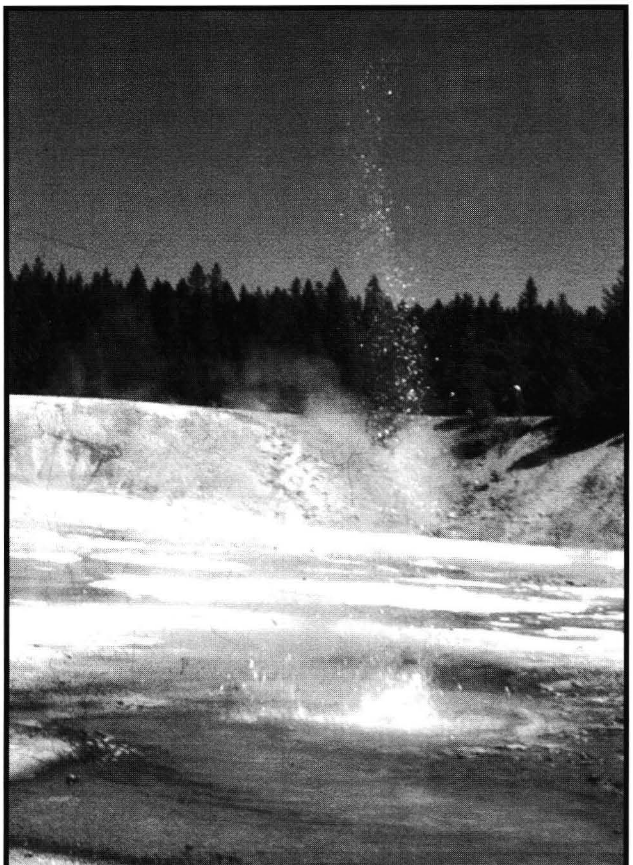
Not until September did Little Whirligig recover to be seen several times per day. However, Whirligig maintained its frequency through the remainder of the 1974 season whereas Constant did not. It is my belief, from this and from the observations of later years, that Constant may be the key member of this complex, its activity or lack thereof controlling the related features.

Ebony Geyser — In 1974, even though it was already graced with a sign noting its demise due to vandalism, Ebony was active. In fact, no fewer than 21 eruptions are positively known to have occurred. On some of those occasions the action was unquestionably part of a series, so that the true number of 1974 eruptions is considerably greater than 21. This activity is summarized in Table I, which speaks more than any narrative could.

Although I personally witnessed several of these eruptions, this is another geyser that I was never privileged to photograph. In general, prior to an eruption, the crater would fill and spill out of the rim of the central vent so as to form a small pool. Usually, perhaps always, this pool did not overflow prior to the eruption. It was only the most vigorous activity that caused any significant discharge during eruption, and most play lasted only a few seconds (though one recorded duration was of 3 minutes).

There is evidence that Ebony is but one in a series of craters that have developed progressively from west to east, each new opening supplanting the activity of the previous. In this theory, Ebony's activity was replaced by that of Bear Den Geyser. Unfortunately, the demise of Bear Den without any new development nor a return to activity in Ebony argues against this idea. In any case, it is believed that Ebony's eruptions of 1974 were its last to date.

Feisty Geyser — Feisty played from the flat area below the Porcelain Terrace springs, where new geyserite is deposited at a furious rate. It is probable that it no longer exists, its vent having been buried years ago. This entry is primarily in historic support of the photograph.



Feisty Geyser erupted from a small, symmetrical crater on the floor of Porcelain Basin below Porcelain Terrace.

In its time, Feisty was one of Norris' finest geysers. The activity was frequent and quite regular, most eruptions lasting several minutes and jetting as high as 25 feet. Several other eruptive vents lay near Feisty, at least one of which reached over 10 feet high.

"Geezer Geyser" — A number of people through the years have contended that Geezer Geyser never existed, that it was instead Fireball, or Arsenic, or a part of the Lava Pool Complex, or something else. It existed. Recall that all these other geysers were also active during 1974, so there was no confusing this hole with another. Its location, eventually found by Rocco Paperiello, is also distinct from the others.

Geezer had been named in 1973, when it appeared on a map produced by Hodapp. It was occasionally active through much of the 1974 season, but the eruptions were so minor in size that there is no logbook entry about it until September 21. That afternoon I reported "An interesting sequence of events out in Porcelain..." starting at 1320, when I noted that heavy discharge from Geezer was visible from Ledge. Five minutes later Geezer was playing as high as 35 feet. The force gradually declined, but the geyser was still playing 10 feet high a half hour later, and this eruption (apparently) did not end until 1440. During that 75-minute duration, Geezer was joined by eruptions in Arsenic, Lava Pool, Africa and Fireball. At the bottom of the page, I added: "The eruption of Geezer Geyser was a cone type — a steady column of water ~1' in diameter. Really impressive."

The next day, September 22, another logbook entry reads:

"Geezer Geyser — doing it again — started ~1615. At 1620, (right to left) Geezer, Arsenic, Fireball, Africa and LW [Little Whirligig] all going at once."

Both of those eruptions were witnessed only by myself and visitors (Algard was on his lieu days and the rest of the staff had terminated their seasons), but the third (and last) recorded major eruption was seen by both Algard and me. This time, I wrote:

"Geezer — is this really Arsenic, except now to 25–30'? ie 1030." Algard appended that with an

"Geezer Geyser" (right foreground) underwent a few powerful eruptions during September 1974, often accompanied by Africa Geyser (left center)

Special Photography Note: Readers familiar with the Norris Geyser Basin will realize that many of the photographis in this article were taken from off-trail locations. All were taken by the author while on work duty and wearing his National Park Service ranger uniform.

"I think so." The thought at the time must have been that this could be Arsenic, in which case the geyser reported as Arsenic would have been something else. Now it is firmly established that that is not the case— Geezer is a valid name for a geyser that I have not seen play since 1974.

Ledge Geyser, here shown during an eruption in 1971.

Harding Geyser — Harding Geyser was named in 1923 in honor of the visit to Yellowstone by the President, although he probably did not see it erupt. This name is one of the four officially approved thermal names in Yellowstone that violate the rule against naming hot springs for people.

Harding is also one of the great rarities among geysers. While its early record of activity is not known, Harding definitely did play in 1966, 1967, 1974, 1975, 1980 and 1981. It is likely that 1974 has been its best year, with 7 or 8 eruptions on record (Table II).

Harding has two vents. One plays almost vertically while the other arches southward toward the access trail between the parking lot and the Museum. The eruptions of June 14 and August 4 both reached 50 or more feet high, so that the angled column almost reached the trail. All the eruptions had durations of 5 to 6 minutes. Most if not all included a brief pause in the middle of the water phase, during which the jetting stopped completely. The eruptions were ended by an initially–powerful but rather brief steam phase. Harding can be a very spectacular geyser.

Markers were kept on Harding throughout the 1974 season, so it is certain that no eruptions were missed. (One nighttime eruption was unseen. Also, on May 27 there may have been an eruption; Jones recorded that the missing marker was probably washed out by rain, but the later record of activity makes an eruption probable.)

In light of the use of markers, it is interesting that the logbook contains *absolutely* no mention of Harding after its eruption on August 4. I do have the memory recollection that Harding was thoroughly "zapped" by the August 14 disturbance. But still... the logbook was maintained until October 2.

Ledge Geyser — Oh, what a story in Ledge. I believe that Ledge underwent more eruptions during the 1974 season than in any other year, before or since. Its complete record of activity is given in Table III, within which there are many logbook narratives plus bracketed 1998 comments.

It is certain that at no other time has Ledge been so regular that predictions were posted at the Museum. Its force of play may have been matched in 1926, but in 1974 it repeatedly threw its massive water column diagonally to a distance of more than 200 feet.

When the season opened, Ledge was observed on intervals of roughly 24 to 26 hours and, based on the activity of the previous years, it was believed that those were the true intervals. However, after being seen on nine consecutive days and generally progressively later on each of those days, Ledge was not observed on June 1. Then it played the next morning. Jones, still the only naturalist on duty at Norris, wrote: "...so much for the periodicity of geysers." What he felt at the time was a long single interval was undoubtedly a triple interval of 38h 41m. It didn't take long to confirm this. On June 9–10 we recorded consecutive closed intervals of 13h 18m and 13h 55m and, two days later, another of just 12h 26m.

Through June, Ledge's average interval was only about 13 hours long. (The actual average of the closed intervals is 13h 08m; I believe that to include inferences would give an average of less than 13 hours.) The shortest closed interval of the month was 12h 26m; the longest was 13h 55m.

On June 30, I wrote in the logbook:

"New geyser? between Ledge and Valentine... (Harvey's Hot Pot?) appears to have erupted during night, dirty H_2O in Ledge's sinter pools. At 0900 was discharging ~1 gpm Temp 191° very muddy H_2O from a low vent on NW, H_2O flowing into Ledge. Main crater water high and violently boiling. 1012 — now full and bubbling slightly."

"Harvey's Hot Pot" continued its activity, and its runoff into Ledge. And immediately, Ledge's intervals became significantly longer, the closed interval of July 6 being 15h 24m. As of that date, the first nine closed intervals of July gave an average interval of 13h 42m.

Although change was underway, it was at about that time that we began predicting Ledge, using 14 hours as the basis. We were free to adjust the posted time, especially since we grew adept at judging the eruption time on the basis of the water level in the "Pressure Pool."

The Pressure Pool, also known as the "Little Finger" (not a very apropos name), is probably the "Mud Geyser" of Haynes, circa 1910. As the time of an eruption neared, surging and splashing in the Main Vent became more frequent and vigorous, and jetting in the small "Finger Vents" between the Main Vent ("The Thumb") and the Pressure Pool grew stronger and steadier. In conjunction with this, the water level rose steadily higher in the Pressure Pool. I clearly recall being able to tell people that the eruption would start within, say, 5 minutes based entirely on this water level. These on–site predictions were highly accurate.

Ledge Geyser in eruption, July 1974. This view looks northward so that the main vent is to the far upper left. The large jet in the lower right foreground is from the Pressure Pool. The Finger Vents are between the two.

Eruptions began with a sudden and tremendous surge of water out of the Main Vent. This was accompanied by Pressure Pool bursts sometimes estimated to be 60 feet high, and violent jetting as tall as 30 feet in the Finger Vents. Meanwhile, the sharply–angled column shooting from the Main Vent often took several minutes to reach full force, and it was at about that time that the play in both the Pressure Pool and Finger Vents died down or quit entirely. The Pressure Pool, especially, seldom played for longer than 10 minutes while the Main Vent water phase maintained its full force for at least 20 minutes before very gradually waning. The water phase duration was sometimes as long as 1 1/2 hours, and the total duration until the end of a distinct steam phase was often in excess of 2 hours.

A number of times during July 1974, Ledge had minor ("aborted") eruptions. Only twice, however, were these events accurately recorded. One had a duration of 14 minutes, the other 16 minutes. On each occasion the eruption appeared completely normal until it abruptly ceased *totally*. The resulting minor intervals were 4h 32m and 5h 20m. At least one additional minor was witnessed and reported by a visitor; it apparently produced a minor interval of only about 3 hours.

Many of Ledge's 1974 eruptions were exceptionally powerful. Out on the open flat of Porcelain Basin below Ledge was a dead tree snag. By actual steel tape measurement, that snag was 186 feet from Ledge's Main Vent. Knowing that made it easy to estimate that the water was frequently thrown as far as 206 feet when there was no wind, and to distances as great as 168 feet into the wind.

Ledge maintained its "14–hour" July intervals through August 13, when it seemed normal in every way. But on the morning of August 14, the day of the Basin–wide disturbance, Ledge was found to be in heavy steam phase. It was still in the same steam phase the next day. And although jets of water began to reappear by August 18, Ledge's only remaining eruptions of the 1974 season took place on September 4, September 5 (probable), September 13 and October 2.

"Norris Geyser" and "Green Apple Cider Spring"— These two features are necessarily dealt with together, as they lay immediately adjacent to one another and showed similar activity. Both erupted out of large, open craters whose jagged edges bore signs of explosive creations. And it is likely that neither now exists as an identifiable feature, having been filled in and buried (at least mostly so) by sinter deposits from Porcelain Terrace runoff.

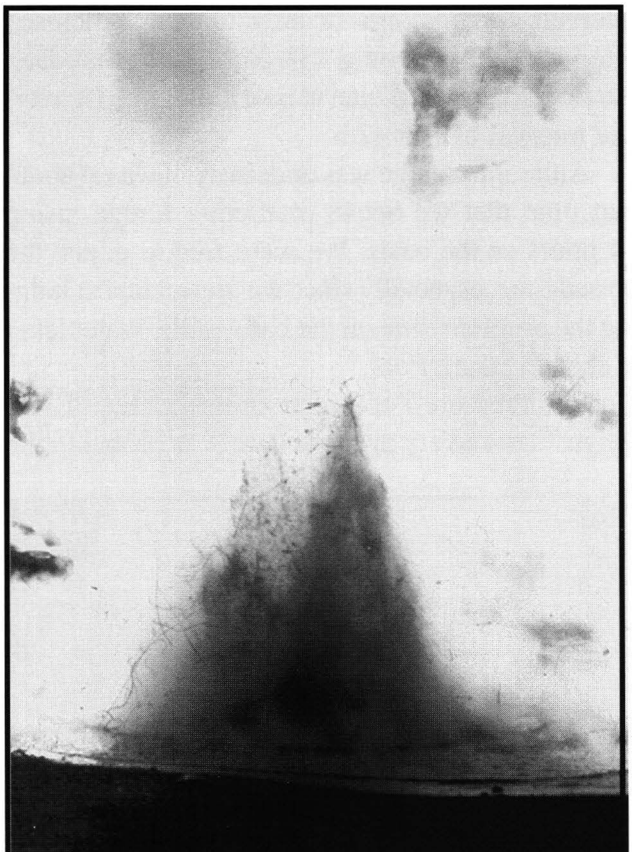
Of the two, "Norris Geyser" was the more active. Although this name appears to be in violation of the "rule" against naming thermal features after real people, that is not factually the case. Rather, it was given in allusion to the oft–asked visitor question: "Where is this Norris Geyser?" Perhaps this was partly generated by at least one highway direction sign that temporarily read: "Norris Geyser's Basin" (note the apostrophe).

Norris was most active after the disturbance of August 14. On August 19, a logbook entry by Jones states that it was "...erupting very muddy water to 30'." (I corrected Jones' original entry identifying this as Ragged [Spouter], commenting that this was "...not Ragged Spouter. This is ~50' W of Green Apple Cider. Norris G.." Though it isn't in the logbook, I recall these eruptions as being as wide as they were high— that is, 30 feet by 30 feet.

The following day Norris was noted the have its water down about 1 1/2 feet, "...very muddy, boiling vigorously. in eruption at 1155; also i.e. at 1530 (just starting?)."

By August 23, the water had cleared but was low and boiling, and on the 24th I wrote that Norris was "full and overflowing, but not erupting." The logbook contains no further entries about Norris Geyser.

Green Apple Cider Spring (different from the historic Apple Green Geyser) was substantially less active than was the adjacent Norris Geyser, but like Norris it was most active for a few days following the August 14 disturbance. When it played, the eruptions were similar in their bursting form but not as high, the largest splashes reaching perhaps 15 feet high.



Pinto Geyser erupting muddy water on August 15, 1974.

Pinto Geyser— During 1974, Pinto was not known to erupt until the time of the disturbance on August 14, when it became one of the first logbook entries of the day (at 0950). It had fairly frequent and vigorous eruptions during that entire episode, with intervals as short as just over an hour, durations of several minutes, and jetting heights as tall as 30 feet. At first the water was quite muddy, with a gray–white color, but the water was clear before the end of the activity.

Pinwheel Geyser — Pinwheel underwent irregular minor activity throughout the 1974 season, and is one of those cases where it failed to be entered into the logbook because of its frequency. For example, on July 18, Cape recorded temperatures of 184.5°F and 192.6°F in the "less active" and "most active" vents respectively. It was after the August 14 disturbance that Pinwheel was most active. Then the logbook contains records from August 15, 16, 17, 22 and 24 where Pinwheel is noted as playing as much as 6 to 8 feet high, often stopping immediately upon receiving runoff from springs elsewhere (such as Blue Geyser).

Somewhere near Pinwheel was another post–disturbance feature. On August 24: "Ferrous Wheel (good name, huh?) splashing to ~2'."

"Ramjet Springs" — The Ramjet Springs are a set of features that are mysterious to almost all observers. They were named, I think, in 1973 and were very active in early summer 1974. But the fact that almost nobody knows about them, not even their location, implies that those might be Ramjet's only years of historic activity.

The Ramjet Springs are located well up the hill to the northwest of Pinwheel Geyser, where there is a shallow runoff draw that drains down to cross the dirt path between Pinwheel and the Bear Den–Ebony area.

In June 1974 the activity of these springs was violent enough that the hissing of their steam emission could easily be heard from the Museum breezeway. On June 12, accompanied by (memory recall only) Bach and Jones, I measured the temperature within several vents and recorded them in the logbook: "NW, jetting = 201°F; NE vent, w/ bacteria = 192°; central vent, w/ small cones = 202°; SE, jetting = 198 °; SW, slight bubbling = 194°".

Both of those "jetting" vents sprayed very steamy water at low angles. I recall that one of them (probably the SE vent) played outward not less than 10 feet where it simply ran into the slope of the opposite side of the draw. Note that two of these vents acted as geysers while they were active.

The only additional logbook entry about Ramjet Springs was penned on August 18, when Bach wrote: "Almost dried up— only a trickle present with most terraces dry."

Intriguing: mentions of cones and of terraces. These can be important springs and they certainly have had significant action in their past. Unfortunately, here is another case where I *know* that I produced a map and written report about the activity. I hope that document will someday be found in the YNP Archives.

Valentine Geyser — I don't seem to recall much about Valentine's activity prior to 1974— I don't possess any photographs of it except from that season. However, the first logbook entries by Jones

Valentine Geyser on June 29, 1974. This eruption is shown reaching a height of not less than 50 feet; the geyserite cone was about 6 feet tall. Note the black square near the bottom center of the photo—one of the concrete bases for the old 1920–era enameled name signs.

do not indicate any surprise about its being active, so it must have been so at least during 1973.

Before the end of 1974, though, Valentine would prove itself to be predictable, something that evidently has never occurred before or since.

The complete logbook record of Valentine's eruptions is given in Table IV. It is an erratic record, to be sure, but in time we were able to infer a lot of information from it, and to make accurate predictions.

There is no question that many eruptions were missed because of their weak and brief natures. In more recent times, these eruptions might well be classed as minor versus major. The minors sometimes had water phase durations as short as 10 *seconds* and almost no steam phase. By contrast, the best eruptions of the season had water phases as long as 20 minutes, heights of about 60 feet, and significant terminating steam phases.

It was with this knowledge that, on the basis of the recorded times we had, I calculated an average interval for July of 6h 58m. A look at Table IV might make this value seem questionable. However, from then until the time of the August 14 disturbance (only two weeks, unfortunately) we made publicly–posted predictions that were highly accurate. We never knew what sort of eruption we'd see, but we knew when we'd see something.

As was the case with nearby Ledge Geyser, Valentine was severely affected by the disturbance of August 14. Only three additional eruptions were seen in the 41 days until my departure on September 24.

Hot Spring Descriptions, 100 Springs Plain (and beyond)

Unnamed "Tantalus Geyser" — This geyser, under this informal name, predates by many years the use of "Tantalus" for the old "Decker (Island) Geyser" near Echinus. It erupted from a small vent within the braided channels of Tantalus Creek near Cinder Pool. In mid–summer 1974 it was distinctly periodic, although the durations were very much longer than intervals that typically lasted only a few seconds. The jetting play reached as much as 8 feet high. When I last visited this site (in 1999) the water within the vent was pulsing but there was no evidence of recent eruptions.

Unnamed "Breach Geyser" — I vaguely recall using the name "Breach" for this geyser, whose *only* known eruptions took place during 1974. The name is fitting, as the geyser plays from a ragged, open fissure within a rocky outcrop that is surrounded by typical Norris–style sulfate–rich decomposed gravel. The location is just under 400 feet north of Cinder Pool, at position B3–650E–720S on the USGS thermal map of the Norris Area.

I temper this by noting that none of the eruptions were witnessed. They were known on the basis of extensive washed areas and, later, from markers that were checked a few times per week.

From the wash, the evidence was that the eruptions jetted water in the northward, upslope direction, some of the spray falling at least 30 feet from the rift. To do this, the play must have been at least as high as the lateral throw. Much heavier wash occurred closer to the vent, and there was runoff downslope to the south. The discharge channels were limited in extent, indicating that the eruptions were quite brief; I guess their durations at less than 1 minute.

I have visited this feature numerous times since 1974. Water is often heard churning at depth and sometimes a bit of fine spray reaches the surface, but I've seen no evidence of an eruption since 1974.

Unnamed Geysers NW of Norris — The unnamed thermal area about two miles west–northwest of the Norris Museum used to contain at least two significant geysers. We would see the large steam clouds from the Museum and sometimes they were reported on the Park radio by the Mt. Holmes fire lookout ranger. On August 23, 1974, Bach wrote in the logbook: "0800 — The summer's nearing its conclusion & we still don't know the origin of those 2 sizeable steam clouds out to the west, ~2 miles from here. Really steaming this AM." More recently we have tentatively identified the site of one of these geysers as being a rift–like opening in the bank of the stream near the middle of the area. The site of the other remains unknown.

Fireball Geyser (showing its fan–like shape), shown when it was nearly perpetual during the disturbance of August 1974.

The Thermal Disturbances of 1974

In *The Geology and Remarkable Thermal Activity of Norris Geyser Basin, Yellowstone National Park, Wyoming* (U.S. Geological Survey Professional Paper 1456), published in 1988, authors D.E. White, R.A. Hutchinson and T.E.C. Keith include as Table 8 a list of information about the "widespread disturbances" known to have affected the Norris Basin. (The authors also refer to the disturbances as "widespread contemporaneous changes.") This table was probably compiled by Hutchinson, a man intimately familiar with Norris, so it is extremely puzzing to see the statement in the table: "Effects of disturbance included turbidity, water and gas discharge, but details not recorded."

That statement is nonsense, for the 1974 staff maintained a detailed logbook throughout the season. In any case, no report about the 1974 season at Norris would be complete without a separate account of the thermal disturbances that were observed that summer. Here is a brief summary of those observations, concentrating on the Basin–wide disturbance that began on August 14.

There is evidence that Norris was hit by at least two minor disturbances earlier in the year. The first took place on June 17–19. The 17th was the day when Constant Geyser began erupting. By the next day it was joined in activity by (Big) Whirligig, a "New small spouter blew out with a bang and a big steam cloud" below Dark Cavern Geyser and, in the Back Basin, Arch Steam Vent washed away its marker. It was on that day that Bach wrote in the logbook about the "weird happenings" among Constant and the Whirligigs.

The second minor disturbance was on July 14. It was characterized by a "strange eruption" by Echinus, as described by Bach. It was preceded by an unusually long preliminary overflow of 21 minutes before "it exploded into an immediate eruption — no preplay, the initial bursts were the most impressive," and it had a short duration of less than 3 minutes. On his return toward the Museum, Bach found Emerald Spring boiling up as high as 5 feet; it later proved to be slightly superheated at 199ºF. These observations might be more akin to the "Echinus–Steamboat–Emerald Zap" of more recent years.

There were numerous other dates on which a number of unusual eruptions were observed in select portions of the geyser basin, and these, too, might have been minor, localized disturbances. There is no question, however, but that the significant event was The Disturbance of August 14.

A look at the logbook record for August 13 shows nothing unusual. In fact, it contains fewer entries than most dates. But upon our arrival on August 14 we immediately began to see unusual events. Either because of new or changed eruptive activity and/or muddied water, we recorded action in Emerald Spring, Vermilion Springs, Colloidal Pool, Blue Geyser, Congress Pool, Pinto Geyser, Africa Geyser, Gray Lakes, Green Dragon, "Fred's Mud Pot," Scummy Pool, Constant Geyser and Whirligig Geyser. Ledge had entered its heavy, billowing steam phase.

Late that afternoon, Algard wrote into the logbook: "Everything is extremely active & muddy today— the rain probably caused some of the muddy colors— but the activity indicates that something else may have occurred."

On August 15, the activity list grew with the additions of Arch Steam Vent, "Butch Geyser," Sunday Geyser, Pinto Geyser, Sand Spring, Fan Geyser, Colloidal Pool, Pinwheel Geyser, and "someone give it a name" [this was probably "Duane's Delight"].

*14 Aug. 1974

Echinus: 8:22, ↙3 10:21, 11:23, 12:26, 1325, 2:27, 3:23, 4:26, 5:27

Emerald Spring: Boiling very vigourously, almost in eruption state, water slightly cloudy, 0810.

Vermilion Springs: Cloudy grey.

Colloidal Pool: Very cloudy grey, boiling vigourously.

Blue Geyser: cloudy grey.

Congress Pool: Boiling [redacted] vigourously, dark grey, slight overflow.

Pinto Geyser 9:00 - In eruption - 10-15 ft - almost constantly (stopped 10:15) 5:30pm

Bear Den - 12:46

see next page Constant - 10:32, 10:38, 11:56 (weak), 12:50 (weak), 2:09 2:12, 2:13 4:32,

Africa - Primarily in a steam phase this A.M. + P.M.

Ledge - In heavy steam phase (billowing)

* Everything is extremely active & muddy today - the rain probably caused some of the muddy colors - but the activity indicates that something else may have occurred. Steamy Pool boiling up to 2 ft.

(over)

A (scanned) photocopy of the original Norris Museum logbook page for August 14, 1974, the day on which the large–scale, Basin–wide disturbance began.

In addition to all these features, numerous geysers that had previously existed erupted with greater frequency. As many as several dozen small muddy spouters appeared in Porcelain Basin on the open flat between Pinwheel and Blue Geysers, any number of vents below Porcelain Terrace began erupting, and there was violent boiling in several Back Basin features such as Mud Spring, Mystic Spring, Dishwater Spring, and so on. *All* of Norris Geyser Basin was involved.

All this action maintained itself for several days and then only gradually declined. The change was perhaps most noticeable in the volume of runoff in Tantalus Creek (from both sub–basins), which by about August 23 had been reduced to barely a trickle. Still, some unusual activity remained in evidence well into September. The entire event, as a distinctly observable process, probably lasted about three weeks.

Hardly had the big disturbance concluded when there was one more minor disturbance, starting on September 13. "Harvey's Hot Pot," a muddy opening on the slope above Ledge Geyser, erupted during the night, covering much of the area around Ledge with thick mud. Later that day we also observed frequent eruptions by "Hodie's Hole" (now Dabble Geyser) and a new muddy hole opened in the Muddy Sneaker Complex. Finally, it was the next day that the numerous "Emerald's Springs" broke out.

Dark Cavern Geyser in June 1974

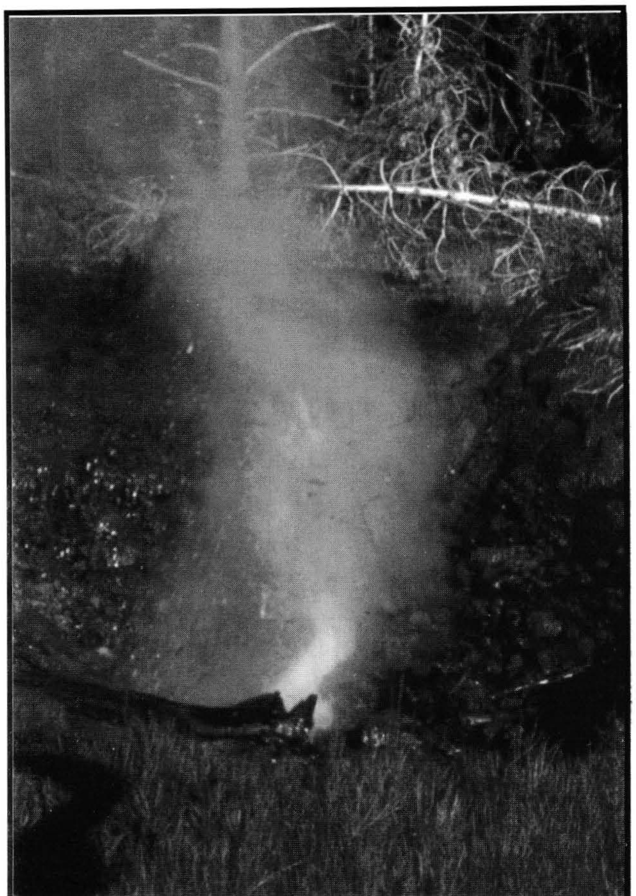
A Few Other Notable Events in 1974

The Elk Incident of June 3 — I checked in for duty on June 2, so this was my first on–duty day at Norris. Starting at about 1600, we first dealt with a dog running loose in Elk Park. Then, around 1700, a visitor reported a grizzly on the road toward *Madison*. But when Jim Jones followed the people to the location, it turned out to be **nine** miles toward *Canyon*... and, of course, it was a black bear. Just after that, an elk calf got separated from its mother by the road and a huge crowd of people. The poor calf was completely surrounded by visitors so, finally, Jones picked the animal up and carried it into the woods across the highway. No sooner was that accomplished when some people drove up with the five–year–old gushing blood from his head, having fallen somewhere. They were directed to Mammoth, where a doctor was still on duty in the clinic. Finally, as Jones tried to start the fuel oil furnace in the house, he broke a plug and then a feeder line, drenching everyone. No heat.

Ranger Off Trail — Some will appreciate this. On August 27, Algard wrote: "Another of our great season's end comments— 'The ranger should not be allowed to step off the walk because he sets a bad example— (Comment made while Duane was trying to talk to about 40 people in Porcelain Basin).' "

Earthquakes — A number of earthquakes were felt that summer, but they became notable on August 30. At 1042 there was a tremor that lasted fully 8 seconds, and others were felt at 1142 and 1335, and at 0007 the next day. It turned out that the main shock was of magnitude 3.5 to 4 (only), centered near Hebgen Lake.

Then, on September 1, there were more quakes, and these were local. Rick Hutchinson called and asked that we record them. We tried, but I penciled into the logbook that we "can't keep count." The times written were: "0930, 0932, 1016, 1020, 1025, 1028, 1029, 1033 (3 sec), 1036 (4 sec), 1053, 1115, 1118, 1124 (1 sec), 1213, 1326, 1346 (strongest yet– 3 sec), 1509 (very good), 1524," [abrupt end of log].



Big Alcove Geyser, shown in this paper simply because few people have the opportunity to see it.

The blue salt deposits — Sometime early in the season we noticed a bluish coloration to some of the gravel behind Congress Pool. As the season progressed, this developed into efflorescences of rich azure blue in several discrete patches. Later, the same deposit also appeared on the floor of Porcelain Basin near Feisty Geyser.

On September 14, I collected a number of samples intent on chemical analysis. At that time I expected to be returning to the University of Montana in pursuit of my Ph.D. That didn't happen. I eventually did conduct a qualitative analysis. It revealed only iron as a significant metal. This material was very different from the more normal sulfate salts that are deposited in acid environments. Perhaps it was some oddball mixture of such minerals, but I've long wondered if I didn't really have a new mineral, "norrisite."

The call from Death Valley — As it turned out, I didn't return to the University of Montana. Instead, on September 20, I received a phone call from the Mining Engineer in Death Valley offering a job as a mining geologist. I took it, of course, and departed from Norris on September 24. I did not work in Yellowstone the next summer, though I was in the Park for about six weeks. All my seasonal positions after that were at Old Faithful. But no two ways about it— the summer of 1974 at Norris was a season never to be forgotten.

References

Virtually all of this paper is based on the hand written logbook maintained by the 1974 naturalist staff of the Norris Museum. The original is in the Archives of Yellowstone National Park. This report is based on a photocopy provided (at my cost) by Lee Whittlesey. There are also a very few cases where I was able to refer to sparse personal notes still on hand from that summer.

Minor points of history and recent naming conventions were double–checked against Lee Whittlesey's *Wonderland Nomenclature* [1988] and Rocco Paperiello's *Report on the Norris Geyser Basin for 1984*, both of which are available from The GOSA Store.

About the "Individual Geyser Activity Logs," Tables I – IV, plus "Geysers Known Active in 1974," Table V

The following pages contain the complete eruptive records for Ebony, Harding, Ledge and Valentine Geysers in 1974, as extracted directly from the Norris Museum logbook. Data has been neither added nor deleted, but is shown here as recorded. Some questionable activity is noted as such. Written information in the "Logbook Comments" column is quoted directly out of the logbook. Deletions or continuations are noted by ellipses (...). Each quote is appended with the author's initials within brackets (such as "[TSB]"). I have also added a few personal recollections out of memory.

Table V summarizes the 67 features known to have been active as true geysers during 1974. A table similar to this appeared in Volume I of *The GOSA Transactions,* where it accompanied a one–page article about the August 14 disturbance written without the benefit of the logbook. Some of the statements in that paper must be revised.

Table I
Individual Geyser Activity Log
EBONY GEYSER in 1974

Date	Time	Interval	Height (ft)	Logbook Comments
5/25/74	1616	——	3	Small (15 ft. dia.) basin filled, held for 20 sec, then drained [JJ] Est. duration 15 seconds
5/26/74	——	<18h		1023 – Ebony marker gone [JJ]
6/14/74	——	——		Marker gone, replaced [DC]
6/17/74	——	——		0835 – Ebony [marker] ok [TSB] ~1100 – had 4' pool [FL] 1135 – Ebony drained and quiet no evidence of recent Bear Den eruption. [TSB] 1238 – gurgling and 2' below rim [GA]
	1600	? >3 days		Ebony, minor eruption. [TSB]
6/19/74	——	~1 1/2 days		marker gone, replaced @0850 [GA]
7/7/74	0914		4	In eruption from pool, no discharge. Marker washed out [sometime previous to this eruption], replaced. [TSB]
	1438	6h 24m		Again at 1438 for 3 min dur. [TSB]
7/9/74	0928 vr	1d 18h 50m	10	Recorded from Museum [by TSB] as Bear Den, later visitor report confirmed to be Ebony
7/13/74	0909	?	10	Slight overflow [TSB]
	0947	36m	10	Slight overflow [TSB]
7/14/74	~0945	~24h		my marker [of 7/13] in place, so no major eruption [TSB]
7/19/74	? 1110	? 5d 01h 25m and 40m, *or* 5d 02h 05m		[Possibly no eruption. Cape wrote: "Vent of Ebony nearly filled and splashed over & drained before Bear Den's eruption." Then a note by
	1150			Algard: "1150 – eruption."
7/20/74	?	?		[Ebony] washed out markers placed on Tuesday, 7/16 [TSB; marker might have been washed on 7/19]

7/23/74	0924	<3d 22h 14m		"... and some sweet soul threw a 9" rock into Ebony's crater." [TSB]
7/24/74	(no eruption)			"... and the rock was lost— it rolled and fell down in." [TSB]
7/25/74	~1100	~2d 2 1/2h		Marker found washed out at 1110, warm water around crater [TSB]
8/3/74	~1120	~9 days	4	Al (Mebane, Chief Naturalist) reported a 4' eruption. [GA]
8/4/74	1334	1d 02h 14m	6	duration ~2 minutes [TSB]
8/10/74	1133	5d 21h 59m		Seen from museum. duration ~4 min [TSB]
8/12/74	1415	2d 02h 42m		[simple time entry by GA]
8/16/74	1042	3d 19h 57m		[TSB] (note this occurred during 8/14 disturbance)
9/8/74	0927	22d 23h 15m		[simple time entry by TSB]

no additional eruptions occurred through September 24, 1974.

Table II
Individual Geyser Activity Log
HARDING GEYSER in 1974

Date	Time	Interval	Logbook Comments
5/22/74	1441 ie		Water running over alcove above Ledge found to be Harding in eruption! Brown muddy water going 10 to 12 ft. at 45º–60º angles from north and south vents. 1448 — Water ended and steam began. 1456 — heavy steam phase over [JJ]
5/27/74	?	? 4 1/2 days ?	0900 — Harding [marker] washed away (by rain it looks like) [JJ] [1998 comment, based on later activity, probably due to eruption, not rain]
5/29/74	no eruption		0900 Harding ... bubbling up to lip of vent [JJ] [1998 comment, I inserted this note to show that Harding refilled and resumed bubbling/boiling within one, at the most, two days of an eruption.]
5/30/74	2155	~3d, or ~8d 07h	Harding erupted – 3 min heavy water (unseen for heavy steam), pause, 3 min lighter water – 10–12 ft. muddy, 2 vents. Heaviest water may have gone 20 ft. Light sporadic for 1 min, then steam. [JJ]

6/6/74	~1730 [?]	~6d 20h	1752 — Harding has changed to no water, only steam. [JJ] [1998 comment, since Harding typically took as little as one day to show water after an eruption, this statement implies an eruption, even though none is recorded as such.]
6/7/74	no eruption		0905 — Harding has water present. [GA] [1998 comment, I insert this information to show again the one day (or less) recovery as evidence for an eruption on 6/6/74.]
6/11/74	~1700	~5 days	2018 — at naturalists training in Mammoth [all day] — Harding erupted per marker. [TSB]
6/12/74	no eruption		0809 — Harding about 1/2 full of water. It erupted at least once on 11 June, probably between 1600 and 1800. [TSB]
6/14/74	1545	~2d 22h	Harding Geyser erupted! Water was very muddy– threw rocks and debris– some bursts went above the trees (40–50 ft. total). Initial eruption lasted 5 min– choked for 20 sec and then erupted 3 more min; steam phase began at 1555. [GA]
7/4/74			2200 — marker OK. [TSB] [1998 comment, the use of markers, which were reliable, showed that these are true intervals.]
7/5/74	overnight	~20 1/2 days	0815 — Harding marker gone, reset ... no H_2O present [BB]
8/4/74	0845	~30 1/4 days	A beautiful eruption @0845 to the tops of trees– lasted 5 minutes– in steam phase @0850. Water clear this time– no muddy or milky. Estimate highest spurts @50–55 ft. [BB]

End of logbook record.

