GOSA TRANSACTIONS

The Journal of
The Geyser Observation and Study Association

Volume IV
1993

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Volume IV
Published May 1993

The *GOSA Transactions* are published on an irregular basis, as merited on the basis of the volume of submissions received by the editor. Numbered issues contain articles reporting on original or historical research about geyser activity worldwide, and are published approximately annually. Special Issues are published about specific topics of extraordinary interest.

The price of each issue is set separately according to size and in keeping with GOSA's non-profit goals. The set price of this issue is $25.00 to the membership of GOSA and $32.50 to non–members, agencies and institutions.

Cover Photograph:

Beehive Geyser, accompanied by smaller Beehive's Indicator and a sharp rainbow, is featured in this issue's articles about Geyser Hill. Photo by David Goldberg, July 29, 1992.

Printed By:

B&J Printing
Apple Valley, California

Printed on Evergreen Gloss recycled paper

The *GOSA Transactions* publishes articles, research notes, notices, and reviews 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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Sacramento, California 95822–0340

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Yellowstone Geysers Known Active in 1992

compilation by T. Scott Bryan

On the following pages are a list of the Yellowstone geysers known by observation to have been active during 1992. Much of the information is based on my personal observations, which were done with this list in mind, but many other members of GOSA, the Park interpretive staff, Yellowstone's Research Geologist, and others made contributions.

This list makes no claim as to completeness. The numbers of geysers cited are minimal, and the actual figures for some of the more remote or seldom visited thermal areas might be much greater. Still, this is the first time that a tabulation of this sort has exceeded a total of 500 active geysers.

The list is organized geographically by geyser basin, and then by recognized spring groups within each basin. When applicable, the springs are then listed in an along–the–trail order. The overall organization is thus the same as used in my book, *The Geysers of Yellowstone*, which also contains the informal "UNNG" (unnamed geyser) designations. Informal names are given within quotes; the UNNG designation is omitted in cases where the name has largely been accepted.

For comparison, the numbers of recorded geysers during the last three years[1] of record were:

Area	1989	1990	1992
Upper Geyser Basin	198	193	184[2]
Midway Geyser Basin	23	22	26
Lower Geyser Basin	124	111	121
Norris Geyser Basin	37	38	50[3]
Gibbon Geyser Basin	11	14	17
West Thumb Geyser Basin	11	11	18
Lone Star Geyser Basin	9	10	7
Shoshone Geyser Basin	42	49	46
Heart Lake Geyser Basin	33	≈30	≈35[4]
Minor Backcountry Areas	4	7	10
Total Number of Observed Geysers	**492**	**485**	**514**

1. For a number of reasons, primarily my own very limited time in Yellowstone, there was no compilation for 1991.

2. A part of the reason for the smaller Upper Basin number in 1992 is limited access and observational time in some of the "gray area" off trail hot spring groups.

3. Much of the information for Norris Basin was obtained from the "1992 Thermal Observations Report for Norris Geyser Basin and Vicinity", produced by Norris Subdistrict Naturalist Sandra Snell–Dobert. Many thanks.

4. The Heart Lake Geyser Basin was only given a cursory visit to its Fissure and Upper Groups.

Yellowstone Geysers Known Active in 1992

Upper Geyser Basin

Old Faithful Group— 2 geysers

Old Faithful
UNNG–OFG–1 ("Teapot")

Geyser Hill Group— 48 geysers

Bronze Spring
Silver Spring
Little Squirt
Cascade
North (Big) Anemone
South (Little) Anemone
Plume
UNNG–GHG–2
UNNG near GHG–2
Beehive
Beehive's Indicator
"Beehive's 2nd Indicator"
UNNG rift above Copper Kettle
Depression
UNNG–GHG–3 (≥7 vents)
Little Cub
Lion
UNNG across from Lion ("Kitten")
UNNG–GHG–5
Beach Geyser (GHG–6)
UNNG–GHG–7
Aurum
UNNG north of Doublet Pool
UNNG southwest of Doublet Pool
Pump
Sponge (subterranean)
Plate
UNNG ("Abrupt")
UNNG between Plate and Abrupt
UNNG (Slot?)
Vault
Giantess
Mottled Spring
Peanut Pool
Butterfly Spring
Dome
Model
UNNG south of Model
Dragon
Roof
"Borah Peak"
Solitary

Castle Group— 10 geysers

Castle
"Gizmo"
UNNG ("Gizmo 'A' ")
Crested Pool
Sprinkler
Terra Cotta (≥5 vents)

Sawmill Group— 14 geysers

Deleted Teakettle
Churn
Sawmill
Uncertain
Tardy
Twilight Spring
Penta
Spasmodic
Oval Pool (2 vents)
UNNG below Old Tardy ("Nifty")
Old Tardy
Crystal's Vent ("Slurp")
UNNG near Frog Pond

Grand Group— 13 geysers

Bulger
Rift
West Triplet
"Sputnik" area (count as one geyser)
East Triplet (minor)
Percolator
Grand
Turban
Vent
UNNG Bush G area (2 seen)
Witches Cauldron (near steady)
Lime Kiln Spring (near steady)

Orange Spring Group— 3 geysers

UNNG Orange Springs (2)
UNNG South Orange Sprs (1)
Pulsar Spouter (steady)

Yellowstone Geysers Known Active in 1992

Giant Group— 8 geysers minimum

Oblong
Giant
Mastiff
Catfish (minor)
Bijou
UNNG Platform Geysers south
UNNG Platform Geysers central
UNNG behind Bijou (several independent(?) geysers)

Round Spring Group— 2 geysers

UNNG–RSG–1
UNNG–RSG–2

Daisy Group— 8 geysers

Bank
UNNG–DSG–1
UNNG ("Bonita's Sputs")
Daisy
Comet
Brilliant Pool
Splendid
Pyramid

Punch Bowl Group— 3 geysers

UNNG–PBG–1
UNNG–PBG–2
UNNG–PBG–3

Grotto Group plus **Riverside**— 10 geysers

Grotto
UNNG ("Central Vents")
Rocket
UNNG ("Variable Spring")
UNNG ("South South Grotto Ftn")
South Grotto Fountain
Grotto Fountain
Spa
UNNG ("Marathon Spring")
Riverside

Chain Lakes Group— 2 geysers

Square Spring (minor)
Link (minor)

Morning Glory Group— 5 geysers

Fan
Mortar
East Sentinel (2 independent vents)
West Sentinel

Cascade Group— 4 geysers minimum

Artemisia
Atomizer
Slide
Sprite Spring

"Westside Group"— 4 geysers

Ouzel (minor)
UNNG–WSG–1 ("Sideshot")
UNNG–WSG–2 ("Bigfoot")
UNNG YM–210 ("South Pool")

Yellowstone Geysers Known Active in 1992

"Old Road Group"— 6 geysers

UNNG northwest of Biscuit Basin G	UNNG–ORG–2 ("Demise")	UNNG–ORG–4 ("Mercury")
UNNG–ORG–1	Cauliflower (minor)	Rusty

Biscuit Basin (Soda Group)— 16 geysers

Jewel	Silver Globe Geyser, south, vent C	East Mustard Spring
Shell Spring	Silver Globe, pair of craters, vent D	UNNG north of boardwalk (2)
UNNG ("Shell's Satellite")	Silver Globe "Slit" (vent E)	Fumarole
Silver Globe Cave (vent A)	UNNG between S.G. spring & geyser	UNNG west of Sapphire (subterr.)
Silver Globe Geyser, north, vent B	Avoca Spring	Island

Black Sand Basin— 12 geysers

The Growler	Cliff	Handkerchief Geyser
Spouter	UNNG between Ragged and Green	UNNG near Rainbow Pool
Ragged Spring	UNNG ("Boardwalk Spring")	Sunset Lake (minor)
"Ragged Spring's Annex"	UNNG within steep bank of stream	UNNG near Pentagonal Spring

Pine Springs Group— 2 geysers

UNNG–PSG–1 ("Deep Hole")	UNNG along fracture zone

Myriad Group— 7 geysers

Mugwump	White	UNNG near Bell Geyser (2)
Three Crater	Lactose Spring	Strata (subterranean)

Pipeline Meadows Group— 3 geysers

UNNG–PMG–2	UNNG–PMG–3 ("Pipeline Meadows")	UNNG–PMG–4

Pipeline Creek Group— 2 geysers

UNNG large pool	UNNG twin vents in geyserite near stream

"Upper River Group"— no geysers observed

Total Observed Active Geysers, Upper Geyser Basin, 1992 = 184

Yellowstone Geysers Known Active in 1992

Midway Geyser Basin

Rabbit Creek Group— 6 geysers

Rabbit Creek Geyser
UNNG north of Rabbit Creek G
UNNG Paperiello #11
UNNG South Rabbit Creek valley
UNNG along fracture zone
UNNG north end Rabbit Highlands

Egeria Spring— 9 geysers

Till
UNNG along old dump road
UNNG–MGB–1
UNNG–MGB–3
Silent Pool
Pebble Spring
UNNG–MGB–4
River Spouter
"New Catfish"

"Main" Area— 11 geysers

Flood
UNNG ("Tangent")
UNNG downstream from Circle Pool
West Flood
UNNG downstream from W. Flood
UNNG on flat (6 observed)

Total Observed Active Geysers, Midway Geyser Basin, 1992 = 26

Lower Geyser Basin

Serendipity Meadows, Great Fountain, and White Creek Groups— 16 geysers

UNNG Serendipity Meadows (2 gey)
Firehole Spring
Great Fountain
UNNG–GFG–1 ("Prawn")
A–0
A–2
UNNG near A–2 (2 geysers)
UNNG–WCG–2 ("Logbridge")
Botryoidal Spring
Diamond Spring
UNNG–WCG–4 above Diamond
"Tuft"
Spindle
UNNG near Spindle

White Dome Group— 6 geysers

White Dome
Gemini
Crack
Pebble (very minor)
Cave Spring
UNNG–WDG–1
[Tangled Creek Group, none]

Pink Cone Group— 8 geysers

Pink Cone
UNNG–PNK–1 ("Dilemma")
Pink
Narcissus
Labial
Labial's West Satellite
Labial's East Satellite
Bead

Black Warrior Group— 5 geysers

Steady
Young Hopeful
Gray Bulger
Artesia Spring
UNNG near Dart Spring

Yellowstone Geysers Known Active in 1992

Fountain Group— 16 geysers

Celestine Spring
Twig
UNNG ("Bearclaw")
Jet
UNNG–FTN–2 ("Sizzler")
Fountain
Spasm
Clepsydra
Jelly
Sub
New Bellefontaine
UNNG north of New Bellefontaine
UNNG Gore Springs (Mask G ?)
UNNG far west flat
UNNG–FTN–3
UNNG next to FTN–3

Kaleidoscope Group— 9 geysers (compiled by Mike Keller)

Kaleidoscope
(Kaleidoscope) Drain
"Three Vent"
Deep Blue
"Firehose"
Honeycomb
Honey's Vent
UNNG (2)

Sprinkler Group— 15 geysers (compiled by Mike Keller)

West Sprinkler
Bridge
UNNG ("Vertical")
UNNG Angle Complex (6 geysers)
Impatient Miser
Other UNNG (5 geysers)

Thud Group— 2 geysers

UNNG–THD–1
Kidney Spring

Camp Group— 2 geysers

Snort
UNNG

Culex Basin, Morning Mist, and Quagmire Groups— 10 geysers

Geyserlet
UNNG next to Geyserlet
UNNG east of Geyserlet (2)
Morning Mist
UNNG Culex Basin (3 observed)
UNNG Quagmire Gp (2 observed)

River Group— 14 geysers

UNNG–RVG–4
UNNG near RVG–4
"Pocket"
UNNG pool in upper flat area
UNNG other in upper flat area (2)
Conch/Fortress
UNNG north of Armored Spring
UNNG ("Brain")
UNNG ("Blurple")
Mound
UNNG adjacent to Mound
UNNG–RVG–2
UNNG near Skeleton Pool

Boulder Spring Group— 1 geyser

UNNG

Yellowstone Geysers Known Active in 1992

Fairy Creek and (North) Fairy Meadows Groups— 9 geysers

Locomotive
UNNG Fairy Creek Group (2)
Column Spouter
UNNG near trail junction
UNNG ("Trumpet Pool")
UNNG Fairy Meadows Group (3)

Imperial Group— 1 geyser

Spray

Sentinel Meadows Group— 7 geysers

Iron Pot
UNNG near The Bulgers
UNNG vent within Queen's Laundry
UNNG–SMG–2
Flat Cone
UNNG near Rosette Geyser (2)

Total Observed Active Geysers, Lower Geyser Basin, 1992 = 121

Norris Geyser Basin

(largely compiled by Sandra Snell–Dobert)

Porcelain Basin— 26 geysers

Dark Cavern
Guardian
Valentine
UNNG above Ledge
Hurricane Vent
UNNG ("Fish", near Milky Complex)
Arsenic
Lava Pool Complex (2 vents)
Constant
Big Whirligig
Fireball
Fan (? correct identity)
Splutter Pot
Pequito
UNNG beyond Pinwheel
Blue
Incline
UNNG ("Lambchop")
UNNG Porcelain Terrace area (≥6)
UNNG near Graceful

Tantalus (Back) Basin— 24 geysers

Steamboat (minor)
Echinus
Crater Spring
Tantalus
Puff–N–Stuff
Big Alcove Spring
Little Alcove Spring
Medusa Spring
Hydrophane Springs (2 vents)
Muddy Sneaker Complex (1 vent)
Yellow Funnel (?)
Dabble
Butch
Double Bulger
UNNG near Double Bulger
Pearl
Vixen
Rubble (?)
Corporal
Veteran
Palpitator Spring
Minute
"Rediscovered"

Note: the above tabulation does not include numerous small ephemeral geysers active only during the seasonal disturbance in July; it *does* include named features which were active only at that time. Yellow Funnel and Rubble are believe to have erupted on the basis of wet surroundings and standing water in runoff channels.

Total Observed Active Geysers, Norris Geyser Basin, 1992 = 50

Yellowstone Geysers Known Active in 1992

Gibbon Geyser Basin

Artists Paint Pots— 2 geysers

Blood (perpetual spouter?)	UNNG–GIB–2

"Sulfur Castle Group" — 1 geyser

UNNG

Geyser Creek Group— 13 geysers

"Anthill" ("Formicary")	UNNG ("Oblique's Steam Jet")	Bat Pool
UNNG in bowl near Anthill	"Big Bowl"	UNNG north of Bat Pool
UNNG on lower flat	UNNG near Big Bowl	"Tiny"
Oblique	"Subterranean Blue Mud"	UNNG east of Bat Pool (2)

Gibbon Hill Group and vicinity— 1 geyser

UNNG ("Punchbowl Geyser")	[Gibbon Hill Geyser remains buried by landslide debris]

Monument Geyser Basin— no true geysers active
Sylvan Springs— not visited

Total Observed Active Geysers, Gibbon Geyser Basin, 1992 = 17

West Thumb Geyser Basin

Lower Group (main boardwalk area)— 9 geysers

Surging Spring	Thumb (minor)	Abyss Pool
Ledge Spring	Black Pool	Roadside Steamer
Percolating Spring	UNNG at edge of Black Pool	King (visitor report)

Upper Group (also known as Lake Shore Group)— 4 geysers

Occasional	Blowhole Spring	Overhanging
Lone Pine		

Potts Basin— 5 geysers observed

Empty Hole Group, 3 geysers observed including UNNG "Resurgent" Geyser (minor)
Mercurial Group, 2 geysers observed from roadway overlook

Total Observed Active Geysers, West Thumb Geyser Basin, 1992 = 18

Yellowstone Geysers Known Active in 1992

Lone Star Geyser Basin

Lone Star Group— 3 geysers

Lone Star
"Black Hole"
The Pepper Box

"Channel Group"— 2 geysers

UNNG–LST–3
UNNG–LST–4

"Campsite Group"— 1 geyser

UNNG–LST–7

Basset Group— 1 geyser

Buried

Total Observed Active Geysers, Lone Star Geyser Basin, 1992 = 7

Shoshone Geyser Basin

Little Giant Group— 7 geysers

Trailside
"Horse Trail Spring"
Little Giant
UNNG northwest of Little Giant
Double
"Meander"
UNNG north of Soap Kettle

Minute Man Group— 10 geysers

Soap Kettle
"Little Bulger's Parasite"
UNNG USGS #11
UNNG USGS #12
Five Crater Hot Spring
Shield
Gourd
Minute Man
"Minute Man's Pool"
UNNG below Minute Man

North Group— 16 geysers

Frill Spring
Pearl Spring
Mangled Crater Spring
Knobby
UNNG USGS #51 or #52
Small
Yellow Sponge
Brown Sponge
UNNG USGS #61
UNNG USGS #62
Fissure Spring
Velvet Spring (west vent only)
UNNG south of Velvet
Lion
Iron Conch
Bronze

Yellowstone Geysers Known Active in 1992

South Group— 3 geysers

UNNG northwest of Outbreak	"Outbreak"	UNNG vent within Coral Spring

Orion Group— 4 geysers

Taurus White Hot Spring	Deep Crater	UNNG USGS #82a

Camp Group— 2 geysers

Geyser Cone	UNNG USGS #119

Western (Fall Creek) Group— 3 geysers

"Pecten"	UNNG USGS #135a	Boiling Cauldron (1 vent)

Yellow Crater Group— 1 geyser

UNNG USGS #110

Total Observed Active Geysers, Shoshone Geyser Basin, 1992 = 46

Heart Lake Geyser Basin

The Heart Lake Geyser Basin was briefly visited by reporting geyser gazers just one time during 1992, and that trip reached only the Upper and Fissure Groups. Accordingly, any enumeration of geysers is obviously difficult. However, in the Fissure Group a number of important changes were seen, including evidence of true eruptions by Shelf Spring and the two small cones near it as well as in other features. If one assumes that the activity elsewhere in the Heart Lake Geyser Basin has remained relatively stable, then:

Total Suspected Active Geysers, Heart Lake Geyser Basin, 1992 = ≈35

Other Yellowstone Areas

Grand Canyon of the Yellowstone – 4 geysers seen from Artists Point, plus Red Rock(?) Geyser = 5 geysers
7 Mile Hole = 2 geysers
Crater Hills Geyser = 1 geyser
Three River Junction area = 2 geysers

Total Observed Active Geysers, Miscellaneous Other Yellowstone Areas, 1992 = 10

TOTAL OBSERVED ACTIVE GEYSERS, YELLOWSTONE NATIONAL PARK, 1992 = 514

Cyclic Hot Spring Activity on Geyser Hill

Upper Geyser Basin, Yellowstone National Park

Graphical, and Interpretive Descriptions of the Geyser Hill Wave, Diurnal Effects, Seasonal Disturbances, Random (Chaotic?) Events, and Earthquakes

by T. Scott Bryan

Abstract

In an effort to better understand the complex relationships between geysers and other thermal features on Geyser Hill, a comprehensive study of eruptive and water level variations was conducted during July, 1992. The results show that there are both long-term and daily (diurnal) cycles superimposed on a general but slight randomness. The causes of these apparently independent cycles are speculated on.

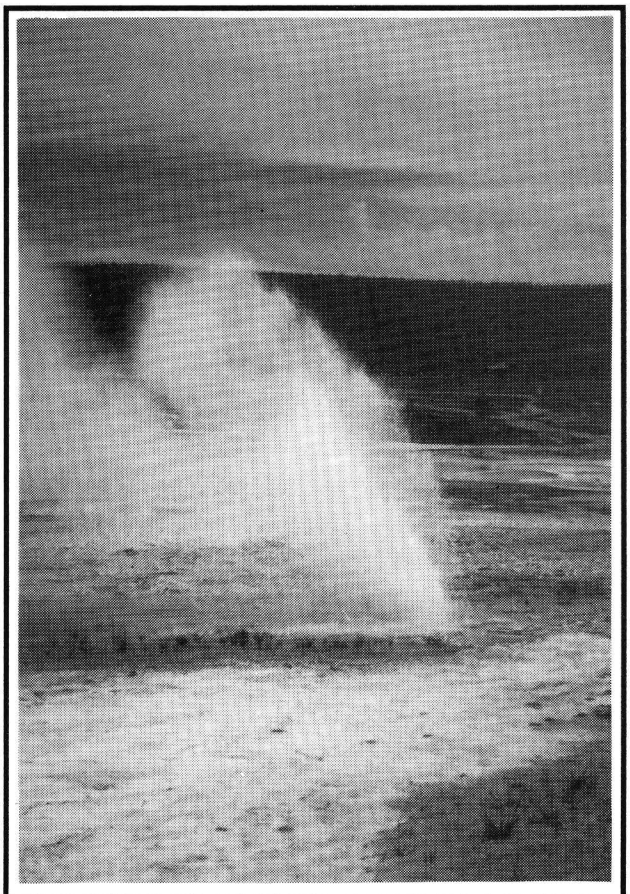
Introduction

This project began small, intending to accomplish nothing more than to describe and explain the eruptive activity of Plate Geyser and the "New UNNG southwest of Sponge", now known as "Abrupt" Geyser. But then, as the strong diurnal nature of Plume and the "Geyser Hill Wave"-controlled intervals of Beehive became apparent, the project grew, rapidly becoming a comprehensive Geyser Hill study. Much has been learned. I hope my thoughts don't "make mountains out of molehills"; I hope that these spurts of water really are controlled by discrete physical events that might be completely understood through future study. The reader must understand, however, that any statements or conclusions within this descriptive and non–mathematical article are solely those of the author, and that they are all tentative. The only absolutes here are the data!

Background

Geyser Hill lies within the upper portion of Yellowstone National Park's Upper Geyser Basin, directly across the Firehole River from Old Faithful Geyser. It covers an area of only 1000 by 700 feet, roughly 17 ½ acres, yet it encompasses at least 40 geysers plus numerous other springs. It is probably the greatest concentration of high temperature geothermal features in the world. It stands to reason that there are complex interactions between the Geyser Hill springs. Perhaps that is why previous efforts to interpret these relationships have been few and limited in scope.

On the basis of direct observations, Marler [1973] described many hot spring connections. Most of these were known on the basis of how some given geyser or pool reacted to an eruption of Giantess Geyser. Giantess, both the largest



Abrupt Geyser, near the start of an eruption on July 7, 1992. Photo by T. Scott Bryan.

single feature and largest geyser on Geyser Hill, has variable effects on Infant, Vault, Plume, Beehive, Lion, Plate, Bench, and Little Squirt Geysers and on Ear, Teakettle, Bronze, and Silver Springs and Doublet Pool. Marler also noted an apparent connection between the Lion Geyser Group and Beehive Geyser [*in* Paperiello, 1992].

The above list is tantamount to saying that everything on Geyser Hill is connected with Giantess Geyser, and therefore that every spring on Geyser Hill is at least indirectly connected with every other spring there (this excepts the sulfurous acidic springs around the margin of Geyser Hill). The Geyser Hill features comprise a single system of interrelated hot springs.

That this is so has also been shown on the basis of geochemical work. Performed primarily by the U.S. Geological Survey (mostly during the early 1960s as part of the extensive post-1959 earthquake program), detailed analyses showed no essential differences between Geyser Hill water sources. This implies that they all feed directly from a single common reservoir which, per geothermometry values, has a temperature of 215±2°C and lies at a depth of 200-250 meters [Fournier, 1992].

Despite this knowledge, the activity of the geysers on Geyser Hill has generally been presumed stable over short spans of time. Observers have expected variations from some norm only on the occasions of eruptions by Giantess, and then for the limited time frame of Giantess' eruption and recovery (usually, about four days total), or on the unusual occasions of large earthquakes. Some have pondered the possible effects of such matters as precipitation, ponded surface water, and barometric changes on local conditions without much success. Now it is realized that a whole assortment of physical processes are active within Geyser Hill. The goal of this study was a better understanding of these cyclic events.

Variations in Geyser Hill Activity

There are at least five ways in which geyser and hot spring activity vary within the Geyser Hill system. Each of these is introduced below. They will then be amplified upon as the data for this paper is considered in detail. Finally, each will have potential causes addressed at the conclusion of the report.

The "Geyser Hill Wave"

In 1990, based in part on observations dating to 1989, Day tentatively reported a relationship between the eruptive frequency of Beehive Geyser and active episodes in Little Squirt Geyser [Day, 1991]. It was noted that near the time when Little Squirt was active, Beehive was likely to have a shorter than average eruption interval. Its intervals would then increase through the next several days until a "skip day" occurred. At this time, Beehive's running average was near 24 hours, but a "skip" interval was of at least 36 hours. This had the effect of resetting Beehive to the morning hours of the second day following the last eruption. That a full day and more really was skipped was repeatedly shown by both continuous observations and the ocasional off–season use of runoff markers. After the skip, Beehive again had shorter than average intervals as this cyclic variation began again.

In some fashion, this resetting of Beehive's eruption time and interval length was tied to the eruptions of Little Squirt. What seemed even more remarkable was that on at least one occasion the role of tiny Little Squirt Geyser seemed to be usurped by huge Giantess Geyser. It was as if Little Squirt served as a control for all of Geyser Hill and that nature sometimes confused the Giantess 'on' switch for that of Little Squirt. As of 1990, it was believed that it was the actual eruptions of Little Squirt that served as the control on other activity.

Now it is recognized that Little Squirt is just one among many features that are influenced by a more deeply seated process. Indicated by cyclic variations in quietly flowing springs as well as by cyclic intervals in geysers, this has come to be called the "Geyser Hill Wave" ("GHW"). The status of the GHW itself is most easily monitored by watching the water levels within several springs located near Little Squirt at the southern end of Geyser Hill. The eruptions of Little Squirt and the short intervals of Beehive (among many other effects) take place when water levels are at their highest in Silver Spring and Bronze Spring. This time is critical to much of Geyser Hill. Recurring every 4 to 9 (usually, 5 to 7) days, this high water level is here referred to as the SMax (for "south maximum").

Diurnal Effects[1]

It used to be that Plume Geyser was marked with a sign which gave not only its name, but also cited a precise value for its interval. The Park Service naturalists had several signs available so that they could be changed in accord with alterations in Plume. Most commonly the signs told of intervals of either 25 or 27 minutes. In fact, at one time Plume did seem to be nearly "stop watch regular." For whatever reason, this is no longer the case. Plume undergoes significant interval variations over the course of each day.

This diurnal variation was first recognized by Day in 1990 [Day, 1991]. He found that early morning (around dawn) intervals were typically 5 to 7 minutes longer than those of mid afternoon. Day's explanation was air temperature. He surmised that Plume's small pool lost more heat to the cool morning air than it did to the warmer afternoon atmosphere. In support of this idea, he noted that the diurnal variation was much less noticeable during the warmer days (and nights) of July and August. Day [1992b] modified this idea in a short paper which opined that it was the inflow of cool water into Plume's crater that caused the delay.

However, weather is probably *not* the cause of Plume's diurnal variation, which is now a strong daily occurrence. During this July study, some of the greatest variation was seen during exceptionally warm weather. Rather than being a difference of 5 to 7 minutes, early morning intervals (which may be as long as 50+ minutes) can actually double the length of that afternoon's typical 30-35 minutes. Also, diurnal variations were evident when storms or cloud cover produced days with little temperature variation. It seems clear that something other than the daily air temperature variation is the cause.

In a more general sense, diurnal variations have been surmised for other Geyser Hill features. Most notable is the almost complete failure of Giantess Geyser to begin an eruption during the day; this observation has been taken as gospel for many years, and even applied during the early 1980s when Giantess' intervals were as short as a few days. The corollary here is Beehive Geyser which, when having longer (24+ hour) average intervals, almost never erupts at night. The cause cited here is wind: the breezes of day cause a cooling of Giantess' large surface pool, somehow forcing the eruptive energy to find another exit (namely, Beehive). That this process is possible is clear. Many other large pool-bearing geysers are known to be delayed by wind, and Beehive's action is definitely influenced by activity in Giantess. Taylor [1992b] suggests that the cause of the diurnal Giantess–Beehive pattern is identical to that causing the Plume diurnal pattern, and that neither results from wind.

Seasonal Disturbances

So–called seasonal disturbances occur regularly at the Norris Geyser Basin, most commonly taking place during the later part of each summer season [White and others, 1988]. The theoretical cause is a decrease in the availability of near–surface geothermal water which allows a sudden upward flux of deeper, hotter geothermal fluids to reach the surface. The result is an increase in the turbidity and eruptive activity of existing hot springs, and the appearance of numerous ephemeral new features. The areal extent of the Norris disturbances is highly variable. Sometimes all portions of the basin are involved. More often it is only a part of the Back Basin. Many of the Norris geysers are active only during at these times, so disturbances are eagerly anticipated events.

Much less certain is whether or not similar disturbance events take place in other geyser

[1] This term is a difficult one. The primary definition of "diurnal" is the antonym of "nocturnal". However, it has also been commonly used in the physical sciences to denote any day–night difference in conditions, events, and processes, without consideration of a specific cause being necessary. This is the use adopted here.

basins. Along the Firehole River, where most springs are clear and alkaline, disturbances would not be likely to produce muddy spring conditions. They would instead be marked by sudden changes in the nature of geyser activity—alterations in frequency, duration, and so on.

Every year a series of "unusual" events takes place in late summer [Bryan, 1992]. While this is commonly taken as an effect of randomness, it could well be because of previously unsuspected disturbance action. This idea, as a strictly theoretical concept, is supported by Dr. Robert Fournier of the U.S. Geological Survey [1992].

At this point, any correlation between the 1992 activity observed on Geyser Hill and disturbance action would be tentative at best, but it is worth noting that on July 9–10 (at Little Cub Geyser) and about August 3 (involving Beehive Geyser and others) were very sudden, large–scale, and historically unprecedented changes in the geysers. That these were due to disturbances is at least possible.

Randomness (Chaos ?)

No matter what repeating processes are taking place within the depths of Geyser Hill, the simple fact is that geysers are never precisely regular. Even the most predictable commonly exhibit plus or minus several percent variation from their mean interval. This is generally, albeit imprecisely, attributed to slight changes in water and/or heat flow into the geyser because of interconnections with other springs ("exchange of function"). That this plays a prominent role is unquestionably so. However, too, there are many cases where so-called random variations have ultimately shown a pattern. Per recent mathematical theories, apparent regularity ("pseudo-regularity") can be an aspect of a chaotic system. Perhaps, then, chaos serves as another factor in Geyser Hill mechanics. Beyond this suggestion, though, chaos is not addressed in this report.

Earthquakes

Earthquakes, whether relatively small and local or large and distant, have been shown to cause significant changes in geyser activity. The best known occasions are the 1959 Hebgen Lake, Montana earthquake (magnitude 7.2 with an epicenter only about 40 miles from Old Faithful), which caused observable changes in hundreds of springs and geysers, and the 1983 Borah Peak, Idaho earthquake (magnitude 7.9 with an epicenter about 200 miles distant), which produced fewer alterations in geyser behavior but changes which were most notable on Geyser Hill. Many other earthquakes have also produced changed and aberrant geyser behavior, even when the tremors have been as small as magnitude 2.5 or thousands of miles distant. In these latter cases, the earthquake effects tend to be limited in both extent and time.

Any earthquake effects will be superimposed on whatever is already occurring within the local geothermal system. Unless they are dramatic, they might well be undetectable, overwhelmed by the variations due to on-going local processes. It is noted that neither the local magnitude 4.4 and 4.2 earthquakes of July 20 nor the major magnitude 7.5 and 6.6 earthquakes in southern California on June 28 had any detectable effect on any Geyser Hill thermal feature.

This Study

This paper is intended to be descriptive of the observed geyser and spring activity more than it is aimed at physical explanations.The results and conclusions of this study are based almost entirely on straight forward visual observations—the eruption times of the geysers and water levels within other springs. This data has been graphically charted and examined by only the most basic of statistical analyses. At no time was any sort of mechanical measuring device utilized. In that sense, this is a preliminary effort which has the potential of leading into a far more detailed examination of Geyser Hill in the future.

Nearly thirty individual thermal features were initially involved in this project. Because some of them proved to be either valueless or physically placed so as to make observations awkward, this number was ultimately reduced to nineteen.

Geyser eruption statistics were considered for: Beehive, Beehive's Indicator, Plume, Depression, Aurum, Lion, Little Cub, Plate, "Abrupt", Roof, Dragon, Cascade, and "UNNG across from Lion" Geysers.

Spring conditions were recorded in: Bronze, Silver, Ear, and "Exclamation Point" Springs, Infant Geyser, and (as eruptive episodes) Little Squirt and Dome Geysers.

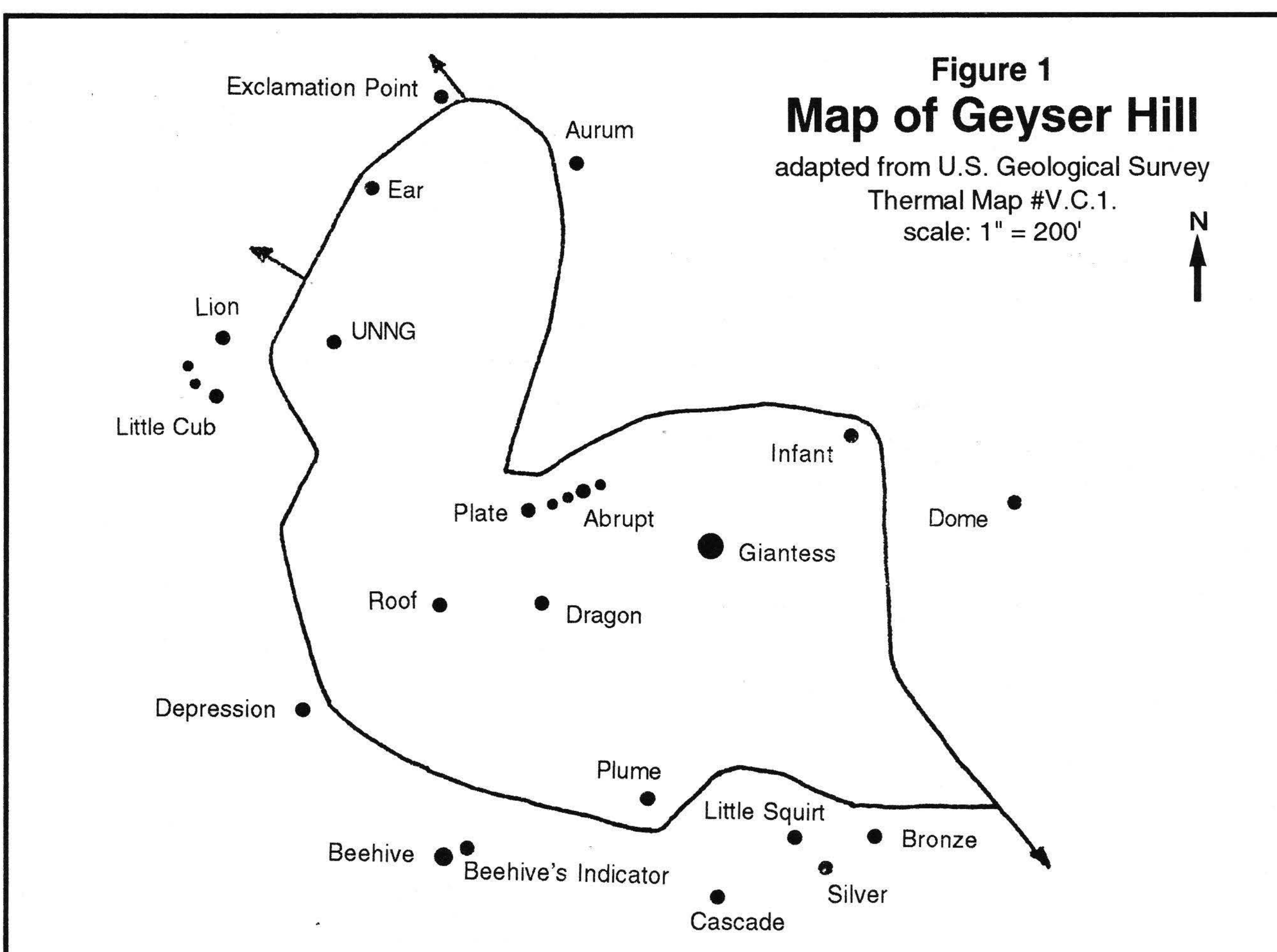
Each of these features is located on the map of Figure 1 and will be described in the following pages.

About the Charts

Many of the observations and conclusions discussed in this paper would be completely incomprehensible without graphical representations which allow large amounts of data to be visualized and understood. The graphs accompanying this report were produced using DeltaGraph Professional 2.0 (Macintosh version). The charts of Plume Geyser's time-interval distribution for July (Figures 5 and 5b) contain 537 data points, for example. In total, the raw data for this report includes several thousand data points. The data pages are not included with this report but will be made available to any who wish them.

While a number of graphs appear within these text pages, of utmost importance are the "master charts". These represent the long-term data span of April 26 through July 27, 1992. All have been drawn to the same horizontal (x-axis time-line) scale so that any given date falls at the same place on each chart. This allows the separate charts to be matched to one another so that the statistical trends of the various features can be directly correlated with each other.

My strong recommendation is that the reader of this paper photocopy these chart pages and appropriately tape them together before reading further. Matching pages are labeled such as "Master Chart A right" and "Master Chart A left" to help you. Note that the matching pages meet



with virtually no tiling overlap. Once the individual chart pages have been joined, they might all be further put together so that all of the graphs are aligned vertically.

Also included in the report are other two-page charts. They should be copied and taped together, also. These have different horizontal axes from the others, however, and so do not directly correlate with the master charts.

Geyser and Spring Observations

Each of the geysers and hot springs listed above is described in brief general terms and then its observational data is briefly analyzed. Those whose activity most directly bears on the Geyser Hill Wave and/or diurnal effects are dealt with first.

Little Squirt Geyser

Little Squirt is a very small geyser near the southwestern limit of Geyser Hill. Mostly ignored, it has long been known to have intervals in terms of days to weeks; it is dormant during some seasons. The eruptions consist of a squirting action which reaches 2 to 4 feet high out of a vent only 3 inches in diameter. The durations are as long as 12 hours, during which there may be occasional brief pauses.

Though it is small, Little Squirt's activity serves as a primary indicator of the GHW. The eruptions occur only at the time of SMax, when nearby Silver and Bronze Springs are at or near their highest possible water levels. Beehive Geyser often has its shortest intervals ended by eruptions while Little Squirt is active. Unfortunately, not every SMax is accompanied by an eruption of Little Squirt; as noted in the introduction, it is but one aspect of the GHW cycles.

The dates of SMax (determined from Little Squirt eruptions and/or Silver Spring water levels) are shown as solid circles on Master Chart A; open circles indicate SMax occasions *not* accompanied by Little Squirt. Since SMax is the primary indicator of the Geyser Hill Wave, these data points on Master Chart A serve as control points for all other master chart data.

Beehive Geyser

Excepting Giantess Geyser, Beehive Geyser is the largest on Geyser Hill. Its historic activity has been highly variable, and eruption intervals of days to weeks were common until the 1970s. More recently, the intervals have been shorter. Even in relatively off years, Beehive can be expected to play at least several times per week and during some seasons, such as 1992, the average interval is less than 24 hours. Beehive is a cone geyser. The steady jet of the eruption reaches 150 to 170 feet high for most of the 5 minute duration.

Because it is a spectacular sight and readily visible from the Old Faithful developed area, Beehive is carefully watched for. Also, because its eruption time can be anticipated or even predicted given knowledge of the GHW, few eruptions go unobserved. An analysis of the intervals serves as a good monitor of the GHW and its SMax.

Day [1992] put together a comprehensive eruption record for Beehive's summer season activity during 1992. This record of 95 data points for the period of May 1 through July 27 is shown on Master Chart A. In developing this data for the graph, I have divided known double intervals by two in order to produce a graphical data point. While doing so produces some inaccuracy, it also avoids gaps in the chart which might otherwise make some of the trends more difficult to visualize. Also, two portions of Chart A have dashed, hand drawn peaks which show my interpretation of the data missing from longer time gaps. (Note: two data points are plotted as exactly 24 hours, the maximum time value readable by the computer program. These two values are actually 24:57 and 24:56.)

As is the case with all the other master charts, the x-axis time-line of Master Chart A is divided into one week spans. The various high and low interval peaks can readily be seen to repeat on intervals of roughly one week. Although there is much internal variation, the general trend of the GHW is clear. The intervals falling at about the time of the SMax were commonly shorter than 16 hours and dropped to less than 13 hours on at least three occasions; the shortest closed interval was 12h 34m. The other extreme included intervals almost exclusively longer than 20 hours, with a closed maximum of 24h 57m. The net average of 18h 10m was almost useless as a predictive tool.

After the time of this study, the activity of Beehive suddenly and dramatically changed in conjunction with unprecedented eruptions by Beehive's Indicator (see below). Possibly triggered by a GHW cycle of only three days (which could be a disturbance effect), Beehive jumped to intervals of 24h 04m and 27h 07m and then suffered an interval of almost four days before falling completely dormant through the next four weeks. A plot of this data (Figure 2) shows shows no indication of impending change other than a "concluding" series of closely spaced SMax times.

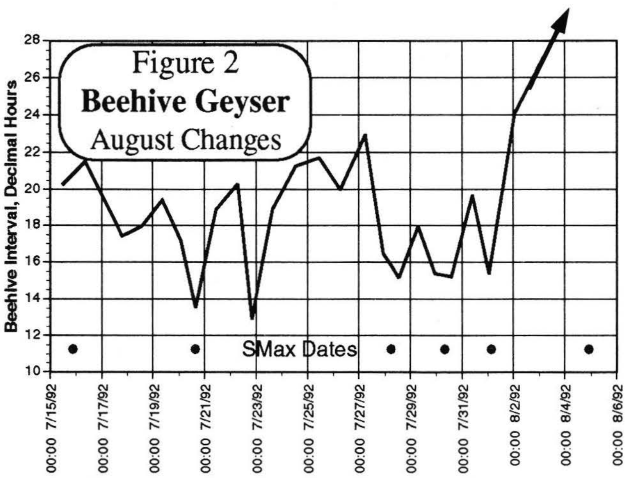


Figure 2
Beehive Geyser
August Changes

Beehive's Indicator

Beehive's Indicator is that curious small geyser near Beehive's cone which commonly erupts for a few minutes prior to an eruption of Beehive but, in most years, at no other time. It is therefore very aptly named. During 1992, its duration before the start of Beehive was usually around 20 minutes— warning enough to allow people to reach the site from the far end of the Upper Basin when the start of the action was seen and announced by radio. However, there appears to be no correlation between the Indicator's duration and the GHW (Master Chart B, which includes only full, closed Indicator durations).

On the other hand, other forms of Indicator activity might relate to the GHW. Although rare and not seen for several years prior to 1992, the Indicator sometimes erupts during the middle portion of Beehive's interval. This action is called a "mid-cycle Indicator". In 1992, this usually occurred between 7 and 10 hours after a Beehive eruption and, therefore, at least a few hours before the next eruption. Most of this play was brief (duration less than 60 seconds) and weak (height not more than 3 feet), so that it is likely that a great many mid-cycle Indicator eruptions went unseen. Nearly all of those that were witnessed fell near SMax. However, since SMax was a time when more than an ordinary amount of attention was being paid to Geyser Hill, it could well be that this time concentration is an observational artifact.

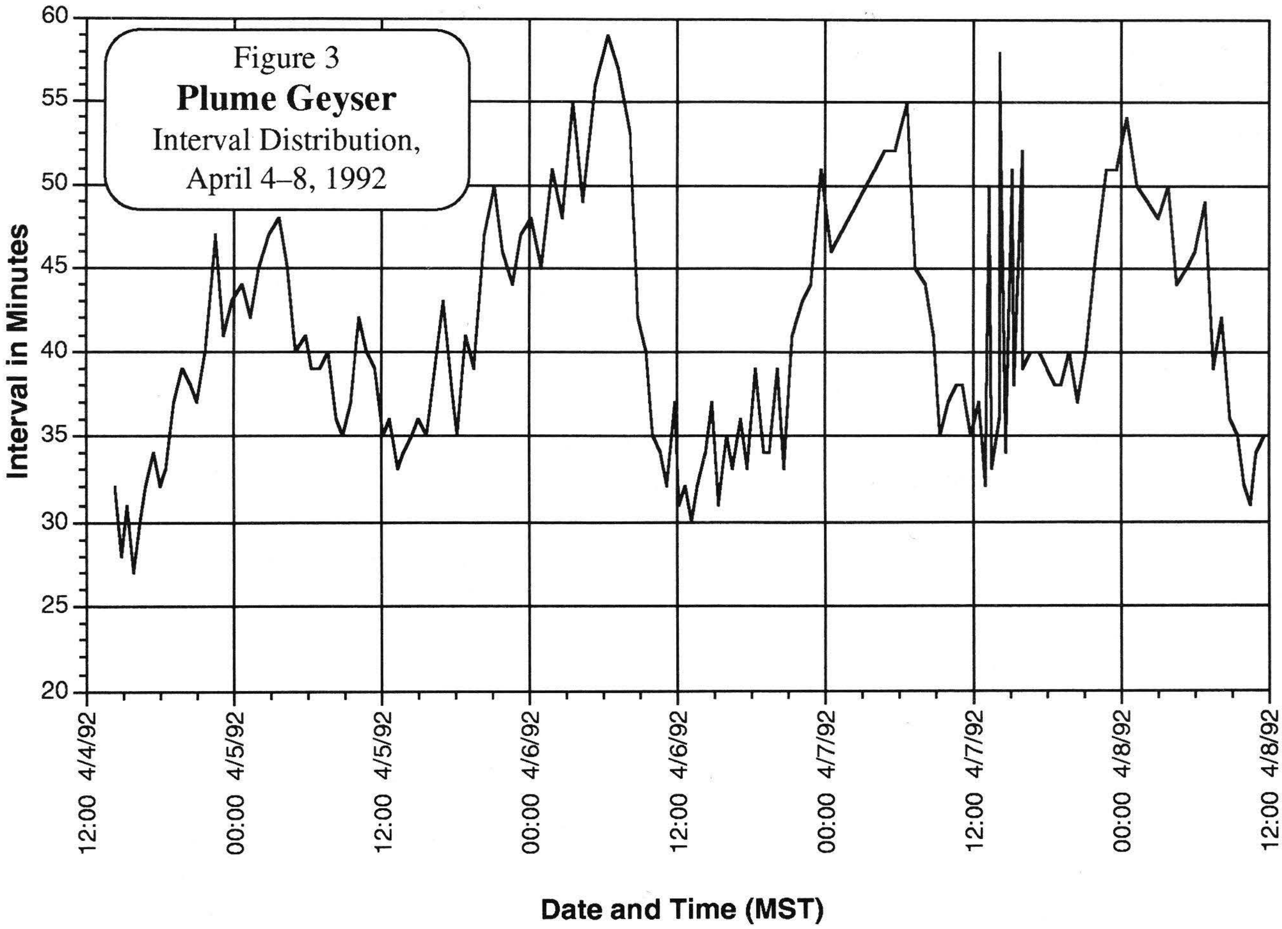
In August, after the end of this study, Beehive's Indicator began having "false Indicator" eruptions. These, again uncommon and unseen for a few years, are Indicator eruptions which take place at a time when Beehive itself could be expected. Instead of resulting in an eruption, though, the Indicator simply plays for an extraordinarily long duration and then quits without play by Beehive.

By August 3, the Indicator was playing every 3 to 5 hours for durations of 30 to 50 minutes without resulting in a Beehive eruption. This action lasted until September 1. Such a long series of independent Indicator eruptions is completely without recorded precedent (nothing previous comes even remotely close). Its relationship to the GHW is entirely unknown.

Dome Geyser

Dome Geyser is highest in elevation of all Geyser Hill features. Its eruptions consist only of small bursts and violent boiling, somewhat belying the large geyserite cone. Actually monitored here were eruptive episodes; once triggered by an initial eruption, Dome continues to play with intervals of a few minutes for the better part of two days.

People have conjectured for years that Dome is directly related to Giantess Geyser, but they have expressed both positive and negative



roles for Dome. One school has said that activity in Dome is a negative sign, at best delaying a potential eruption of Giantess by bleeding energy from the Geyser Hill system. Others said just the opposite, believing that Dome's action is an indication of "building pressure" in Giantess. In either case, if Dome does relate to Giantess, then it should also relate to the GHW.

In the three months following May 1, 1992, Dome was active on only four occasions, with intervals of >26, 9, 24, and 13 days. The dates are plotted as triangles on Master Chart A. Although this is sparse data, three of the four Dome initiations occurred at the time of SMax; the fourth was two days after a SMax. Giantess is known to have begun eruption at the time of a 1990 SMax. None of this clearly answers the question as to Dome's effect on Giantess. However, since Giantess and Dome have seldom erupted together and since both clearly can be synchronous with SMax (possibly as one *or* the other), this author feels that activity by Dome is most likely a negative indicator for Giantess .

Plume Geyser

Plume was born as a geyser during 1922. Active for only two years before lapsing into a dormancy, it rejuvenated in 1941 and has been active ever since. Prior to the 1959 earthquake, the intervals were mostly in the 59 to 75 minute range. Following a period of irregularity after the earthquake, beginning in 1962 and lasting until a steam explosion blew out a second vent in 1972 Plume showed highly regular intervals of 25 to 29 minutes [Marler, 1973]. No variation from this high degree of constancy was ever described. Even after the 1972 explosion, Plume remained regular although the play was of very different form (bursting rather than a slender jet) and duration (intermittent bursts over the course of about 1 minute rather than steady for 2 to 2 ½ minutes).

Something certainly has happened. Just what and when is uncertain, but Plume now shows a strong diurnal variation in its intervals. That this is a still-developing trend is shown by the progressively greater degree of daily variations. Plume's diurnal nature was not noted at all until 1989. In 1990, the difference between the longest and shortest intervals of a given day was just 5 to 7 minutes. In 1992, this difference was as great as 29 minutes.

Plume's diurnal pattern is illustrated by three data sets included in this report. The first of these is the result of an instrumental monitoring conducted for 96 continuous hours from April 4 to 8 by Yellowstone's Research Geologist, Rick Hutchinson [Thompson, 1992]. The daily interval range was not less than 15 minutes during this period, and on April 6 was 29 minutes (30 to 59 minutes). This data is illustrated on Figure 3. The average length of these 141 intervals was 40.43 minutes. (Note that the times on this chart are Mountain Standard Time; the times on all other charts are Mountain Daylight Time. This difference is important when the time of the diurnal peak is considered in detail.) The frequency distribution of these intervals is shown on Figure 4 (with other histograms for comparison; see second page following).

The second set of data covers the span from July 1 to 27 and is shown on Figure 5 (a 2-page strip chart version of this same data is Figure 5b). At no time here was there a continuous 24-hour monitoring, yet the diurnal nature of Plume's intervals is still obvious. For dates on which there is relatively complete data, the daily range was never less than 9 minutes and twice was as great as 18 minutes. This data set includes 537 intervals which average 35.39 minutes; this frequency distribution is Figure 6 (with Figure 4).

Although there are a few differences between these two sets of data (most notable is the fact that the July average is 5.04 minutes (or 14.2%) shorter than the April average, primarily due to the loss of 50+ minute intervals), there are more similarities. The diurnal peak interval typically occurs during the morning hours between 03:00 and 09:00 (there are exceptions). Following the peak the intervals decrease in length so that they are nearly down to the daily minima by noon. Then they remain unchanged (excepting internal variability) until late in the day.

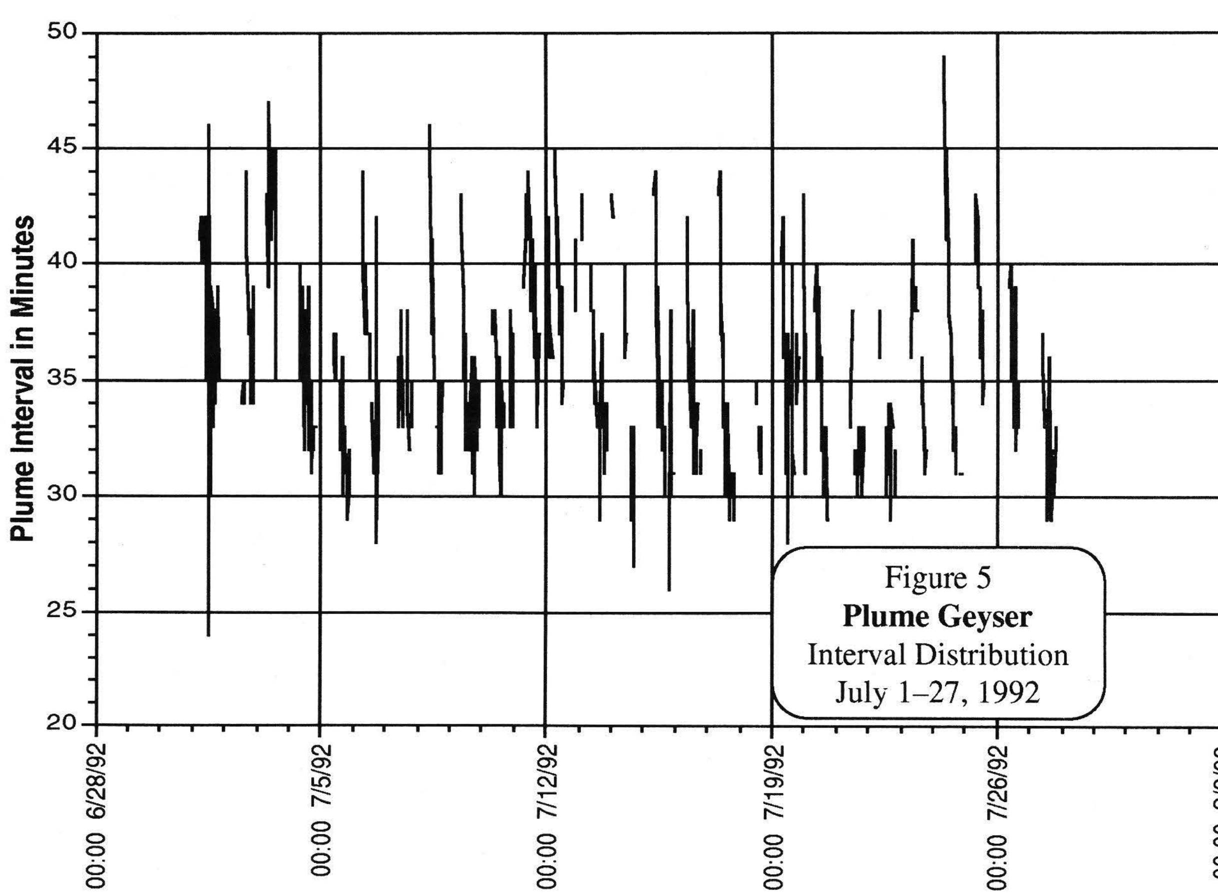


Figure 5
Plume Geyser
Interval Distribution
July 1–27, 1992

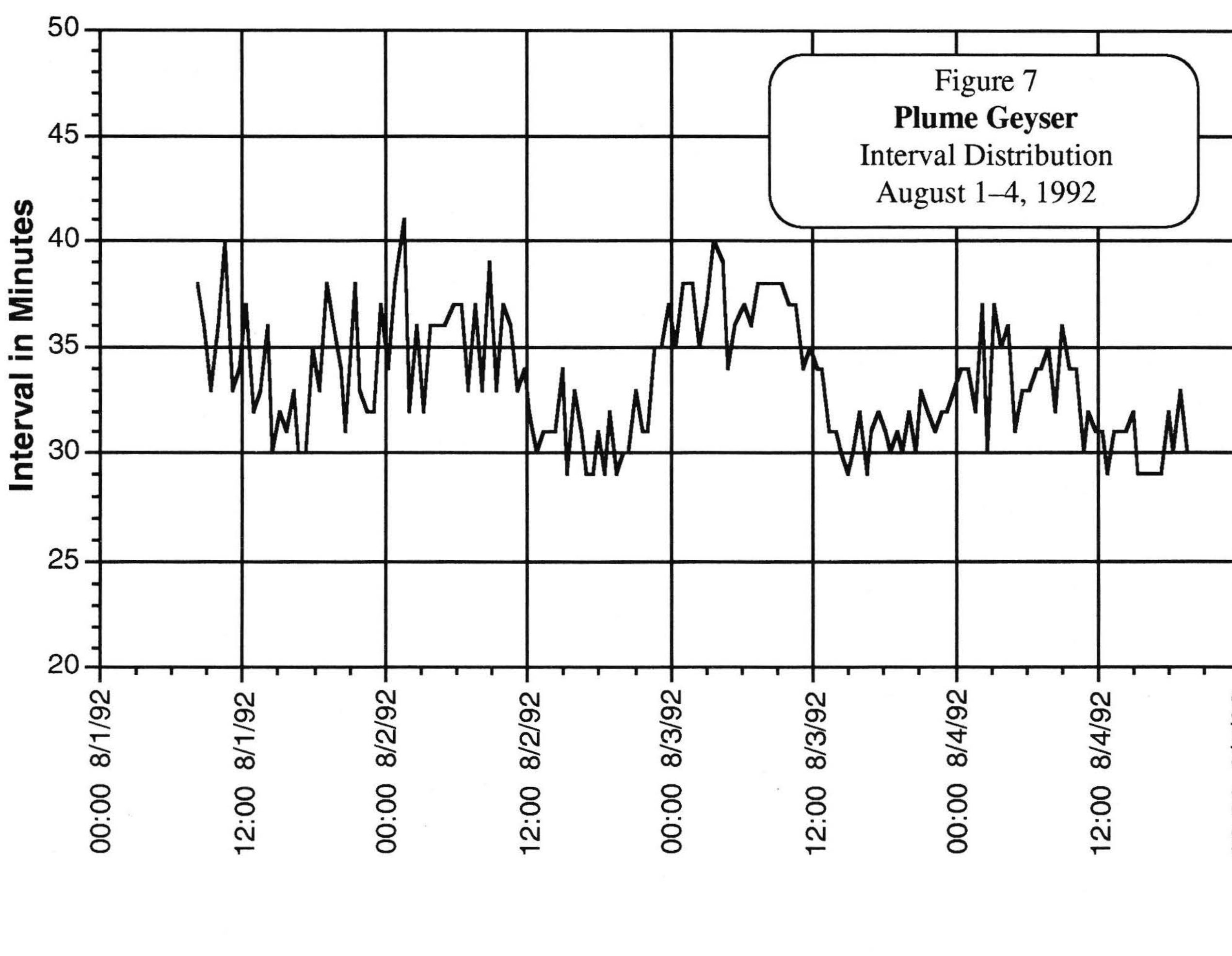
The third set of data covers 84 hours of continuous visual observation between August 1 and 4 during a GOSA project organized by Ralph Taylor. It takes only a glance to see that this data is substantially different from that of April and July. The net average interval is different (33.32 minutes for 149 intervals, 2.07 minutes under that of July). The diurnal pattern is evident but strongly attenuated (Figure 7). Even more, the overall interval distribution is much tighter than before (Figure 8). The time difference between July 27 and August 1 is small, but this was the time frame of Beehive Geyser's sudden increase in intervals prior to its dormancy which began on August 7. Did Plume respond to the same force that affected Beehive?

Within all of this data were two occasions when Plume developed an extremely erratic pattern. Neither of these can be explained at this time. Taking place on April 7 and July 1, Plume produced intervals which were alternately long and short, ranging from 33 to 58 minutes on April 7 and from 24 to 46 minutes on July 1 (see Figures 3 and 5b). The fact that both of these episodes began at about noon on each date might be important; on both occasions Plume had just recovered from the diurnal peak. This is a matter for future investigation.

Plume is a member of the Geyser Hill complex of springs. Even before it exhibited the diurnal variations, its intervals were known to increase following the start of a Giantess eruption. Therefore, Plume should also participate in the GHW, and it is clear that it does.

On all the charts showing Plume's July intervals, there is a prominent wave-like aspect to the data. This is especially noticeable if the daily minimum or maximum intervals are considered alone. This is clearest on Figure 5b, where the solid circles across the 23-minute line near the bottom of the chart indicate the times of SMax. Plume clearly tends to shorter intervals at about the time of SMax and runs substantially (as much as 8 to 10 minutes) longer when the southside water levels are low.

Taking all the Plume data together, while



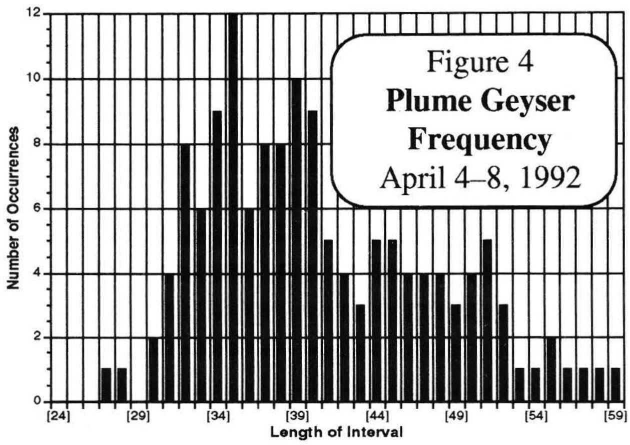


Figure 4
Plume Geyser Frequency
April 4–8, 1992

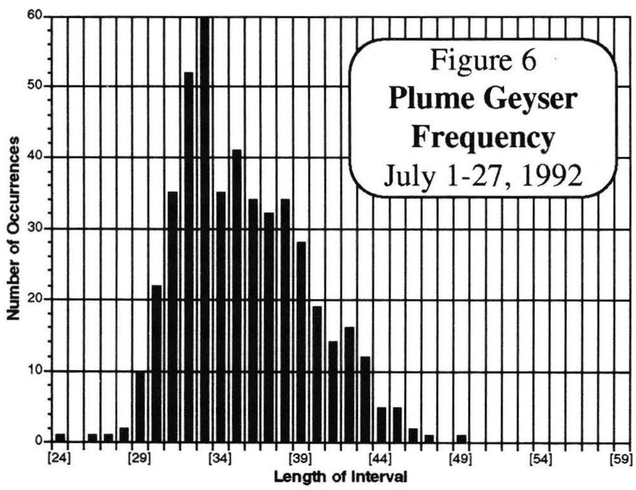


Figure 6
Plume Geyser Frequency
July 1-27, 1992

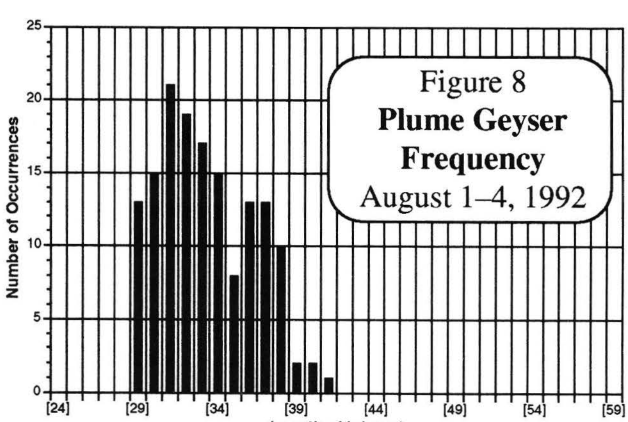


Figure 8
Plume Geyser Frequency
August 1–4, 1992

one process influences its intervals on a daily basis, another causes the Geyser Hill Wave which moves the diurnal pattern up and down the interval length scale. An eruption of Giantess would throw still more variety into the sequence.

One final interesting point: Plume's intervals are dramatically altered by eruptions of Giantess. Beehive is also affected by Giantess. Yet there is no evidence that Plume either influences or is influenced by Beehive! Despite their nearness to one another, any direct connection between Beehive and Plume must be tenuous.

Depression Geyser

Depression Geyser erupts from a small pool low on the west-central side of Geyser Hill. According to Marler [1973], eruptions were infrequent prior to the 1959 earthquake. Thereafter it began erupting every 3 to 4 hours, which intervals gradually increased to and stabilized at the present 5 to 7 hours by the middle 1980s. The eruptions consist of erratic bursting up to 10 feet high over a duration of roughly 3 minutes.

Prior to this study it was entirely unknown whether or not Depression was related to any other Geyser Hill features so as to be influenced by their activity. It is, but Depression's comparatively long intervals make it only marginally useful as a GHW monitor.

The impact of the GHW seems to be fairly strong here, but it is only clearly seen when its data graph (Master Chart D) is compared to the average Plate and Aurum scatter rather than directly to the SMax dates. On the graph, the 36 data points have been connected by a simple spline curve in an effort to clarify the pattern. (A spline curve does nothing more than smoothly connect data points in the order they were plotted, ignoring any gaps within the data.) Because there is a rather strong similarity between this spline curve and curves drawn through the Aurum and Plate data, all three of these curves and the SMax dates are reproduced in Figure 9. Most intriguing in this is that while all of these geysers are affected by the GHW in similar fashion, the effects show up in Depression about one to two days after they appear on the upper part of Geyser Hill.

Aurum Geyser

Aurum Geyser occupies a position near the northeastern limit of Geyser Hill. During most of its history it has acted in a cyclic fashion, and dormant periods were often several months long. Because of this, it is not known how it might have been altered by the 1959 earthquake. The 1983 quake, however, resulted in regular and frequent

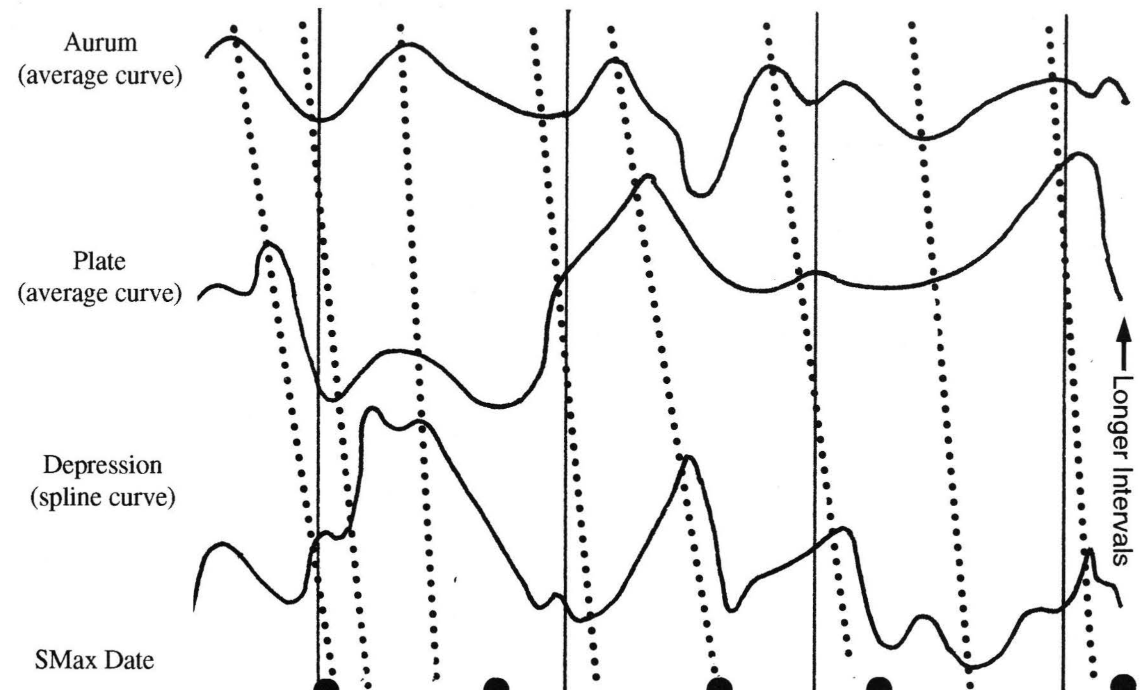


Figure 9. Running average and spline curves for Aurum (top), Plate, and Depression Geysers with SMax dates, July 1–27, 1992. Dotted lines connect possible corresponding events between these geysers.

action which has continued until now. Eruptions usually recur at intervals of 3 ½ to 4 ½ hours. The play lasts a little more than 1 minute. Aurum has become stronger during the past few years, and its angled jet can reach over 25 feet high.

Since Aurum is about as distant as possible from Silver, Little Squirt and the other strongly indicating SMax features, it was felt that its activity might be antisympathetic— that is, Aurum's activity decreasing as it increases elsewhere on Geyser Hill. Instead, it is sympathetic, as everything on the Hill seems to be. The basic interval data is shown on Master Chart D, but the relationship is most readily seen when an average curve of its closed intervals is compared with interval curves for Depression and Plate (Figure 9). Notice that there are apparent correlations between the three curves, and that specific events (such as longer intervals) tended to occur about one and two days earlier at Aurum than they did at Plate and Depression respectively.

There is evidence that Aurum is influenced by the wetness of its surface surroundings. It has been noted that during extended periods of very dry weather, the intervals tend to lengthen. Day [1991b] confirmed intervals as long as 20 hours during the July-August, 1990 dry season; but within that same stretch of time, the intervals would drop to a regular 3 to 4 hours for a few days following good rains. If Aurum is this sensitive to external, non-geothermal conditions, then clearly it is all but useless as a reliable GHW monitor.

Plate Geyser

Plate Geyser is a small, usually unnoticed feature at the southwestern base of Sponge Geyser's sinter cone. It is not discussed by Marler [1973] and is believed to have developed as a geyser sometime in the late 1960s as a delayed result of the 1959 earthquake. The crater is the northwestern-most of a linear chain of vents which includes the new "Abrupt" Geyser[2]. Plate has shown highly variable activity through the years.

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[2] One of these craters, about half way between Plate and Abrupt, was referred to during 1992 as Slot Geyser. This is incorrect. Slot, named by Watson during post-1959 earthquake mapping, lies "about 45 feet southeast of Plate", which distance places it at or beyond the far end of the fracture or, possibly, at what was initially reported in 1992 as the "Second New Thing" a few feet south of Abrupt. (See also Footnote 3.)

During most seasons it is entirely dormant except for short periods during eruptions by Giantess Geyser; even this is a sometimes thing. At other times, though, it is a regular geyser. With durations of about 3½ minutes, it sends vigorous bursts of water as high as 10 feet. Most 1992 intervals were between 1½ and 2 hours.

Since Plate is quite directly connected with Giantess, it was expected to participate in the GHW, and it very clearly does so. A plot of its intervals is shown as Master Chart E. Especially after the middle of June, there is evident correlation between Plate and the interval cycles shown by Beehive Geyser.

Because of Plate's direct relation to Giantess, it might be expected to show the influence of Dome Geyser, too. It did so for each of the four Domes during this study period. The Dome of May 26 coincides with Plate's first day of predictably reliable intervals; June 4-5 was a time of extremely short intervals; June 27-28 (when Dome started at night) saw both excessively long and short intervals; and July 11-12, when Plate underwent shortened and then lengthened intervals andBeehive underwent a large data excursion). On July 26, Plate showed a Dome-like effect in company with a sharp rise in Beehive's intervals although Dome was not active. Master Chart E includes the dates of Dome's activity.

As noted under the discussions of Depression and Aurum Geysers, some relationships become most apparent when the data is presented as a simple spline or running average curve. Figure 9 includes these curves for these three geysers. There are strong resemblances between the curves for Depression and Aurum and that of Plate. Notice, though, that the various peaks and valleys in the Plate data took place about one day earlier than they did at Depression and one day later than at Aurum! This is possible evidence in support of the Geyser Hill Wave actually being a true wave-like event taking place at depth: while the GHW has similar influences over much of Geyser Hill, the resulting events are not strictly simultaneous.

"Abrupt" Geyser

During the first week of May, 1992, the Park Service trail crew rebuilt the boardwalk across the top of Geyser Hill. The new walk follows the same route as the old but stands higher so that only support posts reach the ground. Near Pump Geyser, the bottom rail of the old walk acted as a dam, diverting some of Pump's discharge around the south side of Sponge Geyser's cone. This water flowed directly into an old crater, one of a series of fracture-controlled openings which includes the craters of Plate and Abrupt[3]. The 1992 rejuvenation of Plate and the first ever recorded eruptions by Abrupt occurred on May 8, two or three days after the old boardwalk dam was removed and runoff ceased flowing into the old crater. Many have tried to correlate the 1992 activity with the boardwalk reconstruction.

It must be noted that at most times in the past there was no water flowing into this crater, but Abrupt had never erupted historically prior to this particular lack of runoff. Also, Plate *has* been previously active, including at times when there *was* water flowing here; and it has been dormant when there was no flow. Given the historic record and the few days' delay between the shifted runoff and the initial eruptions, I am not convinced that there is any relationship between the geysers and the boardwalk work. In fact, I believe this to be an entirely natural event which would have resulted in eruptions by Plate (if not by Abrupt) on May 8 even if the boardwalk had not been changed.

An examination of Beehive Geyser's interval record before and after May 8 shows a steadily decreasing interval trend (Figure 10).

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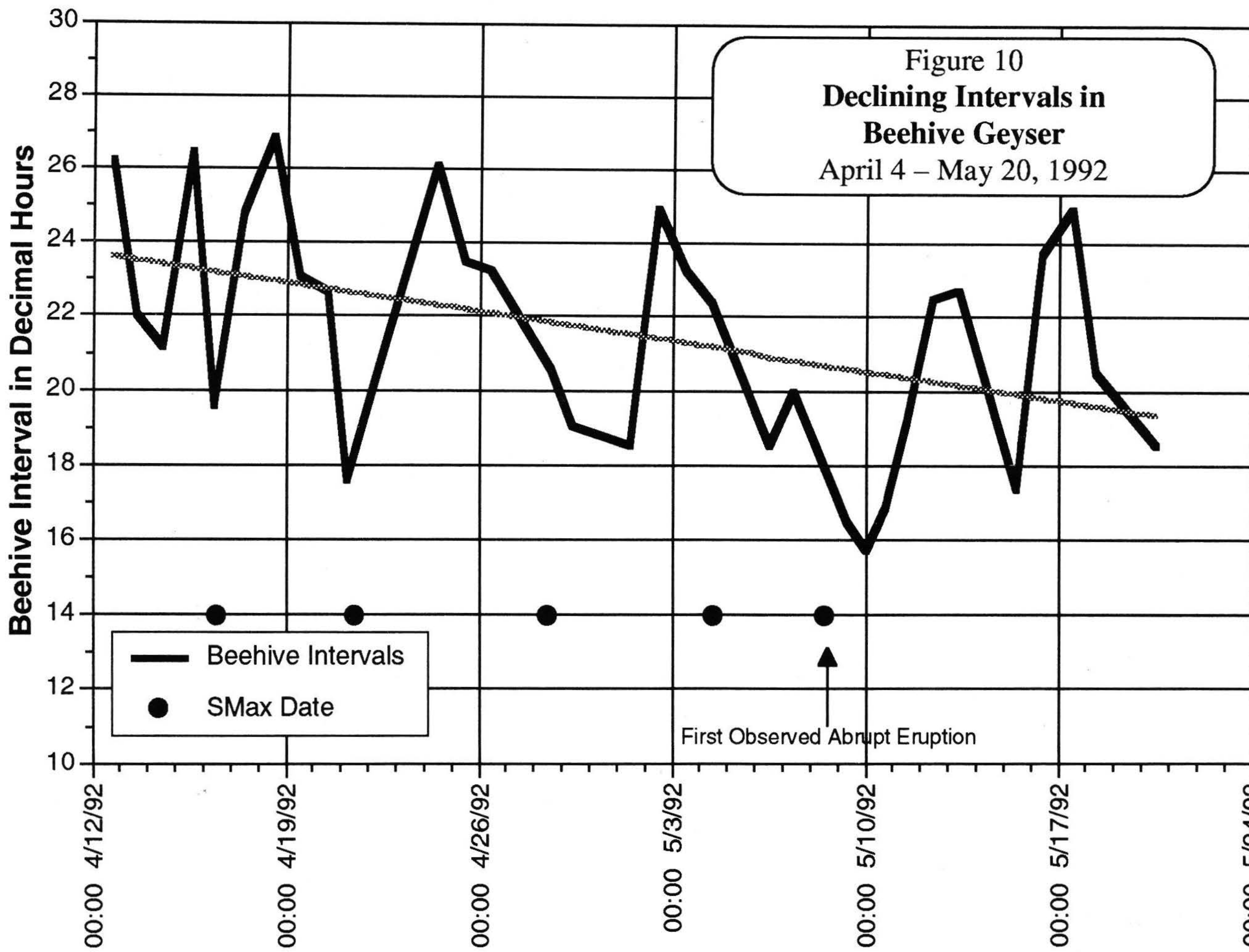
[3] The name "Abrupt" is entirely informal at this time. It was decided on by a general consensus of observers present around July 20, 1992. Two other names have been suggested. "Argentum" ("silvery") was favored by some in allusion to the angled nature of the eruption which looks much like that of Aurum ("golden"); however, there is nothing silvery about this geyserite. Others liked "Murua", Aurum spelled backwards because the angled water jet plays in a direction opposite that of Aurum. Abrupt, however, aptly describes this geyser's initial appearance, changes in behavior, and initiation of eruption... and probably its ultimate demise.