Table III
Individual Geyser Activity Log
LEDGE GEYSER in 1974

Date	Time	Interval	Logbook Comments
5/23/74	~1103		... 30 ft. bursts from E. vent ... Continued bursts from E. vent. Main column (NW vent) ~70 ft. No sound of rocks thumping in E. vent as last summer– could explain the bursts. [JJ]
5/24/74	1319 ie	~26h	[1998 comment, though not recognized until June 10, these intervals in excess of 24 hours were undoubtedly all double intervals.]
5/25/74	1306 ie	~24h	
5/26/74	1600 ie	~26h	late (1–1 1/2 hrs into) eruption [JJ]
5/27/74	1507	~24h	Major eruption, main vent to 90'. Still steady water at 1539, to 30'–40'. [JJ]
5/28/74	1558	24h 51m	[1998 comment, again noted as a double interval]
5/29/74	1630 ie	~24 1/2h	early in eruption [JJ]
5/30/74	1747	~25h	
5/31/74	1847	25h 00m	
6/1/74	no eruption seen		[1998 comment, probably occurred in evening. Note that Jim Jones was the only naturalist on staff until June 2, 1974.
6/2/74	0928		Ledge in major eruption– so much for the periodicity of geysers. [JJ]
6/3/74	early daylight		0900 — already erupted [TSB] [1998 comment, for whatever reason, Ledge was not again recorded until 6/6/74.]
6/6/74	1350 ie		late in eruption [TSB]
6/7/74	1500	26h 30m	First time I've seen the beginning of an eruption — fantastic! [TSB]
6/8/74	1715	26h 15m	
6/9/74	1827	25h 12m	... Truely [*sic*] stupendous. [TSB]
6/10/74	0820	13h 18m	Ledge in eruption! Is it really on a 12–13 hour interval instead of 25? [TSB]
	2015	13h 55m	Ledge again. [BB] [1998 comment, this was the clincher, and within only a few days (just when was not recorded) we began public predictions.]

6/11/74	——		at naturalists training all day
	2018	24h 03m/2	
6/12/74	0844	12h 26m	Have predicted next eruption for 2115 ± 1 hour [TSB]
	no report!		
6/13/74	1130 ie	26h 46m/2	
6/14/74	1330 ie	~26h/2	[1998 comment, logbook has this entered as 0130 (by GA), but it is placed between other entries at 1130 and 1545.]
6/15/74	1508	25h 38m/2	
6/16/74	1710	26h 02m/2	
6/17/74	~0700		ie at 0810 [note: the progress of eruptions was easy to judge as they were *very* regular]
6/18/74	0923	~26h 20m/2	
	2247	13h 24m	
6/19/74	1143	12h 56m	
6/20/74	——		marker gone, reset @0920 [GA]
	1357	26h 14m/2	
6/21/74	1503	25h 07m/2	
6/22/74	0900 ie		very late steam phase [TSB]
	1613	25h 10m/2	
6/23/74	0900 ie	~14h	ending; probably erupted 0600–0700 [TSB]
6/24/74	0943	~25h/2	
	2249	13h 06m	
6/25/74	1143	12h 54m	
6/26/74	1159	24h 16m/2	
6/27/74	1200 noon	24h 01m/2	**Super!** [GA; written in heavy, bold print with a huge exclamation point.] 10–4 [JJ]
6/28/74	1302	25h 02m/2	Very large (~75') bursts from SE vent [TSB]
6/29/74	1513	26h11m/2	
6/30/74	1619	25h 06m/2	
7/1/74	2040	28h 21m/2	[1998 comment, note start of trend to longer intervals.]
7/2/74	0955	13h 55m	... pressure pool eruptions going 20–50 ft for the first 10 min... [GA]

7/3/74	1100	25h 05m/2	good eruption– pressure pool not quite as impressive as yesterday. [GA]
7/4/74	1314	26h 14m/2	
7/5/74	1714	26h 00m/2	
7/6/74	0838	15h 24m	... The old vent on the bank above the upper Ledge vent was very active this morning, discharging large amounts of water & boiling violently during Ledge's hot periods. At start of eruption all activity in this vent ceased. Could this be the cause of the longer intervals? [TSB]
	2257	14h 19m	
7/7/74	1302	28h 24m/2	
7/8/74	1640	27h 38m/2	... indicator started at 1515 [GA]
7/9/74	~0700	~14h 20m	appears to have erupted ~7:00 A.M. [GA]
	2128	~14h 30m	
7/10/74	1145	14h 17m	
7/11/74	1628	28h 43m/2	Great — wind stopped just as main vent surged — ~10 ft. beyond dead snag — gigantic SE bursts. [GA]
7/12/74	0645	14h 17m	
	2015	13h 30m	
7/13/74	0939	13h 24m	Measured to 189', very light wind. Measured off our distances [using steel tape]. Snag is 186' from main vent. We have seen eruptions to: 202', 196', 181' (no wind); 155', 158', 168' (into wind). [TSB]
7/14/74	1326	27h 47m/2	... out to 206' [BB]
7/15/74	1645	27h 19m/2	excellent eruption — appeared once again to have gone beyond the dead snag... [GA]
7/16/74	0630-0700	~14h	[estimated time by GA without further comment]
7/17/74	1434	>31h/2 [!]	Indicator vents started 12:15–12:40. did no reach stumps due wind. — pressure pool eruptions, several to ~50 ft. [GA]
7/18/74	1745	27h 11m/2	Good eruption reaching out to near dead stumps. [DC]
7/19/74	~0630	~12h 45m	
	1945 vr	~13h 15m	
7/20/74	0830	~12h 45m	to ~180' [TSB]

7/21/74	1000	13h 30m	[1998 comment, eruption time recorded by BB, but then a start time of "~1045" entered by JJ. Very probably this indicates an aborted eruption. See next entry.]
7/22/74	1146	?	good eruption — Ledge stopped erupting completely only 14 minutes later @1200. No water, no splashing – almost no steam. What's happened?? [BB; underlining in original]
	1618	4h 32m minor	[1998 comment, first recorded aborted eruption and minor interval restart.]
7/23/74	~0630	~14h	
7/24/74	~0750	~25h 20m/2	eruption very strong at 0810 [TSB]
7/25/74	1043	~26h 53m/2	SE vent bursts to 75' [TSB]
	2345	13h 02m	[recorded by GA]
7/26/74	1445	15h 00m	good show; lasted only 16 min, so perhaps will go again @ about 7:15 p.m. [BB]
	2005 vr	5h 20m minor	regular eruption [GA, based on visitor report]
7/27/74	1314	17h 09m	good eruption [DC]
7/28/74	1851	29h 37m/2	
7/29/74	0910	14h 19m	not too impressive– mostly steam by 0930 [GA]
7/30/74	1551	30h 41m/2	impressive; tried to abort at ~10m and ~13m, then very powerful. [TSB]
7/31/74	~0600	~14h	[definitely occurred, was minor eruption]
	0905 vr	~3h minor	Visitor report confirmed
8/1/74	1119	26h 14m/2	SE good, main vent not even to logs. [GA]
8/2/74	1557	28h 38m/2	early burst to ~200' with the wind. SE vent 65–75'; tried to abort at ~15 min. [TSB]
8/3/74	0600-0630	~14 1/4h	based on 0800 steam [JJ]
8/4/74	1156	~29 1/2h	
8/5/74	1702	29h 06m/2	
8/6/74	~0715	~14h 10m	ie water at 0800 [GA]
8/7/74	1237	~29h 20m/2	good eruption [GA]
8/8/74	1644	28h 07m/2	
8/9/74	~0700	~14h 20m	ie water at 0800 [BB]
8/10/74	1255	~30h	good eruption [DC]

8/11/74	1737	28h 42m/2	nice [GA]
8/12/74	~0730	~14h	in eruption @0900, ~0730 [BB]
8/13/74	1103	27h 33m/2	
8/14/74	?		"In heavy steam phase (billowing)" was entered by GA, but there is no time of observation recorded! [1998 comment, Note that this was the date of the major basin–wide disturbance.]
8/15/74	[no eruption]		In heavy steam phase, still no H_2O visible [DC]
no further record until:			
8/18/74			throwing H_2O to ~30' at 1545 [TSB]
8/23/74			spouting water (considerable volume) to 30'–40' at 0925 [TSB]
8/29/74			Surges of H_2O coming from 1st finger & thumb vents almost continuously — no H_2O in pressure pool. [GA]
9/4/74			Spouting some H_2O from thumb & finger vents this P.M. [GA]
	1355	~21+ days	***Finally** in eruption at 1:55. Not as spectacular as most were this summer, but a good 100–125 ft. the first 10 min. Hopefully this means that Ledge has recovered and we will see it daily once again. [GA]
9/5/74	?	?? ~14h ??	Billowing steam this A.M. From the appearance of the runoff channels, Ledge may have had an eruption early this morning. [GA]
9/6/74			did not erupt last night. [TSB]
9/8/74			remains completely dry [TSB]
9/11/74			some H_2 Opresent this A.M. [GA]
9/13/74	~1014	~9 days	Commenced a minor eruption, max height ~50 feet. [TSB]
9/21/74			hardly any steam even [TSB]
9/22/74			sounds like the Ledge of old ... 1100 – beginning to have pre-play 1630 – still splashing, no build-up, no eruption [TSB]
9/23/74			1100 – acts like eruption is imminent, excellent strong preplay from all vents, but water low in SE vent and not(?) rising. 1400 – no change. [TSB]
9/24/74	yes		erupted sometime last night — [based on runoff

			channel] 'twas a good eruption. [TSB, who departed this afternoon for a winter job in Death Valley]
9/25/74	?		appears to have erupted again during the night [GA]
9/26/74			has water this A.M. and has apparently been splashing for some time ... the pressure pool is 1/2 full ... the interesting thing is that the water is crystal clear – no murkiness at all. I have not seen this before. [GA]
9/27/74			Very quiet this A.M. [GA]
9/28/74			Quiet — no water [GA]
9/29/74			Very quiet all day [GA]
9/30/74			Quiet again this A.M. — but every morning the sinter is wet on the upper shelf — since the marker is in place, one has to assume that the finger vents are becoming active ...[GA]
10/1/74			Pressure Pool is full of H_2O ... looks like the Ledge of old [GA]
10/2/74			No eruption during the nite — the pressure pool is still full & the finger vents still active — strange. [GA]
	1235	~19 days	Finally ... beautiful eruption.

10/3/74 — Norris Museum closed for 1974 season.

Table IV
Individual Geyser Activity Log
VALENTINE GEYSER in 1974

Date	Time	Interval	Height (ft)	Logbook Comments
5/22/74	1730 ies			Valentine in heavy steam [JJ]
5/24/74	1025–1800			Marker OK at 1025, reset at1808 [JJ]
5/25/74	1606 ies			... in steam phase [JJ]
5/26/74	1915 ies			... in heavy steam [JJ]
5/30/74	night			washed marker set at 1120 [JJ]
	1630	~12 hours		
6/2/74	?			marker replaced @1730 [JJ]
6/5/74	1800 iew	< 3 days ?		

6/6–7/74	night			marker replaced @1100 [TSB]
6/7–8/74	night			marker replaced @1115 [BB]
6/8–9/74	night 1928			marker replaced @1110 [simple time entry by TSB]
6/11/74	daytime			time of eruption unknown, staff at annual training in Mammoth
6/15/74	early daylight			based on wet runoff channel [DC]
6/16/74	1157			[TSB, took photos in alcove]
6/17/74	0810			
6/18/74	0947			
6/19/74	night			marker replaced @0930 [BB]
6/20/74	night			marker replaced @0920 [GA]
6/22/74	1426		50	... good eruption, to 50' in first 5 minutes [TSB]
6/23/74	0930 ies			
6/24/74	1640			...water phase lasted ~10 sec, then weak steam phase [TSB]
6/25/74	0936	16h 56m	50–60	... good eruption at start [TSB; since I recorded this interval, it must have been a closed interval]
6/26/74	?			(Logbook has name entry but only a dash where the time entry should be; written by Bach.)
6/28/74	~1120	? > 2 days		Very weak [TSB]
6/29/74	1318	? 26 hours	50	... to 50', took pictures [TSB; this includes the photo within the text of this report]
6/30/74	0910 1553	? 19h 52m 6h 43m	50	... quite good [TSB]
7/1/74	1540			Weak eruption [GA]
7/1 to 7/6 — no reports!				
7/6/74	0920 iew 2210	 12h 50m		Looked good from Sieve Lake [TSB]
7/7/74	0910	11h 00m		very weak and steamy [TSB]
7/10/74	0700 (est)			apparently a decent eruption judging from the runoff channel [GA]

7/13/74	0834		50	... water phase lasted ~7 min [TSB]
	1535	7h 01m		
7/16/74	1431			weak as usual [TSB]
7/17/74	1205	21h 34m		fairly good eruption [GA]
7/21/74	1608 iew			[GA]
7/23/74	1637			[TSB]
7/24/74	1325			[TSB]
7/25/74	0953			very weak [TSB]
	1738			quite strong but total dur ~10m [TSB]
7/26/74	1345			[BB]
7/27/74	1141		50	"... sickly — maybe 50 ft" [GA, a very interesting comment!]
7/28/74	1603			measly [GA]
7/30/74	~0830			[TSB]
	1528	~7 hours	50–60	... and very nice... [TSB]
7/31/74	1207			... the usual. This was the first predicted eruption this year. Was predicted for 1200 ± 30 min! Average interval for July = 6h 58m. [TSB; see text for comment on this figure]
8/1/74	~0800			... appears to have erupted ... right on schedule [TSB]
	1415	~6h 15m		"ditto" [TSB]
8/2/74	0945 ies			erupted 0930–0940 (est.) [GA]
	1601	~6h 26m		nice eruption, easily 60' [TSB]
8/4/74	0900 ies?			heavy steam phase @0900??? [BB]
	1312			[TSB]
8/6/74	1523			[TSB]
8/10/74	~0945			[TSB]
8/11/74	1330 ie late			[TSB]
8/13/74	0944			good eruption [TSB]
8/18/74	0838 ie			[TSB]
9/6/74	~0830	~19 days		probably erupted [TSB]
9/7/74	night			marker (placed 9/6) gone [no time given; TSB]

No further Valentine Geyser entries through September 24, 1974.

Table V

Geysers Known Active During 1974

The following is a list of those springs at the Norris Geyser Basin that were positively known to undergo *true* geyser activity during 1974. Asterisks (*) indicate geysers that were active only during the disturbance that began on August 14, 1974. This list does not include perpetual spouters nor any ephemeral features that were created by and active only during the disturbance. Not counting multiple vents, there are 67 features in the list; that there were additional active geysers in this year is certain but undocumented.

Porcelain Basin

Africa Geyser
Arsenic Geyser
Basin Geyser
Bear Den Geyser
Blue Geyser
Carnegie Drill Site
"Christmas Geyser"
Colloidal Pool*
Congress Pool
Constant Geyser
"Crackling Lake Geyser"
Dark Cavern Geyser
Ebony Geyser
Fan Geyser
Fireball Geyser
Feisty Geyser
"Geezer Geyser"*
"Glacial Melt Geyser"*
"Green Apple Cider Spring"*
Guardian Geyser
Harding Geyser
Iris Spring
"Junebug Geyser"
"Labial Geyser"*
Lava Pool Complex (several vents)
Ledge Geyser
Little Whirligig Geyser
"Norris Geyser"*
Onyx Spring
Pinto Geyser*
Pinwheel Geyser (minor; *major)
Primrose Spring
"Ramjet Springs" (two vents)
Splutter Pot
Valentine Geyser
Whirligig Geyser

Back Basin

Arch Steam Vent
Blue Alcove Spring
Blue Mud Spring*
Corporal Geyser
"Dabble (Hodie's Hole) Geyser"*
"Dog's Leg (Private Geyser) Spring"
Double Bulger
"Downfall Geyser"
Echinus Geyser
Emerald Spring
Firecracker Spring
Minute Geyser (minor)
Mud Spring*
Mushroom Spring
Mystic Spring
"Orby (Butch) Geyser"*
Palpitator Spring
Pearl Geyser
Perpetual Spouter
Porkchop Geyser
"Puff-n-Stuff Geyser"
"Rediscovered (Scotties' Spouter) Geyser"
"Rubble Geyser"
"Son of Green Dragon Spring"*
Steamboat Geyser (minor)
UNNG near Cistern Spring
UNNG "Emerald's Springs" (15 vents)
Veteran Geyser
Vixen Geyser

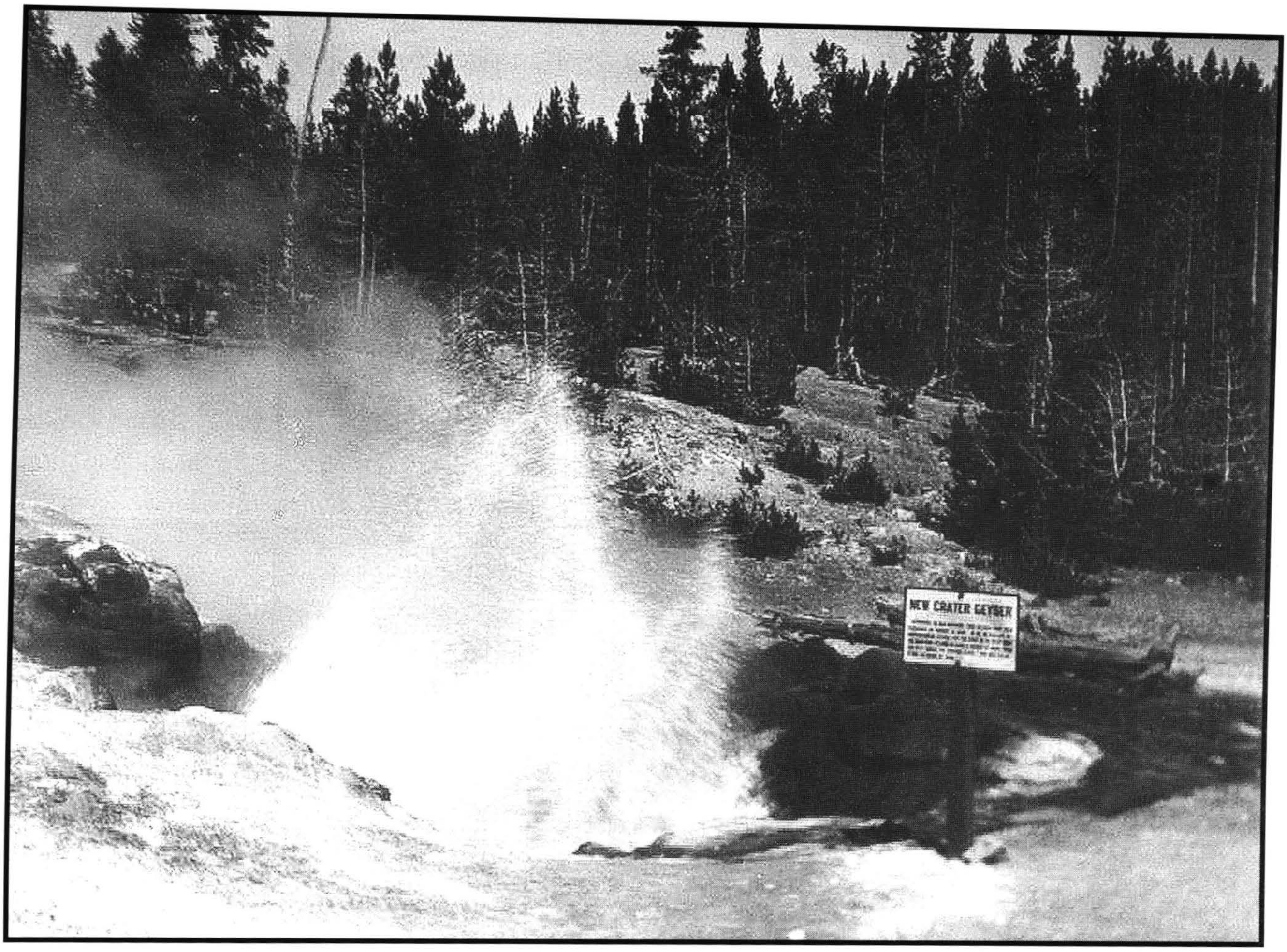
100 Springs Plain

UNNG "Breach Geyser"
UNNG "Tantalus Geyser"

NEW CRATER GEYSER

According to old records, this geyser came into existence on August 11, 1878. It is, in reality, a subterranean geyser for the vent is so deep that the eruption seldom attains a height of more than ten feet above the ground level. The red color is due to oxide of iron.

text (black lettering) on enameled interpretive sign



The picture above is a reproduction of a hand–tinted lantern slide in the personal collection of Scott Bryan. Its origin is a mystery. The slide bears the title "New Crater Geyser back of Norris Museum," but nothing more. A search for information was conducted during March–April, 2002. Contacted were Lee Whittlesey, Archivist for Yellowstone National Park, Jack Davis of Olde America Antiques in Bozeman, independent researcher Rocco Paperiello, and finally Gigette Gould, in the Photo Archives of the Montana Historical Society. None were able to identify the slide's origin. Ms. Gould's response is the most telling:

"I spent some extensive time researching your photograph of New Crater Geyser. I started by going through each one of our Haynes Lantern slides, trying to find a similar shot, but was unsuccessful. Then I researched the F.J. Haynes collection for photographs of this geyser. I noticed that all of his shots were taken from the other side of the geyser and the sign was never visible. I also checked the Jack Haynes collection—views from 1936 and 1953— his shots also were all taken from the opposite side of the geyser and did not show the sign. The last search involved going through our Yellowstone Postcard collection, once again nothing even remotely similar."

"Resurgent Geyser", Potts Hot Spring Basin, 1997-2001

by Ralph C. Taylor and James B. Grigg

Abstract

The authors have been studying the Potts Hot Spring Basin under the auspices of the National Park Service, initially in Resource Management and in the past three years with the Yellowstone Center for Resources. During this study, one medium–sized geyser, informally named "Resurgent Geyser," has been active each year. The initial vandalized condition, the repair of the damage, and the activity of Resurgent Geyser for the years 1997-2001 are discussed in this paper.

Introduction

Potts Hot Spring Basin is a small thermal area along the west shore of the West Thumb of Yellowstone Lake. This small thermal area has been closed to visitor use for many years, and there has been no systematic study of the area since a report by Wolf and Paperiello [1985] described the Potts Hot Spring Basin thermal features. The area is closed to all visitor use because of its fragile nature and the unstable ground found in many portions of the basin. During our survey of the area, we made frequent observations of activity, mapped much of the area, and produced a complete report describing our findings [Taylor and Grigg, 1999]. The present paper reproduces much of the material from that report that describes "Resurgent Geyser," and adds information gathered in 2000 and 2001.

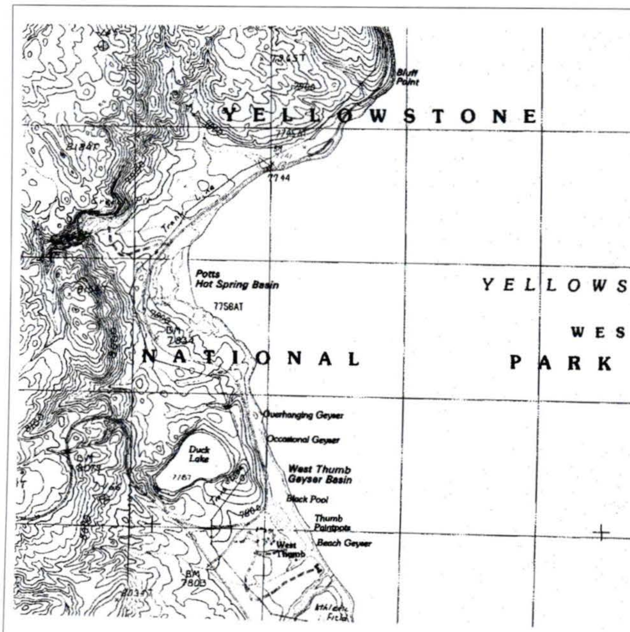


Figure 1– Map of West Thumb Geyser Basin and Potts Hot Spring Basin, from USGS West Thumb Quadrangle 7.5 Minute Series (Topographic), West Thumb, Wyoming Provisional Edition 1986 number 44110-D5-TF-024.

Location

Potts Hot Spring Basin is located about 1.8 kilometers (1.1 miles) north of West Thumb Geyser Basin, between the Grand Loop Road and the shore of the West Thumb of Yellowstone Lake. The map in Figure 1 is a section of the USGS West Thumb Quadrangle 7.5 Minute Series (Topographic), West Thumb, Wyoming Provisional Edition 1986 number 44110-D5-TF-024. All of Potts Hot Spring Basin is closed to visitor access, but the northern portion of the basin can be seen from a pullout along the road. The southern part of the thermal area, the "Empty Hole Group," cannot be seen from any point along the road. "Resurgent Geyser," the subject of this paper, is located in the "Empty Hole Group" and is consequently not visible from any publicly accessible viewpoint.

The thermal area of Potts Hot Spring Basin extends along the shore of Yellowstone Lake from a few hundred meters south of the mouth of Little Thumb Creek to the clearing containing the "Empty Hole Group," as shown in the map in Figure 2. The hatched pattern outlines the approximate extent of the thermal area. The thermal areas occur in clearings in the mixed conifer forest. Much of the area is sinter sand overlying geyserite sheets. The northwestern portion of the basin is a boggy area with hot pools and mud features in thick grasses and

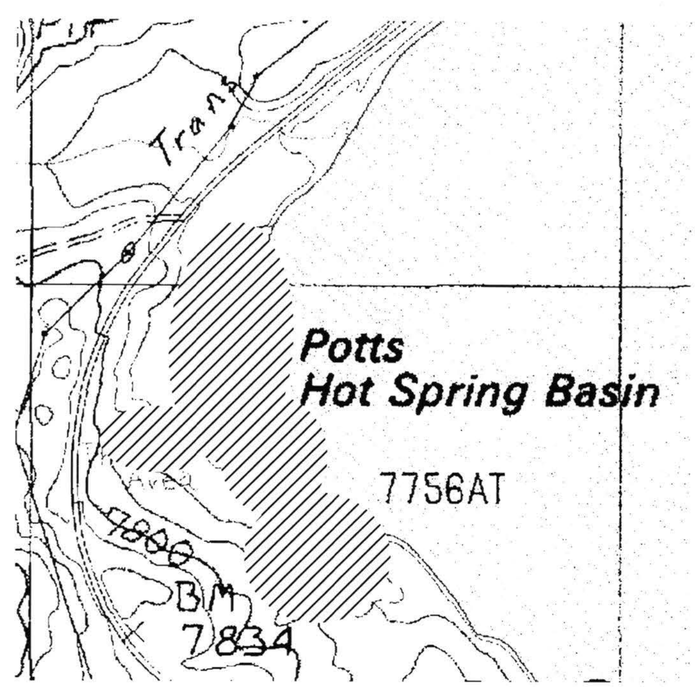


Figure 2 – An enlargement of the West Thumb Quadrangle topographic map. The Potts Hot Spring Basin is onshore, approximately within the area of the hatched pattern.

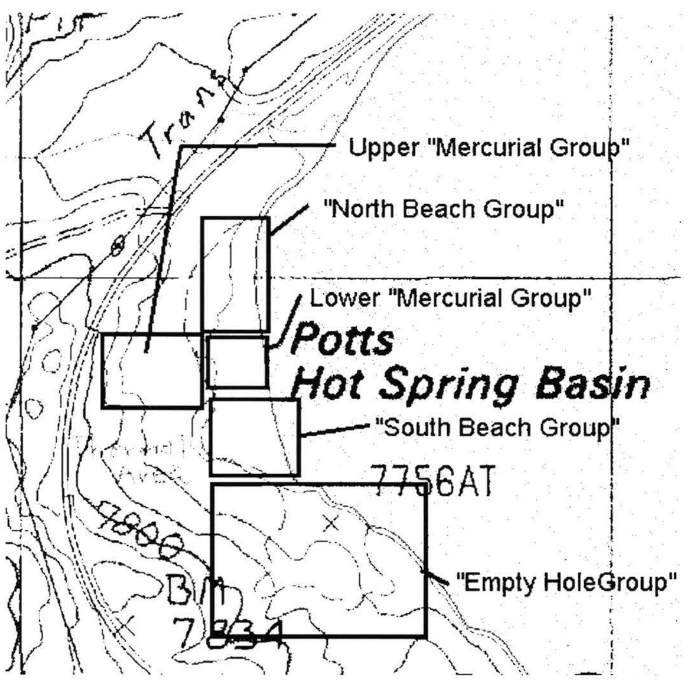


Figure 3 – Map of Potts Hot Spring Basin, showing the group names used in this report. "Resurgent Geyser" is within the "Empty Hole Group." [Editorial Note: the vertical and horizontal lines on this and Figure 2 are topographic section lines.]

sedges. In some parts of the basin, thin layers of geyserite overlie hot water and mud. Walking in these parts of the basin is dangerous, as the grass conceals deep, hot muddy pools. We did not survey these grassy regions, as the ground was too difficult to cross, and the features were mud–walled with little sinter and appeared to be short–lived.

Feature Groups in Potts Hot Spring Basin

We divided the Potts Hot Spring Basin into five groups of features. The divisions are somewhat arbitrary, but help in describing the area. The map in Figure 3 shows the approximate location of the groups. The "North Beach Group" is the northernmost extent of the thermal area. It is located along the shore of Yellowstone Lake near a large lagoon dammed by the old roadbed. The lower section of the "Mercurial Group" is to the south of the "North Beach Group," and contains several geysers and numerous large pools. These groups are separated by a stand of trees that extends nearly to the lakeshore. To the west of the lower section of the "Mercurial Group" is a raised flat geyserite region containing a few large pools and well over 100 small spouters and springs. We denoted this region as the upper section of the "Mercurial Group." To the south of the "Mercurial Group" along the lakeshore is the "South Beach Group," which consists of large hot springs and a few geysers on a flat plain only a meter or two above the lake level. During spring high water in many years, the lake covers some of this group. The fifth group is the "Empty Hole Group" located to the south of the "South Beach Group" on a raised mound consisting of many geyserite layers covered by sinter sand. This group is several meters above the "South Beach Group" in elevation.

"Resurgent Geyser"

The geyser that is the subject of this paper, "Resurgent Geyser," is located in the "Empty Hole Group" along the old Grand

Figure 4 - Geyser 9 EH, "Resurgent Geyser" (UNNG–POT–1 of Bryan [2001]), as we first saw it in September 1997. Author Taylor and Rocco Paperiello (in white shirt) are at right.

Loop Road roadbed. It was the largest frequent geyser in Potts Hot Spring Basin during our study in 1997 and continued to erupt with much the same frequency through 2001. It is also the only relatively large geyser that remained continuously active from our first visit in the fall of 1997 to the end of the summer season in 2001.

A Vandalized Geyser

We saw an eruption of "Resurgent Geyser" on our first visit to the Potts Hot Spring Basin in 1997. Rocco Paperiello accompanied us on that occasion and, based on his description and the description in the Wolf and Paperiello report [1985], we were expecting a large eruption, perhaps as high as 2 meters (7 feet). When the eruption started, there was an impressive amount of water discharged, but the height of the eruption was only 30 centimeters (12 inches) or so. Examination of the geyser formation revealed that a number of rocks had been jammed into the vent, 30 centimeters (12 inches) or so below the surface. These rocks had been fitted together in a way that almost completely blocked the vent. The careful fitting of the rocks made it clear that the blocking was intentional vandalism. Figure 5 shows the vent of "Resurgent Geyser" blocked by the rocks before our cleanup.

After discussing the situation with NPS personnel, we obtained permission to attempt to remove the rocks. On 9 September 1997 the authors removed the eight rocks with some difficulty, but with no apparent damage to the geyser vent. The difficulty in removing the rocks stemmed from the frequent minor eruptions, which occurred every minute and a half to two minutes and filled the crater with superheated water. This activity meant that we had only a few seconds to work, and it also kept the rocks quite warm. The eight rocks removed are shown in Figure 6, along with a two–way radio for scale. The radio is about 8 centimeters (3 inches) wide.

We did not see an eruption after removing the rocks that day, but placed markers in the runoff channel. The markers were washed when we returned on 11 September 1997, and again on 12 September 1997. We finally witnessed a major eruption on 16 September 1997, and were gratified to see that the eruption reached fully 2 meters (7 feet) in height.

Physical Description

The formation of "Resurgent Geyser" consists of a round sinter mound with a prominent circular opening whose axis tilted about 15 degrees from the vertical toward the southwest. The vent itself was about 30 centimeters (12 inches) in diameter at the top of the cone, and 18 by 30 centimeters

Figure 5 - The vent of "Resurgent Geyser" in 1997 showing the rocks lodged deep in the opening.

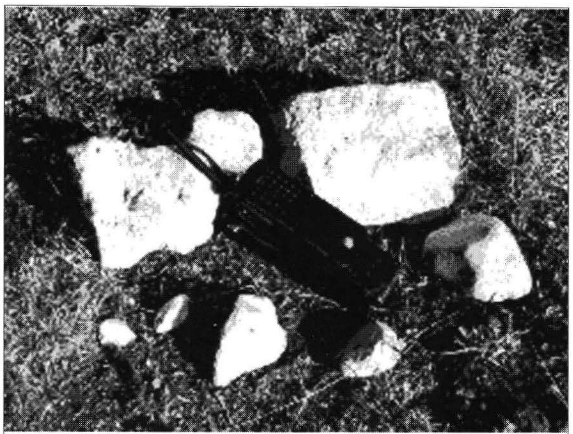


Figure 6 – Rocks removed from "Resurgent Geyser." The 'CB' radio is about 8cm (3 inches) wide.

(7 by 12 inches) at the bottom of the external opening. The cone is approximately 100 centimeters (40 inches) in diameter and about 20 centimeters (8 inches) tall, and is solid sinter. When Wolf and Paperiello described "Resurgent Geyser" in 1984, they noted:

> ... this geyser erupts from a slightly decayed old vent which has probably been recently reactivated. The vent is very irregular in shape, about 10" to 12" [25 to 30 cm].
>
> The extreme age and evidently recent rehabilitation of the cone and vent of this geyser, suggested the name. [Wolf and Paperiello, 1985]

In 1997, there was a significant amount of fresh geyserite beading at the south side of the vent (see Figure 7), indicating that "Resurgent Geyser" had been regularly active for some time. The geyserite had a definite pink color, probably caused by trace amounts of manganese in the sinter.

Figure 8 shows the formation of "Resurgent Geyser" and the surrounding terrain. The wet gravel surface at the left is the runoff channel. During a major eruption, this channel filled with water to a depth of 5 to 10 centimeters (2 to 4 inches) for a width of at least 1 meter (3.3 feet). The old Grand Loop Road grade is the gray area above and to the right of the geyser vent. The "South Beach Group" and the "Mercurial Group" can be seen in the distance. The smooth surface in front of the vent in Figure 8 is partly a geyserite splash pan. The dark gray surface below the splash pan was a clay surface.

Figure 8 - "Resurgent Geyser" formation and runoff channel, looking north toward the "Mercurial Group".

When we first observed "Resurgent Geyser" in eruption with the rocks still in the vent, we noted that the water was prevented from hitting the clay by the blockage. We expected the clay to erode very rapidly when we removed the rocks, but after five weeks, the clay had hardly eroded at all. The surface of the clay was hard to the touch, but the clay was slowly deteriorating by mid October. The clay was eroded from the splash zone by midsummer of 1998.

Figure 7 - "Resurgent Geyser" formation detail, showing the vent and the geyserite beading at the bottom.

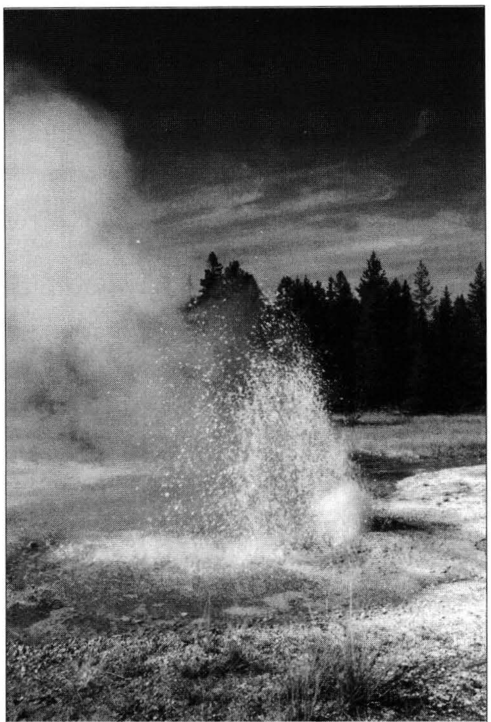


Figure 9 - "Resurgent Geyser" in eruption, after the rocks were removed from the vent.

Activity

"Resurgent Geyser" had both minor and major eruptions. In 1997 and 1998 immediately following a major eruption the water level was almost a full meter down in the vent, and there was only slight boiling. Within two minutes after the end of the major eruption, the first minor eruption occurred. The minor eruptions lasted about one minute, and occurred about every two minutes. There was considerable variation in the durations; some durations were as short as 35 seconds and some were as long as 1 minute 45 seconds. We did not observe any pattern that allowed one to determine when a major eruption would occur based only on observation of minor eruptions, but minor eruptions immediately following a major eruption tended to be short, on the order of 30 to 40 seconds. The water reached near the top of the cone during a minor eruption, but very few drops of water escaped the vent. Water temperature was 94°C (201°F) during a minor eruption.

By the summer of 2001 the minor eruptions had become much less vigorous, and the water level fell less between minor eruptions. The character of the play between major eruptions had changed from a definite series of minor eruptions separated by quiet interludes to a cyclically varying boiling.

The major eruptions of "Resurgent Geyser" were typical cone type eruptions. The initiation was by a surge of water above the rim of the cone, followed by a steadily building water column. Figure 9 shows the peak of a major eruption of "Resurgent Geyser" after the rocks were removed from the vent. The maximum height of the drops of water was about 3 meters (10 feet). The eruption built slowly, reaching its maximum about halfway through the eruption. As the eruption continued, the strength slowly declined, until the water column was only 30 centimeters (12 inches) or so in height near the end of the eruption. Figure 10 shows "Resurgent Geyser" near the end of a major eruption. The water column remained generally steady throughout the eruption, although there were pulses of stronger play every two or three seconds. When the eruption ended, the water rapidly dropped in the vent, to almost 1 meter (40 inches) below the top of the cone, for about a minute. The water level then rose, and the series of minor eruptions began again.

After several weeks of using markers and observing several major eruptions, we estimated that the eruptions were occurring about 8 to 12 hours apart. We then removed a StowAway™ temperature logger being used in another research project and placed it on "Resurgent Geyser" for one day.

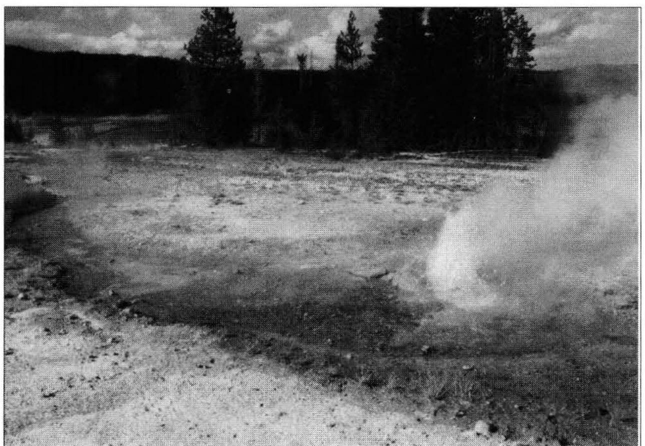


Figure 10 - "Resurgent Geyser" major eruption, near the end of the eruption. Note the full runoff channel at the left.

During this time, from 12:00 (noon) on 25 Sep 1997 until noon on 26 Sep 1997, the logger recorded six eruptions with a mean interval of 4h35m17s and a mean duration of 8m48s.

The StowAway logger is a small, battery–powered device that uses a thermistor to measure temperature. It is capable of recording over 32,000 readings, at an adjustable rate. The eruption times can be determined by noting the quick rise in runoff water temperature. "Resurgent Geyser" had no runoff from minor eruptions, so major eruptions were easy to detect. Also, because of the strong runoff stream, it was possible to determine the eruption durations directly from the temperature record.

A few weeks later, a second instrument became available, and we recorded the activity of "Resurgent Geyser" between 14:00 on 10 Oct 1997 and 04:00 on 15 Oct 1997. The recording ended when the thermistor wire was chewed in half, possibly by a coyote. During the five days that the recorder functioned, the logger recorded evidence of 24 eruptions. A plot of the intervals for this time is shown in Figure 11. The intervals ranged from 3h31m44s to 5h07m44s. The mean interval was 4h27m13s, with a standard deviation of 26m39s.

In 1998 we monitored "Resurgent Geyser" for a much longer time in two deployments. The first deployment was for nearly eight days from 8 August to 16 August; the second deployment was for almost 26 days from 12 September to 8 October.

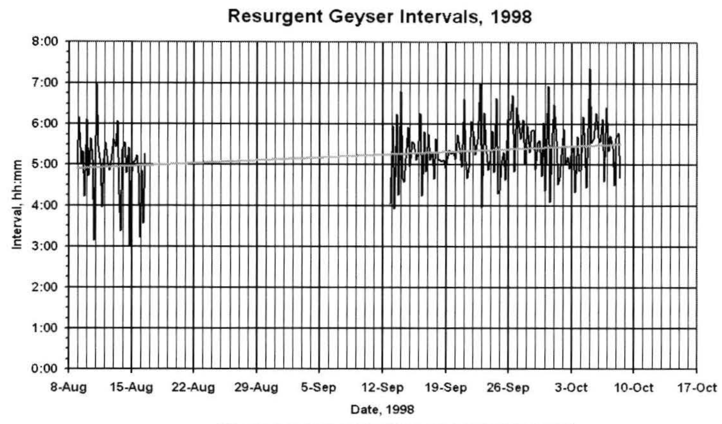


Figure 12.

The graph of Figure 12 shows the intervals during those times. The intervals ranged from 2h59m36s to 7h23m00s. The mean interval was 5h16m39s; the standard deviation was 46m10s. There was a slight trend to increasing intervals over the whole time, and a cyclic variation between 5 and 6 hours with peak intervals between three days and a week apart. We have no explanation for this variation in interval.

In 1999 we deployed a logger for seven days in August. Figure 13 shows that result. The intervals varied from 5h13m12s to 7h15m12s. The mean interval was 6h15m07s with a standard deviation of 30m44s. There is some evidence of the cyclic variation seen in 1998, this time varying from 5h45m to 6h45m. The short monitoring period only revealed one cycle of the variation.

Monitoring in 2000 for twenty days in August and September showed an increased interval between eruptions, as shown in the graph of Figure 14. Intervals ranged from 5h15m30s to 8h20m00s. The mean interval was 6h57m42s and the standard deviation was 47m07s. There is some evidence of a cyclic variation with longer intervals occurring weekly. There was no significant change in the intervals over the monitoring period.

Finally, in 2001 a monitoring period of nineteen days showed that intervals had again increased over the previous year, and indeed they increased during

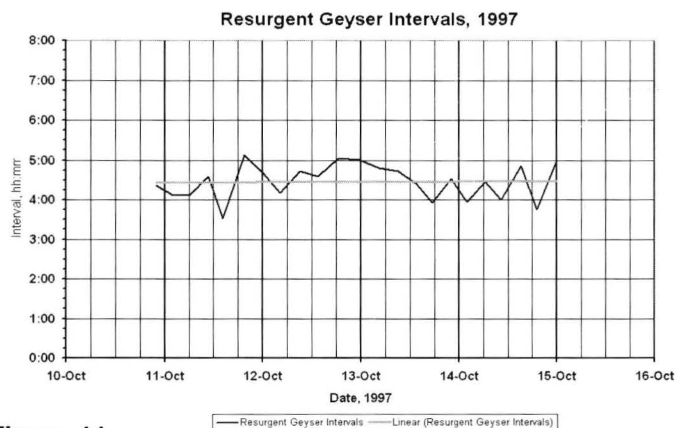


Figure 11.

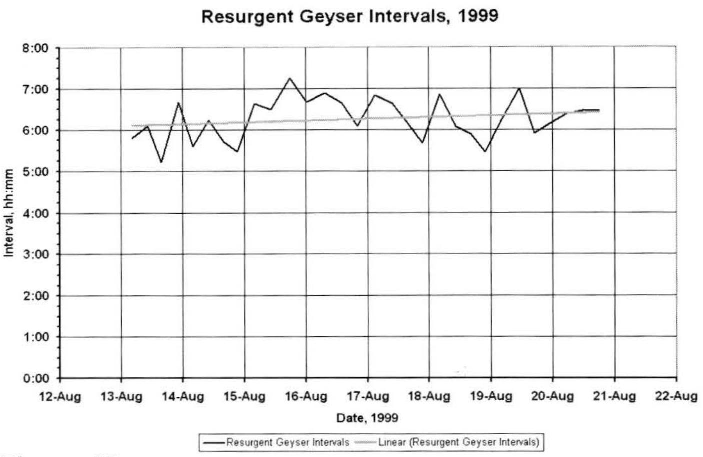


Figure 13.

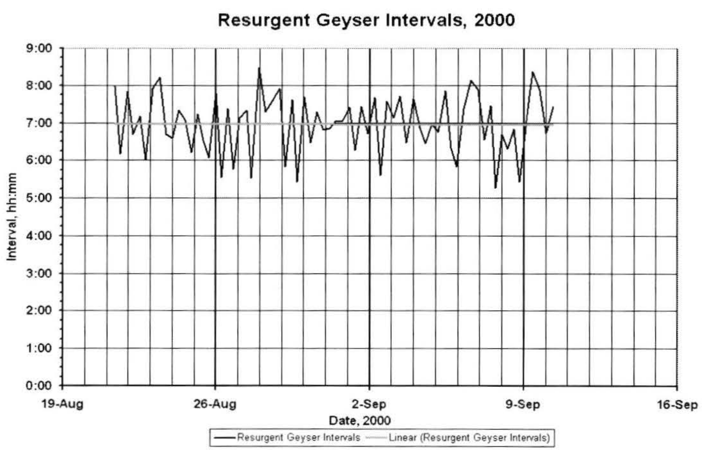


Figure 14.

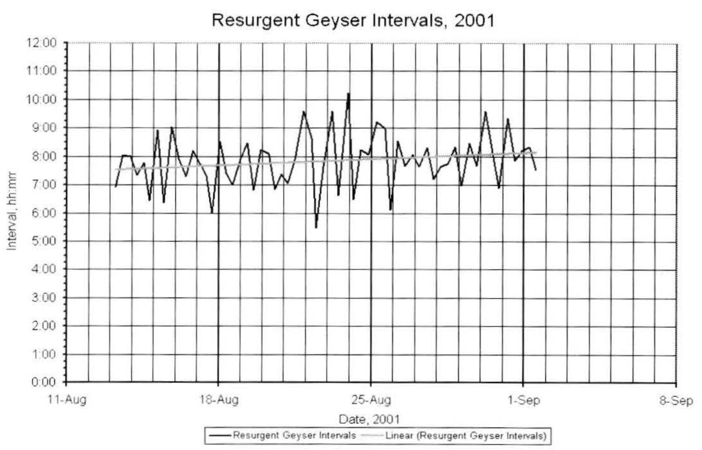


Figure 15.

the 19-day period of monitoring (Figure 15). For the sixty eruptions in the period of monitoring, the mean interval was 7h50m01s with a standard deviation of 57m30s. The range of intervals was 5h20m00s to 10h14m00s. The interval of over ten hours was the longest that we ever observed for this geyser.

The activity of "Resurgent Geyser" has continued for the period from the fall of 1997 to the fall of 2001 with a gradual but relentless increase in interval. Geysers in Potts Hot Spring Basin have tended to be either stable but very small (eruption heights less than 50 centimeters [20 inches]) or large but short–lived. "Resurgent Geyser" is the exception in that its two to three meter eruptions have remained constant in character for fully five years. From the beading on the sinter around the vent we conclude that the activity that Wolf and Paperiello saw in 1984 was probably the initial reactivation of the feature, and that activity has continued at some level since then. This geyser emits a surprisingly large amount of water; for the entire duration of the eruption there is a stream nearly a meter wide and about 5 centimeters deep (about 3 feet wide and 2 inches deep) flowing in a well-defined sinter channel.

From the appearance of the vent and the sinter–lined runoff channel, we conclude that this geyser is many decades old. However, since "Resurgent Geyser" is immediately adjacent to the old Grand Loop Road, which was in use until about 1970, we also conclude that the geyser was inactive for much of the first half of the 20th Century. There are no records of a large geyser close to the road, and it is highly unlikely that a geyser erupting to two meters from a vent in the road shoulder could be overlooked.

Overall, we noted a year–to–year increase in eruption intervals as shown in Figure 16. The increase is significant and consistent, with intervals increasing by 40 to 60 minutes per year.

Figure 17 shows that the durations of the eruptions gradually increased until 2001 when the mean duration dropped by almost two minutes.

On several occasions in 1998 we recorded long series of minor eruptions leading up to major eruptions (see "Record of Observations"). The mean interval was 1m50s on 2 August and 2m05s on 29 August. The mean duration of the minor eruptions on 2 August was 1m08s and on 29 August was 1m06s. There was no particular pattern to either the intervals or durations for the hour leading up to the major eruption. It was possible to get an idea of how near a major eruption was by touching the water in the basin in front of the vent; in the hour or so before the major eruption the water was quite warm to the touch (around 50ºC). The activity during the minor eruption was a splashy boiling and bursting at a depth of around 40 cm (15 inches). As the major eruption approached, the water level during the minor eruptions became closer to the surface, but only a few droplets escaped the vent. By 2001 the minor activity had declined to a cyclic ebullition with no clearly distinguishable pause in activity.

The eruptions of "Resurgent Geyser" were vigorous but not especially powerful. The water column consisted of large droplets, some as large as 1 centimeter (0.4 inch), but were expelled from the vent relatively slowly. The eruptions lasted six to ten minutes, and gradually diminished in force until the water column no longer cleared the vent of the geyser. There was no perceptible steam phase.

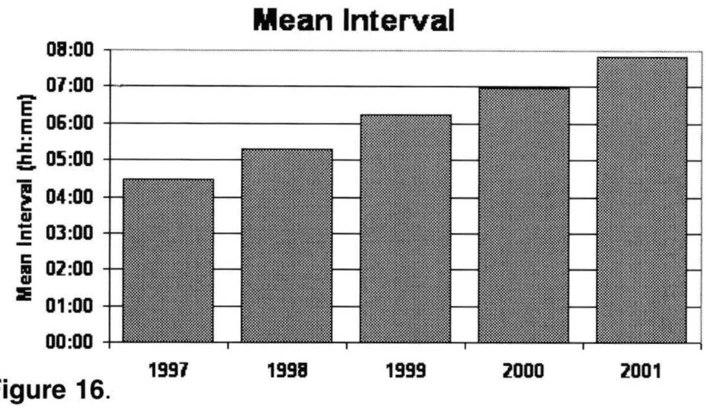


Figure 16.

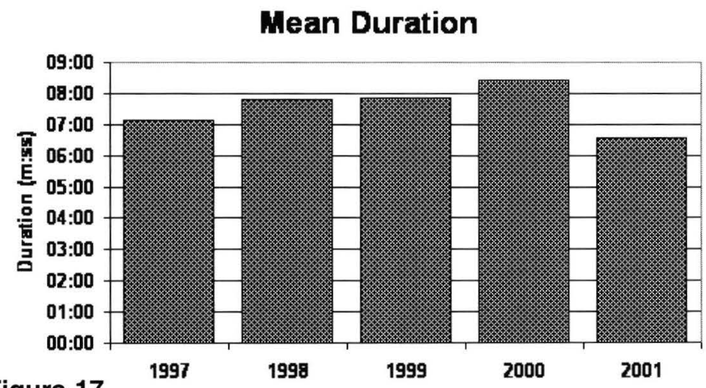


Figure 17.

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Taylor, Ralph C. and Grigg, James B., 1999, *Potts Hot Spring Basin Survey, 1999*: GOSA Press.

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"Resurgent Geyser" — Record of Observations, 1997–2001

4 Sep 97					
11:33:10		minor			
11:36:50		minor		i=3:40	
11:38:54		minor		i=2:04	
12:18:30	12:29:12	major	d=10:42		Note: interval from last minor is not closed
12:31		minor			
9 Sep 97					
18:55		minor			
18:57:26		minor		i=2:xx	
19:01:11		minor		i=3:45	
19:02:30		minor		i=1:19	
19:05:01		minor		i=2:31	
19:07:00		minor		i=2:01	
19:08:31		minor		i=1:31	
19:10:18		minor		i=1:47	
19:12:20		minor		i=2:02	
19:14:20		minor		i=2:00	
19:16:20		minor		i=2:00	
12 Sep 97					
Markers washed; remarked					
18:01:25	18:02:26	minor	d=1:01		
18:03:19	18:04:25	minor	d=1:06	i=1:54	
18:05:05	18:06:24	minor	d=1:19	i=1:46	
18:06:56	18:08:19	minor	d=1:23	i=1:51	
18:09:14	18:09:59	minor	d=0:45	i=2:18	
18:10:47	18:11:54	minor	d=1:07	i=1:33	
18:12:43	18:13:36	minor	d=0:53	i=1:56	
18:14:40	18:15:41	minor	d=1:01	i=1:57	
18:16:19	18:17:30	minor	d=1:11	i=1:39	
18:18:17	18:19:19	minor	d=1:02	i=1:58	
18:20:11	18:21:41	minor	d=1:30	i=1:54	
18:22:38	18:23:12	minor	d=0:34	i=2:27	
18:24:16	18:25:20	minor	d=1:04	i=1:38	
18:26:15	18:27:05	minor	d=0:50	i=1:59	
18:27:55	18:28:50	minor	d=0:55	i=1:40	
18:29:54	18:30:47	minor	d=0:53	i=1:59	
15 Sep 97					
Markers washed; remarked					
16 Sep 97					
16:20:09	16:29:34	major	d=9:25		h=2-3 meters (6-10 feet)
16:31:27	16:31:58	minor	d=0:31	1:53 after end of major	
...					
16:58:14	16:58:49	minor	d=0:35		
17:01:42	17:02:52	minor	d=1:10	i=3:28	
17:04:08	17:04:50	minor	d=0:42	i=2:26	
17:07:35	17:08:23	minor	d=0:48	i=3:27	
19 Sep 97					
Markers washed; remarked					
16:33:50	16:34:33	minor	d=1:43		
16:37:29	16:38:05	minor	d=1:36	i=3:39	
16:38:54		minor		i=1:25	
16:41:00		minor		i=2:06	
20 Sep 97					
Markers washed; remarked					
25 Sep 97					
StowAway recorder deployed in "Resurgent Geyser's" runoff channel					
12:20:30	12:29:36	major	d=9:06		
12:30:52	12:31:35	minor	d=0:43	1:16 after end of major	
16:44ns		major	d<4:22:xx		
26 Sep 97					
StowAway recorder removed from "Resurgent Geyser"					
15:14 ns	major				
10 Oct 97					
StowAway recorder deployed					

15 Oct 97
StowAway recorder recovered
9 May 98
Active; minor eruptions were observed.
31 May 98

11:51:40	11:52:32	d=0:00:52		Minor
11:55:48	11:56:47	d=0:00:59	i=0:04:08	Minor; marker placed.

13 Jun 98
Marker from 31 May was washed; replaced marker.
21 Jun 98

18:22:20	18:23:19	d=0:00:59		Minor
18:24:11	18:25:05	d=0:00:54	i=0:01:46	Minor
18:26:05	18:28:09	d=0:01:04	i=0:02:04	Minor
18:28:10	18:29:06	d=0:00:56	i=0:01:57	Minor
18:29:49	18:30:54	d=0:01:05	i=0:01:48	Minor
18:31:51	18:32:50	d=0:00:59	i=0:01:56	Minor
...				
20:07:00ns	20:15:40	d>0:08:40		Major

27 Jun 98
Active—having minor eruptions.
5 Jul 98

15:58:15ns	16:06:00	d>0:07:45		Major

2 Aug 98

10:07:40	10:09:00	d=0:01:20		Minor
10:09:32	10:10:39	d=0:01:07	i=0:01:52	Minor
10:11:15	10:12:21	d=0:01:06	i=0:01:43	Minor
10:13:02	10:14:14	d=0:01:12	i=0:01:47	Minor
10:14:53	10:17:30	d=0:02:37	i=0:01:51	Minor
10:17:47	10:18:48	d=0:01:01	i=0:02:54	Minor
10:19:36	10:20:53	d=0:01:17	i=0:01:49	Minor
10:21:19	10:22:14	d=0:00:55	i=0:01:43	Minor
10:23:22	10:24:29	d=0:01:07	i=0:02:03	Minor
10:25:11	10:26:07	d=0:00:56	i=0:01:49	Minor
10:26:53	10:28:30	d=0:01:37	i=0:01:42	Minor
10:28:46	10:29:53	d=0:01:07	i=0:01:53	Minor
10:30:50	10:31:58	d=0:01:08	i=0:02:04	Minor
10:32:41	10:33:37	d=0:00:56	i=0:01:51	Minor
10:34:25	10:35:35	d=0:01:01	i=0:01:44	Minor
10:36:18	10:37:12	d=0:00:54	i=0:01:53	Minor
10:37:52	10:38:57	d=0:01:05	i=0:01:34	Minor
10:39:37	10:40:17	d=0:00:40	i=0:01:45	Minor
10:41:09	10:41:58	d=0:00:49	i=0:01:32	Minor
10:42:48	10:43:41	d=0:00:53	i=0:01:39	Minor
10:44:35	10:45:45	d=0:01:10	i=0:01:47	Minor
10:46:28	10:47:21	d=0:00:53	i=0:01:53	Minor
10:48:17	10:49:21	d=0:01:04	i=0:01:49	Minor
10:49:49	10:58:48	d=0:08:59	i=0:01:32	Major; h>3 m (10 feet).
11:00:06				Water is very low in vent, more than 1 m below surface.
11:08				Water down 1 m, vigorous boiling.

8 Aug 98
Temperature is 94°C (202°F).
18 Aug 98

13:40ie	13:43 off			

23 Aug 98
14:40~ie
25 Aug 98

12:02ie				Major
16:58:30ns	17:05:13	d>0:06:43	i~04:56	Major, h>2 m

31 Aug 98

12:40ie				Major

1 Sep 98

13:25:50	13:33:58	d=0:08:08		Major

Temperature is 91.7°C (197.1°F), pH is 8.02, and conductivity is 2000mW.
6 Sep 98

12:42ie				Major

13 Sep 98

16:03:24ie	16:11:15	d>0:07:51		Major

19 Sep 98

09:15				Major

20 Sep 98

15:15				Major

25 Sep 98				
14:49ie				Major
29 Sep 98				
13:45:39				Minor
13:47:58			i=0:02:19	Minor
13:49:49			i=0:01:51	Minor
13:52:01			i=0:02:12	Minor
13:54:13			i=0:02:12	Minor
13:58:14			i=0:04:01	Minor (possible double interval)
14:00:14			i=0:02:00	Minor
14:02:02			i=0:01:48	Minor
14:04:39			i=0:02:37	Minor
14:08:06			i=0:03:27	Minor
14:09:50			i=0:01:44	Minor
14:11:18			i=0:01:28	Minor
14:13:09			i=0:01:51	Minor
14:15:26			i=0:02:17	Minor
14:17:18			i=0:01:52	Minor
14:18:38			i=0:01:20	Minor
14:20:53			i=0:02:15	Minor
14:22:38			i=0:01:45	Minor
14:24:27			i=0:01:49	Minor
14:26:03			i=0:01:36	Minor
14:27:29	14:29:03	d=0:01:34	i=0:01:26	Minor
14:29:54	14:30:53	d=0:00:59	i=0:02:25	Minor
14:31:54	14:33:01	d=0:01:07	i=0:02:00	Minor
14:33:53	14:34:43	d=0:00:50	i=0:01:59	Minor
14:35:36	14:36:39	d=0:01:03	i=0:01:43	Minor
14:37:53	14:39:11	d=0:01:18	i=0:02:17	Minor
14:40:26	14:41:43	d=0:01:17	i=0:02:33	Minor
14:42:36	14:43:18	d=0:00:42	i=0:02:10	Minor
14:44:17	14:45:28	d=0:01:11	i=0:01:41	Minor
14:46:13	14:47:41	d=0:01:28	i=0:01:56	Minor
14:48:11	14:49:19	d=0:01:08	i=0:01:58	Minor
14:50:18	14:51:16	d=0:00:58	i=0:02:07	Minor
14:52:28	14:53:39	d=0:01:11	i=0:02:10	Minor
14:54:48	14:55:47	d=0:00:59	i=0:02:20	Minor
14:56:36	14:57:34	d=0:00:58	i=0:01:48	Minor
14:58:30	14:59:34	d=0:01:04	i=0:01:54	Minor
15:00:27	15:01:20	d=0:00:53	i=0:01:57	Minor
15:02:19	15:03:25	d=0:01:06	i=0:01:52	Minor
15:04:03	15:04:55	d=0:00:52	i=0:01:44	Minor
15:05:59	15:07:05	d=0:01:06	i=0:01:56	Minor
15:07:59	15:08:43	d=0:00:44	i=0:02:00	Minor
15:09:56	15:11:33	d=0:01:37	i=0:01:57	Minor
15:12:46	15:14:49	d=0:02:03	i=0:02:50	Minor
15:14:59	15:15:45	d=0:00:46	i=0:02:13	Minor
15:16:32	15:17:34	d=0:01:02	i=0:01:33	Minor
15:18:24	15:19:09	d=0:00:45	i=0:01:52	Minor
15:20:51	15:21:54	d=0:01:03	i=0:02:27	Minor
15:23:13	15:24:26	d=0:01:13	i=0:02:22	Minor
15:25:55	15:26:40	d=0:00:45	i=0:02:42	Minor
15:28:27			i=0:02:32	Minor
15:28:58	15:37:40	d=0:08:42		Major
13 Oct 98				
13:57ns				
8 Jul 99				
12:18:49				Major
16 Aug 99				
20:08	20:15:20	d~0:07:20		Major
25 Aug 99				
Temperature is 94°C (201°F).				
29 Aug 99				
12:56:20ie	13:07 off			
12 Sep 99				
18:51 ns				Major
13 Oct 99				
13:57 ns				

Iceland's Geysir Aroused by Earthquakes in June 2000

by Gudmundur Pálmason
Orkustofnun, Reykjavik

Abstract

Geysir, the namesake of all geysers, reactivated following two earthquakes in June 2000. Geysir's history and the rejuvenation are described in this paper, as is the action by its neighbor, Strokkur.

Introduction

The Icelandic proper name Geysir is used for several erupting hot springs in Iceland, the best known of which is sometimes referred to as the Great Geysir (or Geysir in Haukadalur) to distinguish it from the others. The name is derived from the Icelandic verb gjósa (with a light accent over the o) which in the dictionary is translated gush, break out, spout, erupt. The word geysir thus means someone who gushes, breaks out, spouts, erupts. The name Geysir first appeared in an Icelandic chronicle in 1647. When the geysers of Yellowstone and New Zealand were discovered by western travelers and scientists in

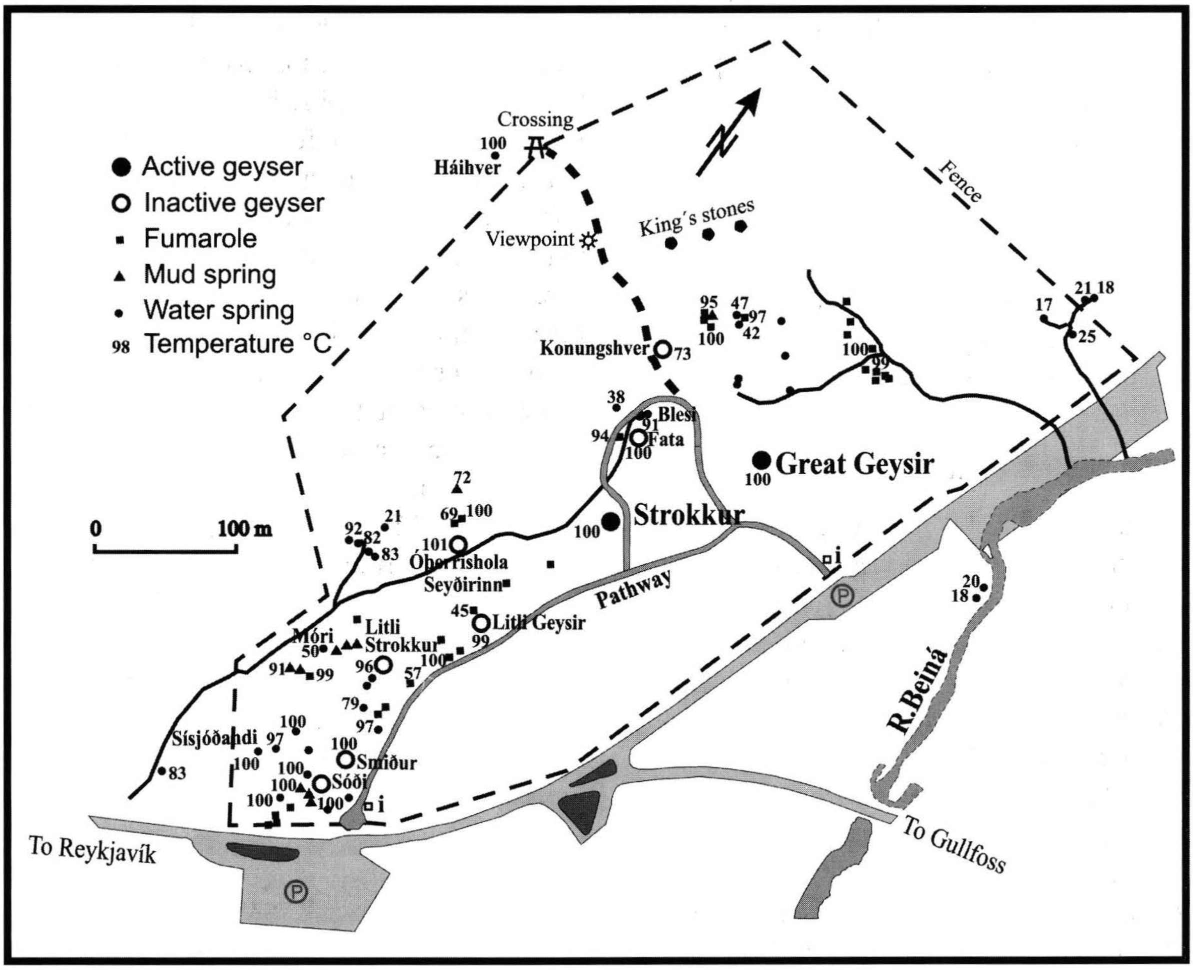

Figure 1. Map showing the geothermal features in the Geysir thermal field. [Modified from a map by H. Torfason. For an index map, see Figure 6]

the 19th century the name Geysir had appeared in European publications and was taken over as a general name for this phenomenon in English and other languages, although with a slightly altered spelling.

Through the centuries, during which Geysir has been known, its activity has varied considerably with time. It has been dormant for long periods and then brought to life by earthquakes, again to gradually diminish in activity until eruptions ceased completely. During recent periods of inactivity it has been possible to induce eruptions by adding soap to the geyser, as was originally discovered in Yellowstone more than a century ago and tried for the first time successfully in Geysir in 1894. This is a controversial operation which has sometimes been allowed and at other times not. Lowering of the water table in the Geysir water basin has also proved an effective way of inducing eruptions.

Geysir and its neighbor Strokkur (which means a churn) are by far the most important geysers in Iceland although there are a number of smaller ones both in the Geysir area (Figure 1) and in other localities in Iceland. A table of geysers in Iceland was given by Barth [1950]. At that time Strokkur was dormant but it was reactivated in 1963. Some geysers have been influenced by the increased utilization of the geothermal resources in the second half of the 20th Century, but efforts are being made to protect the more important ones.

Scientific studies of Geysir

Scientific studies of Geysir began in the middle of the 18th Century with measurements of the shape and dimensions of the Geysir pipe and the temperature of the water at the surface. Eggert Olafsson and Bjarni Palsson traveled in Iceland in 1752–57 and collected their observations on all aspects of Icelandic life in a book published in Danish in 1772. In the following years the book was translated into German and French, and an abridged English version was published in 1805 [Olafsson, 1805]. Besides visiting the Geysir area they also made the first shallow drillings in two geothermal fields to study the sulfur resources which at that time had some economic value.

In the following decades and well into the 20th century a number of European scientists and travelers visited Geysir and wrote about their observations in papers or books. Of these may be mentioned Uno von Troil [1777], Sir John Stanley [1793], Sir George Steuart Mackenzie [1811], O. Krug von Nidda [1837], Robert Wilhelm Bunsen [1847], Karl Schneider [1913], and Tom. F.W. Barth [1940, 1950]. Icelandic scientists also contributed to these studies, e.g., Jonas Hallgrimsson (1838), Th. Thorkelsson [1910, 1928, 1940], Th. Thoroddsen [1910, 1925], Tr. Einarsson [1937], and Th. Sigurgeirsson [1949]. Mackenzie was the first to suggest a model with a steam filled cavity outside the Geysir pipe to explain the eruption sequence of Geysir but this was soon found to be unsatisfactory. One of the best known contributions was that of Bunsen and his collaborator Alfred Descloizeaux. They spent two weeks at Geysir, observed 10 major eruptions and made temperature measurements down the Geysir pipe. Bunsen concluded that the eruptions were initiated within the 23 meter deep pipe beneath Geysir but not in the surrounding rock formations. Thorkelsson emphasized the role of gases in initiating eruptions. After Geysir was revived in 1935, Einarsson [1937] made some studies and further temperature measurements. He concluded that the critical mechanism for initiating the eruptions was superheating of the water which caused explosive boiling in the water column at 10 to 15 meters depth where the temperatures came closest to the boiling point curve. He considered the later tem-perature measurements of Sigurgeirsson [1949] as proof that this was the correct explanation (Figure 2).

Little is known about the age of Geysir. The first historical accounts mentioning the Geysir thermal area date from 1294 when earthquakes resulted in great changes in the area. Some hot springs disappeared and new ones were created. The silica mound which has been built up around the spring is about 1.5 meters thick and is underlain by a soil stratum beneath which there is again evidence of subterranean heat [Einarsson, 1967]. Tephrochronological studies of the underlying strata indicate that the area has been active for at least 8,000 years and it could be still older [Torfason, 1985]. There are even indi-

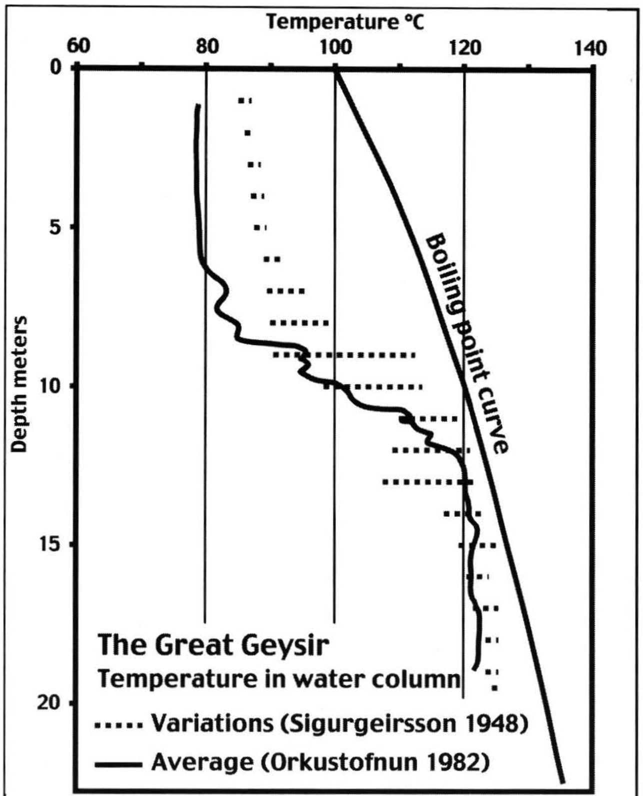

Figure 2. Temperature in the Geysir water column, showing both the rapid variations prior to an eruption and an average profile at rest.

cations that the area may have been active during the last interglacial stage.

Little is known about the underground piping system of Geysir and Strokkur. Despite their close proximity, about 110 meters, they have different eruption behaviors. The silica content of the water differs slightly, about 500 ppm in Geysir and about 450 ppm in Strokkur. The silica geothermometer points to reservoir temperatures of about 240 and 230°C respectively [Pasvanoglu, 1998]. The difference is likely to be due to a slight mixing with colder ground water in the case of Strokkur.

It is not within the scope of this article to review the theories that have been proposed to explain the behavior of Geysir. This has been done, e.g., by Allen and Day [1935], Barth [1950], and Luketina [1995]. It is worthwhile, however, to mention some results which appear to have received little attention in some of the previous reviews. One is an experiment by Sigurgeirsson in 1948 to measure the amount of superheat in the Geysir water column prior to an eruption. This was done with a thermistor thermometer which allowed observation of rapid variations of temperature in the Geysir column. The characteristic behavior was one of rapidly fluctuating temperature, as observed over a period of two minutes at each depth (Figure 2). Thereafter eruptions were induced by lowering the water table by 60 centimeters using the channel cut through the rim of the silica mound in 1935. The thermometer was kept at a depth of 10 meters for one hour between two eruptions and the temperature observed in the same manner as before. Fluctuations of about 10°C were observed, and the average value increased gradually as the next eruption approached. The maximum temperature reached 5 to 6°C above the boiling point at 10 meters depth prior to the eruption. Tr. Einarsson [1949] who was one of those who reactivated the spring in 1935 considered this as proof of the importance of superheating in initiating an eruption. The superheating would also rather nicely explain the explosive boiling that appears to take place underground at the beginning of an eruption.