The gray power curve falls close to the running average interval. This decline in intervals corresponds to a nearly 20% increase in energy available to Beehive Geyser between April 12 and May 20. Given the connections between Geyser Hill springs, other features should have also partaken of this energy flow. May 8 was the first date on which Beehive's activity actually stabilized within the interval range it held for the succeeding three months (compare the Figure 10 trend with that of Master Chart A). May 8 was also the first date on which Abrupt and Plate Geysers had eruptions. And finally, May 8 was also a SMax date. In other words, May 8 was a notable day in a number of ways.

The eruptions by Abrupt are impressive, especially during their first few seconds. Beginning with amazing suddenness, Abrupt spews a large volume of water as high as 25 feet to the east at about a 45° angle. Although the water volume rapidly decreases, the height and lateral throw are maintained. As time goes on, the eruption becomes steamier and the remaining water is jetted at a progressively more acute angle so as to sometimes reach laterally as far as 30 feet from the vent. During the early stages of activity, when the intervals were mostly within the 4 to 5 hour range, the durations fell between 7 ½ and 14 minutes (mostly, 8 to 11 minutes). Later, when intervals were many hours to even days long, the durations grew to as much as 20 minutes.

As noted above, Plate has had eruptive episodes since the late 1960s, but none of the other craters along the fracture has ever been known to erupt (unless the southeastern opening is Slot Geyser; see footnote 2). Abrupt was first seen by naturalist Tom Hougham from the Old Faithful Visitor Center at 13:43 on May 8. (For reasons that will be made clear below, it is likely that Plate played a few minutes before Abrupt, but it wasn't actually seen until about 5 hours later.)

Although it produced intervals as short

as 4 hours during its first few days of existence, Abrupt was never a reliable performer. There were entire days without any observed eruption, and by early June intervals of 7 hours and more were the rule. On June 16 there began a span of more than four days during which no eruption was seen and probably none occurred. Similar inactive stretches took place during the following weeks. The complete known record of activity for May 8 through July 27 is shown as Master Chart F. Closed intervals are plotted when known (or closely inferred in a few cases); eruption times for which no interval can be inferred are plotted on the 1-hour line.

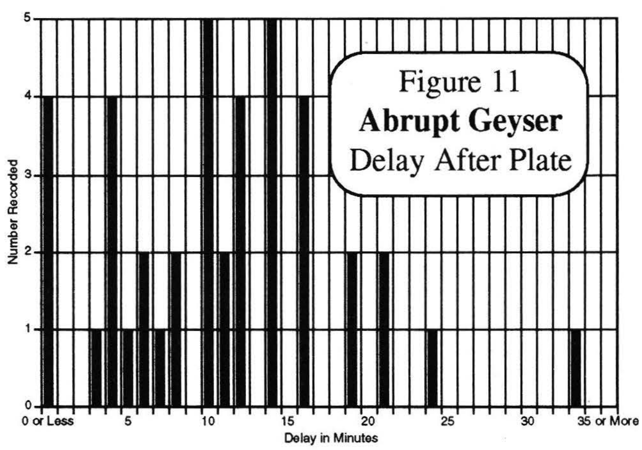


Figure 11
Abrupt Geyser
Delay After Plate

That Abrupt is directly tied to Plate is made clear in two ways. First, 90 of the 92 recorded eruptions of Abrupt began a few minutes after the start of Plate's eruption. Only two of the 92 began prior to Plate; both of these seemingly aberrant cases fell early within the activity record and could be data errors. The distribution of the Plate-to-Abrupt delay is shown on Figure 11. This histogram includes only closed delay intervals. If in-eruption times were included, the graph would show that fewer than 10% of the cases involved delays of more than 20 minutes.

Secondly, occasions such as June 3-4, June 16-20, July 2-4, and so on, when Plate had typical intervals of near 2 hours (rather than the more "normal" 1 ½ hours), match time spans when Abrupt was either infrequent or completely unseen (compare Master Charts E and F).

From the above it would seem that much of the energy for Abrupt's eruptions was received from, or through, Plate. Plate's eruption amounted to a priming device for Abrupt, forcing water via the connecting fracture into Abrupt's plumbing and providing the additional heat energy needed for an eruption. If Abrupt was not near eruption, then the action of Plate had no effect. Also, if Plate was relatively infrequent, then insufficient energy was transferred to trigger Abrupt. Thus, a monitoring of Plate's interval variations could give an indication of energy flow into Abrupt. In keeping with all its known history, Plate can be expected to decrease its activity before much time has passed; Abrupt almost certainly will then pass from the scene, too.

Little Cub Geyser

Given the recent discovery of a report by Marler which showed that there was evidently a direct eruption relationship between the Lion Group and Beehive during 1947 [*in* Paperiello, 1992], it was expected that the Lion Group's activity would show the effect of the GHW. It is a surprise that it either does not or does so only in Little Cub.

Little Cub Geyser is the most frequent performer of the Lion Group. Its interval is roughly one hour, frequent enough that any changes due to the GHW should be clear. Obtained during July 1-27 (mostly from the Visitor Center log book) were 192 intervals. These range from 47 to 82 minutes with a total average of 65.69 minutes. It

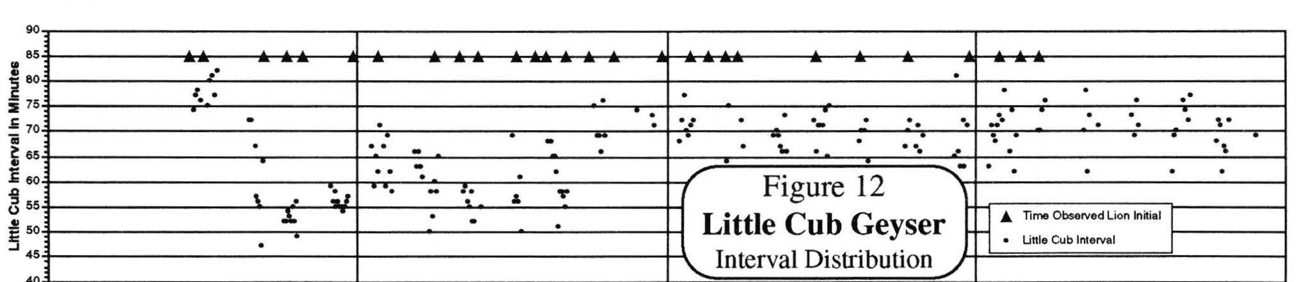


Figure 12
Little Cub Geyser
Interval Distribution

is true that many of the times were listed as "in eruption" so that many of the data points are subject to some error, yet Little Cub's overall behavior appears to be consistent. A first glance at the time-interval plot (Figure 12; Figure 12b is a two–page strip chart showing the same data with more detail) seems to show a diurnal pattern somewhat similar to Plume's. However, any progressive decrease on one particular date is countered by an increase on another day. Simply put, Little Cub's intervals are quite randomly distributed within its range and, unless it was prior to July 9, it appeared to be entirely unaffected by the GHW.

Notable in the Little Cub data are sharp changes in behavior that took place between July 1 and 3 and July 9 and 10 (Master Chart G and Figure 12). On July 1, the average of nine intervals was 77.78 minutes. From July 2 through 9, the average of 73 recorded intervals was 58.65 minutes, and there is some indication of a GHW influence (especially on July 5). From July 10 onwards, the average interval was increased to 69.25 minutes, and GHW influences seem to be entirely absent. These figures represent first an overnight 25% decrease and then an 18% increase in average frequency. Figures 13 and 14 compare these contrasting frequency distributions.

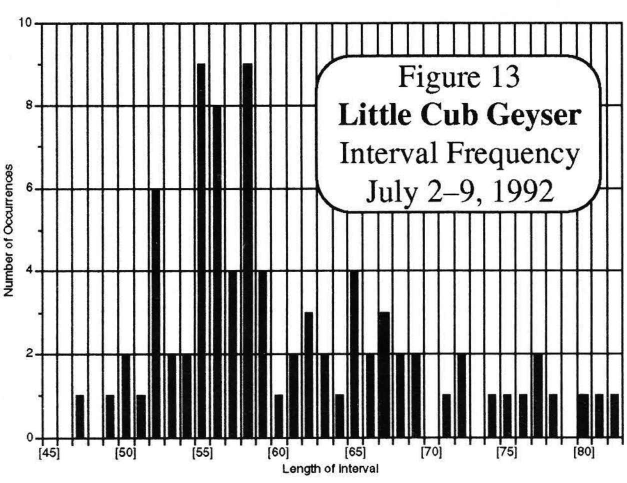


Figure 13
Little Cub Geyser
Interval Frequency
July 2–9, 1992

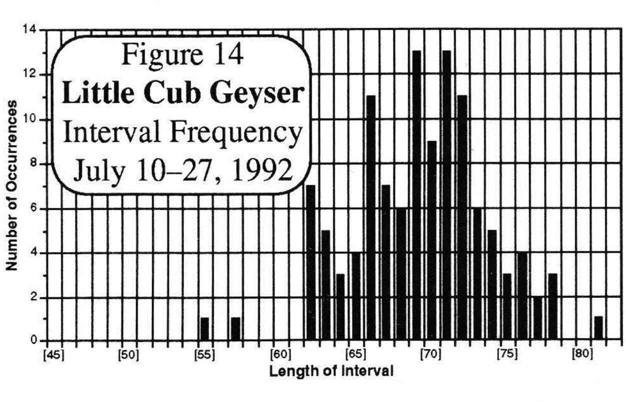


Figure 14
Little Cub Geyser
Interval Frequency
July 10–27, 1992

These changes seem to have occurred without a clearly detectable cause. Though they appear to have resulted from some sort of exchange of function, no nearby spring (Lion included) is known to have shown a corresponding change. It is worth noting, however, that July 9 was a SMax date, and that a later study [Taylor, 1992b] found similar changes in Little Cub near the time of a SMax.)

Both Master Chart G and Figure 12 also show the known times of initial eruptions by Lion Geyser. Although there are many gaps in this record, there appears to have been no change in Lion's behavior to correspond with the July changes in Little Cub. Little Cub's intervals also show no consistent change according to whether or not Lion was in an active phase. While it is known that Lion is more likely to erupt at about the time of a Little Cub, neither geyser seems to truly control the other.

Lion Geyser

Lion Geyser is the dominant member of the Lion Group. A cyclic geyser, it will lie quiet for a period of several hours until an active phase is begun by an "initial eruption". The initial is stronger and of longer duration (usually >6 minutes) than those that follow within a series. The follow-up eruptions recur at intervals of around 1 hour and have durations of 4 minutes or less.

An active series may include anything from two to seven eruptions (including the initial). There is definitely a correlation between the length of the initial-to-initial cycle interval and the number of eruptions within the previous cycle—cycles of only two or three eruptions most commonly have intervals of 6 to 10 hours, while those with as many as seven eruptions may require as long as 16 hours to cycle (obviously, there are exceptions). The limited 1992 data is shown in Figure 15. The gray curve shows a third degree fit to the data.

As was the case with Little Cub, it was anticipated that the number of eruptions per Lion cycle, and therefore the cycle intervals, would bear a relationship to the GHW. Despite quite a few gaps in the data, Lion's activity does not appear to be even slightly influenced by the GHW. That this should be so is very surprising. The fact that Lion's behavior showed no obvious changes corresponding to the radical alterations in Little Cub's behavior between July 1 and 3 and July 9 and 10 is also a puzzle without explanation. These two geysers are positively known to be connected with one another, yet neither caused a distinct change in the action of the other (Master Chart G or Figure 12).

"UNNG Across From Lion"

This geyser plays from a small pool about 30 feet across the boardwalk from Lion Geyser and Goggles Spring. It has almost always been observed to act as an intermittent spring, briefly producing runoff at intervals of 7 to 9 minutes. Only rarely has it been seen to erupt as a geyser, and then usually to heights of only 1 foot. During July, 1992, this spring underwent several witnessed eruptive phases. The eruptions recurred on intervals of 7 to 9 minutes, just as do the normal quiet overflows, and had durations of just a few seconds. During a few of these eruptive episodes, the geyser sent some water bursts as high as 4 to 5 feet, and one observed burst was accompanied by rocketing jets as tall as 10 feet.

So far as is known, this geyser's action did not correlate with the GHW. However, once it was known to be active, repeated checks of its state revealed that it probably underwent eruption series only shortly before and after the time of an initial eruption of Lion.

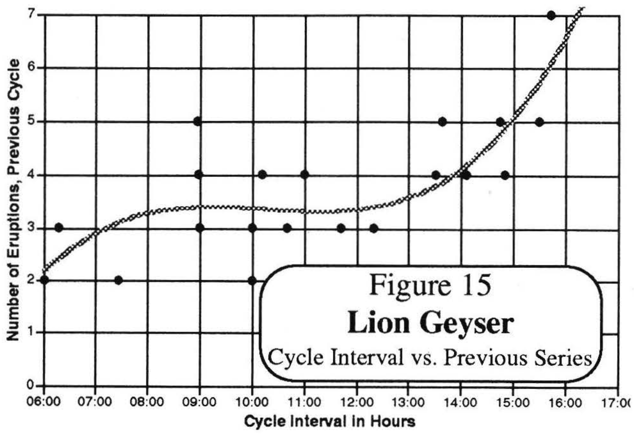


Figure 15
Lion Geyser
Cycle Interval vs. Previous Series

Dragon Geyser

Dragon Geyser is the largest pool on the central portion of Geyser Hill. Although it has been known as a geyser at times in the past, any such activity has been rare. It has either increased its activity in 1992 or, possibly, has always been somewhat more active than commonly recognized. (Due to its location, it is not commonly observed and even this year was seen only because of the close attention paid to Plate and Abrupt, from which Dragon is in plain sight.)

There is far too little data to allow any conclusions to be drawn about Dragon and the GHW. Suffice to say that it was seen to bubble vigorously on a number of occasions, and three times a few bursts 1 to 2 feet high were recorded. Another eruption probably of Dragon, seen by Janet Johns from near Aurum Geyser, might have had a burst as much as 8 feet high.

Cascade Geyser

Cascade Geyser is a rare performer. Located on the steep river bank at the south end of Geyser Hill where it might be expected to strongly participate in the GHW, it is difficult to observe from the boardwalks. On July 25, perhaps notably *not* at a time of SMax, Cascade was seen in eruption from near the Old Faithful Inn. This eruption, 3 feet high and lasting perhaps 30 seconds, was not noticed by people on Geyser Hill. This might have been a random event.

Roof Geyser

Among the springs initially included as part of the Geyser Hill project but then dropped from continued observation was Roof Geyser. Actually a fairly significant geyser located on the west-central portion of Geyser Hill, it erupts from within a deep crater with an overhanging geyserite roof so that its water is seldom visible from the boardwalk. It was monitored for several days during early morning hours when its billowing

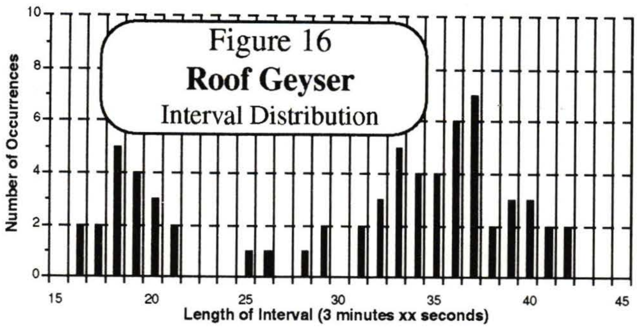


Figure 16
Roof Geyser
Interval Distribution

steam cloud marked the onset of an eruption.

Given its location, Roof might be expected to participate in the GHW. Instead, it showed a remarkable constancy. Its intervals ranged from 3m 16s to 3m 42s with a strongly bimodal distribution (Figure 16). The GHW cycles produced no observable changes whatsoever.

Giantess Geyser

The discussion of Giantess Geyser is left to the last. Although it is the single most dominant feature on Geyser Hill, it was only a minor part of this study. Giantess undergoes eruptions on an infrequent basis, usually having active episodes at intervals of several months. The last eruption prior to this study was on March 25, 1992.

When not active, Giantess overflows continuously with most of the runoff flowing to the southeast of the crater. Periodically, the normal pool boiling is punctuated by what has been termed a "northface boil". As much as three feet high, this doming action can pour large enough quantities of water out of the pool to produce a second runoff to the north. It is believed that the northface boils increase their force and frequency shortly prior to an eruption so that a careful observation of them may have predictive value.

During this study, Giantess was remarkably quiet. Although some northface boils were seen, they were infrequent and brief. And although Giantess unquestionably participates in the GHW, no evident correlation between the Wave and the boiling in Giantess was seen. Furthermore, neither was there any apparent increase in the northface boiling following the dormancy of Beehive which began on August 7 [Murray, 1992].

Water Level Observations

General visual observations of the water levels and boiling status of six springs on Geyser Hill are utilized here. For Silver Spring, Bronze Spring, and Little Squirt Geyser, this data covers July 1 to 28; for Infant Geyser, "Exclamation Point" Spring, and Ear Spring the data collection began on July 7.

Late during this time frame, the water level recording method utilized within the Sawmill Complex elsewhere in the Upper Geyser Basin was adapted to these features. Here, the status of each spring was converted to a numerical value. In each case, a value of "0" (zero) indicates a minimum water level and/or degree of boiling activity. A value of "4" is the maximum, indicating water levels at their highest observed point and/or the most vigorous boiling action. Without recording instruments, these readings were usually conducted once per day during the morning hours; there is some evening data which was taken at times of rapid change.

The water level records have been plotted on Figure 17. Without belaboring the point, the water level changes in Silver and Bronze Springs show the progress of the GHW. Their water level peaks (values of "3" and "4") correspond tightly to the times of SMax, which are indicated by levels "2" (water visible) and "4" (in eruption) for Little Squirt.

There are a couple of surprises within the data for the other observed springs. Correlation between the GHW and the water level in Infant Geyser is weak. While some level peaks coincide, others do not. Infant is supposed to be very directly connected to Giantess Geyser, and so it should respond in a fashion similar to other connected features. However, on reflection this lack of coincidence might not be so strange— Infant seems to now have a very different water chemistry from other springs; its odor and the occasional presence of elemental sulfur(?) on the pool surface indicate probable acid water quite unlike the alkaline fluid of all the other Geyser Hill springs of importance. Perhaps Infant has somehow become disassociated from the rest of Geyser Hill.

Further away at the end of Geyser Hill

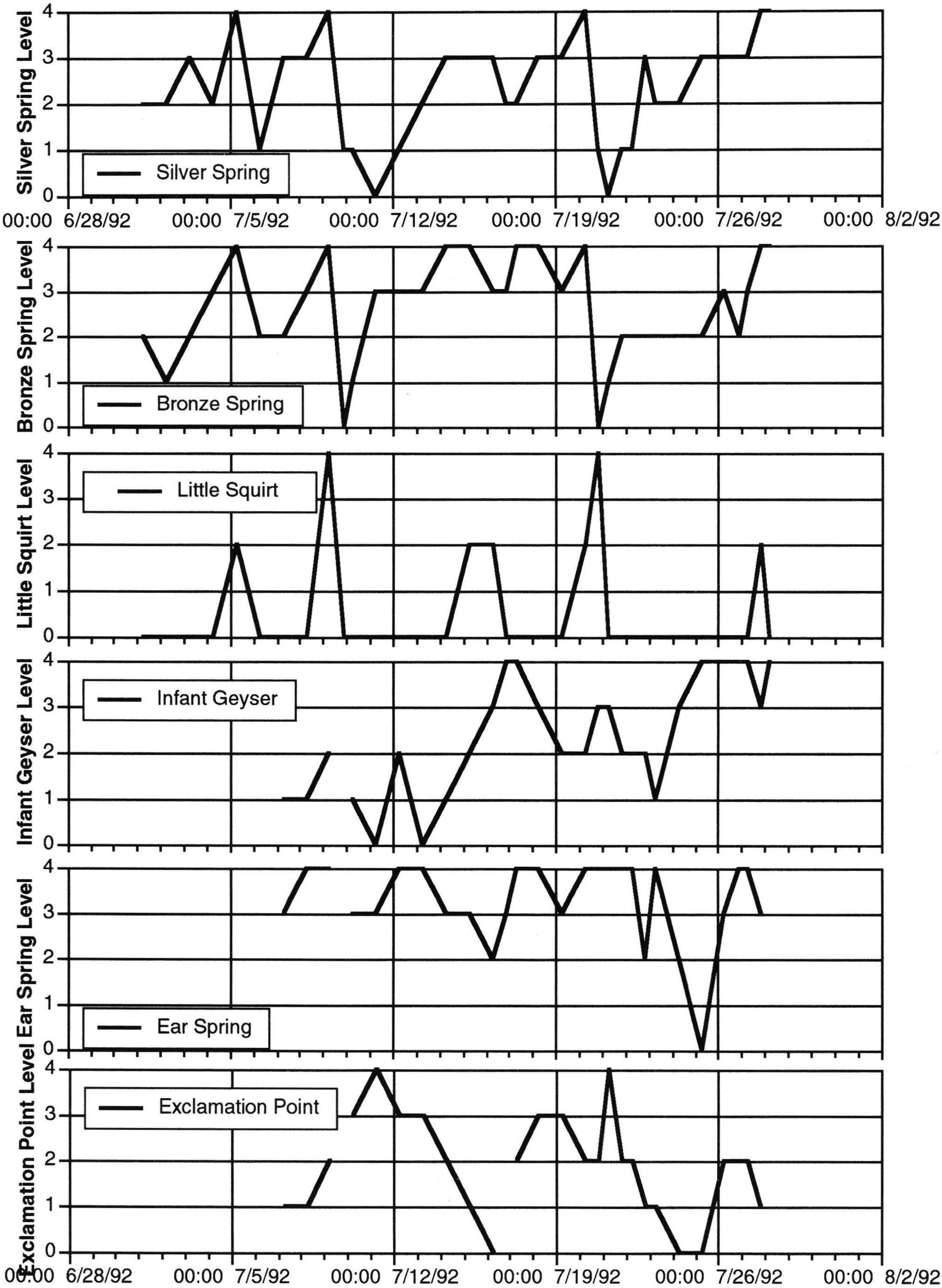


Figure 17 — Water Level and Activity Observations

most distant from Little Squirt, water levels and boiling action were recorded in Ear Spring and "Exclamation Point" Spring (informally named here because of the shape of its two openings). While there were some differences in degree and timing, many of the water level and boiling variations in these springs correspond quite closely to the GHW and its SMax times.

On the basis of this last, I believe that all portions of Geyser Hill are involved in the Geyser Hill Wave. While there are a few differences in the observed timing of events from one place to another, all springs probably participate in SMax effects. Those in which no reactions could be seen during this study, such as Little Cub, Lion, and Roof Geysers, probably would show effects if more accurate instrumental monitoring could be employed. It would be good, too, to include observations of additional springs such as Goggles Spring and North Goggles Geyser; Peanut Pool (near Infant Geyser) appeared to take part in the GHW, but it proved impossible to monitor its low water levels from the boardwalk.

Causes of Geyser Hill Variations

The primary purpose of this paper is to describe the basic nature of the activity variations seen among the Geyser Hill hot springs and geysers, and to show that these variations are, in part, regularly repeating events of predictable nature. While it is not the main goal here to explain why these occur, the following sections consider some possible causes of these variations.

The Geyser Hill Wave

The Geyser Hill Wave (GHW) appears to be an event which affects all portions of Geyser Hill. It is seen in the form of significant changes in the water level of several springs, especially toward the south end of Geyser Hill. Especially prominent among springs which either do not or only seldom overflow, it may also vary the boiling action in some superheated features. Geysers respond by either erupting or changing their interval distributions in accord with the progress of the GHW.

The GHW is a regular event. Although its period is known to range from 3 to 9 days, most 1992 periods were between 5 and 7 days. The limited data available indicates that it might have been even more regular during 1990 when it truly could have been termed weekly. It is important to note that the GHW has been observed during several consecutive years, during which the specific activity of the springs involved has shown tremendous variation— for example, it was as prominent during 1990 and 1991, when Beehive Geyser had erratically distributed average intervals greater than 24 hours, as it was during 1992, when Beehive was both more regular and frequent. Whatever the specific activity of the geysers might be, the Wave seems to take place regardless of season, storm systems, precipitation, wind, or any other observable factor.

In general, the progression of the GHW is as follows:

1) The culmination of the Wave (herein called the SMax) takes place when water levels are at their highest on Geyser Hill. This is most obvious in Silver Spring, which may reach the verge of overflow (actual overflow is unknown in this spring), and nearby Bronze Spring, which will intermittently overflow and may erupt (although it did not erupt during this study). SMax appears to be the only occasion on which Little Squirt Geyser can erupt, and although it does not do so on every Wave cycle, Little Squirt's eruption is probably the most accurate way of determining the time of SMax. Beehive Geyser will have its shortest intervals at the time of or just after this peak. If Little Squirt plays, Beehive's intervals will be 2 to 4 hours shorter than if Little Squirt does not play;

2) Following SMax, the water levels drop. The drop is greatest and most rapid if Little Squirt plays. The level in Silver can then fall as far as 18 inches within 2 or 3 hours. If Little Squirt fails to erupt, then the water level decline is much slower and somewhat erratic, and might be as little as 4 inches;

3) As the cycle continues, eruption intervals become longer and water levels fall in features scattered the breadth of Geyser Hill;

4) As the water level begins to rise once again in Silver and Bronze, the eruption intervals of at least most of the geysers continue to lengthen. Beehive will have its longest intervals near the end of the cycle; during 1992, these intervals were typically 5 to 7 hours (roughly 30% to 50%) longer than those at SMax. Proportionally similar interval changes are also seen in Depression, Plate and Aurum Geysers, and the boiling action of Ear Spring tends to decrease or even briefly stop (on one occasion, its temperature dropped to 196°F);

5) As the time for the next SMax is closely approached, eruption intervals decrease slightly and boiling action increases;

6) The large-scale drop in intervals occurs at the next SMax time. The cycle repeats.

It is clear that the GHW imparts both more water and more energy to Geyser Hill at the time of SMax. It is, I believe, important to emphasize that both factors are involved: an increase in water supply is indicated by the higher water levels, and an increase in energy flow is shown by the more frequent eruptions and more vigorous boiling. In addition, there is some evidence that hot springs on the northern and eastern portions of Geyser Hill are affected by the Wave somewhat sooner than are the features to the south.

Needed, then, is a process of distinct origin which takes place repeatedly and regularly, and which progresses across Geyser Hill.

Since most of Geyser Hill comprises a single hot spring system, one potential cause of a Hill-wide change might be variations in barometric pressure. That hot springs can be influenced in this way is certain. Yellowstone's Splendid Geyser is positively known to be pressure sensitive, most likely to erupt at time of sudden drops in the barometer (this, of course, only in those years when it is active at all). White [1968] cites numerous studies from elsewhere where springs and wells showed such changes, and he found barometric water level changes in several features at Steamboat Hot Springs, Nevada.

However, barometric pressure does not seem to be a cause of the Geyser Hill Wave. As noted, the Wave appears to take place without regard to the weather, and variations in its frequency cannot be shown to correlate with either high or low pressure conditions. Furthermore, any barometric adjustments within a given system of hot springs should be nearly simultaneous. (Because a "tighter", more restricted plumbing system would react with a lower efficiency, some features might be expected to show a weaker, delayed response, but not to an extreme degree.)

Here we have evidence for a true wave-like nature to the GHW. It shows its maximum effect as much as two days sooner on the north part of Geyser Hill than it does on the south. This pattern does not fit with barometric adjustments.

Given the reliable nature of the GHW, any other surface conditions (wind, precipitation, etc.) can also be eliminated, for they are much too erratic to produce such a repetitive phenomenon. This forces us to consider the deep subsurface as the source of the GHW. The one thing which could happen here is aquifer (or reservoir) eruptions.

White [1967; 1968] defines and shows evidence for such action at Steamboat Hot Springs. An aquifer eruption is "the intermittent ejection of water from an individual aquifer... [which] can be expressed at the ground surface or water table by geyser or subterranean geyser activity..." White further notes: "The concept that two or more aquifers can discharge continuously or intermittently and at different rates and cyclic intervals is helpful in understanding the complex behavior of many geysers, pulsating springs, and geothermal wells." (Note the distinction between this and a subterranean geyser. The latter is simply a geyser whose action is far enough below the ground surface that no liquid water is visible at the surface.)

Aquifer eruptions can be expected in any system where the flow of water through or from the aquifer has become restricted by reduced permeability. Yellowstone is known as a site of extensive system self-sealing. In a recent paper, White [1991] uses self-sealing to account for the great elevation differences between hot springs which, based on essentially identical chemistries, must have a common water source. The most notable example is Solitary Geyser versus Old Faithful Geyser. If the reservoir had direct, open access to Old Faithful, the water would be expected to flow there, to the lower elevation. Geyser Hill lies directly between the two, so the same can be said of it. If extensive self-sealing was not present, Solitary Geyser would not exist.

The main supply reservoir (aquifer) for Geyser Hill (indeed, for all of the Firehole Valley thermal areas) lies at a depth of about 250 meters. Its water is hottest beneath Geyser Hill (per geothermometers, 215±2°C). As one moves north and northwest from Geyser Hill, the reservoir temperature decreases [Fournier, 1992]. (This helps explain why geysers and hot springs become gradually less numerous in that direction; or alternatively, why Geyser Hill is the most intense concentration of stable geysers in the world.)

Immediately to the east of Old Faithful and Geyser Hill is the Mallard Lake Dome, a resurgent dome within the Yellowstone caldera. I propose that a higher igneous heat flow exists beneath the dome, and it is this that powers the reservoir flow. It is logical that if the reservoir temperature decreases away from the dome, then it increases toward and beneath it. It could well be that the water flow within the reservoir is relatively unimpeded until it reaches the areas of the Upper Geyser Basin. Its water first finds surface release at Geyser Hill. The upward decrease in temperature and pressure and resulting mineral deposition as water leaves the reservoir has produced self-sealing.

If this is the case, then the discharge from the reservoir can be expected to vary because of aquifer eruptions. Since aquifer eruptions can be regular, cyclic events, this could be the cause of the Geyser Hill Wave, the SMax occurring when the eruptive force reaches the surface. That it is most evident in the springs toward the south end of Geyser Hill might be a function of lower elevations within a relatively open Geyser Hill plumbing network.

At this point, of course, this is nothing more than a hypothesis. Fournier [1992] supports the concept, and notes that long-term, frequent, and comprehensive geochemistry and temperature studies of the Geyser Hill system might prove the idea. (Such a study could well decide the issue of seasonal disturbances, too.)

The Diurnal Effect

By contrast to the Geyser Hill Wave, where a potential cause is quite clear, understanding the diurnal variations of Plume Geyser is more difficult. Superimposed on the Geyser Hill Wave , this is incontrovertably apparent only at Plume— a fact which by itself might be a surprise and a problem.

Diurnal variations have been seen in other features and at other localities, evidently as a result of either one of two causes. A number of Yellowstone geysers have a tendency to erupt more frequently (that is, on shorter intervals) at night than by day; well known examples are Daisy Geyser and Morning Geyser. On Geyser Hill, virtually all of Giantess Geyser's initial eruptions occur at night, while daylight play is by Beehive Geyser. In each of these cases, the suspected cause is wind. In Yellowstone, night tends to be very calm. As the daylight hours pass, breezes pick up during the late morning and often become very strong winds by midafternoon. This wind, either by cooling the surface of pools or blowing water from the pool and into overflow, or both, alters the heat flow of the spring, requiring a longer time to recycle between eruptions. If the wind becomes strong enough, the intervals can become so long as to produce no eruptions for the duration (in Russian studies, "infinite" intervals [Steinberg, 1980]). For Geyser Hill there has been a standing belief that such winds are the cause of the coupled diurnal natures of Giantess (daylight eruptions rare) and Beehive (nighttime eruptions uncommon).

At least one Yellowstone geyser has been known to do the opposite. Vachuda [1989] found that Great Fountain Geyser had a tendency toward longer nighttime and shorter daytime intervals. Indeed, the average times of day of the maximum and minimum intervals were offset by almost exactly 12 hours, and the difference between those extremes was about 12% of the net average.

Vachuda was not able to come up with a plausible cause.

The situation at Plume Geyser is different from any of the above, however. Once among the most extremely regular geysers anywhere, its diurnal nature was not observed prior to 1989. The daily variations seen during 1990 amounted to 5 to 7 minutes. During this 1992 study, they were never less than 9 minutes and sometimes reached as much as 18 minutes during July (these figures represent 25.4% and 50.8% of the monthly average interval), and ranged from 15 to 29 minutes (37.1% to 71.7% [!]) during the shorter but continuous monitoring in April.

The general nature of the diurnal variation is this: Plume has its longest intervals during the late night or early morning hours, generally between 03:00 am and 09:00 am (refer to Figure 5b). The intervals then decrease rapidly so that by about noon they "stabilize" (meaning, they show rather little variation) until that evening, when they begin to increase after 9:00 pm (21:00). Although there were variations in the strength of the diurnal effect (possibly due to a seasonal control!), the same pattern was observed during all 1992 periods with detailed observations.

It is easy to develop hypothetical causes for such an interval pattern. Unfortunately, none seem to be strong candidates. Discussed in order will be 1) temperature; 2) wind and precipitation; 3) barometric pressure; and 4) earth tides.

The daily (diurnal) variation in air temperature was cited as the potential cause by Day [1991a]. The premise was simple. At night the lower air temperature equates to a greater heat loss from Plume's small pool surface, which in turn demands a longer quiet interval in which to gain the heat needed for an eruption. This idea, while simple and possible, has two serious problems. First, it is difficult to see how this much heat could be lost, given the small size of Plume's vent and the fact that the ponded water normally lies protected and insulated several inches below the ground surface. Further, if this process was at work, then there should be a greater degree of such cooling at times of strong winds. During July, no such correlation could be found, and in fact the month's longest observed interval fell on the morning of July 24, an extraordinarily hot and calm day.

Related to this cause is the inflow of water from other springs higher up Geyser Hill. There is a steady flow of this runoff water into Plume. Although it is a very small volume (there is a raised rim about all sides of Plume's opening), it could be theorized that this water, colder at night and warmer by day, cools and quenches Plume's action. This sounds logical, but again it does not correlate with the known record from July. There were short intervals at times of cold weather, and long intervals on hot days. Also, if this was the cause the greatest quenching ought to be seen in the coldest hours just before dawn, yet the daily maximum frequently takes place hours before or after that time. Essentially identical observations were made during September, 1992 by Taylor [1992b].

Other direct weather–related causes— wind and precipitation— can be dispensed with quickly. Day [1992b] modified his earlier stand (simple air temperature variations) with a short paper in which he correlates Plume's diurnal nature with precipitation. Since only the slightest bit of water is able to flow directly into Plume's crater, Day hypothesizes that this inflow of rain water is via some other spring hole nearby. In Day's opinion, Plume "is now almost completely a weather dominated geyser."

I disagree. As already noted under the discussion of temperature, Plume's July diurnal variations did not correlate with the weather. The daily changes were sometimes extreme during fair weather and slight during storms, but every possible opposite was also seen. Wind obviously should have its deleterious effect when it is blowing. In Yellowstone that is invariably during the day; then, however, is when Plume had its most consistently short intervals. Neither the presence or absence of either wind or rain had any observable effect. And once again, Taylor's [1992b] September observations agree with my July findings.

In short, then, simple daily weather variations do not seem to cause Plume's diurnal behavior. But also changing daily is barometric pressure, known from both Yellowstone and elsewhere to cause variations in hot spring activity.

Aside from the barometric changes associated with storm systems and air masses, barometric pressure tends to give a diurnal change. Simply, cooler nighttime air is denser, so there is higher pressure by night than there is by day. Compared to the total pressure value, this diurnal variation is slight; adjusted to Yellowstone's elevation, it amounts to roughly 0.1/23 or only 0.43%. Still, it does exist.

White [1968] was able to show a remarkably clear correlation between barometric pressure (including the diurnal component) and hot spring water levels at Steamboat Hot Springs, Nevada. This was so remarkable in spring vent 35 that I reproduce White's graph as Figure 18.

As might be expected, high barometric pressure corresponds to lower water levels among hot springs. (Note that pressure is inverted on Figure 18 so that times of high pressure can be more clearly and directly related to the corresponding water level.) The corollary is that water levels rise under lower pressure. The case at Steamboat Springs involved a non-flowing spring but, by extrapolation to a flowing spring or geyser, the higher water level of low pressure (e.g., day time) might produce a slightly higher heat flow and shorter intervals.

At Plume, intervals are shorter during the day when barometric pressure is diurnally low. At first thought, then, this idea looks good. But if so, one must ask why the much larger scale barometric changes of storm systems and shifting air masses apparently fail to produce any change at all. Therefore, barometric pressure functions are unlikely to be the cause of Plume's diurnal pattern.

Last and most complex is earth tides. All parts of the Earth are affected by the tides. The scale of relative "high" and "low" tides is far less within solid rock than it is in open bodies of water, but it is still present. The possible role of earth tides in changing geyser activity has sometimes been controversial, and evidence for both increased and decreased eruption intervals has been cited.

White [1968] notes numerous studies which showed evidence of an earth tide effect on hot spring and well activity, and he found this effect in some springs at Steamboat Hot Springs, Nevada (Figure 18). The effect, perhaps surprisingly, is that hot spring water levels drop at the time of a high tide (or more properly, at the time of the moon's daily upper culmination). The

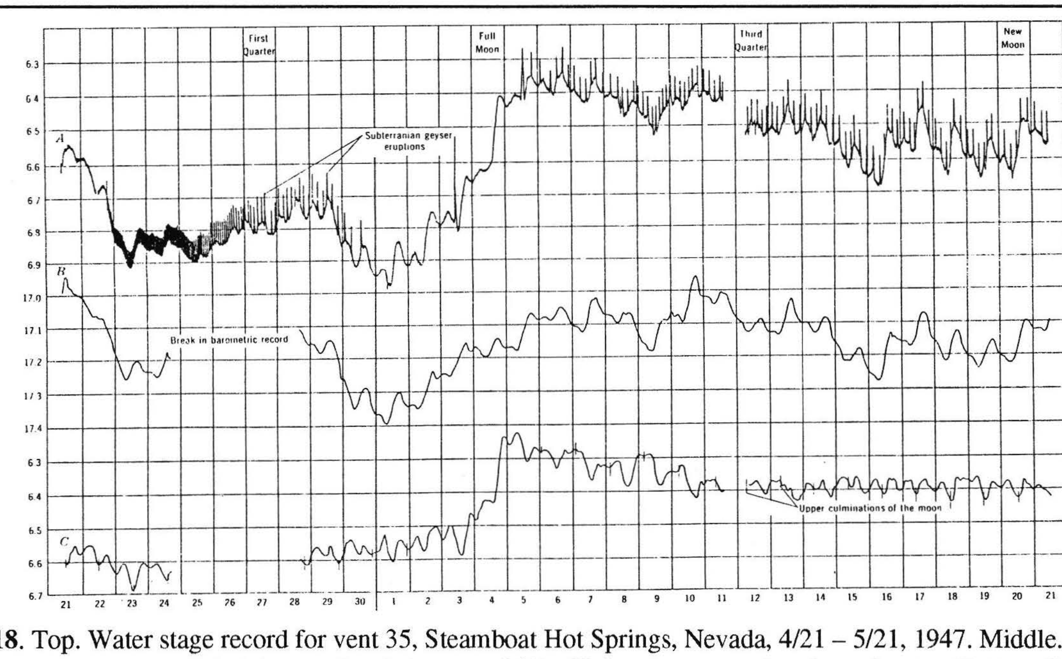


Figure 18. Top. Water stage record for vent 35, Steamboat Hot Springs, Nevada, 4/21 – 5/21, 1947. Middle. Barometric pressure for the same period, inverted and shown at 84% efficiency expressed as feet of water. Bottom. Residual curve, water level in vent 35 adjusted for barometric effect and showing culminations of the moon. [from White, 1968]

reason works like this. The high tidal pull of the earth toward the Moon causes a slight stretching which pulls open the pore spaces and fractures within the rocks. Thus, a plumbing system is of somewhat larger volume so that the water drops to a lower level. By extension, this might mean that there is less discharge and therefore longer intervals intervals in a geyser at the time of high tide.

Checking to see if this is correct is simple enough. On July 1, 1992 the upper culmination happened at 14:32 (2:32 pm) MDT. Very approximately, this time increases by 51 minutes per day (secondary variables can change this tide time by plus or minus several minutes; upper culmination on July 2 was at 15:29; on July 3 it was at 16:22).

The diurnal variation of Plume is such that the long intervals always occur at night or early morning. But since the time of upper culmination progresses through the entire 24-hour clock as the moon orbits the earth over the course of a month, it is quite obvious that earth tides are *not* the cause of this diurnal pattern.

It is possible that seasonal changes do affect Plume and its interval distribution over the long term. Comparison between the April 4–8, July 1–27, and August 1–4 data sets show that the diurnal effect became weaker (Figures 3, 5, and 7) and the frequency distribution tighter (Figures 4, 6, and 8). Taylor [1992b] states that Plume had returned to the April pattern during his observations of September 19–27, 1992. It appears that some sort of progressive change took place as the season progressed, and that this seasonal progression was punctuated by a rather sharp change occurred sometime between July 27 and August 1 corresponding with the impending dormancy in Beehive.

In summary, Plume Geyser exhibits a strong diurnal variation, with intervals longer by night and early morning than by day. There must be a cause, but no obvious physical or environmental process is able to account for it. Perhaps Plume is especially sensitive to tiny changes in its water/heat flow so that only the slightest variations are able to produce big changes in the observed activity.

Taylor [1992b] has suggested that the process behind the diurnal effect in Plume is identical to that which causes the dominately nighttime Giantess–daytime Beehive eruption patterns (and that that observation is therefore not wind–caused?) In any case, the diurnal effect probably results from a combination of factors.

Whatever its cause, it is certain that the entire diurnal effect itself is influenced by both unidentified seasonal variations and the Geyser Hill Wave, making this entire matter a decidedly complex issue.

Other Causes of Variations

There are processes other than any of the above which can produce variations in geyser and hot spring behavior. None of these seem capable of causing cyclicly regular changes, though, so they will be little more than mentioned here.

Seasonal disturbances are well known at the Norris Geyser Basin. They take place during the dry season of mid to late summer when a decrease in the supply of near surface, relatively low temperature geothermal fluid allows a stronger flow of deeper, higher temperature water to reach the surface. The onset of a disturbance is usually very sudden and results in a dramatic increase in geyser numbers, frequencies, and vigor.

The late summer season is often a time of sudden alterations in geyser behavior in the Upper Geyser Basin, too, and it is not uncommon for many such events to take place in apparently isolated hot spring groups within a very short time span. I have inferred [Bryan, 1992; using 1986 as an example] that these episodes are a result of seasonal disturbances. At the end of July and the start of August, 1992, there was a series of events of this sort: Beehive Geyser very suddenly slowed down and then ceased erupting, Castle Geyser began having highly frequent minor eruptions, Rift Geyser entered an extended dormant period, and so on. This date is earlier in the season than usual, but a seasonal disturbance also occurred earlier than normal at Norris, on July 14. This can be readily accounted for by 1991-92 being an extraordinarily dry year.

Fournier [1992] suggested that evidence for seasonal disturbances in the Upper Geyser Basin ought to be readily provable via a comprehensive, detailed, and season-long geochemical study. However, disturbances usually occur just one time per year, and in no way can this sort of action account for either a weekly Geyser Hill Wave or a diurnal effect.

Hot springs also show unaccountable, apparently random changes in behavior. This usually involves only a single spring or closely related group of springs. It is possible that these changes result from chaotic behavior, which is capable of lending a "pseudoregularity" to a system. To check this idea more thoroughly would no doubt require highly detailed activity and water stage records as well as a thorough understanding of chaos theory and higher mathematics.

Exchange of function is another process that can affect geyser activity. Here there is a shift in water and/or energy flow from one spring or spring group to another, correspondingly increasing or decreasing the spring activity. Just how or why this works is largely unknown. While there are a few cases where exchanges have approached regularity (historically, Beauty Pool to Chromatic Pool and Grotto Geyser Group to Giant Geyser Group as examples), most exchanges are random and entirely unpredictable. Any given exchange can be very brief or it might be seemingly permanent. It is probable that the abrupt interval changes seen in Little Cub Geyser on July 2 and July 9 during this study were the result of some kind of exchange of function, which in turn might have somehow been triggered as a GHW–related event.

I hypothesize that most exchanges, especially those involving large-scale, long-term shifts, occur because of the rupturing of some self-sealing blockage somewhere among the connections between spring groups; evidence for this lies in the often murky water of the springs involved for a short time following the exchange. Smaller scale, shorter duration exchanges might rely on other causes, such as chaotic water flow now and again forcing water to follow different routes through the subsurface system, or a "vapor lock" of pressured but confined steam inhibiting the passage of water through (or to) some particular fracture in the rock. Alternately, a "fluidic switch" such as is used in hydraulic systems could act as a plumbing system valve.

Note that with this I am suggesting that there is more than one cause of exchange of function, very different processes resulting in similar activity changes.

But again, although exchange of function can induce cyclic change in a geothermal system, it is highly unlikely to repeat on a consistent daily or weekly basis.

Earthquakes were dispensed with in the introductory section of this article. While it is certain that they can cause tremendous activity changes among geysers and hot springs, they obviously do not recur with cyclic regularity. Earthquake activity has nothing whatsoever to do with something like a Geyser Hill Wave or diurnal variation.

Conclusion

The geysers and hot springs on Geyser Hill are subject to numerous events and processes which can change their activity. While many of these variations are unpredictably random in frequency, both the Geyser Hill Wave (which encompasses all of Geyser Hill) and the diurnal cycles (clearly seen only at Plume Geyser and superimposed atop the Wave) are regular enough for their effects to be anticipated if not actually predicted. Each of these processes should occur for a discernable reason.

The Geyser Hill Wave is likely to be the visible result of deep seated hydrothermal reservoir eruptions. This conclusion is supported by direct observations and theory.

The mechanisms suggested by varous other observers and researchers for Plume's diurnal eruption pattern are essentially refuted with this paper, which admits that it does not itself provide any satisfactory explanation.

The truths of the Geyser Hill Wave, diurnal effects, seasonal disturbances, and more could well be shown by detailed geochemical studies.

This project is extensive enough to satisfy post graduate (even Ph.D.) level work in geological sciences. This report is therefore and quite obviously only the barest of introductions.

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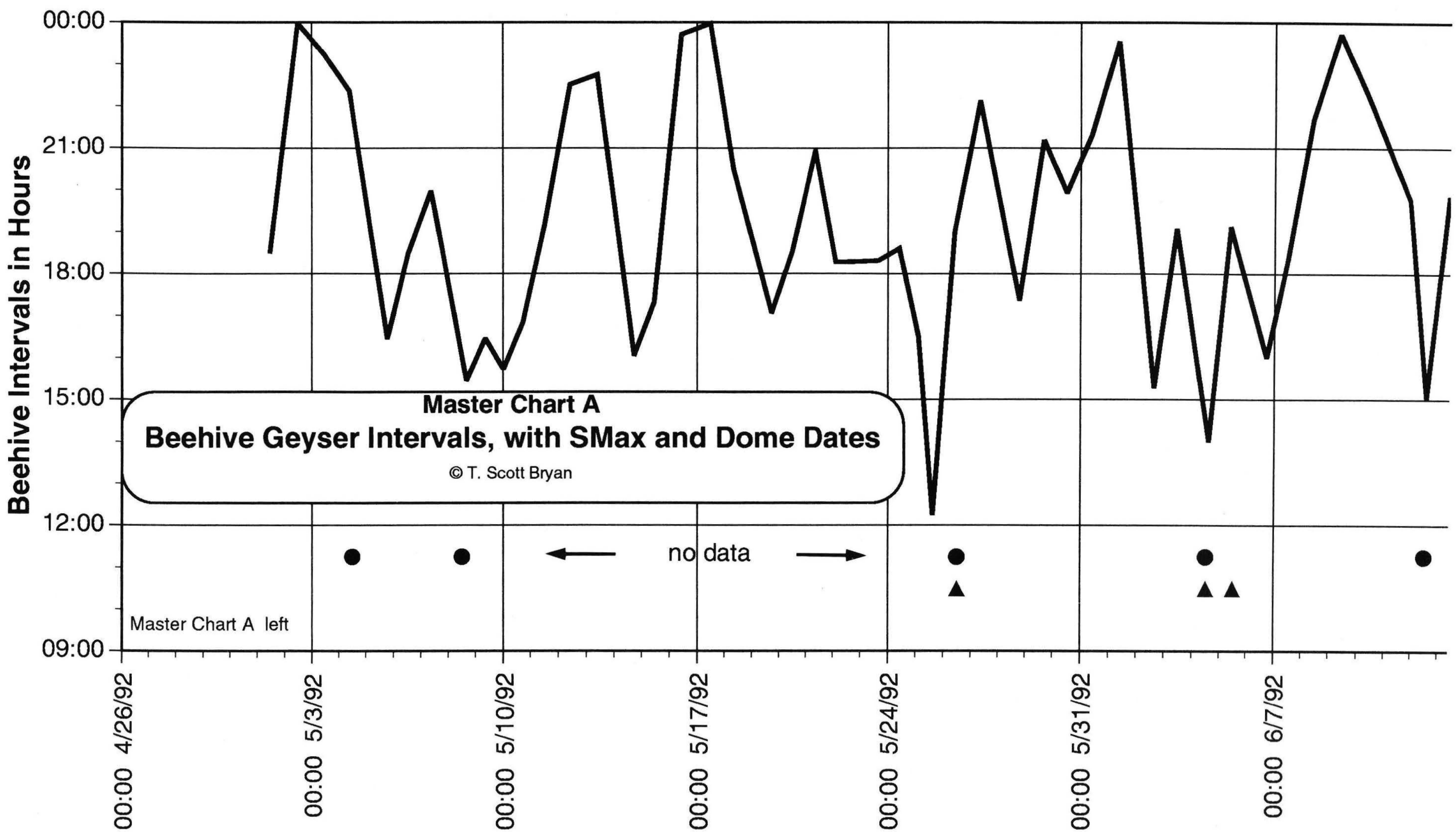
Master Chart A
Beehive Geyser Intervals, with SMax and Dome Dates
© T. Scott Bryan
Beehive Intervals in Hours
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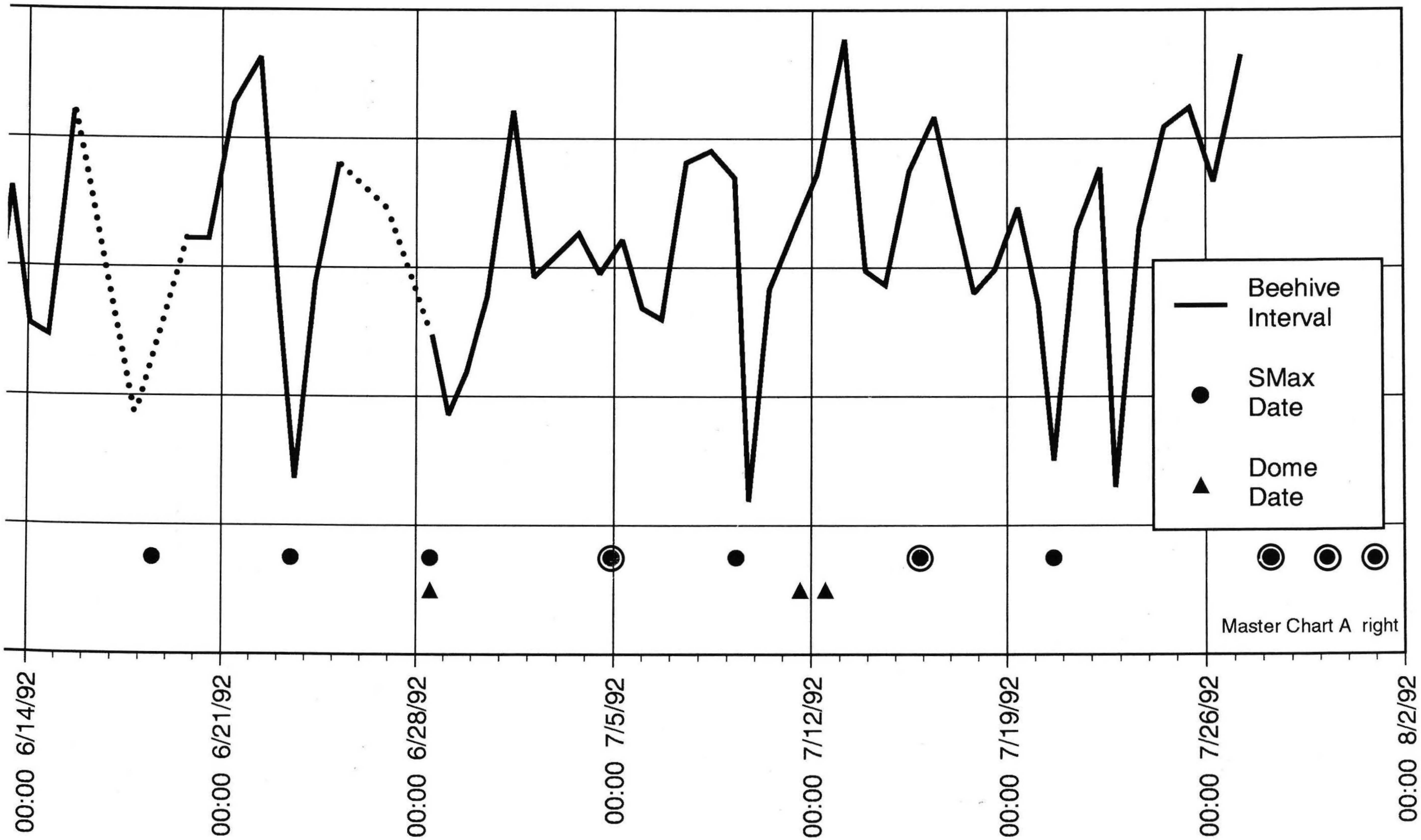
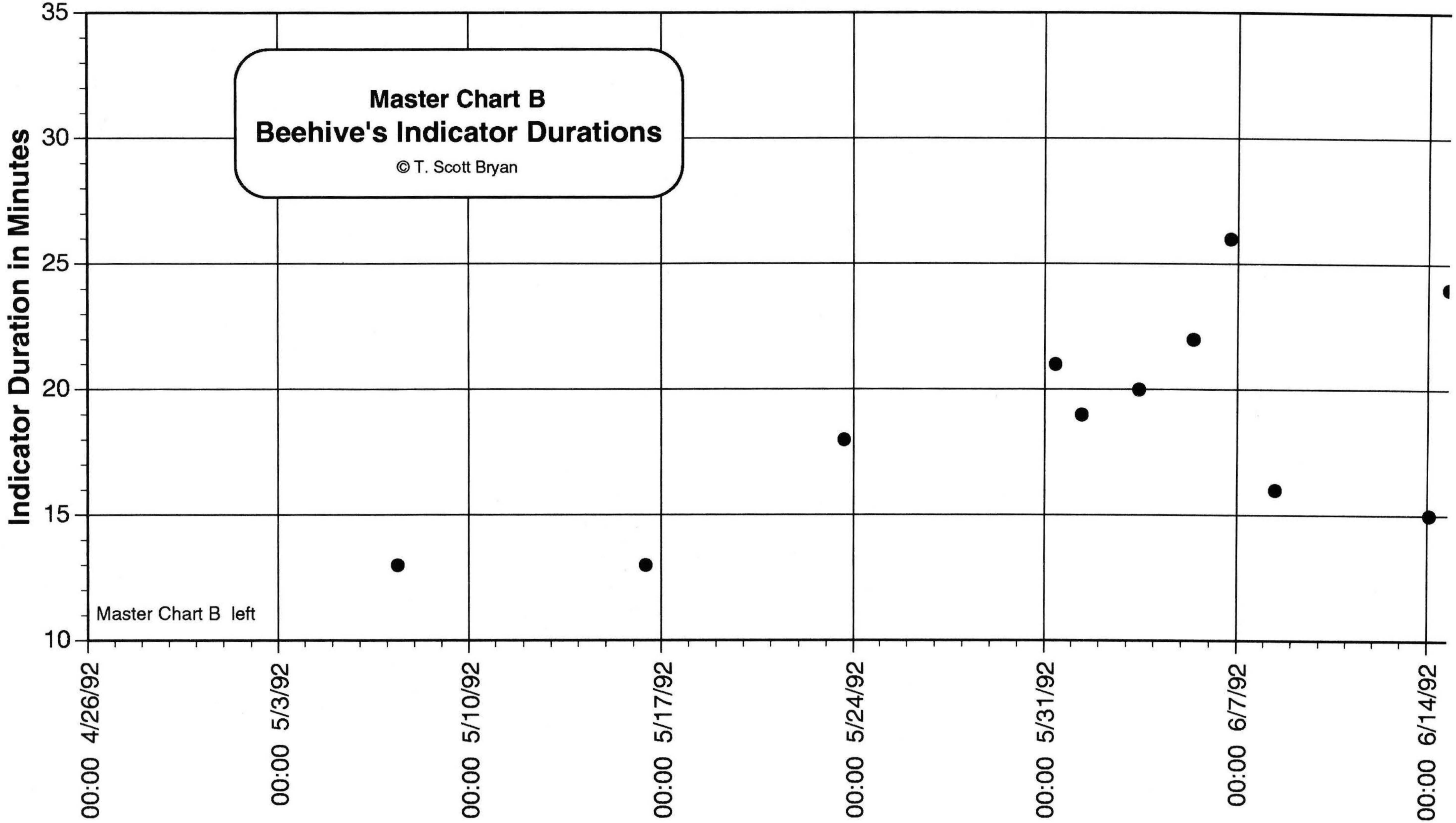
21:00
18:00
15:00
12:00
09:00
no data
Master Chart A left
00:00 4/26/92
00:00 5/3/92
00:00 5/10/92
00:00 5/17/92
00:00 5/24/92
00:00 5/31/92
00:00 6/7/92


Beehive Interval
SMax Date
Dome Date
Master Chart A right
00:00 6/14/92
00:00 6/21/92
00:00 6/28/92
00:00 7/5/92
00:00 7/12/92
00:00 7/19/92
00:00 7/26/92
00:00 8/2/92


Master Chart B
Beehive's Indicator Durations
© T. Scott Bryan
Indicator Duration in Minutes
35
30
25
20
15
10
Master Chart B left
00:00 4/26/92
00:00 5/3/92
00:00 5/10/92
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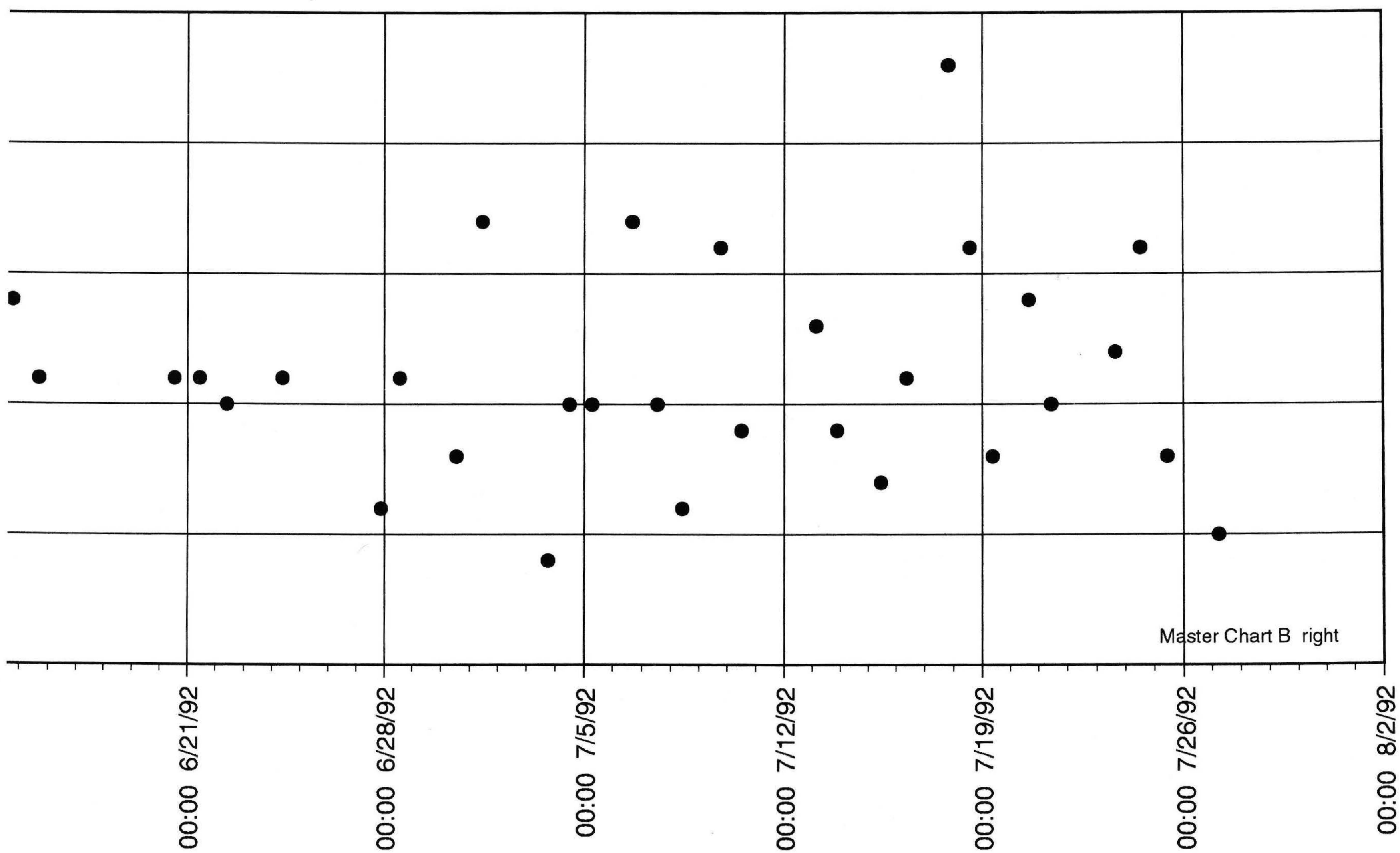
00:00 6/7/92
00:00 6/14/92


Master Chart B right
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00:00 7/5/92
00:00 7/12/92
00:00 7/19/92
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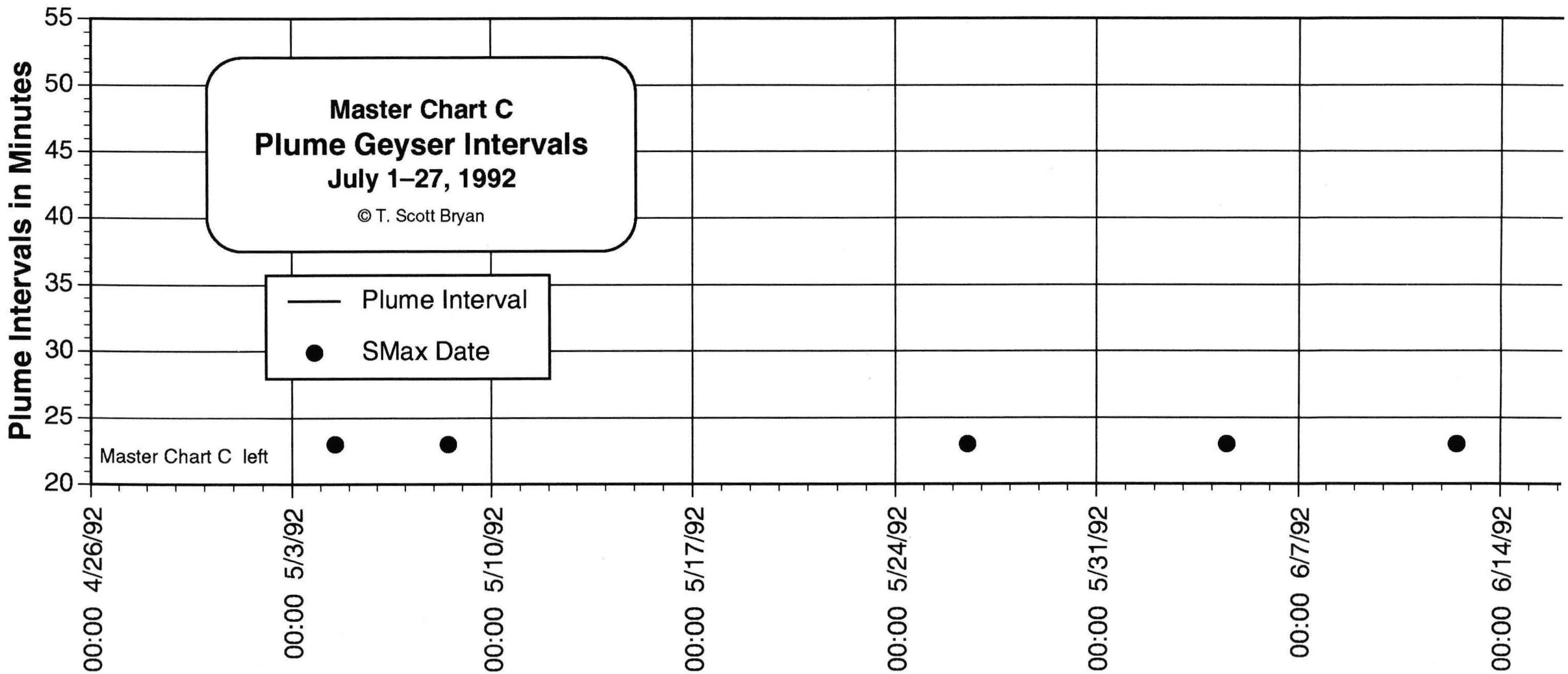
00:00 8/2/92


Master Chart C
Plume Geyser Intervals
July 1–27, 1992
© T. Scott Bryan
Plume Interval
SMax Date
Plume Intervals in Minutes
55
50
45
40
35
30
25
20
Master Chart C left
00:00 4/26/92
00:00 5/3/92
00:00 5/10/92
00:00 5/17/92
00:00 5/24/92
00:00 5/31/92
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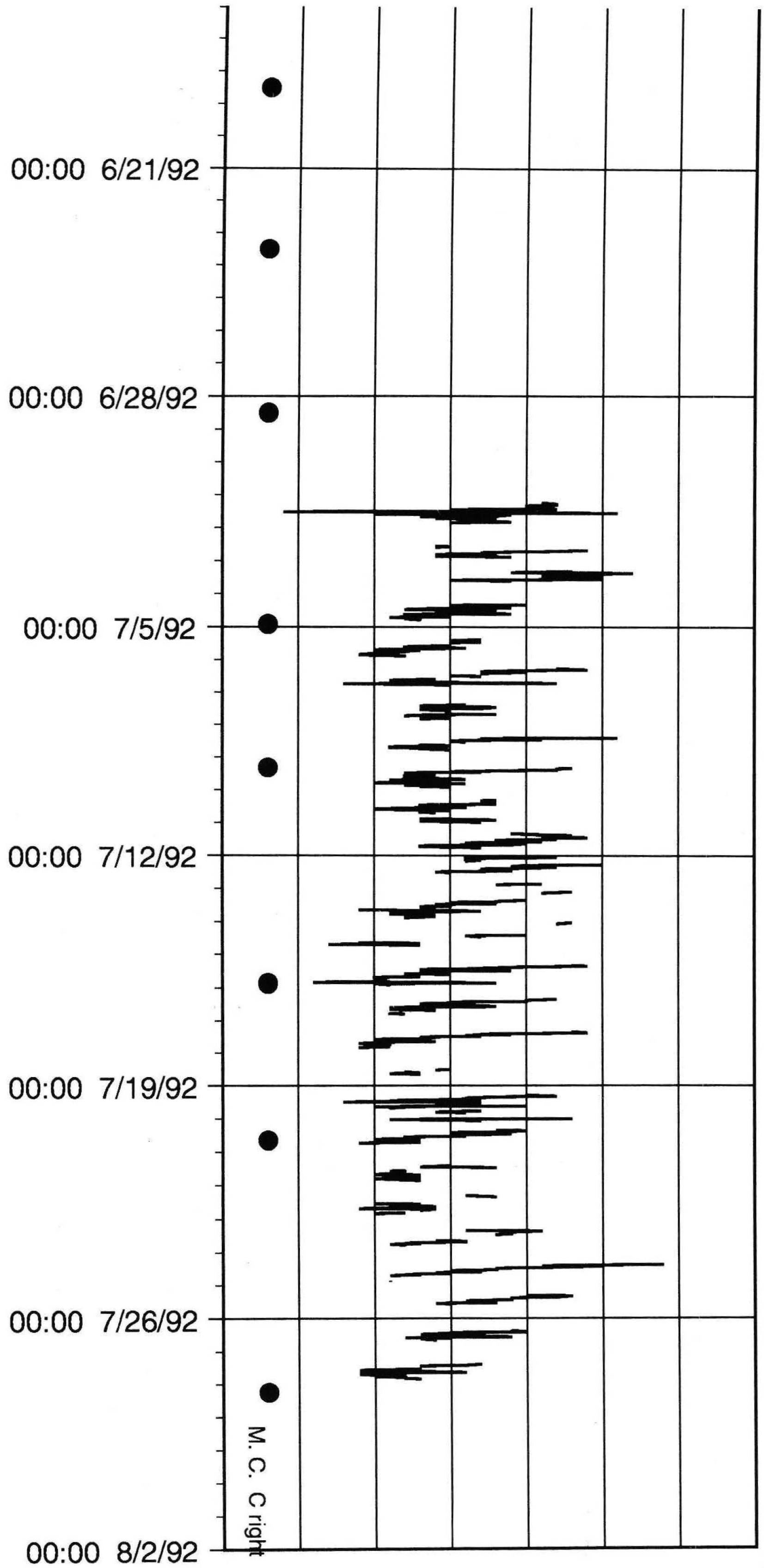
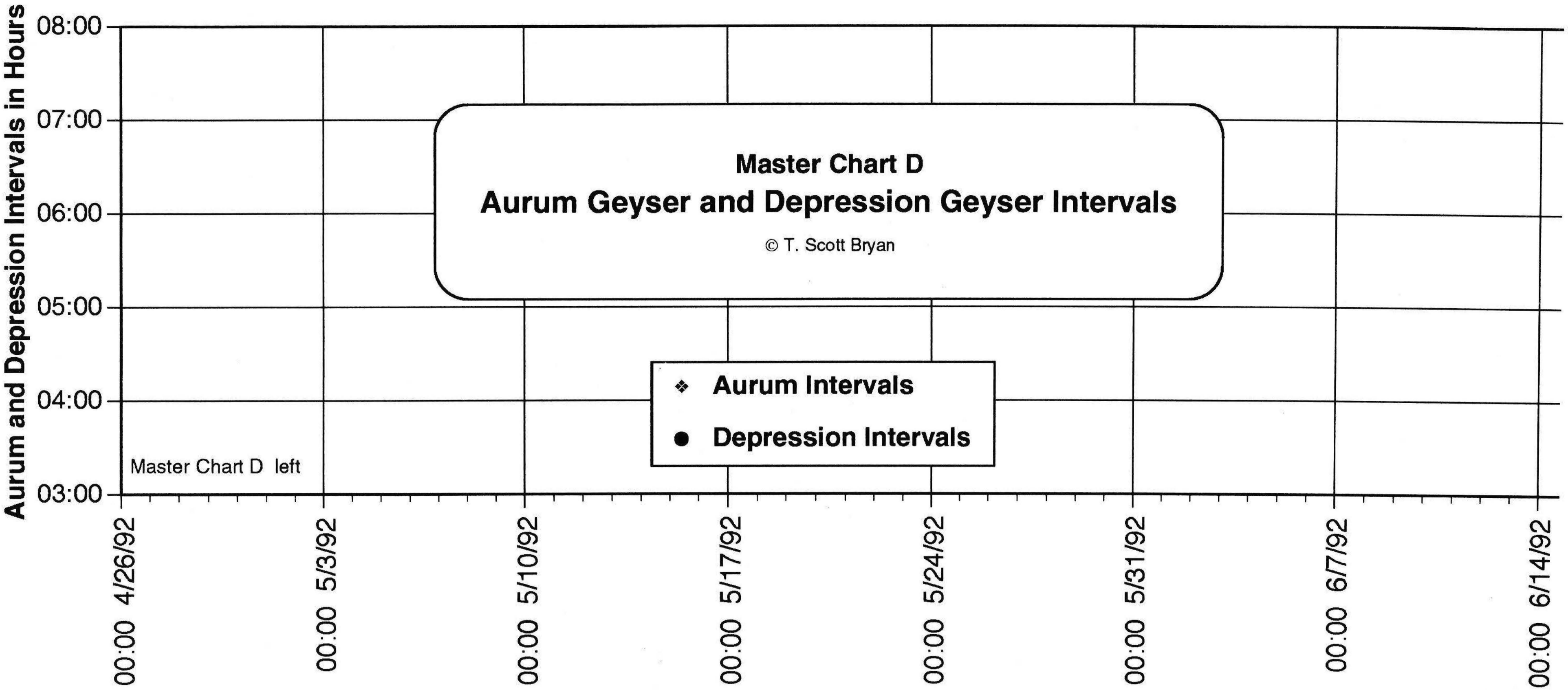
00:00 6/14/92


00:00 6/21/92
00:00 6/28/92
00:00 7/5/92
00:00 7/12/92
00:00 7/19/92
00:00 7/26/92
00:00 8/2/92
M. C. C right


Master Chart D
Aurum Geyser and Depression Geyser Intervals
© T. Scott Bryan
Aurum and Depression Intervals in Hours
08:00
07:00
06:00
05:00
04:00
03:00
Master Chart D left
Aurum Intervals
Depression Intervals
00:00 4/26/92
00:00 5/3/92
00:00 5/10/92
00:00 5/17/92
00:00 5/24/92
00:00 5/31/92
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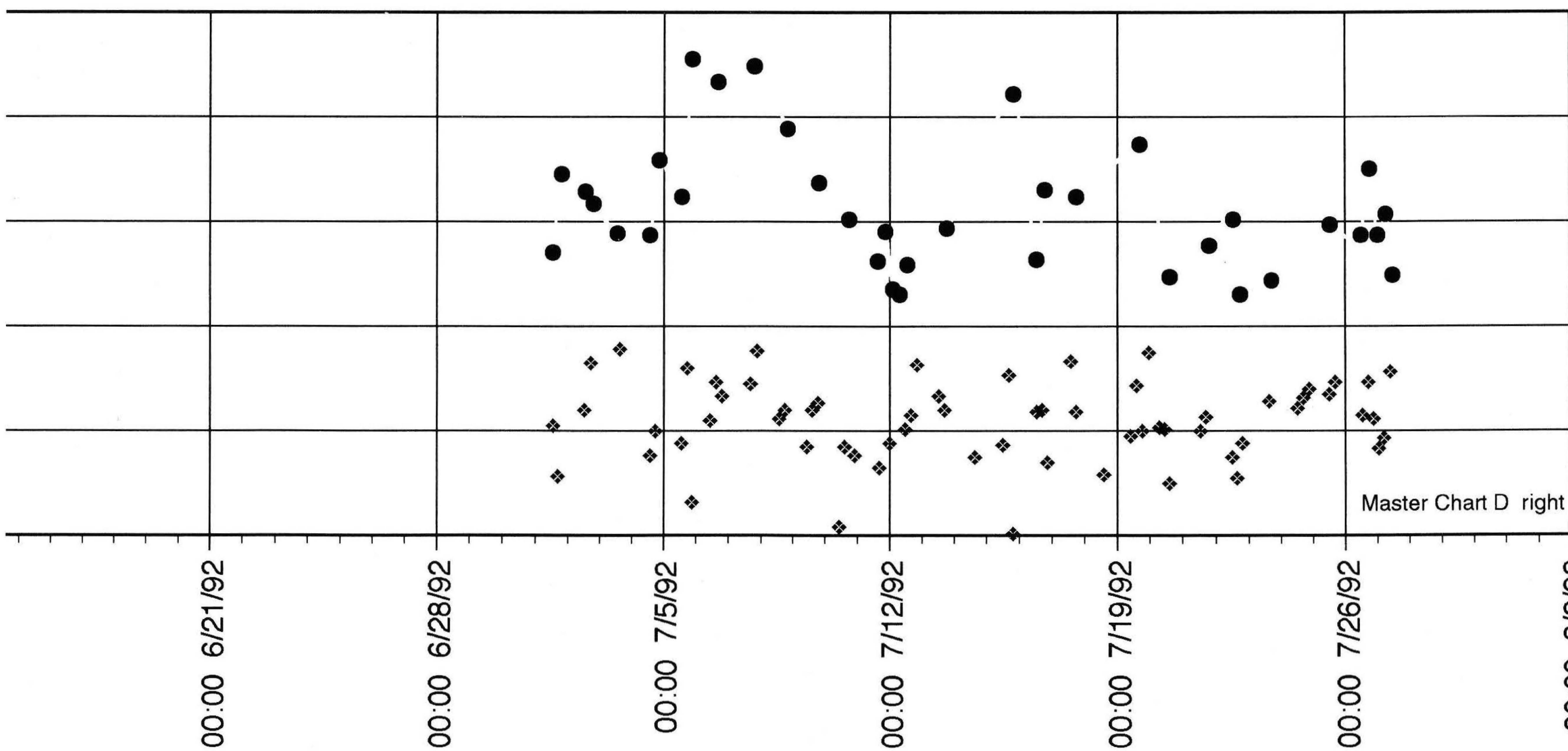
00:00 6/14/92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00:00 7/19/92
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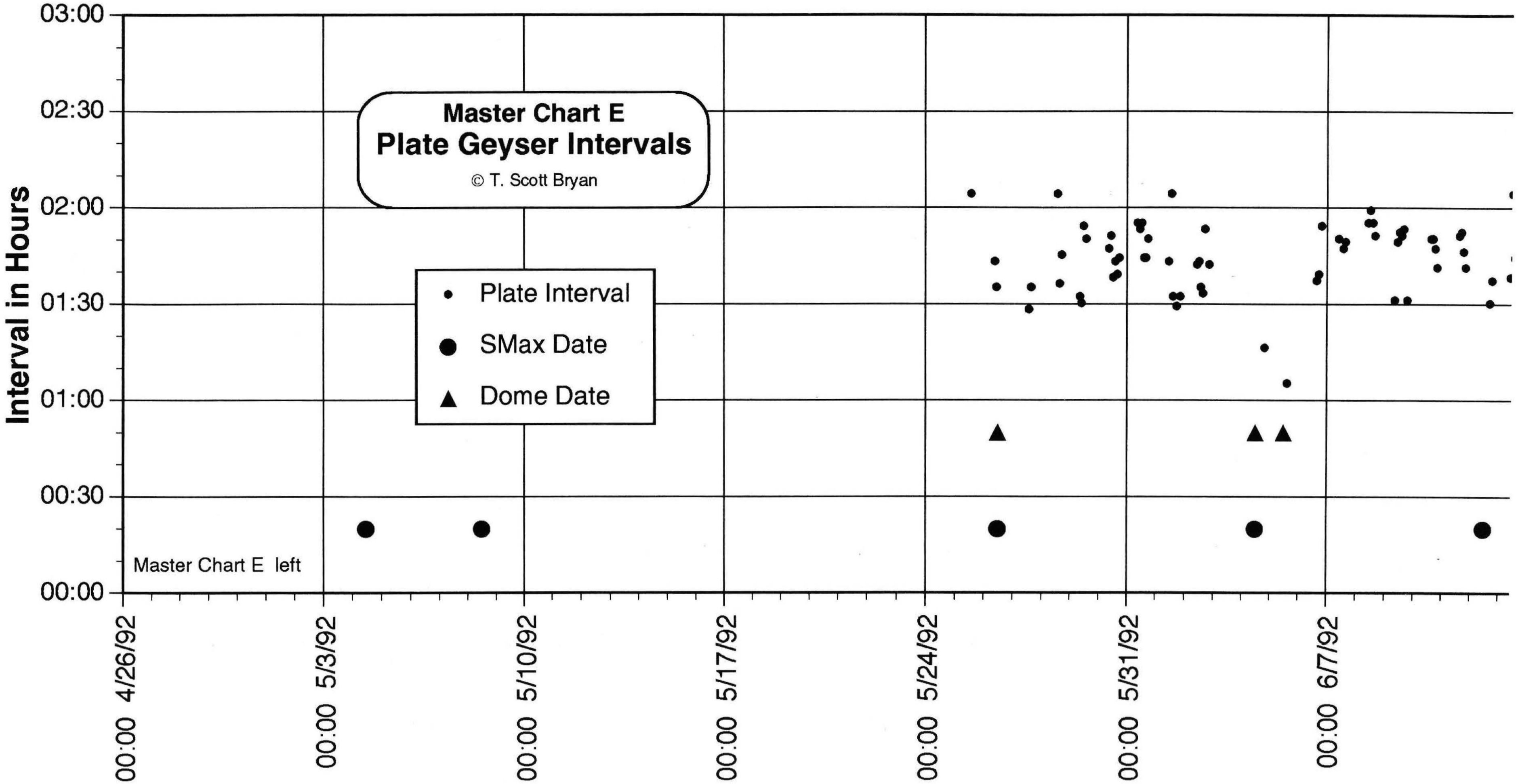
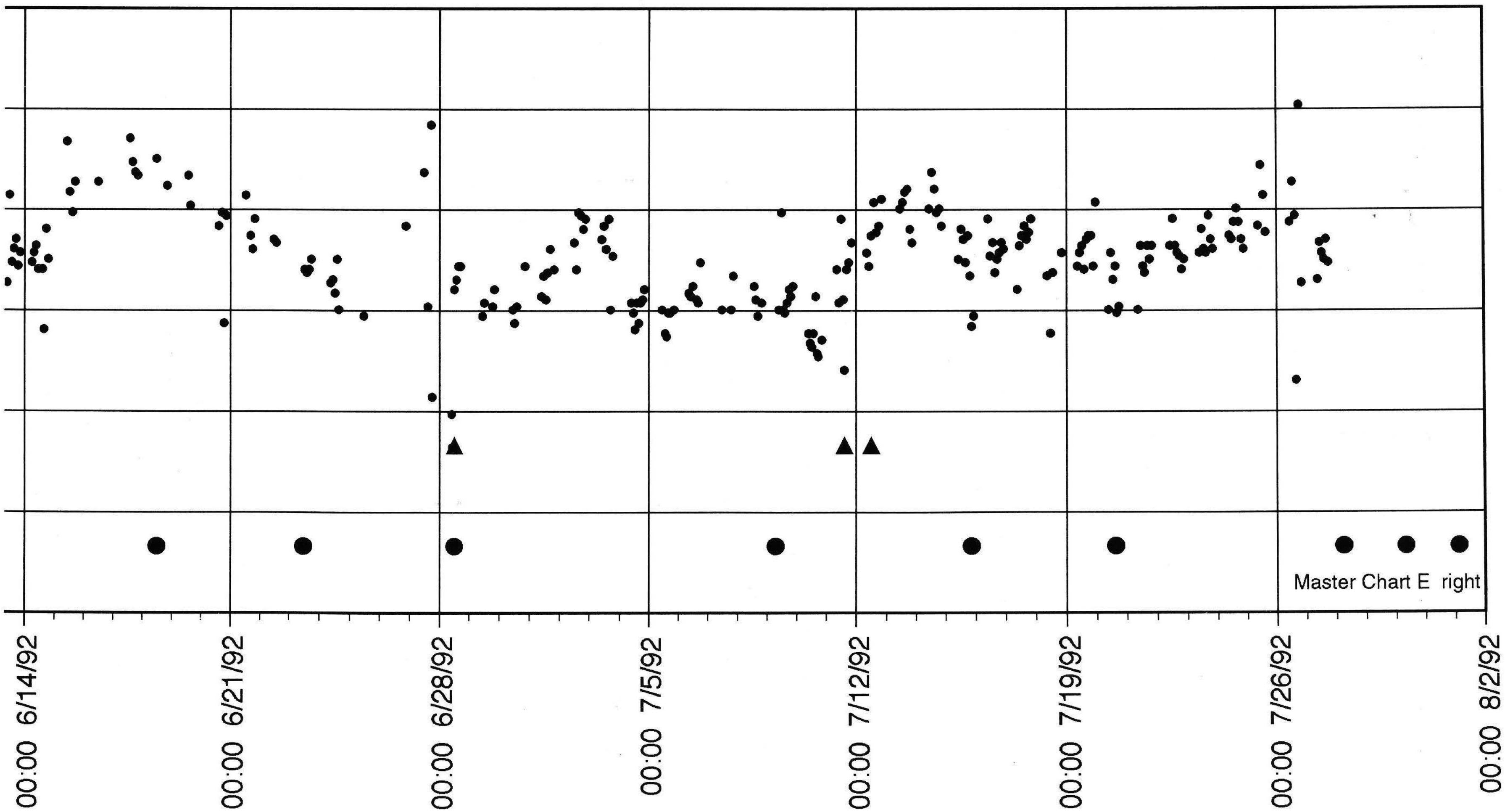
00:00 8/2/92


Master Chart E
Plate Geyser Intervals
© T. Scott Bryan
Plate Interval
SMax Date
Dome Date
Interval in Hours
03:00
02:30
02:00
01:30
01:00
00:30
00:00
Master Chart E left
00:00 4/26/92
00:00 5/3/92
00:00 5/10/92
00:00 5/17/92
00:00 5/24/92
00:00 5/31/92
00:00 6/7/92



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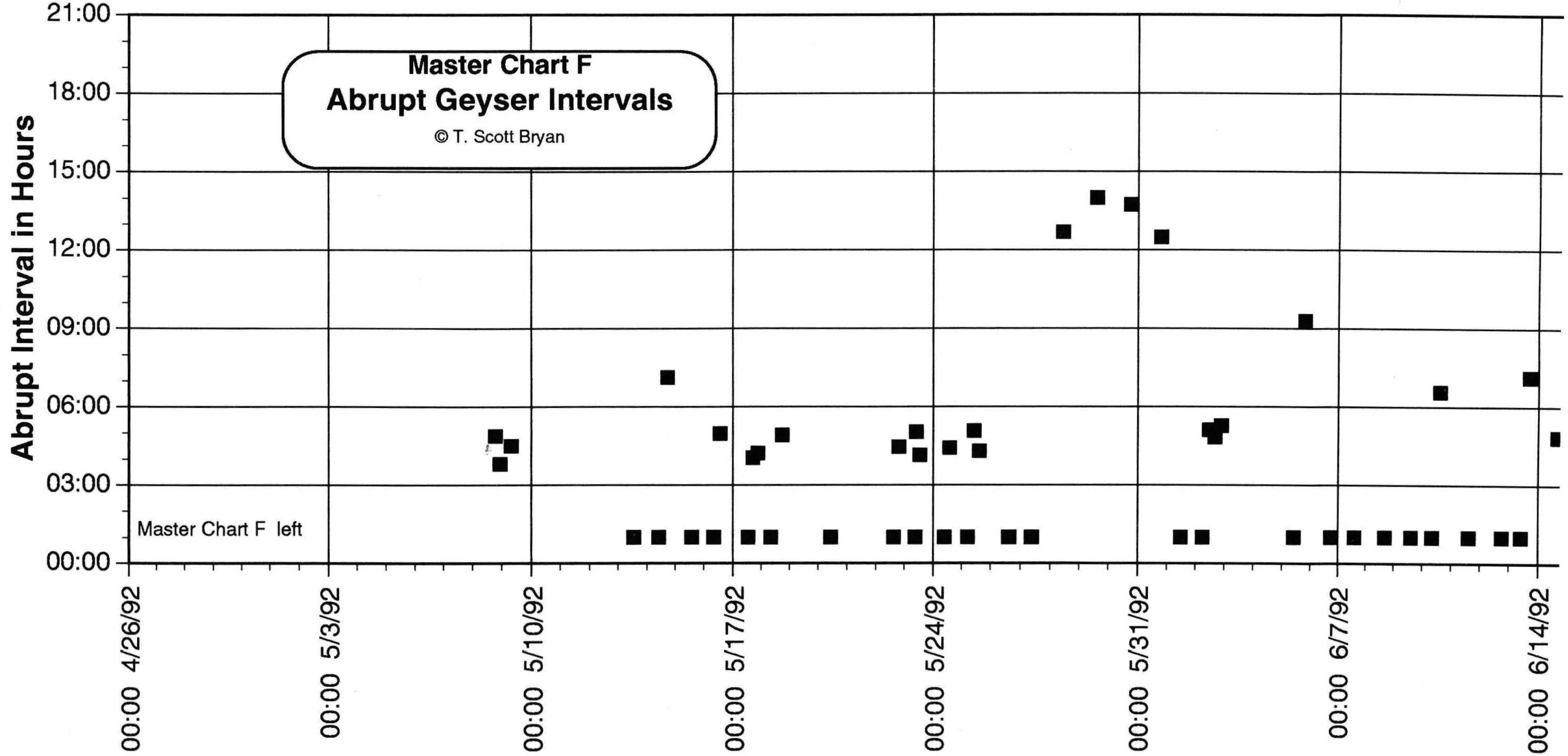
Master Chart F
Abrupt Geyser Intervals
© T. Scott Bryan
Abrupt Interval in Hours
21:00
18:00
15:00
12:00
09:00
06:00
03:00
00:00
Master Chart F left
00:00 4/26/92
00:00 5/3/92
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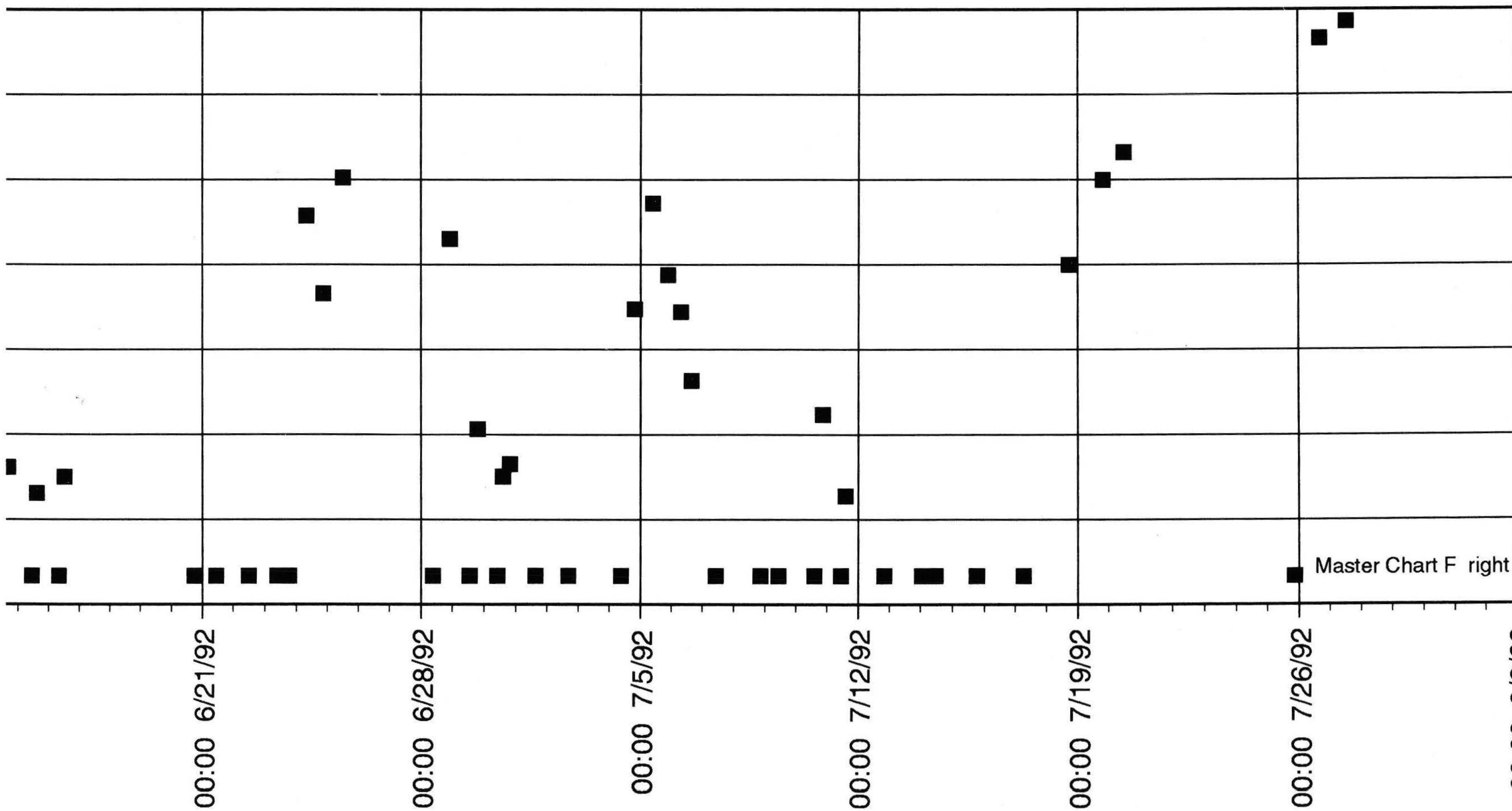

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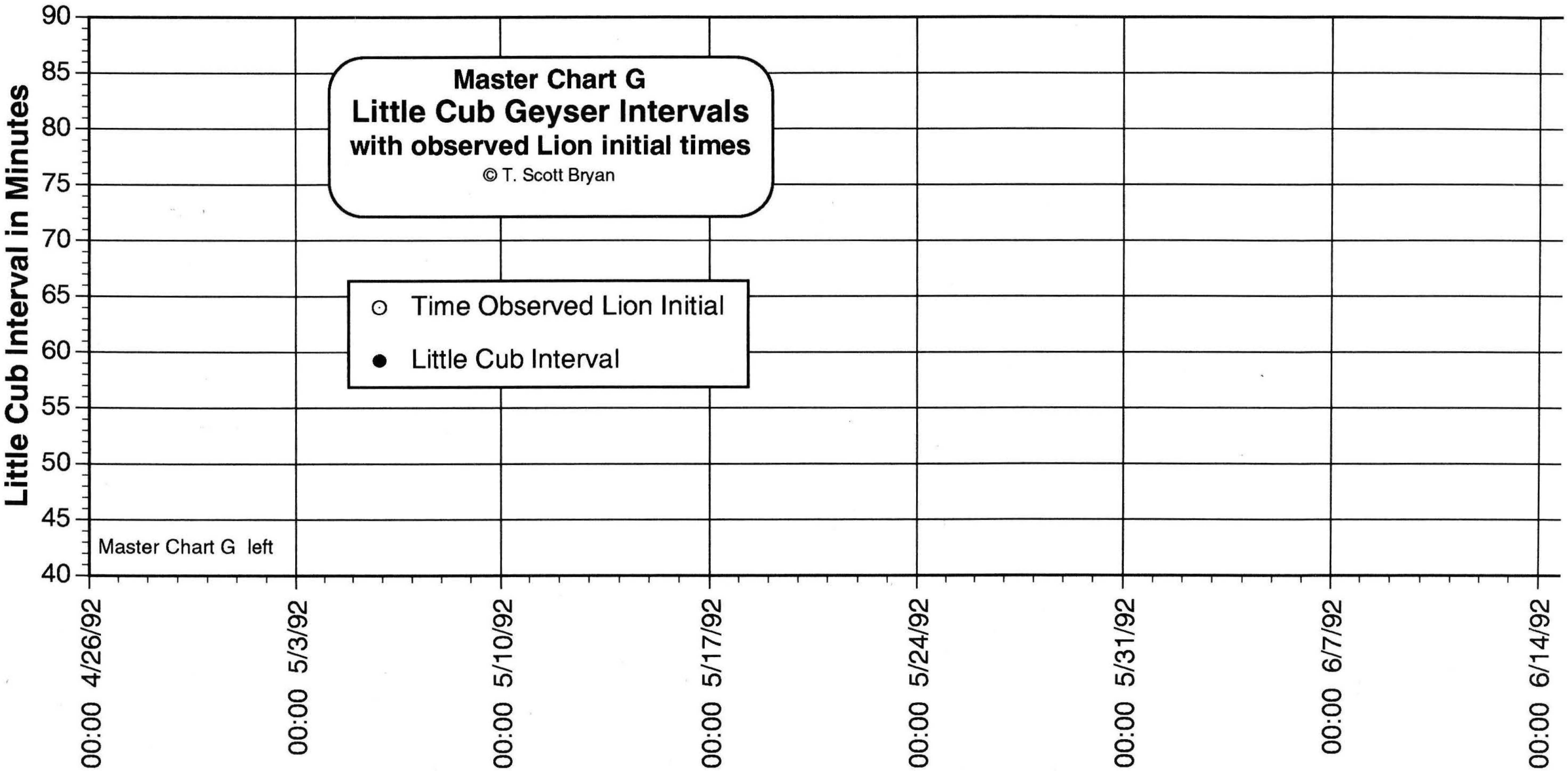
Master Chart G
Little Cub Geyser Intervals
with observed Lion initial times
© T. Scott Bryan
Time Observed Lion Initial
Little Cub Interval
Little Cub Interval in Minutes
90
85
80
75
70
65
60
55
50
45
40
Master Chart G left
00:00 4/26/92
00:00 5/3/92
00:00 5/10/92
00:00 5/17/92
00:00 5/24/92
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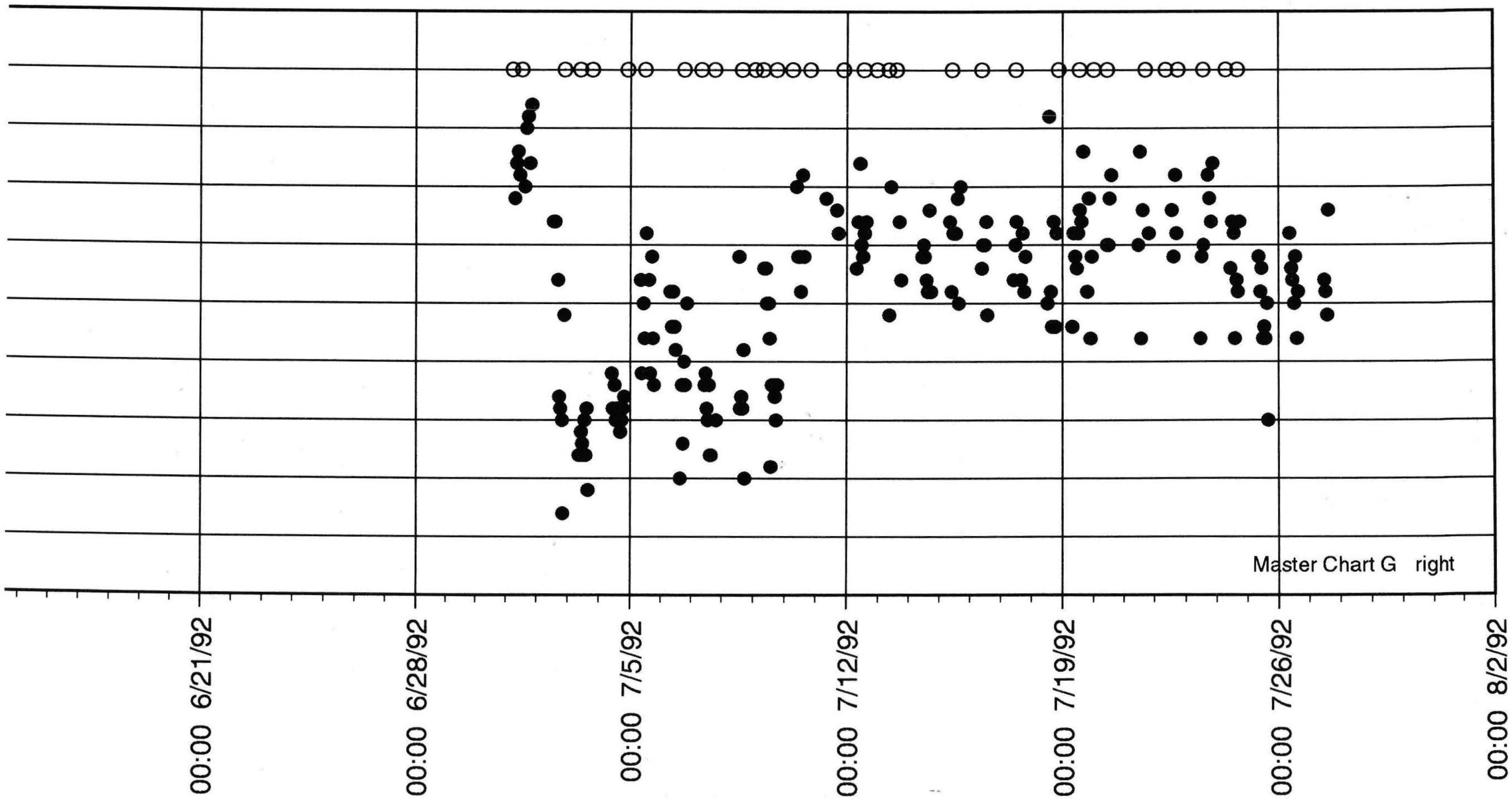
00:00 6/7/92
00:00 6/14/92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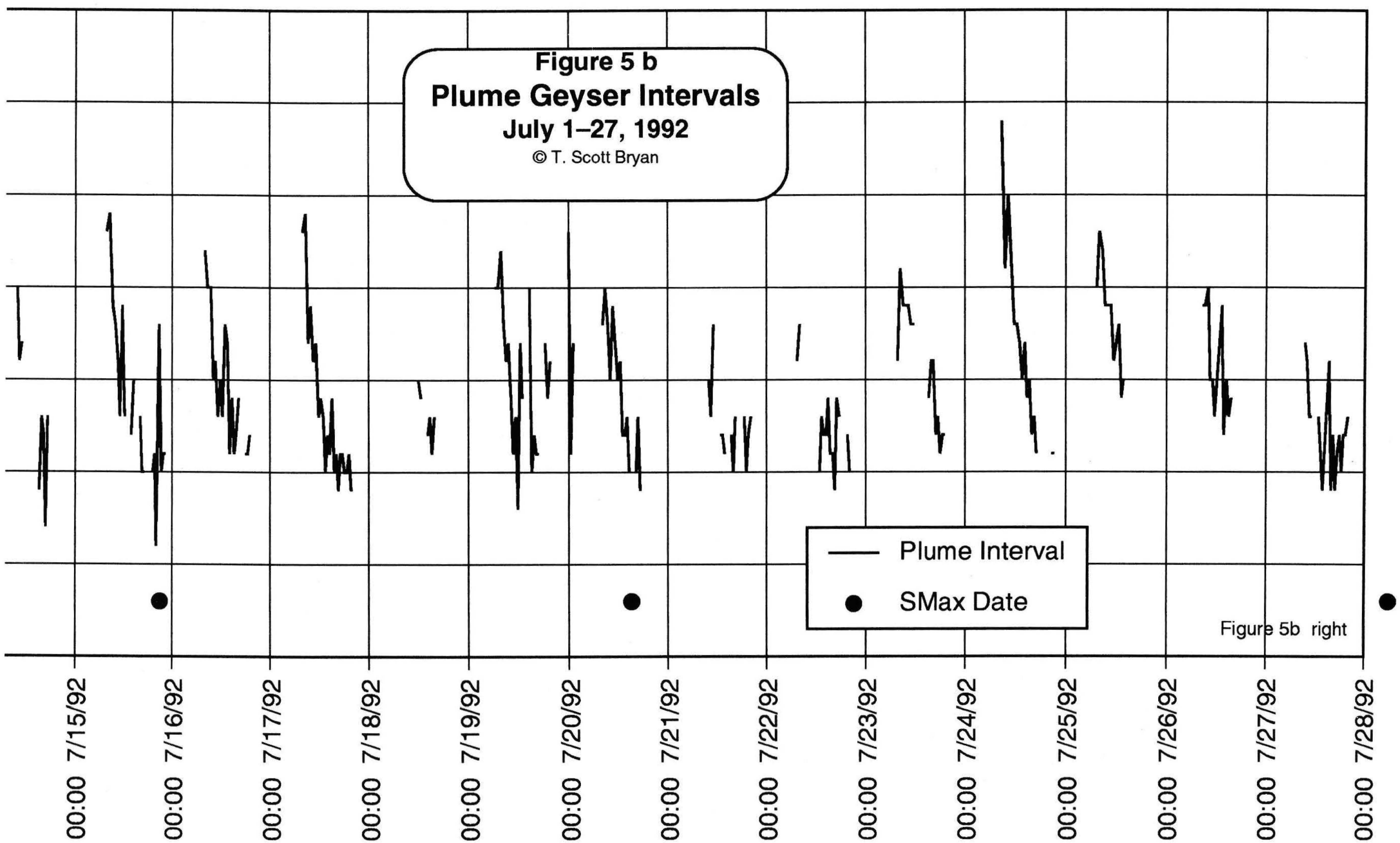
Figure 5 b
Plume Geyser Intervals
July 1–27, 1992
© T. Scott Bryan
Plume Interval
SMax Date
Figure 5b right
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00:00 7/17/92
00:00 7/18/92
00:00 7/19/92
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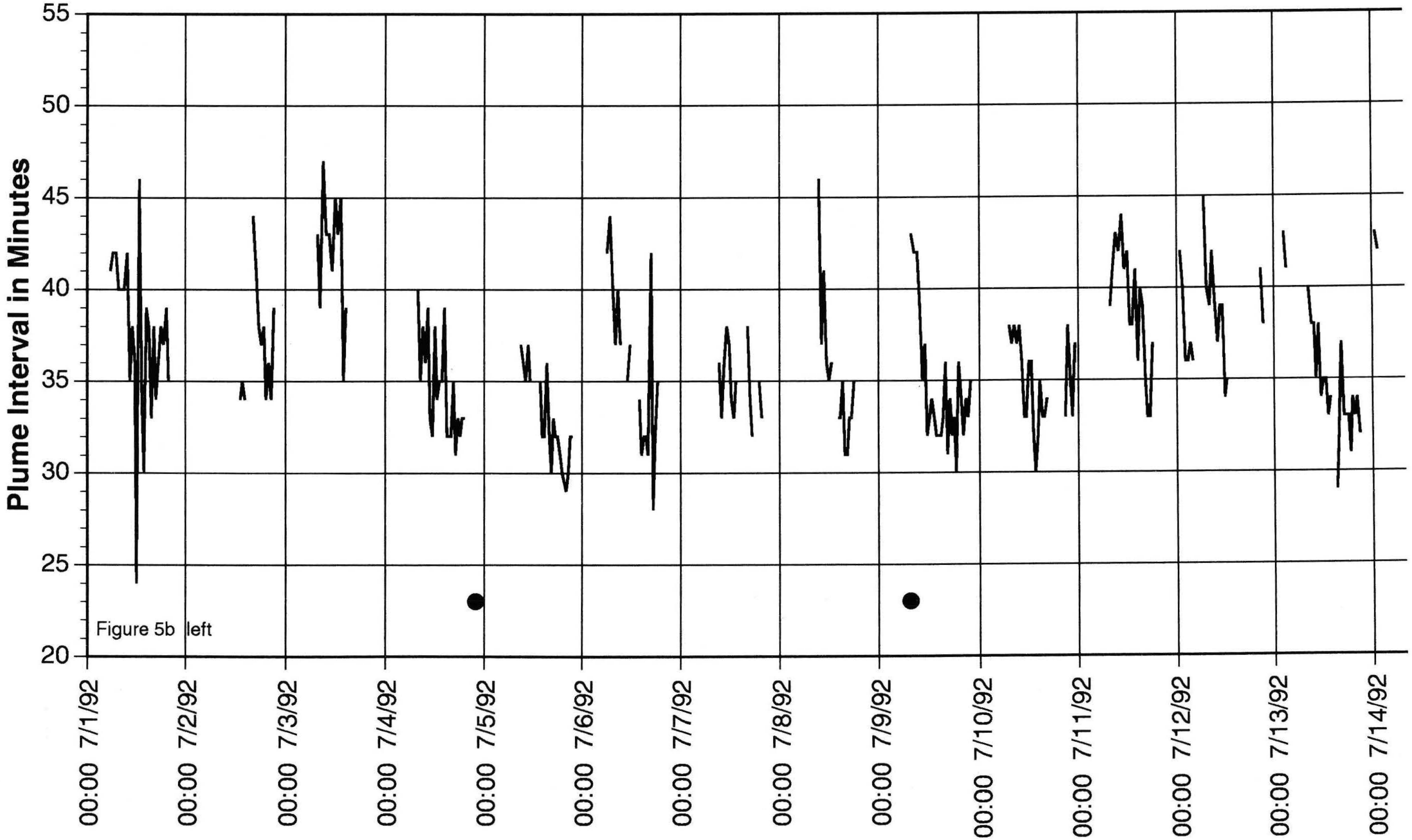
Plume Interval in Minutes
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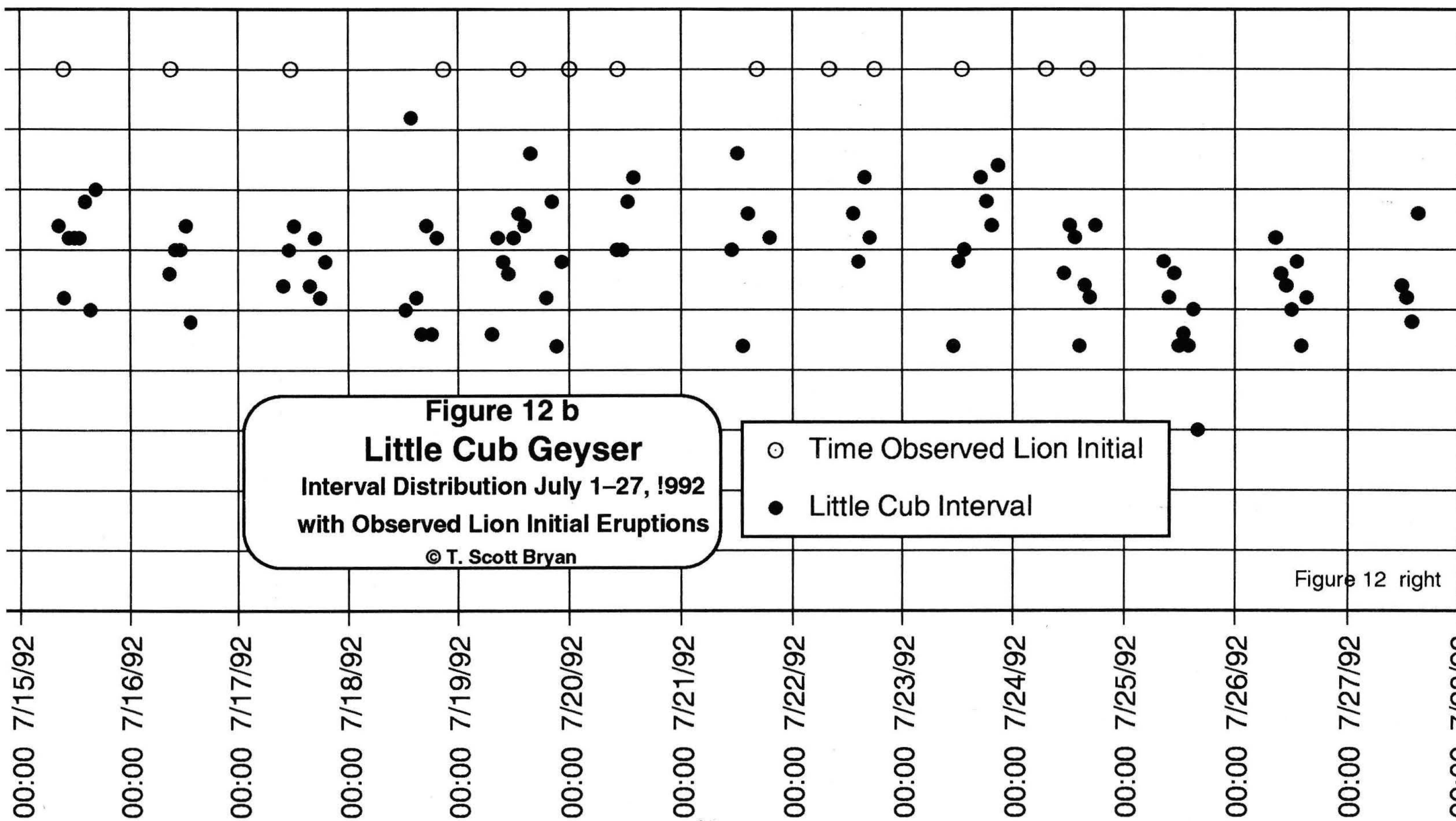
Figure 12 b
Little Cub Geyser
Interval Distribution July 1–27, !992
with Observed Lion Initial Eruptions
© T. Scott Bryan
Time Observed Lion Initial
Little Cub Interval
Figure 12 right
00:00 7/15/92
00:00 7/16/92
00:00 7/17/92
00:00 7/18/92
00:00 7/19/92
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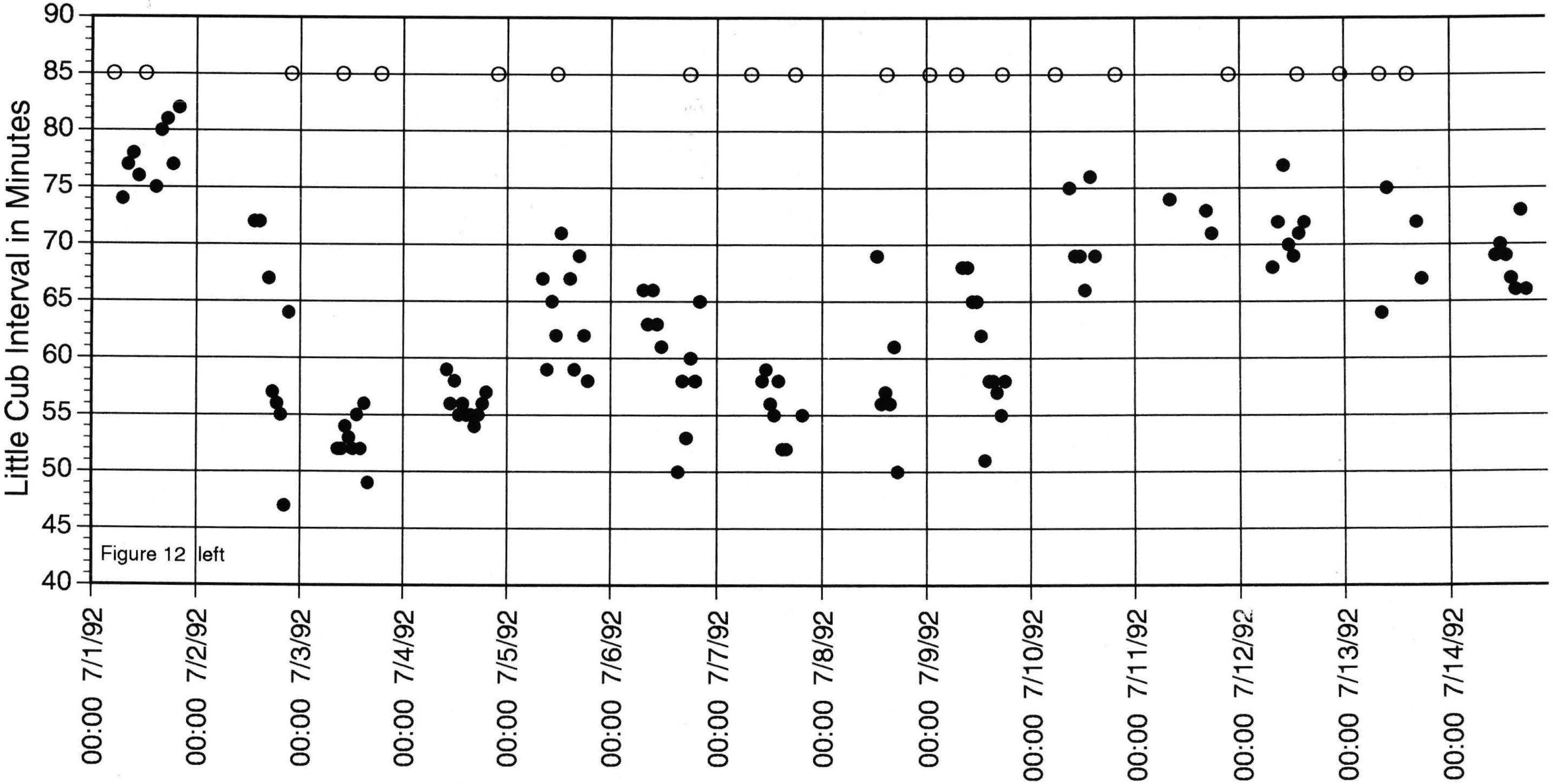
Little Cub Interval in Minutes
90
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80
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Figure 12 left
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00:00 7/11/92
00:00 7/12/92
00:00 7/13/92
00:00 7/14/92

Evidence for the Geyser Hill Wave and Diurnal Effects on Geyser Hill During the 1980s

by T. Scott Bryan

Abstract

An examination of eruption interval data for Giantess and Beehive Geysers during 1981-1983 and for Plume Geyser during 1989-1990 indicates that the Geyser Hill Wave has been in operation during this entire span of time in a fashion similar to that observed during 1992. A similar look at miscellaneous Plume Geyser data shows that its diurnal effect was either absent or only weakly present until 1989.

Introduction

This paper is a follow-up to my report "Cyclic Hot Spring Activity on Geyser Hill" [Bryan, 1993, previous paper herein], which should be thoroughly read before this. That report, based on 1992 observations, examines a long-term (about one week) cyclic variation in hot spring water levels and geyser eruption intervals that result from a subsurface event commonly known as the "Geyser Hill Wave" (GHW), and a shorter-term (daily, or diurnal) variation in Plume Geyser intervals. Potential causes are considered for both events.

The existence of both the GHW and diurnal variations was not suspected until 1990 [Day, 1991], and any firm understanding of either came about as a result of the 1992 study. The obvious and immediate question raised there was whether or not either of these cyclic processes existed during earlier years. In an effort to answer that, selected eruption statistics for Giantess and Beehive Geysers during 1981-1983 and for Plume Geyser during 1989-1990 have been analyzed for evidence of the GHW. Other Plume data covers only very short and rather random time spans. It is not useful for long time studies, but might reveal short period variations; this was searched for evidence of a diurnal effect.

The primary source of this data is a set of computer (Macintosh) data files compiled by Heinrich Koenig and available from GOSA as "Data Logs for Major Geysers" [Koenig, 1990]. In turn, Koenig had extracted this data primarily from the log books maintained at the Old Faithful Visitor Center. Further extraction of data from the log books might better reveal the diurnal effect, but a balance of the evidence is that it would not.

Beehive and Giantess Geysers, 1983

There is a good activity record for Beehive Geyser during the period of May 30 through October 16, 1983. The start times for every eruption by Giantess Geyser are also available for the same time span. This data is presented as Figure 1 (a three-page strip chart). The similarity between this Beehive plot and that for Beehive during 1992 [Bryan, 1993 herein, Master Chart A] is quite remarkable. Portions of these two years are compared in Figure 2.

Very clear from the 1992 study was that Beehive's intervals were strongly controlled by the Geyser Hill Wave. Knowledge of the average interval was essentially useless as a predictive tool, whereas monitoring the progress of the GHW allowed one to make relatively accurate predictions. Beehive consistently had its shortest intervals (12½ to 16 hours) near the time of the Wave's SMax (that is, the time when GHW–controlled water levels were at their highest in the south side of Geyser Hill). Its longer intervals (typically 20 to 24 hours) occurred shortly after the SMax. Overall, the average repeat period of the GHW, and therefore of Beehive's minimum (or maximum) intervals, during 1992 was about 6 days.

The 1983 pattern shows a nearly identical variation to Beehive's intervals. The minimum intervals (10 to 14 hours) repeat with a cyclic period of around 8 days, between which were longer intervals (mostly, 18 to 24+ hours). One can conclude that both annual patterns had the same cause, namely the Geyser Hill Wave.

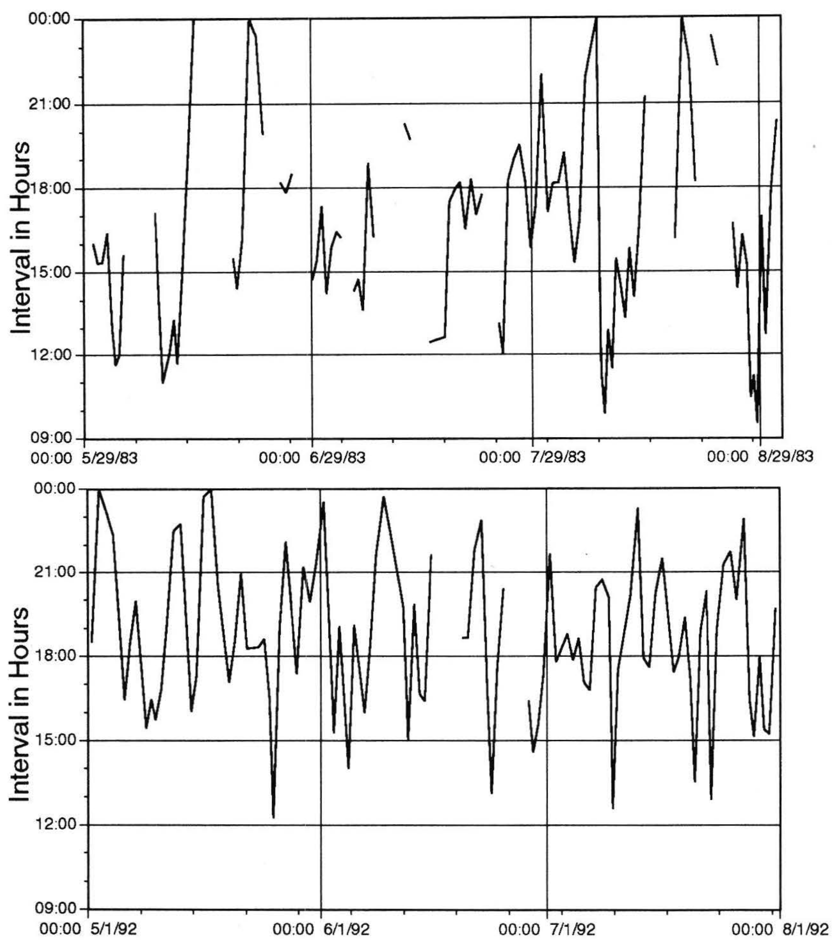

Figure 2. The Beehive intervals of1983 (top) and 1992 (bottom), shown to the same vertical and to nearly identical horizontal (time–line) scales for comparison. The strong similarity between the two plots makes it likely that Beehive was affected by the same underlying physical controls (the Geyser Hill Wave) during both seasons.

Also evident in the 1983 data is an apparent relationship between the GHW and the start times of Giantess' eruptions. Excepting some (but only some) of the "aborted" eruptions*, Giantess most commonly began playing 1 to 3 days before but *never* 1 to 3 days after SMax. Further, when aborted eruptions (indicated as 'a' on Figure 1) are included, Giantess' overall 1983 average interval was just 7.77 days. This is tolerably close to the GHW cycle period (about 8 days) judged independently from the Beehive data, and implies that Giantess' eruptions occurred as GHW-controlled events.

It is notable, by the way, that on July 31, 1983 there was an eruption by Dome Geyser at a time when Giantess might have been expected. This is the only eruption of Dome in the entire data log for 1983, and might be taken as further evidence for a Giantess–*or*–Dome eruptive relationship.

Giantess Geyser, 1981-1983

In view of the relationship between the GHW and Giantess Geyser's 1983 eruption times, plus additional observations from other years, I believe that it is nearly impossible for Giantess to erupt at times other than shortly before the SMax of the Geyser Hill Wave.

Giantess had its most intense eruptive activity of this century between August, 1980 and the Borah Peak, Idaho earthquake of October 28, 1983. It had 23 eruptions during 1981, 35 in 1982, and 41 in 1983. A fact not previously realized (to my knowledge) is that Giantess' intervals during this time were bimodal in distribution and, in my opinion, controlled by the GHW. Figure 3 shows the whole-day interval distribution of all 99 of these intervals. Figures 3a, 3b, and 3c separate them into the three years (the 37-day interval of 1981 is omitted).

The two modes of this distribution centered on about 13 and 20 days during 1981, and around 8 days and 18 days in 1982 and 1983. It is my belief that the 1981 values represent 2x and 3x multiples of that season's GHW period, while those of 1982 and 1983 show 1x and 2x multiples.

---

* "Aborted" eruptions (as designated by Park Geologist Rick Hutchinson [1983]) were first observed during the time considered by this report, in 1982. These eruptions began as did any other: massive overflow and minor bursting was followed by a pause of 35 to 50 minutes, which then led into either a water or mixed phase eruption. Unlike a full eruption, however, the eruptive activity came to a complete end after an extraordinarily short total duration. One duration was just 53 minutes. More typical were durations of a few hours, and nearly all were substantially shorter than the 12 to 40+ hours of a full water or mixed phase eruption.

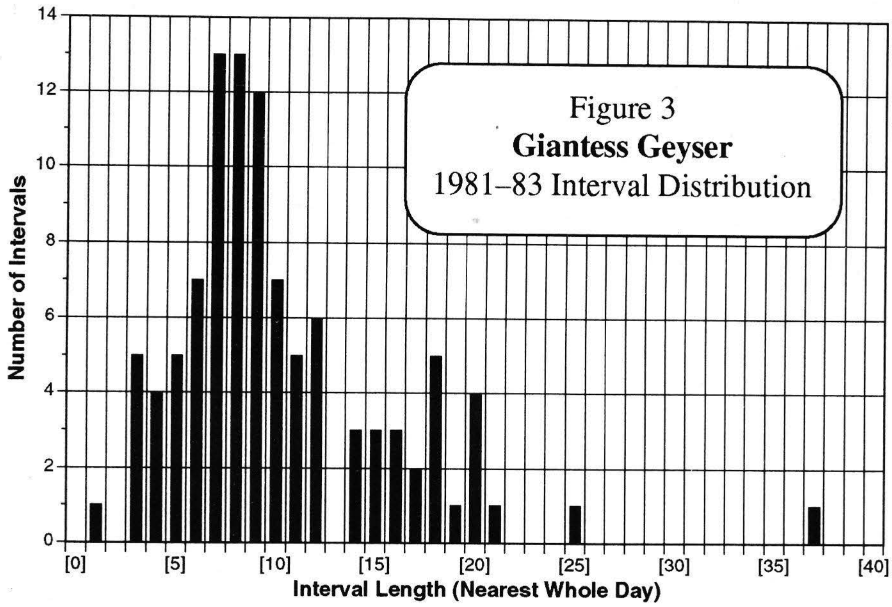

Figure 3
Giantess Geyser
1981–83 Interval Distribution

During 1981, the short, 2x mode was preferred by Giantess. In 1982 there was a similar balance between the short (1x) and long (2x) modes. And in 1983 Giantess played almost exclusively on the short mode. (A look at Figure 3 alone does not seem to show a strongly bimodal distribution. In fact, the greater number of short mode intervals in 1983 overwhelms the other data. The bimodality is especially clear in Figure 3b.)

This progressive change in pattern might be taken as the result of either gradually increasing energy available to the Geyser Hill system as a whole or some sort of progressive exchange of function toward Giantess within Geyser Hill. But in either case, the modes correspond quite closely to single, double, and triple GHW periods.

Plume Geyser, 1989-1990

The data logs contain outstandingly good eruption statistics for Plume Geyser during the span of January 1, 1989 through February 28, 1990; the only large gaps in this data correspond to the dates when Yellowstone was closed between the successive winter to summer and summer to winter seasons. In total, there are 3,614 individual data points and 2,991 closed single intervals. This data is presented as Figure 4, a six-page strip chart which also shows the eruption times for Giantess and Beehive Geysers.

It must be remembered that there was no knowledge of the Geyser Hill Wave at this time. It takes only a glance at the chart to see that it was present, producing a strong wave-like aspect to the Plume graph. By simply "eyeballing" and sketching through this data, I judged 42 GHW cycles. With extremes of about 4 and 11 days, these gave an average repeat of 7.3 days. Clearly, this is only approximate, but in the complete absence of any Silver Spring, Little Squirt, or other SMax data, it is my belief that this value equals the average period of the GHW during 1989-1990.

Although it is a slightly less certain thing, I believe also that the eruption times of Giantess Geyser during 1989 can again be related to the GHW. Six of the seven eruptions occurred within the three days *before* the SMax dates indicated by the Plume cycles, very much as was seen in the 1983 data. There is no corresponding Plume data for the seventh eruption, in November.

Furthermore, the eruptions of Beehive Geyser which took place during this same time span have generally been taken as resulting from or triggered by Giantess' action. In fact, they were also controlled by the GHW. Rather than occurring with Giantess, most of Beehive's eruption times fell two to three days *after* the Giantess— and, therefore, at the time of SMax. The correlation here is quite high, at ≥70% (in my judgement, at least 14 of the 19 eruptions for which there is corresponding Plume/SMax data).

The Length of the GHW Period

Based on the data cited here plus other records and the 1992 study, there is good evidence that the Geyser Hill Wave has been operating since at least 1981, and that its repeat period has been relatively constant over that twelve year span. By examining the yearly data in various ways (which are admittedly much less mathematically precise than desirable), I have deter-

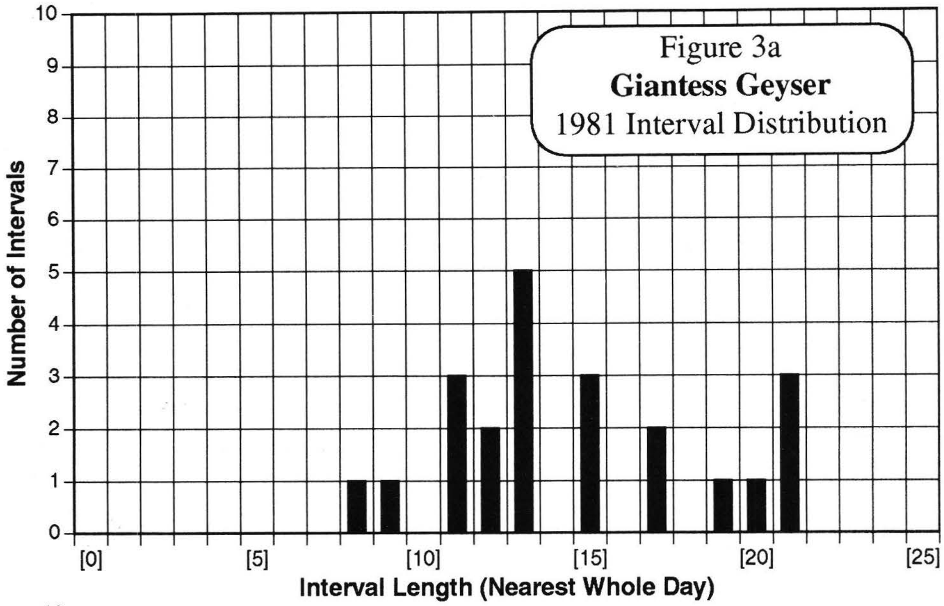
Figure 3a
Giantess Geyser
1981 Interval Distribution
Number of Intervals
Interval Length (Nearest Whole Day)
[0]
[5]
[10]
[15]
[20]
[25]

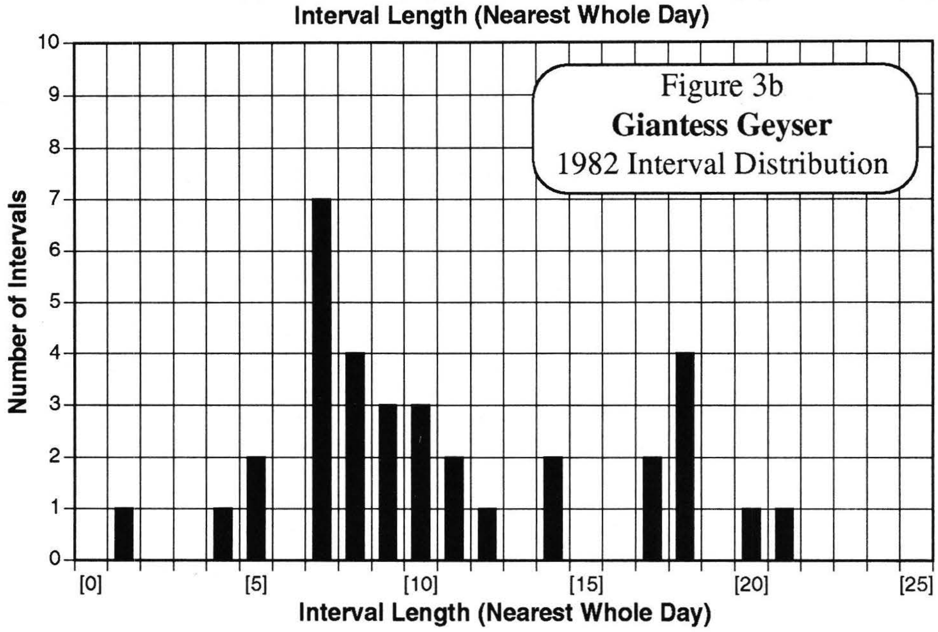
Figure 3b
Giantess Geyser
1982 Interval Distribution
Number of Intervals
Interval Length (Nearest Whole Day)
[0]
[5]
[10]
[15]
[20]
[25]

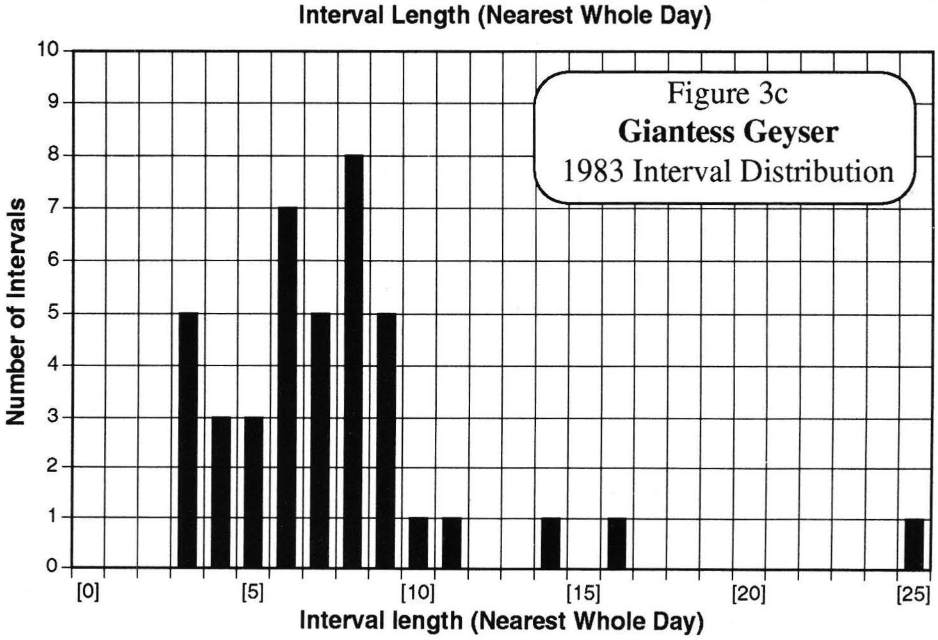
Figure 3c
Giantess Geyser
1983 Interval Distribution
Number of Intervals
Interval length (Nearest Whole Day)
[0]
[5]
[10]
[15]
[20]
[25]

mined the periods to have been (all approximate):

1981 ≈ 6.5 days
1982 ≈ 8.0 days
1983 ≈ 7.8 days
1989 ≈ 7.3 days
1992 ≈ 6.0 days

For the sake of brevity and given a lack of consistent long-term data, I do not cite similar statistics for other years. However, considering the decade plus that is involved, I feel that this is a remarkably slight variation, showing that the Geyser Hill Wave is an essentially permanent and stable subsurface phenomonon.

The Diurnal Effect at Plume Geyser

Very much contrasting with the above evidence for an on-going Geyser Hill Wave, few conclusions about a possible diurnal variation in Plume Geyser are possible. Virtually all of the Plume statistics that are available in the data logs are for limited dates centered about eruption times of Giantess Geyser so that the Plume intervals are, at least partially, altered by a "Giantess effect." Even so, a diurnal variation at all similar to that of 1992 should be evident. Such data is available for every year between 1981 and 1992 excepting 1984, 1985, and 1987. There is some, but only slight, evidence for a diurnal effect during these years, but never is it as clear or so consistently daily as during 1992.

The only data I present as a graph is that for July 1989 (Figure 5, a two-page strip chart adapted from Figure 4 data). As can be seen, some dates show evidence of 1992-style diurnal changes, but other dates definitely do not. The patterns that do appear could be due to chance. If there was a diurnal effect present during 1989 (or in fact, during any year prior to 1989), then it was far weaker and less consistent than during 1992. (Compare Figure 5 here with Figure 5b of the previous paper.) This does not mean that it was not present, but the only way to certainly settle the matter would be to analyze some continuous, 24-hour data, which probably does not exist.

Ralph Taylor, who has independently conducted Geyser Hill studies since 1983, related the findings of this paper to his own studies. Taylor wrote:

> I have some data from 1989 (7–9 August) that cover times from 06:30 or 07:00 to 20:00 or 23:00. *None of these data sets show any diurnal cycle.* The standard deviations were on the order of 1m 30s and there was only a four minute total variation, fairly randomly distributed over the day. [More limited] data for 11–16 August show even less variation. My 1990 and 1991 data don't include any full day observation intervals, but show *no evidence of diurnal variation* in 10 hour stretches. [Taylor, 1993] [emphasis added]

It seems clear, then, that the diurnal effect seen during 1992 is a new process. If it was in existence earlier, then it developed to a far stronger degree during 1992 than during any previous year of record.

A Possible Relationship Between Plume and Giantess

Completely aside from either the Geyser Hill Wave or diurnal effects, it is known that Plume is directly influenced by eruptions of Giantess Geyser. Observers have long discussed this "Giantess effect" in which Plume's intervals become much longer than usual for a time following the start of activity in Giantess. What I do not believe most people have understood (myself included) is how inconsistent this effect actually is, or how brief its duration when it does take place. The following points can be made:

—Plume does not indicate an impending Giantess eruption in any way.

—Sometimes the first interval by Plume following the onset of Giantess will be very long (as great as 80+ minutes), yet on other occasions there is no effect at all.

—Even when the effect is present, Plume returns to normal very quickly, usually within just one or two intervals.

In other words, any effect by Giantess on Plume is only a sometimes and very temporary thing.

There is, however, something more to this relationship. I noted in the preceding paper about the 1992 activity that there were occasions when Plume exhibited highly variable intervals at mid day. I hypothesized that these might have had something to do with the diurnal decrease toward minimum length intervals at mid day. I find that that position should be modified.

Such "spike dates" were numerous during 1989. Some are indicated on Figure 4 by large asterisks above the spikes (asterisks shown for February and March only). Notice that most Giantess eruptions directly correspond to Plume spikes, and that those spikes without a Giantess have the same "look" as the others.

On reflection, all of these spikes resemble Plume's "Giantess effect" data from several years during the earlier 1980s. It might be, then, that the so–called "Giantess effect" in Plume really is not a Giantess effect at all. Instead, it is Plume responding to some process taking place at depth within Geyser Hill— something that *can* trigger Giantess when the energy balance within the Geyser Hill system is "right", and which *will* affect Plume in any case, even when there is no Giantess eruption.

To call these "Giantess false starts" is probably too strong a term. However, I suspect that the times of Plume spikes were associated with episodes of unusually strong boiling and/or overflow action by Giantess as well as changed behavior in other springs. There are no known reports of such activity; in 1989, Taylor witnessed a spike event while on Geyser Hill, and he noted "no unusual events" in his journal. But this effect is probably very subtle, possibly detectable only with instrumental water stage recorders.

Closing Note— Winter 1992–1993 Changes in Plume Geyser

Following the Hebgen Lake earthquake on August 17, 1959, Plume Geyser's activity was infrequent for a few days. Marler, in his thermal report for 1959, inferred that this was because of "water flowing into Plume's crater from a steadily erupting spring which started the night of the 17th." When this flow was blocked, Plume responded with a markedly increased eruption frequency.

In 1960, with the natural drainage in place, Plume had typical intervals of 2 to 3 hours through September. Then, as the action in the new spouter declined and the volume of water flowing into Plume's vent decreased, Plume gradually increased its activity until the intervals were as short as 33 minutes [Marler, 1960 report].

It is clear, then, that inflowing runoff water does influence Plume's intervals, in much the fashion contended to by Jens Day. However, the fact remains that the diurnal action of 1992 was not accompanied by variations in such runoff. In other words, this simply becomes another factor known to cause activity changes.

Since the reactivation of Plume in 1940 (a correction from the 1941 date in Marler's *Inventory...*), the long post–earthquake intervals are the only such on record— until the winter of 1992–1993. Beginning in December, Plume had average intervals approaching 60 minutes long. This was a marked contrast to the 33 to 40 minute averages obtained during the summer of 1992. By mid–February, intervals as long as several hours were seen, and these had stretched to as long as 4+ *days* by the middle of March at the termination of the winter season. This is a remarkable change.

Yet no other hot spring on Geyser Hill, not even those closest to Plume, exhibited any corresponding change whatsoever! Studies of the Geyser Hill Wave and diurnal effects in the summer of 1993 could be very interesting!

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Day, J., 1991, A surprise about Plume, and other geysers: The Geyser Observation and Study Assn., *The Geyser Gazer SPUT* (newsletter), v. 5, no. 1, p. 91–4.

Hutchinson, R.A., 1983, Geothermal Activity in the Thermal Basins of Yellowstone National Park, 1982: unpublished annual report.

Koenig, H., 1990, Data Logs for Major Geysers: The Geyser Observation and Study Assn., two 800KB computer disks, Macintosh (WriteNow format).

Taylor, R.C., 1993, Personal communication, editorial comments to draft of this report.