A typical sequence of events in a complete Geysir eruptive cycle is shown in Figure 3. The first sign of an impending eruption is that the surface of the water rises and falls back again several times, accompanied by rumbling sounds underground. This is followed by several low eruptions of water, 10 to 15 meters high, which throw out part of the water in the Geysir pipe. Then everything is quiet for about a minute, whereupon a water–steam column suddenly shoots up into the air to a height of 30 to 60 meters. This last steam dominated phase of the eruption lasts for 5 to 10 minutes at the end of which the Geysir pipe is empty. It takes 10 to 15 hours to fill again. In many cases only the first water dominated phase of the eruptive cycle is realized depending on, among other things, weather conditions. The whole cycle takes typically about half an hour.

Further research into the eruption mechanism of Geysir has been hampered somewhat by the inactivity of the spring for most of the 20th Century. One thing seems clear however. One and the same model is not likely to apply to both Geysir and Strokkur. The latter has been very active since 1963 after an inactivity of almost 70 years. The water

Figure 3. A typical sequence of events in a complete Geysir eruption, from top left: a. The water level in the basin is lowered by letting off water through the channel in the rim of the basin. The opening of the channel is the black rectangle on the far side of the water basin (arrow); b. The water level starts to bulge upward and flow over the rim, accompanied by rumbling sounds deep down; c. Several sucessive water eruptions to a height of 10–15 meters; d. Everything is quiet for about one minute; e. The steam–water eruption begins suddenly reaching a height of 30–60 meters and lasts typically for 5–10 minutes; f. Gradually the steam column dwindles until finally a weak vapor emanation comes from the 23 meter deep empty Geysir pipe. The whole sequence takes typically about half an hour. (Photos: G. Pálmason, June 1982).

column is constantly at the boiling temperature and the pipe is not emptied during an eruption, contrary to the situation in Geysir where the pipe is emptied in a full eruptive cycle and upon filling again cools considerably after each eruption. The difference in behavior between these two springs was noted by many observers in the 19th Century who remarked that the many theories to explain Geysir's behavior did not necessarily apply to Strokkur. The drilling into the bottom of Strokkur has markedly affected its natural behavior. From descriptions of its eruptions between 1789 and 1896 it is clear that the eruptions lasted often for more than an hour with longer intervals in between. After the drilling in 1963 the eruptions were frequent with an average interval that was about 8 minutes just before the earthquakes in 2000. Each eruption lasts for less than a minute. From the point of view of tourists visiting the area the present behavior is an appealing one, and they never have to wait for more than a few minutes to withness an eruption. Proposals have been made to drill a hole into the bottom of Geysir, in a similar way as was done with Strokkur, but it is unlikely that such an operation will be permitted as it would very likely cause an irreversible change in the unique eruption sequence of Geysir.

Interest in the study of natural geyser action in Iceland has perhaps diminished after it was shown how to build an artificial geyser, which imitated the eruptive activity of natural geysers. Such a geyser was built in Reykjavik in 1998 near the hot water storage tanks for the Reykjavik district heating system. It is connected to geothermal drillholes within the city with a reservoir temperature of about 130°C. By adjusting valves in the piping system connected to the drillhole, it is possible to vary both the interval between eruptions and the eruption height within certain limits set by the reservoir temperature. For 130°C inflow temperature, an eruption height of 25 to 30 meters is obtained from this artificial geyser.

Earthquakes influencing the activity of Geysir and Strokkur in the past

Throughout its known history, Geysir has repeatedly been affected by earthquakes taking place in South Iceland. Written accounts of such changes exist from 1294, 1630, 1784, 1789, 1808, and 1896 [Thoroddsen, 1925]. No doubt there have been other similar events that have not been documented. The earthquakes have taken place in the so–called Southern Iceland Seismic Zone which is a fracture zone connecting the western and eastern branches of the active rift zone through Iceland. They have affected many hot spring areas in and around this zone, increasing or decreasing their activity. Towards the end of the 19th Century Geysir had become dormant but earthquakes in 1896 revived it and it remained active for approximately 20 years.

Figure 4. The final steam dominated phase of a Geysir eruption. The eruption height is about 45 meters. [Photo by Mats Wibe Lund, 1987]

Since about 1916 and until 2000 it has remained inactive except when attempts have been made to reactivate it by man–made means. In 1935 the water table was lowered by about 60 centimeters by cutting a channel through the uppermost part of the silica deposition rim around the spring water basin. This resulted in renewed activity which lasted for some years. In 1982–1990 permission was given to put soap into the spring a few times each summer to induce eruptions. Most of the photographs that exist of Geysir in action are from that period (Figure 4). After 1990 soaping was not allowed and the spring remained inactive until two major earthquakes took place on 17 and 21 June 2000 about 40 to 45 kilometers away (magnitude [M_s] 6.6). These earthquakes influenced in a regular pattern the deep groundwater pressure distribution over a large part of southern Iceland as shown by data from a large number of geothermal drillholes drilled in the area in recent decades. The Geysir area was also affected and Geysir itself was brought to life again, although on a more limited scale than when it was at its best in the past.

Strokkur has also had a varied history of changes, brought about by earthquakes, although its history is much shorter than that of Geysir. Strokkur was first mentioned as a geyser in 1789 when after an earthquake it became very active and its eruptions exceeded in height those of Geysir. The Strokkur pipe and crater probably existed before that time and sometime in the distant past it has been an active geyser. In the beginning of the 19th century Strokkur was a very powerful geyser with eruptions lasting sometimes more than an hour and reaching 50 meters in height. Its activity gradually decreased in the latter half of the century and after the earthquakes of 1896 it became dormant. It remained so until 1963 when it was decided to drill a 40 meters deep hole into the bottom of the spring. This operation was successful in reviving the spring and since then it is the main touristic attraction of the Geysir area, erupting at intervals of 8 minutes on the average to a height of 25 to 30 meters. Strokkur is nowadays the most impressive geyser in the area (Figure 5). The frequency of its eruptions apparently increased slightly after the earthquakes in June 2000, but no long–term observations exist to confirm this.

It is noteworthy that in the 40 years since Strokkur was reactivated by drilling, it has gradually built up a silica mound around the eruptive crater, which is now becoming prominent and even approaching in size the one around Geysir. A channel has been kept open through the rim of the crater to enable some of the water to flow away and thus to keep the water level stable despite the build–up of the silica mound. The rate of build–up of the Strokkur mound is probably related to the frequency of its eruptions. If an average interval between successive eruptions is assumed to be 8 minutes, the total number of eruptions since 1963 is

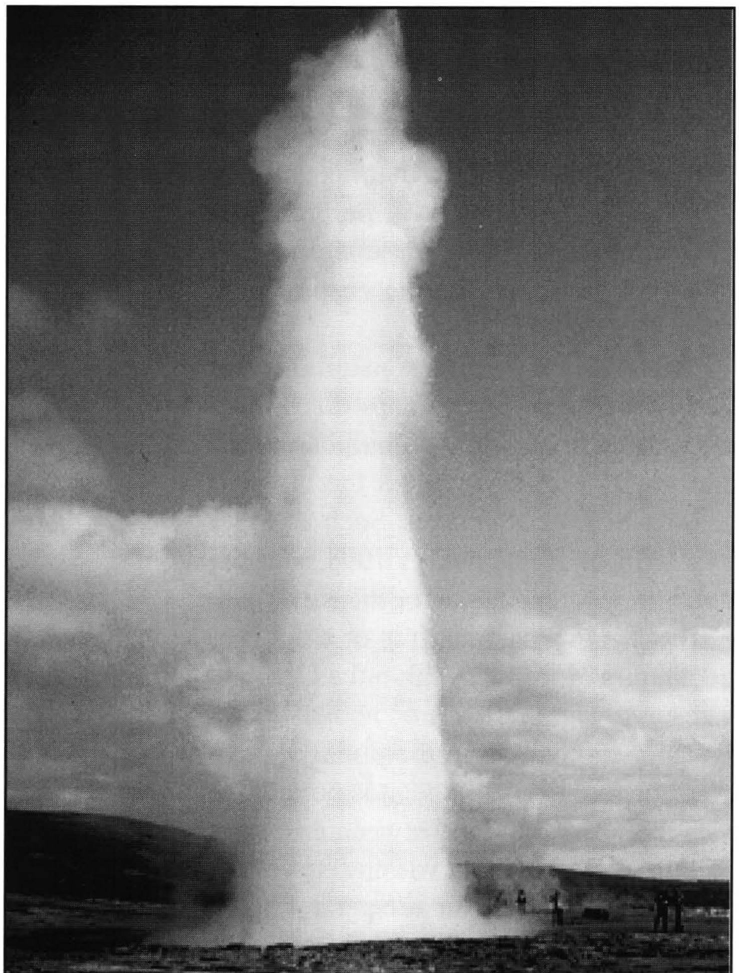

Figure 5. Strokkur erupts to a height of about 40 meters. [Photo by G. Pálmason, July 1973]

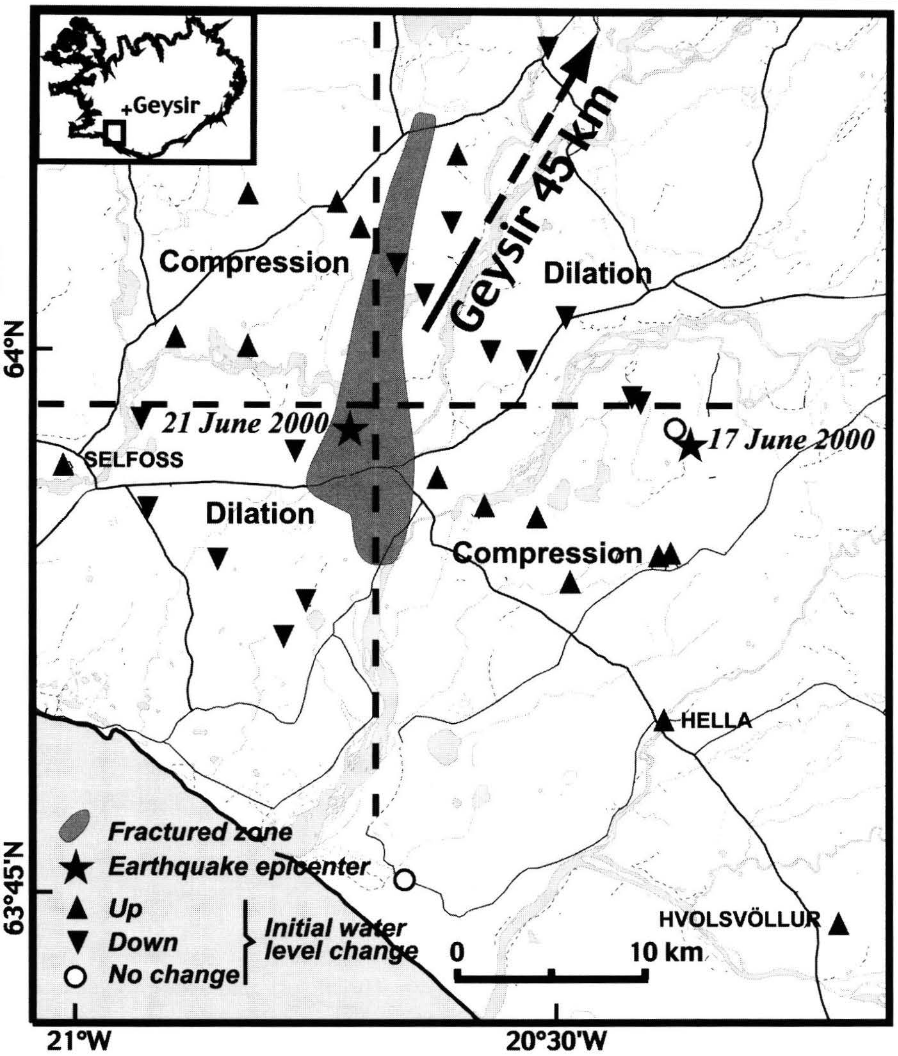

Figure 6. The two earthquakes of 17 and 21 June 2000 in South Iceland affected in a regular pattern the water levels (pressures) in geothermal drillholes as observed to a maximum distance of about 75 km from the epicenter. The map shows the initial changes in some of the holes following the second earthquake on 21 June. A similar pattern emerged after the first earthquake on 17 June. The water levels returned to equilibrium values over a period of several months. Geysir at a distance of 45 km from the epicenter showed increased eruptive activity. [Data from the Geoscience Division of Orkustofnun.]

about 2.6 million. Furthermore, assuming that the thickness of the mounds of Strokkur and Geysir increases at a similar rate during each eruption, this may provide a method of estimating the time needed for the build–up of the Geysir mound. Although the average interval between eruptions of Geysir over long periods of time is very poorly known, this may be compatible with an age of several thousand years for the Geysir silica mound.

Geysir stimulated by the earthquakes in June 2000

As mentioned earlier, the earthquakes of June 2000 profoundly affected the deeper geothermal water system in southern Iceland [Bjornsson et al., 2001]. Although such effects have been known and observed in a qualitative way for centuries, this was the first time that systematic observations of water levels or pressures could be made. These observations were made possible by the availability of a large number of geothermal drillholes in the area, drilled for space heating and other uses in the second half of the 20th century. Figure 6 shows the initial response of the water level or pressure in some of the holes immediately after the earthquake on 21 June 2000. In most cases the water levels returned to their previous values within a few months.

The two June 2000 earthquakes were of the strike–slip type, with mostly north–south trending right lateral fractures. The pressure changes observed in the drillholes immediately after the earthquakes form a pattern of four quadrants with alternately zones of compression and dilation, which reflects the changes that have taken place in the crustal stress field after the earthquakes. The Geysir area is in the Northeast dilation quadrant of the 21 June event, indicating that fractures in that area may have opened up slightly as a result of the earthquake.

Several other springs in the Geysir area were also affected by the earthquakes, but these will not be discussed here. The discharge from Geysir increased slightly and it is much more responsive to a lowering of the water table than before. The eruptions are, however, mostly water eruptions to a height of 8 to 10 meters, at intervals of 2 to 3 hours. This corresponds to the first phase of a complete eruption cycle. The final phase ending with a steam dominated eruption column is very seldom reached unless soap is used. Thus, although Geysir's activity has increased somewhat as a result of the earthquakes, it has apparently not reached the same level of activity as it has done after some major earthquakes in the past.

Strokkur has apparently not or only slightly been affected by the earthquakes, but insufficient long–term observations exist to confirm this one way or the other.

Acknowledgements

The pressure data from drillholes in South Iceland are from the Geoscience Division of Orkustofnun in Reykjavik. Mr. Thorir Sigurdsson at Geysir and Dr. Helgi Torfason have provided information on the changes in the Geysir area as a result of the earthquakes in June 2000. Constructive comments were provided by Drs. M. Khodayar and R. Stefansson. Information about the artificial geyser in Reykjavik was provided by its designer Mr. Isleifur Jonsson. Mr. Mats Wibe Lund (www.mats.is) generously supplied a photograph of Geysir in action (Figure 4).

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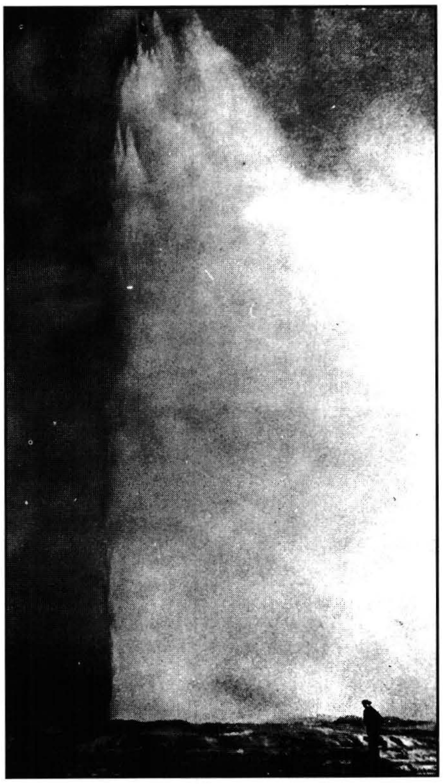


Geysir, as it appeared in 1935. [Photo copied years ago by Scott Bryan, from Barth, 1950]

GOSA

The Geysers of New Zealand

Part 1: The Rotorua Geothermal System

by A.D. Cody, R.F. Keam and K.M. Luketina

Abstract

The Rotorua geothermal field contains the largest, most spectacular and most consistently active geysers in New Zealand. The historic and current activities of these geysers are described in this paper.

INTRODUCTION

The Earth's "lithosphere", comprising the crust and upper mantle, is made up of plates which are slowly moving relative to each other. New Zealand lies over part of the boundary between the Australian and the Pacific plates (Figure 1). Although in the New Zealand region subduction is occurring in different directions beneath different sections along the boundary, associated volcanism is confined to the part where the Pacific plate is being subducted beneath the Australian plate. This active volcanism, largely andesitic and rhyolitic, lies along a north–east trending band known as the Taupo Volcanic Zone, stretching from Mt Ruapehu in the central North Island to White Island off the Bay of Plenty coast and beyond that beneath the sea (Figure 2). The Taupo Volcanic Zone contains most of New Zealand's active volcanoes, and about twenty-five high temperature geothermal systems (with waters hotter than 100 degrees Celsius) (Figure 3). Recent volcanism has occurred also in five other areas around the North Island, but the only high temperature geothermal system found outside the Taupo Volcanic Zone is at Ngawha, in Northland. Low temperature geothermal fields (with waters between 30 and 100 degrees Celsius) are found widely distributed in both the North Island and the South Island, and in the latter they are particularly associated with the active Alpine Fault (Figures 4A and 4B). All of New Zealand's natural geysers are found in the Taupo Volcanic Zone.

In the early 1950s Ron Keam listed about 130 geysers that had then recently been active in New

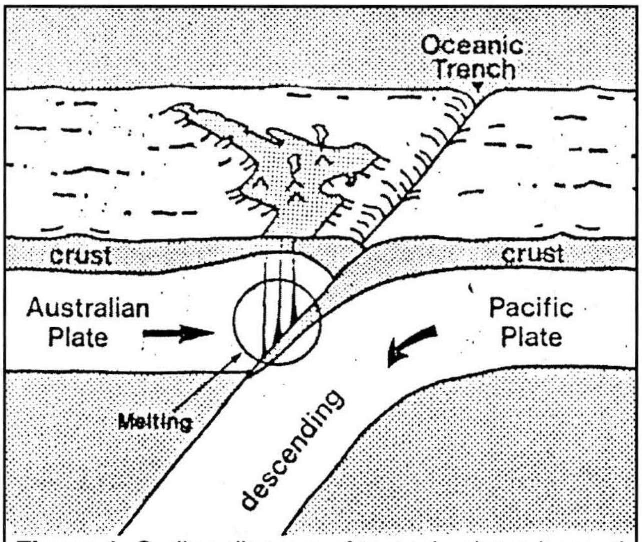


Figure 1. Outline diagram of tectonic plates beneath the Taupo Volcanic Zone. [Courtesy Institute of Geological and Nuclear Sciences, from a display at the former visitors' centre, Wairakei]

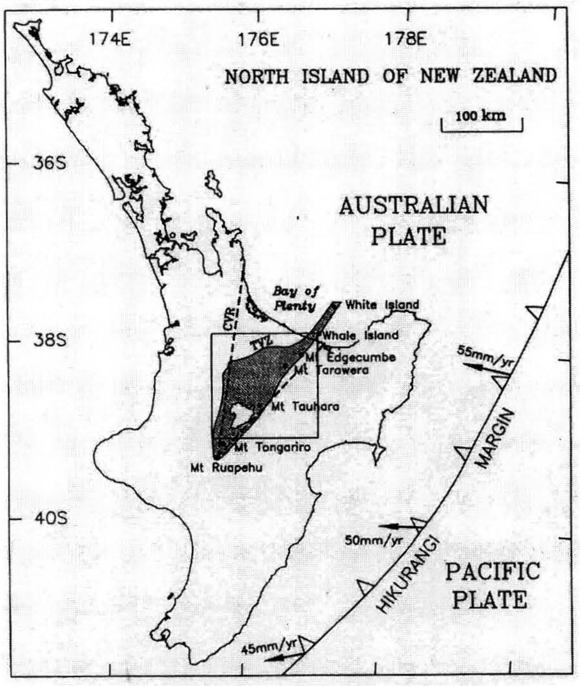


Figure 2. The location of the Central Volcanic Region, the Taupo Volcanic Zone and the surface trace of the Australian Plate–Pacific Plate tectonic boundary. [Adapted from Hunt, Glover and Wood, 1994]

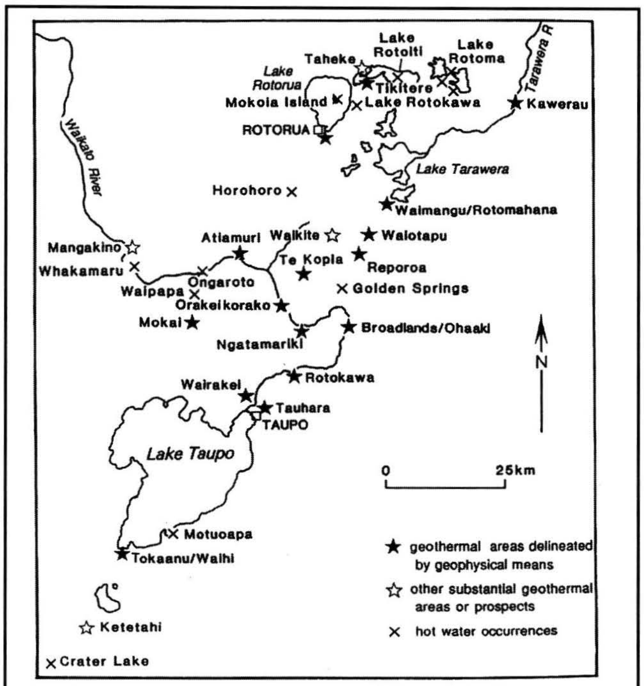
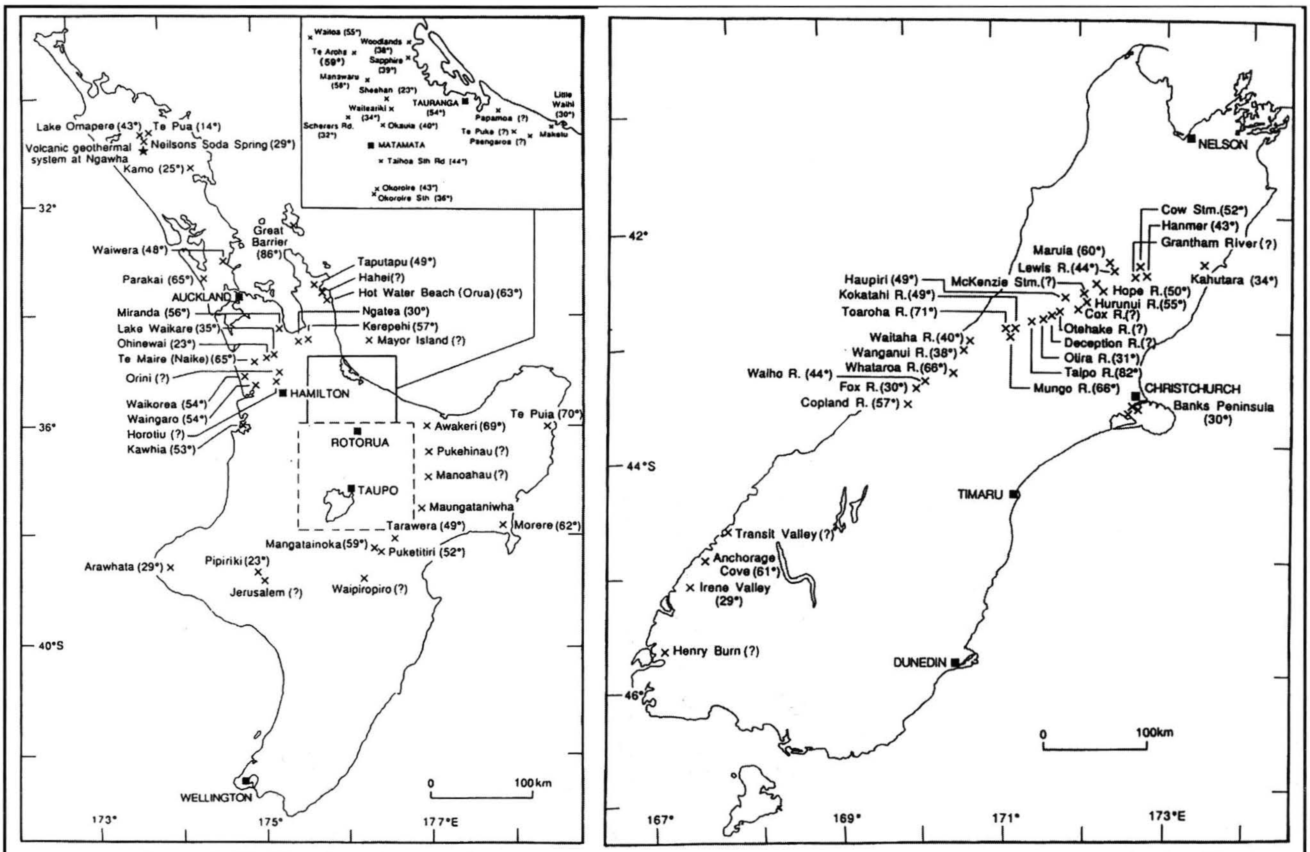


Figure 3. The southern part of the Taupo Volcanic Zone and Central Volcanic Region, showing the location of known high–temperature geothermal systems. [Adapted from Hunt and Bibby, 1992]

Zealand. Now there are only about 70, many of the others since that time having been drowned beneath a hydroelectric lake or rendered inactive by their fluid being drawn off for heating and geothermal power development. Of those that remain, the largest, most spectacular, and most consistently active geysers are found at Whakarewarewa in the Rotorua geothermal field. The Orakei Korako geothermal system, which is situated between the city of Rotorua and the town of Taupo, has the largest number of still active geysers, many of them small and ephemeral, with at least 35 having been active in the past five years. Several geysers also rise in the three contiguous geothermal fields Waimangu, Waikite, and Waiotapu, which are situated some thirty kilometres south of Rotorua, and there is one geyser at Te Kopia which lies between Waikite and Orakei Korako. The small geothermal field at Tokaanu, at the south end of Lake Taupo, has a few geysers, but these generally erupt only when lake level is high. Many geysers were present in Wairakei Geyser Valley and at The Spa in the



Figures 4A and 4B. The location and maximum temperature (ºC) of low–temperature waters in the North Island (left) and South Island (right). [Adapted from Hunt and Bibby, 1992. Here and Figure 3, see also Mongillo and Clelland, 1984]

Wairakei/Tauhara field at Taupo, but these all ceased erupting when geothermal water stopped discharging at the surface a few years after a geothermal power station began operating there in 1958 [see Luketina and Cody, this volume].

When considering the following notes the reader is reminded that descriptions of the behaviour of such variable features as geysers really apply to limited time periods — in most cases to the last few years — and that activities have in many cases changed markedly over the decades. Quite a few details are presented about earlier activity regimes, but they are far from exhaustive and should in fact be regarded as indicative only. 'Full' descriptions (if ever such could be achieved) would require an enormous amount of space — as those who have spent significant parts of their lives assembling material on the Yellowstone features will, we are sure, agree wholeheartedly.

THE ROTORUA GEOTHERMAL FIELD

The city of Rotorua is built on a high temperature geothermal system whose surface activities are largely concentrated in areas situated at Whakarewarewa, Arikikapakapa, Kuirau, Ohinemutu, Government Gardens, and Sulphur Bay (Figure 5). For over 100 years, the geysers close to Rotorua have been one of New Zealand's foremost tourist attractions. Most of them rise at Whakarewarewa (Figure 6), largely in the tourist complex, which is split between an area supervised by the Maori Arts and Crafts Institute and an adjacent area of Whakarewarewa Maori village.

Early in the 1980s the activity of the Whakarewarewa geysers began declining when the fall in geothermal aquifer pressures, induced by tapping of underground hot water for homes and tourist accommodation, began to take effect. With the example of Wairakei Geyser Valley's geyser extinction casting a shadow over a major tourist attraction, an intensive monitoring program was instituted by Government.[1] Among other things this study recorded changes in geothermal aquifer pressures at various locations in the Rotorua geothermal system. There were still at this stage many unbelievers, especially those with vested interests, who were burying their heads in the sand and attempting to attribute the altered geyser behaviour to weather, 'natural changes', and anything else but the bores in their own back yards. When the accumulated evidence of declining pressures at last became irrefutable, quite draconian regulations were introduced to reduce the draw–off. These included shutting down all bores within the Rotorua Geothermal Exclusion Zone, a circle of radius of 1.5 kilometers centred on Pohutu Geyser (Figure 5).

As a result of the shut–down geothermal aquifer pressures began to rise. From 1987 to 1992 this rise quantitatively was much as scientists expected and continued with some levelling off until 1997. Since then there has been an increase in the rise rate, but the reason for this has remained obscure. A difficulty in interpretation arises from the fact that pressures in the undisturbed system before the bores were introduced are not known. The activities of some of the geysers on Whakarewarewa's Geyser Flat gradually began returning towards their former levels, with eruptions reaching heights and frequencies comparable to their earlier values. However, this seeming recovery has not been maintained and concerns continue that, since 60% of the area of the Rotorua geothermal system lies outside the Exclusion Zone and therefore is still being tapped, the main geysers remain under threat. Indeed, other geysers at Whakarewarewa have not revived, and it is possible they may never do so. The recent recovery in geothermal aquifer pressures seems to have caused rather uneven effects at different places in the Rotorua geothermal system.

WHAKAREWAREWA

The Whakarewarewa geysers have been well-documented in Lloyd's 1975 publication *Geology of Whakarewarewa Hot Springs*. Some of the information below has been extracted from that little volume, which is accompanied by a detailed map of the area. Other published documents have been used in this report, as well as personal observa-

[1] Much of that work has been published in *Geothermics* Special Issue vol.21, nos. 1 and 2, (1992), with an update in *Geothermics* Special Issue vol. 29 nos. 4 and 5, (2000).

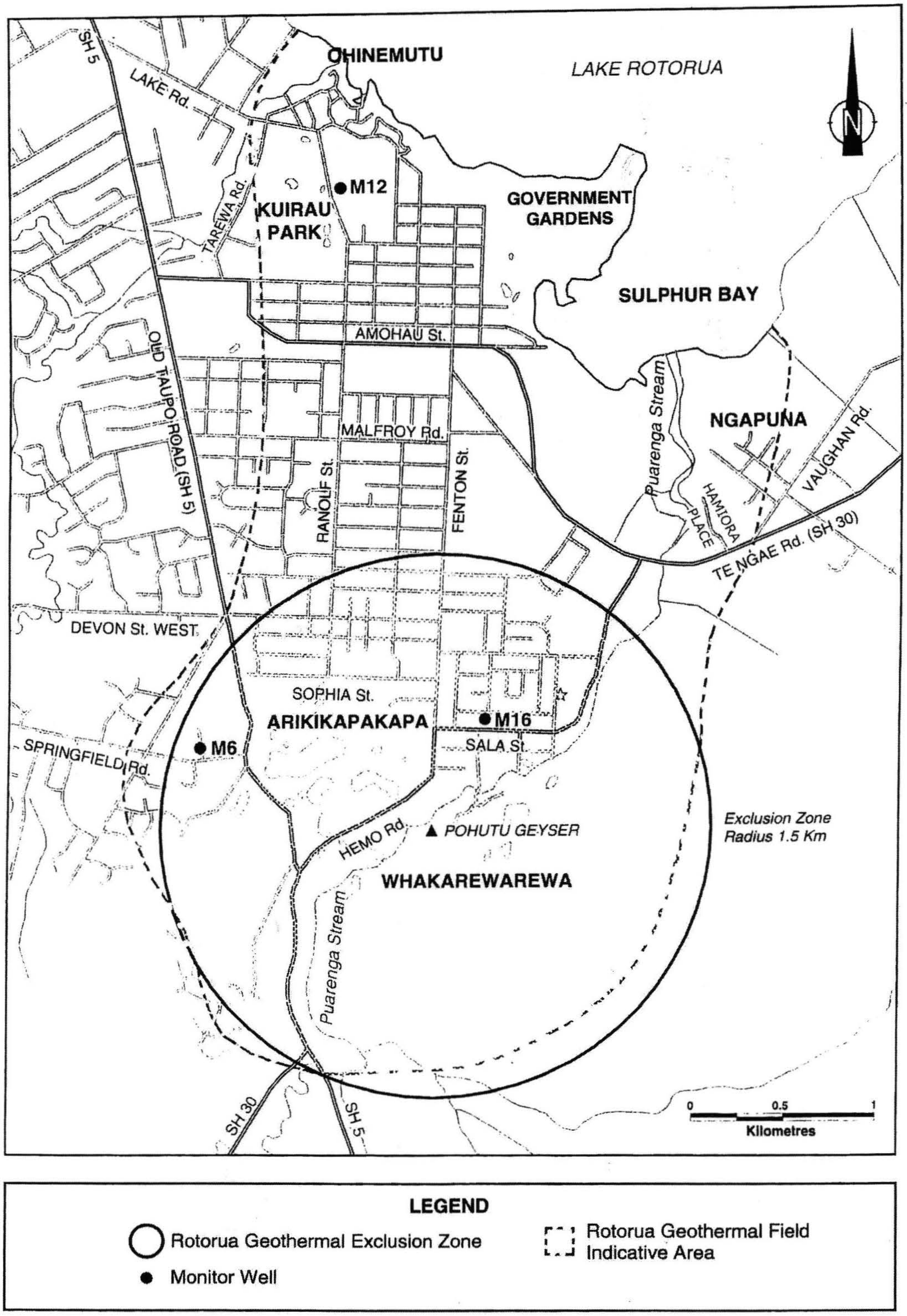


Figure 5. Part of Rotorua city showing the approximate boundaries of the Rotorua geothermal system and the Rotorua Geothermal Exclusion Zone, and the locations of monitor wells, and roads and areas mentioned in this paper. [Bay of Plenty Regional Council, 1999, p. 4]

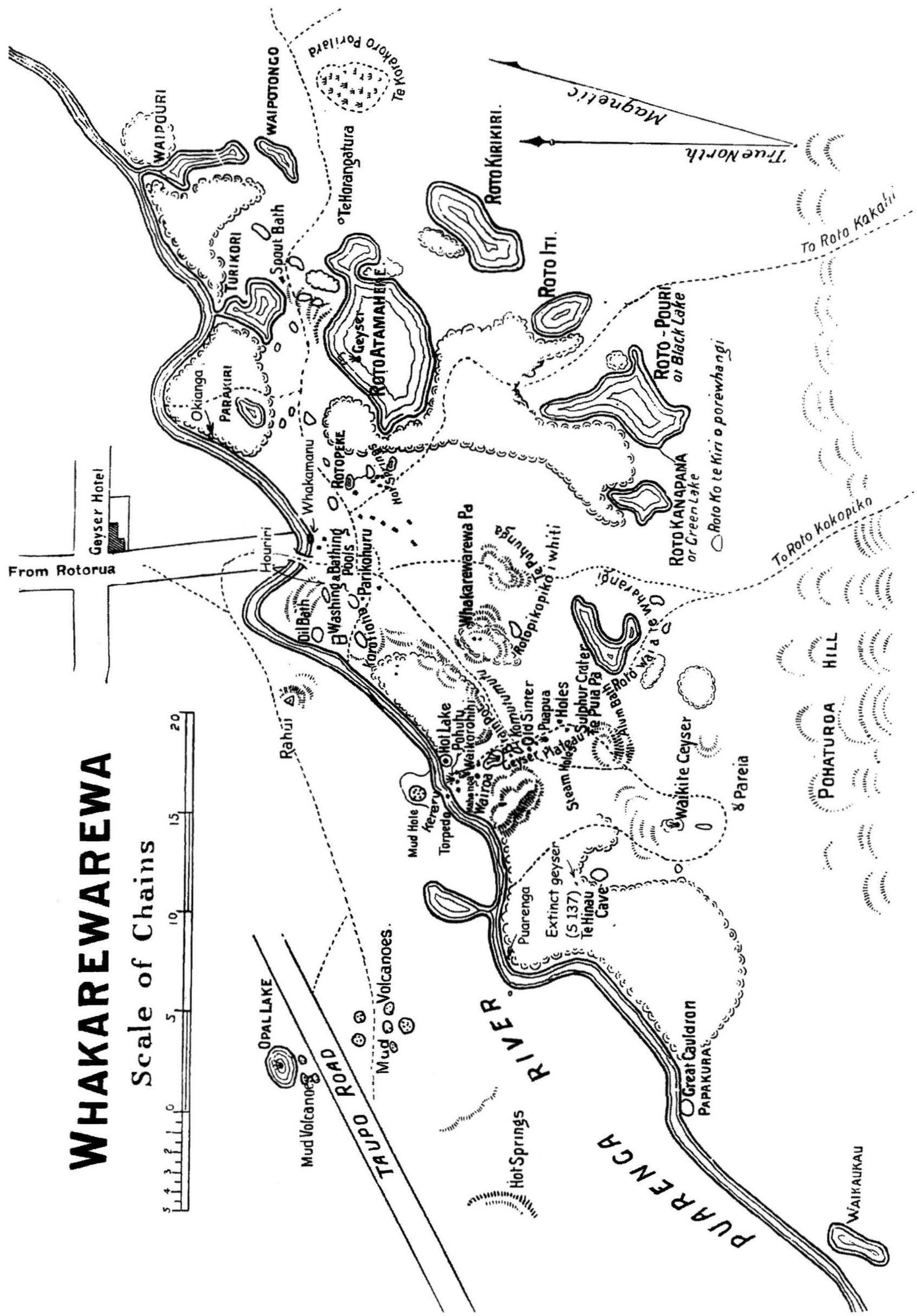


Figure 6. Whakarewarewa thermal area, as mapped by photographer Josiah Martin, circa 1891, with additions by R.F. Keam from the map by E.F. Lloyd, 1975. [Original map published in Cunningham, 1893, between pages 28 and 29]
Note: 1 chain = 66 feet or 20.1268 metrres.

tions of the authors and other parties.