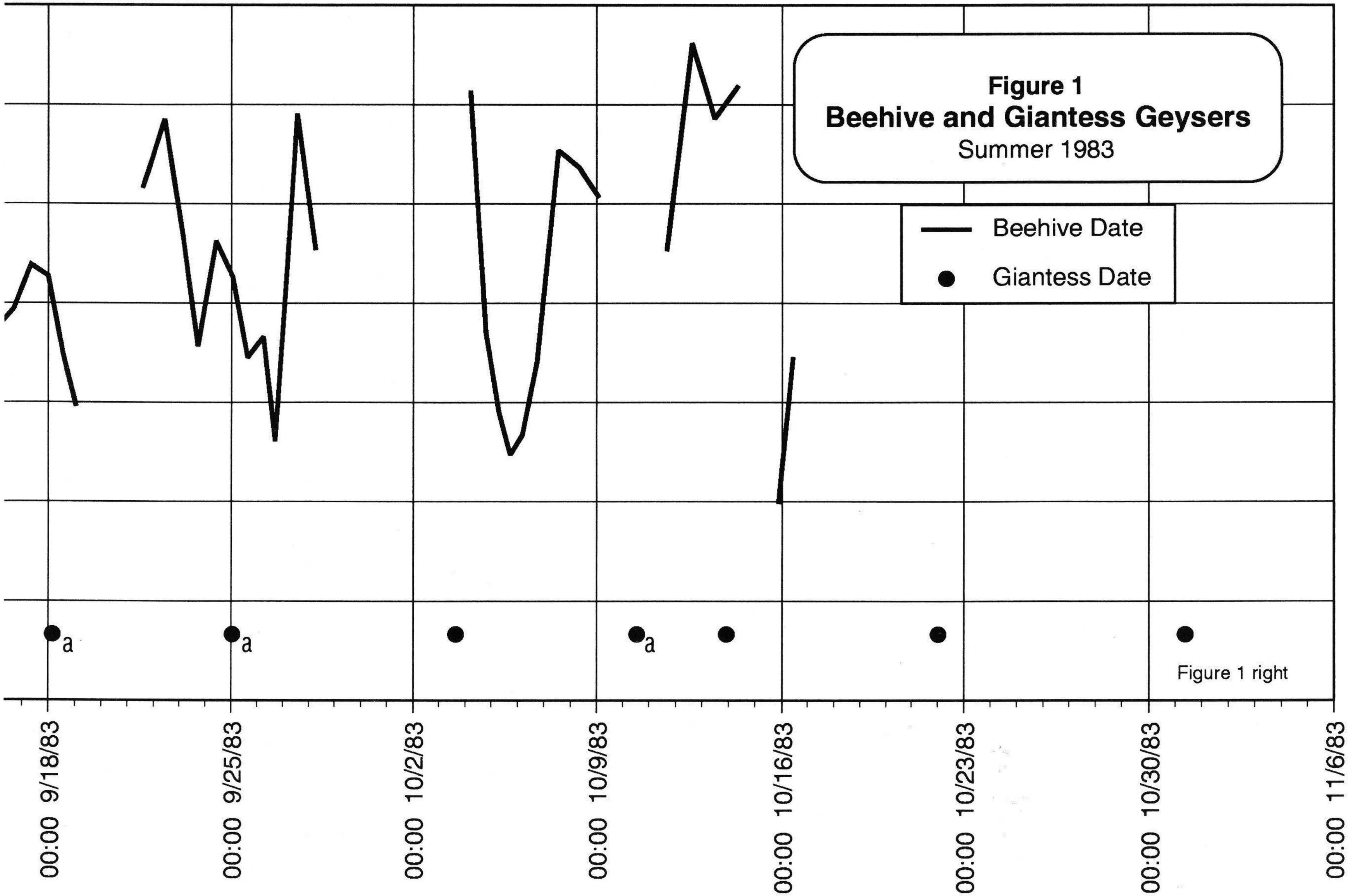
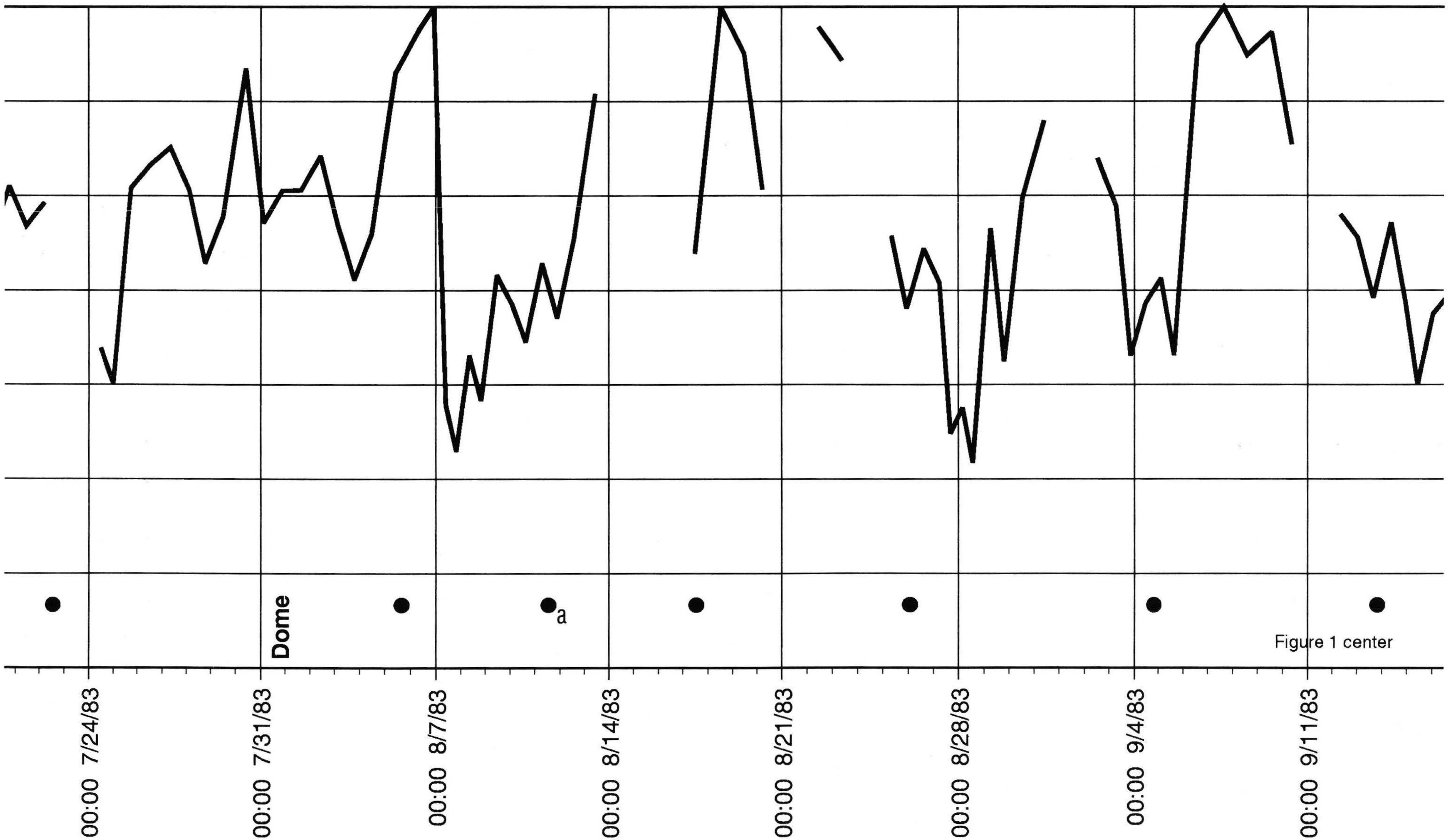
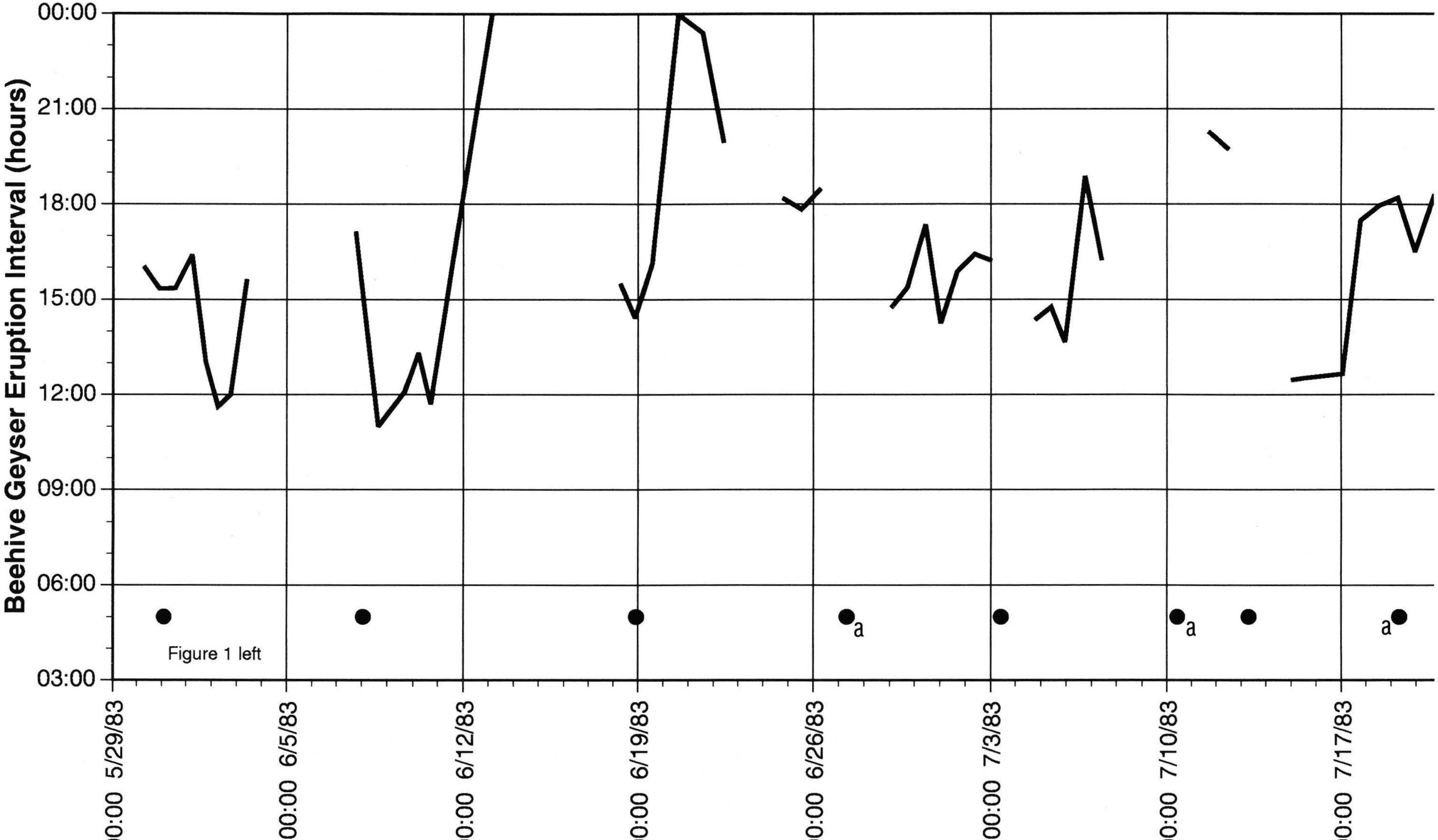


Figure 1
Beehive and Giantess Geysers
Summer 1983
Beehive Date
Giantess Date
a
a
a
Figure 1 right
00:00 9/18/83
00:00 9/25/83
00:00 10/2/83
00:00 10/9/83
00:00 10/16/83
00:00 10/23/83
00:00 10/30/83
00:00 11/6/83



Beehive and Giantess, Eruption Date and Time


Beehive Geyser Eruption Interval (hours)
00:00
21:00
18:00
15:00
12:00
09:00
06:00
03:00
a
a
a
Figure 1 left
00:00 5/29/83
00:00 6/5/83
00:00 6/12/83
00:00 6/19/83
00:00 6/26/83
00:00 7/3/83
00:00 7/10/83
00:00 7/17/83

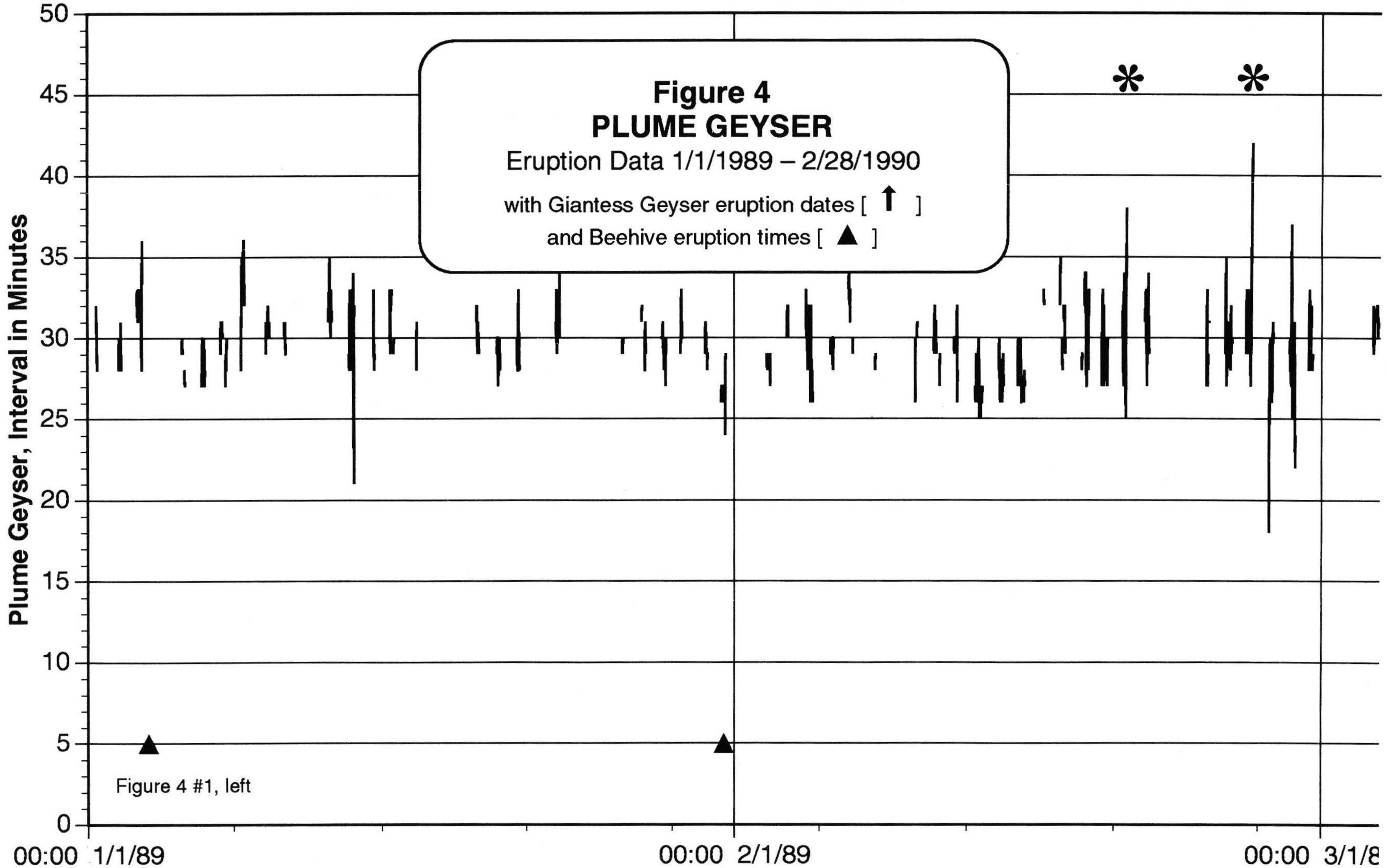


Figure 4
PLUME GEYSER
Eruption Data 1/1/1989 – 2/28/1990
with Giantess Geyser eruption dates [ ]
and Beehive eruption times [ ]
Plume Geyser, Interval in Minutes
Figure 4 #1, left
00:00 1/1/89
00:00 2/1/89
00:00 3/1/8

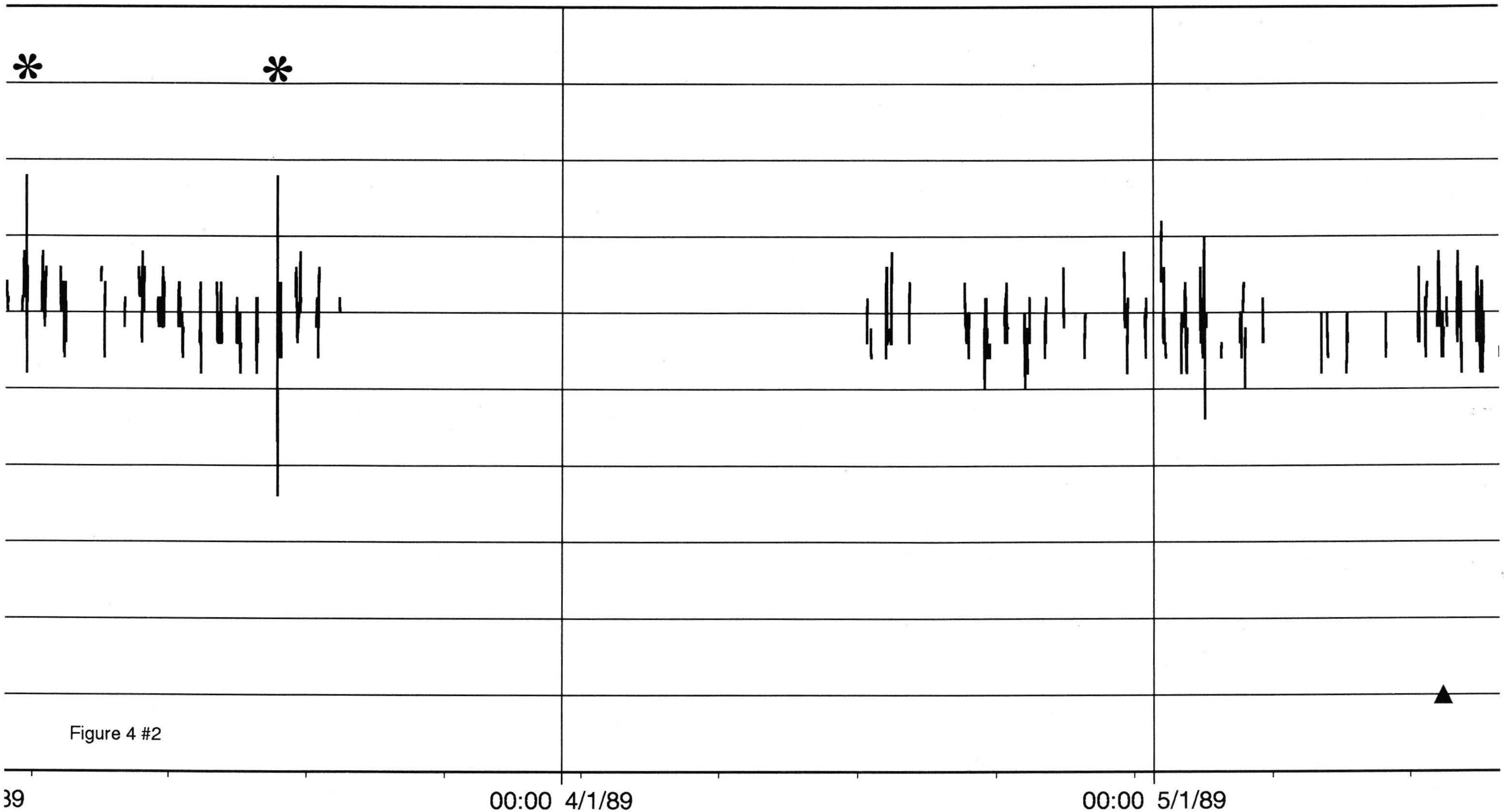


Figure 4 #2

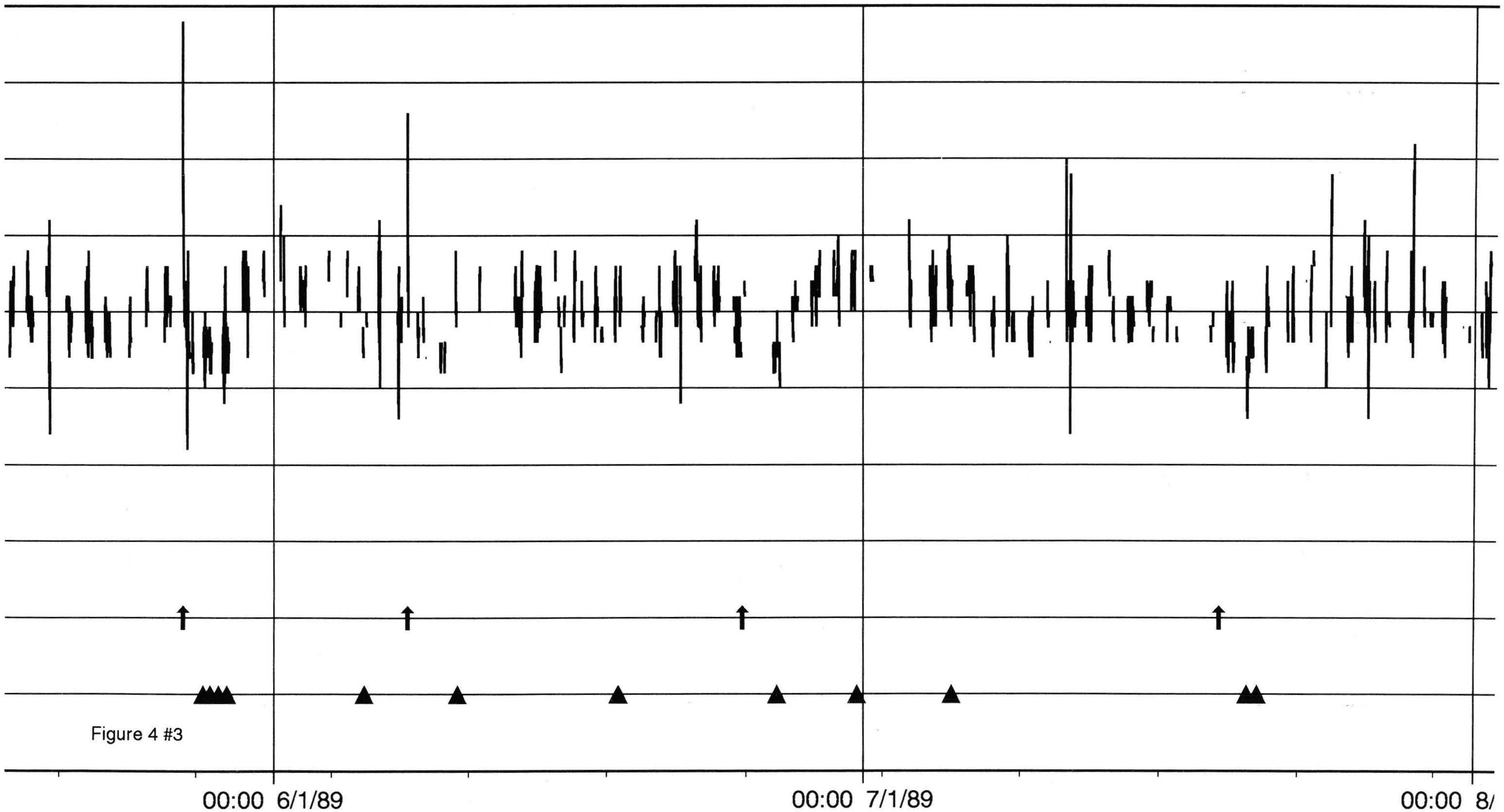


Figure 4 #3

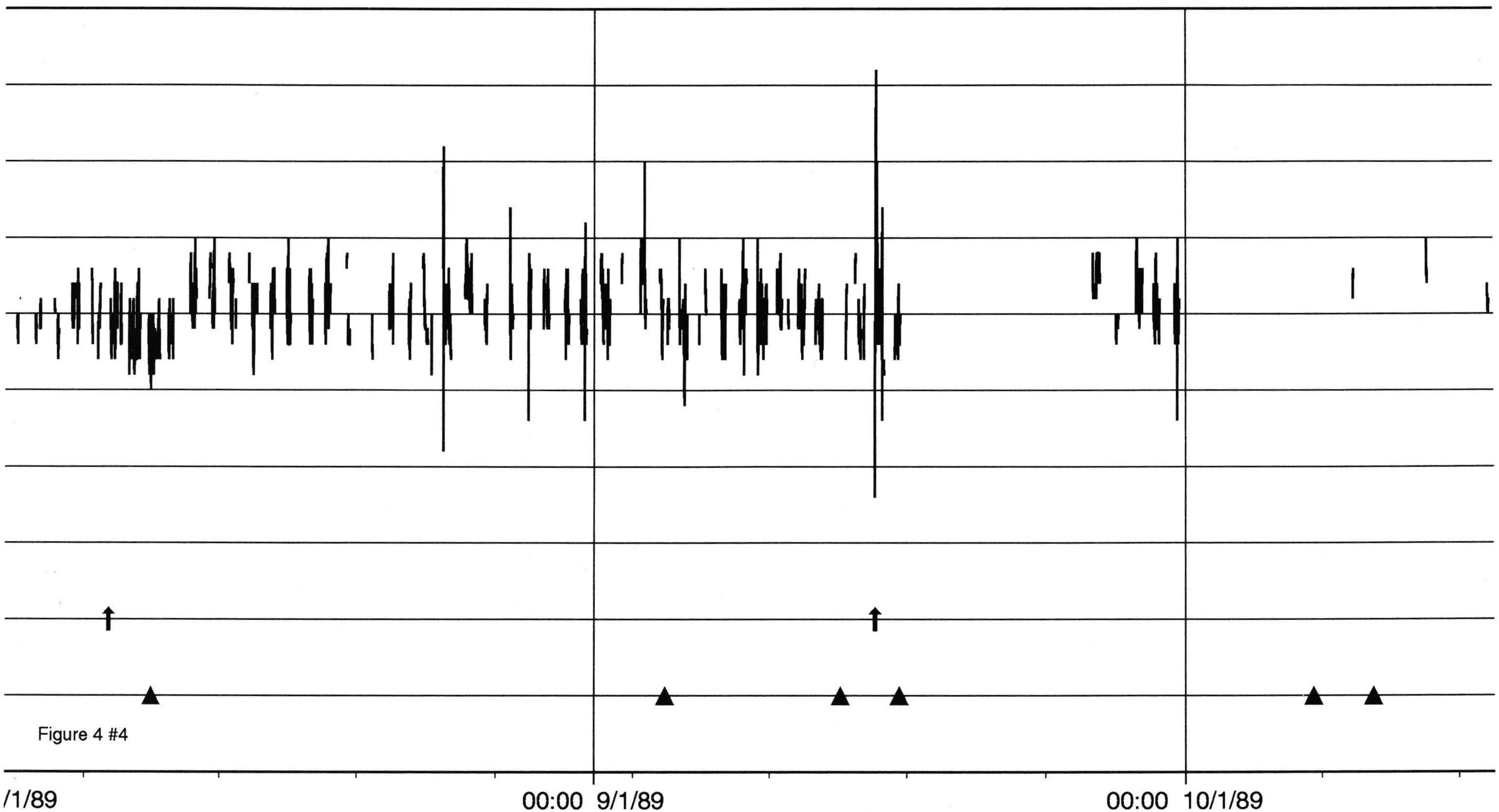


Figure 4 #4

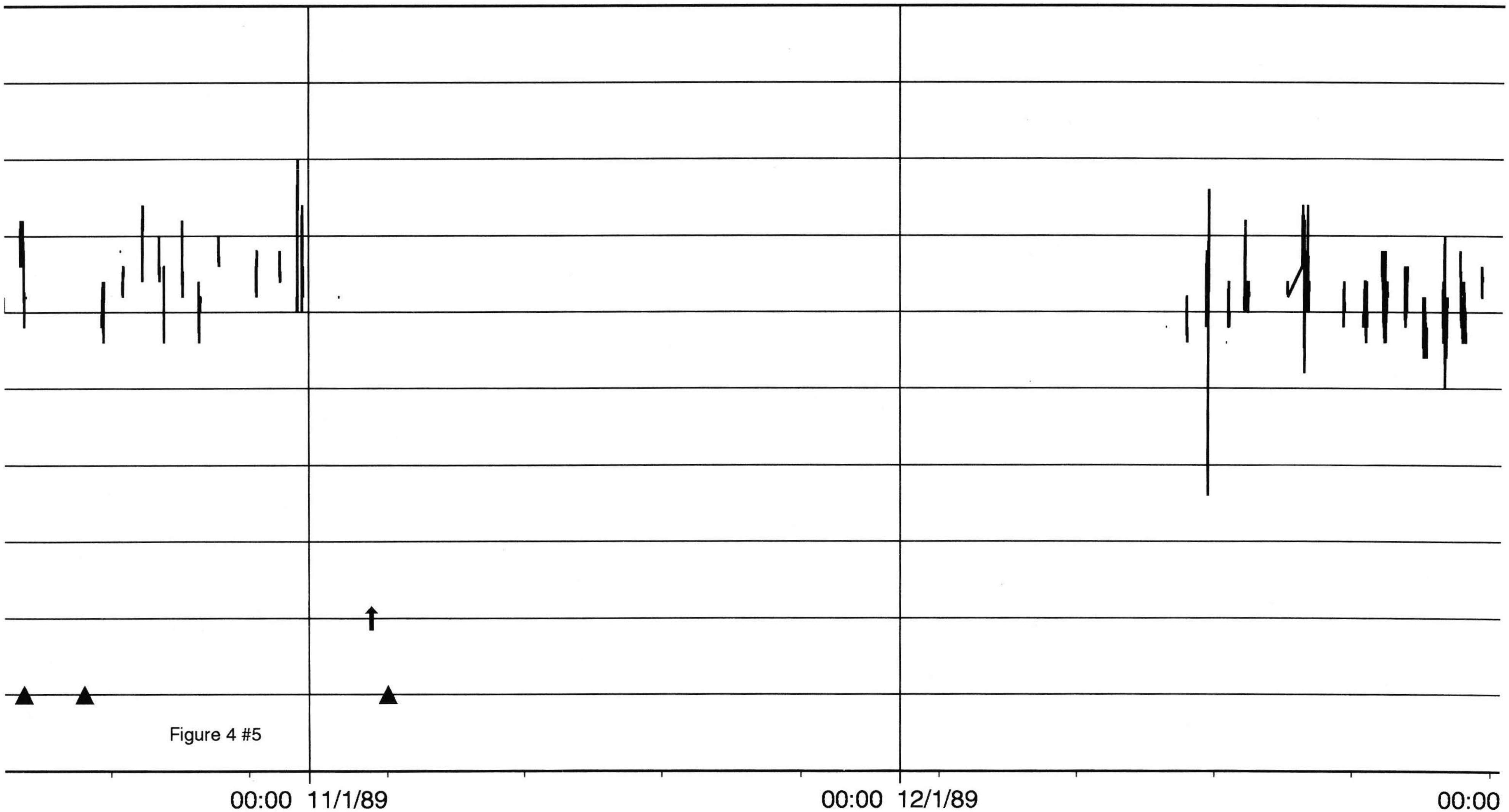


Figure 4 #5
00:00 11/1/89
00:00 12/1/89
00:00

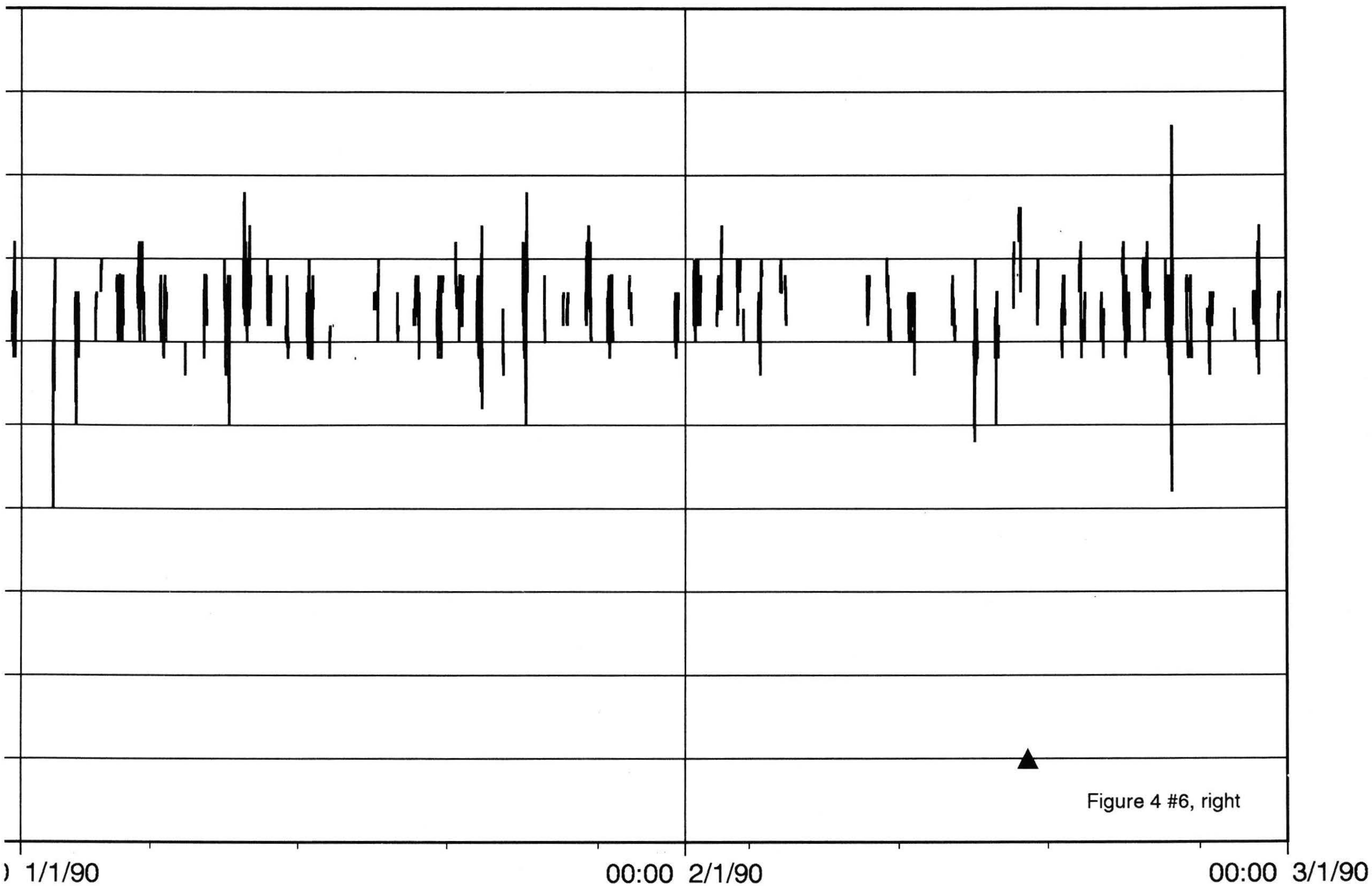


Figure 4 #6, right

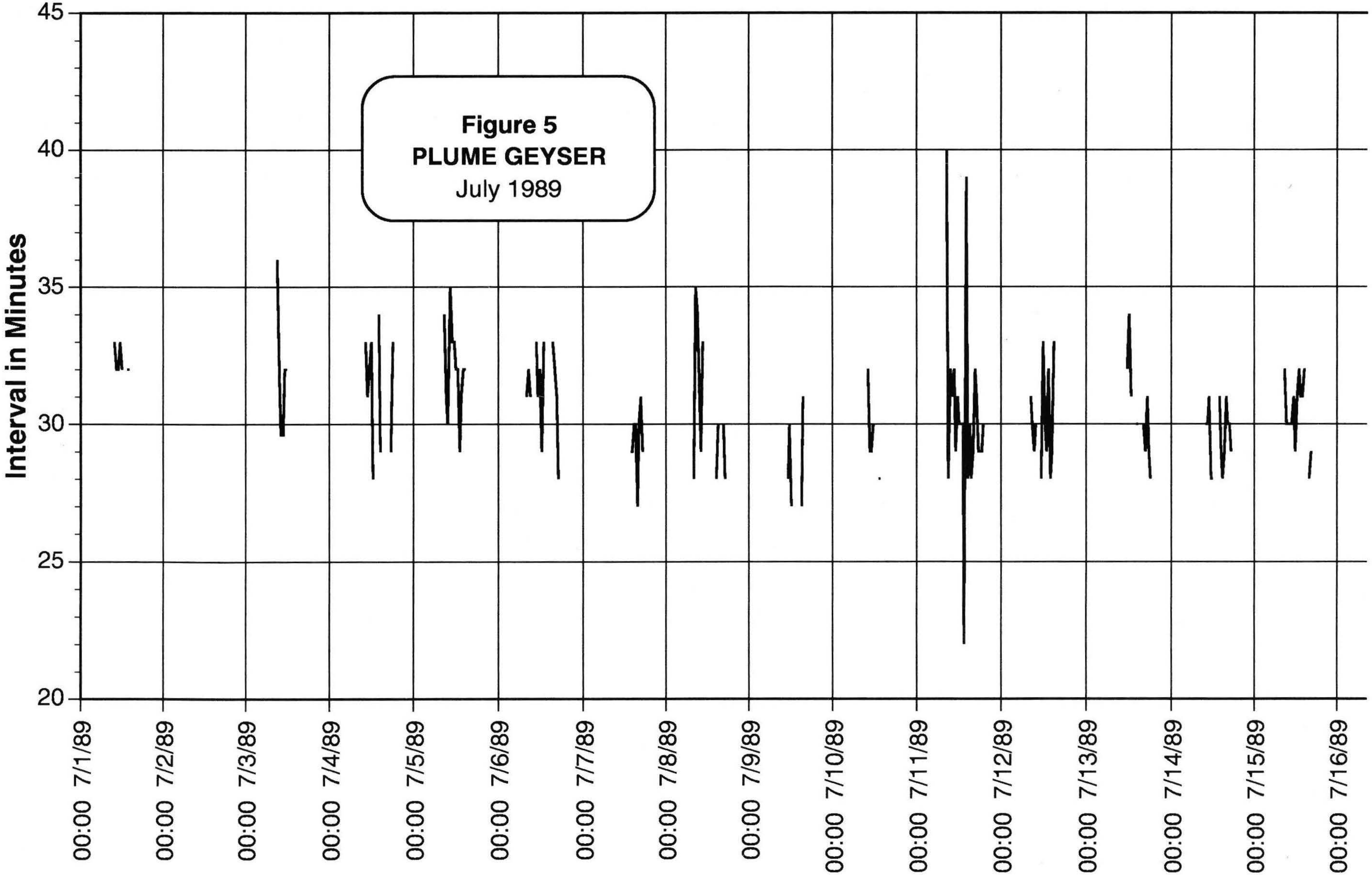
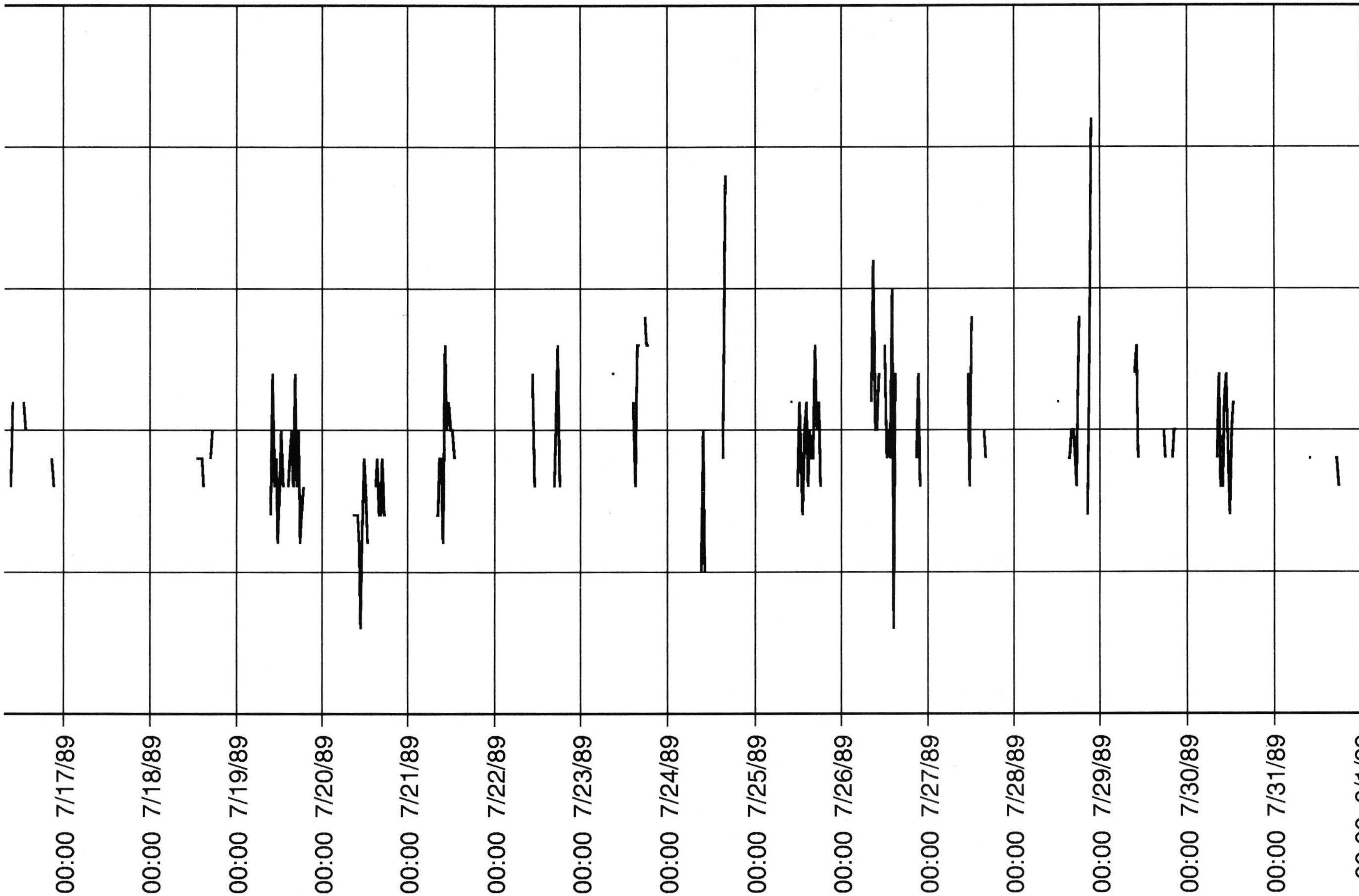


Figure 5
PLUME GEYSER
July 1989


00:00 7/17/89
00:00 7/18/89
00:00 7/19/89
00:00 7/20/89
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00:00 7/22/89
00:00 7/23/89
00:00 7/24/89
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00:00 7/26/89
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00:00 8/1/89

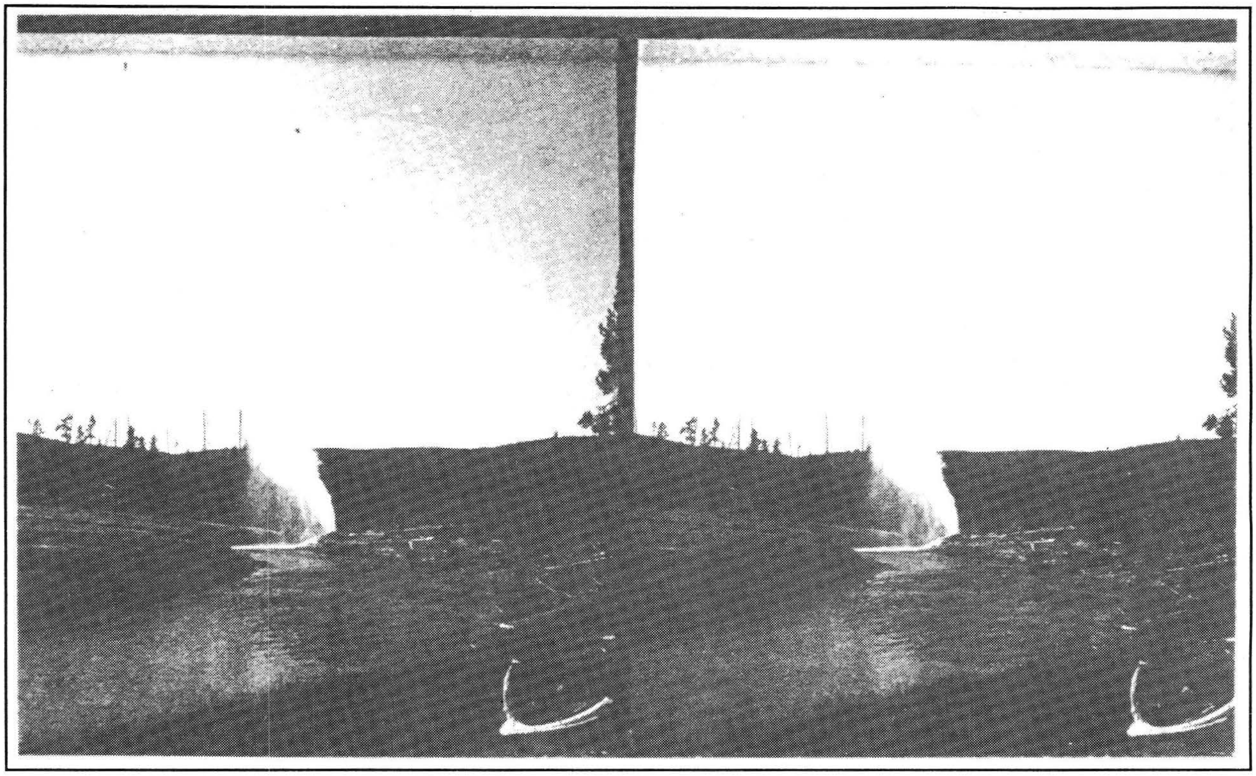

Figure 1. Mortar Geyser in solo eruption, playing water at angle into Firehole River. Stereopticon from Montana State Historical Society, file photo # H-4039. Date unknown (c.1890(?))

WHY MORTAR IS FAN: AN ANALYSIS OF THE HISTORY OF THE FAN AND MORTAR GEYSER COMPLEX

by

Paul Strasser

ABSTRACT. Most geyser aficionados have considered the historic record of the section of the Upper Geyser Basin extending from Fan Geyser to Riverside Geyser as essentially complete and understood. Specific records of geyser activity in this area extend back to the Washburn-Langford-Doane expedition of 1870; members of this expedition named a feature "Fan Geyser" and reported one of its displays.

Although published accounts of Yellowstone's history acknowledge a certain level of confusion concerning the identities of Mortar Geyser and Riverside Geyser, it is generally assumed that the identities of the geysers and hot springs were sorted out in a reasonable manner - that Fan is Fan and Mortar is Mortar.

This assumption is incorrect.

When the historic record is analyzed

it becomes apparent that this area has a very confused and misunderstood history. In undertaking this analysis I compared each historical entry with what was said by the author's contemporaries and also with what was known at the time of the entry. I then compared each entry with the area's more recent thermal activity.

Among the conclusions are:
- The original "Fan" is the feature now known as Mortar;
- Fan rarely erupted during the late 19th century in the spectacular manner of its modern eruptions;
- It is likely that neither Fan nor Spiteful Geyser existed in their present form at the time of the creation of the National Park in 1872;
- Riverside Geyser has at various times been called Fan, Mortar, Riverside, and Well;
- Nearly every name in the area was given, at one time or another, to every other feature.

The result is a rewriting of the thermal history of the Fan and Mortar complex. Its current eruption behavior is the most spectacular in recorded history. Further, it is likely that the thermal activity here will manifest itself in even more spectacular fashion in the future.

Introduction.

In my report on Fan and Mortar in the first edition of the Transactions [Strasser, 1989] I used a quote from George Marler [Marler, 1973], attributed to the Norton expedition of 1873, as an example of the early confusion regarding the identities of various geysers in the Fan and Mortar area. Although Norton believed he was observing Fan, there is little doubt the eruption he observed was Mortar:

"... [We] arrived just in time to witness the Fan Geyser getting up steam for an eruption. When we arrived we could hear a sound as of throwing cordwood into a furnace. This continued several seconds, ceased and was followed by great quantities of steam from the smoke-stack; then the two valves opened, shooting out swift, hissing jets of steam. The next moment there would be an unearthly roar from the double crater, both would fill, and from each aperture a column of water two feet in diameter shoot upwards over eighty feet - one ascending nearly vertical, and the other at an angle of about forty-five degrees, thus forming the 'fan'. The eruption would continue from two to four minutes, then the flow cease for eight or ten seconds, and then the entire movement would be repeated. These repetitions continued twenty or twenty-five minutes and then ceased altogether..."

At the time, it did not occur to me that Norton was not alone, that the confusion was pervasive in the early decades of Yellowstone National Park. Upon release of [Whittlesey, 1988] I closely examined the information about Fan, Mortar, Spiteful, and Riverside Geysers. It was with some surprise that I discovered that many of the entries made little sense when compared both with the contemporary accounts of the day and with modern activity in the area. This analysis of Whittlesey's report resulted in a rereading of the entire historical record a more objective, dispassionate eye.

This paper is structured as follows:
- A discussion of the area's recent appearance and activity;
- A review of pertinent historical records of the area;
- A summary table of the historical records;
- A chronology of the changes in behavior within the group, based on the historical record, including discussions of a

few of the more unusual or provocative assertions;

- Speculation on possible future changes in behavior, based on the above.

Riverside Geyser and the Fan & Mortar complex: Current Appearance and Behavior.

Before an analysis of the historical record is undertaken it is necessary to briefly describe their current appearance and eruptive behavior. The area in question is in the Upper Geyser Basin and extends from Riverside Geyser on the south to Spiteful Geyser to the north, a total distance of approximately 630 feet (Figure 2.) All of the thermal features in question are located on the eastern bank of the Firehole River.

Riverside Geyser is located on a north-to-northwest trending curve in the Firehole River. Its name is very appropriate; its sinter formation rises directly from the eastern edge of the river. The cone has two vents. The northern is cavernous and easily visible from the opposite side of the river (the current trail configuration permits viewers to observe Riverside only from the river's western bank). This is not the main vent, which is the southern of the two vents and is situated on the flat section of the cone.

The following is a description of the behavior of Riverside's eruptions during at least the past quarter century: In the hours preceding the eruption the main vent slowly filled with water, finally resulting in a period of overflow. Following this overflow period, which lasted from one to two hours, varying from year to year, the eruption commenced.

Just prior to the start of the eruption the northern vent may have splashed water voluminously, often confusing new visitors who frequently believed that the eruption proper emanated from this source. The overflow abruptly increased, the main vent splashed, and a water column arced up and away from the vent.

The water column was oblique, erupting to the south-southwest at an angle of approximately 70°; most of the erupted water landed in the Firehole River. Maximum height of approximately 75 feet was attained quickly. The eruption diminished in force slowly over the next ten minutes. Most eruptions lasted about 20 minutes [Wegel 1978], ending with a weak steam phase.

In any year the mean interval was remarkably constant. In this sense it is one of the Park's most regular geysers. In recent years the average interval has ranged from 9 hours 17 minutes in 1940 [Hutchinson 1978] to approximately 7 hours 10 minutes by 1992.

Riverside's intervals are strongly bi-modal. Few, if any, eruptions take place at precisely the average interval. A typical year was 1977, when one peak occurred about 15 minutes before the average and the second peak occurred 15 minutes after the average [Wegel 1978]. As of now no methodology exists that can predict on which peak a particular eruption will begin. In the early 1990's the average interval increased to slightly over 7 hours, due to a greater preponderance of long mode intervals.

Other geysers demonstrate interval bimodality, notably Old Faithful and Flood [Marler 1966, Koenig 1983]. In both of these cases the variance in interval length is directly attributed to the duration of the prior eruption, with longer intervals following eruptions of longer duration. In the case of Riverside no such relationship between duration and interval exists. The cause of the bimodality in Riverside is unknown.

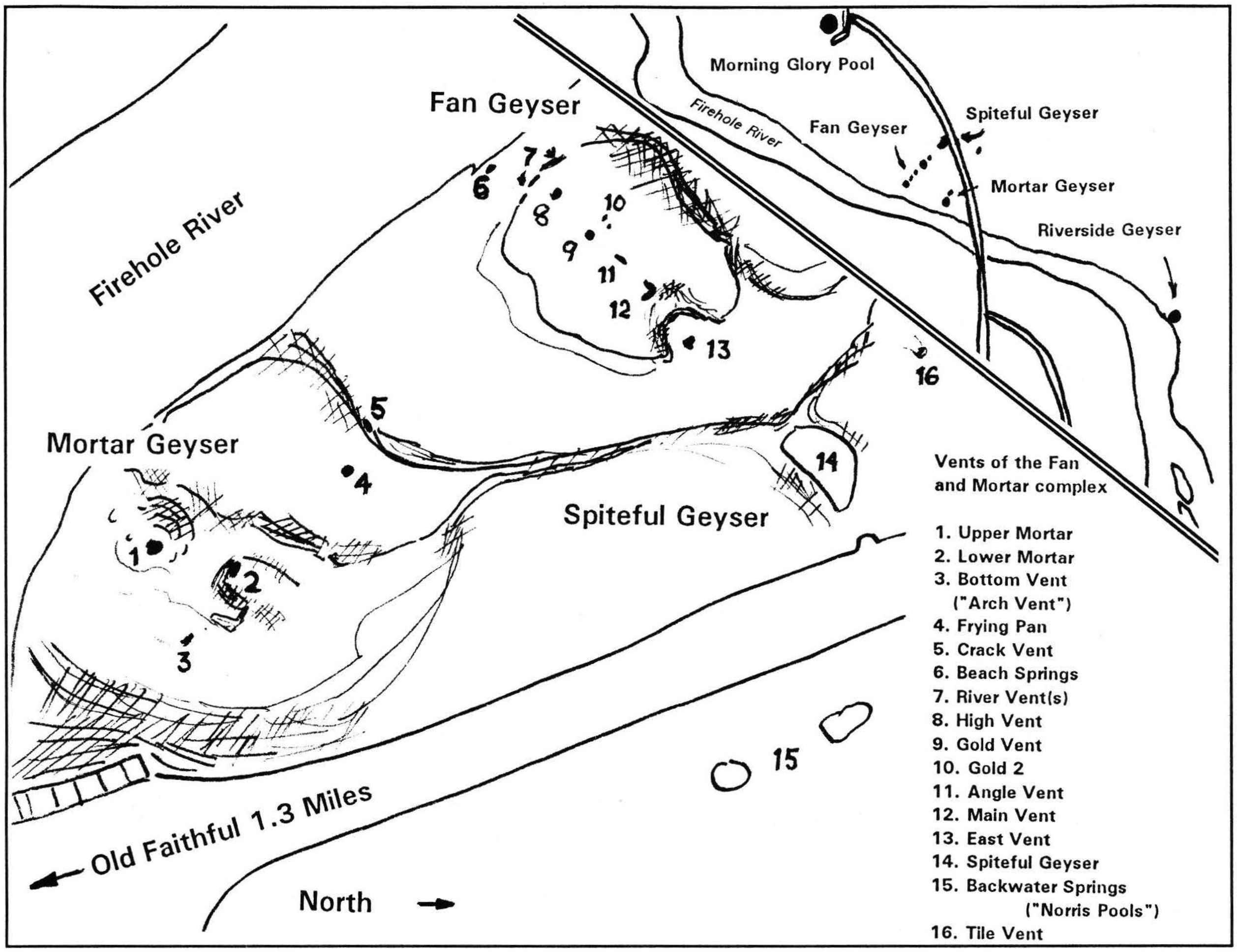

Figure 2. Map of Fan and Mortar Geysers, modified from [Strasser 1989].

There is no evidence that Riverside Geyser is connected with the Fan and Mortar complex. Studies have been done in the past by several geyser gazers; the result of these investigations were conclusions that they are completely independent [See Schwarz, D. in this issue for additional data]. Some evidence has emerged since 1987 that Riverside might be indirectly connected with the Grotto-Giant complex [Bryan 1989].

Riverside is a very regular geyser whose principal claim to fame is the beauty of its eruptions. In terms of analysis by geyser enthusiasts it is somewhat ignored other than by John Wegel, whose dedication to Riverside was regarded with fascination by many in Yellowstone. Riverside is so reliable and unchanging a feature that some observers have nicknamed it "Xerox Geyser" because one eruption seems like a duplicate of every other.

The Fan and Mortar complex (Figure 2). For a complete description of Fan and Mortar please refer to [Strasser 1989]. Behavior noted herein was that which was commonly observed between 1978 and 1992. The names of the individual vents are of recent origin and are in common usage. A discussion of their history is found in [Strasser 1989].

Fan Geyser erupts from several vents along a fissure in the sinter. From west to east, these vents are:

River Vent. Five separate small slits on the side of the Fan terrace. The northernmost is the most significant, about 2 feet long. Minor eruptions were steam mingled with water ejected downward. Major eruptions were heavy steam and spray ejected horizontally.

High Vent. Directly above the River Vent on a small sinter hillock. Minor eruptions played water to 3-4 feet. Major eruptions played water to 10-15 feet.

Gold Vent. Surrounded by Gold-hued sinter, about 4 feet east of High Vent. Minor eruptions were water 4-5 feet. Major eruptions played water to 15-20 feet.

Gold 2. Three small openings 18 inches north of Gold. Minor eruptions played water to 6-12 inches. Major eruptions played water to 5 feet.

Angle Vent. An east-west slit about 2-3 feet east of Gold. Minor eruptions played steeply angled spray to the east, about 2-3 feet high. Major eruptions played water vertically to 10-20 feet.

Main Vent. A ragged V-shaped hole in the sinter 3 ft. east of Angle. Minor eruptions played infrequent drops above ground level. Major eruptions played several different water columns: vertical to 80 feet; north to 40 feet; west to 30 feet, east at angle of 40-70° to a height of 90-140 feet

East Vent. A 12 inch hole at the front of a small alcove on the eastern edge of Fan's terrace. No minor play. Major eruptions ejected water to the east at a very oblique angle to a height of 40-50 feet; also some vertical play to 20 ft.

Sometime in October 1992 a portion of the fissure extending from the west side of the East Vent, but within the East Vent's alcove, blew out. The resulting hole took part in at least one major eruption in a forceful manner. Its water column was sheetlike in appearance and at least 20 feet high [Stephens and Day, 1993], giving the east vent a more vertical appearance, akin to Daisy.

Tile Vent. Buried under the roadway. It erupted during major eruptions of Fan and Mortar from a small culvert 15 feet north of Spiteful. Eruptions consisted of spray and steam horizontally to 3 feet.

Mortar Geyser is a cone south of Fan on the bank of the Firehole River. Mortar Geyser consists of three separate vents, only two of which are known historically:

Upper Mortar is the southernmost, at the top of the cone. Minor eruptions played occasional heavy random splashes. Major eruptions played water, primarily vertically, to 40-90 feet, changing to powerful steam.

Lower Mortar is just north of Upper, in a saddle on the cone's northern side. Minor eruptions consisted of low, heavy splashing with droplets occasionally ejected to 10 feet from the vent. Major eruptions were highly variable, often playing water obliquely to the south to a height of 30 feet changing to heavy, periodic steam; Other eruptions were nearly vertical with maximum height of nearly 40 feet. In other eruptions Lower Mortar hardly erupted.

Bottom Vent was first noted by Koenig in 1983 [Strasser 1989] . It is located about 6 feet east of Lower Mortar, where the outer slope of the cone meets the roadway embankment. The Bottom Vent consists of two small openings in crumbling sinter blocks that merge only a few inches below ground level; the rapid erosion of the sinter will undoubtedly result in a single orifice in a few years. Its minor eruptions consisted of infrequent droplets to 1 to 2 feet, which occurred when voluminous minor splashes in Lower Mortar, but not necessarily simultaneously with them. In 1988 it was first observed to erupt during a major eruption of Fan and Mortar. Its activity consisted of a steady stream of water to 8 feet.

Fan and Mortar are intimately connected underground. Both minor and major activity are so intertwined that they are frequently, though inaccurately, considered a single geyser [Strasser 1989].

Since 1979 all major eruptions of Fan and Mortar were concerted. They are spectacular, with water emanating at many different angles to many different heights. The activity surges and wanes simultaneously. During the hour long eruptions the complex will stop after 9 to 17 minutes and then re-start; the activity resumes in a less powerful manner. These changes occur simultaneously in both geysers.

Mortar was a relatively frequent solo performer in the mid-1970's; its eruptions were often associated with activity in Spiteful [Martinez 1980].

The minor activity of both geysers is also intimately connected [Strasser 1982, 1989]. There is distinct cyclical behavior that repeats itself approximately every hour. For a full discussion of the minor cycles and their relationships to major eruptions, see [Strasser 1989].

Spiteful Geyser. Spiteful is a 15 ft. long, ragged crater to the east of Fan and on the same fissure as Fan. The crater emerges through solid, well-laminated sinter deposits. Spiteful's eruptions have been rare recently (2 eruptions known since 1977). In 1973-1977 it erupted in series separated by several hours-days of inactivity, its eruptions consisting of splashes to 15 ft. Along its eastern edge are cracked sinter blocks. Along these cracks several spouters have been recorded in the last two decades.

Other less significant features are now discussed.

The "Beach Springs" are a collection of seeps at the base of Fan's mound directly below the River Vent. The "Frying Pan" is a foot-wide pebble-filled basin located between Mortar and Fan. "Crack Spring" is a slit on the side of Mortar's northern embankment directly below the Frying Pan. "Norris Pools" are two pits on the eastern side of the asphalt trail; the southern Norris Pool was named Backwater Spring by Martinez in the mid 1970's [Martinez 1980] because its water level would drop following an eruption of Spiteful Geyser.

RIVERSIDE, FAN AND MORTAR: HISTORICAL REVIEW

This section will analyze available historic descriptions of this area of the Upper Geyser Basin. Each separate entry is assigned a number, which will be used as reference guides within the body of this paper and in the bibliography. Each entry consists of the year and author, followed by the observer's notations. When in quotations it is verbatim; unquoted entries are primarily data or Whittlesey's [1988] observations. My comments follow each entry.

The entries will be listed chronologically, by year.

1. 1870 - Lieutenant Gustavus C. Doane, describing "Fan Geyser": "Still farther below [Grotto] and on the opposite bank of the stream are two small craters, with apertures two feet each in diameter; these two are connected, one throwing steam and the other, water, and also alternating with *another small crater below.* First the stream would rush from the upper crater roaring violently, then this would suddenly cease to be followed by a fan like jet of water rising from the lower crater to the height of over 40 feet, often playing for perhaps two minutes; then this would suddenly stop

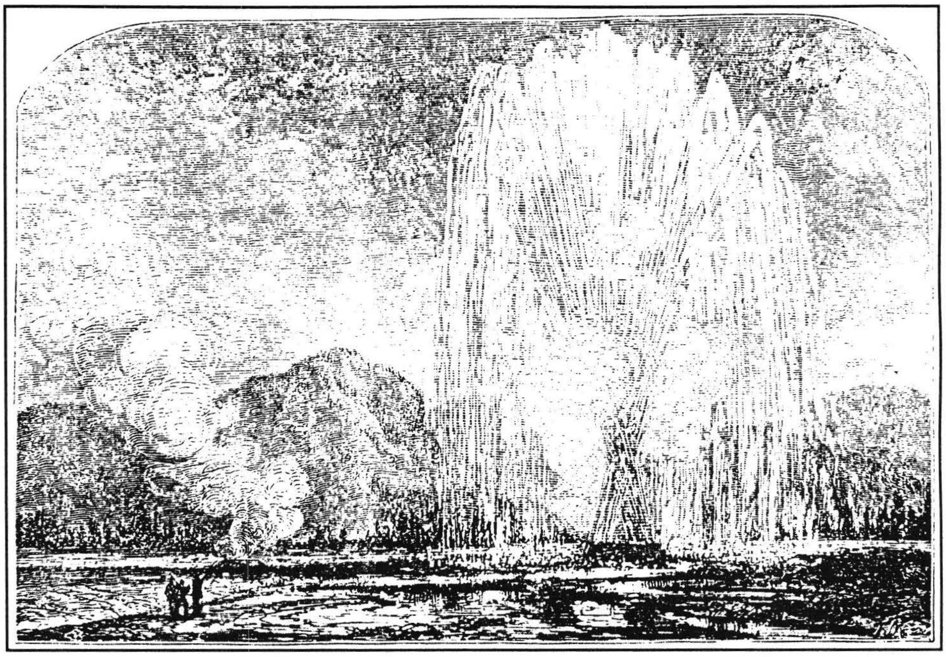

Figure 3. "Fan Geyser" woodcut, from Langford's second Scribner's article. Taken from [Bonney and Bonney, 1970], p. 354.

the fact that it discharged two streams from its vent which spread out very much like a Fan."

4. 1870 - Henry Washburn: "No. 5. Fan Tail, irregular shape, throwing a double stream 60 feet high."

flowing and the steam would rush forth again for a time. Occasionally the small crater threw a transverse stream, sometimes alternating with either of the others and thus they played on for hours, after which all would subside to a gentle boiling."[emphasis added]

(This entry on "Fan Geyser" will be discussed in conjunction with the following three entries; all of which were made during the 1870 Washburn-Langford-Doane expedition.)

2. 1870 - Nathaniel Pitt Langford: "Fan has a distorted pipe from which are projected two radiating sheets of water to the height of sixty feet, resembling a feather fan. Forty feet from this geyser is a vent connected with it, two feet in diameter, which, during the eruption expels with loud reports dense volumes of vapor to the height of fifty feet."

3. 1870 - Walter Trumbull: "Crossing the river, we named the "Fantail" geyser from

COMMENTS. The geyser described by these observers was given two different names by the same expedition: Fan and Fantail (alternately, Fan Tail).

Of the four descriptions from 1870, Doane's is the most specifically descriptive. Doane said "Fan" consists of two vents, an upper and lower. His "upper" vent erupted steam vertically while his "lower" vent erupted at an angle to a height of 40 feet. (Langford stated a maximum height of 60 feet, both low by modern standards.) This description is reminiscent of the modern Mortar Geyser.

In addition, Doane described a third small crater, located "below" the first two. Note that Doane used the word "below" earlier in this entry to signify "downstream". According to Doane this small crater "threw a transverse stream".

In contrast, Langford described Fan as a "distorted pipe from which are projected two radiating sheets of water..." Note the plural form "are". If Langford was describing a single vent it makes no sense, even though the word "pipe" is singular. Langford also did not mention a direction to a third vent. Only Doane did, and it is specifically "below," that is, downstream. However, he also states that it was erupting a "transverse" stream of water. "Transverse" has two distinct meanings: *athwart*, that is, side to side; alternately, it also means *across*. If one is to argue that this was the source of the "criss-crossing" streams his directions do not make much sense, since the two larger vents are not taking part in the criss-crossing play.

Trumbull mentioned two streams from a single vent, while Washburn simply mentions a double stream.

These cannot all be correct.

At this point it is important for modern observers to consider the viewing opportunities available to the early explorers. There were no artificial constraints to mobility, such as trails or boardwalks. It is likely that most of the early narrations in this report (those from the 1870's up to the mid-1880's, at least) were written by people watching the geyser from the west side of the Firehole.

It is reasonable to give credence to the most objectively detailed descriptions from any era. Doane's might be accepted as closest to what this expedition observed. Since there is no vent downstream from the modern Fan that erupts in concert with it - the closest recorded geyser in that direction is East Sentinel, over 600 feet to the northwest - a reasonable explanation is that all these authors observed an eruption of the modern Mortar, with only minor activity from the area of the modern Fan. Mortar's modern behavior closely resembles Doane's description of the eruption observed in 1870. In addition, the modern Fan Geyser is located downstream from Mortar and it erupts along with Mortar, which also matches Doane's description.

Doanes' description of the modern Fan as merely "another small crater" does not correspond to its modern activity or appearance. This will be discussed later.

Whittlesey [p. 500] states that Langford described "... two radiating sheets that crossed each other..." The "criss-crossing" stream description is not in his diary description, nor does it appear in any of the other Washburn expedition's descriptions. It does, however, appear in a woodcut illustration for Langford's Scribner's Monthly article [Fig 3].

Where did the idea of criss-crossing streams come from? None of the 1870 expedition members wrote anything about such a remarkable eruption characteristic (except, perhaps, Doane's "transverse" streams from the "crater below".) Instead, there are specific references to two radiating sheets of water and two columns erupting at different angles.

Langford's measurements make one believe he was describing Mortar's vents, which are closer to this size than any of Fan's vents.

It is possible that Langford and Trumbull may have been describing only the Main Vent of Fan, which erupts water in multiple directions. Doane, however, specifically cites a high vent erupting water vertically and a lower vent erupting at an angle. Trumbull and Langford don't mention any of the other vents, which is also contradictory to Doane's account.

Doane's discussion of an eruption duration of hours is difficult to reconcile with any other account from any era.

Riverside Geyser was not observed in 1870. Also, no mention was made of the crater of Spiteful.

It should be noted that George Marler [Marler, 1973, p.70] also believed that Doane described Mortar, but he went no further with the implications of that speculation.

Some readers might believe that Doane might have been describing modern

Mortar while Washburn, Trumbull and Langford described modern Fan. It is difficult for me to accept this since it would mean that Doane ignored Fan while the others ignored Mortar, or they saw two different eruptions and didn't compare notes.

5. 1871 - Captain J. W. Barlow, describing Fan: "... we reach three geysers erupting in concert. When in full action the display from them is very fine. The water spread out in the shape of a fan, in consequence of which they have been named the 'Fan' geysers."

COMMENTS. This is reminiscent of the 1870 accounts, especially the discussion of "three geysers", perhaps Upper and Lower Mortar, and an unnamed vent of modern Fan. Some may note that Barlow witnessed an eruption of this geyser in 1871, although Hayden (#7) specifically stated that Fan was not seen by his party in 1871. The Barlow party was independent of the Hayden expedition; they were both in the geyser basins at the same time, but there was apparently some competition between the two parties.

Could Barlow's account simply be a description of the modern Fan Geyser, rather than Mortar? It is unlikely. Barlow used the plural "Fan Geysers"; a possible reason is the distance between the modern Mortar and Fan. If Barlow had seen the modern Fan and Mortar erupt in concert he would have seen far more than three separate vents in action.

6. 1871 - Barlow, on "Riverside": "One hundred yards farther up the east side of the stream is found a double geyser. A stream from one of its orifices plays to the height of eighty or ninety feet, emitting large volumes of steam. From the formation of its crater it was named the 'Well' geyser."

COMMENTS. This is considered one of the first descriptions of Riverside, although there is no mention of Riverside's arcing water column. Also, Riverside is closer to 200 yards from Fan than Barlow's 100 yards. Nevertheless, this distance precludes the notion that Barlow might be discussing modern Mortar, which is in the immediate vicinity of modern Fan.

7. 1871 - F.V. Hayden: "The Fan Geyser consists of a group of five geysers, which play at one time, throwing the water in every direction... I did not see Fan in action in 1871, nor were any notes concerning it obtained by the other members of the party."

COMMENTS. Hayden specifically stated that his party did not observe an eruption of Fan in 1871. This description is possibly a combination of second-hand information from the reports of the Washburn expedition of 1870 plus whatever inferences he could make from the appearance of an area where major eruptions were known to take place. There is no discussion of the location or appearance of the "five geysers". His map of 1871, discussed in #8, does not clarify what he saw, since Hayden said that no notes concerning it were obtained by his party.

I believe Hayden's 1871 5th annual report contains several errors. His map (fig. 4) shows "Fan Geyser" at the location of Mortar, although, by the standards of the day, this was accurate. 'S.Gs' (small geysers) is notated near the location of Spiteful Geyser - one is not certain what he meant by the plural. Spiteful's crater is not present. It is possible the 'S.Gs' refers to the Norris Pools, which were considered "old craters" in 1886 (see Weed #36, 1886). The location of the modern Fan Geyser is noted only by a single small, unmarked circle, approximately at the location of the

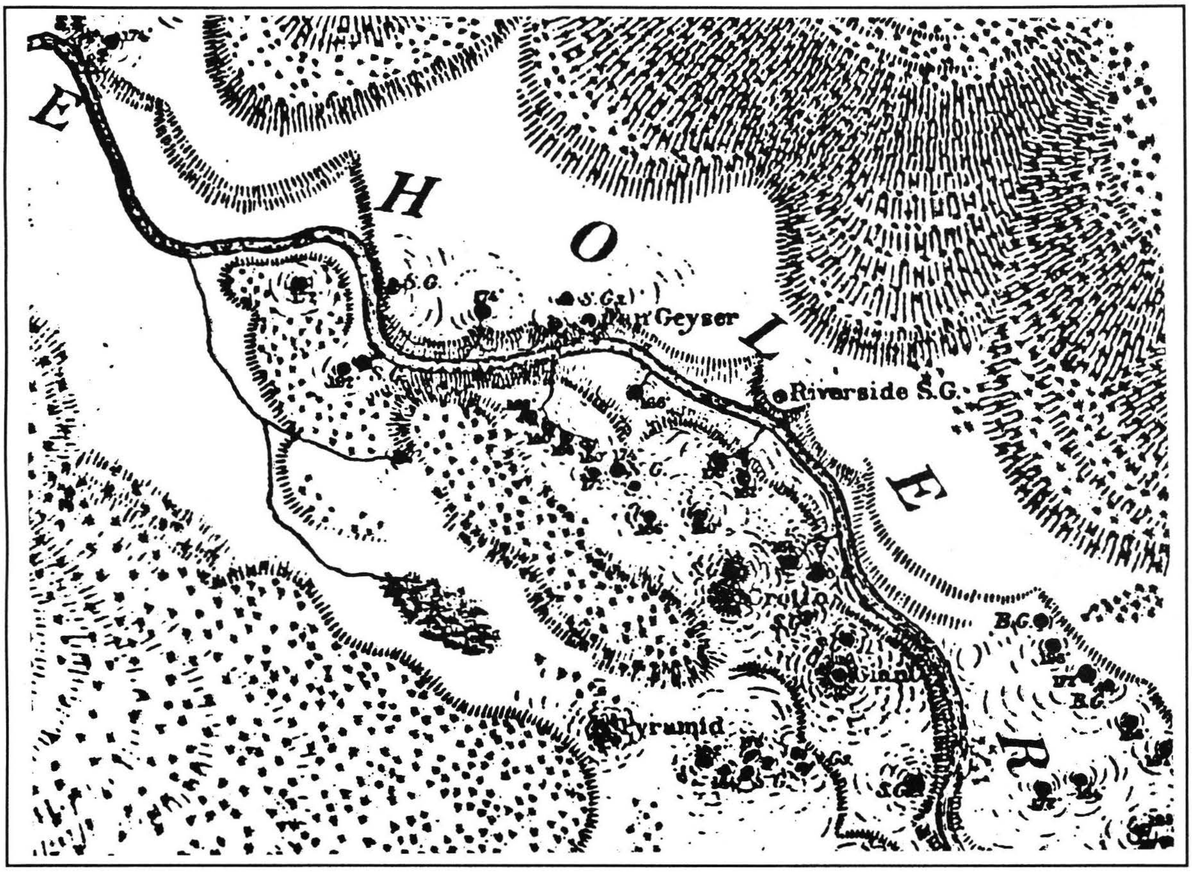

Figure 4. Section of map of the Upper Geyser Basin, including the area of "Riverside," "Fan," and several "S.Gs" (small geysers.) From Hayden 1872.

High Vent. Riverside Geyser is marked and named at the correct location of the modern Riverside (although it is also noted as a "small geyser"!)

A contradictory woodcut on p. 113 (fig. 5) entitled, "Riverside Geyser, Upper Geyser Basin" somewhat resembles the modern Mortar Geyser. Note the vertical eruption, as opposed to famed oblique jet of Riverside. A photograph (figure 6) from that era is clearly reminiscent of the woodcut, although taken at least one decade later.

Whittlesey (p. 1508) states that he is of the opinion that Hayden confused the two, and named the modern Mortar Geyser as Riverside. I disagree. Since the map location and the woodcut are contradictory, Whittlesey must therefore make the claim that the accurate map location is incorrect.

This is unlikely, although debatable. If Whittlesey is correct, then Hayden's report must have named the same feature both Fan and Riverside.

Woodcuts from that era were notoriously fanciful (see pp. 124 and 125 in Hayden, vol. 5 for other examples). The map in question was based on "field notes and sketches of A. Shonborn;" the position of every other spring and geyser of note on this map is shown with reasonable accuracy.

(A. Shonborn, upon whose field

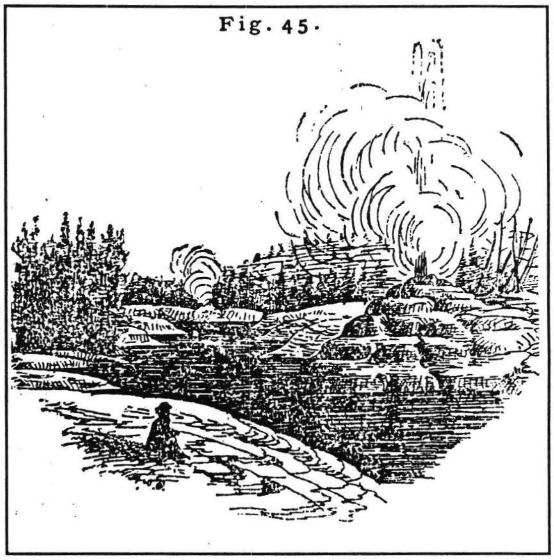

Figure 5. "Riverside Geyser." The formation is more reminiscent of Mortar Geyser. Woodcut from Hayden 1872, p. 113.

notes the map was based, did not take part in the map's creation. He committed suicide after the Hayden expedition. The map was drawn by another, E. Hergesheimer. One wonders what was lost in the translation. [Whittlesey 1991, personal communication])

If, as Whittlesey asserts, the map is incorrect, then it is one of the more astonishingly accurate mistakes in Yellowstone's history. At the place marked "Riverside" is a large geyser that erupts over the river's waters.

In addition, as discussed above, "Fan Geyser" on the map is in the "correct" position - that is, the position of the present Mortar Geyser, since most, if not all, of these early observers felt that the modern Mortar was Fan.

Nevertheless, confusion was created. Apparently, quite a few people looked at the woodcut instead of the map. For the next several years the modern Mortar was called "Riverside" by many observers, which added to the general confusion. Since Hayden was responsible for this report, the blame can be put on his shoulders. We thus had a situation where one feature had two names.

8. 1871 - F.V. Hayden: "In the case of the Fan Geyser, the main jet, instead of being vertical or nearly so, escapes at an angle of about 60° with the horizon, and the falling water has hollowed out the disintegrating sinter quite deeply for a space of about 115 feet from the vent."

COMMENTS. This is a very odd entry. Hayden's specifically stated (#7) that he did not see an eruption of "Fan" in 1871, nor were any notes on its activity taken by members of his party. What is the factual basis of this description?

The discussion of an oblique angle of the main jet can describe the present Fan, but also describes Lower Mortar. However, the description of falling water hollowing out disintegrating sinter "quite deeply" to 115 feet away from the vent does not describe Fan at all. Both of Fan's principle vents, the Main and East, aim their water at the slope of sinter on which Spiteful sits, a slope that is still in place.

Does Hayden's description fit the modern Mortar? The sinter north of lower Mortar - the direction that its oblique spray would land - might possibly be thought of as "hollowed", if one accepts the abrupt dropoff to the west of Spiteful as a "hollowed out" area, but this is a stretch. Another photograph that predates the road embankment (figure 7) shows no indication of any hollowing out of sinter in the complex.

9. 1871 - F.V. Hayden: "When Fan Geyser was in full eruption, its partner, 30 yards off, was steaming gently. Fan stopped for a moment, and its partner fairly roared with a rush of steam, which stopped as soon as Fan opened again. Yet they are not in full sympathy; for, on another occasion, Fan was steaming or boiling very gently, while its partner was boiling furiously, and throwing water 5 or 10 feet high, but with quiet intervals, during which Fan showed no access of force. (Under some circumstances one is inclined to question whether Fan's partner may not possibly serve as the vent for two distinct geyser tubes.)"

COMMENTS. This commentary is from a general discussion by Hayden of interconnections among geysers in Yellowstone rather than the section specifically addressing "Fan Geyser." It is unfortunate that Hayden did not describe more fully the nature of the water columns he observed. Also, there is no mention of the "five geysers" he discussed in his 1871 entry (#7).

Hayden's "other occasion" in some ways resembles the modern minor activity of the complex, during which Mortar (Hayden's "Fan"?) will boil or steam very gently while the modern Fan (Hayden's "partner"?) boils and throws water 5 to 10 feet high. What is confounding is that, with a stretch of imagination, the opposite is also possible. At differing times during the minor cyclical activity in the complex, Lower Mortar is churning water while Fan is quiet, and later some of Fan's vents are playing water while Lower Mortar is much quieter.

Also, Hayden's description of the major activity of these two features - *alternate* waxing and waning - does not resemble modern eruptions, in which the activity of the two coincide. There are several other historical entries that mention similar anomalous (to us) behavior.

10. 1872 - Harry Norton: "... [We] arrived just in time to witness the Fan Geyser getting up steam for an eruption. When we arrived we could hear a sound as of throwing cordwood into a furnace. This continued several seconds, ceased and was followed by great quantities of steam from the smoke-stack; then the two valves opened, shooting out swift, hissing jets of steam. The next moment there would be an unearthly roar from the double crater, both would fill, and from each aperture a column of water two feet in diameter shoot upwards over eighty feet - one ascending nearly vertical, and the other at an angle of about forty-five degrees, thus forming the 'fan'. The eruption would continue from two to four minutes, then the flow cease for eight or ten seconds, and then the entire movement would be repeated. These repetitions continued twenty or twenty-five minutes and then ceased altogether..."

(Continuing, later in the same book:) "... the Fan Geyser ...is the last one of prominence on this side of the river. The entire formation is flat, and about one hundred feet in length. It has five distinct craters, and when getting ready for a display much resembles the workings of a giant stationary-engine. Its eruptions occur four or five times in twenty-four hours, each one continuing from eighteen to thirty minutes. The water from the largest crater is thrown to the vertical height of one hundred feet."

COMMENTS. The first portion is a satisfactory description of an eruption of Mortar. It is understandable that Norton thought he was seeing "Fan", since this is what any available map or written report would indicate. It is important to note that he did not describe any activity from the present "Fan", even the steam activity seen by Doane.

The second section is less a narrative than a general description and is less persuasive than the first. The entire formation is certainly not flat, what with the large cone of Mortar and the formation of Fan (commonly described as containing cones) There is no indication of the source for the listed frequency of four or five per in 24 hours, nor does the actual eruption he described coincide in height or duration with this more general description.

11. 1873 - Rev. E. J. Stanley: "This is said to be one of the prettiest spouters in the region... its machinery is surely the most complicated of any, and, having five distinct orifices, it sends up as many jets of water and steam, sometimes reaching an altitude of a hundred feet, the jets ascending and descending in such a manner as to resemble the outlines of a feather fan. It spreads itself three or four times a day..."

COMMENTS. Since Rev. Stanley most likely did not see an eruption ("this is said") we should ask: what is the source of his description? Hayden in 1871 (#8) and Norton (#10, continuance) described "five geysers" or "five distinct orifices", a description absent from Hayden's 1872 report (#9) and Norton's specific description of the eruption he witnessed. Also, there is no evidence of any report up to this time of an eruption attaining a height of 100 feet, nor that it erupted four times a day.

12. 1873 - Theodore Comstock, describing an eruption of "Fan": "This began at 2:43 p.m., almost precisely at the same moment when the eruption began in the Riverside. Gradually increasing in intensity, it was throwing a large column of water at 2:49 p.m., which continued, but gradually diminishing, until 2:54 p.m. at which time it almost ceased, sputtering occasionally, however, until 2:56 p.m." This record shows a remarkable similarity or sympathy between Fan and the [Mortar]."

COMMENTS. Comstock described only a single column of water, which is more reminiscent of some Mortar eruptions than of Fan, with its numerous water columns. His discussion of Riverside gave no mention of its behavior.

The description of the eruption does not match modern behavior. The modern Fan does not slowly increase in force over a span of six minutes.

Since observers likely thought that "Fan" was the modern Mortar, could Comstock have been describing an unusual dual eruption of the modern Mortar and Riverside? Even though there is no evidence of a subterranean connection, they can erupt concurrently.

Could the sentence beginning "Gradually increasing..." be describing the modern Riverside? The duration of about 13 minutes for the eruption is in keeping with Riverside's historical and current behavior.

If he was seeing the modern Fan and Mortar, then Fan's eruptions have changed dramatically since 1873. This is, as will be discussed later, a distinct possibility.

13. 1875 - Captain W.E. Strong: "The Fan group is composed of three geysers in fan shape, which throw columns about eight inches in diameter to the height of fifty to sixty feet, the jets crossing each other and giving a very beautiful appearance. They play several times each day, but at no regular periods. Its eruptions produce a loud, rushing noise, with water and steam alternately."

14. 1875 - Strong, concerning "Riverside": "Riverside" played irregularly and was rarely seen, and it threw a small column about eight inches in diameter to the height of fifty to sixty feet.

COMMENTS. Whittlesey (p. 1509) is of the opinion that Strong was describing the present Mortar in (#14). I agree. I also believe that his "Fan" description (#13) is also primarily the present Mortar. Both entries use the same measurements (columns eight inches in diameter to a height of fifty to sixty feet), and #13's description of alternating water and steam is reminiscent of Mortar. The sole concern is the number of vents (3) in #14. Now, by this description, Fan now has three vents, all of which cross each other! It seems likely that many observers of the day considered everything in the Fan and Mortar complex as "Fan Geyser."

Readers might be alarmed at the contention that Strong gave the same name to two geysers. Recall Hayden's similar error in his 1871 report.

Strong never stated that he witnessed an eruption of "Fan" geyser. His use of the present tense in #13 is more commonly used by people describing a geyser's known tendencies rather than to comment on what they witnessed, when the past tense is usually used.

It is possible that he got his description of "Fan" from an observer who was familiar with modern Mortar and called it by the Washburn-Doane name; in the same context, Strong likely obtained his description of "Riverside" from someone who thought that the modern Mortar was known by that name. Actually, both sources were describing the same feature.

15. 1876 - M.A. Switzer, describing Riverside: "We proceed down the river about 500 yards [from Grand Geyser] and find the Riverside spouting. This is located at the edge of the river. It does not throw water straight up but at such an angle that some of it falls on the other side of the river."

COMMENTS. This was the first description of Riverside that accurately portrayed its water column erupting at an angle over the Firehole River.

Paradoxically, by the standards of his time, he was also somewhat incorrect. There is no evidence, other than Hayden's map and Barlow's description of 1871, that this feature was ever known as "Riverside". At that time this was one of the many names attached to modern Mortar. But, since Mortar was also known as Fan, Fantail, Riverside, (and perhaps Well Spring), such an error is somewhat forgivable. In some respects we have Switzer to thank for emphasizing the move of the very appropriate name "Riverside" to this feature.

One must note that at some point in the next few years Mortar entered a period of time in which its Upper Vent erupted water obliquely into the river. Switzer may have been correct -- this was indeed "Fan", that is, the modern Mortar.

16. 1877 - Thomas Sherman: "There is a rushing sound ahead, and hastening on we find the Fan Geyser in full play. Issuing from a number of small openings close together, it spreads its waters in a graceful semicircle not unlike a huge fan. For many minutes the brilliant sheet of water stood before us, and scarcely had it subsided when we had the good fortune to see the beautiful display of the Riverside Geyser."

COMMENTS. This was the first description that may describe an eruption of a feature similar to the modern "Fan". Sherman described "a number of small openings... spreads its water in a graceful semicircle not unlike a huge fan." Several of Fan's vents, such as the High, Gold and Angle, could be described as a "number of small openings". Also, note that these vents have apparently shrunk in size from "two feet" in Hayden's discussion to just "small vents." It is important to note that the activity of the larger and more powerful Main and East vents, which distract from the appearance of the semicircle, are not mentioned.

Whittlesey mentions that Sherman described Riverside as erupting at an angle of 65 to 70° over the river. Whittlesey continues, "...his statement that it erupted just on the heels of Fan Geyser makes one suspicious that what he saw was present Mortar Geyser."

Again, this is one of a series of entries that likely describe modern Mortar that mention an oblique eruption. These could never be easily dismissed. Several descriptions are so precise as to location and eruption behavior, including the following entry, that at my first reading I began to suspect that the geyser they saw erupting obliquely was indeed modern Mortar. As is shown by the enclosed photographs, this suspicion proved correct.

17. 1878 - A. C. Peale "I saw but one eruption of Fan, which occurred September 11. The following are the notes.

1st Spurt at 12:13 PM; stopped suddenly in 2 min 10 sec.

2nd Spurt at 12:15:40, stopped suddenly at end of 2 min 25 sec.

3rd Spurt at 12:18:35, stopped at end of 25 sec.

4th Spurt at 12:20:30; stopped at end of 2 min 10 sec.

"The intervals of quiet are 30 sec, 30 sec, 1 min 30 sec, after this the steam escaped gently. The 3rd period the height reached was not very great, but on the fourth it was high. None of the spurts was accurately measured. Only one orifice spouted. The one farthest from the river gave off a slight amount of steam but no water, and the "perpetual spouter" steamed during the entire eruption. The column was not perpendicular, but slanted toward the river. The amount of water ejected was slight and was largely broken into spray. The Riverside was quiet during the action."

COMMENTS: This description provides modern readers with our first objective description of the characteristics of an eruption. Readers may believe that the periodic manner of the eruption is somewhat similar to modern observations. However, the intervals and durations noted by Peale differ completely from modern eruptions. Peale's notes are more in keeping with the late, waning stages of modern eruptions.

This was the first report to mention the "perpetual spouter." (The "perpetual spouter" was accurately described and located as a vent on the fissure of the modern Fan by Weed in 1886 (#34)).

Whittlesey (p.1149) is of the opinion that Peale saw Mortar rather than Fan: "His descriptions make it appear that what he saw was Mortar erupting independently of Fan." I am unsure. The only named feature -- the perpetual spouter -- is a vent on Fan's rift, and is noted specifically as such in the mid-1880's. So was he seeing a small solo eruption of Fan? His statement, "The amount of water ejected was slight and broken into spray," does not readily describe either geyser. Again, this might be an example of designating the entire complex as "Fan Geyser"

Peale described two vents, only one of which sprayed water. This sounds like Mortar. He described the water column as "not perpendicular, but slanted toward the river." One might think this is Riverside. However, the rest of the description does not fit Riverside at all.

If it is Mortar, then we are again confronted with a report of a slanted water column. Since the written evidence is beginning to support the idea that Upper Mortar erupted with a more oblique water column in the 1870's a considerable amount of the confusion concerning the identities of Riverside and Mortar becomes more understandable.

Figure 6. "Down the Firehole from the River Bridge", no date. Photograph #4199, Montana State Historical Society. The title is in error, since this photograph was taken from the steep west bank of the river opposite Mortar Geyser, rather than from the bridge, which at the time was located near Riverside Geyser. This is another example of the confusion surrounding the identities of these thermal features.

18. 1878 - Hayden, describing Fan: "There are two craters, the streams from which cross each other. These two craters have orifices of about 2 feet in diameter ... The crater of the geyser is composed of pink geyserite, which rises from the river in a series of rounded masses which are beaded with silica."

COMMENTS. Again the number of vents of "Fan" have changed, from five in 1871, three in 1872, and two in 1878.

I am quite confident that this description is of Mortar. (Marler also believes Hayden was in error, and cites an illustration on p. 192 of Hayden, 12th Annual Report, as also revealing of the error [Marler 1973, p.68]) Those who contend that his 1871 and 1872 entries are of the modern Fan must reconcile the differing number of vents, geyser formation and eruption characteristics. In fact, Hayden's description of the formation so closely resembles that of Mortar that any other conclusion is untenable.

Here is one of the few entries that described criss-crossing streams of water, but it is in the present tense, and is used to describe the eruption behavior of a geyser whose formation is clearly Mortar's. The next entry, which is one of the few that can reasonably be accepted as describing a major eruption of the modern Fan, makes no such mention of such an entrancing aspect of the eruption. Criss-crossing streams from the modern Mortar may seem like historical heresy, but later entries will begin to bear this out.

19. 1878 - W.H. Holmes: "On the opposite side of the river, which here is comparatively quiet and some 40 feet wide, stand two low geyser cones or piles set into the gray domes bank and projecting slightly into the river. The upper one suddenly ceased as I reached the bank and the lower one began to putter, very quickly a splendid fan-shaped jet was thrown into the air and its thousand darted jets trembling from right to left. To the left, and beyond this, within 6 feet a second stream of water of unexampled beauty was projected into the air to the distance of 100 to 200 feet and what was most surprising was that it stood at an angle of 40, another little jet nearer me shooting but at a similar angle towards me. It is quite impossible to describe the wonderful spectacular display that followed or to give any adequate idea of the beauty of the two principal jets or of the restless force with which they were projected upward. For over a minute this eruption continued amid much waving and rolling of steam. Suddenly the effort ceased and the jets sank back while at the same moment the other vent above, which remained quiet while the jets were playing,began to puff again. This had hardly continued a minute when the three jets first were again shot into the air precisely as before. This lasted again for a minute and ceased, the other playing steam meantime. For ten successive times this gorgeous display was repeated... I felt when all was quiet as if I had seen enough for one day."

COMMENTS. To better understand this report let us put ourselves in Holmes' place. We were standing on the western ("opposite" side, to modern observers) of the Firehole River. His "upper one" (modern Upper Mortar) ceased, and Lower Mortar shot those trembling darts to the north - that is, from our vantage, right to left.

(His use of the phrase "thousands darts trembling from right to left" may strike modern observers as somewhat appropriate, although a little flowery. However, Holmes uses nearly the exact same language to describe an eruption of Great Fountain: "... *the cluster of jets breaking from the main columns in dartlike points and trembling into the surrounding pools.*" It is difficult to imagine two geyser eruptions whose appearances are more diametrically different than those of Great Fountain and Fan.)

By this reckoning, the cones described by Holmes are Upper Mortar and Lower Mortar, and not Fan. I shall leave it to the reader to examine the photos from this era and to decide for oneself.

Beyond this display, to our left, Fan erupted at an angle **away** from us to a distance of 100 to 200 feet. There is a small jet erupting to the west, towards us.

The directions make sense, although some parts of the description do not make perfect sense with modern eruptions. Also, the variations in behavior are not in keeping with modern activity, especially the rapid waxing and waning with no diminution in power. This indicates a distinctly different mode of dual eruption and demonstrates that the plumbing system of Fan and Mortar have changed considerably in the intervening century. also, note that Holmes makes no mention of criss-crossing streams.

Nevertheless, this is the first report of an eruption similar to modern play. Remarkably, there are few others.

20. 1879 - Augustin Seguin: "By lucky chance" saw Fan Geyser in eruption, making a "show of its two sprays of water which cross in the form of a fan."

COMMENTS. Seguin's description is reminiscent of Moran's woodcut that accompanied Langford's descriptions of the 1870 expedition. This is a rare example of an individual who specifically stated that he saw criss-crossing streams.

Please note that in modern eruptions there is little, if any, visual evidence of criss-crossing streams in Fan. Some of the smaller water columns from Fan might, from some angles of observation, appear to cross each other, but this is notoriously difficult to see. It is only when Fan is viewed from the north with proper lighting and wind direction that the crossing phenomena is observed. More importantly, it is little more than a footnote, an interesting aside, in the totality of the spectacle of a major eruption. One might contend that the evidence of considerable change in the system's plumbing is so overwhelming that modern Fan might have, at one time, had criss-crossing streams, but the intervening explosions and/or erosion has removed such an interesting spectacle from its retinue of eruption phenomena. However, the evidence that it was modern Mortar that exhibited criss-crossing streams is considerable.

Additional evidence, presented later, attests to Mortar's water landing obliquely to the east, inundating the road in some eruptions between 1938 and 1940. Also, in 1992 observers saw eruptions of Upper Mortar whose water column was angled to the east.

Like the discovery of the "tilted" Mortar (obliquely, over the river) the idea of a "criss-crossed" Mortar also makes many of these early entries much more understandable.

21. 1881 - H. Banard Leckler party: "The Fan Geyser, when in action, is certainly a very pretty sight; the stream, some twenty-four inches wide by ten inches thick, when leaving the orifice, gradually spreads out till it forms the shape the name indicates. The water does not rise perpendicularly, but comes forth at an inclination of thirty degrees, pointing toward the stream, and, upon a calm day, is thrown over the river upon the opposite bank, forming an arch of water through which you look upon a wild scene of woods and rapids, while above everything is hidden by the ascending steam. It must be very beautiful when viewed upon a quiet day, as we were all greatly pleased, though the wind was blowing strongly against the water, and considerably marred the effect said to be generally produced."

COMMENTS. This description was probably of Riverside Geyser. It is the only feature that *currently* erupts water in an arc that spans the river. This was the first of several notations that describe Riverside by a variety of other names. The massive proportions of the water column preclude the thought that this description was of an historical, oblique eruption of Mortar.

22. 1882 - "Mr. Fitch", describing an eruption of Fan: "Here the water bursts forth through the crevice of a rock and forms a fan-shaped spray."

COMMENTS. Albeit brief, this is the first record of a "crevice" to describe the vent of Fan. Because he saw only a spray of water, it is possible he saw an eruption of the smaller vents of Fan, such as the Gold, High or Angle. A major eruption from the Main and East Vent cannot be considered mere spray, nor do they erupt from crevices. It is also possible that vandalism, which was in evidence in the Upper Basin prior to 1882, may have changed the appearance of both vents and the resulting eruptions. Regrettably, it is unlikely that we can ever pin down with precision the cause of any change in behavior in this group.

23. 1882 - Herman Haupt, Jr., describing Fan: "About two hundred yards north-west of the Riverside Geyser is the Fan, or Fantail, Geyser, intrinsically small, but from its display very interesting. It consists of a group of five geyser-tubes opening at the same point, having a common crater and discharging at one and the same time. Each one of the of the tubes is inclined a little from its neighbor, and all radiate from a centre; so that the effect of the eruption is to produce a huge outspread fan one hundred feet in height and as many wide. The central stream being higher and the four lateral ones shooting out to a less distance, the result is a fan of hot water which rivals the most showy production of the 'german' of the 'opera' Frequently, when the fan is spread, a fine bow will encase its entire margin, adding an exquisite fringe such as never produced by the arts of man. It is a marvelously strange spectacle, as it occurs three of four times a day,-- though the exact time is irregular-- it will repay the tourist to saunter about in the neighborhood and wait to see it. The display lasts about fifteen minutes, sometimes occurring in the light of a full autumnal moon, when it is beautiful in the extreme and seems very coquettish in its behavior."

COMMENTS. The entire description, from the nature of the eruption to the nature of the vent, is fanciful. There is no group of five geyser tubes opening at the same point, having a common crater. Only Hayden, early in the previous decade (a description he later changed) mentioned such an arrangement of vents, but he later used other numbers and physical descriptions.

Some readers may wonder if Haupt is describing the Main Vent of Fan, but his description of the size and directions of the water columns is in conflict with reality. In addition, he did not mention the rest of the vents of Fan, nor nearby Mortar.

Since so much of this description is verbal flourishes, one wonders if Haupt, from whose guidebook this quote is taken, ever saw an eruption. No **observer** ever noted an eruption frequency of 3 to 4 times a day. His discussion of "Riverside" below (#27) makes me believe he never saw either geyser in eruption, or else was a notoriously poor note-taker.

24. 1883 - Margaret A. Cruikshank, describing Riverside: "The first thing that informed us that we were nearing our destination was a geyser in full blast. It was close to the river just where we had to cross it by a bridge... It was 'the riverside' firing away across the river at an angle..."

She added that Riverside Geyser erupted three times per day, lasting 10-13 minutes, and that the bridge could not be crossed while the eruption was in progress.

COMMENTS. This was most likely a completely accurate description. The mention of a "bridge" (which existed at the time near Riverside) confirms the likelihood that Cruikshank correctly recorded an eruption of Riverside.

25. 1883 - Walter Weed: "21 Fan Geyser This Geyser was seen in eruption Aug 24 at 10AM. The column of water consisted of a number of jets of spray, which reached a height of forty feet, tho the general height was much lower. The eruption lasted about 3 minutes, and was succeeded by a short steam period, when spurts of spray were again ejected: this was repeated with more or less violence, for about 7 minutes when, the eruption ceased, and the crater was gently steaming. The total duration of the eruption was thus seen to be 10 minutes. At 10:50 AM the Fan went off again, but the eruption was less violent than that of earlier."

1883 - Walter Weed, continuation of above: "No. 21. Riverside The only eruption of the Riverside witnessed was on Aug. 24th at 10:30 A.M. After a few feeble preliminary spurts, volumes of steam rose from the crater and jets of water were suddenly shot up in the air to a maximum height of 50 feet. These jets were from the large or main vent hole, those from the small vent rising 15 to 20 feet only. In about 5 minutes the jets decreased in activity, the general height being 25 to 30 feet, the occasional jets of spray [rising ten feet higher]. At 10:42 the main vent sent up a column of water 35 feet high, which sank in a moment to 20 feet, and then lower, until only feeble jets of spray were emitted and the steam continued to rise in clouds. The total duration of the eruption was 15 minutes, and at its close the steam still rose quietly from its crater. The eruption was accompanied by a loud but muffled noise, as if a padded board were struck by a hammer."

COMMENTS. These two notations give us a detailed account of the behavior of Fan and Mortar. If we assume that Weed's "Fan" is the modern Fan, and that his Riverside is the modern Mortar (an automatic assumption that, for once, is probably correct) then it is apparent their activity have changed substantially.

First, although Weed mentioned many "jets of spray" from Fan, he then describes only one crater. Second, the maximum height was only 40 feet.

Third, Fan and Mortar did not play simultaneously, as is the case with every known eruption of Fan in the modern era. According to Weed's detailed notes, Fan played first at 10:00 AM for about 10 minutes, followed by a Mortar eruption at 10:30 AM which lasted for 15 minutes, followed by Fan again at 10:50. AM. They have not been observed to behave in this manner during this century.

26. 1883 - George Thomas, describing Fan: "It spouts for about a minute then subsides."

COMMENTS. This does not match any description of any era. As Whittlesey notes, "perhaps this was a minor eruption, or another geyser altogether."

27. 1883 - Herman Haupt, Jr.: "[Riverside] spouts irregularly, and sends a column sixty feet high. The crater stands on the summit of a mound that has been built up in six of more terraces, each smaller in area than the former one, thus making a curve with the edges of the terraces rounded off. There is no definite period when an eruption may be expected, but twice or thrice a day a 'spout' may be seen, lasting about seventeen minutes."

COMMENTS. Haupt described the cone of modern Mortar Geyser. His eruption description of this feature also is reminiscent of Mortar. Riverside's arcing water display is not described.

In Haupt's discussion of "Fan" above (#23), he correctly described the distance between Fan and Riverside as about 200 yards. Why, then, does he now describe the modern Mortar as Riverside?

28. 1884 - Walter Weed: Saw Riverside erupt on August 29 to a steady height of 100 feet, at an angle, for fourteen minutes, followed by a 25-minute steam phase. He drew and described Riverside in an effort to make it clear that this was not Mortar.

COMMENTS. This is apparently an accurate description of Riverside, and indicates that whatever confusion existed at the time of his earlier entry (#25) has ended. His duration is in keeping with modern accounts. It rarely erupts at an angle to a height of 100 feet; 75 feet is much more common. It is important to note that Weed is beginning to straighten out the confusion about identities. He knew, in 1884, which geyser was Riverside.

29. 1884 - Walter Weed, describing Spiteful Geyser: "The basin is elliptical with sharp ends, and is formed in the horizontally deposited and laminated sinter--some of the layers being 2 1/2 inches thick and massive in structure--This deposit is vertically jointed, by cracks 2 ft. to 4 ft. apart. In structure and appearance this deposit resembles that forming the platforms of the Riverside, Fan, etc...

"Except just before an eruption the basin is empty; the water in the fissure can be heard thrashing about, and spray is occasionally ejected--Just before an eruption the basin begins to fill, the water splashing and surging about in the basin, and when this is nearly full jets are thrown up, in quick succession; forming a very fine fountain some 25 to 30 ft. high---the spouting being of about 1 1/2 minutes duration, when the violence became less and splashing a little the basin was empty, followed by a loud gurgling noise---There is no steam period. Water very pale green. No algous growth..."

COMMENTS. This was the first mention of Spiteful Geyser. It wasn't shown on Peale's 1878 map -- Weed hand-wrote the name onto the map and assigned it #23 in 1884. The significance of this will be discussed after the next listing.

Whittlesey believes that Weed's "Riverside" notation actually referred to modern Mortar. This is confusing, since Weed accurately described a Riverside eruption in another 1884 entry (#28). However, the modern Riverside's cone does not resemble the laminated structure found near Spiteful. Mortar's cone isn't an exact match either, but it is certainly closer both in appearance and proximity. (#34) and (#28) make it clear that Weed's "Riverside" is the modern Riverside; his "Fan" is the modern Fan.

30. 1884 - G.L. Henderson, from a poem:
"The Spiteful stones unwary heads,
her water sources being dry."

COMMENTS. Whittlesey believes that Henderson named Spiteful. If this is the case, why was Henderson's most important memory of Spiteful the fact that "Spiteful stones unwary heads, her water sources being dry"?

Was Spiteful tossing "stones" into the air? Did this occur without water also being ejected?

If Henderson's poem corresponds to reality, one conclusion is that Spiteful was created by a steam explosion at the time of, or immediately prior to, Henderson's observations. This question is equally relevant if his poetry was based on hearsay. A steam explosion, or its immediate after effects, can explain a dry crater hurling stones into the air.

Some may question this conclusion. In response, one notes that Weed added Spiteful to a map, and first described it, in 1884. Why did all earlier observers ignore Spiteful? Why is its crater, the largest in the area by far, missing from <u>all</u> earlier maps? Perhaps it did not exist in its present form. The presence of "small geysers" at this location in Hayden's 1871 map may indicate the predecessor features to the crater of Spiteful.

Whittlesey (p. 1684-85) believes the name Spiteful was first used in 1884, and that "there is massive usage of the place name beginning suddenly" in that year. Also, he states "Spiteful became suddenly very noticeable as a geyser that year."

Evidently, it was also the first year its large crater (the only large crater in the complex) was noticed by anyone.

31. 1885 - W. H. Dudley: "The Fan" is a small geyser comparatively, and yet it is quite pretty, throwing a stream sixty feet into the air and sustaining it for from ten to fifteen minutes."

COMMENTS. His brief description is much more in keeping with modern Riverside, or perhaps Mortar, than Fan.

32. 1885 - Walter Weed: saw Fan erupt September 7 for four minutes to a height of 40 feet, and Riverside on September 6 to 75 feet for 15 minutes.

COMMENTS. This Fan eruption corresponds to his 1883 observation while his Riverside eruption data is in keeping with its modern behavior.

33. 1885 - Weed and William Hallock: Saw and recorded the following eruptions of Spiteful Geyser:

Date	Time	Ht.	Dur.	Observer
8/24	0959	30ft.	3 min.	Weed
8/24	1019	25	3	Weed
9/02	1115	25	3	Weed
9/02	1245	25	4	Weed
9/03	1010	25	3	Weed
9/10	1703	25	2 1/2	Weed
9/11	1610	25	--	Hallock
9/11	1630	25	--	Hallock
9/11	1650	25	--	Hallock

COMMENTS. Note that the eruptions suddenly end in the middle of the day. This may demonstrate that Spiteful was erupting in a similar manner to that observed in the 1970's, when eruptions would take place in a series of three or four, followed by hours or days of quiet.

Weed also noted that Spiteful's vent was "clogged up". Whittlesey believes that this might indicate early vandalism. It is also possible that Weed's description refers to the remnants of a recent steam explosion. Since it *was* erupting that year one wonders what vandalism could have taken place that permitted its large eruptions to still occur.

34. 1886 - Walter Weed: "The name of Fan has *always* been given to the first geyser north of the Riverside and a picture of it is given in the 1878 annual report. This year however a change has been made, and the name Fan given to a small geyser vent back of the Perpetual Spouter and on the fissure with the Spiteful; and the old vent has been given a new name the Mortar."[emphasis added]

COMMENTS. This is the most significant entry from this era. It confirms many of my contentions about the misnaming of the features in the area.

The "first geyser north of the Riverside" is the modern Mortar. Weed states that this geyser has *always* been given the name "Fan". This is the only acknowledgement that the observers of that era called modern "Mortar" by the name "Fan".

The remainder of Weed's entry is equally telling. He transferred the name "Fan" to a **small** geyser vent back of the Perpetual Spouter and on the fissure with the Spiteful..." This is the first reference to Fan's modern location on the same fissure as Spiteful.

What is the "Perpetual Spouter?" There is only one earlier mention of it, in

Peale #28. The location given by Weed doesn't precisely clarify its location.

What did Weed mean by "in back of"? It depends on where he was standing. It is likely that "in back of" meant "farther from the river".

Modern observers are familiar seeing the complex from only one vantage point: from the east, the location of the asphalt trail. Weed et al. did not have any such artificial encumberence of movement; any interpretation of historical documents must be made from their perspective. From Weed's description, we may infer that the east-to-west lineup of the newly named vents is Spiteful - Fan - Perpetual Spouter. His next entry confirms this order.

The "Perpetual Spouter" was most likely one of the modern Fan vents. It is possible, based on the amount of sinter deposition, that it is the Gold Vent. Note that as far back as 1871 (Hayden's map, figure 4) a minor feature was noted as existing at the approximate site of the High Vent.

What was the "small geyser vent" that he named Fan? Later entries will assist us in determining the precise location of Weed's "Fan."

Also, note the lack of confusion about Riverside, thus confirming his 1884 observation.

35. 1886 - Hague, Weed, and Iddings: Saw Mortar erupt a total of eleven times.

COMMENTS. This is most likely the true, modern Mortar, since the observations are possibly by Weed himself. Fan Geyser, known by Weed as a completely separate feature, was not mentioned at all.

36. 1886 - Weed: "The Perpetual Spouter, the Fan Vents, the Spiteful, and the old craters across the road are all on one fissure line. That these vents are connected with the Mortar is proven by the following facts which subsequent observations confirmed. On Aug 2nd the Perpetual Spouter was playing rather more vigorously than usual at 3:40 p.m.---and at 3:42 the Fan began to spout. The maximum height was 15 ft., the duration 2 minutes. During this action of the Fan, the Perpetual Spouter kept up its action and this continued till at 4:12 an eruption of Mortar occurred, shooting a perfectly steady stream at an angle of 70°-75° across the stream, the height being 30 ft. to 50 ft. and the column resembling that of the Beehive. This lasted 6 minutes and was followed by 2 minutes of violent but rapidly decreasing steaming. During the first part of the eruption, the Perpetual Spouter spurted vigorously far more than usual, but before the Mortar ceased, the jets of water stopped and a jet of steam alone escaped with loud roaring, continuing during the steam period of the Mortar, altho' diminishing rapidly in volume, toward the end and finally ceasing altogether. The Perpetual Spouter was now quiet and the usual [spurting] action of the vents began [again] vent B (the touch hole of the Mortar) was not noted before the eruption of the Mortar, but it was quiet after the eruption; at 4:39 the vent spouted for thirty seconds, 3 ft. to 5 ft. high [then] quiet til 4:43 when this spouting was repeated, the jets being 5' - 10' high. [At] 4:48:30 the vent spouted again--height 10 ft.---accompanied by violent gurgling in Fan and Mortar, and increased action at the Perpetual spouter (sic). At 4:51, the thrashing in the Fan was very violent and the Mortar began to steam. [At] 5:18 vent "b" spouted again and at 5:32 Mortar spouted as at 4:12 lasting 6 minutes. During the last half of the eruption of the Mortar the Perpetual spouter began to roar, and acted exactly as before. This sequence of events was observed on several occasions afterwards, so that [we know] it is not accidental."

COMMENTS. This detailed observation is fascinating. Since Weed clearly knew the difference between Riverside and Mortar by now (#28 attests to this fact), his description of an oblique water column must be accepted as fact. In addition, the height of 30-50 feet, and the duration of 6 minutes followed by 2 minutes of violent steam is similar to many eruptions of Mortar, rather than Riverside.

His description of the action of the Perpetual Spouter and the "Fan Vents" prior to the eruption is reminiscent of the current behavior of the group before major eruptions, when the minor activity of the Gold, High and Angle vents increases to a height of 8-10 feet. This is a certain sign of an impending major eruption.

The activity of the "touch hole of Mortar" (also his "b" vent -- modern Lower Mortar) is also similar to modern activity. Occasionally it takes little part in a major eruption, but can also splash to 5-10 feet midway during the eruption.

Weed's description of the modern Fan's activity differs dramatically from its recent behavior. A maximum height of 15 feet is more in keeping with the Gold or High vent. He did not mention any activity that could be interpreted as Main Vent or East Vent play. He never even discussed their existence. The fact that the "Perpetual Spouter" stopped and started indicates that at least Weed knew that the name was not completely accurate.

He also mentioned, for the first time, the "old craters across the road" that are probably the modern "Norris Pools."

37. 1886 - Weed: Riverside was erupting every 5-7 hours during July.

COMMENTS. Although brief, this is the first entry that implies a frequency and regularity reminiscent of Riverside's modern behavior.

38. 1887 - G.L. Henderson: statistics on Fan - height 50-70 feet, duration 10 minutes, interval 8 hours. (1885 table: interval once in 3 days.)

COMMENTS. Did Henderson know about Weed's renaming the previous year? His statistics are more in keeping with the modern Riverside than with any "Fan" description of the day.

39. 1888 - G. L. Henderson: Mortar erupting 30 feet high, duration 15 minutes, interval "four every other day."

COMMENTS. No explanation. Note that this entry somewhat resembles Weed and Hallock's 1885 description of Spiteful Geyser, as well as Spiteful's activity in the 1970's.

40. 1889 - A.M. Mattoon, attempting to explain the confusion about Fan and Mortar: "Two names appear to have been given it, but the one most commonly applied is 'The Fan'. Its crater is situated quite close to the Firehole River and the stream is thrown some sixty feet high, not vertically but slanted toward the river, and the jet stretches its arch clear across the stream, filling the entire curve with falling spray, thus bearing some resemblance to a huge out-spread fan. The other name applied to it is 'The Mortar'. The crater does indeed look not unlike that military engine for throwing bomb-shells, called a mortar, mounted so close to the water in the stream that one might stand upon its brim and spring into the river..."

COMMENTS. Mr. Mattoon has done what no other observer was able to do: transfer both the names "Fan" and "Mortar" to the same feature, possibly Riverside. Regardless, this is one of the more confused and inaccurate description from that era.

41 1889 - A.B. Guptill, describing Fan: "...has an eruption every eight hours, generally following the Riverside, its ejected waters spreading out in fan shaped jets, from the fact of its having two crater orifices which throw out diverging streams. The pink geyserite forming its crater is quite unlike that of any other geyser."

COMMENTS. First, Guptill did not state that he personally observed any eruptions. His use of the present tense tends to confirm this fact. Guptill has accurately described modern Mortar Geyser. The "two crater orifices" is significant, but much more telling is the description of the pink geyserite, which is an accurate description of the color of the sinter surrounding Mortar. The following entry confirms that he knew which geyser was Riverside.

That Guptill and Mattoon confuse Fan, Mortar, and Riverside indicates that Weed's 1886 official name changes did not reach a wide audience. These observers are replicating the confusion prior to Weed.

This is also another entry which claims that Riverside and "Fan" are connected underground. There is no modern evidence to suggest that any interconnections exist.

42 1889 - A.B. Guptill: "[Riverside] consists of two chimney-like craters, the larger being at the same time the higher. The geyser 'plays' from the lower opening only, though visitors are apt to arrive at a reverse conclusion when viewing the locality between periods of eruption. An overflow of water is a certain indication of approaching activity, occurring about thirty minutes previous to eruptions and continuing until the outburst, which takes place about every eight hours, throwing an arching column to a height of 80 or 90 feet, the entire contents of the discharge falling into the river."

COMMENTS. This entry could be placed into a modern guidebook with only minor revisions. In recent years the overflow has lasted at least double Guptill's 30 minutes. He is the first person to note that overflow is an indicator of an impending eruption.

43. 1890 - Haynes guidebook: Mortar interval "very uncertain." Fan's interval "every eight hours."

COMMENTS. This is such a short entry that the innumerable possible misinterpretations need not be explored. There are numerous smaller entries such as this. Several follow, with no commentary.

44. 1894 - Olin Wheeler: Riverside's interval 8 hours 15 minutes.

45. 1894 - Wheeler: Fan's statistics - height 30 feet, duration 10 minutes, interval 8 hours.

46. 1895 - Wheeler: Riverside's interval 7 3/4 hours, duration 20 minutes.

47. 1895 - Wheeler: Fan's statistics - height 30 feet, duration 12 minutes, interval 3 hours.

48. 1895 - Haynes guide: Fan's statistics - height 60 feet,duration 10 minutes, interval 4-6 hours. (These statistics remained the same in Haynes guides through 1910.)

49. 1896 - Burglehaus table: Riverside's interval every 7 hours, height 100 feet.

(*Records indicate that the identity of Riverside became definite sometime around 1890.*)

50. 1897 - Wade Thayer: "Little Mortar firing broadsides into the stream."

51. 1902 - Hague: Saw Fan and Mortar erupt in concert on August 14. Stated elsewhere that Fan is playing "as usual" with Mortar this season.

52. 1904 - Haynes Guide: Mortar's interval is two hours; "it plays more frequently than Fan."

53. 1908 - Reau Campbell: "[Fan's] fanshape eruptions occur about every eight hours, duration 10 to 15 minutes, height 15 to 20 feet."

54. 1910 - E. F. Colborn: Mortar's statistics - height thirty feet, duration five minutes, interval two hours.

55. 1911 - Haynes guide: Intervals between eruptions of the Fan vary from four to six hours; it plays for ten minutes but only six or eight feet high. The Mortar plays every thirty feet high for five minutes every two hours."

56. 1911 - Hague: Mortar was "in action daily" with Fan Geyser at that time and that of the two geysers, Mortar threw the higher column of water, estimated at 25 feet. "They may play together or act independently; as regards eruptions they do not appear to stand in close relationship."

COMMENTS. Riverside's identity has been established.

The descriptions of Fan and Mortar are remarkable in their unremarkableness. Although they were relatively frequent performers, their heights of 15-25 feet and intervals of hours demonstrated that they were of only minor interest to the public.

In 1914, Fan apparently entered a 24-year dormancy, interrupted by one known concerted eruption of Fan and Mortar in June 1921. Mortar was not inactive through this period, as the following entries indicate.

57. 1927 - Phillips: "Occasionally its main crater, which resembles a huge pharmacists's mortar, fills and throws jets violently in all directions."

58. 1932 - George C. Crowe: "Mortar Geyser is active frequently, playing to a height of from twenty to thirty [feet]. The duration of play is from eleven to 15 minutes."

COMMENTS. This observer saw only solo eruptions of Mortar Geyser and does not mention Fan Geyser.

59. 1938 - George Marler: Judging by the results of their activity on the 14th [of August] I should say that on this date was the only occasion they have played so far this season.

"The Mortor [sic] began erupting at 12 noon on the above indicated date. It played to a height of not less than 60 feet, drenching the road with a flood of water which was thrown out at an angle in a northerly direction.

"Due to the great amount of water and vapor an my position (at the Riverside) I was not able to tell whether the Fan began playing at the same time or not. It was, however, 1 P.M. before all of the activity had subsided in the Fan. The Mortar was at a maximum of activity for about 10 minutes. It was 12:30 before water entirely ceased coming from the vent.

"A small steam vent across the river played for an hour and a half."

COMMENTS. In most of Marler's reports of this era, Mortar is spelled "Mortor." This spelling is corrected within the remainder of this paper.

This is the first account of an

eruption of the modern mode. A few comments are warranted. First, note the angle of the eruption of Mortar. It played in a direction that soaked the road. Marler implies that this was due to an angled water column rather than to wind.

Again, Mortar has changed its angle of attack. Reports and photos have demonstrated tilted Mortars and vertical Mortars.

Some readers might be puzzled by this northwest angle. In 1992, many observers, including the author, were surprised by a few Mortar eruptions whose water columns landed on or near the road, unaided by any wind. We attributed this new direction to the continuing erosion of the orifice of Upper Mortar. It seems likely that as Mortar's cone erodes away its water column will waver in a variety of directions.

60. 1938-39 - Marler: "In May [1938] I had my first view of these famous geysers. They were very impressive. This was the only known activity for that season. Five eruptions were known to have occurred during the 1939 season. Night eruptions were undetermined. I was in the immediate vicinity of three of the 1939 eruptions, being at the site of the geysers at the start of one of them. The eruption lasted for more than an hour. The major display occurred during the first 12 minutes. The concerted action of both geysers impressed me to a higher degree than eruptions of other geysers I had witnessed to that date."

COMMENTS. The discrepancy of "first observed eruptions" between #59 (August 1938) and #60 (May 1938) is perhaps due to the time when these two entries were written. #59 was written in 1938 or early 1938, while #60 was written sometime between 1970 and 1973. Based on the vagaries of memory I suspect that #59 is the accurate date.

Marler's descriptions of the eruptions are very similar to current observations, with one striking difference: "The vent farthest away from the river, and below the main fissure, discharges the greatest volume of water and erupts to the greatest height. At about a 45° angle its water arches over the road; the height being not less than 125 feet." [Marler, 1973, p. 77]

This is differs dramatically from Fan's present behavior. Marler is describing the East Vent, which plays a moderate column of water at a very oblique angle to the east. Its height is rarely more than 40 feet.

Since the 1969-1970 rejuvenation of the complex the most significant vent is the v-shaped orifice I named the "Main Vent" in 1979. There is no question that the Main Vent presently erupts the tall, angled water column that arches over the road.

In [Strasser 1989] I expressed surprise that Marler, perhaps the most experienced geyser observer in the Park's history, could miss such a basic observation. In an effort to explain this possible error I suggested that Fan's behavior could have changed in the intervening years. This is possible, because Marler also describes the activity of the opening now know as the Main Vent:

"Of the vents on the upper section of the fissure, the one where the water was noted to bulge, plays to a height of from about 60 to 80 feet. The vents nearer to the river erupt to lesser heights." [Marler 1976, p.76]

Marler only noted a single water column from this, the Main Vent. Since modern observers can see as many as six separate water columns emerge from the Main Vent, a logical conclusion is that the plumbing system of modern Fan, noted earlier to have changed dramatically in the 19th century, continued to change long into this century.

One other possible scenario is that the East Vent is a recent addition to the panoply of Fan's vents. None of the historical accounts mentions a vent erupting from the East Vent's alcove. This is a perplexing omission, since the East Vent's alcove is perhaps Fan's most prominent physical characteristic.

61. 1939 - George Marler. "I witnessed a most spectacular eruption of these geysers on the 22nd [of May]. The Fan began playing first and was followed almost immediately by the Mortar. The activity started at 9:05 A.M. and lasted until 10:30. The eruption seemed to be of unusual magnitude due to the fact that several pieces of geyserite weighing a pound or more were torn from about the main vent of the Fan. It was about two minutes before the Fan reached a maximum height, which could not have been less than 125 feet as the water was being arched over the road. From the vent on the apex of the mound of the Fan the water reached a height of about 50 feet. The water from this vent was noticeably muddy and small pebbles were constantly being lifted in the water column. The several vents in the fissure from which the Fan issued were all active and the various angles at which the water played suggested the shape of a fan.

"The Mortar played to a height of about 50 feet. After 15 minutes of continuous activity a steam phase ensued that lasted intermittently until 10:30. During the first 10 minutes of the steam phase the pressure was so great as to make the disruption of the cone a seeming possibility. A great quantity of muddy water issued from the main crater of Mortar. The water also contained many small stones.

"The Riverside erupted during the activity of these two geysers."

COMMENTS. Marler's description clarifies which vent of Fan's erupted the highest. He clearly delineated between the vent "on the apex of the mound" (the modern Main Vent) and his "main vent" which erupted at an angle over the road. This would logically imply the modern East Vent. Such eruption behavior is contrary to modern activity, in which the East Vent is considerably smaller than the Main Vent. It appears that the Main Vent has usurped both the intensity and behavior of Marler's original main vent.

His Mortar description is similar to modern observations, except he mentions both "the cone" and the "main crater," which implies that Marler considered the modern Lower Mortar as Mortar's main vent.

His discussion of Riverside is without additional comment on his part, so he doesn't imply a connection.

62. 1939 - George Marler, June Report.

"On the 20th these geysers became active at 4:05 P.M. and continued active until 5:30. In all respects the eruption was very similar to the one on May 22nd. The Mortar played to a height of about 60 feet while the north vent of the Fan arched the water out at least 125 feet from the orifice.

"The maximum height was attained during the first few minutes of the eruption. All vents played continuously for 15 minutes then every few minutes for the next hour and a quarter they would become active for about one minute periods. A small steam vent on the opposite side of the river played for about two hours."

COMMENTS. Marlers's most intriguing comment is his mention of the small steam vent on the opposite side of the river. No modern observer has either seen this vent nor been able to determine its location through close visual inspection.

63. 1939 - George Marler (September report): "I have checked 5 eruptions of the Fan and Mortar the past season. Last year I checked but two. For size and beauty these geysers certainly fall into the first magnitude class. The last eruption was on Sept. 17th at 2:30 P.M. The activity lasted 20 minutes."

64. July 1940 - George Marler: "These geysers were active only once during July. I was fortunate enough to witness the complete eruption. The eruptions from the several vents of these geysers began simultaneously. Preceding the activity, however, the Mortar was making several abortive attempts not at all unlike Old Faithful. It was in this state of preliminary play when I drove up at 1:45 P.M. July 8th. After observing it for five minutes the activity began. The eruption lasted until 2:35. The water played out steadily from not less than nine vents during this period. The activity seemed to hold at maximum height for about ten minutes."

COMMENTS. This start is reminiscent of what modern observers call an "Upper Mortar Start," which begins precisely as Marler here describes.

65. August 1940 - George Marler: Two eruptions of these geysers have been reported to me. Both eruptions occurred on August 30th. Don Andrus reported seeing it playing at 1:30 A.M. Naturalist Tompson reported it playing at 8 P.M. on the same day."

COMMENTS. If true, this is the shortest interval between major eruptions ever reported. Geyser gazers have occasionally encountered such disparate entries regarding other geysers that routinely turn out to be erroneous. Although the author does not automatically assume that this is the case, it is certainly a possibility that one or both of these reports is not correct.

66. 1945 - H. T. Lystrup: "These two geysers have been observed during the summer playing to-gether and also independent of one another."

COMMENTS. This is reminiscent of those irritatingly brief descriptions from Fan and Mortar's early years. There is no record of modern major solo eruptions of Fan. Lystrup and Marler often did not see eye-to-eye; perhaps it was accounts like this that bothered Marler.

67. 1946 - George Marler. "Major, daylight activity occurred in these geysers but once during this season. On August 12th, about 11:00 A.M. they began playing. The activity, interspersed with short periods of repose, lasted for about an hour. There are about nine vents that the water plays from during the period of activity. From two of these vents, the Mortar and northern-most one in the structure of the Fan, the eruptions are of a major character. From the Fan the water played to a height of fully 125 feet. The water plays out at about the same angle as the Riverside and directly north. The road is deluged during the eruption.

"This period of activity was more violent and of greater duration that those I observed during the 1940 season. On previous occasions the eruptions did not last for more than five minutes, but the height of the activity was apparently equal to the one this year. During the eruption the Fan, in addition to a continuous shower of rocks, ejected a hub cap and two tin cans. Many of the rocks were tossed, by measurement, 300 feet from the orifice. During the closing minutes of the eruption the Mortar has a violent steam period comparable to that of the Clepsydra."

COMMENTS. The measurement of 300 feet is astonishing. If correct, ejected debris landed in the trees, far beyond the "Norris Pools." Only rarely has Fan recently erupted beyond the Norris Pools.

68 - 1947 - George Marler: Reports that both Fan and Mortar erupted during 1947.

69 - 1948 - George Marler: Reported that both Fan and Mortar erupted this year.

70 - 1949 - George Marler: "The Fan and Mortar erupt simultaneously. Two eruptions were noted for the season. The activity lasts from seven to ten minutes and is very spectacular, water being played from nine separate vents. The Mortar has a marked steam phase at the close of the eruption."

COMMENTS. Marler implies that Fan and Mortar's eruptions were shorter in duration in 1949 than those he witnessed in the previous decade. It is a common error in geyser reporting to use the present tense without any additional qualification; such usage implies a constancy and permanence of behavior that is unwarranted.

71 - 1950 - George Marler: "... The experiment with the Fan and Mortar will be described because of its location and what the soaping revealed.

"Fan and Mortar are connected underground. The Fan, it has several vents, is merely a rift in geyserite laid down by some earlier activity. The weathering of this older geyserite has produced many fragmental pieces of sinter of many sizes. This broken sinter has been source material for thoughtless people. One of the vents of the Fan is now sealed as a result of having been covered decades ago with blocks of geyserite. These blocks are now cemented together and to the surface.

"The soaping induced Mortar to erupt but the major vents of the Fan did not play. Many small pebbles were ejected from the Mortar. The eruption did not remove large rocks which could be seen in its crater.

"About two hours following this soaping a unit of the Fan, the one nearest the road, erupted [Spiteful]. This was the first I had ever seen any evidence of eruptive activity from this crater, or any indication that it might be a part of the Fan's system. The first phase of the eruption lasted about two minutes, which was followed by an emptying of the crater. The empty crater showed no well leading to any source of water. The bottom of the crater was merely a surface of broken rocks of varying sizes.

"Prompt advantage was taken to remove some of these rocks. After a few labored moments boiling water began breaking around the rocks, refilling the crater and another eruptive phase ensued. The water (massive) played to a height of about 12 feet for about two minutes. Innumerable small pebbles were rising and falling in the water column. Again the crater emptied, again work was resumed. During the eruptive period, which lasted about half an hour, two additional eruptive phases and emptying of the crater occurred.

"During the time work in the crater was possible at least a half ton of rocks - geyserite - was removed. The size of the rocks and their positions indicated that at some time a deliberate effort had been make to choke the well of this geyser. Its long quiescence would seem to indicate that such an effort had proven at least partially successful."

COMMENTS. Potential vandals should note that inducing Fan to erupt was unsuccessful. It is not surprising that Marler's soaping of Mortar resulted in an eruption of Spiteful. This relationship was noted in the 1970's by Martinez (Martinez 1978), and noted in the group's fluctuations in minor activity by Strasser in 1990 (Strasser 1991).

The extraordinary amount of debris removed by Marler is noteworthy for a variety of reasons. No doubt this large crater's proximity to the Morning Glory parking lot resulted in a large visitation by a mostly indifferent crowd of visitors. In addition, one wonders how much of this debris was as old as the 1880's, when Spiteful was first observed and possibly created by a steam explosion.

72 - 1956 - George Marler: reports Fan and Mortar as active.

73 - 1957 - George Marler: reports Fan and Mortar as not erupting.

SUMMARY OF ENTRIES

The following table briefly notes the observations mentioned above. The column entitled "What he said he was seeing," refers to the name given to the feature(s) by the author. The column "What he was really seeing" refers to the modern name of the feature the author described.

An asterisk (*) signifies an entry in which the author most likely did not see the geysers described erupt.

A single question mark signifies a minor level of uncertainty.

A double question mark signifies a large amount of uncertainty.

The number of vents, when shown, are those specifically described. Heights, when shown, are those attributed to the various vents described.

Number	Author	Year	What he *said* he was seeing	What he was *really* seeing	Number of Vents and height in Feet (if listed)
1.	Doane	1870	Fan	Mortar	3; 40', transverse, steam
2.	Langford	1870	Fan	Mortar	2: 60', steam to 50'
3.	Trumbull	1870	"Fantail"	Mortar	1
4.	Washburn	1870	"Fan Tail"	Mortar	2; 60'
5.	Barlow	1871	Fan	Mortar	3

6.	Barlow	1871	Riverside	Riverside	2; 80-90'
7.	Hayden	1871	Fan	?not known *	5
8.	Hayden	1871	Fan	?Mortar*	-
9.	Hayden	1872	Fan	Mortar	2; 5-10'
			"Fan's partner"	Fan	
10.	Norton	1872	Fan	Mortar	2; 80'
11.	Stanley	1873	Fan	*	5; 100'*
12.	Comstock	1873	Fan	(not certain)	-
			Riverside	(not certain)	-
13.	Strong	1875	Fan	Mortar *	3; 50-60'
14.	Strong	1875	Riverside	Mortar *	50-60'
15.	Switzer	1876	Riverside	Riverside	-
16.	Sherman	1877	Fan	Fan(?)	"a number"
			Riverside	?	
17.	Peale	1878	Fan	Mortar	1; "spouted"
			Perpet.spouter	Fan	1; "slight steam"
18.	Hayden	1878	Fan	Mortar	2
19.	Holmes	1878	Fan	Fan & Mortar	2; 100-200' distant
20.	Seguin	1879	Fan	Mortar	2
21.	Lockler	1881	Fan	Riverside	1; "across river"
22.	Fitch	1882	Fan	Fan	"crevice"
23.	Haupt	1882	Fan	?	5; 100*
24.	Cruikshank	1883	Riverside	Riverside	-
25.	Weed	1883	Fan	Fan, Mortar?	"A number"; 40'
26.	Thomas	1883	Fan	?	-
27.	Haupt	1883	Riverside	Mortar??	1; 60'
28.	Weed	1884	Riverside	Riverside	1; 100'
29.	Weed	1884	Spiteful	Spiteful	1; 25-30'
30.	Henderson	1884	Spiteful	Spiteful	-
31.	Dudley	1885	Fan	Mrtr?Rvrsd?*	1; 60'
32.	Weed	1885	Fan	Mortar?	-; 40'
			Riverside	Riverside	-; 75'
33.	Weed, Hallock	1885	Spiteful	Spiteful	-; 25'
34.	Weed	1886	Perpet. spouter	Fan	name change
			Fan	Fan	name change
			Mortar	Mortar	name change
35.	Hague, Weed,	1886	Mortar	Mortar	-
36.	Weed	1886	Perpet. Spouter	Fan	1
			Fan	Fan	"many"; 15'
			Mortar	Mortar	2; 30-50 across river, 5-10'
37.	Weed	1886	Riverside	Riverside	-
38.	Henderson	1887	Fan	Rvrsde?Mrtr?	50-70'
39.	Unattrib. table	1888	Mortar	Spiteful?	1; 30'
40.	Mattoon	1889	Fan and Mortar	Riverside*??	1; 60'
41.	Guptill	1889	Fan	Mortar	2
42.	Guptill	1889	Riverside	Riverside	2; 80-90

43.	Haynes	1890	Mortar	Mortar?	-
			Fan	Fan?	-
44.	Wheeler	1894	Riverside	Riverside	-
45.	Wheeler	1894	Fan	Fan	30'
46.	Wheeler	1895	Riverside	Riverside	-
47.	Wheeler	1895	Fan	Fan	30'
48.	Haynes	1895	Fan	Mortar?	60'
49.	Burglehaus	1896	Riverside	Riverside	100'
50.	Thayer	1897	Little Mortar	??	-
51.	Hague	1902	Fan and Mortar	Fan&Mortar	-
52.	Haynes	1902	Mortar	Mortar	-
53.	Campbell	1908	Fan	Fan	15-20'
54.	unattrib.	1910	Mortar	Mortar	30'
55.	Haynes	1911	Fan	Fan	6-8'
			Mortar	Mortar	30'
56.	Hague	1911	Fan and Mortar	Fan&Mortar	25' (Mortar, higher of the two)
57.	Phillips	1927	Mortar	Mortar	-
58.	Naturlst rprt	1932	Mortar	Mortar	20-30'
59.	Marler	1938+	Fan and Mortar	Fan&Mortar	-
60+	- All geysers known by their modern names -				

WHAT THE RECORD SHOWS: MODIFICATIONS TO THE GENERALLY ACCEPTED HISTORICAL ACTIVITY IN THE AREA

Many modern observers of Fan and Mortar speak fondly of a perceived "golden age" of eruption activity during the 19th century, when these two geysers erupted spectacularly as often as every 8 hours.

This never occurred. There is no historical documentation of any such activity. It is might be difficult for someone who has had to wait for hours (or days) for an eruption of Fan and Mortar to appreciate this fact: the last two decades are indeed Fan and Mortar's golden age.

There are few recorded eruptions of significance from the Fan and Mortar complex prior to 1938. The most intriguing is Holmes' entry (#19) from 1878.

Mortar was the dominant geyser in the group until 1938. Prior to that year large eruptions of Fan were not common. It was only after 1969 that Fan truly emerged as a common, spectacular feature.

During the first few decades of the Park's existence the behavior in the complex primarily manifested itself as Mortar eruptions from 30 to 70 feet tall. During that period Fan rarely, if ever, erupted spectacularly. Most observed eruptions were noted more for their forceful steam phases rather than for their water display, which was usually described as less than 40 feet high.

A Tilted Mortar

Observers in 1870-1872 (Doane #1, Norton #10) describe vertical play from Upper Mortar, but later observers (Sherman #16, Peale #17, Weed #36, most notably) describe with some accuracy a slightly oblique Upper Mortar water column, arcing over the river to a height of 30-50 feet. It is likely that both are true; the opening of

Figure 7. "Mortar Geyser." No date. Photograph #5739. Montana State Historical Society.

the vent of Upper Mortar - which is still eroding - changed during that time in such a way that the appearance of the water column changed as well. Figures 1 and 7 are examples of a tilted Mortar.

It is highly unlikely that these observed eruptions were all from Riverside. Weed #36 is very explicit in his description of a tilted Mortar eruption playing in conjunction with an eruption of the modern Fan; he also correctly identified Riverside in an earlier entry (#28) so there is little doubt he knew which feature was which.

This observation makes much of the confusion between Mortar and Riverside understandable. Not only were there two geysers in this area whose sinter formation was on the eastern bank of the Firehole, but they both consisted of two vents and both ejected columns of water obliquely in the direction of the river.

To make matters more confounding, Marler (#59) in 1938 described Mortar's water column drenching the road, which would introduces solid evidence of an entirely different direction.

On Riverside Geyser

I question whether Riverside was a regular performer in the 1870's and early 1880's. Accurate descriptions of Riverside eruptions were so rare - one each in 1871(?), 1876, 1883 and 1884 (#'s 6, 15, 24, and 28) - that it is difficult to imagine Riverside's astonishing regularity of the past hundred+ years to go unnoticed for so long. Assuming that it was indeed active during the 1870's and early 1880's the only possible explanation for the lack of data is its secluded location. Its water column does not draw the eye unless one is in the area from Grotto Geyser to Mortar; the visibility of its steam cloud, seen on warm days from throughout the basin, was less easily ignored.

On Fan Geyser

Fan Geyser did not erupt as it does today. Many eruptions were in conjunction with Mortar, but several consisted of play from only one vent (Doane #1, Hayden #9, Peale #17 (his "perpet. spouter") Weed #34), while other eruptions emanated from several vents (Sherman #16, Holmes #19, Fitch #22(?), Weed #36).

Except for a few descriptions (such as (#1-4) and Holmes #19), the maximum observed height of Fan was from 15-40 feet. Evidently, Fan's power *subsided* between 1882 (Weed #35), when it reached 40 feet, and the early 20th century (Campbell, #53, Hague, #11), when its height was 15 to 20 feet. It is conceded that some of the other more subjective entries were written by people who observed spectacular play from Fan, but many of these are so confusing or clearly drawn from other sources that their reliability is questionable.

The exception of the Haynes guides (#48) from 1895-1910 which described a height of 60 feet and an interval of 4-6 hours for Fan might be dismissed. These published statistics did not change during that time, which one immediately suspects is from lax editing, especially when accurate field observations from these years demonstrated much weaker activity. These specific descriptions of eruptions during that time never record a height remotely close to 60 feet.

On the Interconnections Between Fan and Mortar

Modern observers might be surprised by the variety of eruption behavior objectively recorded in the 19th century. The most common form of "dual" eruptions was a "ping-pong" effect, when Fan would erupt briefly, then Mortar, then Fan, and so on. Figure 8, for example, shows a larger eruption of Fan (to 40-50 feet) with no evidence of any eruption from Mortar. Even wisps of steam are not evident from Mortar. No such solo Fan activity has been seen in the modern era. Also, note in figure 8 the pronounced vertical play from the location of the modern Main Vent and the East Vent. There is no evidence of the arcing water now seen from either of these vents.

As a counter to this solo Fan Geyser, again note Figure 7. There is only a minor amount of steam from Fan Geyser, out of frame to the left, thus indicating activity of a minor scale. In fact, **there is no photograph available prior to the 1930's that shows both Fan and Mortar in major eruption simultaneously**.

The closest thing to a "dual eruption" that was found is the photograph in figure 9, taken in 1895, that shows Upper Mortar erupting vertically, with steam(? if anything) from Lower Mortar. Meanwhile, The vents of Fan are hardly engaged in vigorous play. The East Vent appears to be erupting to a height of six to ten feet, and some vent (Gold?) is steaming heavily. Perhaps early visitors observed this sort of heavy steaming which was referred to as either a small, powerfully steaming vent or the "perpetual spouter." (Doane #1, Weed #36, etc.)

Clearly, the subterranean connections between Fan and Mortar have changed substantially. I believe there is compelling evidence that the two systems have merged to the point where they are essentially one geyser. As the decades have progressed, episodes of complete independence of action have diminished to the point where such examples have become non-existent. It is

Figure 8. "Fan Geyser." No date. Photograph #3375, Montana Historical Society.

difficult to imagine a set of circumstances, barring an earthquake, which would disconnect the two.

On the Existence of Spiteful

It is questionable whether Spiteful existed prior to 1884. The Hayden map of 1871 (fig 4) shows "small geysers" at that spot, and not the largest crater in the complex. Further, Weed had to **pencil in** both the name "Spiteful" and the **feature itself** on Peale's 1878 map (Whittlesey, 1989). Regrettably, this map was not available for publication in this paper.

One also might wonder if the vents of Fan changed their appearance at about this time. No observer before Marler (1976) accurately describe the fissure and the various openings, especially the cavernous East Vent and the large, V-shaped Main Vent. There is no evidence that either orifice existed in their present form prior to the 1930's. I am anxiously awaiting copies of Weed's sketches of this area from the National Archives. These will certainly help us to understand the system's history.

Only Seguin (#20) and Weed (#34, notably) discussed the nature of the fissure from which the modern Fan erupt. The remainder primarily describe "Fan" (i.e., Mortar) as having two large craters.

On the Criss-Crossing Streams

The most captivating aspect of some

Figure 9. Unnamed, undated. Photograph #3450, Montana State Historical Society.

of the early descriptions of "Fan" was its criss-crossing water columns. This has been routinely accepted as accurate by modern readers. I question this. As stated earlier, any criss-crossing of the streams in modern eruptions is notoriously difficult to see and is a mere sideshow to the overwhelming power of the eruptions.

I hypothesize that these descriptions were not of the modern Fan, but were possibly of Mortar. First, most of these observers were actually describing Mortar, not Fan - that is a basic point of this paper.

Second, the few very detailed descriptions of Fan eruptions (Holmes #19, Weed #36) make no mention of criss-crossing streams. Recall Hayden's 1878 description (#18) which accurately describes Mortar's cone and also mentions the criss-crossing streams.

Third, both of Mortar's vents have played in a variety of directions. During some eruptions, both historical and modern, Lower Mortar is nearly quiescent. In others it erupts vertically, in others it erupts obliquely. In 1992 it erupted with a slight tilt to the south, as if the water column was spraying up and against Lower Mortar's thick vertical wall.

Couple this activity with an oblique angle to the north from Upper Mortar (mentioned by Marler #59), and the result is criss-crossing streams.

Such a display would be quite memorable. It should also be noted that Mortar's most recent erosion pattern has almost resulted in such a display. In 1992 several Mortar eruptions had Upper Mortar eject a more fan-shaped water column, with much of the water shooting vertically while a large portion landed to the northeast. Lower Mortar's eruption almost criss-crossed it. Frankly, in this group almost anything might be possible.

One must always remember that many early observers saw eruptions from the opposite side of the River. Also, they **never** saw it from the bridge or from the road embankment, the two most popular (and, essentially, the only) vantages for the modern observer of Mortar.

A REVISED CHRONOLOGY OF THE ACTIVITY OF RIVERSIDE GEYSER AND FAN AND MORTAR GEYSERS

The analysis provided in the preceding historical entries can give us a clearer picture of the area's thermal activity since their discovery in 1870. A chronology follows. The feature names correspond to their **current** names rather than the names used by the observers at the times in question.

Numbers in parentheses refer to the historical entry.

1870's: Mortar erupted relatively frequently, perhaps several per day. Its eruptions were sometimes accompanied by steam or water from the vents of Fan. Only rarely, if ever, was anything more spectacular in evidence from Fan. The variability in Mortar's eruptions was indicated by some eruptions as powerful and from both vents, with a slight criss-crossing of the water columns, while others played from only one vent.

The occasional dual eruptions were of a different character than the modern duals. Instead of the simultaneous waxing and waning of the activity of Fan and Mortar, they historically played briefly while the other was quiescent, then vice-versa.

Riverside Geyser was less frequent than now.

Spiteful Geyser did not exist. Instead, a few small geysers existed in the vicinity of the current crater of Spiteful.

1880's: Mortar was still the predominant geyser in the Fan and Mortar complex. Fan's maximum observed height was 40 feet. In many ways the character of their eruptions was similar to the present, especially the waxing and waning of activity and the changes from water to powerful steam.

Erosion in Mortar's Upper Vent resulted in it erupting at an angle towards the river.

Sometime in the 1883-1884 period the existence of Spiteful Geyser was first noted. The precise time of its creation via steam explosion is not known. In the first few years of its activity it erupted in series, with eruptions occurring every hour for a few hours, followed by a quiet period of hours to days.

Riverside became more regular in the 1880's.

1890's: The activity in the Fan and Mortar complex subsided. Spectacular eruptions were not observed. The typical maximum height of Fan was 15 to 25 feet. Mortar erupted to 25 feet.

Riverside was regular.

1900-1937: Fan and Mortar waned in activity and entered a dormant period only rarely interrupted by eruptions. Riverside became a dominant, well-known and regular geyser.

1938-1968: Fan and Mortar began to rarely exhibit spectacular eruptions

Figure 10. "Mortar Geyser." 1895. Photograph #3449, Montana State Historical Society.

reminiscent of their current behavior.

1969-1992: Fan and Mortar erupt cyclically, averaging about three years of activity in every five [Strasser 1989]. During active periods eruptions occur on average of every 3-5 days, with extremes of 1-14 days normally seen in any given year.

Spiteful was more active in the mid-70's, when eruptions took place cyclically. A dormant period began in 1978, interrupted by two known eruptions in 1984.

As this era continued the independent behavior of Fan and Mortar became less and less apparent, until by 1992 their minor and major activity, temperature fluctuations and water level fluctuations followed patterns that were predictable and reliable enough to consider them as a single geyser unit.

Predicting the Future: Physical and Eruption Behavior Changes

If their recent eruption frequency continues, the erosion in the Fan and Mortar will continue to alter their appearance, both in their physical structure and their eruption behavior.

Note figure 10. Mortar's cone is comprised of apparently solid and compacted sinter. There is no large gully between the cone and the area now occupied by the bridge embankment. Lower Mortar is difficult to detect. What caused this dramatic change in appearance?

It was likely a combination of both human interference and natural erosion. Koenig (1993) speculated that the bridge embankment may have been a contributing factor, channeling more runoff onto sinter that had never experienced that amount of runoff. I might also suggest that the actual construction of the embankment might have caused a large portion of the erosion when the engineers, having to provide firm footing for the bridge, could have chopped through some sinter in order to reach a more substantial surface.

In any event, the modern appearance of the whole of Mortar's cone is quite different from its historical appearance.

Not all erosion can be blamed on human interference. Note, in figures 6 and 10, the equally stable appearance of the cone near Upper Mortar's orifice. Gazers from the 1970's recall that it was still an extremely strong, stable cone in the early 1980's.

Erosion has increased substantially since then. Upper Mortar's water column is beginning to emerge at a wider angle. Its eastern side appears to be constructed of little more than a poorly balanced pile of loose sinter, being eaten away on all sides.

The sinter area between Mortar and the bridge embankment is also turning into a mass of loose blocks of sinter. The recent creation of the Bottom Vent, and its emergence as an erupting vent of Mortar Geyser, is evidence that this erosion is increasing at a remarkable clip.

Lower Mortar, meanwhile, is little changed from the 1970's. Its steep southern wall and two "chair arms" are mostly in place, although the eastern arm's chopped end (probably caused by vandalism in the 19th century) is eroding relatively quickly.

What this erosion means to future Mortar eruptions was speculated upon in another paper [Strasser 1989]. To expand on the speculation, the author would not be surprised if Upper Mortar's cone would suddenly break near the top, with the water column emerging in a wide fan or sheet of water, inundating the road to the east while still continuing to erupt vertically to a considerable height. This will probably have little effect on the power of Lower Mortar's eruptions, since it is only a surface change and not at depth where a Lower/Upper Mortar connection is made.

Readers will recall that Mortar once erupted at an angle into the Firehole, contributing to enormous confusion over the identity of this geyser vs. Riverside Geyser. It is also possible (although not proven) that Mortar's two vents erupted at one time in a criss-cross fashion, contributing to the confusion with Fan.

If the erosion trend continues, Upper Mortar might erupt with a large, fan-shaped water column. Readers might appreciate the ultimate irony of a geyser that once looked like a fan, hence named Fan, then looked like a "riverside" and hence named Riverside, then might again look like a Fan.

The erosion of Fan's structure is equally interesting. Note figures 9 and 10. The area between Fan and Mortar, now a steep-sided, shallow gully through well laminated sinter deposits, was at the time of this photograph (1895) a smooth, flat continuous sheet. When did this erosion take place? I surmise that it is primarily a result of the major eruptions in the past half-century. If this is the case it is a strong indicator that major eruptions were not common prior to this time, or else this erosion of a smooth sinter sheet would have bee already in place.

The alcove of the East Vent is considerably wider and deeper than it was only 20 years ago. Stephens and Day [1993] reported a large erosion event took place sometime in October 1992, in which a portion of the crack that extends from the East Vent (located near the front (east side) towards the rear (west) of the alcove blew out. During the next major eruption this crack erupted a sheet of water at a slight angle to the west. Photographs show that the original east vent showed no diminution in force.

Such changes will likely continue in the future. The most likely spot along the Fan fissure for additional erosion/explosive events is in the East/Main Vent area, since this is the area with the most powerful eruptions and also an area with a very large cavity beneath the ground at a depth of approximately 4-8 feet.

Observers might be surprised some day to approach Fan and Mortar only to see a large, gaping crater surrounded by sinter debris at the site of the former Main and East Vents.

Even if such a monumental change doesn't take place, the structure of Fan will nevertheless continue to erode rapidly.

Other changes that are less predictable must also be considered as possible. This includes the possibility of renewed steam explosions along the Spiteful-Fan fracture. All the principal vents along this fracture have come into existence through steam explosions of some kind. One likely area for renewed explosive activity is under the asphalt. There are features erupting immediately next to and under the roadway; only time will tell whether the small culvert known as the "Tile Vent" is of sufficient size to bleed off all the energy.

ACKNOWLEDGEMENTS. This paper would not be possible without the extraordinary efforts of Lee Whittlesey, whose ten-year odyssey of historical research resulted in what is the most comprehensive compilation of early data about any National Park in America.

The publication of Whittlesey's monumental study, **Wonderland Nomenclature: A History of the Place Names of Yellowstone National Park** gave enthusiasts of Yellowstone's geysers a special opportunity to analyze the activity of the Park's past thermal activity. Whittlesey's full manuscript of over 2000 pages provided the author with the opportunity to more fully understand this area's history.

Lee informed me that one of his hopes upon the completion of his mammoth work was that geyser gazers with some knowledge of a feature might use his book to understand the geyser and validate or (as in the case of this paper) demolish prior beliefs. His enjoyment of this effort this extends even to those sections where he disagrees with my conclusions.

Lee also frequently sent additional notes and comments which added to the content of this paper.

Thanks also to Rocco Paperiello, whose review of a preliminary draft was of considerable help. Both Rocco and Lee uncovered many of the photographs shown herein which confirmed my hypotheses of a tilted Mortar.

Additional thanks go to Heinrich Koenig, who informed me that my first draft was poorly designed and difficult to follow. He was right. He also was a sounding board for many hypotheses which, fortunately, never saw the light of day.

Much thanks to Rick Hutchinson and others in the National Park Service whose continued support were of great assistance.

Lynn Stephens and Jens Day provided many observations of recent behavior in the group during periods of times when I was not in the Park. Scott Bryan reviewed this paper, his comments are appreciated.

Final thanks to the many observers from long ago who did their best to figure out one of the most confusing groups of geysers in Yellowstone.

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Fan and Mortar Geysers in the summers of 1991 and 1992

David Schwarz

Abstract: Fan and Mortar Geysers erupted relatively frequently during the summers of 1991 and 1992. Eruption intervals from three to four days in 1991 and two to three days in 1992 were most common. Observed cycle lengths averaged 60 minutes (+/- 15 SD) in 1991 and 55 minutes (+/- 13 SD) in 1992. Almost all eruptions were preceded by either a River Vent pause or a short cycle with no play from Angle. No relationship was found between Fan and Mortar and Riverside Geyser or Link Geyser.

Description of the Vents

River Vent: This is a group of vents on the vertical bank of the Firehole River on the side of Fan's platform.

High Vent: High is the small vent on the slightly raised mound at the end of Fan near the dropoff to the river.

Gold Vent: Gold is the next vent away from the river along Fan's platform, surrounded by yellow stained sinter.

Angle Vent: Angle is barely noticeable when it is not actively splashing water. It is the next vent along Fan's formation. Its splashes are angled sharply away from Gold Vent.

Main Vent: This is the vent that breaks through the riverward edge of the decaying "bridge" of sinter at the center of Fan's formation. It is the source of Fan's largest jets, including the one that crosses the trail near Spiteful Geyser.

East Vent: Also referred to as "the Grand Canyon" and "Amphitheater," this vent lies within the gaping hole toward Spiteful Geyser from the sinter "bridge".

Lower Mortar: Lower Mortar is the open, lower cone of Mortar.

Bottom ("Arch") Vent: These vents are located among a pile of loose sinter at the base of Lower Mortar's cone, between Lower Mortar and the trail.

Upper Mortar: This is the large, eroding cone of Mortar nearest the river.

Frying Pan: This small vent is located on the downward slope from Lower Mortar toward Fan. It is not easy to see from the trail unless it is actively steaming or sputtering.

A Brief Description of the Cycle

Note: In this report, "cycle" will refer to the period of time from one River Vent start to the next. The part of the cycle during which the vents of the complex discharge water will be referred to as the "minor activity."

During the interval between eruptions, Fan and Mortar went through a series of cyclic activity. In 1991 and 1992, these cycles recurred roughly every 50 to 75 minutes, with extremes of 29 minutes and 110 minutes.

Most observers consider the start of the cycle to be the start of activity in River Vent. Gold Vent generally began its activity in the next 20 minutes. Angle usually started within 12 minutes after Gold. If Frying Pan was going to take part in the minor activity, it would start sputtering 20 to 40 minutes after River Vent, almost always well after Angle had started. River Vent stopped 25 to 40 minutes after it started. Frying Pan and Angle often continued on and off for several minutes after River Vent had stopped. In about 20 minutes, Lower Mortar began splashing off and on, and continued to do so until River Vent started again, marking the end of one cycle and the beginning of another. If an eruption was going to take place, it would usually, but again, not always, happen around the time Frying Pan started or was expected to start.

Sometimes River Vent stops without any of the platform vents having played. This activity is referred to as a *River Vent Pause*. Minor activity after a pause appeared to discharge more water than and often lasted longer than other periods of minor activity.

River Vent sometimes turns off after Gold has started but before Angle can start. Paul Strasser reports that the temperature changes within the vents during these cycles were identical to those during a "normal" cycle, and therefore different from those of a River Vent Pause. However, like pauses, these cycles were immediately followed by many more eruptions than were normal cycles in 1991 and 1992.

Main Vent and Upper Mortar both splashed occasionally just before River Vent started and just before it stopped. This activity often occurred during pauses or after River Vent had turned off without Angle having played.

Activity of 1991 and 1992

Eruption Intervals

At the beginning of the summer of 1991, Fan and Mortar's intervals were between three and a half and four days. In early July the interval decreased to between three and three and a half days. The trend toward decreasing intervals continued so that by late July and August, occasional intervals of less than three days were recorded. There were two apparently aberrant intervals of 5+ days during the summer, one ending on July 15, the other on August 8. In 1992, intervals were primarily between two and three days, with two of probably less than two days and perhaps four or five greater than three days. By far the most common interval was around 2 days 14 hours.

Cycle Lengths

Cycle lengths in 1991 ranged from 15 to 89 minutes, with an average of 60 minutes and a standard deviation of 15 minutes for 70 observed cycles. This average was consistent to within two minutes for both the period from July 9 to July 21 and the period from July 25 to August 8. Long cycles did not necessarily indicate impending eruptions, although there were usually several 60+ minute cycles during eruption intervals. Some of the longest cycles occurred as long as two and a half days before an eruption. In the same manner, sometimes a series of short cycles would be followed by a pause and an eruption.

Cycles in 1992 ranged from 24 to 100 minutes in length with an average of 55 minutes and standard deviation of 13 minutes for 230 observed cycles. The mean cycle length decreased from 57 minutes during the period of June 17 to June 29, to 55 minutes from June 29 to July 18, and to 53 minutes for the period from July 20 to August 12.

Signs of Impending Eruption

As in previous years, the only sure sign of an eruption was strong, continuous jetting by Gold, Angle, and High Vents, which usually started between 20 seconds and three minutes before the eruption. Infrequently, the jetting began as many as 22 minutes before the start of the eruption.

The only other possible signs were River Vent pauses and cycles without Angle, which usually resulted in high water levels in Lower Mortar and Main Vent. The periods of minor activity following these high water levels were considered by most watchers to be the most promising for an eruption.

From June 1991 through the rest of that summer, a River Vent pause immediately preceded all eruptions for which preceding cycle data was taken (7 of 9 eruptions).

In the summer of 1992 (through August 12), 12 eruptions were preceded by at least one pause. Cycles without activity by Angle Vent preceded 5 eruptions. Only two eruptions, both in May, were reported to come after normal, complete cycles. Information about the preceding cycles is not known for 4 eruptions between June 15 and August 12. Two consecutive pauses, without an intermediate cycle, preceded at least one eruption and three consecutive pauses preceded at least three eruptions.

Eruptions

A vast majority of eruptions in both 1991 and 1992 began with classic starts. "Grand Canyon" or "East Vent" starts were seen twice in 1991 and four times in 1992. Eruptions which were counted as "East Vent" starts were those during which East Vent achieved its full height before Main Vent and Upper Mortar started erupting. The determination was sometimes subjective.

During all eruptions, Lower Mortar stopped playing about one minute into the eruption and restarted one to two minutes later. The entire eruption would wax and wane, with Mortar gradually changing to steam, until about 18 minutes after the start, when there would be a complete pause. This pause would last about two minutes, after which the eruption would resume weakly for two to three minutes. Activity would continue on similar intervals until the eruption finally ended 35 to 45 minutes after the start.

Sometime before the first pause in the eruption, the fissure above Spiteful would usually, but certainly not always, stop sputtering and Spiteful itself would drop one inch to one and a half feet below overflow.