The concentration of springs at Whakarewarewa can conveniently be subdivided into five areas, each of which has as its focus a number of boiling alkaline chloride springs and geysers. These concentrations can be identified as Geyser Flat, the Waikite group, Papakura group, Kainga group, and Roto–a–Tamaheke. The groups have no sharp boundaries, and between and around them are numerous smaller springs and mud pools which merge into those of other groups.

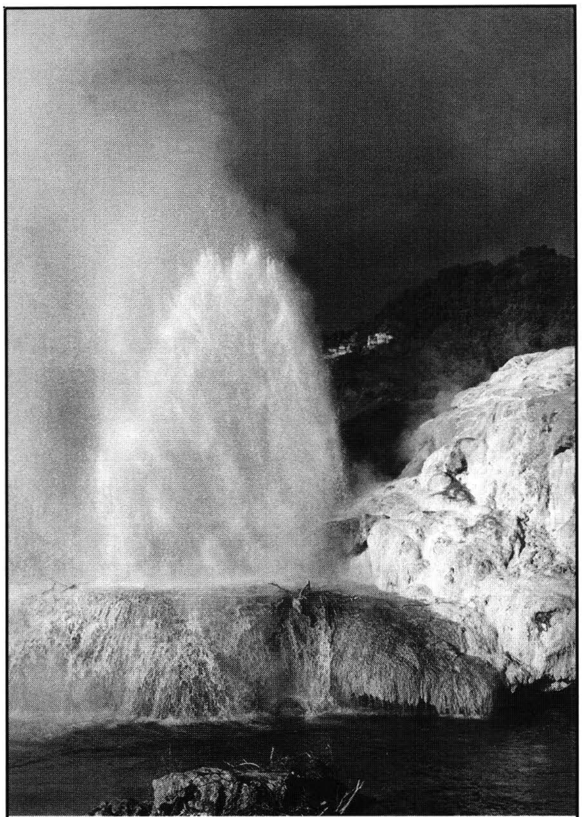


Figure 8. Kereru Geyser. Note the dark color of its sinter compared to that from the Geyser Flat features at upper right. (see Footnote 3). [E.F. Lloyd photo, 1965; cf. Lloyd, 1975]

Geyser Flat group

On or adjacent to the gently sloping sinter sheet known as Geyser Flat lie six well–known geysers which are either currently active or have been active within the last eighteen months. Listed in order from north to south they are **Kereru, Prince of Wales Feathers, Pohutu, Te Horu, Waikorohihi,** and **Mahanga** (Figure 7). All except Kereru lie along an obvious fracture which Lloyd named "Te Puia (i.e. The Geyser) Fault", and he showed with fluorescein dye that most of the fault geysers' conduits are connected.

According to Lloyd, **Kereru** ("Wood Pigeon") (Figure 8): "...erupts a fan-shaped jet at irregular intervals to a height of 10 metres, lasting approximately 30 seconds, followed by recurring eruptions to 3 metres, which sometimes expel pale green water. The colour is believed to be due to iron (ferrous) sulphate which is reduced by hydrogen sulphide to iron sulphide (pyrite). Grange[2] mentions that Kereru sinter contains pyrite, explaining its black colour — so different from the sinter deposited by the geysers on higher ground that Kereru is believed to be independent of all other springs on the Te Puia Fault."[3]

Figure 7. Geyser Flat, showing Prince of Wales Feathers Geyser (left), Pohutu Geyser (centre) and Waikorohihi Geyser (right) simultaneously in eruption. [Arthur Iles photograph, circa 1905]

[2] Grange, L.I., 1937, p.119

[3] On a visit on 8 June 2002 I [RFK] noticed that the sinter near Kereru is not so dark as it used to be. Presumably this is because deposits originating from Prince of Wales Feathers geyser and Pohutu geyser are now accumulating more rapidly there than those originating from Kereru itself.

Ashley Cody has assembled evidence that **Prince of Wales Feathers** was formed about the time when Mount Tarawera, 20 kilometres to the east, erupted in 1886.[4] It now often plays in a column to heights of between 8 and 12 metres almost continuously, only pausing to catch its breath a small proportion of the time (Figure 9). However, it sometimes exhibits an entirely different behaviour where it might erupt for a few seconds to only about 2 metres at intervals of a few minutes. Its jet is inclined at an angle of about 20 degrees to the vertical. Cody's evidence about its origin includes references to a new geyser being formed from a fracture in the sinter, and Lloyd and Cody have both seen similar productions of surface fractures in its near vicinity in recent years.

Pohutu ("Splashing Water") is the largest geyser currently active at Whakarewarewa and in terms of fame (but not regularity) is the New Zealand equivalent of Old Faithful. During much of the twentieth century it generally erupted in a steady jet to heights of about 20 metres and sometimes continuously for many hours (Figure 9). Its eruptions were normally preceded by those of Prince of Wales Feathers. This rose to its maximum height just as Pohutu commenced playing and usually ceased erupting before the onset of an intermittent splashing style of eruption heralded the termination of the display from Pohutu itself. The splashing stage rather resembles a smaller version of eruptions of Echinus geyser at Norris in Yellowstone National Park. Much of the discharge from Pohutu, especially in its splashing stage, falls directly into neighbouring Te Horu.

Records of Pohutu's activities during the hours of 6:00 a.m. to 8:00 p.m.were kept from 1910 for many years by a caretaker whose office was a little hut overlooking Geyser Flat. Grange notes that during 1916 Pohutu played only during January and February, that it was fairly active in 1919, was relatively quiet in 1924 with a three–month dormancy, had a record number of eruptions (613) in 1926, and was dormant from 21 April 1932 to 7 June 1934.[5] The longest continuous eruption noted during these years was 12 hours 10 minutes on 13 May 1920. At one period when eruptions were infrequent a flag was raised to alert visitors when Pohutu commenced playing so that they could proceed to Whakarewarewa to enjoy the spectacle.

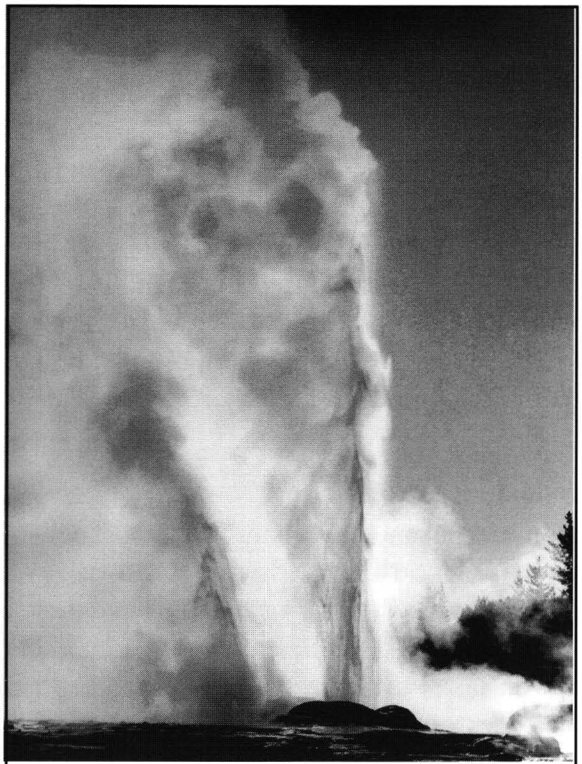


Figure 9. Pohutu Geyser (right) and Prince of Wales Feathers Geyser. [E.F. Lloyd photo, 1960; previously published in Lloyd, 1975]

In 1998 Pohutu eruptions became much more numerous and short–lived, lasting only 1 to 3 minutes but playing 50 to 80 times each day. From 17 March 2000 it played nonstop but with eruption column heights varying; sometimes strong and about 20 metres high, at other times occasionally weakening to about 5 to 10 metres high with splashing spurts before strengthening again to its full column height. This continuous eruptive behaviour is unprecedented in historical descriptions[6] (and contrary to erroneous recent newspaper reports suggesting there was a period in the early 1930s when it had a continuous eruption lasting about 40 days).

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4 e.g. *New Zealand Herald* articles of 22–23 July 1886 about a "...new geyser playing alongside Pohutu..." and also *Otago Daily Times*, 22 July 1886.

5 Grange, L.I., 1937, p.89, p.113.

6 The first detailed investigation of Whakarewarewa was that by Hochstetter in 1859: See (e.g.) Hochstetter, F. von, "New Zealand" 1867.

Prince of Wales Feathers also erupted continuously during this time. However, on 7 March 2001, Pohutu and Prince of Wales Feathers both stopped playing for about 20 minutes, and the following day they did not erupt for at least 6½ hours. Full column displays from Pohutu became rare after that and Prince of Wales Feathers often stopped. Recently, however, guides from the Maori Arts and Crafts Institute have reported more frequent unfaltering full column eruptions lasting more than 60 minutes accompanied by full column eruptions of Prince of Wales Feathers.[7]

The impressive basin of **Te Horu** ("Cauldron"), lies right beside Pohutu and has been dormant for most of the last twenty years. In pre–bore times (i.e., before the 1960s) and up until about 1972, the boiling and overflowing of Te Horu was one of the signs an eruption of Pohutu was imminent (Figure 10). Te Horu would then erupt to about two metres height, and was once reported to have reached a height of about 12 metres. Once Pohutu was established in full eruption, Te Horu would stop overflowing and start to recede before the onset of Pohutu's splashing stage. In its more recent 'dormant' state Te Horu's water level fluctuated over a range of a couple of metres but neither boiled nor overflowed. Records of its water level changes for an interval of many months were obtained by J.T. (Jim) McLeod on behalf of the Institute of Geological and Nuclear Sciences. McLeod simultaneously recorded the activities of the adjacent geysers.

In late 1998 Te Horu's water–level cycle peaks began rising higher and higher, and in December of that year it suddenly recommenced overflowing, although without boiling. Initially these overflows were strong (estimated rate: 10 to 20 litres per second) and hot (70 to 75 degrees C), but since then its waters have gradually cooled and its overflows now occur only during eruptions of Pohutu alongside. The discharge occurs as a flow of about 2 to 10 litres per second at 58 to 70 degrees C and floods over a nearby sinter escarpment into the Puarenga stream. During Pohutu's long–continued 2000–2001 eruption Te Horu's flow was continuous but it never boiled and sometimes the discharge temperature was as low as 45 degrees C.

Waikorohihi is a small geyser with an inconspicuous vent about 20 metres south of Pohutu and Te Horu (Figure 11; see also Figure 7). Sandbags had been laid around the vent, presumably in September 1888 as part of experiments to divert its overflow and induce Pohutu to play better.[8] These sandbags are now completely sinter–encased and allow a small circular pool of water to collect momentarily above the vent. The erupted jet rises to lesser or greater heights according to whether the pool is full or not at the instant the ejection occurs.

Figure 10. Te Horu Geyser ('The Cauldron') beside the sinter formations around the vent of Pohutu Geyser. [W.B. & Co. (W. Beattie photograph), protected 1 October 1912]

[7] During June 2002 the observations of some of the authors were as follows: On 8 June Lloyd and Keam witnessed a full column eruption of Prince of Wales Feathers with no full column stage of Pohutu. On 26 June Cody witnessed a steady full column eruption of Pohutu lasting more than 90 minutes accompanied by a steady full column eruption of Prince of Wales Feathers.

[8] Malfroy, C., 1892, p.583.

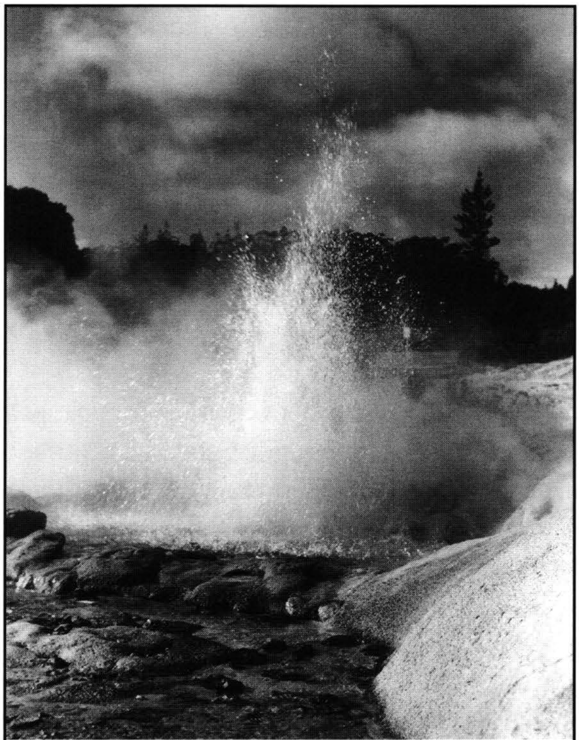

Figure 11. Waikorohihi Geyser. [E. F. Lloyd photograph, 1958; previously published in Lloyd, 1975]

During the 1980s and early 1990s Waikorohihi typically erupted 10 to 20 times a day, with a splashing pulsating eruption 5 to 8 metres high and with an overflow of about 10 litres per second. It has been known to splash as high as 13 metres. An eruption could last an hour. However, since late 1998, and coinciding roughly with resumed overflows of Te Horu, Waikorohihi has very rarely erupted, and between April 2000 and March 2001 there was no report of anyone having seen it in action. On 8 March 2001 an eruption was seen but this has not been repeated since then (to mid June 2002).

Mahanga, about 3 metres south of Waikorohihi, commenced its surface discharges in October 1961, although its vent was well–formed before then and the name was possibly in use from pre–European times. Until the year 2000, when concentration of discharge from the Te Puia fault vents into Pohutu and its satellites began, Mahanga erupted every few minutes to heights of from 2 to 6 metres (Figure 12). In so doing it produced a series of jets each of which might be held for a few seconds at a time. This somewhat resembled Waikorohihi's behaviour. Before 1961 Mahanga's partially blocked vent intermittently discharged a jet of steam with a hissing sound. It clearly had in still earlier times been a geyser because it was surrounded by bulbous geyserite. The shape of one bulb had led to its being given the informal name "Boxing Glove." The name Mahanga means "The Twins" and may originally have referred to it and Waikorohihi geyser or else to it and a now extinct vent three metres to the west. From early 2000 Mahanga geyser has had an erratic history. It ceased playing for a year, but resumed briefly in mid April 2001. It ceased erupting again, played on 8 May 2001, and was then quiescent until 28 March 2002. On that day and also on 30 March it played all day approximately every minute for 10 to 20 seconds, 3 to 5 metres high. From then until the present (mid June 2002) it has reverted to quiescence.

The currently inactive **Wairoa,** next to the south along Te Puia Fault, was once the tallest geyser at

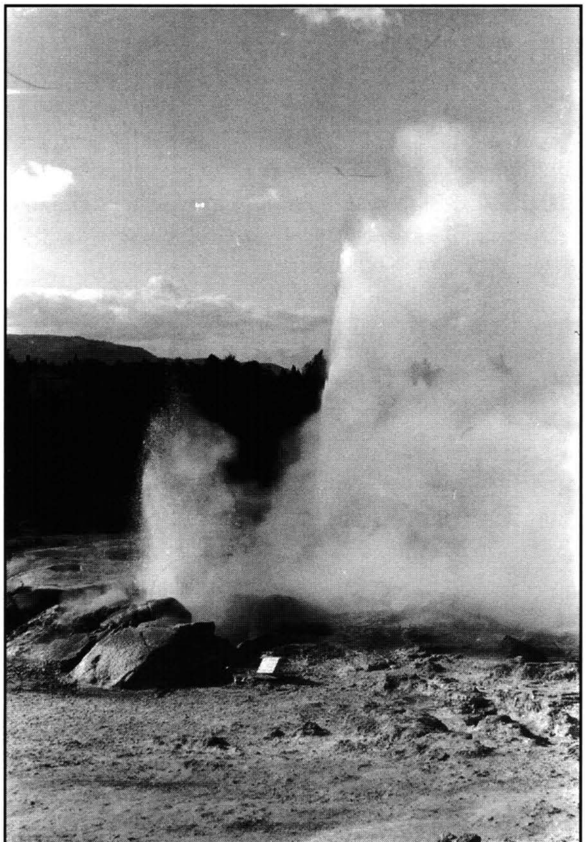

Figure 12. Mahanga Geyser (foreground) and Pohutu Geyser. A view looking northwards along Te Puia Fault. [R.F. Keam photograph, 1715 hours, 22 January 1963]

Figure 13A. Wairoa Geyser. [Charles Spencer photograph, circa 1905]

Whakarewarewa, but it has not erupted since 1961 (Figures 13A and 13B). According to Lloyd [1975, p.16]: "A typical Wairoa eruption ejected a splendid water column to a height of 60 m for a minute or so, followed by smaller, spasmodic shots." It erupted naturally for a time after the 1886 volcanic eruption, but by the early 1900s responded only when 'soaped'. Soapings were restricted to special occasions such as when visiting dignitaries were being entertained. A wooden cover was locked in place over its narrow funnel-shaped vent to prevent unauthorised triggering, and the very survival of this cover for some years indicates that no natural eruptions were occurring at this time. One of us [RFK] has observed two or three soapings and can vouch for the fact that the eruptions were extremely impressive. The initial soapy flood poured over its lip while a frothy column commenced rising gradually above the vent. With an increasing roar the column then steadily climbed for about 30 to 40 seconds and having reached its culmination just as steadily subsided in a comparable length of time. For several years alkaline chloride water has been inaccessible within the vent of Wairoa. Its return, and the consequent possibility that its geyser activity would revive, would be one of the critical signals that the Rotorua geothermal system was recovering from the depleted state it was in when all the bores were operating. Hope can perhaps be kept alive by the fact that alkaline chloride water was indeed found in Wairoa for a few weeks in 1989. In its current 'standard state' its water boils powerfully and continuously deep within its vent, but the high sulphate content (about 400 ppm[9]) and low chloride content (about 45 ppm) indicates that it is dominantly steam heated condensate and groundwater at present.

Three apparently extinct geysers can be found along 110 metres of the Te Puia Fault south of Geyser Flat. In order they are **Waiparu**, **Puapua,** and **Waiporu**, which is the most southerly vent. While no records have been found to indicate that the first and last erupted in historical times, Puapua is different. This is a large, open, deep basin, somewhat resembling Te Horu, and like the latter has a water level that fluctuates cyclically

[9] "ppm" — "parts per million"

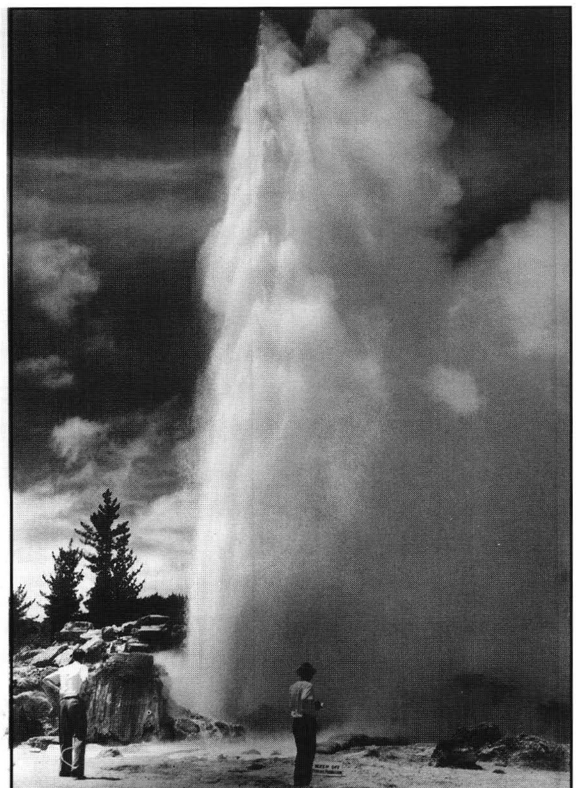

Figure 13B. Another view of Wairoa Geyser. [E.F. Lloyd photograph, 1961; previously published in Lloyd, 1975] and remains very hot. Puapua boils strongly every 10 to 15 minutes while its water level rises. On the inner slope of its sinter basin a little above its high water level is a small vent, and intermittent small eruptions (sometimes to as much as 1 metre) occur from this when Puapua water ceases boiling and begins to fall. During 2002 such eruptions with small total discharge, lasting about 1 minute, and recurring at intervals of 10 to 15 minutes, have frequently been observed.

Figure 14. The Komutumutu sinter formation before its destruction. [E.F. Lloyd photograph, 1961; cf. Lloyd, 1975]

Around these old southerly vents one sees extensive deposits of sinter, now broken and decaying. Evidently activity here had once been intense. Lloyd identified a band of pumice incorporated within the sinter as being an airfall deposit from the Taupo Volcanic eruption (circa AD186). This indicates that geysers here (and not necessarily just the named vents) were active before and also well after that date. The Taupo pumice weathers at Whakarewarewa in a characteristic way and provides a useful time marker elsewhere also in the sinters.[10]

To conclude the commentary on features lying along Te Puia Fault, one must mention **Torpedo** 'geyser' which is situated near Kereru geyser. It was inadvertently omitted on Lloyd's map. Torpedo was active until the 1950s or 1960s but had not been noticed after that until it resumed noisy explosive eruptions at irregular intervals during 1989. It is not a true geyser but a vent beneath the surface of the Puarenga stream from above which, at irregular intervals, stream water would suddenly be projected to heights of from a few centimetres to a few metres, accompanied by a loud "Pop!" Evidently steam pressure would build up in the feeding channels of this feature until it exceeded the hydrostatic head of the overlying stream and sediments, then, at this moment, the steam would suddenly force its way out of the vent, throwing the overlying water into the air and producing the sound by immediately imploding in the cold water. There is some evidence that at different times different sub–stream vents were involved. At the present time the stream above its site shows gas bubbling up continuously, and guides report that during 2002 it has several times bumped noisily and caused upwelling of the stream surface.

Te Komutumutu, ("Brain Pot"), was a vent surrounded by a remarkable, near–circular, thirty centimetre high sinter cone just east of Te Puia Fault (Figure 14). It had possibly once been a geyser but the vent had been sealed with sinter in recent times. In its active stage, some centuries ago, tradition records that after an inter–tribal fracas the vanquished local chief was put to death and his head cooked in the feature. In the early to mid twentieth century, the sinter cone, which was in a vulnerable position very close to tourist paths, was broken from time to time, and repaired in a rather amateurish way with cement. But in the late 1970s a local villager attacked it in a fit of anger, reputedly because of its symbolism as a constant reminder of tribal shame and humiliation. Notwithstanding the law against inflicting such damage on a geothermal feature, no complaint was made, or if made was not followed up — presumably because of the sensitive cultural aspects at root. Small fragments of the former cone can be recognised amongst the general decayed sinter

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[10] Lloyd, E.F., Personal communication.

lying in its vicinity, and a portion of its patchwork reconstruction still stands.

Lloyd mentions several sporadic outbreaks as having occurred from two vents in the general vicinity of Te Komutumutu and Wairoa. One is an unnamed vent 16 metres north–west of Te Komutumutu that had a series of eruptions to 0.6 metres height during the 1970s, but it has not erupted since. A nearby vent erupted at least once in 1912. The nineteenth century scientist Hochstetter depicted geysering from another vent several metres south of Te Komutumutu, but, as Lloyd notes[11], the original Hamel photograph on which the woodcut is based shows no eruption.

A small unnamed geyser existed in the 1950s on Geyser Flat about 20 metres west of Waikorohihi. It played to a height of only about 10 centimetres and was very inconspicuous.

Kainga group

In the Kainga group in Whakarewarewa Maori village the large alkaline chloride spring **Parekohoru** is used as the main cooking pool. (Of course the villagers now have electricity, but natural heat is cheaper and using it for cooking is traditional.) This pool, which simmers gently in its 6 metre diameter and roughly circular basin, lies some 200 metres north–east of Geyser Flat. It has been known to erupt, and the sinter terrace radiating from it is evidence of long–continued discharges. In recent times the overflow has been confined to an artificial channel and the mineral water is led to some baths. During the 1990s Parekohoru has suddenly boiled and overflowed in large surges on many occasions, usually accompanied by strong ground tremors that could be felt by anyone standing nearby. During the 1950s such surges and accompanying ground shocks were a regular feature occurring then at intervals of approximately one hour.

About twenty metres from Parekohoru are the **Korotiotio** geysers. They rise from connected basins surrounded by irregular massive sinter accumulations. These geysers were casualties of the bores–induced decline and had ceased surface overflows by the early 1980s. However, several sudden hydrothermal eruptions, much more powerful than the normal geyser eruptions, occurred in 1982. While 'normal' activity has still not resumed, since 1989 geysering has recommenced. When active Korotiotio now overflows and erupts 5 to 8 metres high for several minutes and there may be several recurrences a day. The main difference now is that the discharge flows underground to the Puarenga Stream instead of across the surface.

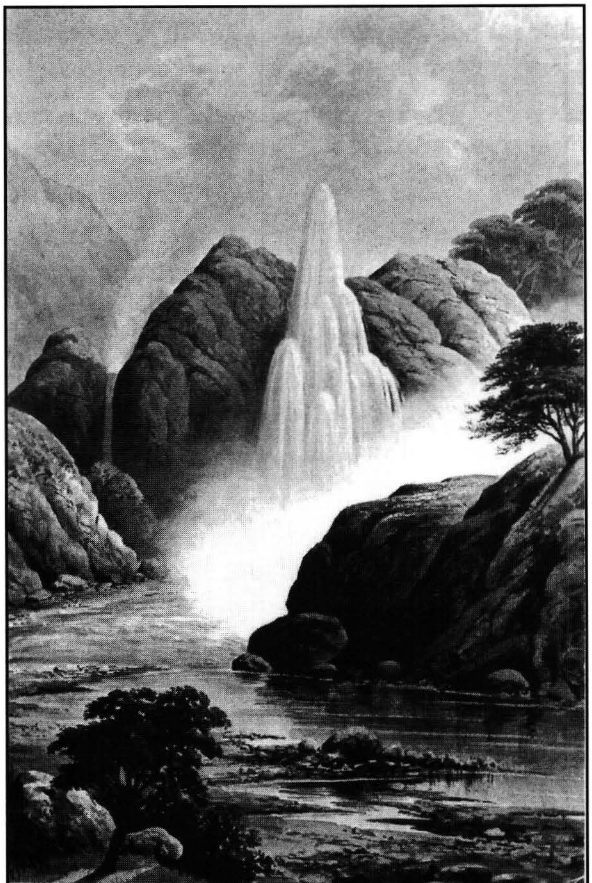

Figure 15. "Whakanapanapa" geyser. Water–colour by J.C.B. Hoyte, early 1870s. Recently identified by R.F. Keam as being Whakamanu Geyser — after taking into allowance some license on the part of the artist, who has swung the overflow of part of Roto–a–Tamaheke lakelet into view to form the hot waterfall depicted. In reality this overflow is out of sight 10 to 20 metres up a side valley to the left. [Hooker and Co., 1968, front cover picture]

The nearby **Houriri** and **Te Haroharo** are also small geysers but no eruptions have been seen from them for many decades. A further 50 metres east of these lies the **Whakamanu** geyser (Figure 15), on the south bank of the Puarenga Stream and just

[11] Fleming, C.A., 1959, p.167, especially Lloyd's footnote.

downstream from the Tryon St. bridge. This erupted to 30 metres on rare occasions when stream level was low. I [RFK] have seen only one eruption and that was in February 1950. The event was clearly unusual and occasioned much discomfort to some neighbouring villagers because its muddy discharge was falling onto at least one adjacent house roof and also some gardens. For some time the pool was partly submerged beneath the stream and had become quite inconspicuous. In 1996, just downstream from the bridge, a thick gabion barrier of boulders was stacked into place along the edge of the Puarenga, presumably to prevent erosion of its banks during rare floods. This has had the effect of isolating Whakamanu once more from the stream. Presently it boils continuously above the vent and its discharge flows through a shallow pool and into the stream.

A small geyser informally named **Okianga** (S488), after a tribal elder who lived nearby, can be found in the Puarenga Stream valley downstream from Whakamanu. Okianga generally plays to a height of about 2 metres every half hour or so, although it experiences periods of dormancy from time to time. It has not played since about late 1999 although the surrounding ground has numerous boiling outflows and Okianga itself continues to discharge. In the soft rock surrounding its small basin channels were cut, decades ago, possibly for bathers who wished to soak in a mixture of stream water and the overflowing geothermal water — and presumably at a time when it was not behaving as a geyser.

Roto–a–Tamaheke group

From the main village access can be gained to the Roto–a–Tamaheke area by proceeding to the east rather than to the west towards Geyser Flat. Roto–a–Tamaheke itself is a large, usually hot lakelet bordered by an extensive sinter flat on which are many boiling springs and several unnamed geysers. Nearby, and extending south to the foot of a high ridge, there are also mud pots and many coloured pools. The Roto–a–Tamaheke area is surprisingly little visited, considering the wealth of its activities. A few years ago paths were built through this area to enable better viewing, with the boardwalks spanning boiling springs and decaying ancient sinter sheets.[12]

One of the features that occasionally erupts near the lakelet is the largest geyser I [RFK] have seen at Whakarewarewa. The large eruption (in August 1962) was induced and is estimated to have reached more than 60 metres in height. It was much more massive than the comparably tall eruptions of Wairoa geyser. A neighbouring vent at Roto–a–Tamaheke erupted simultaneously to a lesser height. Several other springs here occasionally exhibit geyser action. The whole area at Roto–a–Tamaheke has undergone dramatic and amazing changes in its surface discharges and heat flow. These have never been written up in detail and deserve an article in their own right. One such change has been occurring over the past few years, beginning in late February 1996. Noises like explosions disturbed local villagers one night, and ground trembling lasting several minutes was felt, but when the area was inspected in daylight there was no surface sign of anything violent having occurred. However, the villagers' mineral hot bath, which drew its supply from the adjoining springs and lake, was cool and muddy for several days afterwards. What became apparent was that water level in springs adjacent to the hot lake had receded and water was flowing from the lake into the spring basins instead of the other way. Evidently the noises heard had been *implosions*. Pressures in the geothermal aquifer in the vicinity of Roto–a–Tamaheke for some reason had fallen below the hydrostatic head of the lake, cooler water had entered the spring vents, steam condensation had occurred, and a runaway process of surface water pouring underground had begun. On a visit on 8 June 2002 Lloyd and Keam found that water levels in all surrounding springs were a metre or more below the bordering sinter flat, that lake level was about 30 centimeters below normal, that gentle boiling in one of the bordering springs was the only sign of activity, and that lake discharge temperature at the outflow flume was only about 25 to 30

[12] Particular care is needed when using these paths because maintenance in any area not commanding much attention tends to become neglected.

degrees C.[13] A similar recession and cooling had happened in the 1940s, but a recovery of activity occurred in the late 1950s. It is suspected that cold Puarenga stream water might be able to find its way into the geothermal system here when geothermal aquifer pressures are low and such could readily trigger the observed changes.

Waikite group

South–west of Geyser Flat lies the Waikite group. Its main feature is **Waikite** Geyser, which is surrounded by an imposing cone-shaped sinter mound ten metres high and fifty metres in diameter (Figure 16). In the 1880s this geyser was often active and in the course of laying out the streets for the then planned town of Rotorua the road builders arranged to construct the main north–south road so that it would lead directly towards Waikite. Waikite has always been erratic with sometimes several years passing without eruptions. However, during the geyser's active phases, eruptions occurred at intervals of some hours and consisted of discrete splashing discharges to heights of up to about 10 metres above the top of the cone. Waikite has not erupted for more than thirty years, but recently the sound of boiling within it has led to speculation that it might one day revive. Indeed, water was discovered boiling at shallow depth within the vent in January 1997, and it was soaped (with permission) to test whether or not this represented a real revival. No eruption was able to be triggered. A clue as to what was happening was provided by the state of two springs on the northern slopes of the cone. These springs had been active in 1951 at a time when Waikite was able to be triggered. Clearly at that time geothermal water was standing at least as high in the geyser tube as the level of those springs, but in 1997 it must have been lower. What, therefore was the nature of the boiling water which was found in the tube at a higher level than the springs? The conclusion reached was that this shallow boiling water was not connected with the geothermal aquifer but merely condensate trapped within rocks that vandals had tipped into the geyser vent and that the boiling sound was occasioned by steam bubbling through the condensate from much deeper within the blocked tube. A water sample was retrieved, tested, and found as anticipated to be acid water without any chloride content.

A fracture, rather like Te Puia Fault, extends southwards across the sinter from Waikite towards a smaller split cone surrounding **Pareia** geyser. In the 1950s–1970s this played every 8 to 20 minutes, for less than a minute, to about three metres above the surface of the sinter cone. From 1981 it remained dormant until it suddenly revived in November 1999. Over the following few months it was erupting 2 to 3 metres high at intervals from 20 minutes to more than one hour, with overflows lasting 1 to 2 minutes. These eruptions continued until late 2001, but in 2002 it has not been reported erupting. Pareia's resumed activity would be a good omen for the eventual recovery of Waikite itself. Along the fracture between Waikite and Pareia there are also other geyser vents. One is

[13] ADC measures lake temperature at its eastern end every month and usually finds it to be 38 to 42 degrees C. By June 2002 hot outflows had recommenced from springs at the eastern end of the lakelet.

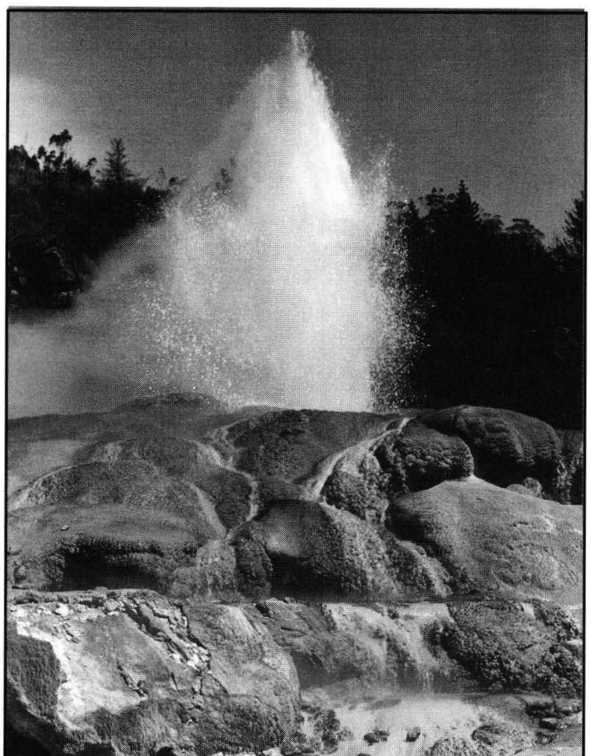

Figure 16. Waikite Geyser (Whakarewarewa). [E.F. Lloyd photograph, 1966; cf. Lloyd, 1975]

right beside the active vent of Waikite but is almost full of debris and it is not known if in historical times it partnered eruptions from the adjacent main vent. Other vents along the fracture were seen in activity when Waikite was playing in December 1951 [RFK observations].