Changes and New Activity for 1991 and 1992

Minor Activity by Bottom Vent

Before 1991, Bottom Vent's activity was confined to eruptions of Fan and Mortar, when it would project a solid, continuous water column five or six feet high and turn to steam along with the rest of Mortar.

In 1991, it was observed to have activity independent of an eruption by Fan and Mortar. This activity consisted of weak, pulsing splashes obliquely toward the trail to about two feet high for ten to fifteen seconds. It occurred within a few minutes either side of the start of activity in River Vent. It was always associated with strong, high water level splashing in Lower Mortar, but usually did *not* coincide with one of these splashes. This type of activity continued into 1992.

Minor activity by Bottom Vent is not a reliable indicator of an impending eruption of Fan and Mortar. It has been observed as much as twenty hours and as little as twenty minutes before the next eruption.

A Change in East Vent

Jens Day noticed on October 11, 1992, that East Vent had dislodged a sinter obstruction from within the vent sometime after September 10. The obstruction had deflected East Vent's eruption into an oblique sheet of water angled toward Spiteful and a narrower, nearly vertical jet. The new

Fan and Mortar eruptions through summer, 1991

time	interval	comments
1/27/91 14:30		ie, vr
2/10/91 .	?	at least once since 1/27
2/14/91 10:30	?	vr
2/18/91 .	?	early A.M.
2/21/91 13:28	?	
2/26/1991 .	?	early A.M.
3/3/91 15:25	?	
3/7/91 13:30	3d 22h 5m	ie, vr
c. 3/13/91	?	
3/17/91 .	?	early A.M.
4/23/91 .	?	at least once since 3/17
4/28/91 18:01	?	
5/3/91 15:28	4d 21h 27m	ie
5/7/91 10:25	3d 18h 57m	vr
5/23/91 13:40	16d 3h 15m	vr
5/30/91 20:42	7d 7h 2m	ie
6/7/91 03:50	7d 7h 8m	(between 02:40 & 05:00)
6/12/91 21:00	5d 17h 10m	vr
6/17/91 00:30	4d 3h 30m	not exact time
6/21/91 07:55	4d 7h 25m	
6/25/91 01:00	3d 17h 5m	(between 23:00 & 03:00)
6/29/91 16:51	4d 15h 51m	
7/3/91 08:26	3d 15h 35m	
7/6/91 11:38	3d 3h 12m	ns
7/9/91 16:36	3d 4h 58m	
7/15/91 13:53	5d 21h 17m	East Vent Start
7/18/91 14:41	3d 0h 48m	
7/22/91 03:32	3d 12h 51m	
7/25/91 13:48	3d 10h 16m	
7/28/91 04:00	2d 14h 12m	(02:30-06:30)
7/30/91 20:51	2d 16h 51m	
8/3/91 08:37	3d 11h 46m	
8/8/91 18:03	5d 9h 26m	East Vent Start
8/12/91 05:00	3d 10h 57m	not exact time
8/15/91 01:00	2d 20h 0m	not exact time
8/18/91 01:58	3d 0h 58m	
8/20/91 23:22	2d 21h 24m	
8/25/91 00:15	4d 0h 53m	not exact time
8/28/91 22:43	3d 22h 28m	
8/31/91 08:58	2d 10h 15m	
9/3/91 14:33	3d 5h 35m	
9/7/91 04:07	3d 13h 34m	
9/11/91 01:30	3d 21h 23m	not exact time

Fan and Mortar eruptions, summer, 1992

time	interval	comments	LM pause	LM restart	S-ful drop?
5/28/92 17:12					
5/30/92 21:24	2d 4h 12m				
6/2/92 12:10	2d 14h 46m				
6/5/92 04:30	2d 16h 20m	time +/- 1h 30m			
6/7/92 22:18	2d 17h 48m				
6/10/92 05:30	2d 7h 12m	time +/- 30m			
6/13/92 00:55	2d 19h 25m				
6/15/92 05:12	2d 4h 17m				
6/18/92 02:30	2d 21h 18m	time +/- 30m			
6/20/92 10:20	2d 7h 50m				
6/23/92 06:35	2d 20h 15m		06:36.10	06:37.27	yes
6/26/92 04:59	2d 22h 24m		04:59.07	05:01.06	yes
6/29/92 23:41	3d 18h 42m				
7/2/92 14:33	2d 14h 52m				no
7/5/92 08:33	2d 18h 0m	East Vent start	08:34.43	08:35.35	yes
7/8/92 12:55	3d 4h 22m	East Vent start	12:56.48	12:57.55	yes
7/11/92 06:28	2d 17h 33m	Spiteful dropped 1.5 '	06:29.20	06:30.46	yes
7/14/92 03:10	2d 20h 42m				
7/16/92 00:00	<2 days	between 22:00 and 02:00			
7/18/92 17:41	2d 17h 41m		17:42.30	17:44.00	yes
7/21/92 04:34	2d 10h 53m	East Vent start	04:35.28	04:37.18	yes
7/24/92 00:26	2d 19h 52m		00:28.31	00:29.18	yes
7/26/92 11:27	2d 11h 1m		11:28.44	11:30.14	yes
7/29/92 05:10	2d 17h 43m	East Vent start	05:11.10	05:12.45	yes
8/1/92 03:53	2d 22h 43m				
8/4/92 03:17	2d 23h 24m				
8/6/92 21:11	2d 17h 54m		21:12.30	21:13.34	yes
8/9/92 17:22	2d 20h 11m		17:23.15	17:24.40	yes
8/12/92 11:09	2d 17h 47m		?	11:14.40	no
8/15/92 07:35	2d 20h 26m				
8/18/92 08:10	3d 0h 35m				
8/20/92 21:22	2d 13h 12m				
8/23/92 14:24	2d 17h 2m				
8/25/92 - 8/26		between 22:00 and 06:00			
8/29/92 10:00					
8/31/92 22:50	2d 12h 50m				
9/3/92 13:13	2d 14h 23m				
9/6/92 12:00	2d 22h 47m				
9/8/92 10:43	1d 22h 43m				

eruption of East Vent is a single jet of water on an angle described as similar to that of Daisy. (Note that this does not affect the jet of water that crosses the trail. That jet issues from Main Vent.)

Late Gold Vent Starts

Jens Day reports that in 1988, a late Gold Vent start (more than 14 minutes into the minor activity) almost always heralded an eruption on that cycle. In 1991 and particularly in 1992, a late Gold start often led to nothing more than weak, steamy minor activity.

Proposed Connections with Other Features

Riverside Geyser

A new theory concerning a possible connection between Fan and Mortar and Riverside has been suggested by Dave Leeking. The theory as I understand it is that if Fan does not erupt during the cycle during which Riverside erupts, it will have little chance of erupting on the succeeding two or three cycles. If it is true, then there should be a period of time for a few hours after Riverside's eruption during which Fan and Mortar erupt significantly less often than at other times during Riverside's interval.

Graphical analysis of Riverside and Fan eruptions from 1988 to 1992, excluding 1989 because of a lack of exact times on Fan, does not seem to support this theory. During any given year, there appear to be gaps of time in relation to Riverside during which Fan and Mortar did not erupt, but when the data is compiled into one graph, there is not a single time period in relation to Riverside when Fan and Mortar did not erupt (please see accompanying graphs).

Furthermore, during any given two and a half hour block of time on the graph, there are roughly the same number of Riversides. This is particularly true when the fact that an eruption less than half an hour after Fan roughly corresponds to one six and a half or seven hours before, and so on, because Riverside's interval is so regular.

If there is a connection between Fan and Mortar and Riverside, it does not manifest itself as an eruption of Riverside in any way affecting the time of Fan and Mortar's eruption.

Link Geyser

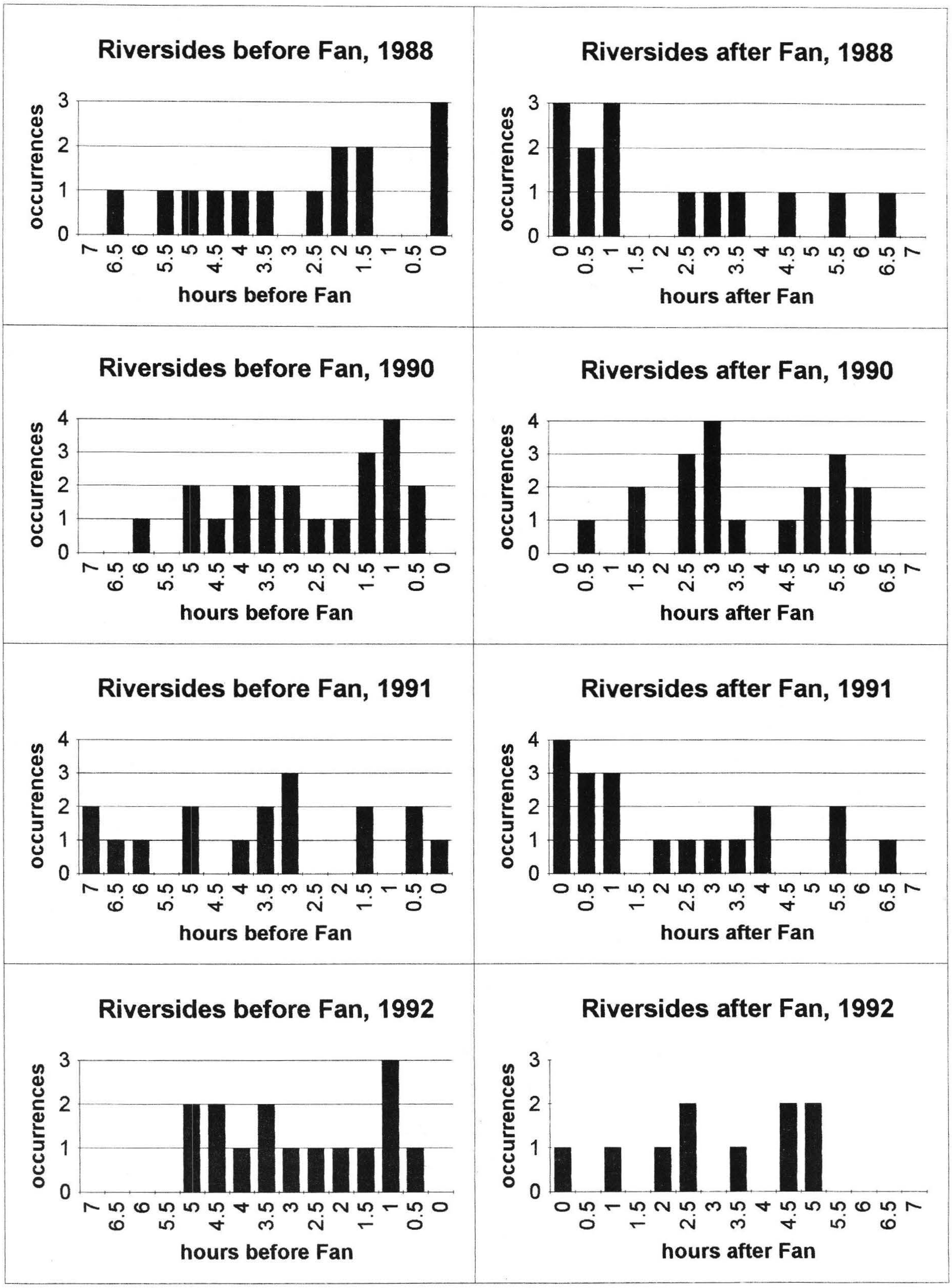
Link minors occurred every two to three hours during 1992. They started both during and between periods of Fan's minor activity. Link was observed to be both in eruption and not in eruption at the times of Fan and Mortar's eruptions. Link's intervals did not seem to change around Fan and Mortar's eruptions. Overall, Link's minor activity did not appear to be related to Fan and Mortar.

How to Tell Whether Fan and Mortar Have Erupted Recently

There are several ways to discern whether Fan and Mortar have erupted in the past twelve hours even if it was overnight and no one saw them. People who wish to waste as little of their lives as possible in front of Fan and Mortar would do well to know them.

The quickest, easiest way to tell is by looking at Lower Mortar's catch basin. The catch basin is a shallow depression on top of the far wall of Lower Mortar's cone. The water in this catch basin dries in a little over a day. If there is water in this basin and it has not rained recently, Fan and Mortar have already erupted.

If it has rained, the only way to be completely sure is to wait for River Vent to come on. If River Vent does not come on at all or if it and the platform vents (High, Gold


Riversides before Fan, 1988
occurrences
hours before Fan
Riversides after Fan, 1988
occurrences
hours after Fan
Riversides before Fan, 1990
occurrences
hours before Fan
Riversides after Fan, 1990
occurrences
hours after Fan
Riversides before Fan, 1991
occurrences
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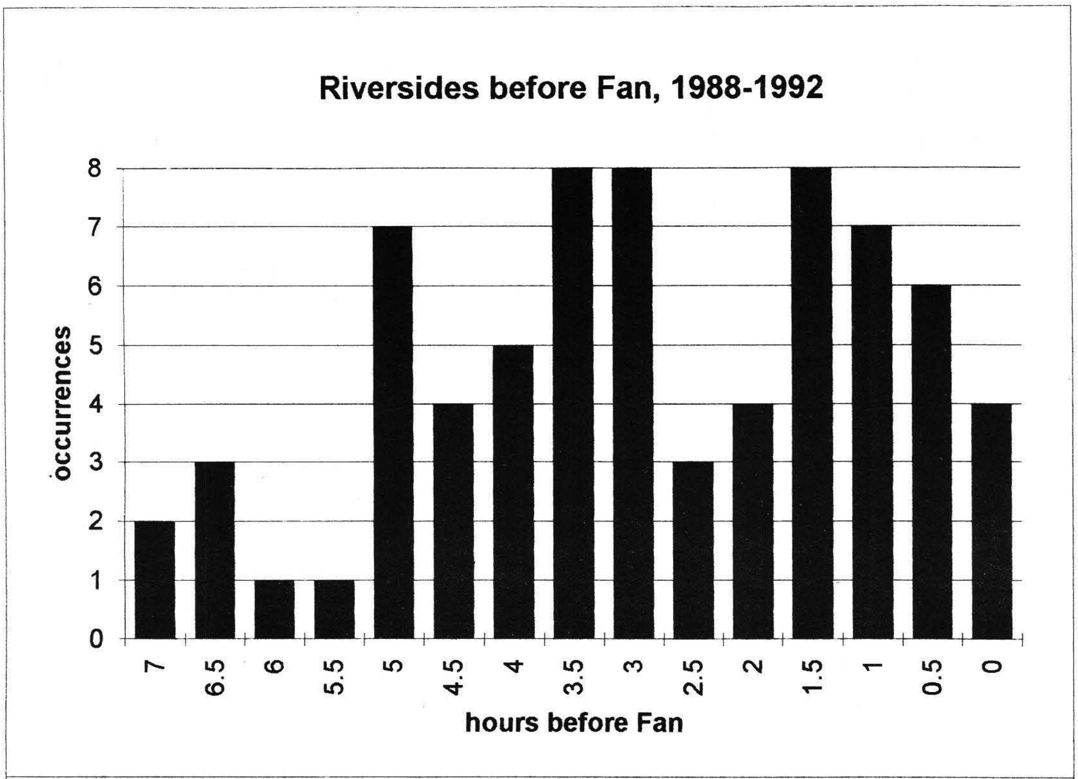
Riversides after Fan, 1992
occurrences
hours after Fan


Riversides before Fan, 1988-1992
occurrences
0
1
2
3
4
5
6
7
8
7
6.5
6
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4
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3
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2
1.5
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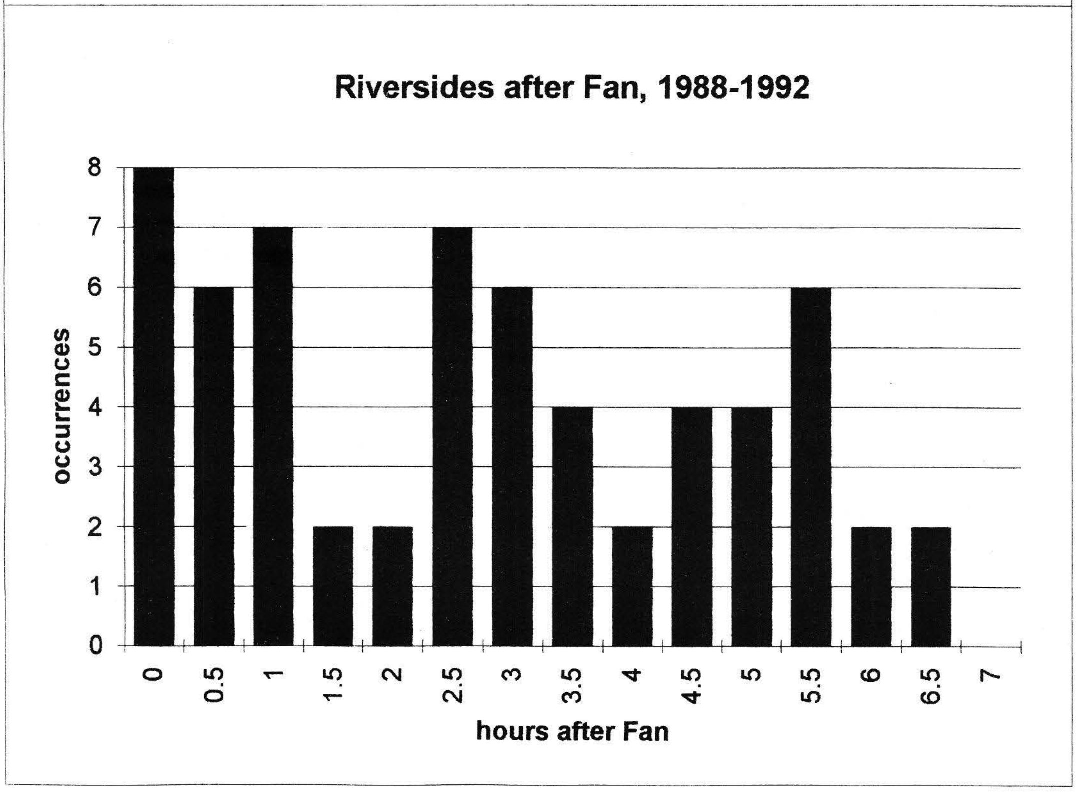
0
hours before Fan


Riversides after Fan, 1988-1992
occurrences
0
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0
0.5
1
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3
3.5
4
4.5
5
5.5
6
6.5
7
hours after Fan

and/or Angle) come on weakly and for a very short time, then Fan and Mortar have probably erupted. If they are having normal, full length, vigorous cycles, it has probably been over a day since the last eruption.

If Fan and Mortar are completely silent, without any rumbling or boiling noise at all for more than 20 or 30 minutes, they have most likely erupted recently. They are almost never completely silent for more than a few minutes around the time an eruption is expected.

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I would particularly like to thank Paul Strasser, Lynn Stephens, and Jens Day for advice and comments on this article.

Mortar Geyser on July 5, 1992.
Photo by T. Scott Bryan

Activity in East Sentinel Geyser, 1991 and 1992
With Historical Perspectives

by Clark Murray

Abstract
East Sentinel Geyser is a rarely seen geyser in the Morning Glory Group, located in the Upper Geyser Basin of Yellowstone National Park, Wyoming. An observed eruption in September, 1991 led to the realization that East Sentinel is capable of two distinctly different types of activity, from two different vents within the same crater.

Introduction

East Sentinel Geyser is located on the east side of the Firehole River, about 250 feet north of Morning Glory Pool and across the river from its companion, West Sentinel Geyser. The large dark crater measures one meter by three meters, and is about three meters deep. On the west side the sinter cone slopes down directly into the river. On the east side the formation is separated from the embankment by a side channel of the Firehole River only used at the time of high water levels.

East Sentinel's crater contains at least two vents, one in the northwest corner and another in the southeast corner. Just south of the mound there is a series of very small, irregularly shaped vents, and within these the water rises and falls in synchrony with East Sentinel. It is unknown if any of these vents show any activity during East Sentinel's rare eruptions. An important member of this group is the "river drain", located below a small cascade and within the river's side channel that partially encircles East Sentinel's cone.

When active, the water within the crater boils almost continually, only slowing down at seventeen to eighteen minute intervals. When the Firehole River is high, as during spring runoff or after a heavy rain, East Sentinel will stop boiling and become a quiet intermittent spring. Large quantities of steam are almost always present, and can be seen from throughout the general vicinity.

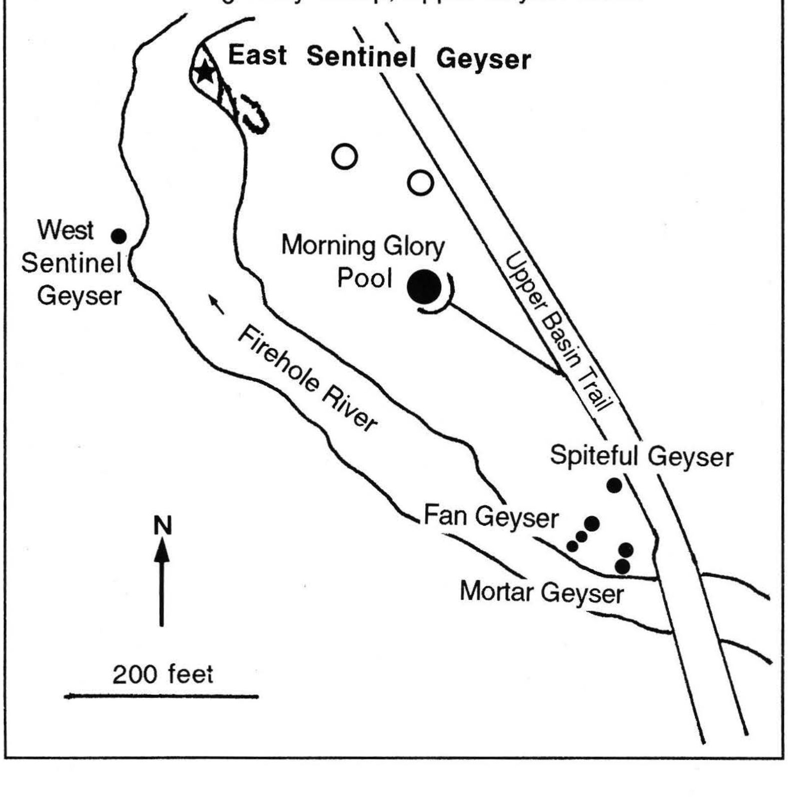
History of Activity

In 1871, Captain J.W. Barlow gave East Sentinel its name, and he reported that it was in constant agitation:

> "...its waters revolving horizontally with great violence and occasionally spouting upward to a height of 20 feet. Enormous masses of steam are ejected..." [Barlow, 1872; *in* Marler, 1973]

In 1878, Robert Strahorn gave almost the same description, but added that the *lateral* distance of the eruption was 50 feet [Strahorn, 1881]. Evidently East Sentinel erupted more frequently during the early history of the park. Barlow and Strahorn talk of occasional eruptions. Walter Weed

Figure 1
Location of East Sentinel Geyser
Morning Glory Group, Upper Geyser Basin



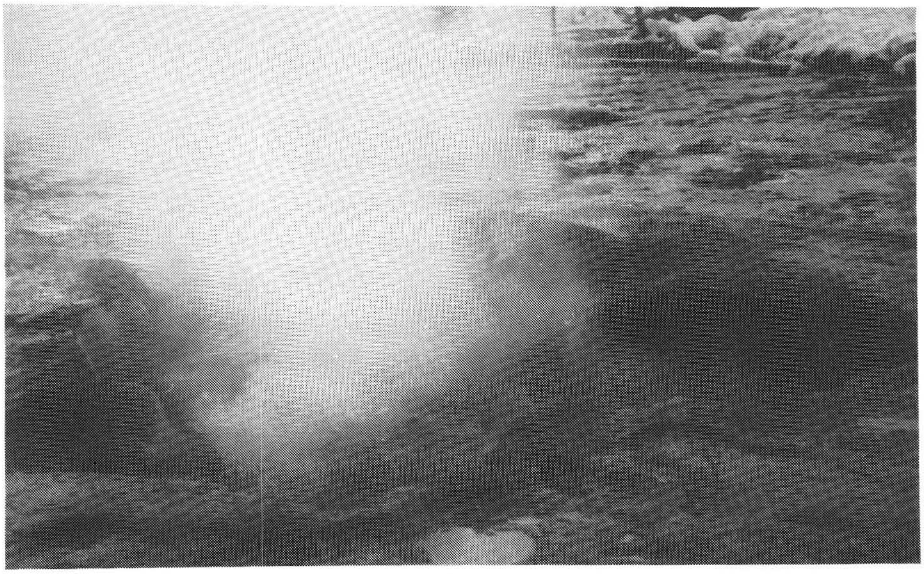


Figure 2. East Sentinel Geyser active on the "Southeast Function" during February, 1993. Telephoto picture from trail by Clark Murray.

[1897], Arnold Hague [1911], and Charles Phillips [1927] all describe eruptions in a way that would suggest somewhat frequent, or at least occasional, eruptions.

After the 1920s, the reports on East Sentinel suggest that eruptions had become infrequent occurrences. Lystrup [1931] reported an eruption at 7:25 am on July 1, 1931; Marler [1941] reported that the eruption of September 24, 1941 reached 30 to 40 feet high for a five minute duration. In 1946, Marler stated that the geyser was active many times during that season, reaching a height of 50 feet and discharging great volumes of water [Marler, 1946]. But by 1951, in a letter to Jack Haynes, he stated that "the Sentinel on the Morning Glory side [of the river] seldom erupts" [Marler, 1951]. Throughout the early 1950s, naturalists stationed at Morning Glory Pool only infrequently reported eruptions by East Sentinel. Finally, Marler reported in his *Inventory* that the January, 1952 eruption was the first that he had seen of East Sentinel [Marler, 1973].* He was unaware of any further eruptions until the night of the 1959 earthquake, and then once again on October 9, 1967.

In September, 1973, Marie Wolf observed a series of frequent minor eruptions from 2 to 3 meters high at about 8 to 15 minute intervals [Wolf, 1992]. This interesting series of eruptions will be discussed in more detail later in this paper.

On rare occasions during the 1970s and early 1980s, eruptions were seen by thermal observers such as John Railey, Herb Warren, Scott Bryan, and Rocco Paperiello, usually from a distance. Naturalist Jim Lenertz was lucky enough to be on site for the start of an eruption in the early 1980s (probably 1981) [Bryan, 1992].

The Cycle of Activity

Under normal conditions, East Sentinel exhibits a consistent pattern of activity. This pattern includes: a rising water level or overflow, a surge in both the water level and the intensity of the boiling, and a final drop in both the water level and the force of the boiling. These cycles are very consistent and regular with 16 to 20 minute periods (see Figure 3). A typical sequence of events is as follows:

1. About 4 minutes following the end of the previous cycle, water overflows the crater into the river. This overflow continues for an average of 11 minutes.

2. A surge in the water level with a consequently heavier overflow and increased intensity in the boiling. If there was to be an eruption, then it would likely begin at this point. The surge lasts 2 to 3 minutes.

3. A sudden drop in the water level, ending the 9 to 14 minute duration (Figure 3) and starting the next four minute pause.

* This statement in contradiction to his written 1941, 1946 and 1951 reports is not as strange as it might seem. At the time Marler wrote the *Inventory*, many of his early notes were unavailable from the National Park Service, and were thought to have been lost. Much of the *Inventory* was therefore pieced together from memory some 30 years after the fact [White, 1992]. Many of these "missing" reports were recently located in the Yellowstone Archives.

Periods of Inactivity

East Sentinel has occasional periods of inactivity in which boiling is either greatly reduced or stopped. During such times, the pool is noticeably cooler but, surprisingly, the same overflow cycle still occurs. These periods of inactivity generally occur in May or June, but have been seen at other times. One possible reason for this could be surface water entering into the plumbing system of the geyser. Marler observed that East Sentinel never erupted when there was high water in the Firehole River [Marler, 1967].

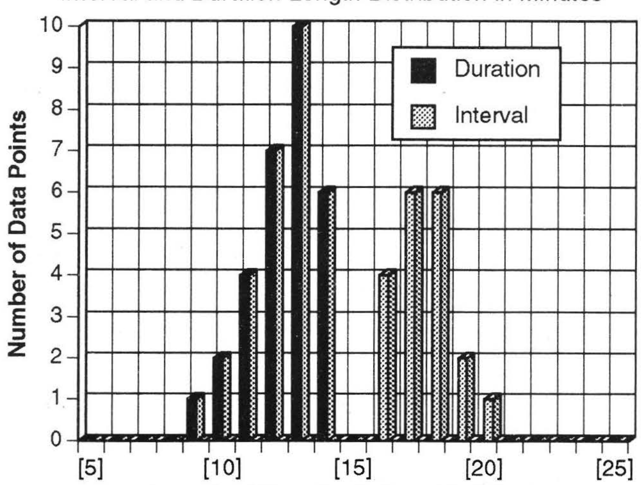
During one period of inactivity, I noted that the higher the river level, the more inactive the geyser. From the trail I could see an opening or "drain hole" below a small cascade and within the river's side channel. Water was pouring into this opening at a rate of several gallons per minute. East Sentinel was completely calm and appeared cooler than normal. The rise, surge, and drop cycle still took place, but there was no boiling. Two days later I returned after the river had dropped several inches. I found much less water flowing into the drain hole, perhaps only one gallon per minute. East Sentinel was once again superheated and lightly boiling, but not surging. By the next day, there was still less water flowing into the drain, and the surging had resumed.

So, for East Sentinel to erupt, there must be very little surface water entering the system. Since it only rarely erupts even then, however, there must be other controlling factors involved as well.

Figure 3

East Sentinel Geyser

Interval and Duration Length Distribution in Minutes



The Eruption of September 14, 1991

On the morning of September 14, 1991, I was waiting at Fan and Mortar Geysers, which at the time were between hot periods. Artemisia Geyser was expected around this time, so I passed the time watching for its steam cloud. At 09:44, the steam rising from East Sentinel suddenly doubled in both size and height, and the steam had a forced look about it. I noted the time and didn't think much more about it, but when the steam didn't diminish after two or three minutes I decided that it deserved further investigation.

When I arrived at the geyser, water was spraying 5 to 6 meters high and about 5 meters out *into* the river. The water in the vent was down, exposing a vent in the southeast corner of the crater. Most of the water erupted at a sharp angle into the side of the crater wall; only the very top of the water column actually escaped the confines of the crater, while the rest was continually recycled. If the full column had been able to erupt unimpeded, East Sentinel would have been a very impressive geyser. As it was, there was just a lot of spray. Still, the beginning of the eruption must have been impressive in order to empty the crater by the time I arrived there.

The 12 minute eruption ended at 09:56, and the remaining water in the crater drained rapidly.

Minor Eruptions and Post-Eruption Recovery

Ten minutes after the end of the eruption, the first minor eruption occurred. It was completely subterranean and consisted of about one half meter of spray lasting four minutes. This was followed seven minutes later by a second minor which lasted about one minute. Five minutes later there was a third and final minor which lasted less than 30 seconds.

By the end of the third minor, water had begun to rise in the bottom of the crater, and it immediately exhibited the rise, surge, and drop pattern of activity that characterizes East Sentinel's long intervals between eruptions. The rate of refilling was very impressive, at almost an inch and a half per minute. Overflow was first reached at 11:21, only 57 minutes following the last minor eruption. Superheated boiling began only 22 minutes after the start of overflow.

False Starts

After overflow was reached at 11:21, it took two hours for the cycle of activity to stabilize into its normal pattern. During the period of instability, two false starts occurred. At 12:26 a cycle began, and only four minutes into it a surge took place, followed by a much larger one at 12:37. This was a massive one meter surge which poured water out into the river. Although an eruption seemed inevitable, the water level ultimately did drop. The next cycle was a typical 17 minute period. But when the following cycle began at 13:00, it took less than one minute for a false start to occur. This one surged to as much as two meters high, and it again seemed impossible that this could not induce an eruption. A weaker surge happened eleven minutes into the same cycle. From this point on, the cycles became more regular, with 16 to 18 minute intervals.

The geyser was kept under constant observation until 15:00, when permission was given to place markers on the river side of the sinter platform. The markers were checked at 20:00 and were unchanged. At 08:30 the next morning, however, it was found that the markers had been washed during the night. That unseen eruption proved to be the last of the series.

Classifying the Types of Eruptions

Since the start of the September 14 eruption was not seen, it is difficult to say what East Sentinel does immediately prior to an eruption, or even what the start itself would look like. But what is clear is that this was very different from most earlier documented eruptions.

Through correspondences with Scott Bryan concerning the September eruption series, it became clear that East Sentinel is capable of at least two different types of eruptions, through two different vents within the one crater. Subsequent observations have shown that these eruption types correspond to at least two different activity functions relating to the different vents.

"Northwest Function": When East Sentinel is on this function, the heaviest boiling occurs in the northwest corner and along the western edge of the crater. The southeast vent is completely inactive. The most commonly reported eruptions occur during this function, and are described as cone-type eruptions jetting water 25 to 50 feet high and as far as 50 feet toward the southwest, often scalding the grass and flowers in a small erosional alcove near the head of the river's side channel. Some of these eruptions are described as short, with durations as short as 30 seconds. However Weed describes an eruption lasting 5½ minutes in 1886 [Whittlesey, 1988], while some of those seen during the early 1980s at least matched that. (Bryan saw one 1981 eruption in progress from near Grotto Geyser, and it continued for a few minutes after his arrival by bicycle.) Bryan reports:

> "The area where this water landed corresponds to the slight valley-like depression which has a small tree growing in its upper part. The lower branches of that tree are dead because of the hot spray of the eruptions of the early 1980s." [Bryan, 1992]

"Southeast Function": When the geyser is on this function nearly all activity is from a vent in the southeast corner of the crater with very little action from the northwest vent. Eruptions are angled out over the sinter platform and into the river, in almost the completely opposite direction from the northwest function eruptions. These eruptions last much longer— in the case of the September 14 eruption, 12 minutes. Eruptions of this type have only been noted in 1973 and 1991-1992.

Marie Wolf recalls:

> "A series of frequent minor eruptions from the vent on the side of the basin away from the Firehole River was seen in September of this year [1973]. From a relatively quiet pool, the activity from this vent would gradually increase until it would suddenly turn into jets to about 6 to 10 feet high. This activity lasted a few minutes and then would gradually die down. The water in the crater would then drop below overflow. Pauses would last about 8 to 15 minutes." [Wolf, 1992]

During my observations in 1992, I demonstrated that East Sentinel often would alternate between the two functions, sometimes having an eruption on one function and then recovering on the other function. Although back to back eruptions on the same function did occur, Rocco Paperiello noted in September, 1981 that a series of minor eruptions, which proved to be a preliminary build up of activity, would start at one vent. Just when it appeared to be ready to produce a major eruption, the opposite vent played 5 to 10 feet high instead. Intervals were in the 10 to 15 minute range, and durations were 10 to 15 seconds. [Paperiello, 1992].

Discussion

It is very probable that East Sentinel erupts more frequently than it is given credit for. First, it's not often checked. Even in 1911, Arnold Hague noted, "The tendency is to pass the Sentinel without halting", something that most of us still do some 80 years later. Second, even if it was checked regularly, the refilling of the crater is so rapid that it would appear normal within 60 minutes of an eruption.

In 1991-1992, markers were being washed frequently. I was in the park many times that year, and on every visit but one I found my markers from the previous visit washed. During July, 1992, the markers were washed away an average of two to three times per week, but by September the frequency had been reduced to about once per week. Was 1992 an exceptional year, or was it just that East Sentinel was being systematically observed for the first time? Perhaps with a concerted effort to collect data in the future we can obtain a more complete understanding of this unusual, dual-vent geyser.

Acknowledgements

Special thanks to Scott Bryan, who first suggested the idea that there could be more than one geyser vent within East Sentinel, and to his efforts to collect data during July, 1992 after I had to leave Yellowstone; to Rocco Paperiello, who provided recollections and almost all the historical information needed for this report; and to Marie Wolf, for her additional recollections.

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EAST SENTINEL DATA 1991-1992

09/14/91	09:44	Start of the eruption		
	09:51	Time I first arrived at the geyser		
	09:56	Eruption ends - twelve minute duration		
	10:06	Minor subterranean eruption		
	10:10	End of first minor - four minute duration		
	10:17	Second minor begins		
	10:18	End of second minor - one minute duration		
	10:23	Start and end of thirty second minor		
	10:24	Rapid refill begins		
	11:21	Time of first overflow		
	11:43	Superheated boiling begins		
	11:55	Heavy half meter boil		
	12:05	Surge in water level		
	12:06	Drop in water level		
09/14/91	12:10	Overflow	-	
	12:13	Surge	-	03 minutes into cycle
	12:22	Drop	-	09 minutes after surge
		Duration	-	12 minutes
09/14/91	12:26	Overflow	-	16 minute interval
	12:30	First surge		04 minutes into cycle
	12:37	Second surge		11 minutes into cycle
	12:40	Drop	-	03 minutes after surge
		Duration	-	14 minutes
09/14/91	12:43	Overflow	-	17 minute interval
	12:54	Surge	-	11 minutes into cycle
	12:57	Drop	-	03 minutes after surge
		Duration	-	14 minutes
09/14/91	13:00	Overflow	-	17 minute interval
	13:01	False start		01 minute into cycle
	13:11	Surge	-	11 minutes into cycle
	13:14	Drop	-	03 minutes after surge
		Duration	-	14 minutes
09/14/91	13:16	Overflow	-	16 minute interval
	13:28	Surge	-	12 minutes into cycle
	13:30	Drop	-	02 minutes after surge
		Duration	-	14 minutes
09/14/91	13:34	Overflow	-	18 minute interval
	13:45	Surge	-	11 minutes into cycle
	13:47	Drop	-	02 minutes after surge
		Duration	-	13 minutes

EAST SENTINEL DATA

09/14/91	13:51	Overflow	-	17 minute interval
	14:02	Surge	-	11 minutes into cycle
	14:04	Drop	-	02 minutes after surge
		Duration	-	13 minutes
09/14/91	14:08	Overflow	-	17 minute interval
	14:19	Surge	-	11 minutes into cycle
	14:22	Drop	-	03 minutes after surge
		Duration	-	14 minutes
09/14/91	14:26	Overflow	-	18 minute interval
	14:36	Surge	-	10 minutes into cycle
	14:39	Drop	-	03 minutes after surge
		Duration	-	13 minutes
09/14/91	14:43	Overflow	-	17 minute interval
	14:53	Surge	-	10 minutes into cycle
	14:56	Drop	-	03 minutes after surge
		Duration	-	13 minutes

End of observation - The next major eruption occurred between 20:00 and 08:30. All the above cycles were on the "Southeast Function".

03/01/92	09:28	Overflow	-	
	09:34	Surge	-	06 minutes into cycle
	09:37	Drop	-	03 minutes after surge
		Duration	-	09 minutes
03/01/92	09:44	Overflow	-	16 minute interval
	09:52	Surge	-	08 minutes into cycle
	09:55	Drop	-	03 minutes after surge
		Duration	-	11 minutes
03/01/92	10:02	Overflow	-	18 minute interval
	10:09	Surge	-	07 minutes into cycle
	10:12	Drop	-	03 minutes after surge
		Duration	-	10 minutes

The above cycles were all on the "Southeast Function". Markers that were placed in September, 1991 were gone by this date.

05/25/92 Markers placed in March, 1992 were gone by this date. The Firehole River's water level was high and East Sentinel was inactive.

EAST SENTINEL DATA

06/12/92	09:18	Overflow	-	
	09:28	Surge	-	10 minutes into cycle
	09:30	Drop	-	02 minutes after surge
		Duration	-	12 minutes
06/12/92	13:07	Overflow	-	
	13:16	Surge	-	09 minutes into cycle
	13:18	Drop	-	02 minutes after surge
		Duration	-	11 minutes
06/12/92	13:23	Overflow	-	16 minute interval
	13:32	Surge	-	09 minutes into cycle
	13:35	Drop	-	03 minutes after surge
		Duration	-	12 minutes

Markers still in place from 05/25/92. East Sentinel performing on the "Northwest Function"

Several eruptions occurred between 06/18/92 and 07/10/92, the last eruption during this period was on the "Northwest Function".

07/14/92	08:30	Overflow	-	
	08:39	Surge	-	09 minutes into cycle
	08:42	Drop	-	03 minutes after surge
		Duration	-	12 minutes
07/14/92	08:48	Overflow	-	18 minute interval
	08:56	Surge	-	08 minutes into cycle
	08:59	Drop	-	03 minutes after surge
		Duration	-	11 minutes
07/14/92	09:06	Overflow	-	18 minute interval
	09:14	Surge	-	08 minutes into cycle
	09:17	Drop	-	03 minutes after surge
		Duration	-	11 minutes

East Sentinel was on the "Southeast function" during this period. Known eruptions occurred on 7/21/92, 7/22/92, and 7/24/92.

09/10/92	18:08	Overflow	-	
	18:17	Surge	-	09 minutes into the cycle
	18:20	Drop	-	03 minutes after surge
		Duration	-	12 minutes
09/10/92	18:43	Overflow	-	
	18:52	Surge	-	09 minutes into the cycle
	18:55	Drop	-	03 minutes after surge
		Duration	-	12 minutes

EAST SENTINEL DATA

09/10/92	19:18	Overflow	-	
	19:28	Surge	-	10 minutes into the cycle
	19:31	Drop	-	03 minutes after surge
		Duration	-	13 minutes
09/10/92	19:38	Overflow	-	20 minute interval
	19:45	Surge	-	07 minutes into the cycle
	19:48	Drop	-	03 minutes after surge
		Duration	-	10 minutes
09/10/92	23:05	Eruption on the "Northwest Function", which recovered on the "Southeast Function".		
09/12/92	09:03	Overflow	-	
	09:12	Surge	-	09 minutes into the cycle
	09:15	Drop	-	03 minutes after surge
		Duration	-	12 minutes
09/12/92	09:20	Overflow	-	17 minute interval
	09:30	Surge	-	10 minutes into the cycle
	09:34	Drop	-	04 minutes after surge
		Duration	-	14 minutes
09/12/92	09:39	Overflow	-	19 minute interval
	09:49	Surge	-	10 minutes into the cycle
	09:52	Drop	-	03 minutes after surge
		Duration	-	13 minutes
09/12/92	10:33	Overflow	-	
	10:43	Surge	-	10 minutes into the cycle
	10:46	Drop	-	03 minutes after surge
		Duration	-	13 minutes
09/12/92	10:51	Overflow	-	18 minute interval
	11:01	Surge	-	10 minutes into the cycle
	11:04	Drop	-	03 minutes after surge
		Duration	-	13 minutes
09/12/92	11:10	Overflow	-	19 minute interval
	11:19	Surge	-	09 minutes into the cycle
	11:23	Drop	-	04 minutes after surge
		Duration	-	13 minutes
09/12/92	13:51	Overflow	-	
	14:01	Surge	-	10 minutes into the cycle
	14:04	Drop	-	03 minutes after surge
		Duration	-	13 minutes

Atomizer Geyser and Its Major Intervals:
July–August, 1985
With Notes on Changes Since 1985

David Leeking

Abstract

During five non-consecutive periods during July and August, 1985, Atomizer Geyser was observed in an effort to make the first-ever, accurate determination as to its true eruptive nature. A total of 13 intervals between major eruptions were logged. Data was also obtained about the minor activity which culminates in the major eruption. Notes about the activity since 1985 are included.

Location and Introduction

Atomizer Geyser is a member of the Cascade Group of hot springs in the Upper Geyser Basin of Yellowstone National Park. Because of its relatively remote off-trail location, long intervals between eruptions, and most durations of only few seconds, it is among the least observed of the Upper Basin's moderate sized geysers. Atomizer is readily visible from the trail above Artemisia Geyser, but is an off–trail feature which cannot be closely approached without special research permission.

Atomizer consists of two small geyserite cones a few feet apart from each other. They lie about ten feet north of the broad center runoff channel of nearby Artemisia Geyser. Except on extremely rare occasions, the eastern cone erupts only at the time of a major eruption; this cone, the "atomizer" of the geyser's name, had only a few small openings at the top of a nearly sealed-off summit until an act of vandalizm in August, 1987. The western cone is topped by an open bowl centered by the vent which narrows as it penetrates downward at a slight angle. This cone produces a series of overflow episodes and progressively higher and longer lasting minor precursor eruptions during the interval between major eruptions. It is during the early minutes of a major eruption that the eastern cone emits an atomizer-like spray of steam and fine water droplets while the western cone plays a steady jet of water as high as 50 feet. This major water phase is followed by a steam phase which gradually declines during the next half hour until it consists only of quietly welling steam emission.

Minor Eruptions

Of all the medium-sized geysers in the Upper Basin which erupt daily, Atomizer is undoubtedly the one about which the least is known. This is particularly true of the intervals between Atomizer's major eruptions, which have only rarely been obtained. Marler [1973, p.54] states that "the intervals between the steam-phase eruptions have not as yet been determined." For many years the Park Service Naturalists and geyser gazers had only vague ideas about the interval between these major eruptions. I heard estimates everywhere from 14 to 22 hours, and at times Atomizer was said to erupt "once per day." It was because of this great lack of knowledge that, during July and August, 1985, I obtained nine exact and four approximate major intervals.

While little had been known about the major intervals, the sequence of events leading up to these major steam-phase eruptions had been well known and remains substantially unchanged from Marler's [1973] account. After several hours of inactivity following the slow petering out of a major eruption's long (over one hour total) steam phase, Atomizer's western cone begins to have periodic overflows. Of varying length, they commonly last about two minutes and are often accompanied by boiling. This boiling becomes more vigorous and prolonged as the first minor eruption approaches.

The first minor eruption occurs when one of the boiling overflows suddenly lifts into an eruption. Because Atomizer has many overflows and boiling periods without erupting, the durations are times from the start of the eruptive lifting rather than from the start of overflow or boiling. There are a half dozen or more minor eruptions during the interval leading to the major.

The durations of the minor eruptions vary between about 25 and 75 seconds, those of the first few minors being shorter than those of the last few before the major. This pattern, though not totally reliable, is consistent enough to allow an observer to crudely judge where Atomizer is within a minor series. The height of the minors also increases as the major approaches, 10 to 20 feet being typical for early eruptions and 18 to 30 feet for later ones in the sequence.

Atomizer's eruption intervals show an interesting pattern. Once begun, the minor eruptions tend to recur on intervals of about 1 hour *until* the final two intervals. The span between the penultimate and the final minor is most often between 1½ and 2 hours long. The interval between the final minor and the major is bimodal, being either 10 to 16 minutes long *or* about 1 hour long.

A major eruption begins in the same fashion as a minor but continues to build in force and height. The jet from the western cone usually reaches between 30 and 40 feet high. Especially powerful eruptions under windless conditions may approach 50 feet; because of the slenderness of Atomizer's water column and the fact that it is jetted at an angle, the height can be reduced markedly by strong winds. The eastern "atomizer" cone's steam eruption begins a little more than a minute after the western cone has begun the major eruption.

Atomizer Geyser as seen during a major eruption in 1988. Photo by T. Scott Bryan.

Observations of July and August, 1985

Between July 8 and August 8, 1985, I obtained nine closed and four approximate major eruption intervals for Atomizer Geyser. They were surprisingly consistent, varying between approximately 13½ hours and 15¾ hours. The data is shown on Table 1. The average of the 13 intervals was 14h 47m. One additional major interval of 14h 52m was obtained on June 25-26, 1984 by Rocco Paperiello. Using truncation, the average interval remains 14h 47m when this interval is added to the 1985 data.

The durations were also consistent, 8 to 10 minutes elapsing until the last water was visible before the western cone's column turned completely to steam. This usually takes nine minutes and is a relatively accurate way of determining the start time of a major eruption when it is first seen in-eruption. I have timed this duration many times over the years, and it has proven highly consistent. Similarly, the steam phases have an event which, per the nine times it was measured in 1985, also proved very consistent in duration. Varying between 30 and 32 minutes, and usually 32, this is the time at which an observer standing near the geyser can

Table 1

Major Eruption Intervals of Atomizer Geyser

July-August, 1985

Date		Time	Interval	Notes
July	8	08:35	—	
	8	22:45	14h 10m	
	9	14:17	15h 32m	
July	14	09:23	—	
	15	00:15	14h 52m	
	15	≈ 15:00	14h 45m	Based on audible steam end at 15:32
July	25	18:45	—	
	26	≈ 09:15	≈ 13h 30m	I.E. late steam; est. start 08:15-08:30
	26	21:53	≈ 13h 30m	
July	31	≈ 18:23	—	I.E. early steam; est. start 18:05-18:10
Aug	1	09:53	≈ 15h 45m	
	2	00:55	15h 02m	
	2	16:29	15h 34m	
	3	07:32	15h 03m	
	3	22:50	15h 18m	
	4	14:02	15h 12m	
Aug	8	≈ 00:07	—	Based on audible steam end at 00:39
	8	≈ 14:11	≈ 14h 04m	Based on audible steam end at 14:43

hear steam escaping from the geyser's vent for the last time. Do note that the steam phase volume can fade in and out as it progresses; the time here is for the *last* fade out. I call this "the last audible steam", and it was an equally useful way of determining the approximate start time of an eruption if one arrived within the first half hour. Such steam phase determinations are noted in Table 1.

Unusual Minor Activity

On the morning of August 1, 1985, at 09:37 I observed a bizarre minor eruption by Atomizer. The normally inactive eastern cone erupted large drops of water, about the size of standard marbles, up to 3 feet high for 2m 35s without any accompanying steam. Preceeding this eruption, the shallow basin on top of the western cone filled with water but did not overflow, and it remained in this state for the first 1m 45s of the eastern cone's eruption. Then it abruptly drained.

This water eruption by the eastern cone, of notably longer duration than any normal minor eruption I have ever seen or heard of, seemed to abort an impending eruption of its bigger neighbor in much the same fashion as South Grotto Fountain does with (North) Grotto

Fountain. This strange eruption was followed by an entirely normal major eruption of Atomizer at 09:53. The water duration was 9 minutes, and the audible steam duration was 32 minutes.

The time interval between this unusual, last minor eruption and the major was16 minutes, fitting into the short mode final interval the geyser has shown for many years.

Of the numerous geyser gazers I spoke with about Atomizer's odd eruption, only Paul and Suzanne Strasser have ever seen one like it. Paul said the first major eruption they ever saw of Atomizer (in about 1979) was one which followed just such a water eruption from the eastern cone. They took little note of it at the time because they thought all major eruptions began that way! This shows, however, that such activity is not unique; in fact, that it has been seen twice in a geyser only infrequently observed might imply a fair degree of frequency for this action.

Changes Since 1985

The 1985 study was limited. While it provided considerable insight as to Atomizer's overall nature, it also raised a number of questions. I suspected that some of the major intervals could be substantially longer than any I recorded during 1985. Scott Bryan and Rocco Paperiello, both of whom have observed Atomizer fairly often, had the same suspicions.

During 1988, I obtained one interval of 16h 34m. Between then and 1990 I also recorded a few inferred double intervals of more than 32 hours. Lynn Stephens told me that she recorded a major interval of greater than 17 hours, and in 1992 Scott Bryan used markers to confirm one interval longer than 19½ hours.

The data also goes the other direction. In 1985 I regretted that I was unable to obtain exact lengths for the short (approximately 13½ hour) intervals. The first of those took me by surprise, since I didn't think intervals that short were possible. In 1986, however, I obtained a precise major interval of just 12h 48m.

These limits make Atomizer much less regular than had been inferred in 1985, yet they are also such as to probably "cancel out", leaving the average interval somewhere near 15 hours.

Observations continuing since 1985 have revealed conclusively that the seemingly reliable "last audible steam" durations used in 1985 must be discarded. Several durations times were between 38 and 51 minutes rather than the 30 to 32 I consistently got in 1985. Others seem to fall at 34 minutes. A question that arises now is: "Is there a relationship between steam phase duration and subsequent interval?"

The other estimating factor, that of water phase duration, has panned out. In all observations it has an extremely consistent duration of 8 to 10, usually 9 to 10 minutes. Thus, if an observer sees the end of the water phase, an estimated start time for interval purposes will be accurate to within ±1 minute.

In August, 1987, the eastern cone of Atomizer was vandalized. Although nothing was ever proved, the time of the destruction was determined to within a few minutes; at about that same time, other vandalism acts were witnessed by visitors near Grotto. The perpetrator was a concession employee. The result was that the Atomizer cone's unique, honeycomb-like orifices were broken to bits. The vent is now a single jagged, rather rectangular opening which measures about 6 by 3.5 inches. Fortunately, Atomizer's overall intervals and character were not changed by the damage, but the eastern cone is now somewhat less of an atomizer than it once was.

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Jewel Geyser

5 August 1992 and 27 September 1992

by: Ralph C. Taylor

Abstract

This report describes the activity of Jewel Geyser during two short periods of observation in the summer of 1992. The number of bursts per eruption and eruption intervals are contrasted with the values from the author's observations in 1989, 1990, and 1991. The 1992 activity had significantly more bursts per eruption and longer intervals.

Introduction

This paper is an update to the author's 1989 and 1990 Jewel Geyser reports [Taylor 1989, 1992]. These reports discussed the eruption frequency and number of bursts per eruption, and described a relationship between the number of bursts in an eruption and the subsequent interval. In 1989, 1990, and May 1991 the eruption patterns were similar in the distribution of the number of bursts per eruption and the eruption intervals. This paper extends the previous report with data for an additional 41 closed intervals recorded during a six-hour period on 8 August 1991 and data recorded in August and September 1992.

I observed Jewel Geyser for 12 closed intervals during a 2-hour period on 9 August 1992 and 13 closed intervals during a 2h40m period on 27 September 1992. The 1992 intervals were signficantly longer than the intervals reported in our previous observations. Also, the burst count in each eruption was significantly higher in September.

Jewel Geyser's Formation

In our 1989 paper on Jewel Geyser we described a "plopping" sound that originated from a point northwest of the main vent just before an eruption. The source of this sound is not visible from the boardwalk, and remained a mystery. We ascribed the sound to a hole in the formation being covered by waves in the rising water.

On 26 September 1992 I was able to investigate the source of the "plop" sound. I accompanied Rick Hutchinson, Yellowstone National Park Research Geologist, to the crater of Jewel Geyser early in the morning. We saw that the sound originates from the eruption of a small vent located about 90 cm north-northwest of the edge of the main pool. This auxiliary vent is about 35mm by 85 mm in size. It is located in a region of beautifully beaded geyserite containing some catch basins filled with filamentous cyanobacteria. One of these basins in a runoff channel north-northeast of the main Jewel Geyser cone has a similarly sized vent that appears to act as a drain. The auxiliary vent appears to be indirectly connected to Jewel's main plumbing since it erupts to a height of a few centimeters just before Jewel erupts. The eruptions of this small vent are barely visible from the boardwalk, but the vent itself cannot be seen from the boardwalk.

The eruptions of Jewel Geyser that I saw on 8 August 1991 consisted of from one to nine bursts. During my 5 August 1992 observations, the number of bursts varied from one to six. All of the eruptions that I saw on 27 September 1992 had five to nine bursts.

The bursts of an eruption last approximately two seconds. During an eruption, the bursts are separated by variable intervals, ranging from 7s to as much as 19s. I was not able to determine any relationship between the interburst time and the strength of the bursts. All bursts, regardless of size, result from a single, violent steam explosion in the plumbing of the geyser.

Observed Eruption Data

This section describes my observations of Jewel's eruptions in August 1991 and in August and September 1992. The new observations are compared with similar observations from our 1989 and 1992 work.

Figure 1 shows the distribution of bursts by size for the days for which observation data is available. We categorized the bursts as small, medium, large, and huge. *Small* bursts reach 1.5 to 3 meters in height and the splashes fall

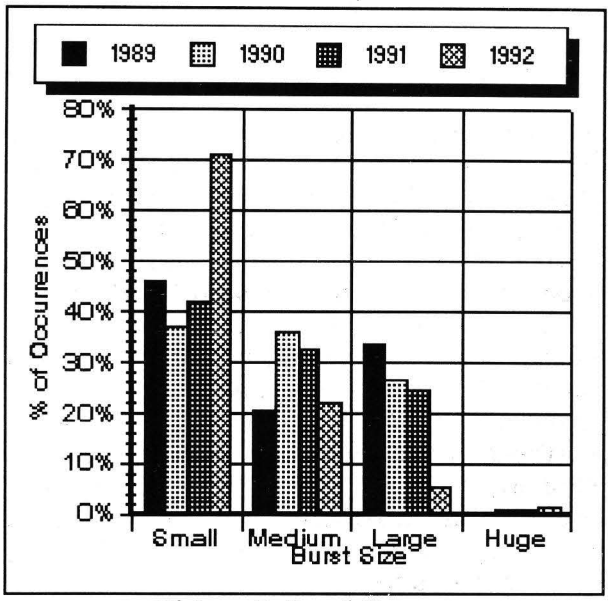

Figure 1 Jewel Geyser
Burst Size Distribution

back into the pool of water around the vent. *Medium* bursts reach 3 to 4 meters in height and splash on the sinter around the vent but do not cross the prominent sinter mound to the southwest of the vent. *Large* bursts reach over 5 meters in height and splash out of the inner formation, across the sinter mound, and to the gravel wash area beyond the edge of the sinter platform. The large bursts collaps so suddenly that the water, having been discharged at a 20 degree angle to the vertical,

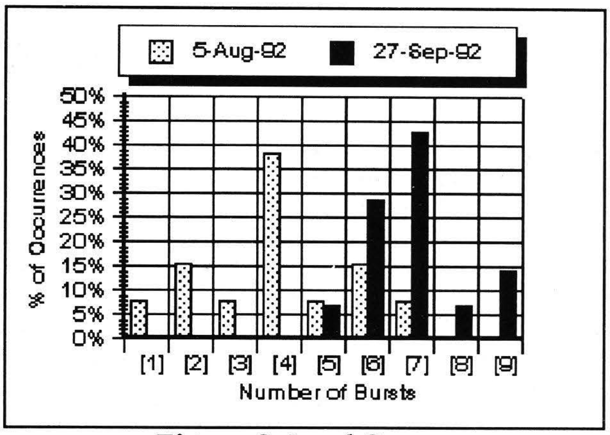

Figure 3 Jewel Geyser
Bursts per Eruption (1992)

falls to the ground in a delayed splash that ends well after the water over the vent has subsided. A few bursts were *huge*, some reaching halfway to the boardwalk. We did not recognize huge bursts as a separate category until 1990. The last column in each burst size section of the chart represents the 1992 observations. The percentage of *small* bursts in 1992 is significantly higher than in 1990 and 1991. The fraction of bursts of *medium* and *large* size is correspondingly reduced. The shift is dramatic; the percentage of *small* bursts increased 20%, while the percentage of *medium* bursts dropped 10% and that of *large* bursts dropped by more than 20%.

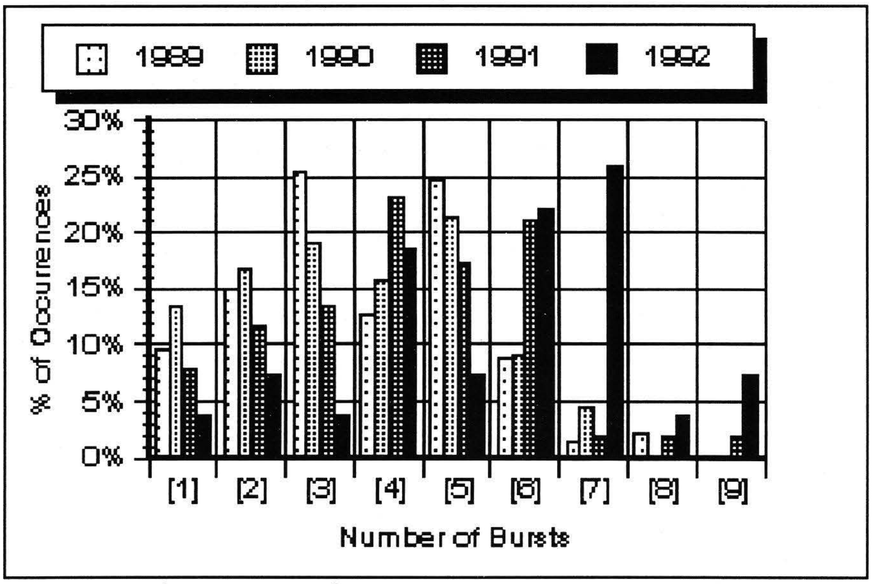

Figure 2 Jewel Geyser - Bursts Per Eruption

The total eruption activity did not decrease, however. Figure 2 illustrates the distribution of the number of bursts per eruption for our observations in 1989, 1990, 1991, and 1992. In 1991 the average number of bursts per eruption began to increase; the increase was greater in 1992. Figure 3 shows that the increase actually occurred between early August and late September. The mean number of bursts per eruption remained about four bursts per eruption for 1989, 1990, 1991, and 5 August 1992 (see Figure 4). However, by

JEWEL GEYSER

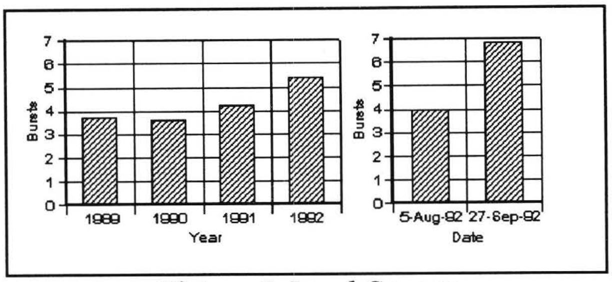

Figure 4 Jewel Geyser
Mean Number of Bursts per Eruption

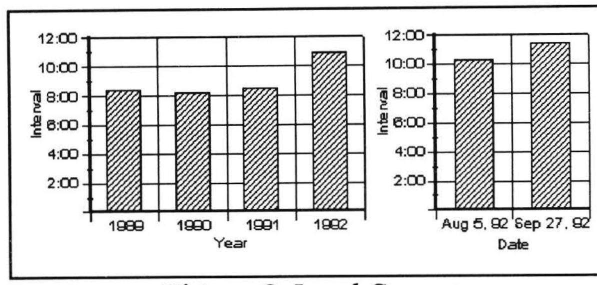

Figure 6 Jewel Geyser
Mean Eruption Interval

27 September 1992 the mean number of bursts was 6.79 bursts per eruption. The apparent increase in the number of bursts could be an artifact of the limited number of observations, but the agreement of the mean number of bursts on 5 August 1992 and the prior three years suggests that a significant change may have occurred. Figure 4 shows that not only did the mean shift, but there were *no* eruptions with 1, 2, 3, or 4 bursts. The significance of the change is unclear, but some important event appears to have occurred between early August and late September 1992.

It is distinctly possible that the increase was related to the leaking of the cap of Research Well Y-8, which was known to be leaking at a rate of 35 gallons per minute in early November [Barker 1992]. This leakage lowered Jewel's pool level so that the water was not visible from the boardwalk and the overflow completely stopped [Bryan 1992]. When I observed Jewel in September, the water level was comparable to the levels seen in previous years, and eruptions were accompanied by overflow from the crater. Robert Bower's observations, reported in *The Geyser Gazer SPUT*, are comparable to the burst distribution that I saw on 27 September 1992 [Barker 1992]. Bower reported a mean of 6.6 bursts per eruption, very close to the 6.79 bursts per eruption on 27 September 1992 and far above the average of about 4 bursts per eruption that I observed on all other days.

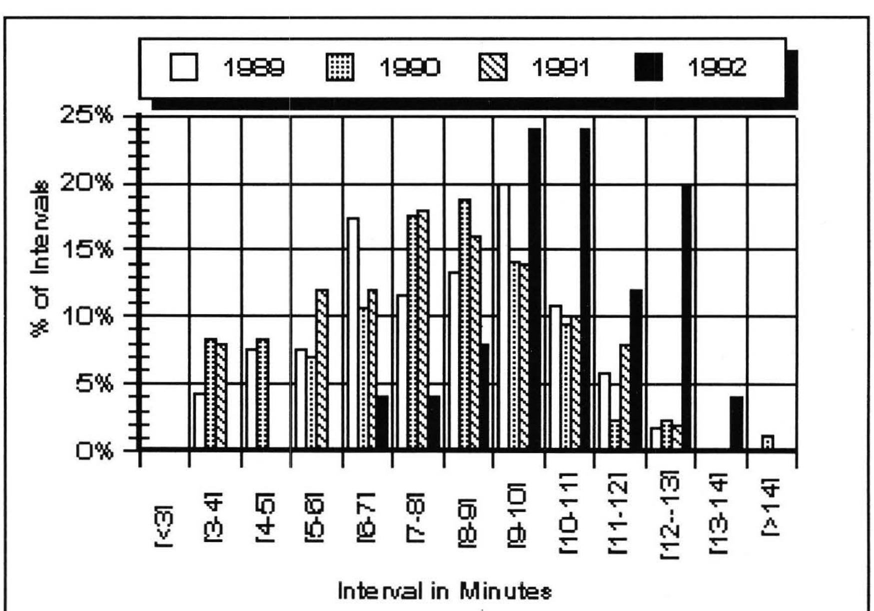

Figure 5 Jewel Geyser - Eruption Interval Distribution

Figure 5 shows the interval distribution for the four years covered by our observations. The interval distributions for 1989-91 are similar, but there is a shift to longer intervals in 1992. As with the burst per eruption distribution, the shift is not only to longer intervals, but there is a complete absence of intervals less than six minutes. Figure 6 shows the mean intervals for our observations in 1989, 1990, 1991, and 1992. As with the bursts per eruption, the mean intervals were generally the same for the first three years and significantly longer in 1992. However, unlike the bursts

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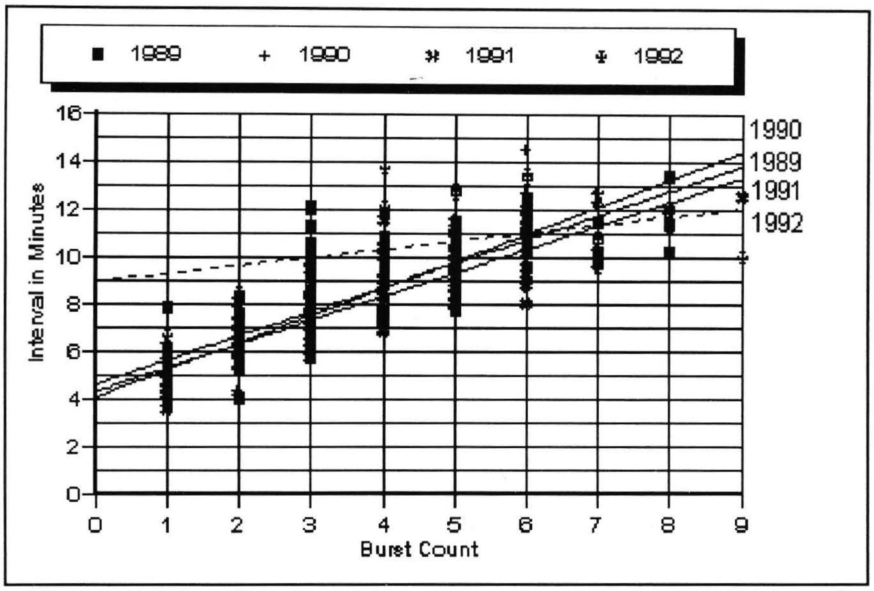

Figure 7 - Jewel Geyser - Burst Count vs Subsequent Interval

per eruption, the mean interval was significantly longer than in the previous years by 5 August 1992, and increased even more by 27 September 1992. This suggests that the increase in activity had begun by early August but had not yet fully developed, at least not to the point of reducing the average number of bursts per eruption. Note that the intervals that I observed are much longer than those reported by Bower in November. The mean of Bower's November intervals was 7m54s, similar to the intervals I saw before 1992, but more than 2m shorter than the 5 August 1992 and 27 September 1992 intervals. This suggests that the shift in intervals occurs before the change in number of bursts, since the intervals had lengthened by 5 August 1992 but the burst count did not increase until later. Similarly, the number of bursts was still elevated in November but the intervals had already recovered to the 1989-91 levels.

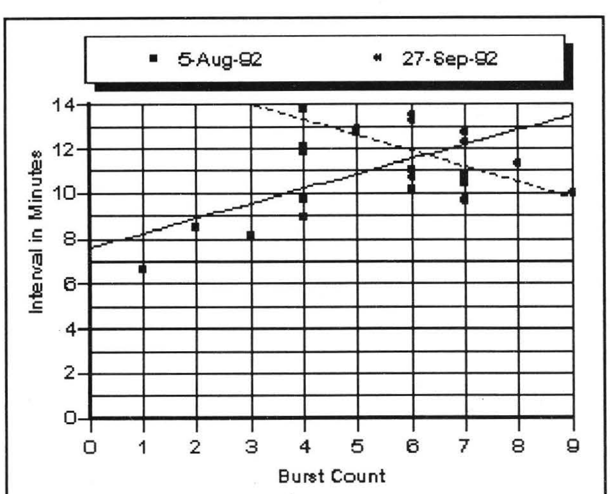

Figure 8 Jewel Geyser
Burst Count vs Subsequent Interval, 1992

Analysis Of Eruption Patterns

Our previous papers described a relation between the number of bursts in an eruption of Jewel Geyser and the subsequent interval. The equation coefficients changed, but the values were similar from year to year. A simplified form of the equation provided a fairly accurate predictor for the time of the next eruption by simply counting the bursts in an eruption.

Figure 7 shows the straight lines fitted to our observed data for the four years of this study. The dashed line with the noticeably flatter slope is the 1992 line. This flat slope indicates that the interval is influenced less by the number of bursts in the preceding eruption.

Figure 8 shows the straight line curve fits for the two days in 1992. There were relatively few observations on both days (12 closed intervals on 5 August 1992 and 13 on 27 September 1992). This small sample size makes the conclusions less certain, but the trends are clear. First, the correlation of interval with the preceding eruption burst count is only 0.534 for 5 August 1992 and -0.526 for 27 September 1992. The correlations for 1989, 1990, and 1991 were between 0.7 and 0.85. This suggests that the relationship between bursts and interval is weaker in 1992 than in the previous years.

The equations for each of the four years are shown on this page. The coefficients are close to the same values for 1989, 1990, and 1991,

JEWEL GEYSER

Date	A_0	A_1	Std Err of Prediction	Adjusted R Square	Correlation Coefficient
5 Aug 89	5.009	0.893	1.078	0.685	0.835
10 Aug 89	3.942	1.134	1.216	0.775	0.885
14 Aug 89	4.136	1.048	0.947	0.719	0.852
16 Aug 89	5.291	1.106	1.628	0.509	0.725
All 1989	4.640	1.021	1.308	0.629	0.795
6 Aug 90	4.351	1.151	1.078	0.838	0.920
7 Aug 90	4.237	1.145	1.323	0.663	0.819
14 Aug 90	3.401	1.219	1.063	0.735	0.864
All 1990	4.100	1.148	1.206	0.724	0.853
26 May 91	5.037	0.793	1.040	0.542	0.774
8 Aug 91	4.257	1.026	1.331	0.670	0.824
All 1991	4.345	1.002	1.271	0.667	0.821
5 Aug 92	7.596	0.656	1.849	0.214	0.534
27 Sep 92	16.168	-0.702	1.200	0.212	-0.527
All 1992	8.990	0.345	1.704	0.095	0.365

Table 1 - Jewel Geyser Burst Count vs Interval Curve Fit Statistics

but change noticeably in 1992. The values have shifted significantly by 5 August 1992, but the slope remains positive (that is, intervals get longer with increasing number of bursts). By 27 September 1992 the slope had become *negative*, so the interval tended to get *shorter* as the burst count increased.

$$I = 4.64 + 1.02 \times Bursts \quad (1989)$$
$$I = 4.10 + 1.15 \times Bursts \quad (1990)$$
$$I = 4.35 + 1.00 \times Bursts \quad (1991)$$

$$I = 7.60 + 0.66 \times Bursts \quad (5/Aug/92)$$
$$I = 16.17 - 0.70 \times Bursts \quad (27/Sep/92)$$

$$I = 8.99 + 0.34 \times Bursts \quad (all\ 1992)$$

The equations are all of the form

$$Interval = a_0 \times Bursts + a_1$$

where a_0 and a_1 are coefficients representing the intercept and slope of the line. a_0 can be thought of as the base interval, or as the interval following a theoretical zero burst eruption. a_1 represents the change in interval attributable to each eruption burst. Table 1 shows the values of these coefficients for each day's data, and for the complete data set for each year. The table also lists the correlation coefficient and statistical error measures that represent the closeness of the fit of the line to the data. The correlation of number of bursts to the subsequent interval stayed high from 1989 through 1991, then dropped to about 0.5 in 1992.

Conclusions

Jewel Geyser's behavior changed noticeably in 1992 as compared to the previous three years. The change manifested itself by early August as an increase in the eruption interval by two minutes from the 1989-91 average of 8m. At that time, the number of bursts per eruption had not changed from 1989-91. Based on a small number of observations, the mean number of bursts in early August appeared unchanged from the average of about four bursts per eruption during the previous three years. Although my data from the previous years did not include September observations, there was good agreement between the 1989, 1990, and 1991 data and the August 1992 data. By late September 1992, however, the mean number of bursts had increased dramatically to nearly seven. This increase in activity by Jewel occurred a few weeks before the leakage of Test Well Y-8 was detected. Although there is no direct evidence to support a connection in the August interval increase and the September burst count increase, the leak at Well Y-8 eventually resulted in lower water in Jewel Geyser. It seems distinctly possible that the interval shifts in August may have been a result of a low leakage rate in the well at that time. Observation of Jewel during the 1993 season may help determine whether the capping of the test well has allowed Jewel to return to its former pattern of eruption.

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A New Look at the Fountain Group

by

Rocco Paperiello

ABSTRACT: This report attempts to do three things. To present as complete an overview as possible of what features exist in the Fountain Group, especially its geysers. To present a short history of activity, with more emphasis on information which is not found in readily available sources. And lastly, to reexamine some of the history of these springs with an attempt to untangle the amazing history of name jumbling which has taken place over the years.

A popular spot in 1991 for many geyser gazers was the Fountain Group especially during the exciting activity of Morning Geyser.

The following sketch map and descriptions are to help those who frequent this area know what additional features they might keep a eye on. There are at least 37 geysers (plus 2 possible) in the Fountain Group of which at least 28 erupted in 1991. Unfortunately 8 of these geysers are not commonly visible from the present boardwalk; although, on unusual occasions, water from 3 of these 8 geysers can be seen when they erupt high enough.