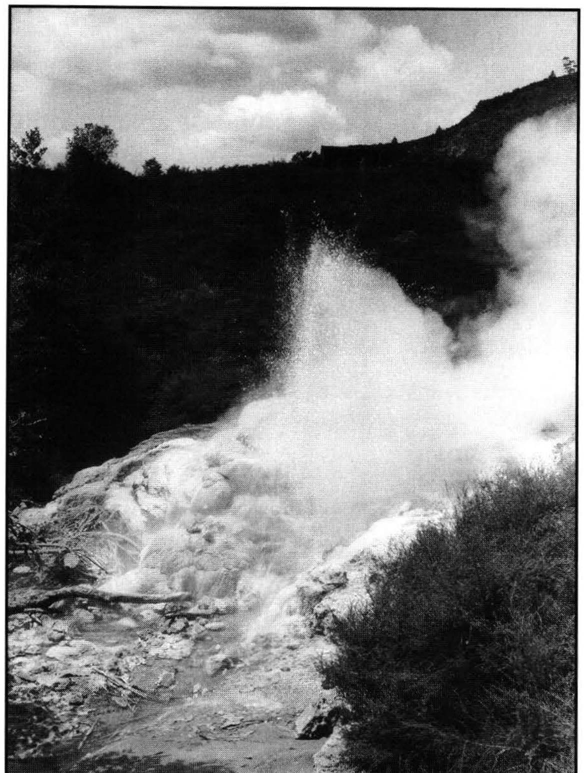

Figure 17. Papakura 'geyser.' It was the cessation of this spouter's eruption that first drew attention to problems caused by the withdrawl of geothermal fluid from bores within the city. [E.F. Lloyd photograph, date uncertain]

Papakura group

At the western extremity of Whakarewarewa lies a small group of alkaline chloride springs including the now inactive **Papakura** geyser (Figure 17). Since at least the 1890s and until 1979 this was the one feature that could be relied upon to be seen in eruption.[14] It was indeed a perpetual spouter, for most of that time ejecting successive bursts to heights of from five to ten metres at intervals of a few seconds from a vent about half a metre in diameter. A generous coating of siliceous sinter covers the surroundings. While geysers such as Waikite and Te Horu quietly ceased their activities in response to the dwindling geothermal aquifer pressures as geothermal bores proliferated, not all that much notice was taken of their quiescence because of the habitual variability of these features. But, in March 1979, when Papakura Geyser suddenly stopped, it became clear that all was not well with the Rotorua Geothermal System. This demise and the later Korotiotio hydrothermal eruptions drew attention to the failures of Korotiotio, Te Horu, Wairoa and Waikite geysers, and alerted scientists to the fact that Pohutu itself, and with it the profitable tourist industry associated with the geysers, was under threat. Lloyd for some time had been expressing concern to members of the local council about the threat posed to natural geothermal activities by domestic and other bores drawing geothermal fluid for heating and recreation, but here was the signal that provided the best opportunity for him to raise the alarm. His position as District Geologist at Rotorua at the time gave him a public voice and Lloyd was able to raise the matter with the authority of his office. Many scientists at first were still inclined to discount a link between the failure of the Wairakei Geyser Valley geysers and the withdrawal of geothermal fluid to supply the Wairakei Geothermal power station, and therefore disputed the existence of a causal link between the Whakarewarewa decline and the exploitation at Rotorua. But in July and August 1986 further dramatic evidence of imminent geyser failure manifested itself when Cody noticed that eruptions from Pohutu had started to discharge steam with very little water. Cody alerted Lloyd and others at the Rotorua office of New Zealand Geological Survey and Lloyd's concerns were backed by the respected former Government Volcanologist, Jim Healy. The issue of preserving Pohutu and the other Whakarewarewa geysers then quickly became one of general public concern.

Here is not the place to detail the debates that

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[14] The only recorded dormancies or irregularities are the following: A dormancy of three months in 1924 (Grange, L.I., 1937, p.89); a dormancy of several hours on 8 February 1927 (Whakarewarewa Caretaker's records, Institute of Geological and Nuclear Sciences file U16/466 General); a dormancy for one day on 23 October 1953 (Lloyd, E.F. diary: personal communication from Guide Rangi); ejection of mud on one occasion (Lloyd, E.F. diary).

ensued, but there was a certain irony in the fact that public attitude outside Rotorua seemed to be largely in favour of shutting down the bores, while within Rotorua there was a split between the domestic bore owners who adamantly opposed a shut down and those who relied more directly on the tourist dollars from sight–seers. It took a few years before the necessary monitoring was implemented and subsequent actions to preserve the geysers were taken.

So far as Papakura geyser is concerned the successes of the campaign came too late. Since its lapse into quiescence Papakura's vent has remained inactive, and for many years now it has been occupied by a calm tepid pool (38 to 45 degrees C) at a level generally 0.5 to 1 metre above that of the adjacent Puarenga stream. Clearly its failure in 1979 signalled the encroachment of cool groundwater into shallow reaches of the geothermal system at the location of Papakura and recent increases in geothermal aquifer pressure starting in 1988 have been inadequate to drive the higher density cold water back. No doubt the fact that the subsurface rock has been cooled is also an obstacle. Even more widespread failures and cooling occurred in the Roto–a–Tamaheke group during 1985–1989, but that group was later able to recover at least partially, until it was overtaken by the changes that began in 1996.

Miscellaneous

The vents, cones, and mounds of several other extinct geysers are evident at Whakarewarewa. The below-surface geometry of **Te Waro** geyser on Geyser Flat was rather rashly explored by Martin.[15] His brief description was published in 1907 by Wohlmann[16], and reads: "The bottom of the shaft is 15 ft [4.6 m] below the surface, and it opens out into a chamber 12 ft [3.6 m] long and 9 ft [2.7

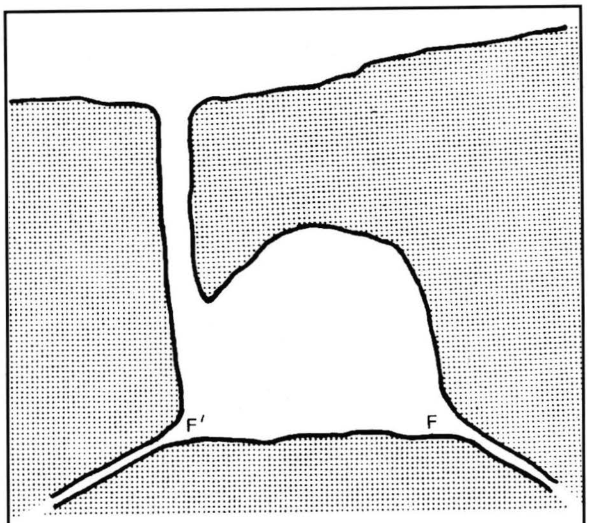

Figure 18. Josiah Martin's sketch of the accessible plumbing of Te Waro extinct geyser. [Lloyd, 1975; adapted from Wohlmann, 1907

m] high, as shown in the above diagram. (see Figure 18) In the floor of the chamber are two fissures, one of which, F, is supposed to connect with Pohutu Geyser, and whence come the rumblings of fiercely boiling water."

Te Waro's vent has since disappeared, apparently having been blocked, and its site is now covered with sinter.

Another extinct geyser (S137), which is hidden in scrub upstream of Geyser Flat, and very difficult to find, can be entered in a similar manner. Its internal accessibility was first tested by Lloyd and W. Crafar[17] in the 1970s and by Cody in 1984 in the course of general surveys of the geothermal features at Whakarewarewa. Entering it is a somewhat eerie experience. The vent has a vertical tube that is 4 metres deep, with a cavern at the base about 1 metre high and 1.5 by 2 metres in area. A basin immediately beside it, and reached through a small cave from the main cavern, still contains water at 85 degrees C. In 1967–1968 this basin had a sinter roof with a narrow vent capping it at the surface, but by 1984 the carapace had collapsed to create the opening about 3 metres in diameter that is to be seen there today.

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15 "Mr Martin" was certainly the photographer, Josiah Martin, who in the early 1890s prepared the map of Whakarewarewa that is used as the basis for Figure 6 in this article. It appeared in the Thomas Cook & Son publication "New Zealand as a tourist and health resort", 1893, 154p.

16 Wohlmann, A.S., 1907, p.27, and quoted in Lloyd, E.F., 1975, p.12.

17 W.F. Crafar, then a technician with N.Z. Geological Survey.

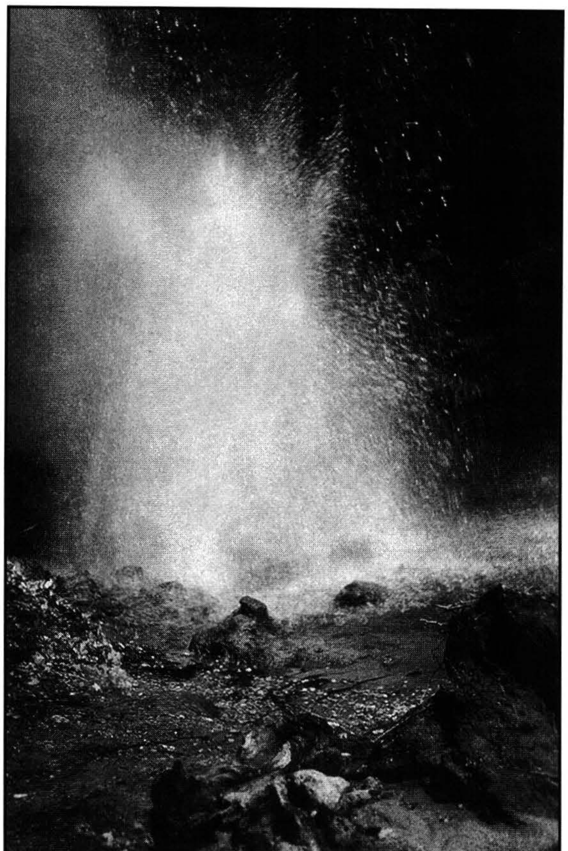

Figure 19. Puarenga Geyser. [historic photo, photographer unknown, circa early 1930s, not previously published]

Other presently inactive geysers include **Puarenga,** 90 metres west of Geyser Flat on the south side (i.e., the right bank) of the Puarenga Stream. This broke out in the 1920s and was active for some months (Figure 19).

ELSEWHERE IN THE ROTORUA GEOTHERMAL SYSTEM

In addition, there are many geothermal features in and around the city, in parks and churchyards in the areas comprising Ohinemutu, Kuirau Park, the Government Gardens, and Sulphur Bay shoreline.

In Kuirau Park the feature informally named **The Mayor's Mouth** by Cody (spring S715) geysered during April to May 1999, after a dormancy of eighteen years[18], and reached a height of 3 or 4 metres for a duration of one minute every forty minutes or so. Several hot springs had existed nearby at Tarewa Rd, and were marked on maps in the 1930s, 1953 and 1967. Houses were erected in the vicinity in the 1960s. The joint double garage of two contiguous properties was built over one hot spring vent, evidently at a time when it was quiescent, with elaborate efforts having been made to eliminate the feature by filling its basin with boulders and channelling its discharge through pipes under the driveway and out of the property. As could have been expected might sometime occur, there was a resurrection of the spring. The occupiers, who were clearly not geyser gazers, complained of heat, and in November 1983 boiling water began spilling out and continued to do so for several weeks. In March 1998 a further outbreak occurred here, and when the concrete garage floor was cut away the concealed basin was revealed. A neighbouring spring also became very active and both erupted 5 to 8 metres high repeatedly, flooding the surroundings with muddy scalding water that swirled up around the house. Altogether four dwellings had to be removed and the land sections were incorporated into the contiguous Kuirau Park. The thermal springs have now been fenced off and left to their own devices. Some control has been achieved by surrounding the two springs that erupted with a 1.5 metre high compacted earth barrier that will prevent it flooding adjacent properties.[19] Whether the revival can be attributed to the rise in aquifer pressure that has followed the bore closures is uncertain. E.F. Lloyd [personal communication] suggests that part of the apparent revival here might have been due to the effects of subterranean leakage from a faulty and now grouted geothermal well. This might also have had some connection with a significant hydrothermal eruption that occurred in Kuirau Park in January 2001. About 1200 cubic metres of debris were thrown from a muddy acid pool (S721). The outbreak lasted about four minutes and reached heights of about 100 metres. Boulders up to 1 metre in diameter were thrown

[18] It erupted from 9 – 17 November 1981.

[19] At Whakarewarewa Maori village it is an accepted risk that geothermal changes could cause dwellings to become uninhabitable. Maori have lived there by choice from pre–European days. In contrast, at Tarewa Road the Rotorua District Council had some responsibility for ensuring the land was suitable for dwellings.

70 metres and a fine fallout of mud drifted downwind dirtying cars and buildings to a distance of 1 kilometre. Interestingly, the ejecta was found to contain blocks of a prehistoric eruption breccia.[20]

In the Government Gardens are situated the now extinct **Malfroy Geysers**. There were two flowing springs (**Oruawhata** and **Chameleon**) which Camille Malfroy, the government engineer in the thermal district from 1886 to 1896, converted into three artificial geysers by confining the discharges from the natural vents in earthenware pipes. Not far away lies **Whangapipiro** (or **Rachel Spring**) whose surplus waters fed the adjacent Blue Baths (of nostalgic recollection to the writer – RFK). It has been known to misbehave, erupting its contents over the adjacent lawns and dismaying the maintenance people responsible for keeping the Government Gardens bowling greens in good condition. In the 1990s it frequently boiled and overflowed, but this has stopped since late 2000 and the water is now calm. Its temperature is about 95 degrees C and it lies about 1 metre below overflow level.

Ohinemutu

This seems to have been the original settlement of the Maori people in the Rotorua district and is an area of intense geothermal activity along the shore of Rotorua lake. It was the site of the first Missionary effort in the district in 1831. In 1835 a Mission station was established near here but within a few months this was destroyed during inter–tribal fighting. During the 1860s there was a spectacular geyser (**Waikite**[21]) at the head of the little bay at Ohinemutu[22], but it was not seen in eruption during the twentieth century (Figure 20). It might have been one of the features that temporarily burst into action during the disturbances accompanying the 1886 Tarawera eruption. Other ephemeral geysers have broken out from time to time at Ohinemutu in recent years, and there was a much more persistent feature that was active in the 1960s. I [RFK] have seen this erupt to a height of about four metres. Whether or not this is the **Tamate Heria** geyser that used to be active in Ohinemutu about a century ago is not known. Currently there is no geyser active here[23]. Ohinemutu lies outside the 1.5 kilometers bore exclusion zone around Pohutu geyser so there are plenty of wells here still taking the life–blood of the natural springs. Unlike elsewhere in the Rotorua geothermal system outside the 1.5 kilometers circle, where punitive royalties were imposed on those drawing fluid, the Maori people of

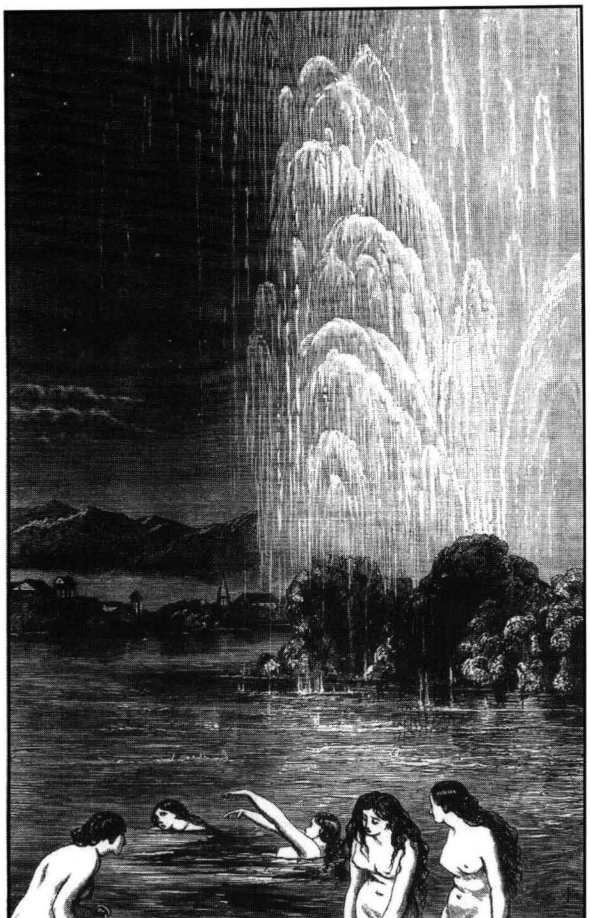

Figure 20. Waikite Geyser (Ohinemutu), Ruapeka Bay and Rotorua Lake. Water–colour by Herbert Meade, 28 December 1864. [From Meade, 1871, frontispiece]

[20] See Slako, M., 2001.

[21] "Waikite" ('To see the water') seems to have been a very popular name Maori people applied in the New Zealand thermal region, it being used for a geyser at each of Whakarewarewa and Ohinemutu as well as a whole area of surface activity some thirty kilometres to the south.

[22] See Appendix.

[23] A resident informed ADC that in about 1978 the Ohinemutu villagers concreted the vent of a geyser there because it continually splashed water over houses and cars and left a tenacious silica residue.

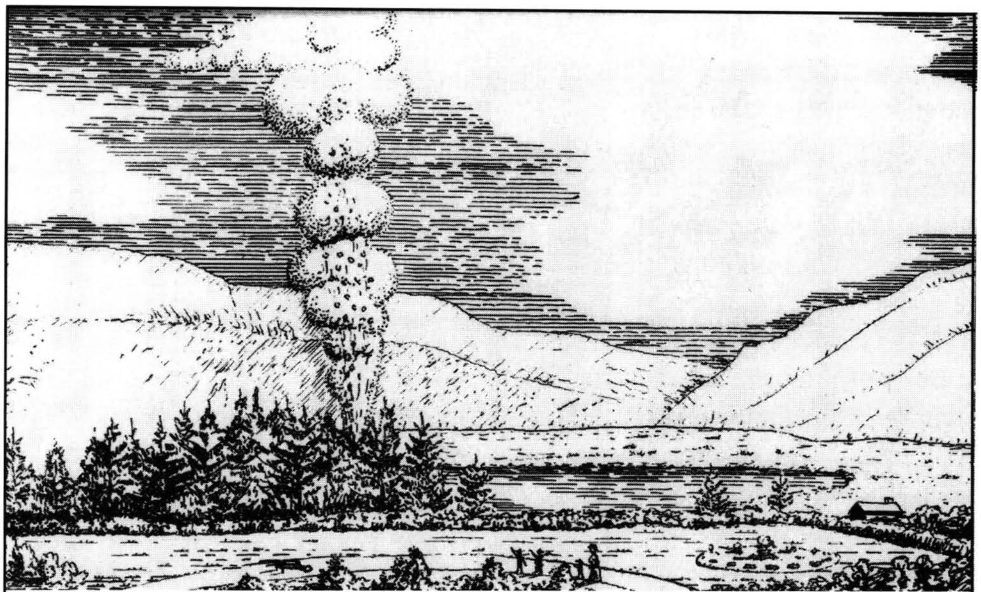

Figure 21. A hydrothermal eruption at the mouth of Puarenga Stream, Rotorua Lake, 1100 hours, 16 April 1894. [From a sketch by Mrs. F.H. Spencer, as published in Allen, 1894, end illustrations]

Ohinemutu are exempt from such charges because of their traditional rights to use the thermal waters.

Sulphur Bay (Arikiroa Bay)

This is a region of somewhat diffuse surface activity lying along the shore of Rotorua Lake east and south–east of the city centre. No actual geysers are recorded as being located there, but the region close to the estuary of Puarenga Stream has repeatedly, at long intervals, been the site of hydrothermal eruptions (Figure 21). ADC has compiled a list of these events and is at present incorporating details into an MSc thesis. There were periods when the activities claimed public attention in the 1890s, and the 1930s. In early 1992 another such blow–out occurred and left a circular crater which encroached on the edge of Rotorua Lake. It was about 6 metres in diameter. On 7 March 1996 another eruption blasted out a crater about 15 metres in diameter on the banks of the Puarenga stream at the end of Hamiora Place alongside a traditional hangi[24] that is still in use today.

[24] "hangi" — Any traditional Maori oven – See Appendix. Such an oven, relying on geothermal heat, was used by Lloyd and Keam for several weeks when monitoring at Orakei Korako in January 1961.

CONCLUSION

As is common in all intensely active regions, there have been many similar ephemeral hydrothermal outbreaks elsewhere in the Rotorua geothermal system and only a few have been mentioned in this article. Since it does not seem appropriate to regard most of them as geysers, they have not been systematically included.

This concludes our description of geysers in the Rotorua geothermal system. It is hoped that we might describe other New Zealand geyser areas in occasional later articles, so, optimistically, we have labelled this current article as "Part 1."

APPENDIX

A vividly romantic description of his visit to Ohinemutu in December 1864 was penned by Lieut. The Hon. Herbert Meade, R.N., and published with much else from his journals and letters after his untimely death a few years later.[25] Meade's account includes the only detailed descriptions of Waikite geyser in that village, so, because of both its appeal and the descriptions, relevant extracts are now quoted:

> Nature is here [Ohinemutu] the public cook. Food is boiled by being hung in a flaxen basket in one of the countless boiling pools; nature also finding salt. Stewing and baking are performed by simply scraping a shallow hole in the earth, wherein to place the pot, and covering it up again, to keep the steam in; or by burying the food between layers of fern and earth in one of the hot-air passages. The great intermittent and annual geyser, "Waikite", bursts out of the midst of a narrow arm of the bay, which nearly divides the town....

[25] Meade, H., 1871, pp.36 - 40.

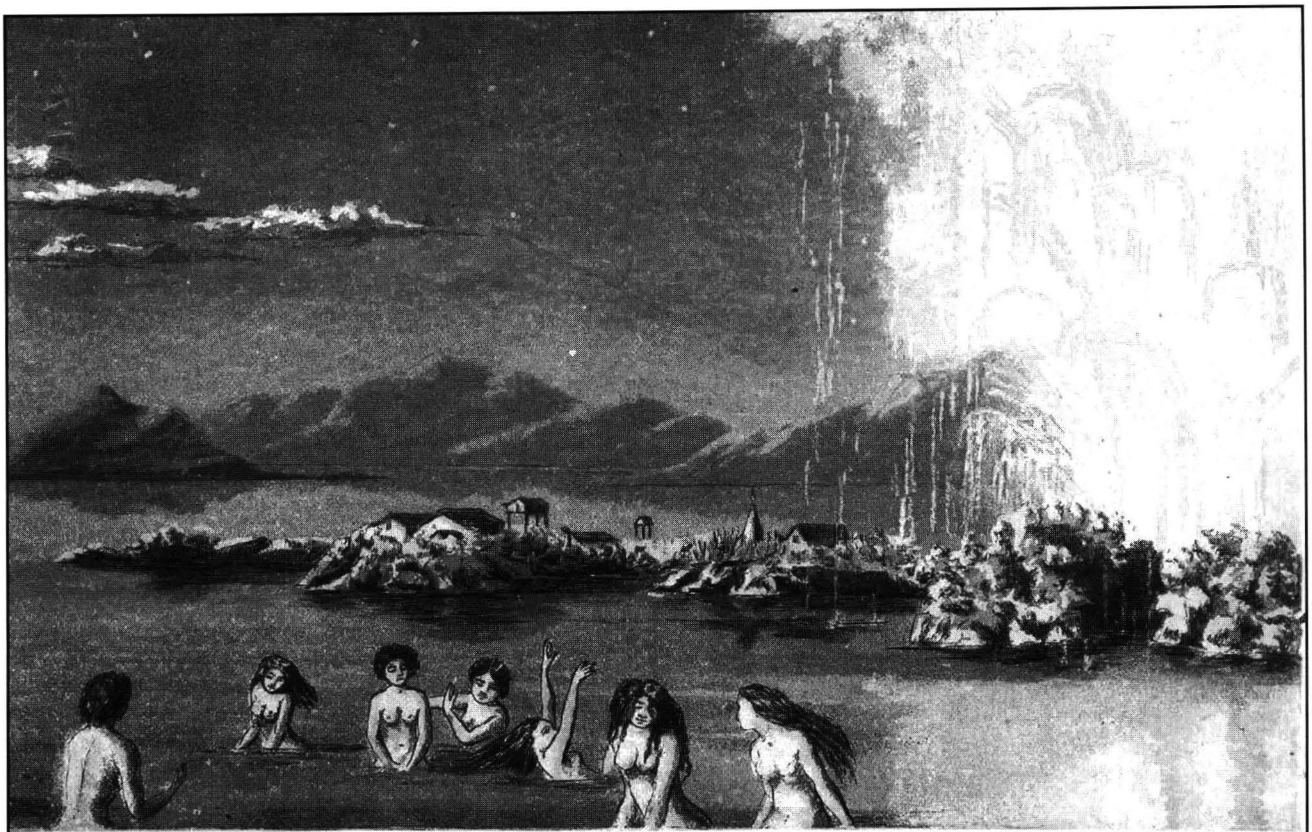

Figure 22. Waikite Geyser (Ohinemutu) in eruption, Ruapeka Bay, Muruika Peninsula and Rotorua Lake. Another reproduction from water–colour by Herbert Meade, 28 December 1864. [From Meade, 1870, opposite p. 39]

We have been very fortunate in the date of our arrival, for the great geyser commenced playing this very morning for the first time this season.

It continues to increase in strength and frequency, till it culminates in February, and then gradually dies away again before the winter. At present the eruption occurs with great regularity every twelve minutes, and lasts about twenty-five seconds.

A vast volume of boiling water, surrounded by glittering jets of spray and curling wreaths of steam, rises in one grand bouquet to the height of 40 or 50 feet, an altitude which it retains for some seconds, and then slowly subsides into the bay whence it rose, where it dies away in a surf of seething foam, leaving huge banks of steam rolling slowly up the dark hill-side. An exceedingly grand sight!

Bathed again this evening, but this time at the fashionable hour of eight.

Young and old of both sexes meet in the lake every evening, almost the whole population taking to the water, which is of an agreeable temperature, like that of an ordinary warm bath, all over the bay, except where the water boils. The whole lake seemed alive, for the rising steam prevented any more than the portion containing the bathers being visible, and the scene was a curious one.

From every side were heard Maori songs and shouts from the players at some native game; and joyous peals of laughter came ringing along the surface of the water from beyond those misty veils.

Apart from these revellers, there were a few groups of staid old men, squatting up to their chins in water and smoking their pipes in conclave solemn. [Chief] Poihipi, with his jolly face, fat corporation, and lighted pipe, looming through the steam, looked the very picture of enjoyment.

We had not been in long, before one of the chiefs called on the girls to come and "haka" to the strangers, and in a few minutes a number of the prettiest young girls in the settlement were seated in a circle in very shallow water, looking like mermaids, with the moonlight streaming over their well-shaped busts and raven locks.

They sang us a wild song, and beat their breasts to the changing time with varied and graceful gestures.

Others soon collected around us; the fear of the Pakehas [Europeans], which most of the girls had shown at first, had by this time passed away, and the choruses of the songs which followed were joined in by scores of voices.

But ever and again even these voices were hushed and stilled, while, with a weird and rushing sound, the great geyser burst from the still waters, rising white and silvery in the moonbeams which shone from the dark outlines of the distant hills, and dashing its feathery sprays high against the starry sky.

The scene was the very incarnation of poetry of living and inanimate nature....

ACKNOWLEDGEMENT

The authors wish to express their gratitude to E.F. (Ted) Lloyd, former District Geologist of the New Zealand Geological Survey at Rotorua, for his multifarious contributions in the preparation of this article. In our opinion Ted should really have been a co–author, but we respect his decision to decline this opportunity. Thank you, Ted, for permission to use your photographs as illustrations, for the joint visits to the areas being described, for many conversations, and, of course, for providing so much information in your book.

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Summary of New Zealand Geysers
Waikato Region outside of Rotorua

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and Ashley D. Cody,
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Abstract
The paper provides a summary of geyser activity in each New Zealand geothermal area, other than the Rotorua Geothermal System. Observational data current to recent years and often into 2002.

Introduction

Elsewhere in this edition of the Transactions, Ashley Cody, Ron Keam and Katherine Luketina provide details of geysers in the Rotorua geothermal system. The other New Zealand geothermal systems that currently have geysers or have had geysers in the past are briefly listed below. Figure 3 of the Rotorua geysers article [see Cody, Keam and Luketina, this volume] can be used to locate the geyser fields mentioned in the current article.

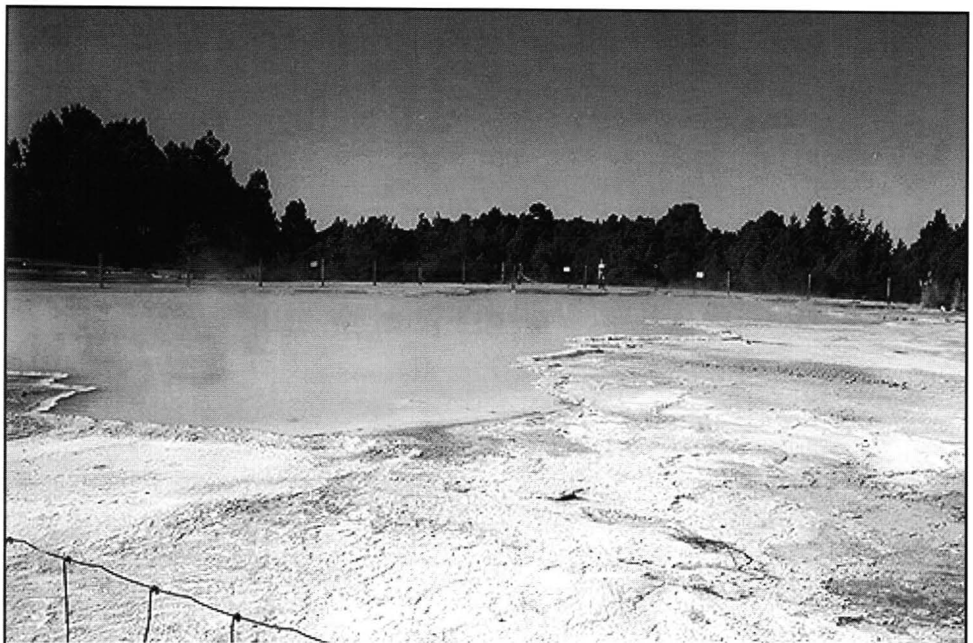
Much of the detail from this small summary comes from *Sinter–depositing Springs and Geysers of the Waikato Region* by Katherine Luketina, Ashley Cody and David Speirs [Waikato Regional Council, in press].

Ngatamariki (1 recently active ephemeral geyser)

The Ngatamariki system has new features appearing from time to time. There are currently five sets of features actively depositing calcite sinters and one actively depositing silica sinters. One set of springs was partially inundated by the creation of the hydro–electric Lake Ohakuri.

About 20 metres south from the main southern spring pool is a flowing spring in marshy soft ground beneath a vertical bank of pumice gravels. This spring, known as *New Southern Geyser*, was formed some time in late 1998, when a fresh bank collapse blocked an upflow, which then filled a cavity behind the landfill and overflowed 0.5 metres above the marshy pool alongside. The new spring against the wall is about 0.8 by 0.5 metres in area, and produces clear alkaline water, with a conspicuous white sinter rind forming on the bank at the surface. For many months this pool had a true geysering action when it would begin boiling and play about 0.3 metres high with an outflow of approximately 0.5 litres per second lasting 30 seconds or so. It would then stop flowing for about 10 minutes or more, before commencing the next eruption. Eventually the surrounding ground collapsed to leave a big open pool that does not exhibit geyser activity.

Ngatamariki — New Southern Geyser. [Photo by Ashley Cody, copyright Waikato Regional Council.]


Ohaaki — Ohaaki Pool. [Photo by Ashley Cody, copyright Waikato Regional Council.]

Ohaaki (1 inactive geyser)

All of the flowing geothermal features at Ohaaki have been irreparably damaged by development of the geothermal field for power generation. Only steam features now remain.

A set of springs by the Waikato River included a geyser that erupted every hour or so, playing to a height of 2 to 3 metres.

The springs were inundated when the hydro–electric Lake Ohakuri was created. Subsidence associated with fluid draw–off from the field for the Ohaaki Power Station has further submerged the springs. It is presumed that the springs are now extinct due to the Ohaaki power station taking their fluids.

Ohaaki Ngawha (Ohaaki Pool) is a large pool 15 metres wide by 45 metres long surrounded by approximately 2 hectares of silica sinter sheets leading down to the Waikato River. The pool and sinter terraces were once famous as one of New Zealand's most beautiful geothermal features. The spring ceased flowing temporarily when a nearby well was test discharged and later permanently when the Ohaaki power station was commissioned. The sinter terraces are now being broken apart due to subsidence and weathering of the sinter. They are also being covered by vegetation.

The bottom of the pool is now cemented to prevent drainage down its original vent and water is maintained by discharge from a well. The outflow has been re–routed away from the silica terrace down a channel dug through the sinters to provide hot water to the nearby Ohaaki Marae (tribal meeting house). Another use for the channel is boiling eggs. If an egg is put into the channel at the top, it will be nicely cooked by the time it reaches the marae. The pool waters are chemically altered and therefore the silica deposition is different from that of the original boiling alkaline upflow.

Orakei Korako (35+ active geysers, 70+ inactive geysers)

Approximately 70 geysers at Orakei Korako were drowned by the creation of the hydro–electric Lake Ohakuri. Thirty–five active geysers remain.

Almost all of the springs of Orakei Korako were affected by the flooding. Those that remain above the water level generally exhibit greater activity because of the increase in hydrostatic pressure. If the water level were allowed to fall to its natural level the entire field would probably return its natural level of activity, although individual springs would not necessarily exhibit their pre–inundation behaviour. The permit to operate the Waikato River hydro–electric dams is now due for renewal Waikato Regional Council, when making their de-

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Editor's Note: Upon recent query it was learned that the name "Orakei Korako" can, and often is, spelled as one word, "Orakeikorako." The 2–word version is presently the "official" spelling, per the Land Information New Zealand database. However, this is the 'pakeha' (non–Maori) way of writing what is probably properly a single word in Maori language.

Orakei Korako — Rainbow Scarp, showing Sapphire Geyser outlet at bottom of the white sinter area at the base of the scarp and Cascade Geyser outlet at the top of the white sinter area halfway up the scarp. [Photo by Ashley Cody, copyright Waikato Regional Council.]

cision and imposing environmental conditions, will take into consideration the effects of the dams on the geothermal features of Orakei Korako and elsewhere.

Most of the present day geothermal features can be viewed or accessed only by boat along the Waikato River on Lake Ohakuri. The topography is of steep hills with sparse road access to the thermal areas. Presently there are approximately 100 springs depositing sinters and approximately 35 have been active geysers in the past decade. During the twelve months to March 2001, approximately 25 geysers were active. The area has not been thoroughly described in recent decades due to poor access and dense bush vegetation over many deeply incised gullies and streams. During 2002 to at least May, nine geysers have been playing many times each day. There are two areas at Orakei Korako that have geysers in them, Te Kapua and Red Hills.

Te Kapua

Te Kapua (Waipapa Valley) is a small valley approximately 0.5 kilometres long by 0.2 kilometres wide on the east bank of the Waikato River. It is the main tourist area and includes hot flowing springs and geysers. Access is by boat across the river. At least three fault scarps cross the valley and many springs rise near the fault traces. Many of the springs have variable activity, flowing occasionally and sometimes exhibiting geyser eruptions.

The site is transected by several major transcurrent normal faults (Golden Fleece, Rainbow and Wainui Faults). A large extent of silica and algae form Rainbow Terrace beneath the Rainbow Fault scarp. Above it and adjoining to the southeast is Golden Fleece Terrace beneath Golden Fleece fault scarp. This terrace is usually dry and presently has only one spring flowing across it. The Artist's Palette Terrace is above and to the east of Golden Fleece Fault scarp.

Diamond Geyser erupts 3 to 8 metres high in pulsating jets for several hours. The vent is approximately 1 metres in diameter and approximately 3 metres above the level of the path, which passes across the outflow. It has an apron of dense creamy white sinters approximately 7 by 15 metres in area. The outflow fans across the southeast portion of Rainbow terrace, where green and orange–yellow masses of algae flourish.

Bush Geyser is about 5 metres from the path and approximately 15 metres from Diamond Geyser. It is hidden in manuka shrubs (a native bush with woody stems and small leaves and flowers). The geyser plays approximately 1 metre high for several minutes every 20 or more minutes, but with very little outflow. The vent and the surrounding ground surfaces to a diameter of approximately 0.5 metres are covered in sinter.

Cascade Geyser typically boils and has weak outflows for approximately 30 seconds every 5 to 10 minutes. Its vent, which is approximately 0.5

metres in diameter, is halfway up Rainbow Fault scarp and about 5 metres from Sapphire Geyser. Dense creamy white sinters extend downslope of the vent.

Sapphire Geyser plays 2 to 3 metres high for 30 to 45 seconds every 20 to 30 minutes. The outflow of about 1 to 2 litres per second flows across a creamy white massive sinter terrace. Note that it has two vents about 2 metres apart, although the northern one is the one which is named Sapphire.

S114, S115, and *S117* are active geysers on the middle level terrace against Rainbow Fault scarp. They occasionally erupt to about 0.5 metres high. All contribute to continuous sinter terrace formations.

S1007 is an active geyser at the base of Rainbow Fault scarp, about 30 metres northeast of Hochstetter Pool. It is a noisily boiling and flowing spring which occasionally erupts about 1 metres high. It lies within an area of recent crumbling collapse on the fault scarp itself.

Dreadnought Geyser, at the western base of Golden Fleece fault scarp, lies in a vent of about 1 metres diameter beneath scarp face. It had an episode of erupting in October 2000. The water is usually below boiling temperature and without any flows. Dense creamy sinter walls and surrounds.

Kurupai is a sinter–depositing geyser which was modified to make it play more spectacularly by Ted Lloyd. It plays to about 20 metres high for minutes or hours continuously, although typically dormant for weeks or months at a time. The vent is a steel pipe about 150 millimetres in diameter within a hole about 2 to 3 metres wide and about 10 metres long.

Artist's Palette

There are 22 geysers on the Artist's Palette above Rainbow Scarp. Most of them are quite small, erupting to no more than 1 metres. Those that erupt higher are described below:

Psyche's Bath, on the south-west side of Artist's Palette terrace, is an active geyser in a sinter lined basin about 5 metres in diameter within kanuka (a prostrate scrubby shrub with vary small leaves and woody stems found only in geothermal areas) scrub at the side of the terrace. The water is generally boiling and about 3 metres below overflow but the spring erupts about 5 to 8 metres high and floods over surrounding ground. It has killed shrubs with recent activity.

S735 is an active geyser on the northeast side of Artist's Palette terrace about 5 metres west of a decomposing old pine tree lying out onto the terrace. It has dense white sinters and surrounds. The geyser plays 3 to 5 metres high for 30 to 45 seconds, but intervals vary from an hour or less up to many hours.

S738 is an active geyser about 5 metres south of the abovementioned pine tree. It has dense white sinters and surrounds. The vent is a small hole about 0.8 metres in diameter. The geyser plays 1 to 2 metres high for a minute or so, but intervals vary from an hour or less up to many hours.

S741 is an active geyser at the centre of the Artist's Palette silica sinter terrace, with dense white sinters and surrounds. The geyser plays 1 to 5 metres high for a minute or so, with intervals of an hour or more. The water level here varies greatly through the seasons. The spring sometimes overflows gently without geyser action.

Square Pool is an active geyser about 10 metres west of Palette Pool, with dense white sinters and surrounds. It has a conspicuous straight side and is about 5 by 7 metres in area. The geyser plays about 1 metres high for several minutes, with intervals varying from an hour or less up to many hours.

S764 is an active geyser on the west side of Artist's Palette terrace about 30 metres north of Psyche's Bath with dense thin grey sinters and surrounds. The pool is about 1.5 metres in diameter. The geyser plays 3 to 5 metres high for 30 seconds or more, but intervals vary from an hour or less up to many hours.

S766 is an active geyser on the south–west side of Artist's Palette terrace about 10 metres north of Psyche's Bath. It has dense sinters and surrounds. There are two vents within a deep basin about 5 metres in diameter, with manuka scrub edges. The eruptions have not been seen but the surrounding wet terrace indicates that the geyser is active.

S772 is an active geyser on the south–west side of Artist's Palette terrace halfway between Palette

Pool and Psyche's Bath. It has dense grey sinters and surrounds. The vent is about 2 metres in diameter. The geyser plays 3 to 5 metres high for 30 seconds, but intervals vary from an hour or less up to many hours.

S773 is an active geyser on the west side of Artist's Palette terrace between Palette Pool and Psyche's Bath. It has dense grey sinters and surrounds. The pool about 20 metres long and oval shaped. The geyser plays about 3 metres high for about 30 seconds, with intervals of many hours or days.

S774 is an active geyser on the west side of Artist's Palette terrace between Palette Pool and Psyche's Bath. It has dense grey sinters and surrounds. The pool is about 20 metres long and oval shaped, and is found within a larger depression that also contains S773. At high water levels S773 and S774 merge into one large pool. The geyser plays about 3 metres high for about 30 seconds or less, with intervals of many hours or days.

S795 is an active geyser on the east side of Artist's Palette terrace between Palette Pool and Pyramid of Geysers. It has dense grey sinters and surrounds. The vent is an irregular hole with a diameter of roughly 1 metres surrounded by broken collapsed sinter sheets. The geyser plays about 1 metres high for several minutes, with intervals ranging from about 20 minutes to several hours. The geyser is unusual in that recordings suggest this is actually two different geysers sharing one common vent to erupt through.

S1012 is an active geyser within dense white sinters in the south–east end of Palette Pool. The vent is about 0.5 metres in diameter. The geyser plays about 5 to 10 metres high for a minute or less, with intervals of half an hour or more.

Red Hills

This area is up river and south of the main tourist area. There are boiling springs along the riverbanks and building sinters. The site has not been visited and not properly identified. There are probably more springs depositing sinter yet to be identified.

S487 and *S488* are active geysers about 0.5 kilometre upriver of Red Hills. A freshwater stream valley enters the east side of the river and alongside the stream there are several boiling flowing and sinter-depositing springs. The geysers are seen erupting by people who use the stream for hot bathing. Each has a vent pool about 1 to 2 metres in diameter. They are perched on banks about 10 metres above the river. They are not accessible by foot.

There are two other geothermal areas associated with Orakei Korako that do not contain geysers. These are:

Waihunuhunu Valley

Waihunuhunu Valley is known as Paradise Inlet by water skiers, who boat into the eastern arm of the lake to bathe in hot water where the springs enter the lake. There may be some alkaline flowing springs still present here but most were drowned by the flooding of Lake Ohakuri in January 1961. The remaining springs are in a deeply incised gully that has not been explored due to bad access; so any sinter-depositing springs remaining here are presently unknown.

Papakainga

Papakainga is the area along the west side of the river near the main tourist reception and accommodation. Some hot springs are situated along the base of the alluvial terrace. The area is swampy and generally not easily accessible. There is a clear alkaline flowing spring of approximately 9 metres by 4 metres area, approximately 76^{o}C and approximately 0.4 litres per second flow. It is situated at the western end of the car park, and its flow supplies a bathing pool. It has dense silica sinter walls and outflow channel deposits. This spring is also used for processing game. It is known as the *Map of Australia* and until 1961 produced regularly fluctuating outflows.

Te Aroha (1 geysering well producing calcite waters of 70°C)

This is a waning geothermal system related to Miocene age Coromandel volcanism (30 to 5 million years old) and is associated with prominent regional faulting. The Te Aroha area is of 3 to 5 million years old geothermal activity but has since been deeply eroded and uplifted. No natural sinter deposits exist but one drilled "spring" known as *Mokena Geyser* deposits calcite sinters. It erupts

Te Aroha — Mokena Geyser. [Photo copyright Waikato Regional Council.]

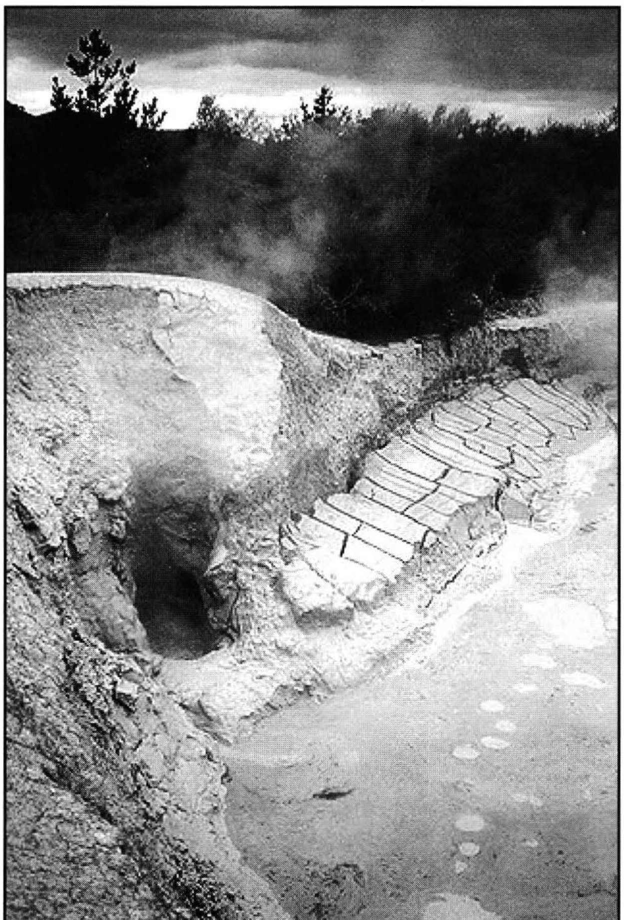
periodically with a geyser action, spouting around 4 metres into the air every 40 minutes. The outflow is diverted to the nearby bathing complex. Although the "geyser" is not a natural feature, it has developed significant tourist appeal and scientific value as New Zealand's only soda geyser.

Te Kopia (1 active geyser)

One pool geyser exists here. This is a true chloride geyser located within a mud pool, and it has the appearance of a mud geyser. It erupts a column of grey muddy water 5 to 10 metres high as a single shot accompanied by a loud detonation. These eruptions occur every 10 to 30 minutes when the geyser is active. It is located within the Department of Conservation (DOC) Scenic Reserve on the east side of Te Kopia Road. Its vent is an oval slot about 0.8 metres by 0.5 metres in area in the west wall of a large hot muddy pool about 30 metres in diameter. Its ejecta has built up a large mud deposit rising more than two metres from the usual pool surface level. This "mud volcano" at the side of the pool may be easily walked across. In May 2002 the geyser was erupting every 7 minutes or so as a single jet eruption, playing to about 8 metres high.

Te Kopia Geyser plasters surrounding vegetation in a thick layer of pale grey mud when it is active. Very wet weather or prolonged high rainfall floods the pool, quenching the geyser. It has been playing during September to December 2000 and manuka and kanuka shrubs to about 20 metres radius have been bent over under the weight of the mud coating.

The Austrian geologist Hochstetter visited the area in the early 1860s and described a similar feature. However, there is some doubt as to whether it is the same feature.



Te Kopia — Mud Geyser vent. [Photo by Ashley Cody, copyright Waikato Regional Council.]

Tokaanu–Waihi–Hipaua (5 occasionally active geysers)

The Tokaanu field contains at least eight sinter–depositing springs, five of which occasionally exhibit geyser activity. The geysers are located within a Conservation Reserve behind the public baths. A path runs through the geothermal area to provide viewing access. Ironically, some of the pools are artificially drained to ensure that their water level does not rise and inundate the path. Nevertheless, nature (or the Maori ancestor overseeing the area) prevails and the path is occasionally closed because of geyser eruptions splashing or flowing over it. Some of the geysers and sinter–depositing springs have been otherwise modified in order to use their heat or water for traditional uses.

The outflow of the Tokaanu field has been affected by several factors. The local ground water level has been affected by managed changes in the level of Lake Taupo, drainage of the surrounding swamp land, and several re–routings of the Tokaanu Stream. In addition there is significant tectonic tilting in the Taupo Volcanic Zone which gives Lake Taupo an effective water level rise of 1 millimetre per year at Tokaanu compared with the lake level at Taupo township.

Increases in lake water level due to tectonic tilting and water level management inundate non-sinter–depositing springs on the Waihi foreshore and affect other springs above water level.

There is extensive small–scale draw–off from the field for heating and bathing by homes, motels, a hotel, a lodge, and a swimming complex. In addition a government–owned bore has been openly discharging since the 1940s, and currently is responsible for approximately 15 percent of the total discharge from the field. The government plans to fill this bore in sometime this year, following prolonged pressure by local government body Waikato Regional Council.

A management plan for the Tokaanu–Waihi–Hipaua geothermal system is being drawn up between the Waikato Regional Council and the local Maori tribes, who wish to halt and possibly reverse degradation of the geothermal features. The pools have the status of ancestors or demi–gods, many having a specific medicinal, practical, cosmetic, or ceremonial use. For example the water of one pool is used only for the bathing of a newborn first–born son.

Te Korokoro A Te Poinga is an inactive geyser no longer depositing silica sinter. It is a hot clear spring about 2 metres in diameter, found in bush close to the Atakorereke Stream. The spring has sinter walls and surfaces but no surface outflow. It was described in 1937 as a strongly boiling (above boiling temperature) clear spring. In 1952, Ron Keam found it still boiling vigorously. The spring is now significantly cooler with maximum measured temperatures of 45°C, and appears to have been affected by well draw off from the system lowering supply pressures. Surface overflow no longer occurs.

Tauwhare Spring is an inactive geyser actively depositing silica sinter. It is a hot clear spring about 5 metres by 7 metres in area at the south–east end

Tokaanu — Taumatapuhipuhi Geyser. [Photo by Katherine Luketina.]

of the Marae, north of the public baths. The spring has sinter walls and surfaces but no surface outflow. It is steadily convecting, with occasional bubble plumes. It is about 30 metres north from the roadside and surrounded by a high fence covered in Japanese honeysuckle. Surface overflow no longer occurs, possibly due to urbanisation effects of draining swampy land and drilling hot wells. It occasionally erupts.

Taumatapuhipuhi Geyser is on a sinter terrace with two other boiling springs. It is a boiling clear spring about 0.5 metres by 1 metres in area at the north–east end of Tokaanu Domain, off to the north of the thermal walkway administered by DOC, and situated on the south banks of Tokaanu stream. Around the geyser vent are deposits of silica sinters and silicified sediments about 15 metres in diameter but of irregular triangular shape. Actively growing sinter is now restricted to around the geyser vent out to a radius of about 1metres. The sinters are a thin nodular or mammillary growth up to perhaps about 20 millimetres thick. A dug channel drains the outflow into two open–air baths.

Taumatapuhipuhi Geyser boils to about 1 metres high for about 30 seconds, recurring every 2 to 3 minutes. During its dormancies the overflow ceases and the vent pool goes calm. Occasionally it will erupt several metres high but these larger eruptions are now very infrequent events. Eruptions appear to be initialised by the concerted action of two different boiling periodicities during times of high geothermal activity in the area. Taumatapuhipuhi has been affected by the dug drainage channel; and has lost pressure due to producing wells having been drilled at neighbouring properties in recent decades. The sinter apron is degrading because the dug channel does not allow the water to flow over it and rejuvenate it. Consequently steam now escapes from many points on the apron, reducing the internal pressure and heat retention, which in turn reduce the geyser's ability to erupt.

Approximately two metres from the main vent is another cyclically boiling spring which also deposits sinter. It also has a channel draining it.

Matewai–Hoani Springs are four hot clear springs, including two inactive geysers actively depositing silica sinter, about 5 metres by 7 metres area at the north–east end of Tokaanu Domain, about 30 metres SW from Taumatapuhipuhi geyser. Matewai Spring has sinter walls and surfaces, with an outflow into Hoani basin, about 10 metres west. The water is steadily convecting, with occasional bubble plumes. Silica deposits as highly porous coral-like masses typical of algal sinters. The springs occasionally erupt.

Takarea–Te Paenga Springs are three hot clear springs 3 to 5 metres in diameter in the central area of Tokaanu Domain. A fenced boardwalk passes between and alongside these pools. An old changing shed stands alongside and tall kanuka scrub surrounds the area. The springs have sinter walls

Tongariro — Tongariro Mountain seen from across Lake Rotoaira. Ketetahi is the steamy area halfway up the mountain in the right of the photo. [Photo by Waikato Regional Council.]

and margins. They flow weakly northwards. There are abundant photosynthetic algae in the outflow. The springs occasionally erupt.

Tongariro (2 active geysers)

Ketetahi is part of the Tongariro Geothermal System and lies on the slopes of the active volcano Mt. Tongariro, presumably deriving its heat from the volcano's magma. The Ketetahi geothermal activity consists of many steam features and acid springs that feed into a warm stream. The land is privately–owned Maori land and access is restricted. There are two geysers, playing every few minutes to a height of about two metres. These are unusual in that they produce acid water and do not deposit sinter. During a 2000 visit, Ashley Cody observed that only one geyser was playing.

Waikite (2 intermittently active geysers)

Hot to boiling springs occur along the base of the Paeroa Fault scarp. Active sinter deposition still occurs but was much more widespread before farm development and extensive drainage of low lying ground occurred. The spring deposits contain some calcite and one spring (active in the late 1980s) produced pure calcite sinters.

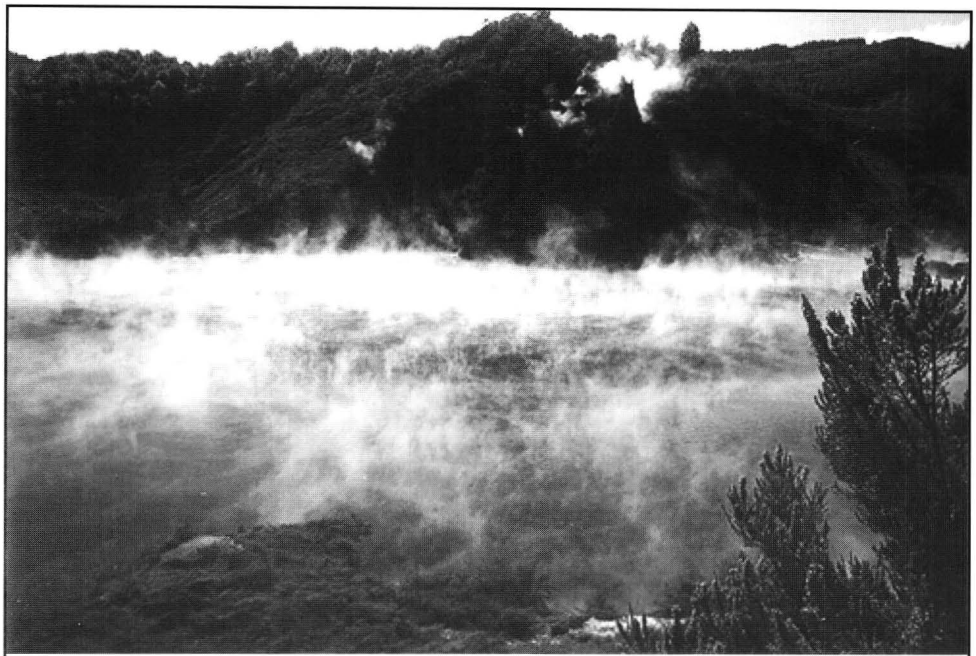
HT Geyser is a boiling clear spring, 9 metres by 6 metres oval in shape, in the base of an amphitheatre in the Paeroa Fault scarp. Close by are overhead high tension power lines, hence the description "HT Geyser." This spring formed in the early 1980s, beginning as a small outbreak of hot ground, then a flowing spring and explosively formed a large crater that erupted many times daily 5 to 8 metres high during the early 1980s until abruptly ceasing in the late 1980s. It is now a constantly boiling and flowing clear spring, depositing sinters along its outflow and around the pool margins.

Manuroa Geyser is a boiling clear spring about 10 metres in diameter in a circular basin on the true right side of the hot springs gully just upstream from the public swimming pool complex. Awesome powerful explosive boiling oscillates about 0.3 to 1.5 metres high with an outflow of about 30 litres per second.

Waikite — HT Geyser. [Photo by Ashley Cody, copyright Waikato Regional Council.]

Waimangu Valley

Several small geysers have been intermittently active over many decades around the shores of Frying Pan Lake and along the valley towards Lake Rotomahana, where two small geysers are active. In Pink Terrace Bay another geyser occasionally plays to about 10 metres high, and in some years one or two other geysers have played here. Along the western shores of Lake Rotomahana an area known as "The Steaming Cliffs" has a geyser informally known as Hole in the Wall. This plays every few minutes 1 to 2 metres high. At *Warbrick Terrace*, constantly boiling springs are building a multi-coloured algae–encrusted silica terrace. About 100 metres upstream the *Iodine Pool* is fed by an active geyser that erupts 2 to 3 metres high every 10 to 15 minutes.



Waimangu — Frying Pan Lake. [Photo by Katherine Luketina.]

Lady Knox Geyser was once a hot spring that, it is reputed, occasionally exhibited geyser behaviour when used by convicts from a nearby open prison for washing their clothes. The spring outlet was subsequently covered over in 1906 by Prison Warden Mr Scanlon to artificially enhance the eruptive behaviour. The vent is a manmade cone surrounding a steel pipe that is visible inside the vent. The soaping tradition continues, albeit by a different type of person for a different reason. Lady Knox Geyser is soaped daily at 10:15 a.m. for the benefit of tourists. The eruption plays about 10 metres high for a few minutes, then continues at about 3 to 5 metres high for 1 to 1.5 hours. It does erupt by itself when left alone, but at very erratic intervals of 48 to 72 hours. The sinters are of unusual silica stearate composition because of the soap. The geyser seems to be highly vulnerable to low rainfall periods when lowered groundwater may influence eruptions. Some years it will play about 10 metres high for 2 to 5 minutes and then continuing at 5 to 8 metres high for up to 2 hours. In 1999 and 2000 this high eruption state only lasted about 30 seconds or so, with a following 3 to 5 metres high play continuing for about 1 to 1.5 hours.

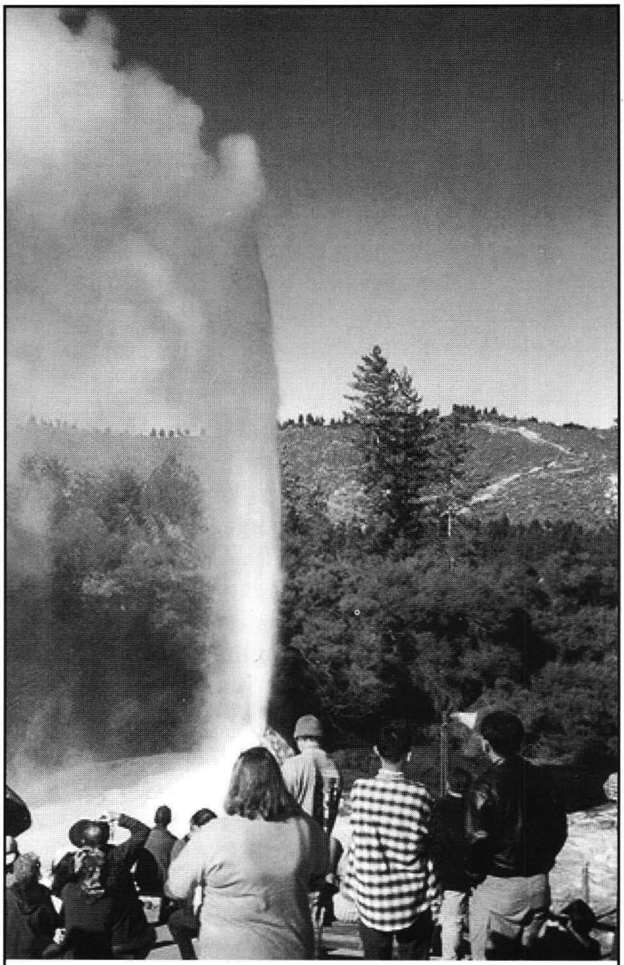
Waiotapu Geyser ("Four Foot Geyser") is a small geyser on the valley floor about 30 metres downstream from Bridal Veil Falls. The vent is about 0.5 metres by 0.8 metres in area with shallow silica sinter puddles and ridges surrounding the vent to a radius of about 3m. The geyser erupts 1 to 2 metres high for about 10 to 15 minutes, at intervals of several hours. It has been playing for the past three years or so, although in the early 1990s it did not play at all for about 5 years or more. It is known amongst older Waiotapu staff

Waiotapu (5+active geysers)

The area in which the main geothermal activity occurs at Waiotapu is a scenic reserve. Waiotapu has five known active geysers but may have two more, in an inaccessible blackberry infested stream valley.

Several hot springs deposit sinters, two of which are unique in New Zealand for very different reasons. Firstly, Champagne Pool actively grows a silica sinter terrace of about 2 hectares in extent. Secondly, Hakareteke Geyser is very acidic yet is depositing sinters, although these are sparse and very minor. However, it is unusual because it is presently the only sinter–depositing geyser in New Zealand that has acid waters.

Champagne Pool is a large hot flowing spring about 30 metres in diameter occupying an explosion crater formed in approximately AD 1350. The spring has grown extensive silica terraces of about 2 hectares in area that are rather unusual because they do not have photosynthetic algae on them due to very irregular flow directions and prolonged drying episodes. The sinters that are found within the spring margins are spectacularly brightly coloured due to the presence of heavy metal sulphides. Constant fizzy bubble swarms of CO_2 evolve. The outflow is about 5 litres per second.



Waiotapu — Lady Knox Geyser. [Photo by Ashley Cody, Copyright Waikato Regional Council.]

as "Four Foot Geyser" because of the height to which it used to play.

Post Mistress Spring is a boiling clear spring about 7 metres in diameter in the bottom of a deep gully at the west side of State Highway 5 opposite the Waiotapu Road junction. It has a steady flow of about 2 litres per second and has thin sinter margins on a soft marshy substrate. It has been known to erupt in the 1970s and earlier.

Springs *S133* and *S134* are boiling clear alkaline springs in stream valley. There are very small grey-white sinters about 1 metres in diameter by the springs, each with a vent of 0.1 to 0.2 metres diameter. There have been no recent observations due to very difficult access. Both springs were observed geysering to about 1 metres high in the 1950s. They were observed by Ashley Cody in 1998 but not since.

North–west Boardwalk Geyser is a boiling turbid grey weakly acid spring about 0.7 metres in diameter on the north side of Primrose Terrace, about 30 metres north-east of Champagne Pool. The vent area is surrounded by grey sinter fragments and blocks to about 5 metres radius. It occasionally has true geyser action but during 1999 and 2000 has been constantly boiling. In the mid–1990s it played 2 to 3 metres high for about 5 minutes with a periodicity of about 20 to 30 minutes and surface outflows.

Hakareteke Geyser is a boiling clear acid (pH 3) spring on the east bank of Hakareteke stream. The vent is about 0.5 metres in diameter with thin silica sinter deposits about 5 metres by 8 metres in area. The sinters are unusual, with a dark grey to black sulphide rich halo to about 2 metres radius of the vent, then changing to brick red ochre colour further from the vent, probably due to iron oxidation. About 1 metres from vent is an unusual spicular white silica deposit about 0.3 metres in diameter, that looks somewhat like a hedgehog coat of spines. The geyser is rarely visited due to difficult access. It was reported as geysering in 1950s by Ted Lloyd and again in the early 1990s. It was visited many times in 2000 by Ashley Cody, who took data logger records of eruptions.

Wairakei–Tauhara (37+ inactive geysers)

The Wairakei–Tauhara system had many geysers and sinter–depositing springs in its pre–development state. The system is identified as having two fields, with the Waikato River forming the boundary between them. The Wairakei field had many sinter–depositing springs in the area known as Geyser Valley in the north of the field, as well as steam features in the Waiora, Te Kiri O Hine Kai, and Karapiti areas.

Most of the features on the Wairakei–Tauhara system were affected by the development and operation of the Wairakei Power Station. At Wairakei, all of the sinter–depositing springs are extinct, but Geyser Valley remains as tourist area where the extinct geyser cones and sinter formations can be seen among steaming ground. Another tourist area is Karapiti (also known as Craters of the Moon), where the naturally occurring steam features have been enhanced by the pressure changes caused by the Wairakei Power Station.

The silky waters of sinter–producing springs feeding the Te Kiri O Hine Kai hot stream were renowned among pre–European Maori as a beauty treatment. The name Te Kiri O Hine Kai means "food for the skin of a young woman." The local tribe allowed use of the springs by all comers, who found easy access to the springs by canoe trip up the Waikato River. Later the stream was popular with European inhabitants of Taupo town and with tourists, and became known as the "Honeymoon Stream" for its romantic setting. The stream ceased to flow when the spring waters were diverted when the Wairakei Power Station was built, but the stream has now been restored, albeit with bore water artificially diverted into the stream bed. A testament to the value local people place on the stream, and to the name "Honeymoon Stream" is that the immediate past mayor of Taupo, in pushing for the restoration of the stream, proudly claimed to have been conceived there!

There were 270 flowing springs in Geyser Valley, of which 132 were neutral to alkaline; and of these 30 were true geysers. These had all ceased flowing by 1965 because of the operation of the Wairakei Power Station, which started production in 1958. By 1966, discharge of chloride water from Geyser Valley had virtually ceased.

Most of the remaining surface features are steam–fed. The remnant sinter from the extinct geysers can now be seen among areas of hot springs and mud pools.

Grange, in his 1937 Bulletin, *The Geology of the Rotorua–Taupo Subdivision*, describes Geyser Valley thus:

> The springs in the Wairakei Valley — also known as Geyser Valley — rise on both banks of the stream over a distance of about 30 chains [about 2,000 feet – *ed.*]. The valley is noteworthy on account of its numerous geysers which play at fairly regular intervals; the eruption of some can be predicted to within a minute. The chloride waters of the geyser and clear springs are alkaline and most of them deposit buff–coloured sinter, whereas boiling mud–pots located at the western end of the valley are acid. The pumice–beds along the valley-sides are being altered to red and yellow clays.
>
> **Champagne Pool,** about 60 ft. in diameter and partly surrounded by steep cliffs, is the most active centre in the group. At intervals of a few minutes the superheated water boils up vigorously at certain points, the column of water reaching at times to 9 ft. Following this activity, bubbles of steam rise over the whole surface. Champagne Pool has a large overflow, which runs over a beautiful cream-coloured sinter terrace called Tuhuatahia...
>
> **Great Wairakei Geyser** has a vent about 10 ft. in diameter and at a depth of 15 ft. suddenly narrows to an irregular vent 3 ft. in greatest length. A fracture crosses the vent. Up till about three years ago it played every ten minutes, but since that time the period has gradually increased; now it is in action every ten hours for ten minutes, sending a column of water about 60 ft. Between eruptions boiling water can be seen at the point where the vent narrows considerably. **Black Geyser**, within a few yards of the stream, is the only geyser surrounded by black sinter. The sinter is black only where wetted by boiling water; farther away it is buff coloured. It plays to a height of a few feet for forty-five seconds at forty second intervals. **The Dragon's Mouth Geyser**, near the Black Geyser, has a rugged sinter vent about 3 ft. in diameter with a conspicuous spine of sinter projecting over its mouth. At a depth of 5 ft. the vent narrows to an inclined vent about 18 in. in diameter. The geyser plays for about three minutes, and during that time most of the over-flow is through a small vent at the base of the cone. Below it is **Lightning Pool**, in which large bubbles of steam shoot swiftly to the surface. **Opal and Sulphur springs**, both of which are turbid, have a small overflow which has encrusted the steep slope to the stream with sinter, coloured orange and green by the algae that grow on it. The **Eagle's Nest Geyser** has two vents close together, 3 ft. and 5 ft. in diameter, which at depths similar to their diameters narrow to 9 in. A series of eruptions commences every half-hour. The **Feathers**, on a sloping surface of sinter, erupts from a narrow crevice, playing fifteen minutes after the water from a spring higher up is diverted from it. The **Twin Geysers** are in a pool about 15 ft. in diameter. The main geyser plays from near the centre of the pool every three minutes to four minutes for thirty-five seconds, to a height of 15 ft., and after every third shot the **Paddle Wheel Geyser** plays for a few seconds at the margin. The pool overflows just

Tauhara — Waipikirangi Geyser. [Photo by Ted Lloyd, Taken with permission from *Volcanic Wonderland*, R.F Keam, 1961.]

> before and during the eruption of the main geyser. **Te Rerereke Geyser**, across the stream from the Twin Geysers, is a deep, wide, boiling spring which erupts at irregular intervals. **Red Coral Geyser**, 3 ft. in diameter at the top, plays every two hours and a half, and its waters cascade down a steep slope about 50 ft. high and coated with pink sinter.

Keam, in *Lake Taupo* [1959], also mentions *Bridal Veil Geyser*, "which sends a boiling flood over its extensive, terrace-like, pink sinter-slope every two hours." In *Volcanic Wonderland* [1961], he also describes the *Devil's Inkpot*, "which plays every two minutes" and *Satan's Toll–gate* and a smaller adjacent spring which "occasionally splash across the path and bar the way — hence the name." In the same publication Keam also mentions *Satan's Punchbowl* ("actively terrace building"), *Crystal Pool*, the *Indicator* and the *Menagerie*.

The Tauhara field is recognised has having two separate upflows, one producing springs in the Waipahihi Valley, and the other producing springs in the AC and Spa Sights areas, in addition to many steam features to the north of the town.

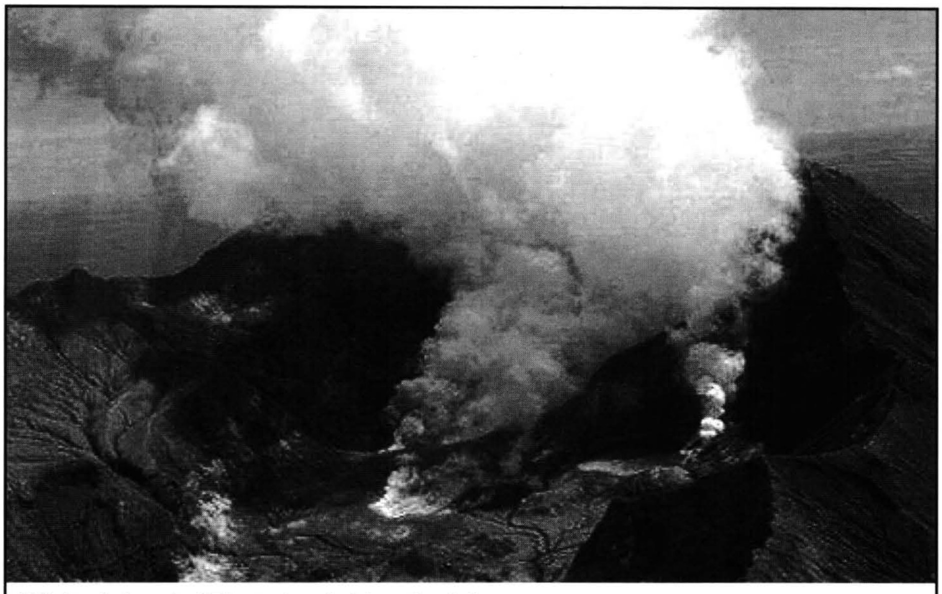
At Tauhara the river–side geysers and sinter–depositing springs are extinct due partially to the effect of the Wairakei Power Station and partially due to the effect of the creation of a gate at the outlet of Lake Taupo to control lake level and river flow.

Several geysers were present at The Spa in the Wairakei–Tauhara field at Taupo but the geysers ceased erupting due to the lowering in water level in the Waikato River for the installation and operation of the Taupo Control Gates prior to 1950. Like the Wairakei chloride springs, these springs were also subsequently affected by the operation of the Wairakei Power station, and had substantially ceased flowing by 1962. The remnant sinter from the extinct geysers can now be seen along the bank of the Waikato River at Taupo township.

Grange describes the geysers at Taupo township:

> A track from the Spa Hotel leads to hot springs near the Waikato River, the most conspicuous being the **Crow's Nest Geyser**, which has built a mound of sinter 7 ft. high and 5 ft. in diameter at the top...The vent 7 ft. below the surface is about 15 in. The base of the mound, which is 3 ft. above the river, has a hole about 1 ft. in diameter. It is inactive for about four hours; the period of rest, according to the proprietor of the Spa, depending on the height of the river, being less when the river is high. When in action it plays to a height of about 60 ft., sending up as many as thirty shots at intervals of two minutes. Nearby, **Waipikirangi Geyser** (98° C.) overflows at the rate of about 10 gallons per minute and erupts when the outlet is blocked. **Hazel Geyser**, a grey, turbid, acid sulphate spring (98° C.), upstream from the geysers, boils up occasionally to a height of 4 ft. or 5 ft.

Keam [1959] mentions three other geysers; a small *unnamed geyser* "that splashes up every few minutes", *Satan's Laundry*, "which splashes unceasingly", and *Eunice Geyser*, with "eruptions reaching twenty feet."



White Island. [Photo by Ashley Cody]

White Island (Whakaari)

This is an active andesite volcano island 60 kilometres offshore north of the Bay of Plenty coastline. It has never had any record of true geysers but occasionally has a constantly spouting small hot spring or pseudo–geyser. This is actually a cool stream of rainwater runoff from the crater floor which flows through a small fumarole. This throws water up about 1 metres high and gives the appearance of a geyser.

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Crypto–geysers of Waimangu, New Zealand

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Abstract

Three thermal features in the Waimangu area, New Zealand, exhibit geyser–like intermittent activity without ejecting elevated water columns above their vents. This paper describes and defines these features as "crypto–geysers" and asks if similar features are known elsewhere (such as Yellowstone).

Definition

As well as the gigantic geyser that gave the Waimangu region its name a century ago, this young New Zealand thermal area has hosted three other discharge features that are most unusual. They have possessed the distinctive intermittency so characteristic of geysers except that they have not projected columns of water into the sky. Because in all cases the fundamental process occurring is certainly the violent, sub–surface boiling of water, and even though for two of them no discharge of liquid water has been identified, they are regarded as hidden geysers. It has seemed appropriate therefore to coin a new term to classify them and I have chosen the name "crypto–geyser" to serve this purpose.

Introduction

The 1886 "Tarawera" basaltic volcanic eruption formed a line of craters 15.9 kilometres long. On Tarawera mountain this rift was about 200 metres across; on the lower–lying country to the south-west it widened, especially at the site of former lake Rotomahana. Here the intruding magma triggered a phreatic eruption.[1] This in turn precipitated and instantly merged into an immensely energetic hydrothermal explosion. This last style of eruption was dominantly what was responsible for producing the roughly circular crater 3 kilometres in diameter and about 150 metres deep that was afterwards found there. Further to the south–west the rift continued as ten separate craters averaging about 100 metres across. It was this south–western area that was later named Waimangu. Rainwater falling in the catchment area of former Rotomahana lake steadily collected in the crater occupying its site and formed a large, deep, new lake in place of its small, shallow predecessor, and the new feature inherited the name of its little forebear.

In the decade following the eruption, although steam continued to discharge in small quantities from a few places in craters on the mountain and there were several places in the new lake Rotomahana where bubbles of gas rose to the surface, it was only along the western shore of the lake and in some of the new Waimangu craters that vigorous surface thermal activity developed. On the western lake shore the activity continued uninterrupted after 1886, but in the Waimangu craters activity declined steadily after their formation and reached a low ebb about 1888. Renewed energy began to be manifest here in the following years and by 1896 significant surface hot water discharges had developed from both Echo Lake Crater and Inferno Crater. This revival constituted the establishment of a new region of surface activity at a place where before 1886 there had been no sign of such, and so the Waimangu thermal area was born (See Figure 1).

There are good reasons for believing that an aquifer containing geothermal fluid had existed at depth beneath the Waimangu area from long before the 1886 eruption and that one of the main

[1] "Phreatic eruption" or "phreato-magmatic eruption"— an eruption style where the dominant process is the explosive expansion of water when high temperature magma comes into contact with it.