1 - Celestine Pool The name Celestine first appeared on Hague's 1904 *Atlas*... In 1981 someone dove into this pool in an illthought attempt to rescue a friend's dog. He died the next day. Rick Hutchinson wrote the following in his 1980-1982 thermal report:

> Celestine Pool - Had frequent minor surging type eruptive activity beginning shortly before the July 29, 1981 thermal fatality caused by a visitor diving in after his friend's dog. The oils and fats released by the dog's body reduced surface tension on the pool, which quickly intensified Celestine's eruptions. The only other known period in historic times that Celestine Pool functioned as a geyser was shortly after the August 17, 1959 earthquake for just nine days. [Hutchinson 1982]

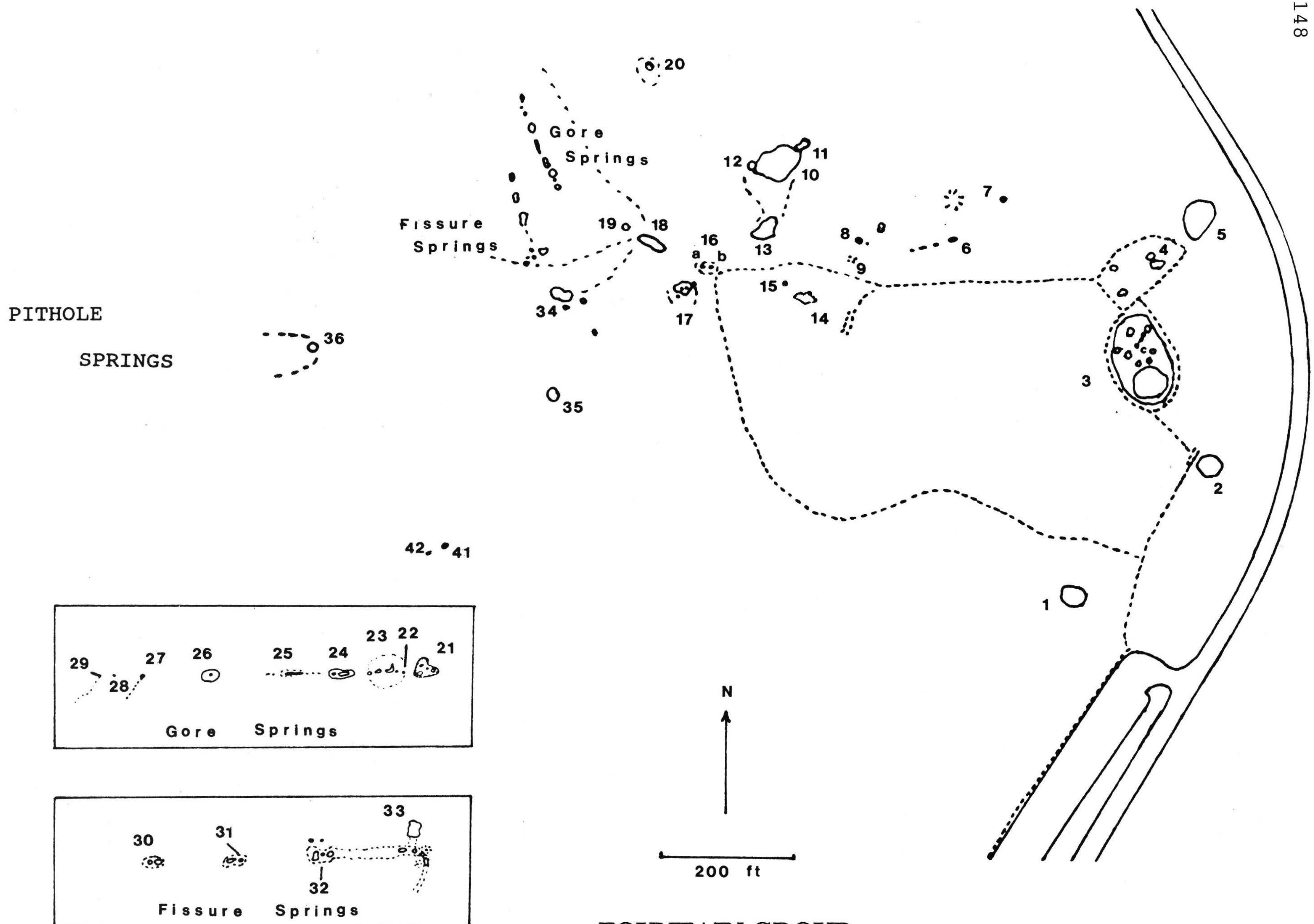
Actually, the first recorded geyser activity for this spring occurred in 1947. [Marler 1947a] Since at least the early 1980's this pool has been frequently active as a geyser although commonly only to about a foot. However, on a number of occasions, including at least twice in 1982 and a few times in 1991, this geyser has had sustained eruptions to about 4 feet for 10 to 15 seconds or more. [Hutchinson 1982, Whipple 1982, personal observation]

2 - Silex Spring Silex is another name which first appeared in the 1904 Hague *Atlas*... Silex Spring has been a notable geyser on a few occasions in the past. Its first recorded geyser activity was made in 1946, and again in 1947 when it was "observed in eruption as a geyser on several occasions." [Marler 1946a, 1947a, RofND July 1947] An active period occurred in late summer of 1973 when eruptions of up to 20 feet were reported. [Hutchinson 1973a, Wolf 1992]

Periods of activity continued through the remaining 1970's. [Wolf 1992, Martinez 1976] In 1977 it was erupting from 10 to 15 feet high with intervals of about 1½ hours. [Whittlesey 1988] In 1978, Silex was very active, with eruptions of 6 to 12 feet, and durations of 5 to 15 minutes. [Martinez 1978] Its last known activity occurred in 1979 with eruptions lasting a couple minutes and again reaching as high as 20 feet. [Bryan 1986]

On a number of occasions in past years, Silex has also been known to stop overflowing and ebb as much as 2 to 4 feet for short periods of time. [Wolf 1992, Hutchinson 1973b]

3 - Fountain Paint Pot This feature was originally called the "Mud Puffs" by the Hayden Surveys, but this was more a descriptive title rather than an actual name. (Note that a number of other mud pots were also called "Mud Puffs" by the Hayden Survey). Some of the early names used for this mud pool included "Mud Cauldron", "Chalk Vat", "Paint Vat", "Devil's Paint-box", and "Devil's Paint-pot". [Whittlesey 1988]



FOUNTAIN GROUP

LIST OF FEATURES IN THE FOUNTAIN GROUP:

Name	Original Name	Other Names	Reference
1 Celestine Pool			[Hague 1904]
2 Silex Spring			[Hague 1904]
3 **Fountain Paint Pot**			[RNM 1928]
	Mammoth Paint Pots		[Notman 1889]
4 Red Spouter			[Marler 1960]
5 Leather Pool			[Hague 1904]
		Mystic Lake	[Haynes 1881]
		White Sulphur Spring	circa 1904
6 "Volcanic Tablelands Geyser"			[Bryan 1986]
7a Old Cone Spring			[Peale 1883]
b"Old Cone"			
8 Twig Geyser			[Lewis 1958]
FOUNTAIN TERRACE (#9 - 33)			[Peale 1883]
9 UNNG			
10 Morning Geyser			[Marler 1948]
	New Fountain Geyser		[Wheeler 1900]
		Dewey Geyser	[Morris 1901]
		Fountain Pool	[Marler 1946]
11 UNNG			
12 UNNG			
13 **Fountain Geyser**			[Hayden 1872]
	the Giant		[Peale 1871]
14 **Jet Geyser**			[RNM 1927]
	Cone		[Weed 1887]
15 "Super Frying Pan"			[Martinez 1978]
	"Stegner's Crack"		[Lewis 1960]
16 **Spasm Geyser**			[RNM 1927]
	Jet Geyser		[Peale 1883]
		Impulsive Geyser	[Comstock 1875]
17 **Jelly Spring**			[RNM 1927]
	Spasm Geyser		[Comstock 1875]
18 **Clepsydra Geyser**			[Comstock 1875]
19 Clep's Well			[Marler 1973]
20 Sub Geyser			[Marler 1959]
	"Clepsydra Thief"		[Lewis 1957]
GORE SPRINGS (#21 - 29)			[Peale 1883]
		Chalybeate Springs	[Haupt 1883]
21 UNNG			
22 Fitful Geyser			[Comstock 1875]
23 New Bellefonatine Geyser			[Marler 1973]
24 UNNG			
25 UNNG			
26 UNNG			
27 UNNG			
28 UNNG			
29 UNNG			
FISSURE SPRINGS (#30 - 33)			[Marler 1973]
30 UNNG			
31 UNNG			
32 UNNG			
33 "Stalactite Geyser"			[Whipple 1982]
	"Broken Geyser"		[Lewis 1960]
34 UNNS	Jelly Spring		[Weed 1887]
		Gore Spring	[Marler 1973]
35 **Bellefontaine Geyser**			[RNM 1927]
PITHOLE SPRINGS (#36 - 40)			[Hague 1904]
36 Mask Geyser			[Lewis 1960]
	Bellefontaine		[Weed 1888]
37 UNNG			
38 UNNG			
39 UNNG			
40 UNNG			
41 UNNG			
42 UNNG			
43 UNNG ?			
44 UNNG ?			

The names of the numbered springs in **bold print** plus Pithole Springs are official. [Whittlesey 1988]

But by far the most important and longest lived of these early names was that of the "Mammoth Paint Pots". The earliest reference to this name that I know of was one recently found by Lee Whittlesey. This name appeared written on an unpublished photograph taken by William Notman in 1889. The name most likely was taken from local usage. Georgiana Synge [1892], who made her trip through the park in 1889, also used this name in the account of her travels.

This name later appeared in all the Haynes Guides from 1890 through 1927. Even the 1927 *Ranger Naturalist Manual* continued to use this popular name. In 1927, the place names committee adopted the present name of Fountain Paint Pot. [Albright 1928] The Haynes Guides from 1928 on, used the present name of Fountain Paint Pot. The 1935 publication of Allen and Day, *Hot Springs of the Yellowstone National Park*, used both names.

Specifically where the name of Fountain Paint Pot originated is somewhat obscure. Lee Whittlesey hypothesized that numerous guide books wrote of the "Fountain Geyser and Paint Pot" and hence the word "Fountain" came to be associated with the "Paint Pot". I believe that since the previous name of "Mammoth Paint Pots" was used by Charles Phillips [1927] in the 1927 *Ranger Naturalist Manual*, the name of Fountain Paint Pot had to have originated with the place names committee formed in the summer of 1927. This committee was comprised of Dr. A. L. Day, Superintendent Albright, Jack Haynes, and Marguerite Lindsley as research aid and secretary. [Albright 1928] Perhaps this committee decided that the name of "Mammoth Paint Pots" was confusing, and since the Hague *Atlas* merely used the name "Paint Pot", the committee simply added the word "Fountain".

As early as 1884 there was an individual treated for thermal burns by after falling into the Fountain Paint Pots. [*Livingston* (Montana) *Enterprise*, Aug 4, 1884]

4 - Red Spouter Soon after the 1959 earthquake two new mud springs developed between Leather Pool and the Fountain Paint Pots. In short time they became roaring fumaroles. In January of 1960 the one to the north began spouting brick-red mud to a height of about 6 feet. It was dubbed the Red Spouter probably by Marler. [Marler 1959a, 1960a, 1961a, 1962a]

As the water table drops, this spring eventually reverts to a fumarole. Upon its reactivation as a spouter in December of 1960, B. Riley McClelland [1961] first called it the "Artery", and a little later the "Broken Artery". In recent years the muddy water which it spouts has sometimes been gray instead of red.

5 - Leather Pool This spring was first called "Mystic Lake" in 1881 by F. Jay Haynes as a caption to one of his photographs. [Whittlesey 1988] By a couple decades later the name "Leather Spring" had came into use. At this time the water from this pool was piped to the Fountain Hotel for hot baths. [Whittlesey 1988, Heath 1905] Arnold Hague wrote the following in about 1911:

> ...on the north side [of the Fountain Group is] a large pool 60 by 70 feet, known as Leather Spring, a name probably derived from the luxutiant[sic] growth of low-temperature algae flourishing at the time. It flow a large body of water. [Hague 1911]

Soon after, however, the name of "White Sulphur Spring" had supplanted (at least in local usage) that of "Leather Spring"; in fact, Arnold Hague himself used this name in his 1915 notebook and stated that it had clear boiling water from two vents and was notable for its sinter rim. [Whittlesey 1988, Hague 1915, p 38-39]

In a 1926 article in the Ranger Naturalist Manual, Charles Phillips [1927] stated: "...beside the road is White Sulphur Spring (formerly 'Leather Pool') that once supplied the water for the geyser baths of the hotel." Frank Haynes, and later Jack Haynes, however, continued to use the name "Leather Pool" in their guide books, and apparently Superintendent Albright [1928] was convinced to return to the use of this name in 1927.

The only recorded geyser activity for this spring occurred soon after the 1959 earthquake, and it continued for about a week. [Marler 1973]

6 - "Volcanic Tablelands Geyser" Scott Bryan [1986] wrote that this geyser "is very informally named 'Volcanic Tablelands' Geyser since its vent lies down the slope directly below a sign with those words." I suspect that Scott was the "very informal" namer. When active, this geyser most commonly erupts while Fountain Geyser is either erupting or building up for an eruption. Its best activity occurred in 1985 and 1986. But even at its best, water reached barely a foot or two over its rocky basin with minimal discharge. At least one eruption was noted in 1991, and this during an eruption of Morning Geyser. [Bryan 1986, personal observation, Wolf 1992]

7a - Old Cone Spring This name was given by the Peale [1883] survey crew in 1878 to the triangular shaped spring behind an old dead cone, and NOT to the cone itself.

b - "Old Cone" The old cone itself enjoyed a brief rejuvenation in July of 1991. According to Mike Keller [1993] there occurred some overflow through the loose graveled sinter on top. Its water temperature was ~180°F.

FOUNTAIN TERRACE:

In his 1878 report A. C. Peale stated that:

> The springs and geysers from No. 7 to No. 16 [Old Cone Spring in the east to the Fissure Springs in the west] are on the main geyser mound, which is almost circular in shape, the drainage radiating in all directions but one, and in that we have the higher level on which the Mud Puffs [Fountain Paint Pot] are located. The mound has been called Fountain Terrace, and on its summit is the Fountain Geyser. It is about 80 feet above the general level. [Peale 1883]

In another place, Peale used the phrase "Fountain terrace, or plateau". The *Ranger Naturalist Manual*, 1927, continued the same use for this name. [Phillips 1927]

The Fountain Terrace includes # 8, Twig Geyser, through # 33, "Stalactite Geyser".

8 - Twig Geyser This geyser was so named by William J. Lewis in 1958. [Lystrup 1958, p 29] In 1878 Peale [1883] noted that this geyser was No. 8 of his "Fountain Group", and spouted "a foot or two". Most geyser gazers are familiar with the 2 vents of this geyser. It was active in 1991.

The water level in a double vented spring just to the east (Peale's No. 7) was used in 1962 as an indicator for Twig. [Lewis 1962, Marler 1962a] This unnamed double vented spring was mistakenly called "Cone Spring" in Marler's 1959 report. In it he stated: "During the years I have observed [this spring], it has been dormant and below overflow stage most of the time. Following the quake it began minor activity from 2 vents, which was continuous the rest of the year."

9 - unnamed geyser This was Peale's No. 9 of his Fountain Group, and was merely described as "3 holes in beaded sinter." [Peale 1883] There are actually 4 tiny vents here arranged roughly in a parallelogram. Usually only 3 are visible with one buried in the gravel. Some geyser gazers have dubbed this "Bearclaw Geyser", while elsewhere the name of "Twig's Satellite Vents" have been used. While I can not say that I am enthusiastic about the name "Bearclaw Geyser", I would definitely object to the latter name. I believe that Gordon Bower [1992] has already presented a cogent argument against its use.

Although active for at least the past ten years, I have never seen the eruptions reach much more than about a foot high. Normally only the 2 northern vents erupt but on uncommon occasions (including a number of times in 1991) a 3rd vent also participates.

10 - Morning Geyser Until near the turn of the century, what was to be later known as Morning Geyser, was only known as a pool which must be near full along with the Fountain Geyser before the Fountain could erupt. [Barlow 1872, Hyde 1887, Guptill 1890, Wheeler 1900] A few photographs taken of Fountain Geyser (and Morning) during this era have also shown both formations covered by a single "lake" of water.

This geyser was first called the "New Fountain Geyser" when it was originally seen in 1899. [Wheeler 1900] An attempt was also made to give it the name of "Dewey Geyser" after the popular figure of the day, Admiral George Dewey. [Whittlesey 1988] In his 1946 and 1947 reports, George Marler used the name of "Fountain Pool", possibly taking this name from common usage. (The monthly *Report*[s] *of the Naturalist Division* were using the name of "Fountain Pools"). [Marler 1946a, 1947a, RofND July, Aug, 1947] The present name of

Morning Geyser was given by George Marler in 1948. [Marler 1948a] Marler wrote the following in a letter to Jack Haynes in 1949:

> During the 1947 season the Fountain Pool erupted ten times, all of the eruptions taking place during the morning hours. The 1948 season showed still a further increase in the frequency of its active periods. From May until the last of September 1948 the Fountain Pool erupted thirty-one times. Again, as during 1947, all of these eruptions with the exception of two, occurred during the morning hours. Between nine and eleven a.m. was the critical period for its functioning; over half the eruptions during the 1948 season taking place within this time range. Due to the fact that there are a confusing number of features in the Lower Basin with the term "Fountain" a part of the name, I have elected to call the Fountain Pool the Morning Geyser. In further references to the Fountain Pool it will be designated as the Morning Geyser. [Marler 1949b]

In the May, 1949 edition of the *Report of the Naturalist Division* it was reported that Jack Haynes and Dave Condon decided that Jack Haynes should include the name "Morning Geyser" in his next guidebook, thus insuring the name's survival.

It should be noted that there were actually at least 12 known eruptions in 1947, 10 of which occurred in the morning hours while the eruption times for the other two are not known. [Marler 1947a, 1947b, 1947c] There were actually 36 recorded eruptions in 1948, 33 of which again occurred in the morning hours, while one started in the early afternoon, another in the early evening, and the last at an unknown time. [Marler 1948a, 1973]

Morning's first known activity occurred from June 26 through September, 1899. The following is a clipping from an 1899 newspaper:

> Chicago - June 27. A dispatch from Yellowstone Park says: "At 9:20 yesterday morning and continuing until 10:25 without intermission there was an eruption from a crater about fifty feet north of the Fountain Geyser, which we have always considered to be nothing more than a pool and having no name. The size of the opening is about the same as that of the Fountain, and I do not exaggerate when I say the height it played was from 200 to 250 feet, and was the grandest I have ever witnessed in the park [Anonymous 1956]

In *Wonderland 1900*, Olin D. Wheeler wrote the following:

> In 1899, a new geyser called the New Fountain, broke out in the north basin, resulting in a decided curtailment of the old Fountain Geyser's eruptions. The new geyser is not yet old enough so that its periodicity and peculiarities are fully known. Its eruptions, however, are more stupendous and much beyond those of any other geyser which the writer has seen. Excelsior Geyser at Midway Basin, the greatest geyser -- when it plays -- in the world, is closely approached by this new giant, in both the magnitude and the grandeur of the display.
>
> The geyser is rather spurty in character, and when in full operation plays from three orifices. In its general action it is not unlike the Fountain or the Great Fountain. It will boil furiously and throw the water quite regularly to a height of ten to fifteen feet. Then, becoming semi-quiescent for a few moments, it will again break loose, and simply hurl into the air, with almost inconceivable force, a solid body of water of immense bulk, to a height of fifteen to thirty feet. Then changing again it will send upward an enormous volume of water to a height of 100, 150, or even, in exceptional spurts, 200 feet.
>
> After a period of momentary quiescence, the geyser will often break out with a violent explosion, when the scalding flood, transformed into millions of white, beautiful beads of crystal and spray, is sent in all directions, to all heights, at all angles, from the three apertures. The water is all torn to pieces and is thrown out and comes down in a perfect avalanche. The geyser then is

a very leviathan at play. It throws out pieces of geyser formation, bits of trees, and geyser eggs, as they are called, small, white rounded, polished stones.

When the eruption ends it comes abruptly, at once, not as the Great Fountain's, with a series of dying, tremendous throbs, as if the great heart were broken. The eruption ceases, the great body of water drops rapidly down into the central cistern and runs into it from the geyser knoll in pretty little cascades, until the surplus is thus carried away and the water level outside of the basin is lowered. Then it is all over.

At times there are large quantities of steam which float away in beautiful vapory forms and often obscure the higher levels of the water column.

A not so enthusiastic report contained the following:

> The Fountain Geyser broke our hearts by becoming irregular in 1899. Another geyser burst out not a hundred feet away and run a very brilliant but irregular career for a short season... The new geyser threw its triple streams farther than the old, but with smaller proportions, because its three exits were smaller... ...interested parties printed it abroad that a new and glorious geyser had broken out, and wanted to give it some political name, which I think would have been fitting because of its fickleness. [Whittlesey 1988, Grant 1908]

The next reported activity for Morning Geyser occurred in 1909. The following was reported in the Aug 21, 1909 *Livingston* (Montana) *Enterprise*:

> Wednesday the wires from Mammoth Hot Springs were busy chronicling the birth of a new member of the Geyser family in the Yellowstone Park. Many reports were sent out, at first it being reported that a small eruption had started, but toward evening the new member had reached its growth and messages were sent, telling that the new one was one of the most magnificent in the Park. A special from Mammoth Hot Springs of that date says: For two or three days past there have been indications of an eruption of some kind near the Fountain hotel in the Yellowstone park. Yesterday a new and magnificent geyser broke out in full force about 100 feet north of the regular Fountain geyser near the Fountain hotel. Today this new geyser, which does not appear to affect any of the others in that vicinity, played to a height of 150 to 200 feet, throwing off immense quantities of hot water, mud and steam.
>
> The new geyser does not play regularly as does "Old Faithful," but at short intervals, the eruptions occurring five or six hours apart and lasting about an hour.
>
> The crater of the new geyser is large and in quantity of water thrown is similar to that of the Great Fountain geyser, though the water from the new one is carried to a much greater height.
>
> The new geyser is one of the largest in the park and will add much to the attractiveness of the lower geyser basin. [Anonymous 1909]

The 1910 *Haynes Guide* added the following:

> In July, 1909,... [Fountain] abandoned its crater for the one adjoining and threw out jagged masses of geyserite more than 200 feet. The water was muddy and full of rock fragments for many hours; and as late as September, large pieces of rock were thrown out during the more violent eruptions.
>
> For two days preceding the breaking out of this geyser in its new place, much disturbance was noted in the vicinity; loud rumblings were heard and the thumping of the entombed steam and water, gaining in violence each hour, alarmed even the most used to the strange phenomena of the geyser region. During the remainder of the season of 1909 the [New] Fountain Geyser played much higher that before [much higher than 75'], like a stream through a smaller nozzle, but its eruptions were less regular. [p 41-42]

Record of activity of Morning Geyser by year:

1899 - Active from June 26 through September, 1899. [Wheeler 1900, Anonymous 1956] Durations of up to 1 hour were noted. [Guptill 1904, p 46] During this active phase Fountain was only seldom seen. [Weed 1899, p 27]

1909 - Active from July through the remainder of the season with "the eruptions five or six hours apart and lasting about an hour." [Haynes 1910, Anonymous 1909, Hague 1911]

1921 - 1 eruption recorded in August

The following is from the August, 1921 *Monthly Report of the Superintendent*:

> The Fountain has been inactive except for one eruption and there seems an indication of a repetition. Ranger Troutman, who witnessed the eruption, estimated that the geyser played to a height of 250 feet and did not fall below 200 feet during the one hour and ten minutes of its activity. About two hundred tourists witnessed the eruption.

This above eruption is almost certainly that of Morning Geyser. Strangely, George Marler reported this eruption as having occurred in 1923. [Marler 1973, p 510]

1922 - 1 eruption recorded in July:

> The Fountain Geyser played only once from the new opening on July 4th. [MRofS July 1922, Albright 1922]

This "new" opening is that of Morning Geyser.

1945 - Eruption of "Fountain" reported for July 28th. Later the reporter, Herbert T. Lystrup, stated that this was actually an eruption of Morning Geyser. Marler [1947b, 1973] stated that a reported eruption of Fountain by a former park employee--in <u>1944</u>--was actually Morning Geyser. This was probably a reference to the 1945 eruption reported by Lystrup. Lystrup reported the following:

> ...Fountain Geyser in the Lower Geyser Basin Played on July 28, at noon. It was reported by Mrs. Marguerite Arnold. She said it played to a height of about 60 feet maximum, and played more or less continuously for 45 minutes. This geyser has not been reported in action since 1936... [RofND July 1945]

Later, probably convinced by Marler, Lystrup stated that this eruption must have been of Morning Geyser:

> Morning Geyser was observed by the former Mrs. Marguerite Arnold during the World War II period. During 1946 it was again observed; this time by Park Naturalist Marler. [Lystrup 1956]

1946 - 2 eruptions recorded. [Marler 1946a, 1949b, 1973]

1947 - at least 1 eruption over the Winter; 11 recorded eruptions from June 11 through September 22. Seven of these eruptions were followed by Fountain; Fountain had 8 independent eruptions. [Marler 1947a, 1947b, 1947c, 1949b, 1973, RofND Aug 1947]

1948 - 36 eruptions recorded. Intervals are from 1 to 6 days. All eruptions were followed by Clepsydra and then usually 2 eruptions of Fountain, sometimes 3. [Marler 1948a, 1949b, 1973]

1949 - 11 recorded eruptions. All followed by Clepsydra and from 1 to 2 eruptions of Fountain. [Marler 1949a, 1973]

A few photographs of Morning Geyser were prepared for sale in 1950 by Jack Haynes Photo Shops. (#50152, 50153, & 50154) These photos were most likely taken in 1949.

(1950 & 1951 - Morning and Fountain are both dormant). [Marler 1950a, 1951a]

1952 - 1 eruption on April 24th; from July to September, 2 to 3 eruptions of Morning per week; less than this in September. All followed by Clepsydra and Fountain. [Marler 1952a, 1952b]

1953 - During the summer Morning Geyser erupted about 2 or 3 times per week estimated. These were again followed by Clepsydra and Fountain. [Marler 1953a, 1973]

1954 - Morning Geyser was active from June through August. Activity in August was of greater frequency than in any previous year; this was presumed due to some of Morning's eruptions followed only by Spasm instead of Clepsydra and Fountain. [Marler 1954a, 1973]

1955 - 22 eruptions of Morning were recorded. 2 eruptions occurred in June (the 11th & 22nd). The next eruption came on July 15th. From July 15 to August 31 Morning erupted every 2nd to 4th day. From August 31 through season not all the eruptions were determined. All eruptions occurred between 8:30 AM to 10:30 AM. [Marler 1955a, 1973]

1956 - 34 eruptions recorded. 4 eruptions in June, 11 in July, 12 in August, and 7 through September 25th. All eruptions were followed by Clepsydra and Fountain except on 2 occasions. On these 2 occasions, Sub Geyser had 3 hour eruptions of 12 to 20 feet high. Both Fountain and Clepsydra had independent eruptions. [Marler 1956a, 1973]

1957 - 56 eruptions recorded. Activity started in April, and continued through at least December. Early season activity was like previous years. But in August there was a "remarkable increase in activity". There were 6 eruptions in June, 6 eruptions in July, 7 eruptions from August 1st through August 15th, and 8 from August 16th through August 31st. (Lewis reported that there were at least 8 eruptions, one each day, from August 21 through August 28 inclusive). There were 19 eruptions from Sept 1st through September 20th. A 12 hour interval occurred on Sept 5th; 3 eruptions in 25 hours on Sept 16th - 17th; and a 3 hour interval on the 19th.

Sometimes Morning would even follow Fountain, starting its eruption from a <u>LOW</u> pool. Also when successive eruptions of Morning occurred in the same day, the second eruption of Morning erupted from a low pool. Lewis reported that this happened at least 4 times. These eruptions lasted about a half hour instead of the usual 40 to 50 minutes (and sometimes longer).

The area was not observed in October, but in November and December only 6 eruptions of Morning were observed, along with 5 eruptions of Fountain. Clepsydra was not known to play during these two months. [Marler 1957a, 1958b, 1973, Lewis 1957]

1958 - 54 eruptions recorded (from March through September). In spite of the high number of recorded eruptions this year, Morning Geyser was actually less frequent than in 1957. The higher number of recorded eruptions was due to the fact that the active period started in March (29th), and continued beyond the beginning of September. McClelland reported that Morning did not became dormant until about December 1st. [Marler 1973, McClelland 1959]

Behavior was similar to that of 1957. There was a continued reversal of the order in the chain action, with an eruption of Fountain preceding that of Morning; also successive eruptions of Morning occurred at times with no subsequent eruption of any other geyser. Clepsydra and Fountain also had some eruptions this season independent of Morning. [Marler 1973, Lystrup 1958]

Synopsis of activity during the 50's:

Durations: Morning's durations were most commonly 45 - 60 minutes; exceptions occurred at times in 1957 and 1958 with slightly shorter durations being the rule. In addition durations as short as 30 minutes occurred with successive eruptions of Morning.

Heights: Many bursts range from 15 to 100 feet. Occasional bursts (especially during last 3 minutes) of up to 150 feet.

Overflow: Almost all the eruptions preceded by lengthy overflows; exceptions occurred in Sept of 1957 and (presumably) at times during the Summer of 1958. There were 2 types of activity which would lead up to Morning erupting from a "low" pool. One occurred when Morning would follow Fountain (rather than with Morning initiating the sequence). (5 instances in 1957). The second type of activity was when Morning succeeded itself with no intervening eruptions of Clepsydra or Fountain (or Spasm or Sub). Intervals and durations were shorter when this latter happened.

1959 - pre-earthquake

Only 14 recorded eruptions. It was believed that Morning, Fountain, Clepsydra all became dormant about December 1, 1958 [McClelland 1959], and both Morning and Fountain were dormant over the winter [Berg 1959]. Only 3 eruptions occurred in May and June, and these were NOT followed by the play of either Clepsydra or Fountain; the 11 eruptions in July and August were more comparable to that of 1958 activity. With but one exception, eruptions of Morning were followed by Clepsydra. Only one eruption of the Fountain followed one of these eruptions of Clepsydra. [Marler 1959a, 1973]

1959 - post-earthquake:
August 17: concerted activity from Morning, Fountain, and Clepsydra starts at 11:37 p.m. (Fountain stopped for a while during the night).
August 18: Morning started having short pauses of 2 to 6 minutes between eruptions of 45 to 50 minutes.
August 19 & 20: By the 20th pauses for Morning increased to 12 to 30 minutes. Fountain stopped on the morning of the 19th.
August 21 - 25: Gradual shortening of eruptive phases of Morning to 10 to 18 minutes with increase in pauses of 40 to 60 minutes.
August 26 - September 1: Brief eruptions of Morning (3 to 5 minutes); pauses of 60 to 73 minutes. Also eruptions considerably reduced in magnitude (only to 10'). [Marler 1964b, 1973]

1964 & 1966 - 2 eruptions(?) in 1964 and 1 eruption(?) in 1966.

There are eruptions of Morning recorded for August 14, and August 20, 1964, and one for Aug 26, 1966 in the logbooks that were kept during those years for the Lower Geyser Basin. According to the 1964 logbook, the August 14, 1964 eruption started at 11:04 am; no other information was recorded. However, the next entry by another ranger shows a 20 to 30 foot eruption of Fountain Geyser from 2:35 to 2:45 pm. [LGB Logbook 1964, Koenig 1990] The entry for August 20, 1964 read:

> Morning Geyser. Began 5 minutes after Clepsydra (steam) playing 20 feet high with wide base. Fountain quiet during unknown length of play. Account taken by Fellows [on] 22 August from visitor. [LGB Logbook 1964]

I will leave it to the reader to decide if these eruptions were actually of Morning Geyser.

1973 - 21 known eruptions (many more were missed).
May 24th - 2 eruptions seen.
June - 14 eruptions recorded (many more were missed). Three recorded intervals averaged ~8 hours. Three durations recorded of 10, 11, and 16 minutes.
July - 5 eruptions recorded. Two durations recorded of 8 and 12 minutes. Returned to dormancy in the latter part of July. Fountain and Morning refilled with slight overflow at times and lapsed into dormancy. [Hutchinson 1973a, Koenig 1990, Wolf 1993]

Characteristics of eruptions:

Morning did NOT prefer "morning hours": no chain sequence with Clepsydra, Fountain, Spasm, or Sub; long period at times of small preliminary splashing. Sometimes extended overflow merely ended and did NOT lead up to an eruption of Morning. Clepsydra stopped about 5 minutes into the play and restarted with wild-phase activity about a half-hour after Morning ended.

Durations: 9 - 16 minutes recorded.

Heights: 50' to over 120'.

Overflow: Eruptions were preceded by up to several hours of heavy overflow into Fountain Geyser. Some extended periods of overflow by Morning did not result in an eruption of Morning but instead merely stopped. [Hutchinson 1973a]

1978 - I have not as yet reconstructed much of the activity of Morning Geyser for this year other than finding out that it was active for a large part of the summer. Sam Martinez [1978], in his report for August 20 through September 3, noted at least 11 eruptions during this period alone. For these 11 eruptions durations ranged from 10 minutes to not quite 12½ minutes. Sam Martinez described the following activity:

> Following an eruption of Morning, the water level in both Morning and Fountain drop. In Fountain the drop is several inches to two feet, while in Morning the drop amounts to between three and four feet...
>
> In the thirty minute period following the eruption, Jet, Jelly, Twig and Sub displayed mild reactions to Morning's activity, mainly as changes in the interval length. Clepsydra never ceased erupting during any of the eruptions of Morning I observed and Fountain remained quiet at all times.
>
> For the next several hours Fountain and Morning refilled at a very slow rate with little or no noticeable activity. Hours before the approaching eruption, Morning begins to

overflow into Fountain's crater over a wide terraced slope... The flow is low at first and increases as the time of eruption approaches. This flow also tends to fluctuate as eruption nears. The longer intervals show this peculiarity more clearly...

During this period of overflow the level of Fountain is usually fixed or just slightly varying. I did receive word from Herbert Warren... about an eruption of Morning which featured an increasingly active Fountain Geyser. ...[an apparent] shifting of energy and boiling between Fountain and Morning... apparently went on for some time before Morning was able to end the exchange in an eruption. During the period of related activity low splashes or boiling surges less than a foot high were seen in Fountain. The water level in Fountain was also higher than normal...

In the normal cycle the next sign... is a small boil which appears in the northeast crater vent at least two hours before the eruption. Another boiling point at the division between the main and northeast vent becomes visible a short time [later]... In less than an hour, usually in about 45 minutes, the main vent begins to bubble in several places along one side... During some of the eruptions the duration of this phase was only about an hour, however, in some of the longer intervals this phase lasted as much as 3 hours. Eventually the boiling... becomes constant...

The intermittent, small bursts of vigorous boiling start 12 minutes to an hour before the eruption... The boiling bursts become very frequent and take up more and more of the surface area of the pool...

The eruption begins with a sudden burst from the pool which can either be a massive plume of slowly rising white water 20 to 30 feet high or a rocketing mass of white jets following a loud steam detonation near the surface of the pool which shakes the surrounding formations... The eruption continues explosively as a new, much larger burst of water takes off in the Great Fountain style. It is followed in rapid succession by a series of large and massive bursts near the maximum, often above 100 feet, however, one particularly large eruption observed on the 22nd didn't reach its maximum [of 190 feet] until almost midway through the eruption...[preceded by a number of bursts over 100 feet]...

The bursting eruption of Morning differs in several respects to Great Fountain. The plumes of water do not ascend vertically even half the time. ...signs in the sinter indicate that few, if any, of the burst arch [to the north]... The deviation from the vertical is a maximum of about 40° toward Fountain and 30° to the sides. The bursts fly out at unpredictable directions and at greatly varying heights...

The bursts decrease slightly in frequency and vigor a few minutes before the end. About 3 minutes before the splashing ceases the water level in Morning drops below the level of overflow into Fountain...

Although Morning was still active when we left [on September 3rd], it was showing signs of slowing down, in particular the increase of interval and the unusual exchange between Fountain and Morning mentioned earlier. Even with no noticeable shift to Fountain the intervals at the end of August were longer and more irregular. [Martinez 1978]

1981 - Active from July 22 through September 1. According to the log compilation made by Heinrich Koenig [1989] there were at least 61 eruptions of Morning recorded during this 42 day period.

However, according to Lynn Stephens [1992]: "In 1981, 82 eruptions of Morning [were] listed in the geyser logs maintained at the Old Faithful Visitor's Center. Prior to 1991, this was the most number of eruptions of Morning recorded in a single year."

On most days, during the above 42 day period, either 1 or 2 eruptions of Morning were noted. There were, however, a few days for which no eruptions were reported, while on at least two occasions, at least 4 eruptions occurred on a single day, with intervals averaging about 6 to 8 hours. (One recorded interval on August 6th was 1 hour 10 minutes -- I do not know how accurate this report was).

Durations: The 15 durations recorded ranged from about 7 to 30 minutes, with almost all of them being between 20 and 30 minutes. [Hutchinson 1982, Koenig 1990]

1982 - At least 46 eruptions were known to have occurred.
Active for 3 weeks in late January and early February.
Active from June 16 to July 15.
Active from July 28 to July 31.
Active on August 14.
Active from August 19 to August 27.

Minor eruptions seen from "parasite vents" in early May, and mid-August.

At its best, 1, and sometimes 2, eruptions were occurring daily. On July 29th there were 3 eruptions, with 2 consecutive intervals of 4 to 4½ hours. In mid-June, of 5 known intervals, 4 were from 13 to 16 hours; the 5th was over 28 hours. Then from late June to July 9th, of 15 known intervals, 11 were of about 22 to 24 hours, 2 were of about 17 to 19 hours, and 2 others were in the 28 hour range. From July 10 to the 15th, intervals were more erratic ranging from about 13 hours to as much as 22 hours. From July 28th to the 31st, consecutive intervals were about 24 hours, 4 to 4½ hours, 4 to 4½ hours, and 27 hours. One eruption was recorded for August 14. During the final active period from August 19 to the 27th the few recorded durations were between 30 and 40 minutes while intervals were generally longer. (The log entries are probably incomplete for this period). [Hutchinson 1982, Whipple 1982, Koenig 1990]

Characteristics of activity:

Very wind sensitive; any steady breeze greater than an estimated 15 km/hr seemed to delay or prevent eruption. Starts would be very sudden. Often, about 5 minutes into the eruption, there would be a sustained "Grand-type" column for 10 to 30 seconds.

There was no evident chain action activity after the eruption. An eruption of Fountain would mark the end of Morning's active period. This eruption of Fountain came about 12 to 20 hours after the last Morning eruption.

The two smaller side (or parasite) vents would commonly erupt with the main vent during an eruption of Morning. There were, however, a few occasions when the parasite vents would have small independent eruptions, sometimes over long periods of time. Most of this activity came from the NW vent.

Durations: Of those recorded (31), durations ranged from about 18 minutes to almost 49 minutes. The average was about 33½ minutes.

Overflow: Most of the eruptions were preceded by long and heavy overflow. When Morning was found overflowing into Fountain, an eventual eruption of Morning would be anticipated. But on at least one occasion, Fountain started even with Morning's overflow. From late June to mid-July, when intervals were frequently about 22 to 24 hours long, overflow would typically last about 14 hours leading up to an eruption. Except on windy days, this period of overflow was usually more dependable than interval in predicting the next eruption.

Height: These eruptions of 1982 were some of the most spectacular ever recorded for Morning Geyser. Most of the bursts were extremely massive, with heights commonly 100 to 150 feet, with some bursts to as high as 200 feet. The largest bursts came at the very beginning and the very end of the eruption.
[Whipple 1982, personal observations 1982, Koenig 1990, Hutchinson 1982]

1983 - 1 eruption on February 10. The log entry stated that this eruption might have been a delayed response to a series of tremors on February 6th. [Stephens 1992]

1991 - Active May 4 & 5: 5 known solo eruptions of Morning.
Active July 4 - 7: 2 concerted eruptions of Fountain and Morning.
Active August 9 - 29: started with a concerted eruption of Fountain and Morning, followed by 118 known solo eruptions of Morning, and concluded with two concerted eruptions of Fountain and Morning. [Stephens 1992a]

(For an excellent description of Morning's activity in 1991 see Lynn Stephen's "1991 Activity of Morning Geyser and Other Features in the Fountain Complex" (in 3 parts), *GOSA Transactions*, Vol III, 1992).

11 & 12 - unnamed geysers These vents commonly erupt along with Morning. Rare independent activity, however, also occurs. This was especially noted in May, and mid-August, of 1982. This activity was minor in character but sometimes continued over long periods of time. Most of this activity came from the NW vent. In May of 1991, between periods of activity for Morning Geyser, there was again noted frequent eruptive activity in these vents. [Whipple 1982, personal observations 1982, Keller 1993, Stephens 1992b]

13 - Fountain Geyser Possibly the first account of this geyser was chronicled by a couple members of the Washburn Expedition in 1870. Langford wrote:

> The valley on our right was very marshy, and we saw at a considerable distance one very large fountain of water spouting into the atmosphere to a considerable height, and many steam jets, but, owing to the swampy character of the ground, we did not visit them. [Langford 1905]

The first certain mention we have of this geyser was by Hayden and Peale [1872] (1871 Hayden Survey), and by Barlow [1872] (Army Reconnaissance of 1871). Both groups appear to have first seen this geyser on August 2nd of 1871. Barlow did not name this geyser, but Peale (in his diary) first named it the "Giant" [Peale 1871]. Only later in the published account of the Hayden survey do we see the name of Fountain Geyser.

Fountain's first (at least partial) dormancy was noted in 1899 from June 26th until October, with an exchange of function to Morning. Geologist Walter Weed wrote this year:

> ...the greatest change is in the Fountain. The old geyser only spouts occ[asionally] now and the more frequent eruptions are from the vents in the old bowls that were filled by overflow before. [Weed 1899, p 27, Whittlesey 1988]

In 1909, a second exchange to Morning Geyser occurred from July to late in the season. [Haynes 1910] "From 1911 to 1916 [Fountain's] eruptions were erratic and seldom witnessed." [Albright, 1920] After returning to frequent play in 1917 through 1920, [Albright 1920, Skinner 1920a, 1920b] Fountain was only seen once in 1921 [MRofS June, July, August 1921, Skinner 1921a, 1921b]. The Superintendent's Report for 1922 stated that Fountain was not playing that year. [Albright 1922] (See also [Skinner 1922]). Fountain was apparently dormant in 1923 & 1924. [MRofS May 1923, RofND June 1925] The next actual record of Fountain erupting is found in the June, 1925 *Monthly Report of the Naturalist Division*:

> At the time this report is concluded, namely July 4th, the ranger in charge of Fountain Station reports the first observed eruption of Fountain Geyser for about a period of about 2 years. It played for a period of 35 minutes and to the maximum height of 80 feet. [p 27]

Charles Phillips later stated (*Yellowstone Nature Notes*, May, 1926):

> The Fountain Geyser, from which the former hotel took its name, has become irregular in late years. It played several times last year [1925], but there are no evidences of recent activity this spring.
>
> Clepsydra has developed into a geyser of considerable power. Its eruptions are by no means as frequent as formerly but the increase in magnitude more than compensates for any loss in this direction... [Phillips 1926a]

In the December, 1926 issue of the *Yellowstone Nature Notes*, Charles Phillips added:

> The Fountain Geyser shows no evidence of new activity and the channels that would carry away the heated water are full of ice and snow. A single eruption of Clepsydra observed attributed no diminution in the usual vigor this geyser has been showing for several seasons. [Phillips 1926b]

Perhaps this is where some of Fountain's energy had gone.

Although Marler stated in his *Inventory...* [p 487], that one eruption of Fountain was reported for each year from 1926 through 1929, I could not find corroboration for

1926. Phillips [1927b] reported an eruption of Fountain for March 20, 1927, and continued:

> The eruption was below the standard of its displays several years back; however, the surrounding sinter showed evidence of recent activity and the geyser may resume moderate activity again this season. No eruptions have been recorded since 1925. [MRofS March 1927]

However, the next eruption of Fountain Geyser was not recorded until June of 1928; it erupted once more on July 27th. [MRofS July, 1928] The next recorded eruption of Fountain was not until September of 1928, by Allen & Day. [1935, p 185].

According to Marler's *Inventory...*, Fountain was dormant from 1929 until 1947. However, eruptions for Fountain possibly occurred in 1931, 1932, and 1936. In a report by Herma A. Baggley, in the December, 1931 issue of the *Yellowstone Nature Notes*, Fountain was reported to have erupted on October 4, 1931. In spite of Marler's above statement to the contrary [*Inventory...*, p 488], Marler himself stated that Fountain erupted once in 1932 [Marler 1947b].

An annual geyser report by H. T. Lystrup in 1945 stated the following:

> Fountain Geyser: This geyser was observed July 28th [1945] by Mrs. Ben. Arnold. It played for 45 minutes. Last played in 1936.

Note that Lystrup mentioned that Fountain erupted in 1936. Possibly it was Marler himself who later convinced Lystrup that this 1945 eruption must have been of Morning Geyser. Lystrup later wrote in 1956 (*Yellowstone Nature Notes*):

> Morning Geyser was observed by the former Mrs. Marguerite Arnold during the World War II period. During 1946 it was again observed; this time by Park Naturalist Marler.

In his 1946 report Marler listed both "Fountain Pool" [Morning Geyser] and Fountain as active geysers without further comment, yet in his *Inventory...* [p 490] Marler implied that Fountain did not emerge from its long dormancy until 1947.

Prior to the earthquake, there was only one observed eruption of Fountain Geyser in 1959, and this followed in chain action one of the 14 eruptions of Morning for that year. [Marler 1959a, McClelland 1959] Protracted dormancies for Fountain have also occurred from 1960 to late 1962 (or early 1963), late 1964 through early 1968, and 1973-1974. [Marler 1960a-1965a, 1967a-1968a, Hutchinson 1973, 1974]

Activity in 1963 consisted entirely of what has been characterized as "minor" eruptions. In June and July, 12 minute intervals and 4 minute durations were the rule. In August, intervals were more erratic and averaged 19 minutes with 8 minute durations. Height of bursts were commonly from 10 to 20 feet with only occasional bursts to 30 feet. This August type of activity continued into 1964, but by mid season "major" eruptions of up to 2 hours duration and bursts to 40 feet were seen. [Marler 1963a, 1964a, Lewis 1963]

Activity in the first part of 1968 was characterized by eruptions about every 12 minutes, lasting from 3 to 4 minutes, to heights of only 6 to 15 feet. "Major" eruptions began to be seen in June, increased in frequency, and dominated the activity by late Summer. Intervals at that time averaged about 6 hours. Activity in 1969 was a close repeat of that of 1968. In 1970 only "major" activity was observed, with intervals of 4 to 5 hours. [Marler 1968a-1970a]

In the Summer of 1983 unusual eruptions of Fountain, with durations of up to 4 to 5 hours, were occurring. During these eruptions Clepsydra would turn off and not restart until after Fountain had quit. [personal observations 1983]

During other unusual eruptions of Fountain (a few of which occurred in 1983 and 1984), this geyser could have a number of "rocket-like" bursts as high as 100'- 125' which appear to come from the extreme eastern side of the pool and are rocketed upward at a slight angle to the west. When looking within the crater, a jagged vent can be seen in the east wall of the crater. One such eruption seen by the author in the Summer of 1984, was heard by Tomáš Vachuda and Bob Hoffman who were at Mound Geyser at the time. They quickly returned to investigate the noise. After the eruption, Tomáš found a number of old coins around the formation which had been disgorged by the unusual eruption. [Whittlesey 1992, personal observations 1984]

14 - Jet Geyser This geyser was apparently never described (nor named) by any of the Hayden Surveys. [Hayden 1872, 1873, 1883] About the only early mention of geyser activity was made by Walter Weed in his 1886 field notebook:

> The old ridge or cone of deposit a few feet south of the Fountain has always been inactive while seen. A little steam issued from the fissure or vents in the summit and water could be heard gurgling far below. There being but a trace of fresh deposit, spouting was not expected. On the 24th of July, jets of water issued from the cone to a height of 10-15 feet---the action continuing three minutes and we can [thus] add this to the list of small spouters near the Fountain [Weed 1886, Whittlesey 1988]

In his 1887 formal notebook, Walter Weed simply designated this feature with the epithet of "Cone".

The name of "Jet Geyser" was originally given by the Peale survey crew in 1872 to what is today's Spasm Geyser [Peale 1883, Comstock 1875] In contradiction to what Marler said in his *Inventory*... [p 504], the placement of Jet to the present feature does NOT date back to the Hague studies; it was mistakenly transferred to this feature in about 1926 (possibly by Charles Phillips) and adopted by the place names committee in 1927. [Phillips 1927a, Albright 1928, US Board 1933] (See entry on Spasm).

During some seasons, the decreasing intervals of Jet Geyser had been used as a means of determining the possible time for the upcoming eruption of Fountain Geyser. Tomáš Vachuda used this method very successfully in 1984. [Vachuda 1984, personal observations]

15 - "Super Frying Pan" Concerning the naming of this feature is the following excerpt from Sam Martinez' 1978 report:

> This feature was tentatively called "Super Frying Pan" Geyser by Rick Hutchinson, although he won't admit it, when it first popped out of the sinter in 1974, but a suitable name has never been proposed. [p 78-8]

Among the tight fractures between Jet and Spasm Geysers which made their presence known soon after the 1959 earthquake, the above was one of a number of vents which appeared from time to time.

According to Scott Bryan [1976]: "Not less than six spots in the sinter gravel have been active as small spluttering spouters. By 1975 one of these seemed to be taking over most of the activity".

The following from a 1960 report by William J. Lewis might be the earliest reference to the fracture system on which this feature lies:

> Stegner's Crack - On July 7, at 3:10 p.m. as Mr. Stegner was inspecting the interpretive activity on the Fountain mound, water was seen boiling up an inch or so along a 4 foot crack between Jet and Clepsydra Geyser. This crack runs in a direction 90° to Jet. This was the first time this action was observed. It continued active all summer. A duration of 20 minutes was recorded on July 13. The boiling along the crack has removed the eroded sinter about it.

On July 8, 1964, the following entry was made in the Lower Geyser Basin logbook:

> ...Near Jet Geyser an 18 inch steam fissure playing through the geyserite was noted. Its position in a roughly north-south alignment was 30 ft. north of Jet geyser & 12 ft. off new boardwalk. Steam and small droplets of water were escaping through the fissure under pressure. A loud hissing noise could be heard from the boardwalk. A smaller vent was noted 8 ft. east of this fissure. This vent was not under steam pressure. It is approximately 3 inches in diameter. [Fellows July 8, 1964]

A few additional such eruptions were also recorded that summer.

16 - Spasm Geyser This geyser has two vents which might possibly be 2 different geysers. The history of this geyser is very interesting and varied.

Vent a - The vent to the west is the original. It was named "Jet Geyser" by Peale in 1872 but not described by him until his 1878 report! [Peale 1883] In 1873 it was named "Impulsive Geyser" by Comstock of the Jones' survey. [Comstock 1875] In his 1911 manuscript Hague described today's Spasm Geyser as follows:

> The Jet Geyser(The Impulsive)... has an open basin 25 feet by 40 feet, sloping inward toward a funnel-shaped orifice 8 inches square. Before an eruption the basin always fills with water, after which it again becomes dry. It plays frequently but irregularly. During visits to the Fountain the Jet has, on several occasions, been seen in action. Observations do not place it in accord with the former geyser [Clepsydra], yet in an impulsive way it seems to be affected by the overflow from the central geyser.

"Spasm Geyser" was the name originally given to today's Jelly Spring, and was placed on the present feature by the place names committee in 1927. This mistake in the placement of these names possibly originated with Charles Phillips in the mid-1920's. [Peale 1883, Hague 1904, Phillips 1927, Albright 1928] (The geyser in the Haynes' photo #11230 on page 49 of Bauer's *The Story of Yellowstone Geysers*, 1937, labeled "Jet Geyser", is actually a photo of Steady Geyser).

In 1956, at least a couple unusual eruptions of Spasm were reported, while in 1957 and 1958, this vent of Spasm geyser was erupting to 20 feet a few times daily. [Lewis 1957, Marler 1958c, 1973] This unusual activity continued in 1959. [Marler 1959a]

This vent of Spasm Geyser has probably not erupted (except for some boiling over the vent) since the creation of the east vent in 1963. In 1963, prior to the blowout of this new vent, Spasm experienced a great increase in thermal energy. At the beginning of most eruptions, jets of water would play at an angle to a height of 30 to 40 feet. Steam detonations at depth caused the ground about the crater to shake. [Marler 1963a] Marler's 1963 report seems to contradict what he wrote in his 1973 *Inventory*... [p 530].

Vent b - This vent was apparently created in 1963. [Marler 1973] Curiously, Marler does not mention this event in either his 1963 or 1964 reports. Eruptions in later years have been from this vent and of a minor character.

17 - Jelly Spring This name was originally given in 1887 by Walter Weed, NOT to this spring, but to a spring located at the base of the Fountain Terrace (map #34 & Peale's No 29) which at a much later date would be called "Gore Spring" by George Marler. (For citations and argument see #34, Unnamed Spring, below). The original name given to this spring was that of "Spasm Geyser"; this was given by Comstock [1875] of the 1873 Jones survey. In his report of the 1878 Hayden survey, Peale continued the use of the name "Spasm Geyser" for this feature. The 1904 Hague *Atlas*... did not label this feature; the label of "Jelly" would appear to be on the correct feature further to the west and at the base of the Fountain Terrace. In his 1911 manuscript, Hague described today's Jelly Spring as follows:

> The Spasm consists of a long pool, with the spring situated at one end. It boils slightly much of the time and throws a jet every two minutes to a height of 2 feet.

It was not until about 1926 that the name Jelly Spring became erringly attached to this present feature (possibly by Charles Phillips). This mistaken placement was adopted by the 1927 names place committee. [Phillips 1927, Albright 1928, US Board 1933]

Over the past few years Jelly Spring has had only rare eruptions. Six eruptions were recorded on May 5, 1991; heights varied from only a couple feet to as high as 15 feet. Consecutive intervals ranged from 25 to 100 minutes. [Stephens 1992a] Another short spot of activity occurred in July of 1992. At least two eruptions reached heights of 7 to 12 feet. [Keller 1993]

When at its best Jelly Spring can erupt to as high as 15 to 20 feet and from as many as 4 vents, usually in sequence. Two of these vents are within the main pool, one is just outside the main pool near its southwest edge, and the 4th vent is just within its front (eastern) runoff channel.

18 - Clepsydra Geyser This geyser was so named by T. B. Comstock of the 1873 Army Survey under Captain Jones:

> The third member of the group is one of the most

> regular in the basin, and on this account the name Clepsydra is proposed for it. [Comstock 1875]

This geyser was apparently inactive in the 1880's and was so noted by Walter Weed in 1887. Rejuvenation of this geyser by at least 1891 is indicated by the following item in the 1892 edition of the guide book published by Frank Haynes:

> Clepsydra Spring, some 50 feet west from the Fountain, has recently developed into an active geyser of no small eruptive power, its frequent displays being really quite violent for so small a "spouter," and very pleasing withal. [Guptill 1892, p 37]

Clepsydra's "wild phase" activity, (a term first used by Marler) was noted by Charles Phillips at least as early as 1926 when he made the following observation in the 1927 *Ranger Naturalists Manual:*

> Clepsydra, named for its fancied regularity for the ancient water-clock of the Greeks, has of late years developed into a geyser of considerable power. Its eruptions are by no means as frequent as formerly but the increases in magnitude more than compensates for any loss in this direction. There is a striking parallel between the rise in power of Clepsydra and the decline of Fountain that suggests an inter-relation. [Phillips 1927]

In 1928, Clepsydra was active at "rather irregular intervals. About every second day there [was] an eruption of much greater power, utilizing four distinct and separate vents... Maximum height 60 feet". [MRofS Aug, 1928] In spite of Marler's stating that his first observation of Clepsydra's "power display" was in July of 1941 [Marler 1946b, 1973], his own report in 1938 would tend to dispute this:

> CLEPSYDRA During August I observed this geyser but once. This eruption began at 7 P. M. the 19th. Water played from three vents. From the central one it reached a height of about 30 feet. This type of play continued steadily until 7:45 when the eruption changed largely into a steam phase.
>
> I was down by the Kaleidoscope when this steam phase began. It was so audible as to immediately attract my attention. Upon reaching the Clepsydra I noted that water was still being sprayed from the central vent. From the east one the water was playing out almost parallel to the geyserite while from the west one steam was issuing under seemingly greater pressure and with greater noise than I have ever noted for any geyser.
>
> After standing near the sign for a while I became somewhat intimidated by the force of this steam pressure and retreated to the walk. I had never observed Clepsydra to play in this function and I was doubtful as to whether this eruption was at all normal. [Marler 1938a]

Other such eruptions were also noted by Marler in 1939 and again in 1940. [Marler 1939a, 1940a]

It is commonly held that following the 1959 earthquake until 1963 [see Marler 1962a, 1963a], Clepsydra continued unabated in its "wild phase" activity. But a February 3, 1960 report by Riley McClelland stated that Clepsydra, on the 26th of January, had returned to its more normal "clock-like" (a Marler term) activity. Clepsydra was back to its "wild-phase" activity in February. [McClelland 1960]

19 - Clep's Well This spring was so named by Marler "because of its pronounced sympathy to eruptions of Clepsydra". Although it does drain at times, this sympathy with Clepsydra has not been so pronounced since the 1959 earthquake. This name first appeared in Marler's 1973 *Inventory...*

Clep's Well was noted as a small geyser in 1887 by Walter Weed at a time when Clepsydra was inactive.

20 - Sub Geyser In recent years, this geyser has erupted from a small pool in the northeast corner of a large depression almost 8 feet deep. In his 1973 *Inventory...*, Marler wrote the following:

> Eruptions [of Sub Geyser] are frequent and in the nature of a heavy surge, recurring about every minute and lasting from 20 to 30 seconds...

The 1959 earthquake initiated its present active cycle.

In his 1959 report, Marler reported:

> Sub Geyser: This spring is located about 100 feet northwest of Morning, on the shoulder of the hill. On infrequent occasions it has been observed erupting. During most of its known history water has stood about 6 feet below the crater rim. The quake initiated eruptive activity which was continuous for the rest of the year. The eruptions were sub-aerial in character, hence the name. The splashing started about 5 feet below the crater rim, reaching about a foot above. Pre-earthquake data are indicative that Sub is connected underground with the other springs in the immediate Fountain Group.

The spouting initiated in 1959 continued through the 1960 season, and played to a height of about 2 to 3 feet above ground level. [Marler 1960a, Lewis 1960] By 1962 the eruptions had reverted to a "sub-aerial" character. [Marler 1962a]

I can find only two references to Sub Geyser being active prior to 1959. In both cases, apparent connections between Sub and Morning Geysers along with other geysers within the group were noted. Underground connections between Sub Geyser and "the other springs in the immediate Fountain Group" were first noted by Marler in 1956. [Marler 1956a] Two years before this date, in 1954, it was first noted that not all of Morning's eruptions were followed by Clepsydra. For a few of Morning's eruptions that season, it would be Spasm which would follow. Its uncharacteristic eruptions would send water to about 25 feet for 10 to 15 minutes, and then go into a 2 to 3 hour steam phase. [Marler 1954a] Now in 1956, Sub would take on a similar role. Marler wrote in his 1956 report:

> [The] two failures [this season] of the Clepsydra and Fountain to follow the Morning... [was caused by] the activity of an unnamed spring... west of the Morning. On June 28 and August 18 when Clepsydra and Fountain failed to follow Morning the unnamed spring did, and was active for several hours. The two mentioned dates are the only times I have seen it active. [Marler 1956a]

The height of these eruptions was from 12 to 20 feet above the crater!

This uncharacteristic behavior of Sub Geyser was reported again in 1957 by William J. Lewis, who this year gave it its first name:

> Clepsydra Thief--When this geyser was active following an eruption of Morning, Clepsydra did not go wild... It played several times daily some days, but on others did not play at all. Its duration was variable, but when it erupted several hours after Morning, it played for about 40 minutes.

By 1962 the activity in Sub Geyser was more like that of today. Marler wrote in his 1962 report:

> The water played from a lower level in Sub Geyser. All eruptions were sub-aerial, the intervals being about one minute, the duration 15 seconds. [Marler 1962a]

Only on unusual occasions has this geyser been seen to erupt above ground level in recent years. This can sometimes occur during activity in Morning or during unusually strong or prolonged activity in Fountain. I had seen a couple eruptions to as much as 2 to 5 feet above ground in 1983 during unusually long eruptions of Fountain, and again in 1991 during eruptions of Morning.

It was in August of 1991 that another unusual occurrence was seen involving both Sub and Morning Geysers. During one of the eruptions of Morning Geyser, the water level in Sub Geyser rose high enough to produced quite a heavy overflow. No obvious eruptive activity could be seen from that distance. [Keller 1992]

GORE SPRINGS:

The name of Gore Springs was given by A. C. Peale to the group of springs which lie along the fracture associated with today's New Bellefontaine Geyser! [Peale 1883, Comstock 1875] The name was in allusion to the "bloody" color of the brilliant ferric oxide in the runoff channel flowing from these springs.

These same springs were called the Chalybeate Springs by Herman Haupt in his 1883 guide book. (Chalybeate means impregnated with salts of iron). The following was found in a couple other early guide books:

> West of the [Fountain] geyser, near the edge of the terrace, is a group of springs depositing ferric acid[sic] so abundantly that the group appears to be deluged in blood. [Winser 1883, Hyde 1887]

The name of "Gore Spring" (singular) was later mistakenly attributed by Marler [1959a, 1973] to a single spring residing within an explosion crater 750 feet southwest of Clepsydra. (See #34 below). Later the USGS incorrectly associated the name "Gore Springs" with the above spring plus a few smaller ones in its immediate vicinity. [USGS 1974]

The real Gore Springs contain at least 8 or 9 geysers! (See # 21 through 29 below). Greatly increased activity along this fracture line appears to have occurred sometime after the 1959 earthquake. Marler wrote in his 1961 report:

> During the past two years... [the] birth of several small geysers along the west shoulder of the Fountain Group was at the expense of Fountain, Morning, and Jet Geysers. Most of the new activity is along a fissure running in a north-south direction. Since the big geysers became dormant, 11 steady geysers have shown up along this fissure and two intermittent ones. [Marler 1961a, p 24]

Of the geysers located on this fracture line, 3 or 4 can not be observed from the boardwalk and, except for New Bellefontaine, the rest have been largely ignored.

21 - (unnamed geyser ?) This spring has at least 4 vents which lie within a small depression just south of New Bellefontaine Geyser. I have never observed any above ground activity from these vents; however, the USGS [1974] thermal map of the area appears to show it as a geyser. I do not know if it was active as either a geyser or a spouter in 1991.

22 - Fitful Geyser The name of Fitful Geyser was given by Comstock [1875] of the Jones Survey in 1873. This small geyser erupts from a small vent on the very southern lip of New Bellefontaine's basin. Comstock described it as follows:

> This geyser... was in action irregularly all the time we remained in its vicinity. The main orifice is near one side of the top of a small heap of sinter, built up by the water somewhat in the shape of a leaning cone. Occasionally the aqueous contents were spurted to the height of three feet above the top, in a course jet, but more frequently the ejections were much less forcibly than the accompanying sound would seem to warrant. [Comstock 1875]

Peale [1883], in 1878, noted similar activity. In 1897 Walter Weed [1897] noted Fitful Geyser as erupting to 5 - 7 feet. A couple reports in other years, however, would seem to indicate that at times, this geyser has little periodicity. [Weed 1883, Hague 1911]

In recent years Fitful Geyser has not been given much notice, but it commonly erupts for a few seconds at a time at irregular intervals; it seems to be most active during Fountain's eruption. Its activity also seems to be somewhat independent from that of New Bellefontaine itself. Fitful has been observed to have been active at least every year since 1982. [personal observations, Keller 1992]

23 - New Bellefontaine Geyser George Marler wrote the following concerning the naming of this feature in his 1973 *Inventory*...:

> There was early confusion as to the priority in the naming of many thermal springs. In the instance of Bellefontaine, Hague's 1904 *Atlas*... shows this spring as being on the south side of the Fountain-Hill complex. The name was also given to the one now being designated as "New" Bellefontaine.

I am convinced that the name of "Bellefontaine" was originally given by Walter Weed to the feature we are now calling Mask Geyser. [Weed 1887, 1888, 1890, Hague 1904, 1911, Haynes n.d., US Dept Int 1914] (See #36 below).

In his 1957 report, William Lewis stated that "this geyser [New

Bellefontaine] erupted almost constantly to a height of only a few inches." His 1963 report has an "Unnamed Geyser" that is most likely New Bellefontaine and he wrote that this geyser "was much more active than usual this summer".

The basin of New Bellefontaine contains at least 4 vents and it erupts from at least 2 of them. A number of much smaller vents on the wide northwest shoulder -- according to Marler [1973] there are 5 vents here -- also spout at times.

24 - unnamed geyser This geyser lies north of New Bellefontaine along an obvious fracture. Its basin contains 2 vents but most of the activity comes from the smaller of the two -- the one to the north. Its occasional eruptions have been known to reach as high as 20 feet, but it more commonly reaches only 5 to 8 feet. It was active in 1991. [Whipple 1982, personal observations]

25 - unnamed geyser This geyser lies at the northern end of the same obvious fracture on which lies New Bellefontaine. It erupts from a series of small fracture vents. Its play is frequent to about a foot or so. Plays to 4 feet or more are much less common. It was active in 1991. [Whipple 1982, personal observations]

26 - unnamed geyser This is the last geyser along this line which can easily be seen from the boardwalk. It erupts from a possible explosion crater more than 10 feet across. In his 1961 report, George Marler wrote about the "birth of several small geysers" in this area including along this fissure since the 1959 quake. He continued:

> The new geyser on the north end of the fissure is the largest and most interesting. It has a series of eruptions during an active phase. The manner in which it is eroding the geyserite about its crater is indicative that no geyser activity has occurred here, at least for a very long period. [Marler 1961a, p 24]

In his 1973 *Inventory*... [p 521], Marler described its activity from 1959 to 1963 as preempting that of New Bellefontaine.

Since its reactivation in more recent years, this unnamed geyser seems largely independent of New Bellefontaine. Its activity in 1991 was unusually frequent. During this season, its eruptions were often larger than its usual activity of 3 to 6 feet. [Whipple 1982, personal observations]

27 - unnamed geyser This small geyser, when active, erupts to about 1'. It was weakly active in 1991. This geyser cannot be observed from the direction of the boardwalk. [Whipple 1982, personal observations]

28 - unnamed geyser This geyser erupts from a small vent to about 1'. When active, intervals have been recorded at 2½ to 4 minutes with durations of 2 to 3 minutes. Again this geyser can not be observed from the direction of the boardwalk. I could not discern any activity other than light steaming in 1991. [Whipple 1982, personal observations]

29 - unnamed geyser This is the last vent lying along this line. It consists of a thin fracture about 4 feet long. Its activity consists of a spray usually to 1 to 4 feet. Recorded intervals range from 1½ to 4 minutes with durations of 1 to 2 minutes. Although I could see a wet runoff channel and some spray in 1991, I could not determine whether this activity was periodic. [Whipple 1982, personal observations]

FISSURE SPRINGS:

In his 1871 report Hayden described the springs along the two long fissures west of Clepsydra:

> About one-forth of a mile west of the large mud-pots are some extensive fissure-springs, one of them 100 feet long and of variable width, 4 to 10 feet. These appear to be merely openings in the crust or deposit which covers the entire surface. [Hayden 1872]

In his 1878 report, A. C. Peale [1883] again briefly described these fissures and named the eastern one the Gore Springs (mentioned above).

One of the old guide books [Haupt 1883] used the name of "Fissure Spring" for one of the springs along the lower or western fissure. Apparently this name did not gain any popularity for no "Fissure Spring" is mentioned for the Fountain Group in later literature nor in Department of Interior Publications until George Marler reintroduced this name a couple decades ago. [Guptill 1890-1907, Haynes 1910-1966, US Dept Int 1912-

1936, Marler 1973]

George Marler gave the name of Fissure Springs to a series of at least 10 vents which lie along a single line at the very base of the sinter mound below Clepsydra and the Gore Springs. At least 7 additional vents lie in very close proximity. Marler wrote the following:

> There are 10 springs along the Lower Fissure, four of which are active, three being small geysers... The earthquake greatly activated this fissure. Three of the vents erupted steadily to heights of about 6 to 8 feet for the remainder of 1959. The two springs on the west end of the fissure were enlarged due to more powerful eruptions. [Marler 1973]

The vents associated with the Fissure Springs contain at least 4 sizable geysers, 2 smaller spouters, and 2 small vents atop small cones. These two latter vents appear to have had some kind of eruptive (or spouting) activity in previous years, but I am not aware of any recent activity. A final vent has been a very noisy, spraying, steam vent since the '59 earthquake. [Whipple 1982, Marler 1973, personal observation]

30 - unnamed geyser This geyser erupts from 2 large vents from within a near cave like opening. This spring was observed as a strong perpetual spouter in the early 1980's. But in 1990 & 1991 this feature was truly periodic to heights of up to at least 8'. This geyser's activity can not be seen from the boardwalk. But its larger eruptions have been noted on a few occasions from the Kaleidoscope area. [Whipple 1982, Keller 1992, personal observations]

31 - unnamed geyser This geyser erupts from the larger of 2 vents within the same pool. Eruptions are frequent and can reach 4 to 6 feet. This geyser has been very active in later years including 1991. Again, this geyser's activity cannot be seen from the boardwalk. [Whipple 1982, personal observations]

32 - unnamed geyser This geyser's main activity comes from the middle (and smallest) of three vents which lie in the same pool. Frequent eruptions in past years have commonly reached 4 to 6 feet. Much higher eruptions in 1991 could actually be seen above the top curve of the sinter mound from the boardwalk. [Whipple 1982, personal observations]

The northern vent within the same basin is commonly a minor spouter. A small vent a few feet to the northeast of this basin has been a very loud, spraying steam vent since the '59 earthquake. [Marler 1973, p 484] A small fifth vent to the southeast has been known to be a spouter in the past [Whipple 1982]; it was inactive, however, in 1991. (These vents are depicted on the map insert).

33 - "Stalactite Geyser" The earliest reference I can find to this geyser was made by William Lewis in his 1960 report. He called it "Broken Geyser" because of all the broken sinter around its opening. Durations were brief with intervals from 1 to 8 minutes. The name "Stalactite Geyser" was given by Jennifer Hutchinson in about 1982. [Whipple 1982]

Possibly the largest geyser of the Fissure Springs, the vent of "Stalactite Geyser" actually emerges from an apparent blowout in the sinter hillside a few feet east of the southern end of the fissure line. Its appearance gives one the impression of relatively recent origin, perhaps due to the 1959 earthquake, but I have yet been unable to confirm this. The very jumbled vent has sinter "stalactites" hanging from its top edge deposited by past water flow from above. In more recent years, eruptions have been less frequent than those from the other Fissure Springs. [Whipple 1982, personal observations]

Activity in 1991 was unusually large and eruptions were commonly seen to as high as 5 feet above the slope of the sinter hill as viewed from the boardwalk.

Below the Fountain Terrace are 2 additional large springs (#34 & #35) at its foot:

34 - unnamed spring This spring, for almost 40 years, was known as "Jelly Spring". But in the mid 1920's, using only the 1904 Hague *Atlas...* as a guide, the naturalist division apparently misinterpreted the map of the Fountain Group, and misplaced the names of both Jelly Spring and Bellefontaine Geyser. These new locations persist to today. [Hague 1904, 1911, Phillips 1927, Haynes n.d., US Dept Int 1914, Albright 1928, US Board 1933]

In A. C. Peale's 1878 report this spring (#34) was No. 29 of his Fountain Group. Peale wrote:

> At the foot of the [Fountain terrace, or plateau], south of No. 13 [Clepsydra], is No. 29, a large cavern-like spring with a pool. No 30 [Mask Geyser] is also here, and beyond this is a wide flat with small springs and numerous steam vents. [Peale 1883]

Peale's table of the Fountain Group gave the dimensions of spring No. 29 as 12 by 30 feet. No 29 is clearly the spring to which George Marler mistakenly noted as the former site of the "Gore Springs" and stated that "most of the springs no longer exist". In his 1973 *Inventory*... Marler further described this spring as having:

> ...a jagged crater about 10 feet wide and 30 feet long. There is unmistakable evidence that the crater resulted from an explosive eruption,...
>
> Spreading out from the base is a sheet of water which has brilliant algal coloration; ...

In his 1959 report Marler added the following:

> During all its known history this spring, located at the base of the hill below Clepsydra, has maintained a steady overflow...
>
> An eruption following the quake completely destroyed the algae. The water had ebbed in the crater about 3 feet and was violently boiling... By November the spring, as well as a new growth of algae, has resumed the pre-earthquake coloration. [Marler 1959a]

To the above spring (#34 on the accompanying map) Marler [1973] gave the name "Gore Spring" (singular). The name of "Gore Springs" was later erringly attached to this spring and a few additional vents by the USGS. [1974]

There are quite a number of sources from which the position that spring #34 is the original "Jelly Spring" can be argued. One such source is found in Walter Weed's 1887 formal notebook. Additional arguments are also presented below.

In his 1887 formal notebook [p 68], Walter Weed unmistakably gave Peale's No. 29 the name of "Jelly Spring". He gave no description. Unfortunately, because Walter Weed renumbered some of the other springs and geysers in his 1887 notebook, it can not be conclusively shown that the spring we now mistakenly call Jelly Spring is mentioned by him under some other name. I do believe, however, that a strong argument for this can be made. Weed's "Fitful" (his # 9) is almost certainly the same as today's Fitful Geyser. Note that, previous to the 1880's, the names Jet & Impulsive were given to the SAME feature. Therefore, since the geyser Weed called "Jet" (his # 11) is correctly placed, and is clearly today's Spasm Geyser, then a third geyser which Weed called "Impulsive" (# 10), erupting to 5 feet, involved a switching of names, and is possibly today's Jelly Spring. (Weed did not use the name "Spasm" at all in his 1887 formal notebook).

Although there is definitely a confusion of names here, we can come to some conclusions. Note that Walter Weed called today's Jet Geyser, the "Cone", and he called today's Spasm Geyser, by its correct name of "Jet Geyser". By a process of elimination, Weed's "Impulsive Geyser" can not be any other geyser in the vicinity of today's Jelly Spring unless it was Jelly Spring itself. Thus I believe it reasonable to conclude that Weed's "Impulsive Geyser" is today's Jelly Spring, and that his No. 29 "Jelly Spring" is the same as Peale's No. 29.

An even stronger argument can be made using an article which Walter Weed wrote the next year. In the *Ninth Annual Report of the United States Geological Survey to the Secretary of the Interior 1887-'88*, we find a very long article written by Walter Weed [1889] entitled "Formation of Travertine and Siliceous Sinter by The Vegetation of Hot Springs". Although this report was not published until 1889, it reflected work accomplished by the end of the 1887-'88 fiscal year namely June 30, 1888. Therefore all the information and descriptions therein were obtained at least by the summer of 1887.

In Weed's above article, the water from a spring which he called "Jelly Spring" (along with that coming from Emerald Spring and Black Sand Spring), took a prominent place in his description of the formation of siliceous sinter. Although photographs of the spring itself were not shown, photographs were shown of what Weed labeled the "Upper Algae Basin, Jelly Spring" (Plate 84), and the "Middle Algae Basin, Jelly Spring" (Plate 85), and finally a third photograph showing "Stony Forms in [the Lower Algae Basin], Jelly Spring" (Plate 86).

When viewing these photographs a few things become quite clear. None of these photographs were ever described as being photos of "Jelly Spring". Nor are these basin formed by water flowing from what we are today calling Jelly Spring. It is quite clear that these waters are flowing to the west and these basins are situated BELOW the curve of the main mound on which sits Fountain Geyser and today's Jelly Spring. Even Walter Weed stated that the "Jelly Springs" lie "at the base of the mound of the Fountain Geyser". In the photo of the "Middle Algae Basin" there is clearly shown a pool close behind which I believe to be today's Mask Geyser.

About Jelly Spring itself Walter Weed [1889] wrote the following in the USGS *Ninth Annual Report*...:

> The tendency of the algous growths to form terraced basins is beautifully illustrated in the basins supplied by waters of the Jelly Springs at the base of the mound of the Fountain Geyser. In these basins the different stages of sinter forming are sharply drawn, from the soft and brightly colored jelly to a hard and stony sinter.
>
> Pl[ate 84] shows the uppermost of these basins; the dam ponding back the water is about a foot high, and is formed of a fibrous sinter, hard and stony below, but grading into a softer material of cheesy consistency above, passing into red and green algous jelly. The algae of this pool or basin are brightly colored, and the forms resemble those of the Emerald Spring, but the pillars[stromatolites] are taller, owing to the greater depth of the water.
>
> In a lower basin ["Middle Algae Basin"], shown in Pl[ate 85], the water is nearly cold, and though the forms are the same as those found in the basin above there is no trace of red, yellow, and green algous jelly...
>
> ...the stony masses found in a lower and empty basin, shown in Pl[ate 86], are apparently quite different in nature, though formed by the incrustation of the shapes shown in Fig. 56. This basin is the lowest of the series, and if some cause had not operated to produce the death of the algae, and an incrustation of the structures, before the filling up of the basin with their siliceous stems, the basin would now form only a bench, indistinguishable from the rest of the sinter flat above it.