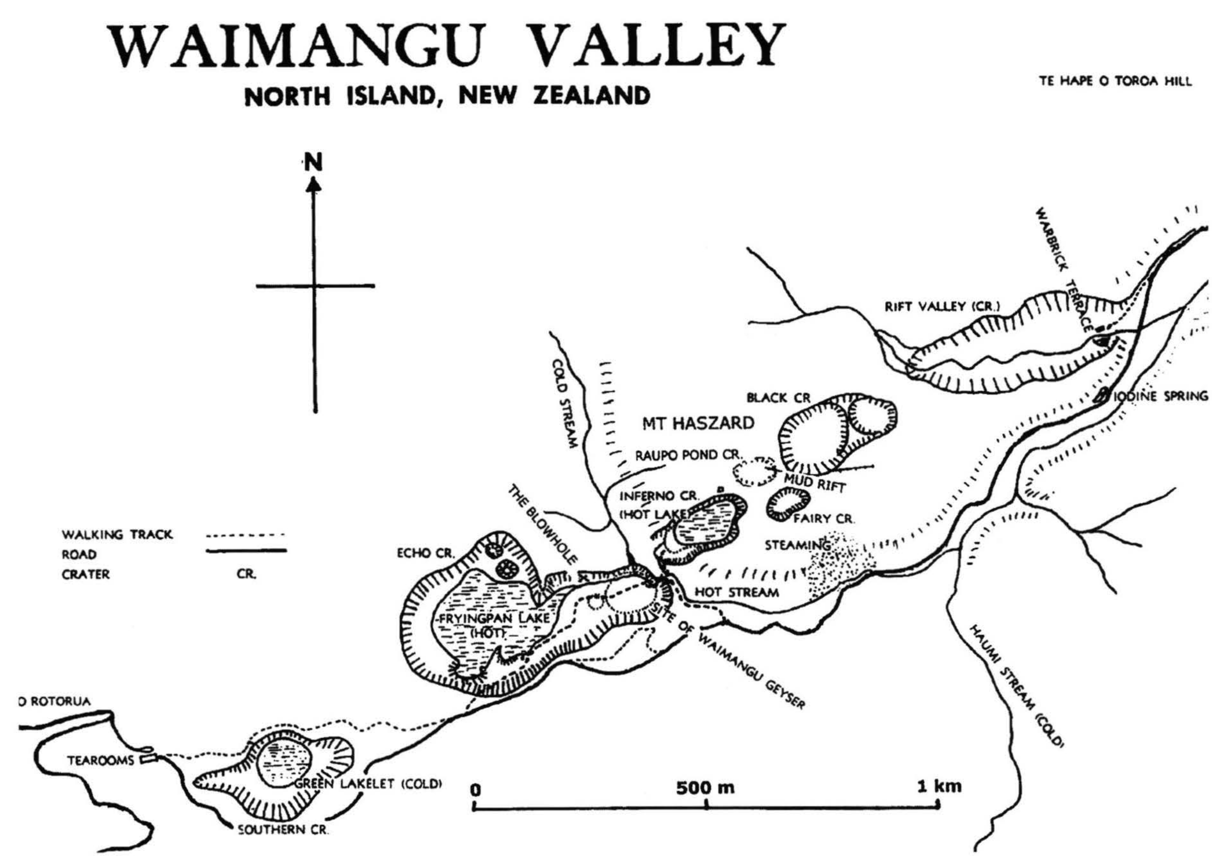

Figure 1. Outline map of the Waimangu thermal area.

effects of the eruption was to provide permeable paths to the surface for that fluid. The culmination of the development of this new surface activity was the outbreak of Waimangu geyser sometime in the winter or early spring of 1900. Echo Lake, which had occupied the floor of Echo Lake Crater from June 1886, had been progressively displaced by sediment derived from the loose 1886 eruption deposits that had been liberally distributed over the surrounding country. The resulting flat floor became known as Frying Pan Flat, partly because of its shape, and partly because of the vigorous thermal activity it exhibited. With the lake having dwindled to an insignificant pool, the word "Lake" was dropped from the crater's name and it became simply "Echo Crater". Waimangu geyser was located at the eastern extremity of Echo Crater.

Immediately to the north-east of Waimangu geyser there is a small rhyolite dome called Mt Haszard in honour of the family of that name, five of whose members were killed in the 1886 eruption. This dome rises almost 100 metres above the valley floor of the stream that bounds it west and south and round to south–east. The 1886 eruption rift transected Mt Haszard and four craters were blown through it. Along the direct line from south-west to north–east they are Inferno Crater, Raupo Pond Crater and Black Crater, and the fourth vent, offset to the south from Black Crater, is Fairy Crater. Raupo Pond Crater is shallow, has gently sloping walls, and indeed was not usually recognised as being a crater by early investigators; all the rest are deep and have near–vertical walls.

The Blowhole

This feature opened in the northern wall of Echo Crater, just above the level of Frying Pan Flat, in about 1892. This was eight years before Waimangu geyser broke out, and when the geyser crater later formed its edge was only about 50

Figure 2. The Blowhole and a small section of Frying Pan Flat. The bold headland was known as "Gibraltar Rock". J.R. Blencowe photograph, ca. 1910.

metres from the Blowhole (See Figure 2). The early descriptions indicate that the Blowhole was a steadily discharging fumarole.[2] Though so close to the geyser, its activities did not seem to be particularly influenced by its gigantic neighbour – except that ejecta from the geyser eruptions gradually accumulated on the floor of Frying Pan Flat and the vent of the Blowhole seems to have gradually migrated up the wall of Echo Crater, partly in response to the minor blockage that resulted from this accumulation and partly from progressive collapse of the Blowhole's roof.

The Blowhole became one of the standard features visited by guided tourist parties, particularly after the geyser's demise in 1904. A few years later its noisy steam emission became intermittent.[3] E.C. McCormack[4] (pers. comm.) stated that there was a six minute cycle; for three of the minutes there was no discharge, and during the other three minutes it discharged as it had done before it became intermittent. Another description indicates that in early 1915 it was discharging for two minutes and quiescent for four minutes.[5] Each discharge was preceded and accompanied by a rumbling. This informant also stated that about September 1914 the discharge ceased entirely for three days.

Very hot water rising in a geothermal feature will of course boil as the hydrostatic pressure decreases. In the case of the Blowhole, the evolution of steam was accompanied by the visible discharge of water only in the form of condensate spray. If water had not been discharged somewhere, the feeding fluid would gradually have decreased in enthalpy[6] and the evolution of steam would have ceased. The very fact that steam did continue to discharge means that higher enthalpy water must continually have been supplied. The residual lower enthalpy water remaining after the loss of its steam fraction must therefore have been disposed of somehow. It is possible that it found its way out through one or more of the other vents around (perhaps including Waimangu geyser). Alternatively it might have flowed back into the geothermal aquifer as part of a one or two phase convection cell. Given either of these models of its working, the Blowhole satisfies the definition of crypto–geyser. It survived a hydrothermal eruption occurring nearby in April 1915. However, in 1917, a much larger one led to its demise. The 1917 event ("Frying Pan Flat eruption") among other things blew out the sediment fill immediately in front of the Blowhole and the opening dis-

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[2] Massy, E.I., (1903), p. 32; (1906), p. 32; and (1911), p. 80.

[3] Baughan, B.E., (1916), p. 144; and (1927) p. 62.

[4] Ernest Carroll McCormack, guide at Waimangu 1913 – 1917, who tragically lost his wife and child from effects of the Frying Pan Flat eruption, 1 Apr 1917, and was himself seriously burned in this event.

[5] Peacocke, M., *New Zealand Herald*, 24 April 1915, Supplement, p. 1 col. 6.

[6] Enthalpy, or more correctly specific enthalpy, is a measure of the heat (energy) content of unit mass of a substance. In the case of water substance the enthalpy of steam at any temperature is much greater than that of liquid water at the same temperature. For liquid water, rises or falls in enthalpy are almost proportional to changes in temperature, the proportionality constant being the specific heat.

appeared under a relatively small deposit. Its site gradually stopped steaming. In recent years, on at least two occasions a cavity has opened where it was, but this cavity, when it appears, is now about half–way up the steep wall of Echo Crater and very difficult of access. I have been tempted to try to reach it, but caution has led to any attempt being postponed, and then the cavity has disappeared when a slip has occurred. One reason for hesitation is the possibility of re–discovering it by inadvertently standing on top of loose material concealing the cavity.

Inferno Crater Lake

Inferno Crater formed as part of the upheavals on 10 June 1886. It has had an extremely complex history which I hope one day to write up in detail. In the early 1890s, hot water began to occupy its floor. For much of the time from then until the early 1920s this hot water discharged over a lip of hard rock comprising an edge of Mt Haszard rhyolite dome. Sometime in the mid 1920s the hot lakelet began oscillating in level, overflowing when at its highest and receding many metres between overflows (See Figure 3). One can recognise in the records slowly changing patterns, punctuated occasionally by more rapid developments. A 'standard' cycle of water level movements presents four stages: From the lowest lake level (anything from 6 to 12 metres below overflow) water level rises steadily for about five days, then an oscillatory stage occurs where the level fluctuates over a range of up to 2 metres but with the average level gradually rising – this lasts perhaps 3 weeks, then there is an overflow stage lasting 3 or 4 days, and the final stage is a monotonic decline in level lasting just over 2 weeks. The standard cycle therefore lasts about 6 or 7 weeks.

Geophones set up near Inferno Crater lake revealed that a seismic tremor began when the rise began, occurred during the rises but not the recessions of the oscillatory stage, and continued through the overflow stage. It cut off abruptly just before overflow ceased and did not resume until the next cycle started.

During 1975–1978 I conducted a series of soundings, from a plywood boat, in both Frying Pan Lake[7] and the lakelet occupying Inferno Crater. The boat was first launched on Inferno Crater lake on 21 May 1975 when the lake was overflowing and a temperature probe was lowered as close to the main vent as I could then determine. It was a remarkable experience working over the active vent at this stage of its cycle. Great eddies welling up from below gently disturbed the lake surface and numerous gas bubbles rose wobbling to the top. The boat occupants, who were on the lake for several hours, had to shift their feet around from time to time as heat conduction tended to raise the plywood hull towards lake temperature – around 75°C – if their gumboots (rubber boots) remained too long in one location.

Figure 3. Inferno Crater and its lakelet at a level about 6 metres below overflow. A small section of sediment-filled Waimangu geyser crater lies in the foreground. The hill enclosing Inferno Crater is Mt Haszard. R.F. Keam photograph, 6 December 1952.

[7] Frying Pan Lake occupies the crater formed on 1 April 1917 at the site of Frying Pan Flat in Echo Crater.

The vent was more accurately located on a later expedition and found to be accessible to about 29 metres below overflow level, but the greatest depth reached on this first occasion was 22.7 metres. From there up to about 17 metres depth the needle of the meter indicating probe temperature swung rapidly and erratically between above–boiling and below–boiling values. It was evident that the probe was immersed in water through which high temperature steam bubbles were rising. The 17 metre minimum depth at which the swings were detected indicates the level to which the bubbles had risen before being completely condensed. It became clear that the seismic tremor recorded by the geophones was caused by the implosion of steam bubbles when they came into contact with below–boiling temperature water or rock.

Clearly Inferno Crater lake is an immense geyser playing at the bottom of the lake. Were one able to arrange a heat–resistant submersible camera to photograph it, the expectation is that it would show a column of mixed steam and water jetting from the vent to a height of at least 5 metres above the vent opening. All the attributes of a geyser are recognisable. The steady rise stage corresponds in a surface geyser to the rise of water level to overflow; the oscillatory stage corresponds to false starts (preliminary plays) to an eruption; the overflow stage corresponds to the main eruption; and the recession stage to the draining back of water into a geyser vent at the end of an eruption. Indeed, Inferno Crater lake is possibly the best feature that exists on Earth where one can study geyser behaviour in a large geyser. Its singular advantage is that all the products of the eruption are caught in the lakelet itself. With suitable corrections for (among other things) evaporation from the lakelet surface, and flume measurements of its overflow, most of the important physical parameters of an eruption can be determined throughout a cycle. J.T. (Jim) McLeod made an investigation of this behaviour the subject of his MSc and PhD studies.[8,9] Inferno Crater lakelet is clearly a crypto–geyser.

[8] McLeod, J.T., (1983); (1992).

Mud Rift

Raupo Pond ('Bulrush' Pond) Crater, on top of Mt Haszard, has been mentioned earlier. This feature did not receive a name in 1886 and indeed the name used here is a derivative of the name Raupo Pond informally used for a shallow rain-water pool that lay over its floor, filled with raupo reeds, during the years when Waimangu geyser was active.[10] It appears that Mt Haszard was fractured during the Earth movements that caused *en echelon* faulting along the 1886 rift during the great eruption. The primary Earth movement was dextral transcurrent faulting along the main rift, the secondary movement was the *en echelon* faulting at a clockwise angle of about 15° to the main rift direction, and the fracture of Mt Haszard was a tertiary split at a clockwise angle of about 50° to the main rift. The existence of this fracture was not commented upon by earlier observers and seemingly was first identified by E.F. Lloyd and myself during our joint exploration in May 1951.

Small hydrothermal eruptions occurred in Raupo Pond Crater in 1906, and during the period from 1913 to 1917. All of these took place along a limited section of the fracture where it crosses the floor of Raupo Pond Crater closest to Black Crater.

Since the 1920s the site of the hydrothermal eruptions has been a basin approximately 32 metres long and 5 metres wide, narrowing to the north-west, and having its long axis coincident with the fracture, together with a separate small circular craterlet at its south–eastern end. Only the main basin was active when I first saw it in January 1951 and the adjacent craterlet was cold and occupied by small healthy native trees. The main basin was filled to a level about 4 metres below its rim with a mud pool through which a line of bubbles rose

[9] The present writer had had the intention of following this a lot further, but diverted into more historical studies, and writing a comprehensive account of the 1886 Tarawera volcanic eruption was instead given priority. I leave it to others to decide if that was the poorer choice.

[10] Donne, T.E. to Bell, J.M., 26 Jan 1907, Tourist and Publicity Department, Head Office file 22/1, National Archives of New Zealand.

Figure 4. The interior of Mud Rift looking northwest. R.F. Keam photograph, 12 July 1952.

marking the central line of the fracture (See Figure 4).[11] During subsequent visits the mud level and the degree of bubbling was noticed to have changed a little but perhaps not more than could be explained in terms of varying mud consistency in response to the amount of rainwater received into the basin. Lloyd and I referred to it between ourselves as "Mud Rift". From time to time in the 1960s the Waimangu resident guide, A.S. (Stan) Marx, reported occasional increases in steam evolution from the vicinity of Raupo Pond Crater when viewed from the Waimangu tearooms about 1 kilometre away. He also reported having heard noises from there. I was fortunate enough to arrive at Waimangu one day[12] just when one of the steam evolution events was occurring and went with the assistant guide, Howard McNickle, to investigate. From about half way up Mt Haszard we became aware of a low "whooping" sound. Cresting the ridge surrounding Raupo Pond Crater we could see that masses of steam were rising from the Mud Rift and the noise was clearly being generated there. When we reached a position from which an unobstructed view could be obtained into the basin we found that the mud was being thrown up all along the central line to heights of up to 4 or 5 metres above the general mud level. The more energetic throws coincided with the "whoomping" sounds, and were accompanied by considerable discharges of steam. Only a very few mud pats landed outside the basin. On later visits I saw evidence of other minor mud projections having taken place. In 1978 a major event occurred with much mud being ejected over the surroundings of Mud Rift. Finally, in 1981, a much greater eruption occurred which entirely emptied the basin of mud and caused the formation of two small craterlets on the line of fracture just beyond the north–western end of the Mud Rift basin. Since it is not the main focus of the present paper I shall not detail here our explorations into the now empty basin and simply say that all activity ceased after the 1981 event and all visible steam discharge from the former Mud Rift is at present stopped. The empty basin narrows downwards until at a depth of about 8 metres below its rim it is about 60 cm wide and at that level it is floored with sandy material we were able to walk along.

The question now arises as to the nature of the hydrothermal feature that presented itself as the Mud Rift. It behaved like a geyser in that it intermittently erupted. No chloride water (i.e. liquid water from the geothermal aquifer[13]) was discharged here. Indeed such chloride water as was boiling to supply the steam being discharged must have been at least thirty metres lower since there

[11] This presumably was its condition when it was seen by Dr Grange in the 1920s. His brief comment is: "...mud boils vigorously in a crevice to the south-west of Black Crater". [Grange, L.I., 1937, p. 94].

[12] Monday, 11 December 1972.

[13] Hot water residing within the Earth's crust dissolves various minerals and invariably accumulates a considerable concentration of chloride ions.

was none in the depths of neighbouring Black Crater whose floor lay approximately that far below Mud Rift. The best estimate of depth to chloride water is provided by water level in adjacent Inferno Crater lakelet which at its lowest lies about eighty metres below Mud Rift. Certainly there must have been a moderately direct hydrothermal fluid connection between Inferno Crater and Mud Rift, because the 1978 outbreak at Mud Rift coincided with an outbreak in the floor of Inferno Crater that blew a small craterlet in the under–water sediments on its floor. (Incidentally this occurred during a main flow from Inferno Crater lake.)

The model proposed for the nature of Mud Rift is that there exists a real geothermal water geyser in the depths of Mt Haszard, possibly at the base of the rhyolite which comprises the dome. This geothermal water we suppose rises along the tertiary fracture at its intersection with the primary rift and usually boils gently with the water fraction finding its way out of Mt Haszard through one or more of the numerous hot springs around the base of that topographic feature and the steam fraction rising through the mud filling Mud Rift. An apparent eruption of Mud Rift is interpreted as being the visible result of an eruption of the supposed geyser inside Mt Haszard with the steam evolved forcing a way out through Mud Rift and vigorously lifting its mud fill. The now inactive state of Mud Rift is regarded as a consequence of the internal geyser having lost so much water after the major eruption of 1981 that geothermal pressures were reduced enough to allow cold(er) water from the surroundings to flow into the geyser's plumbing and modify (at least for the time being) the geothermal water flow patterns there. A reason for being certain that pressures did reduce is provided by the loss of the mud fill: whereas pressure at the top of the geothermal aquifer inside Mt Haszard must previously have been great enough to support the depth of mud in Mud Rift, when the mud was lost that pressure would have reduced approximately to atmospheric pressure. If the proposed model be correct, Mud Rift is a third crypto–geyser at Waimangu.

In conclusion I should like to invite American readers to contemplate whether there might be geothermal features in the U.S.A. that could be classified as crypto–geysers. Certainly there is one other candidate that comes to mind in New Zealand. That is the Parekohoru "cooking pool" at Whakarewarewa.[14] One can imagine a smooth gradation between real geysers and crypto-geysers depending on whether steam bubbles rising within an intermittently discharging open pool break the pool surface or not. Using such a criterion, Te Horu (beside Pohutu geyser at Whakarewarewa) has sometimes exhibited geyser behaviour and sometimes crypto–geyser behaviour.[15] In contemplating their different manifestations one can recognise that crypto–geysers could be subdivided into "submerged" geysers (Inferno Crater lakelet, Parekohoru, Te Horu) and "subterranean" geysers (Blowhole, Mud Rift).

Acknowledgement:

I should like to thank E.F. Lloyd for his comments on the draft of this article.

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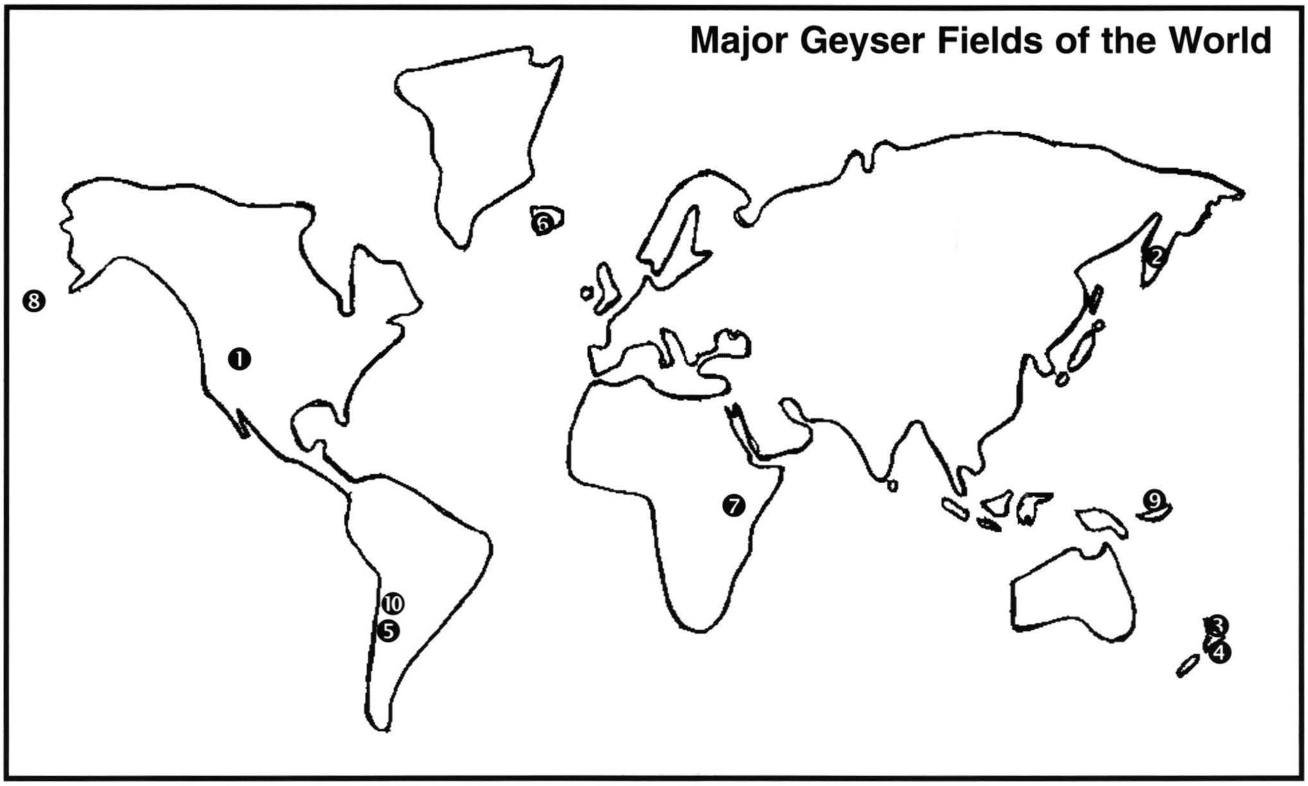
[14, 15] See the article *The Geysers of New Zealand* (part 1) elsewhere in this volume.

Size Comparisons of the World's Major Geyser Fields

A compilation of maps by T. Scott Bryan

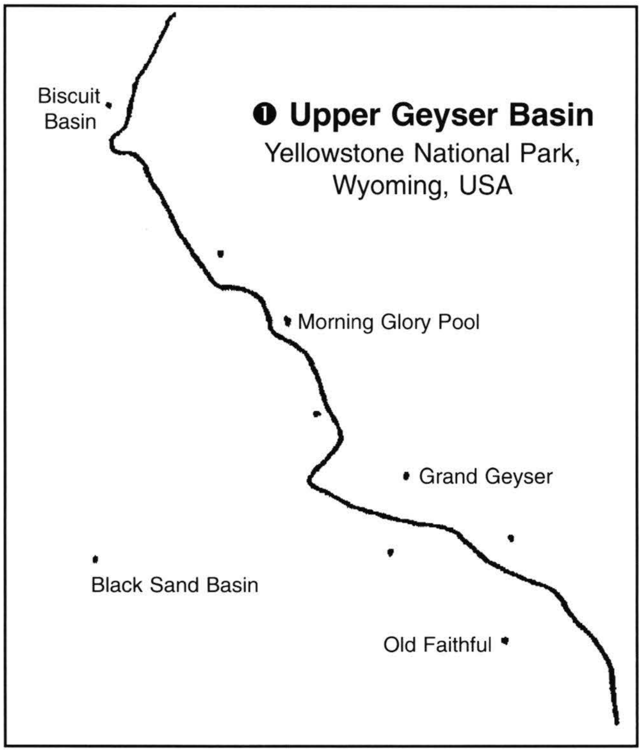
The important geyser fields of the world are remarkably small in areal extent. As illustration of this, these pages simply present a series of comparitive maps. The world map below shows the geyser fields included here. Each of the maps is reproduced to the same scale, where 2 centimeters = 1 kilometer (or about 1.25 inches = 1 mile). Each map is additionally oriented with geographic north up. The maps are presented with no further comment.

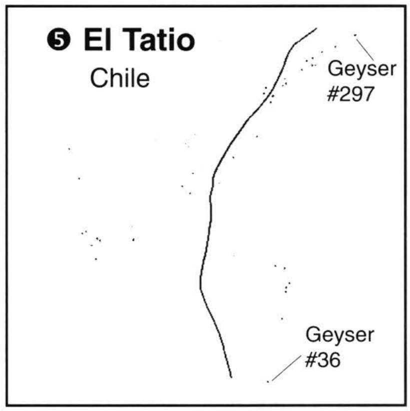


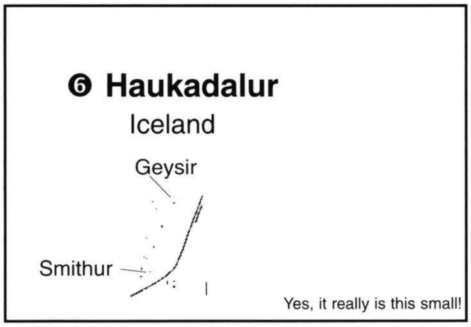
Major Geyser Fields of the World

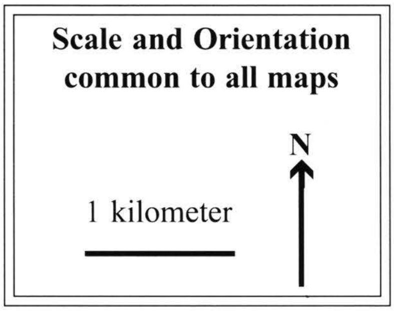
Key to the Map Numbers

1. Upper Geyser Basin, Yellowstone National Park, Wyoming, USA
2. Dolina Geizerov, Kronotsky Nature Preserve, Kamchatka, Russia
3. Whakarewarewa, North Island, New Zealand
4. Orakeikorako, North Island, New Zealand
5. El Tatio, Antofagasta Province, Chile
6. Haukadalur, Iceland
7. Lake Bogoria area, Kenya
8. Geyser Bight Thermal Area, Umnak Island, Alaska, USA
9. Kasiloli (Koimumu), New Britain Island, Papua–New Guinea
10. Puchuldiza (and Tuja), Iquique Province, Chile (photograph)

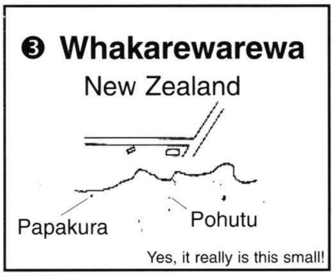




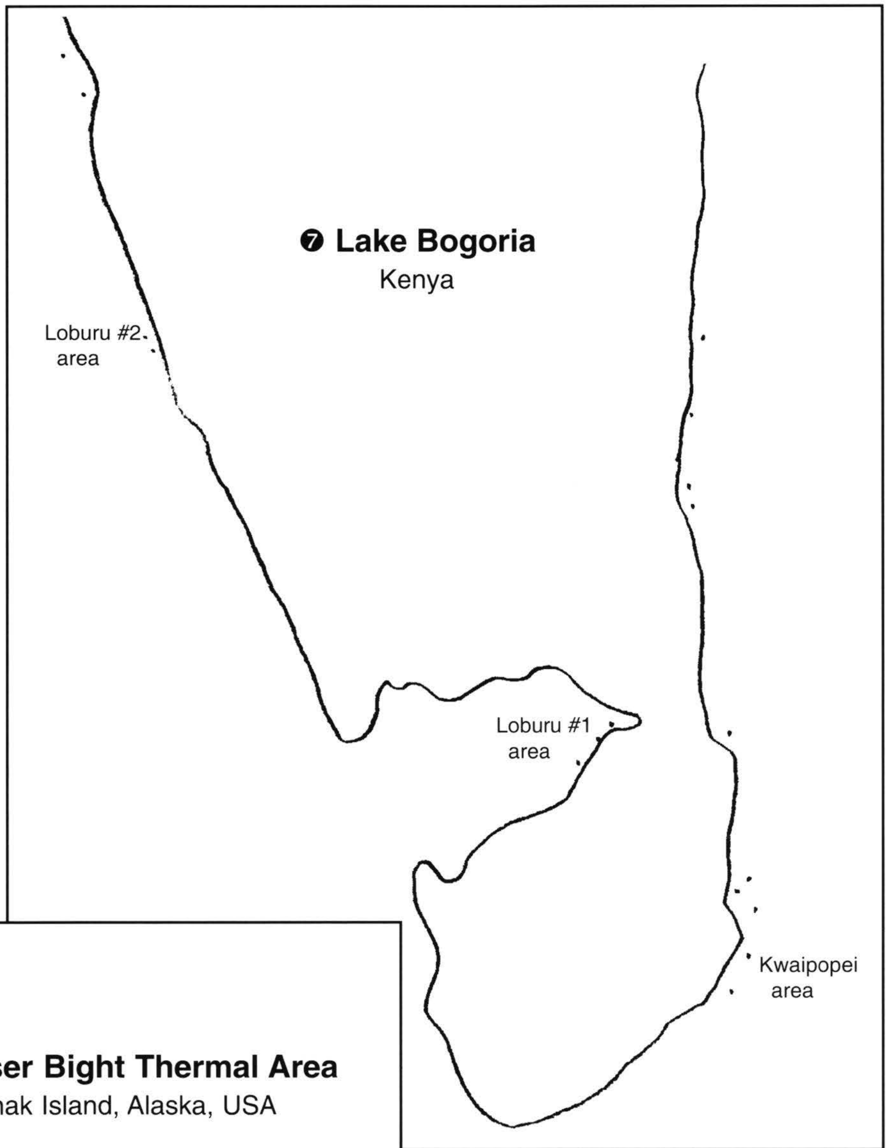


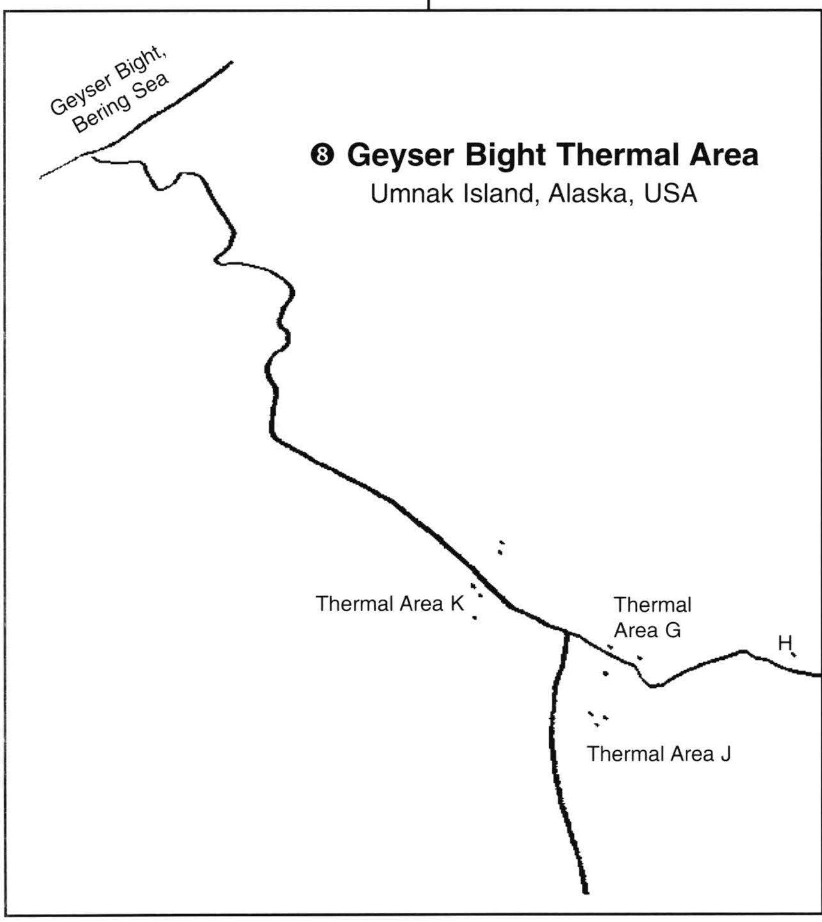


❿ My original version of this article included a map of the overall Puchuldiza–Tuja region. However, in view of recent information indicating that Puchuldiza is the site of impending geothermal and gold mining developments as well as questions about its number of true geysers, it seems better to include a documentary photo of what is claimed to be a geyser at Puchuldiza. (Source: www.eng-him-tours.cl, with permission)


❸ Whakarewarewa
New Zealand
Papakura
Pohutu
Yes, it really is this small!


❹ Orakeikorako
New Zealand
Gift Shop
Artists' Palette
Golden Fleece and Rainbow Faults and Terraces
The Nest


❼ Lake Bogoria
Kenya
Loburu #2 area
Loburu #1 area
Kwaipopei area


Geyser Bight, Bering Sea
❽ Geyser Bight Thermal Area
Umnak Island, Alaska, USA
Thermal Area K
Thermal Area G
H
Thermal Area J


❾ Kasiloli (Koimumu)
New Britain Island, Papua–New Guinea

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to The GOSA Transactions, Volume VII

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Tara Cross became interested in geysers as a child on family vacations. Although she enjoys all geysers, her main interests are Fan and Mortar Geysers and Yellowstone's backcountry areas. A May 2001 graduate with a Bachelor of Arts in History from Southern Adventist University, she currently works as a library and archives assistant at the Yellowstone Research Library, in Mammoth Hot Springs.

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Dr. Ron F. Keam has been interested in hot springs and geysers since the age of five, His early career was in mathematics and theoretical physics, but interests geothermal were greatly stimulated by his fellow university student, E. F. ('Ted') Lloyd. Keam later transmuted into a geophysicist. He has conducted geological and historical research in many of New Zealand's geothermal areas, favoring Waimangu above all. Now "three–quarters retired" from the Physics Department, University of Auckland, he holds postgraduate degrees in Mathematics and Physics and the equivalent of a Bachelor's degree in Geology. E–mail to: r.keam@auckland.ac.nz

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Dr. E. F. ('Ted') Lloyd became hooked on volcanoes as a teenager, and that interest was quickly extended to the associated hydrothermal systems. While studying at the University of Auckland, Lloyd met fellow student Ron Keam, resulting in a collaboration that has now lasted more than 50 years. After college, Ted joined the New Zealand Geological Survey, in Rotorua, where his first assignment was to monitor geysers and hot springs threatened by geothermal exploitation at Wairakei. Subsequent studies included The Spa (Taupo), Orakeikorako, Waiotapu and Whakarewarewa. He also participated in geothermal projects in Ethiopia and the Azores. Now retired as the Rotorua District Geologist for the New Zealand Geological Survey, he lives in Rotorua.

Katherine Luketina has worked for the past five years as a geothermal scientist for Waikato (New Zealand) Regional Council, a local government environmental protection agency whose area encompasses approximately 80% of New Zealand's geothermal resources. Her role includes environmental monitoring, formulation of policy, reporting on the state of the geothermal resource and advising on resource use matters. She has a Master of Science degree in Physics from the University of Auckland, where she studied geyser hydrodynamics under Associate Professor Ron Keam, and she also has a Post–Graduate Diploma of Environmental Management from the University of Waikato. E–mail to: Katherine_Luketina@ew.govt.nz

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Dr. Lynn Stephens is a Professor of Accounting at Eastern Washington University, where she teaches courses in business statistics and decision making in addition to accounting. She has been a Volunteer Thermal Observer in Yellowstone since 1988. As part of her duties, she collects and analyzes geothermal data and prepares the electronic version of the Old Faithful Visitor Center logbook. She is a frequent contributor to *The Geyser Gazer Sput* newsletter, and authored several articles for previous volumes of *The GOSA Transactions*. She is a past member of the GOSA Board of Directors and now serves as the GOSA Treasurer.

Ralph Taylor graduated with a Bachelor of Science degree in Electrical Engineering from the University of Cincinnati. He retired in 1997 following a 37–year career in the machine tool industry. A visitor to Yellowstone since 1966, he has spent the past five summers at Old Faithful, working as a volunteer for the National Park Service, Yellowstone Center for Resources (YCR), conducting electronic monitoring of geysers. He authored several papers for previous volumes of *The GOSA Transactions* and also an article about geyser monitoring for *Yellowstone Science*, a publication of YCR. Taylor is the current President of GOSA.

James Bronco Grigg, a long–time employee of Yellowstone National Park, was unable to provide a biography due to a balky computer and the time constraints of outside committments. We wish he and his bride, Tina, all the best in the future.

List of Readers:

Each article in this volume was read by at least two content readers, who then provided corrective comments to the editor and authors. With the greatest of thanks for their efforts, these people are:

Lee Whittlesey
Kristian Wang
Ralph Taylor
Paul Strasser
Lynn Stephens
R. Stephansson
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Tom Farrell
Tara Cross
Nancy Cross
Jeff Cross
Janet Chapple
Gordon Bower
Butch Bach

and several others who are unknown to the editor or who wish to remain anonymous.

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Researchers are encouraged to produce articles for *The GOSA Transactions*, Volume VIII, which is expected to be published during 2003. Please advise the Senior Editor about your article topic and anticipated length at the earliest possible date. Submissions guidelines are available upon request.