In Weed's 1888 formal notebook, the feature he named "Jelly Spring" is definitely not an eruptive feature, and some additional detail of the spring itself is added:

> 29 The spring itself is a deep, oblong fissure bowl with light gray lining and filled to the brim with perfectly clear, glass green water, that boils quietly, without bubbling or disturbance, giving a very constant overflow which runs over a flat area forming a large but very shallow pool. A tongue of white projects from the spring out into this pool in strong contrast to the old gold, bronze and brown that surround it and into which it gradually merges. This white area indicates the place of hottest temperature where the algae that cover the floor of the shallow pool, cannot exist. The odd effect of the colors is enhanced by the irregularity with which the colors are distributed, owing to the sudden change of temperature on adjacent areas, due to currents of hot water, the tint depending upon the temperatures and supply. ...but these tints occur at different temperatures in the channel into which the greater portion of the overflow gathers after leaving the shallow pool and after flowing in these channels a few yards and supplying one or two lesser "basins", it flows into the terraced basins shown in the photographs. [These are the same "algal basins" as described above].
>
> ...jelly at outlet 112°.
>
> The upper part of the basin is shut off by a ridge of serpentine green algae-sinter, the bottom a dull purplish

tone, the deposit red, the temperature of the water 105°.
The 2nd basin photographed has been filled with warm water (Temp 104°) and the forms shown in the view are now coated with a mossy, yellow bronze covering which in the shade, or the underside of prostrate forms, is a bright arsenic green. [Weed 1888, p 21-22]

There is one last note which needs to be made concerning Weed's photographs of the "algae basins" which form by the overflow from his "Jelly Spring". The photograph which many people have claimed to be of today's Jelly Spring is labeled by Walter Weed himself as the "Upper Algae Basin, Jelly Spring, Lower Geyser Basin". His text also clearly indicates that this basin was formed by water coming FROM his "Jelly Spring", and was NOT "Jelly Spring" itself. This fact alone would disqualify it from being what we are today calling Jelly Spring.

Arnold Hague died before he could publish Part I of his massive *Monograph XXXII* on the *Geology of the Yellowstone National Park*. But an unpublished manuscript, circa 1911, entitled the "Firehole Geyser Basin", was a preliminary portion of this monograph. In a section labeled the "Fountain Geyser Group", Hague described a feature which he called "Spasm Geyser" which is clearly <u>today's</u> Jelly Spring. His description of "Jet Geyser(The Impulsive)" is clearly today's Spasm Geyser. Thus, his very long description of a third feature which he called "Jelly Spring" can not possibly be today's Jelly Spring.

To exactly which spring the word "Jelly" is connected on Geology Sheet XXII of Hague's 1904 *Atlas*... is difficult to exactly determine, but it would appears to me to be placed well to the west of present day Jelly Spring, and in fact, appears to be placed on the feature to which Marler gave the name of "Gore Spring", namely Peale's spring No 29. (See # 34 on accompanying map). There also appears to be a white "terrace" extending to the west from the indicated spring. Both Hague's text (given below), and Geology Sheet XXII would corroborate the fact that Walter Weed's label of "Jelly Spring" was placed on No. 29 of Peale's Fountain Group.

About "Jelly Spring" Arnold Hague wrote the following in 1911:

Jelly Spring at the southwest <u>base</u> of the sinter mound of the Fountain, presents certain surface features in marked contrast to those already described. The spring itself is an oblong fissure bowl, with light-gray lining, and filled to the brim with clear green water that boils quietly without bubbling, giving a constant overflow, which spreads out over a flat area, forming a large but shallow pool. It changes somewhat from year to year, depending upon volume and temperature of the overflow stream. The following description held true for a number of years, and in its main features is probably still correct so far as algous growths are concerned. A tongue of white algae projects from the spring into the pool, in strong contrast to the old-gold, bronze, and brown species that surround it and into which it gradually merges. This white area indicates places of highest temperature, where the species that cover the floor of the shallow pools cannot exist. The peculiar effect of the color is enhanced by the irregularity with which the delicate tints and shades are brought together, owing to sudden changes in adjacent areas, due to currents of hot water. After running in shallow channels for a few yards the water flows into terraced algae basins, so characteristic of most geyser basins, and nowhere are they better developed than at Jelly Spring, where every stage of change is shown, from the earliest gelatinous pulpy growths to the compact flinty rock structure. [Hague 1911]

All the early editions of the *Haynes Guide* [1912-1927] further support this interpretation of the placement of the name of "Jelly Spring", (along with that of "Bellefontaine" for today's Mask Geyser). This placement also corresponds to that in the maps originally published by the Department of the Interior in their "General Information" pamphlets for Yellowstone National Park from 1912 through at least 1936. [US Dept Int 1912-1936] Jack Haynes' own notes further stated that "Jelly Spring" was located about 250 feet southwest of "Jet Geyser" (today's Spasm Geyser). [Haynes n.d.]

The first hint we have of today's incorrect interpretation (and placement of names) comes from Charles Phillips' 1926 description of the "Lower Geyser Basin" found in the 1927 *Ranger Naturalist Manual*. This change was set in concrete by the 1927 place names committee. The editions of the *Haynes Guide* published from 1928 on, reflected this change.

35 - Bellefontaine Geyser The word "Old" was added by Marler, but the name Bellefontaine Geyser has been officially approved. [Marler 1973, Whittlesey 1988, US Board 1933] The specific resting place for the name "Bellefontaine" as it appears on the 1904 Hague *Atlas*... appears not to be on this feature nor on "New" Bellefontaine Geyser.

The name "Bellefonatine" was given by Walter Weed in 1888 to the feature we now call Mask Geyser (see #36 below). The maps in the editions of the *Haynes Guide* from 1910 to 1927 also appear to follow this placement for "Bellefontaine". Jack Haynes' own personal notes stated that "Bellefontaine Geyser" was situated:

> ...about 800 feet southwest of Fountain Geyser,... [It is] one of a group of small geysers of which one or more are usually in eruption. [Haynes n.d.]

Today's incorrect placement of the name Bellefontaine was possibly made by Charles Phillips by 1926. He wrote in the 1927 *Ranger Naturalist Manual* that "Bellefontaine is... frequent but scarcely sustains its title of 'beautiful fountain'." [Phillips 1927] This mistake was set in concrete by the 1927 place names committee. [Albright 1928, US Board 1933] The maps in the editions of the Haynes Guides from 1928 on, reflected this new placement.

Marler [1938] reported Bellefontaine as an active geyser in 1938. He later wrote in his 1973 *Inventory...*:

> During the early 1950s I observed a few eruptions, others were reported. The activity did not last for more than two seasons when dormancy again ensued. There is no record of the frequency of the activity; the height of the eruption was from 6 to 8 feet.
>
> The 1959 earthquake brought about a rejuvenation, which lasted for the rest of the year. Eruptions occurred on about 50 to 70 minute intervals; the durations 3 to 4 minutes; the height about the same... Since 1959 there has been no known eruptions...

The accuracy of Marler's last few sentences is questionable, and largely contradicted by his own earlier reports and those of William Lewis.

The only annual report of Marler in the (pre-earthquake) 1950's, in which I could find mention of Bellefontaine being active, was that of 1955. However, I did find Bellefontaine listed as an active geyser in Marler's 1959, 1960, 1961, & 1962 reports, in spite of what he said in the *Inventory*... Information in these later reports would seem to contradict some of what Marler reported above. In Marler's 1959 report we read:

> An active cycle was stimulated by the quake. For the first few days it was active most of the time. Its intervals gradually lengthened, but periodic activity persisted for the rest of the year.
>
> About 200 feet south of Bellefontaine a new crater was formed the night of the 17th. An explosion tore out a block of sinter about 5 feet square. No further activity was observed. [Marler 1959a]

In Marler's 1960 report we further read:

> An unusually forceful eruption the night of the quake made some enlargement of the crater; [and] a new eruption cycle was initiated. During all of 1960, it played on short intervals, the average being about 6 minutes. The eruption is merely a big surge or splash. [Marler 1960a]

William Lewis also reported Bellefontaine active in his 1960 report with activity more like that of the present day. Recorded intervals were from 2 to 21 minutes, with eruptions of only a second or two. In contrast to what Marler [1962a] wrote, Lewis' 1962 report stated that Bellefontaine was dormant.

As far as I have been able to

determine, Bellefontaine was inactive in the 1970's, and most of the 1980's. Since its reactivation in 1989, eruptions have been infrequent and more commonly seen to heights of about 4 feet. When in an active cycle, single burst eruptions with intervals of about 5 to 50 minutes interspersed with long periods of quiet have been the rule. Strong cyclic eruptions were noted in mid-summer of 1991. Exceptional eruptions of up to 15' have also been seen, including at least one in 1991. [Whittlesey 1992, Wolf 1992, personal observations]

There are 2 additional loosely allied groups of springs somewhat separated from the main body of the Fountain Group. The largest of these 2 groups lies largely in an east-west line in the extensive flat area almost directly to the west of the main body of the Fountain Group. These have been called the Pithole Springs.

PITHOLE SPRINGS:

The 1904 Hague *Atlas...* showed a small consolidated group of springs south of today's Kaleidoscope Group and west-northwest of the Fountain Group which were labeled the "Pithole Springs". Accompanying the USGS Professional Paper 435, there is a "Map of West Central Yellowstone National Park Showing Principal Geyser Basins and Thermal Groups". It is included in an article by George Marler [1964b] enumerating the effects of the 1959 earthquake. It isolates the area of the Pithole Springs and calls it the "Pithole Springs Group". The position of this group generally corresponds to the position as shown for the Pithole Springs on the earlier Geology Sheet XXII in the 1904 Hague *Atlas...* and Marler's map is probably taken in most part from that of Hague.

In neither case, however, would it seem to appear that either the Pithole Springs (or the "Pithole Springs Group") were meant to include the much larger group of springs further to the south and immediately west and west-southwest of the main portion of the Fountain Group. But when one would try to find these "Pithole Springs" in the locality indicated on either map, there is nothing there. In a few occasions relative positions of groups of springs on the plates in the 1904 Hague *Atlas...* have been skewed from their proper position. About the only group of springs which could be represented by the label "Pithole Springs" is the group of springs in the flat area almost due west of the Fountain Terrace. Marler seems to have come to this same conclusion. In his later reports, springs found in this area are included within what he called the "Pithole Springs Group". [ie Marler 1959a-1961a] So I have decided to make the same use of this name.

This area contains a couple heavily flowing springs, a couple large pools, and at least 5 geysers.

36 - Mask Geyser This geyser erupts from an exceptionally beautiful pool whose vents are so arranged to strongly suggest a mask. This name was given by Naturalist William Lewis [1960] in about 1960. Marler [1961a] later noted: "the largest and most important of the geysers in the Pithole Springs has been called Mask Geyser by Lewis because its crater reminds him of the 'mask worn by the ancient Greeks in their plays'."

Mask Geyser was the original "Bellefontaine" of Walter Weed and Arnold Hague. This feature (No. 30 for both Peale and Weed) was described as "an intermittent bulger" by Walter Weed in his 1887 formal notebook, and a small drawing of its basin and vents is unmistakably that of today's Mask Geyser. His notes provided the following description:

> 30 20' x 30' Water clear. Rim of hard geyserite in large forms with wrinkled surface & flat top. Low water level about 12' diameter -- 4"-6" below the rim. Spring is an intermittent bulger... [Weed 1887]

In 1888 Walter Weed named it the "Bellefontaine" and added the following:

> Bellefontaine. Temp. 170°.75. The eruption consist in a perfuse bubbling and the formation of a foaming water hillock, accompanied copious overflow. Temp. at this period 177.5°. [Weed 1888]

In an 1890 notebook, Weed used the name of "Bellefontaine Spring".

In an unpublished treatise entitled the "Firehole Geyser Basins", Arnold Hague [1911] wrote the following:

> At a somewhat lower level and more to the westward [of

> Spasm and Clepsydra], occurs a circular spring of clear blue water of great beauty, known as the Bellefontaine, and similar to the springs just described, bubbling more or less all the time, accompanied by a copious run-off of highly heated waters.

It is Mask Geyser which fits both the above description and the location; this is not true of either of the present day "Bellefontaines". In addition, both the map in Hague's 1904 *Atlas...*, and the maps in the earlier editions [1910-1927] of the *Haynes Guide*, appear to place the name "Bellefontaine" on what we call today Mask Geyser. This placement of "Bellefontaine" is even more evident when we realize that the feature labeled "Jelly" is not present day Jelly Spring but the feature Marler later labeled "Gore Spring" (#34 on accompanying map).

It was not until the mid-1920's do we see the location of the name "Bellefontaine" changed to the feature we today call "Old" Bellefontaine. [Phillips 1927, Albright 1928, US Board 1933, Haynes 1928-1966]

Mask Geyser entered an eruptive cycle during the 1958-59 winter. [Marler 1961a] Recorded intervals in 1960 ranged from 15 to 47 minutes with durations of up to 10 minutes. The eruption was "characterized by frequent ebbing, swelling, and eruption with a constant repeat of the cycle." [Lewis 1960] Intervals lengthened somewhat in 1962 and 1963. [Lewis 1962, 1963] In 1964 intervals of 13 to 20 minutes were recorded with durations of merely a few bursts to as long as 3 minutes. [LGB Logbook 1964] In the early 70's Mask Geyser erupted to heights of 6 to 10 feet for 4 minutes at intervals of 3 to 4 hours. [Whittlesey 1988]

Mask Geyser is also probably the feature referred to as "Ornamentation Geyser" by Jennifer Hutchinson in her 1982 notes. [Whipple 1982] In recent years eruptive activity has been strongly cyclic, with intervals of about 20 minutes. Its doming eruptions in the early to mid 80's were commonly seen to about 4 feet, but in 1991 they were barely reaching to about a foot. [personal observations]

37 & 38 - unnamed geysers The larger of these two geysers, #37, was seen by the author in 1988; it erupted from what appeared to be then a large pool directly in line with the boardwalk when standing near Spasm Geyser, and a little to the north and well beyond Mask Geyser. The eruption consisted of several massive bursts to about 4 or 5 feet. The eruption lasted about a minute. In his 1988 report, Scott Bryan wrote:

> On July 24, [1988] I observed two previously unreported geysers on the flat valley floor west of the geyserite mound of the Fountain Group. I am somewhat uncertain as to exactly where these springs fall on the USGS Thermal Map, but believe the following to be correct.
>
> One of the geysers is a rather large oval pool, probably 25 feet long in the bigger dimension. If my identification is correct, then it lies at USGS Coordinate E4-180E-740S. This pool caught my eye while I was at Spasm Geyser. Some of the bursts appeared to reach over 10 feet high. The eruption continued for several minutes and was followed by a rapid partial draining; I guess the drop in water level to have been at least 2 feet. The recovery rate was surprising, and another eruption followed the end of the first in only 9 minutes. Subsequent checked periods were 12, 23, 18, 16, and 11 minutes. All durations were about 5 minutes. This is a significant geyser.
>
> The second new geyser [#38] lies about 50 feet further to the west. It appears to arise from a small pool (diameter 3 to 4 feet?). Its eruptions did not seem to be coordinated with those of the first geyser. The intervals ranged from a few seconds to several minutes, and most durations were about 20 seconds. The greatest height was probably 4 feet. [Bryan 1989]

39 - unnamed geyser This geyser erupts infrequently to about 4 to 10 feet from a large jagged vent directly west of Mask Geyser, and beyond #37. I have only noted a couple eruptions in past ten years and none in 1991.

40 - unnamed geyser This small geyser erupts from a small vent a short distance beyond (to the west of) #39 above. The vent is difficult to locate except when the geyser is erupting. Intervals in 1991 were about 30 minutes with durations of 5 to 10 minutes and height of 2 to 3 feet. There is considerable discharge during an eruption.

The second group of springs separated from the main body of the Fountain Group lie in a flat area about 250 feet southwest of "Old" Bellefontaine. It is a much smaller group and contains one geyser of note.

41 - unnamed geyser This geyser lies directly in front of you and about 900 feet distant when looking from the area of the parking lot. Scott Bryan [1986] lists this geyser as "UNNG-FTN-3". Some geyser gazers have also been using the name of "Frolic Geyser".

The earliest reference to this geyser that I have been able to find was in the 1964 Lower Geyser Basin Logbook:

> Unknown Geyser 70 yds south of Belle Fountaine[sic]
> Played 9:50 AM height 5'
> duration ½ to 1 min
> [played] 10:30 AM

It was later labeled a "geyser" on the 1974 update of the 1966 USGS Thermal Map of the "Fountain Area".

This geyser erupts in a beautiful fountain to heights commonly reaching 15 to 25 feet. The play comes from a large hole in a sheet of flat brown sinter, and erupts at about a 15° angle. A few exceptional eruptions to as high as 50 feet were seen in 1989. Intervals have ranged in recent years from about 7 to 60 minutes, with durations usually under a minute. Though the durations are usually fairly consistent, even consecutive intervals can vary greatly.

42 - unnamed geyser In 1989, I thought I could see a second small geyser just to the southwest of #41 above, but even through binoculars I could not be sure of its periodicity. Its maximum height at that time was only a foot or two. The following is from Scott Bryan's 1988 geyser report:

> As has been suspected, there is a second geyser in this area [of FTN-3]. About 30 feet southwest of FTN-3, this "FTN-4" played less frequently with a bursting action reaching about 10 feet high. [Bryan 1989]

43 - (unnamed geyser ?) Visible with binoculars from the parking lot, there appears to be a third very small geyser about 20 feet or so to the west of #42 above. Maximum height is about 2 to 3 feet. This vent may have actually been a spouter instead of a true geyser.

44 - (unnamed geyser ?) There have been reports of a geyser erupting a thin spout of water from a vent at least a hundred yards closer to the parking lot than #41 above. I have never seen any eruption myself and do not know of any more precise location for its vent. [Fittro 1991]

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Geyser Springs
Gibbon Geyser Basin, Yellowstone National Park
Historical and Current Observations
By Genean, Tom and Chris Dunn

Abstract

Geyser Springs is a small geothermal area in the Gibbon Geyser Basin of Yellowstone National Park. The area presents a varied mix of both alkaline and acidic thermal features, including fumaroles, geysers and mudpots. This report describes the features and their activity.

Location

Geyser Springs is located on the east side of Paintpot Hill within the Gibbon Geyser Basin. This group of geothermal springs drains into Geyser Creek, a small stream that flows into the Gibbon River from the east about four miles south of Norris Junction. The area is no longer accessible by a maintained trail.

Observations and Studies of Geyser Springs:

The explorers of the first two Hayden Surveys of 1871 and 1872 apparently did not observe the features of Geyser Springs. Geologist A.C. Peale mentions the name of a feature that later writers place in Geyser Springs. He states, "*about two miles down the cañon [Gibbon Canyon from Monument Geyser Basin] is another small group in which there is a geyser which we call "Oblique," that spouts out obliquely over the road.*" (Hayden, XII, p. 133) According to Lee Whittlesey, in Wonderland Nomenclature (1988), a map made by Walter Weed in 1884 located this feature in the Geyser Springs area. However, Wolf and Paperiello (1985) conclude that Weed was incorrect in his interpretation of Peale. They "*believe that the site of the geyser is to be found along the Gibbon River about two miles below Gibbon Meadows.*" The latter description seems to match Peale's statement as no reference to a road appears in any reports of Geyser Springs that the authors reviewed.

Allen and Day studied Geyser Springs during their research from 1925 to 1932. They published their results in Hot Springs of Yellowstone National Park in 1935. They concluded "*Geyser Creek Basin,*" as they term it, is a mixed area of both alkaline and acidic thermal features. Details of their results will be presented later in this paper.

Ranger naturalist notes, such as Geyser Creek Basin by Richard Frisbee in 1961 and tourist guidebooks refer to the Geyser Creek features. For instance, Jack Ellis Haynes in the 1953 Haynes Guide describes, "*an unnamed geyser in the Geyser Springs group*" that erupts to heights of "*25 feet at six minute intervals.*" Marie Wolf and Rocco Paperiello (1985) present detailed observations of Geyser Springs in their unpublished report, Report on Lesser Known Thermal Units of Yellowstone National Park, 1981-1985. T. Scott Bryan (1991) describes several larger features in The Geysers of Yellowstone.

The writers visited Geyser Springs on six occasions over a period of three years from 1990-1992. The following report describes the individual features and notes similarities and differences between these recent studies and those of the earlier observers.

Introduction to the Features of Geyser Springs

Geyser Springs is divided into two main interconnected basins with a few widely spaced springs in the upper drainage of Geyser Creek. Several isolated springs are reached by following Geyser Creek south out of the upper basin. Two large springs are located up a draw to the west of Geyser Creek. Additional springs are located south and west of the creek. Above and across a saddle to the west of the Geyser Creek drainage are several large barren areas with a few perpetual spouters and many vents and fumaroles. These deposit free sulphur and appear to be remnants of extensive thermal activity in the past.

Wolf and Paperiello provide excellent physical descriptions of the features. Their measurements will be used extensively in this paper. All feature descriptions from the 1980's will be from their report, unless otherwise noted. Maps prepared by Rocco Paperiello and presented in the report noted earlier are the best and most detailed maps available. They are reproduced at the end of this article for reference.

Lower Basin

Allen and Day described the lower, northern basin in this way,

"Deep and narrow (65 yards wide), . . . (it) extends in a direction nearly north and south for 175 yards on both sides of the creek, continuing on toward the northwest for 100 yards farther in a mere strip of ground 30 or 40 yards wide. Rhyolite gravel surrounds the basin. The floor, more or less flooded with water and extensively colored by algal growth, is, in places, encrusted with a thin sheet of sinter concealing hot mud and affording a very insecure footing. Free sulphur is rather scarce, though one large spring in the northwest corner contains a heavy precipitate and there is a conspicuous crust on the sinter rim of another, while along the western edge of the area there is a considerable number of very small acid springs with sulphate salts showing here and there. Large, sinter-lined alkaline springs carry most of the water."

Entering Geyser Springs from the north, the first area is 30 to 40 yards wide on the west bank of Geyser Creek. In the center is a large spring with a sinter rim built up about a foot above the surrounding platform (Feature #1). Some observers call this *"Bull's Eye Spring"*; this unofficial name comes from the hole, the *"bull's eye,"* through the sinter rim on the south end of the spring. Wolf and Paperiello measured the size of the spring as 12 by 8 3/4 feet. Frisbee (1961) described this feature as a spouter to one foot, with clear water and a geyserite rim and he recorded its temperature as 204^{0}F. Bryan (1993) witnessed *"true eruptions at various times during the 1970's."* Wolf and Paperiello described the activity in 1982 as *"frequent periodic boiling and roiling to 2 to 3 feet at times, with a heavy discharge"* and concluded this feature is a geyser. In 1983, Wolf and Paperiello noted the water level was *"well below overflow and the pool was quiet with no boiling."* In 1985 the water level was below overflow, but *"it was roiling and boiling mostly from 1/2 to 1 1/2 foot."*

On all visits by the authors in 1990-92, this spring perpetually boiled up from 1/2 to 1 1/2 feet above the surface of the pool. The water level was high enough to overflow its channel and to splash over the sinter rim in several spots. Orange and brown cyanobacteria grew in the overflow areas. Yellow, sulphur colored deposits were noted 3 to 6 inches below the inner side of the rim. This is likely to be the *"heavy precipitate of free sulphur"* noted by Allen and Day. They described most areas of Geyser Springs as a mixed alkaline and acidic area: *". . .the alkaline waters emerge from the ground in the middle of the basins at the lowest levels, while the sulphate waters come to the surface on the slopes or on the extreme edges of the basin, and are distinguished from the former by their exceedingly small flow as well as their chemical character."* This feature, in the middle of the basin, is an exception with its sulphur precipitate and acidic water, as measured by Allen and Day (477 PPM of SO_4 compared to 70-160 PPM in other large pools or geysers).

In mid-July 1993, geyser observer Bryan (1993) noted *"bursting as a truly intermittent geyser, some splashes easily 3 feet high."*

Feature #2 sits above and west of *"Bull's Eye"* at the edge of the basin. It is a large pool, measured 30 by 24 feet. Its color and activity show considerable variation over time. Frisbee (1961) described this feature as a *"spouter"* reaching 1 to 2 feet with a temperature of 200^{0}F and brown water. In 1982, the pool was quiet and pale blue in color. In 1985, observer Milida Vachuda saw a 4-foot eruption and later in the summer, the pool was *"yellowish-green in color and bubbling."* The pool was vigorously boiling 3 to 6 inches high with a murky, blue-green color in all visits in 1990-92. Surrounding Feature #2 is a frying pan area (Feature #3) pockmarked with holes and shallow pools. This latter feature apparently has shown little change since the 1980's.

Features #4, #5 and #6 sit on the western bank of Geyser Creek. Features #4 & #5 show geyser activity. Feature #4 unofficially is known as *"Anthill Geyser." "Anthill"* is a small cone about 6 inches in diameter. Frisbee (1961) did not mention this tiny geyser. From 1982 to 1985, *"Anthill"* erupted *"frequently"* with durations ranging from 6 to 9 minutes and heights ranging from 2 to 6 feet. According to Bryan (1991), the intervals range from 1 1/2 to 5 minutes with durations approximately the same. He observed steam and spray ejected to 4 feet. Bryan (1993) stated, *"When at its best, Anthill's steam is forceful enough to be heard at a considerable distance, even from well down in the wood below the basin."* Eruptions in *"Anthill's"* neighbor (Feature #5), a pool measuring 6 by 4 1/2 feet with a scalloped sinter rim, rarely are seen. Frisbee (1961) described this pool as a clear spring at 205°F. When in action, the pool bursts to 2 feet high about half the time.

When the authors visited Geyser Creek in 1990, no activity was seen from *"Anthill."* Feature #5 boiled constantly to 1 to 2 inches. In 1991, although *"Anthill's"* cone appeared nearly buried in mud with only a 1 inch opening, the small geyser periodically ejected a few drops of water to 6 inches in height. In 1992, the cone was washed clean exposing a tear-dropped shaped vent with a rusty orange-brown color lining the throat. At intervals ranging from 5 to 12 minutes, water rose in the vent of *"Anthill,"* overflowed, washing the cone clean, and ejected clear droplets from a few inches to a foot and a half out over #5.

The pool (#5) also showed geyser activity. When filled, the pool boiled steadily from deep within its vent and overflowed into sinter-rimmed runoff channels to the north and to the southeast. Following the end of a water ejection period in *"Anthill,"* the pool dropped quickly to 6 to 10 inches below the rim and all boiling ceased for 1 to 2 minutes. Boiling resumed and after about 10 minutes, *"Anthill"* again ejected water for 1 to 2 minutes and at this time the pool refilled, overflowed, and continued to boil for 8 to 10 minutes. Apparently this is the first observation of the two small geysers erupting simultaneously. Feature #6, described in the 1980's as *"a small, quiet spring,"* also showed activity changes with its neighbors in 1992. Although steady streams of bubbles rise through the pool constantly, the spring surges and the bubbles increase in number and in frequency at the time of the heaviest overflow from #5.

Feature #7, described by Wolf and Paperiello as a *"small pool found within a cave-type opening,"* showed no changes through 1992.

Feature #8 showed *"frequent small eruptions (to 1 foot) during 1974,"* according to Bryan (1993). Wolf and Paperiello described as *"two quiet pools in an old sinter formation with water level below ground,"* In 1990 it showed some increase in activity. The authors observed vigorous boiling in the north pool under the southern ledge of sinter.

Feature #9 was seen in the 1980's as an intermittent spring, *"29 by 24 inches, rapidly cycling from discharging to nondischarging."* When observed by the authors, it showed a slight pulsation with no discharge.

Feature #10 changed dramatically from 1961 to 1992. Frisbee (1961) described this feature as a spouter to 1 to 2 feet with brown water and a temperature of 200°F. When seen in 1985, it spouted perpetually from 1 1/2 to 3 feet. *"Its water was milky opaque white and spiny sinter surrounds its large 7 by 6 foot basin."* On one observation trip in 1985, the water was 10 to 12 inches below its runoff channel and on a second trip, the water continuously overflowed. When the authors first saw this feature in 1990, it continuously spouted to 1 1/2 feet with water spilling down the runoff channel. However, in June 1992, the area consisted of steaming hot ground with no water visible.

Feature #11 remained similar to observations in 1985 when it was depicted as a perpetual spouter. Frisbee (1961) described this pool as a spouter to one foot with clear water and a temperature of 200^{o}F. However, the water was characterized as *"cloudy whitish"* in 1985, and was nearly clear in 1991 and 1992 with what appeared to be iron colored deposits around the rim.

Feature #12 changed significantly over time. In 1961, Frisbee pictured this pool as a gray, turbid spring with a temperature of 202^{o}F. In the 1980's Wolf and Paperiello described it as a *"bubbling pool"* and the authors observed no differences in 1990 with bubbling noted in the center of its approximately 3 foot pool. However, in 1991, the pool showed an increase in size and activity with gravel thrown up through the pool to 3 inches above the surface. By 1992 it enlarged to 5 feet in diameter. The gravel and small rocks were tossed 6 inches above the surface with firecracker-like sounds in the pool and thumping from apparent steam explosions below the pool.

Wolf and Paperiello identified fifteen features on either side of Geyser Creek as observers travel south. The ground in the center of the basin is treacherous and pock-marked with holes and thin sinter. A reasonably safe trail can be found about 5 to 10 feet up on the western side of the basin.

Feature #13 showed no change through 1992, but remained a *"small, discharging spring."*

Feature #14 is the large level area on the western side of the creek. It remains much as Allen and Day described it in 1935, *"the floor, more or less flooded with water and extensively colored by algal growth, is, in places, encrusted with a thin sheet of sinter concealing hot mud and affording a very insecure footing."* Bryan (1993) observed at least two small geysers prior to the early 1980's in this large flat basin. Wolf and Paperiello reported a perpetual spouter to 1 foot in 1982, but no other such observations are known.

Features #15, 16, and 17 respectively are described as a *"frying pan,"* a *"small bubbling spring,"* and a *"frying pan area."* Only the latter, #17, showed significant changes in 1992. In June 1992, the authors noted an 8 foot by 4 foot milky gray blue pool with boiling noted in three distinct areas within the pool. The southern vent burst to 1 1/2 feet and firecracker-like bursts steadily brought gravel and sand to the surface of the pool.

Features #18 (a) and (b) are interconnected pools that lightly bubble with variable water colors ranging from blue in 1985 to brown rimmed with foam in 1991 to greenish in 1992. Frisbee (1961) described this as a clear spring with a temperature of 159^{o}F. Feature #19 is also a small bubbling pool. Bryan (1993) reported an observation by Clark Murray of 4 foot eruptions from one of these pools in 1991 or 1992

Feature #20, portrayed by Paperiello and Wolf as a *"bubbling spring,"* exhibited a fine precipitate, similar to Sulfur Dust Spring in 100 Springs Plain in Norris Geyser Basin, but the precipitate in the pool was greenish tan in color rather than yellow.

Feature #21 is an interesting perpetual spouter. In the early 1980's it sprayed clear water to about 2 feet. In 1990-1992, the water level sat below the rim and the water sprays only reached about 3 to 6 inches in 1990 and up to 1 1/2 feet in 1992. This is a very colorful small pool with a bright red vent in the northwest corner and an orange rim.

Feature #22 through #25 are pools, springs, and vents in very treacherous ground, with no obvious changes in the last 12 years.

Feature #26 is a beautiful deep clear pool with a thin overhanging sinter rim on its east side. Bones are clearly visible in the bottom of the pool, giving rise to its official name, Bone Pool. Its temperature has remained constant at 176^{o}F. as measured in 1961, 1985 and again in 1992.

Feature #27 is another perpetual spouter, sitting at the edge of the creek on the western bank. Reports from the 1980's place the bursts to 1 foot high; in 1991, the authors noted bursts to 3 feet.

Features #28 to 32 are small springs. Feature #32 sits below the large boulder south and west of Avalanche and acts as a intermittent steam vent. Its activity often coincided with Avalanche. Bryan (1993) observed that *"most eruptions occur while Avalanche is nearing the* *end of its eruption, and it also isn't uncommon for it to briefly puff a few times about the time Avalanche starts. . . .The force is highly variable, from loudly gushing to barely welling a bit of steam."*

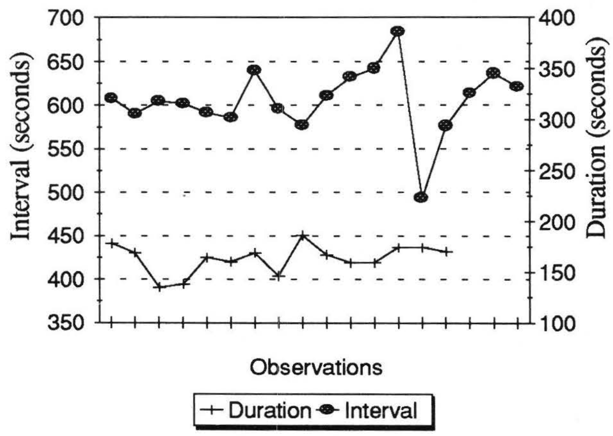
Feature #33 carries at least two names, Oblique and Avalanche Geyser. As noted earlier, A.C. Peale's Oblique Geyser may be located in another area. Water erupts from at least 12 to 17 vents to 25 to 30 feet high, roaring like an avalanche in a high mountain area, and is not sent *"obliquely over a road."* There is no sign of an old road in this area now. Therefore, the authors agree with Wolf and Paperiello that Walter Weed misinterpreted Peale and this is not Oblique Geyser. This geyser is unique in Yellowstone for the large collection of odd shaped rocks covered with various colors of algae. In places the mineral coatings also transform the rocks into fantastic objects worthy of close examination. The eruptions which maintain the unique *"living rock garden"* starts with a puff of steam which is quickly followed by a release of water and steam from all vents.

The frequent eruptions also support very colorful mats of orange-brown cyanobacteria in the runoff channels to Geyser Creek.

"Avalanche Geyser" is one of the most regular performers in the park. Allen and Day depicted the geyser as follows: *"Of the two geysers, both on the eastern side of the basin, the more powerful rises in a heap of rough rhyolite fragments situated 10 to 15 feet up the steep bank, overflows when it erupts and again drops out of sight after the short period of action is over. Eruptions in August 1928 recurred every six minutes, reaching an estimated height of 25 feet."* Data from 1961 stated *"Rock Pile Geyser"*, as naturalist Frisbee called it, *"shoots many streams of water through a pile of rocks."* He reported it erupted at 8 to 10 minute intervals for durations of 2 minutes to heights of 15 to 20 feet. Water temperature was 201^{0}F. Intervals recorded in 1984-1985 average 10.04 minutes with a standard deviation of 40.4 seconds. Durations averaged 2.72 minutes with a standard deviation of 13.8 seconds (see data on the next page). Data from 1990, 1991 and 1992 revealed intervals of 9.74 minutes with a standard deviation of only 28.2 seconds. Recorded durations

An eruption of ***Avalanche Geyser*** showing a few of the many vents and the odd-shaped rocks

1984 - 1985 Data for Avalanche Geyser



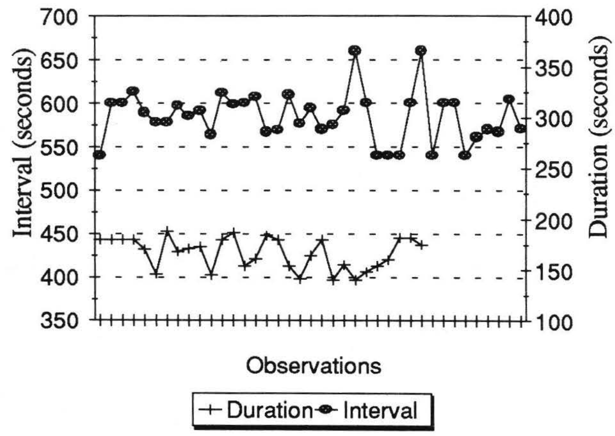
Observation	Duration	Interval
	seconds	seconds
1	178	608
2	169	590
3	135	605
4	138	602
5	164	591
6	160	586
7	169	640
8	146	596
9	186	577
10	167	610
11	159	632
12	159	642
13	174	684
14	174	493
15	170	576
16		613
17		636
18		621
min	135	493
max	186	684

from 1990 and 1992 averaged 2.78 minutes with a standard deviation of only 15.6 seconds (See figures on this page).

Feature #34 is a perpetual spouter with a temperature of 193°F measured by Frisbee (1961).

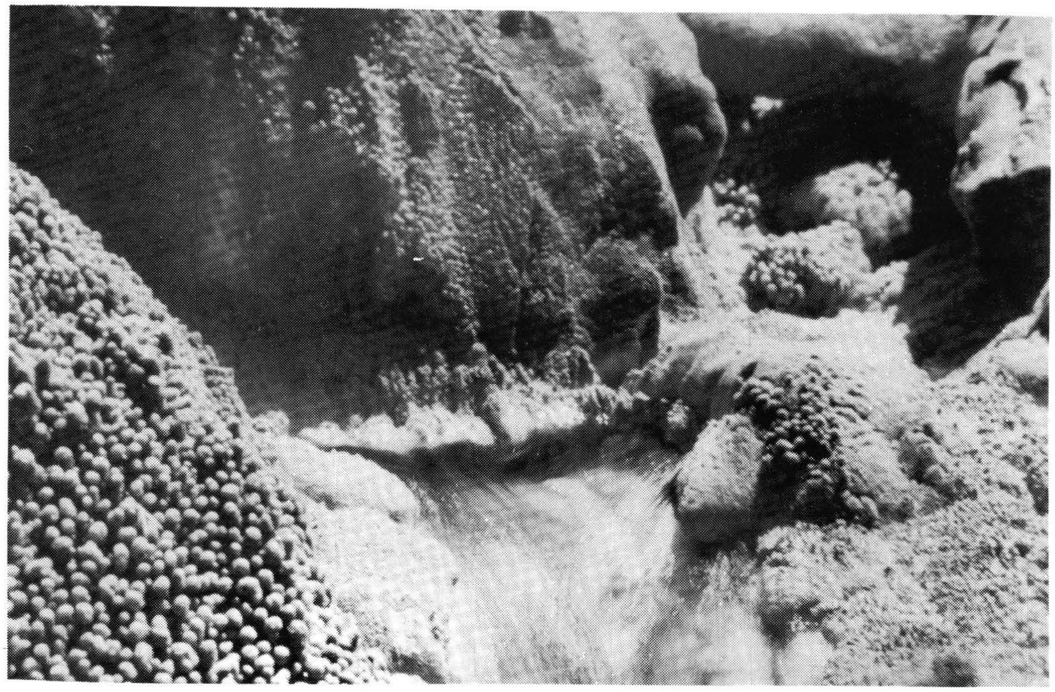
Feature #35 is a geyser, although its activity at times appears nearly constant. Allen and Day describe it as follows: *"The second geyser situated on the rim of the basin, 55 yards north of the first, merely raises a slight commotion at short intervals in a small pool occupying the middle of a sinter bowl some 15 feet across."*

1990-1992 Data for Avalanche Geyser



Observation	Duration	Interval
	seconds	seconds
1	180	540
2	180	600
3	180	600
4	180	613
5	170	589
6	146	578
7	188	578
8	168	597
9	171	585
10	173	591
11	145	564
12	180	612
13	187	599
14	154	600
15	161	607
16	184	567
17	180	569
18	154	610
19	141	577
20	164	594
21	180	570
22	140	575
23	155	591
24	140	660
25	148	600
26	154	540
27	160	540
28	182	540
29	182	600
30	175	660
31		540
32		600
33		600
34		540
35		561
36		570
37		567
38		605
39		571
min	140	540
max	188	660

This 15-foot bowl gives rise to the name of this feature, *"Big Bowl Geyser."* However, it is identified as *"Necklace Geyser"* by naturalist Frisbee. He described geyserite beads around the vent with a water temperature of 204°F. He gives the interval as 10 to 20 seconds and the duration as 10 to 15 seconds with bursts to 5 feet. Wolf and Paperiello reported the pauses in



Details of the beadwork around ***"Big Bowl Geyser"***

View looking north from ***"Big Bowl Geyser"*** activity ranged from *"little pause"* in 1982 to *"pauses between 9 and 22 seconds"* in 1985. Bryan (1991) reported intervals of about 15 seconds and durations of 5 seconds. The authors also noted pauses in bursting activity of 4 to 12 seconds. During this time the pool lightly boils within the bowl. Most bursts were 4 to 6 feet in height with an occasional burst to 15 to 30 feet. This feature has ornately formed smaller pools which catch the overflow. Formations in and around the pools are covered with beautiful beaded sinter and are unique creations of nature. Both this feature and Avalanche Geyser are alkaline with chlorine measured at 645 PPM by Allen and Day and SO_4 measured at 95 and 70 PPM.

Feature #36 is a perpetual spouter next to Big Bowl and unofficially known as *"Little Bowl Spouter."* Frisbee measured its temperature as 204°F.

Directly across the main basin and up a small ravine are two interesting acidic features. Feature #37 is a large light gray mudpot, while Feature #38 above it is unofficially known as *"Blue Mud Geyser."*

Wolf and Paperiello report the earliest records on *"Blue Mud Geyser"* come from Tomas Vachuda in 1982. This is a subterranean geyser that erupts muddy blue water. The opening is 29 by 22 inches according to measurements by Wolf and Paperiello. Below this surface opening, the chamber enlarges quickly. The geyser play occurs at an angle roughly from south to north with a few bursts reaching out of the opening as established by coatings of blue mud on wood next to the opening. The eruption of blue mud lasts only about a minute with a period of silence following the eruption. Eventually splashing resumes deep within the cavern gradually increasing in activity until the next eruption. The intervals in 1984 and 1985 ranged from almost 17 minutes to nearly 30 minutes. In 1990, the intervals ranged from 7 to 16 minutes with durations of 30 to 60 seconds. The rim of the opening exhibited a convoluted coating of wet, shiny blue mud. In 1991, no eruptions were noted. The water level was deep within the cavity and no longer visible. The blue mud coating on the rim was dried and cracked, indicating rare and/or weak eruptions. In 1992, water was visible below the surface, the

Feature #37, the mudput below *"Blue Mud Geyser"* splashing occurred for almost 30 minutes before a weaker eruption with blue muddy water reaching only about a foot below the surface at its maximum.

Feature #39 is the final feature in the lower basin. It is a perpetual spouter on the west bank of Geyser Creek as the creek enters the lower basin.

Upper Basin

Allen and Day described the second, higher basin as follows:

"A short distance up Geyser Creek to the south, on a higher bench, is a smaller basin 50 by 100 to 125 yards, of similar character. Rhyolite fragments in a state of partial decomposition are strewn along the eastern side, while conspicuous outcrops of gravel consisting largely of ancient sinter, recemented by opal, appear on the high, steep western slope. In this little area there are half a dozen large alkaline springs heavily lined and bordered with silica. Among these the most notable is a beautiful large pool of perfectly clear water in a constant state of ebullition (90^{o}C [194^{o}F])."

This area, though small, contains 32 features identified by Wolf and Paperiello. The features will be briefly listed for reference with more detail provided for the larger and/or more unique features observed.

Feature #40 is a very large pool, 27 feet across, on a saddle behind Avalanche Geyser between the Lower and Upper Basins. Frisbee (1961) characterized it as a large, clear spring with a temperature of 186^{o}F. In 1985 Wolf and Paperiello similarly described this feature as a quiet pool with a temperature of 186^{o}F and a pH of 5.9. Although the temperature was slightly lower (181^{o}F) in 1992, the pool was actively boiling in several places and had a black muddy runoff channel about six feet across. The water was a murky grayish brown. The hillside on the east is marked by a landslide.

Features #41 through #49 are delineated as follows by Wolf and Paperiello and appeared unchanged through 1992. Feature #41 is *"a moderate sized spring with a small discharge and algae growing in pool; there is a sinter rim."* #42 is a *"pool with a small discharge."* #43 is a *"frying-pan type spring."* #44 is a *"perpetual spouter that appears to spout through a bed of black obsidian sand, at times to 1 foot."* In 1990 the authors noted underground thumps with the boils in this pool. #45 is a *"small, fragile, leached cone; in 1985 it was sporadically spitting droplets of water."* #46 is a *"frying-pan type spring."* #47 is a *"collection basin for the small discharge above."* #48 is a *"violent subterranean spouter with clear water. It appears to be a new collapse in a very old feature."* #49 is a spring.

Feature #50 is an interesting series of 4 apparently interconnected springs. The dimensions are as follows, according to Wolf and Paperiello: the southwest pool is 41 by 25 inches; the west pool is 49 by 27 inches, the middle is 48 by 31 inches and the eastern pool is 78 by 69 inches. The western and middle pools are superheated, measured at 203^{o}F and 200^{o}F in 1992 and exhibited boiling when the authors placed a temperature probe in the water. Although not observed, the pools must periodically well up and overflow as each had a distinct berm of broken sinter piled up 6 to 12 inches away from the rim. The scalloped sinter border is washed clean within the area of the berm.

Feature #51 is probably the beautiful clear pool mentioned by Allen and Day. It measures 19 by 12 feet with a massive scalloped sinter rim. It is unofficially known as *"Bat Pool,"* named by park naturalist ,Bryan. A colony of bats lives in a crack in a nearby rhyolite boulder, kept warm by the steam from the superheated pool. They noisily scurry down into the crack when observers look within. The pool is a geyser with large boils occurring every 2 to 3 minutes, reaching 2 to 3 feet in height. Measured temperatures range from 198 to 208^{o}F.

Features #52 to #59 are basically unchanged from the observations of Wolf and Paperiello. #52 is a *"series of small vents, all collapse features; some with water; the one farthest north is a subterranean spouter."* #53 is a spring, "*separated from #51 by a thick sinter bridge and is its [#51] discharge vent (massive discharge). It has a beautiful, sinter edged run-off channel.*" #54 is a "*beautiful deep blue pool, about 6 by 6 feet.*" #55 is a "*beautiful deep, blue sinter-rimmed pool, 21 1/2 by 7 1/2 feet with an overhanging rim.*" In 1990-1992 it exhibited continual boiling from two areas in the center of the pool. #56 consists of "*two small sinter rimmed pools.*" #57 is "*another sinter rimmed pool with some discharge.*" #58 is a series of 6 vents in a runoff channel. #59 is a "*tiny spring with an extremely shallow, small basin with little discharge.*"

Feature #60 is an interesting little geyser when not inundated by runoff from its larger neighbors. When seen in 1985, Wolf and Paperiello reported, "*This geyser has a tiny vent within a very shallow small basin. Every couple minutes it fills slightly and the vent spits out a few inches; this massive eruption is over quickly and the water drains back into the tiny vent.*" When the authors first observed this geyser in 1990, its pattern was changed. The shallow pool slowly filled with steam venting from the bottom. Gradually the escaping steam quieted as the pool filled without reaching overflow. Then the pool slowly drained. The eruption began when the pool was empty and it sent spurts of water to 4 inches as the pool slowly refilled. In 1991 and 1992, the geyser was inactive, filled with runoff from Bat Pool, and covered with orange-brown cyanobacteria.

Feature #61 appears to be an intermittent spring, although Bryan (1993) reported his observation of 1 foot eruptions. When observed in 1985, it was portrayed as follows: "*This is a curious ragged pool. Its basin measures about 25 by 23 1/2 inches. Over a period of a few minutes, it will fill its few inches deep basin. The upwelling water will slightly roil the surface, but that is all. You keep expecting an eruption; just as it gets to the point where it is about to overflow its basin, it will instead suddenly drain very rapidly with no water showing within its vent. The water will soon begin to rise again and start the process over.*" When observed in 1990, the water level stood about 3 inches below the rim with no change in level and the water steadily boiled during the observation period. In 1991, the water stood about an inch below the rim with a light boil and no change in level. In 1992, the water was 6 inches below the rim and the pool was receiving runoff from Bat Pool. Small bubbles rose through the water to the surface.

Features #62 through 67 and #69 through #72 did not appear to change through 1992, but remained as pictured by Wolf and Paperiello. #62 is a "*small discharging pool within the runoff channel from #53.*" #63 and #64 are unnamed springs. #65 is a "*large bright orange pool.*" #66 is a "*rather large, coolish looking pool which receives the overflow ultimately from #53. It seems to receive more water than it discharges.*" #67 is a "*series of small unimpressive vents with no discharge.*" Similarly, #69 is an "*area of numerous, unremarkable, small, collapse vents.*" #70 is a "*series of small springs, mostly collapse vents and with no discharge.*" #71 is "*a tiny perpetual spouter from twin tiny vents, spurts a few inches high, and forming a pretty but very shallow basin.*" #72 is "*a brown, muddy pool; it has 3 vigorous spouting vents.*"

The final feature of note in the upper basin is #68, Tiny Geyser. According to Lee Whittlesey in Wonderland Nomenclature, this feature was named by naturalist Bryan in 1971. According to Bryan (1991), every 2 to 3 minutes Tiny Geyser erupted to heights of 1 1/2 feet for five seconds when in an active cycle. The name derived from the size of the vent which is only an inch in diameter. In the center of an area of disintegrating sinter, the small vent sits at the western edge of a slight depression about 1 1/2 feet by 1 foot in diameter. The water leaves the vent at a 45 degree angle and reaches the edge of the depression. The ejected water appears to contain sulphur as both the sinter in the depression and the vent itself are stained yellow. In 1985, Wolf and Paperiello reported intervals of 1 1/2 to 2 1/2 minutes with durations of 20 to 30 seconds. Only a few of the spurts of water were ejected above the rim of the vent and the maximum height they observed was 6 inches. They measured the water temperature at 198°F. In 1990 Tiny Geyser followed the same patterns as just delineated, but in 1991 no activity was seen. In contrast to these earlier observations, in 1992, on each of three occasions, Tiny was continuously active for 15 to 30 minutes of observation with no pauses. The ejected water reached 18 inches from the vent and kept the entire 1 1/2 by 1 foot diameter depression wet. The water temperature was 200°F.

Isolated Springs

The final isolated springs of this area are reached by following Geyser Creek south out of the Upper Basin. Shortly after leaving the Upper Basin, a narrow draw leads west from Geyser Creek. Feature #74 was not observed by the authors. Frisbee (1961) portrayed this as a sizzling sandy spring with a water temperature of 199°F. Wolf and Paperiello characterized it as *"another perpetual spouter; its basin is about 58 inches across with a gray bottom; there is a fair discharge. The water is mostly clear."* At the top of the draw are two large springs, Features #75 and #76. These features were observed from the ridge above in 1992 and appeared to be as described by Wolf and Paperiello in 1985. Feature #75 was *"a square shaped pool about 15 by 12 feet with a small discharge. There were two main centers of spouting from 1/2 to 1 foot in height. The water was an opaque, greenish milky color."* Frisbee noted bursts to 2 to 3 feet and water temperatures of 197°F. Feature #76 was a *"cream white spouter with heavy splashes from 2 to 3 feet high. Its pool was roughly dumbbell shaped about 8 by 4 feet but laying in about a 10 foot in diameter basin; its water level was below overflow but appeared to be capable of having discharge from a higher pool--perhaps the water level is seasonal. In 1985, its temperature was 202°F; pH about 3.8."* Frisbee (1961) measured temperatures at 199°F.

The authors chose not to explore this draw in 1992 when clear evidence of a bear's day bed was found at the junction with Geyser Creek on June 23, 1992. The fresh remains of an elk carcass with meat still left on the bones was discovered nearby. Upon returning on July 3, 1992, markings from the day bed remained but the carcass was completely gone.

Feature #73, south of the junction with the draw, changed considerably from 1961 to 1992. Frisbee (1961) depicted a gray spouter to one foot with a temperature of 196°F. Wolf and Paperiello characterized this feature as a *"strong perpetual spouter [that] emerges amidst a jumble of rocks and sticks, all of which are covered with a rust colored precipitate and edged with spiny red sinter. The water is clear and reaches 12 to 18 inches. The basin is about 5 feet by 3 1/2 feet. In 1985, the temperature was 199°F; the pH was between 3.0 and 3.4."* By 1992, the pool doubled in size to 8 by 7 feet with considerable overflow into a gray colored runoff channel. The water itself was opaque gray and no evidence of the rust colored precipitate or the spiny red sinter was observed. The pool remained a strong perpetual spouter to 1 to 3 feet in height. The temperature was 178°F.

Feature #77, *"two small upwelling springs next to the stream about 11 and 15 yards from #73"* were not observed by the authors.

Feature #78 sits within a rocky alcove on the steep western hillside above Geyser Creek. It is a large mud-pot, 6 by 4 feet at the surface narrowing down into a funnel shape. The level of mud appears to vary with rainfall or subsurface water, ranging from less than a foot below the surface in 1992 to 6 feet below the surface in September 1985. The mud appeared very thin with slight boiling in 1992 and was 184°F. The temperature was measured at 197°F in 1985. The hillside south of the mud-pot was covered with ferns and no evidence of a grizzly den was found in 1992 although both Frisbee (1961) and Wolf and Paperiello (1985) marked the den on their maps.

Continuing upstream, many tiny springs and sizzling vents (Features #79, 80 and 81) can be heard and seen in the creek bed just before Geyser Creek flows down a tiny waterfall from the east and into a lush cool pool (Feature #82) lined with tiny water plants with miniature yellow flowers.

On a western ridge just above the Geyser Creek drainage sit two very large active springs.

On the south is *"The Monster"* (Feature #83). This impressive perpetual spouter sits at the base of a very steep 50-foot high ridge. The pool measured 20 by 12 feet according to Wolf and Paperiello. Most bursts range from 3 to 6 feet in height but some reached 10 to 12 feet. Criss-crossed over the pool are several 8 to 10 inch in diameter lodgepole pine logs coated with the light brown muddy water erupting from the pool. The surface of the water showed evidence of a black oily film. In 1961 the temperature measured 195^{o}F. In 1985 the temperature was 199^{o}F; the pH was 4.8 to 5.5; in 1992, the temperature was 190^{o}F.

To the north and west of *"The Monster"* sits a black perpetually spouting pool with obsidian sand churning and being tossed into the air with each burst (Feature #84). The single runoff channel, coated with a black precipitate, breaks into many tiny cascades flowing into Geyser Creek. Each little channel is coated with the black precipitate all the way down the ridge to Geyser Creek. The pool measured 195^{o}F in 1961, 198^{o}F in 1985 with a pH of 5.5 and 191^{o}F in 1992.

On a higher ridge less than a half mile west and south of *"The Monster"* and the obsidian pool and on the south flanks of Paintpot Hill lies an extensive area of old hot springs deposits with a few interesting perpetual spouters and free sulphur deposits. The area can be reached by climbing the steep hillside west of *"The Monster"* or by following the transmission lines south from the Artist Paint Pots trail. It is indicated by vegetation-free areas on the Norris Junction, WY USGS 7 1/2-minute topographic map.

The saddle exhibited many collapsed holes with no apparent underground water source until a foot wide bright green creek emerges from the south. In and around this creek are many small vents and springs. On the west side of the small basin is a unique perpetual spouter, rusty red in color and shaped like an open flower 2 1/2 feet in diameter. The clear water continuously spouts 1 to 1 1 /2 feet high. In mid-July 1992, Bryan (1993) observed intermittent geyser activity. He reported *"intervals were about 20 to 40 seconds, durations all <20 seconds. The height was just 1 foot, and there was almost no discharge."*

At the south end of the barren leached valley in a rock-enclosed basin is another perpetual spouter with opaque gray water churning about 1 1/2 feet below the surface. A red precipitate is seen on the rocks at the northern end of the basin.

A few hundred yards further west is a narrow drainage with many vents depositing free sulphur. One area contains a series of tiny *"turrets"* an inch in diameter and 2 to 4 inches high, looking like tiny castles. Inside each *"turret"* are crystals of sulphur. The ground is hot and the crust is thin and treacherous. According to Bryan (1993) this area is called *"Sulphur Castle Springs."*

Summary:

Geyser Springs is a little known but fascinating thermal area with large regular geysers, a subterranean mud geyser, many colorful pools and spouters, bats and even bears. The area demonstrates nearly all types of thermal activity from sulphur-depositing fumaroles, alkaline sinter- depositing springs and geysers to acidic mudpots. It is well worth spending time exploring and timing its intriguing features.

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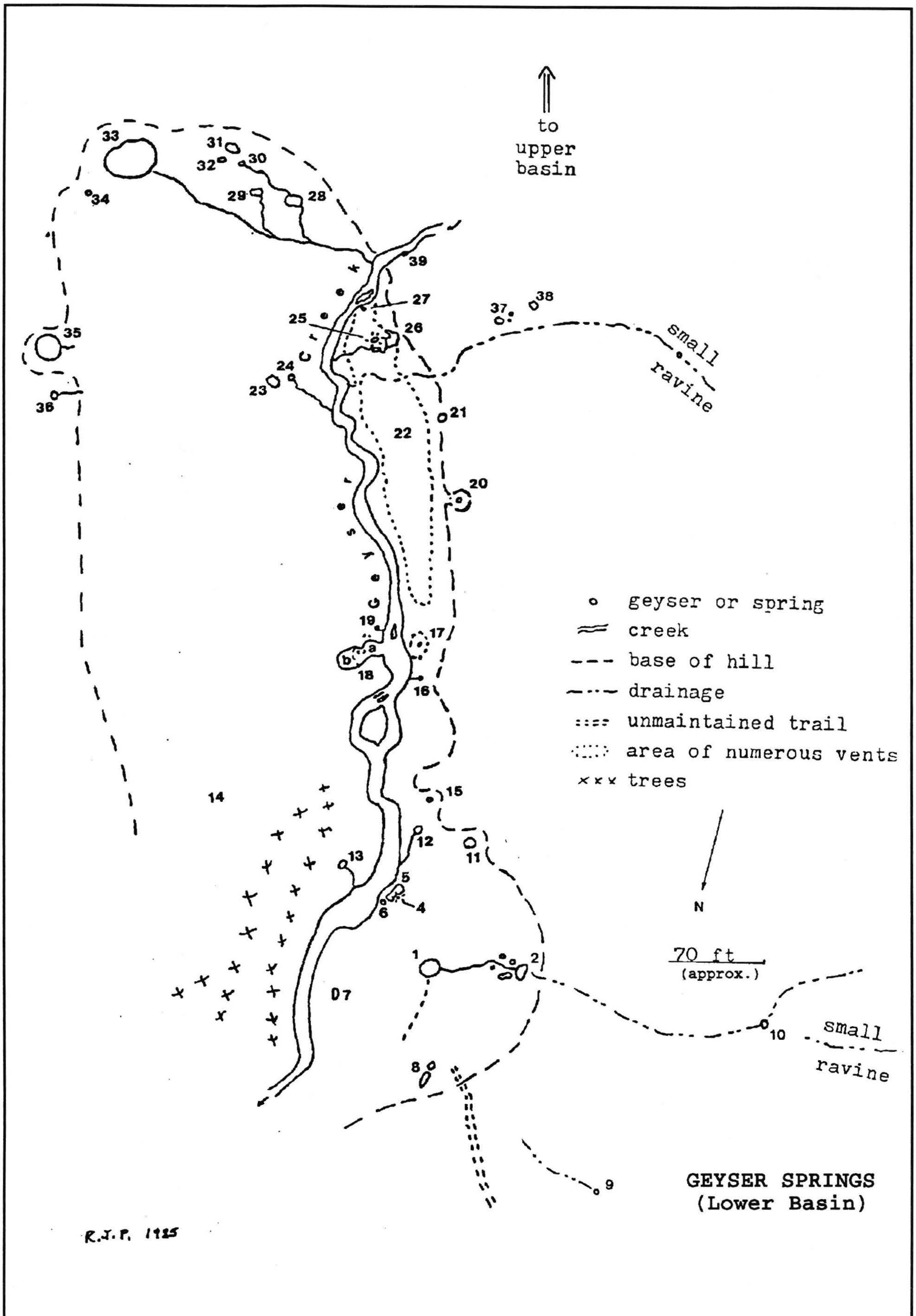

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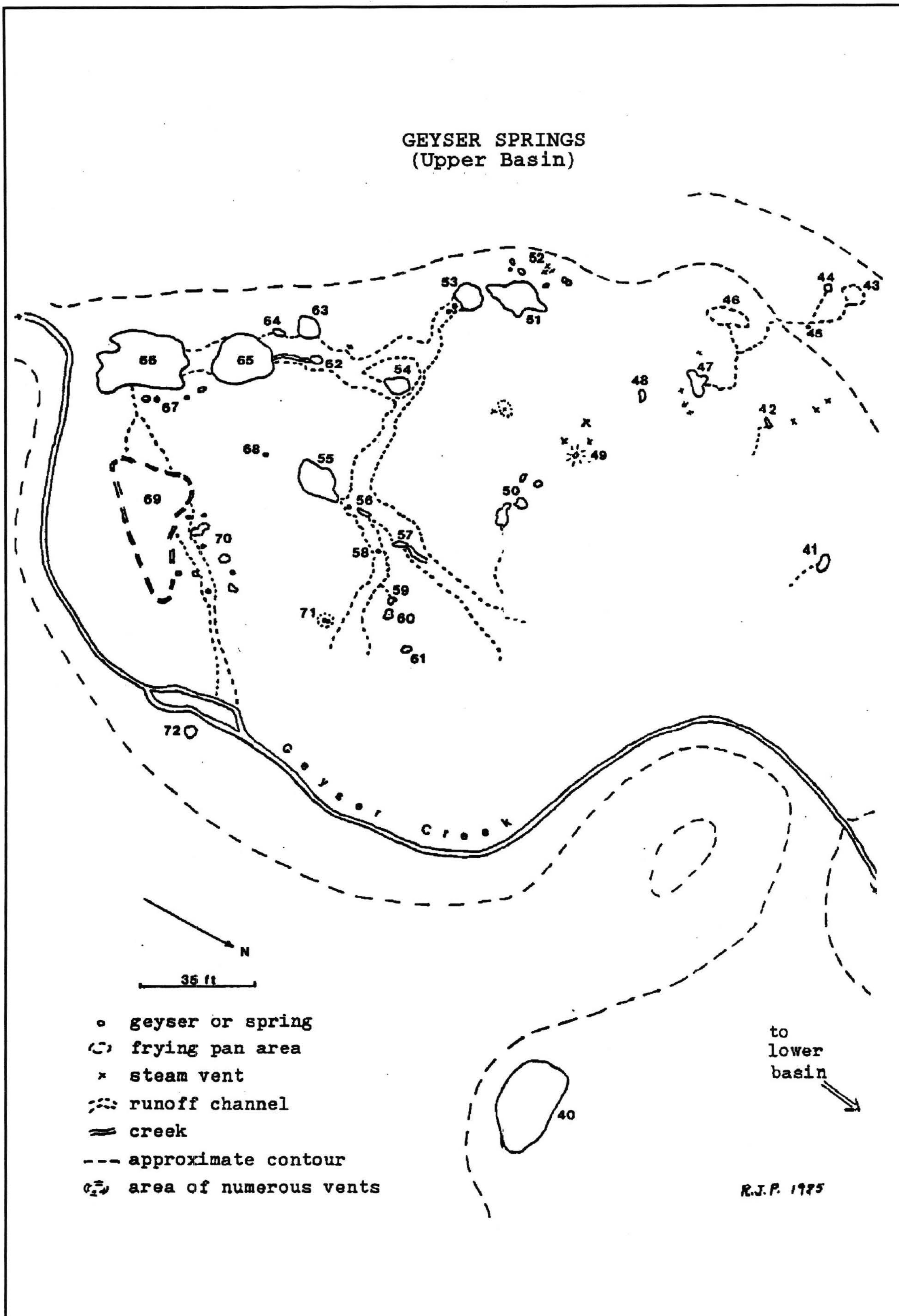
GEYSER SPRINGS
(Lower Basin)
R.J.P. 1985


GEYSER SPRINGS
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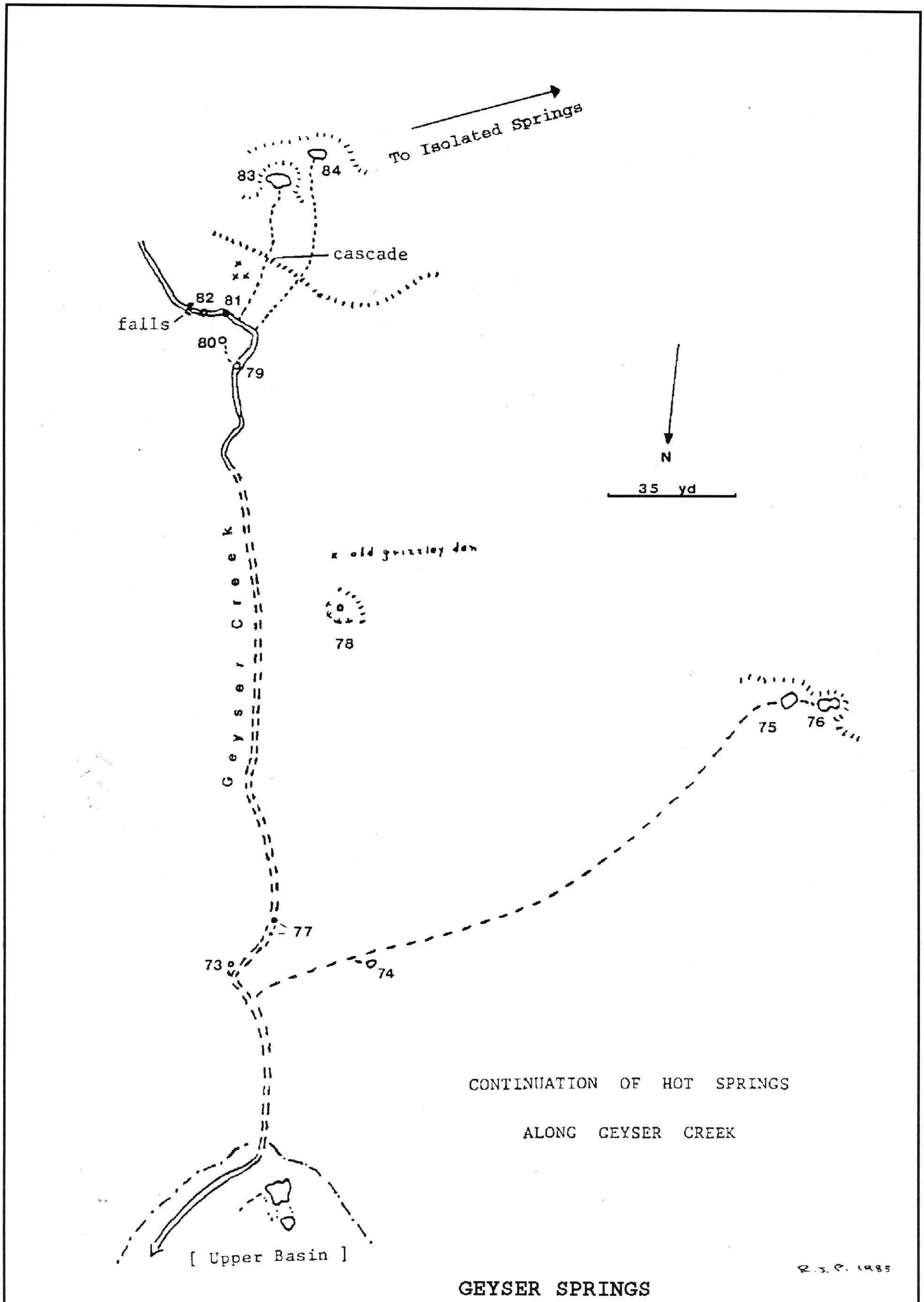


GEYSER SPRINGS

A Visit to Josephs Coat Springs, Coffee Pot Hot Springs, and "Fairyland Basin"

by

Lee Whittlesey & Rocco Paperiello

ABSTRACT: This report presents an account of our trip to a few infrequently or rarely visited thermal areas in the northern Mirror Plateau area of Yellowstone National Park. The areas visited are placed into an historical perspective, and some sketch maps are also included.

On June 6-8, 1992, our party of five visited Josephs Coat Springs, Coffee Pot Hot Springs, and what we have called the "Fairyland Basin" at the junction of Broad and Shallow Creeks in Yellowstone National Park. These latter two areas have been visited by a bare handful of people over the park's history, owing to the difficulty of access. Our party consisted of Julie Gayde, John Richardson, Matt Tekiela, and us. We left Artist Point and hiked about eight miles on the Wapiti Lake Trail to a small hot spring on Moss Creek. This spring had a good flow and the odor of sulphur was quite heavy; what appeared to be free sulphur was being deposited both within the spring and for a considerable distance along its runoff channel. This spring is incorrectly labeled "Orange Rock Springs" on the 1986 (provisional) USGS 7½-minute quadrangle map. ("Orange Rock Springs" was in fact the original name given for present Josephs Coat Springs by Captain William A. Jones [1875] of the 1873 Army Reconnaissance).

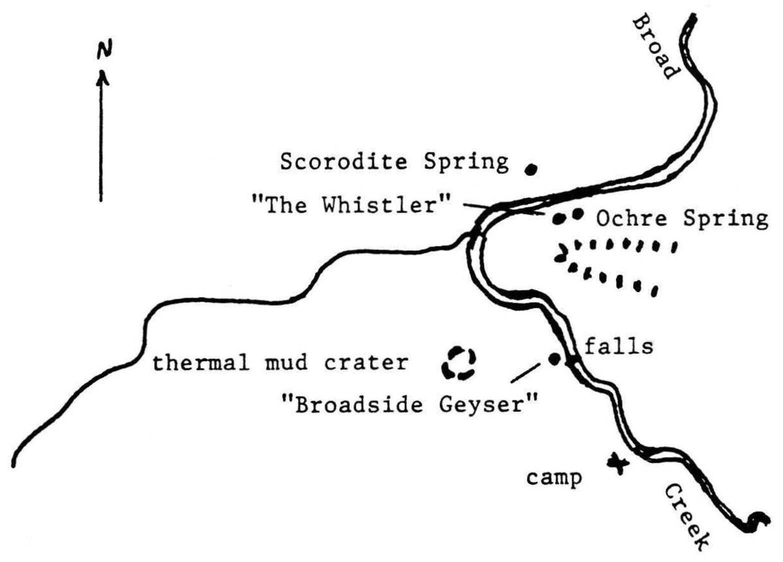
From this point we took a compass heading toward Josephs Coat Springs. We soon reached a small unnamed stream which eventually flows into Broad Creek at these springs. This we followed. Traveling through this area was relatively easy with minimal down timber. We would advise hikers to leave this stream when it starts dropping into a narrower defile, and stay on the ridge to the east. There is a convenient game trail which takes off to the right and gains this ridge at about the right spot. We reached the back-country camp site 4-B-1 in about six hours. Because 1992 had a very dry spring, we were able to do this hike in early June.

Lee: I found the springs at Josephs Coat much the same as when I visited them in 1976 and 1978 -- very colorful as befitting their name and with lots of water. (See sketch map).

Josephs Coat Springs were so named by Arnold Hague (or Walter Weed) in 1884. [Weed 1884] A few years later Arnold Hague described the area as follows:

> This group of springs is situated along both sides of the stream bed between rhyolite ridges which rise abruptly for two or three hundred feet. Solfataric action has completely decomposed the rhyolite into smooth, rounded slopes of soft earthy material unsurpassed in beauty of color by any other locality in the Park; orange, yellow, vermilion and white are interblended in a most striking manner. A hundred narrow vents deposit crystals of yellow sulphur far too delicate for transportation. Added to this coloring are the deep greens, reds and yellows derived from the algeous growth lining the hot water channels running off from the numerous springs. Mineral and vegetable color vie with each other in brilliancy. [Hague 1887]

Whistler Geyser -- never a true geyser, but officially named as such [Jones 1875, Hague 1886, Allen & Day 1935, Majors 1962, Hutchinson 1976b]-- was at the time of our visit quite evident. It was the only violent steam vent in its immediate area. Observed as early as 1873 by Captain Jones' [1875] expedition, it was later named "The Whistler" by Arnold Hague [1886] of the Geological Survey in 1884. It has a rectangular



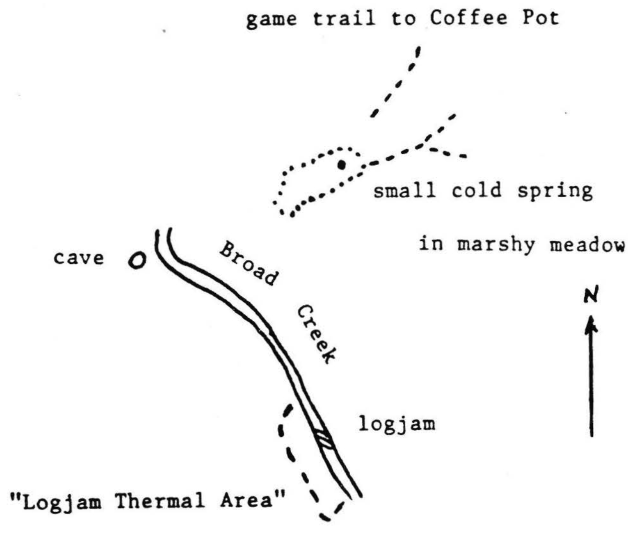
SKETCH MAP #1 **JOSEPHS COAT SPRINGS**

opening about 1'x ½', faces the creek, and is just where Arnold Hague placed it: "five feet above the creek level and ten feet back from the creek." Even that early, the belief was that it was a steam vent and not a geyser. In 1888, Walter Weed noted: "There is absolutely no evidence to support the theory that it is a geyser." And so it remains. From Alan Hanks visit in August, 1932, we obtain the following description:

Similar to a frying-pan in shallowness, this spring in other respects -- its clear alkaline water, constant flow, deposition of siliceous sinter and the growth of algae about its borders -- quite belies that classification. The Whistler breaks out in a small heap of detritus on the northern side of the promontory,... and is partially roofed over by a sheet of beaded gray sinter, from beneath which quite a volume of steam rushes out with a hissing sound. [Allen & Day 1935]

Lee: When I visited this area in 1978, I found Whistler to be but one among a group of steam vents along the stream bank, making the identification of Whistler's vent uncertain. In 1992, however, these other vents had largely diminished and the remaining feature, Whistler, was as described by Hague. The 1986 provisional USGS 7½-minute quadrangle map places the name of Whistler in the wrong place -- much too far to the west and on the wrong side of Broad Creek.

Scorodite Spring [Weed 1884] lies across the creek and slightly upstream from Whistler, and lies in a basin of about 13 x 8 feet. It is constantly spouting to about 1 to 2 feet with occasional surges of 3 to 5 feet. In 1884 Hague [1887] found in the deposits of this spring small amounts of scorodite, a mineral composed of a hydrous arsenate of iron ($FeAsO_4 \cdot H_2O$), hence its name. In 1962, Harry Majors found this green mineral in layers which were exposed upon breaking off the deposits around the spring. Ironically, not having available Weed's notebooks and hence unaware that Hague had already named this feature Scorodite Spring, Major's party gave it this same name in 1962. [Povah 1962, McIntyre 1962] In a water sample taken from this spring in 1974, J. M. Thompson of the USGS found one of the park's highest arsenic concentrations. [Hutchinson 1976b] In November of 1976, park Geologist Rick Hutchinson [1976b] found this spring to have a temperature of 91°C and a discharge of about 3.5 gpm. Similar conditions were noted by us in 1992. The width of its sintered discharge channel, however, would seem to indicate overflow can be much greater at times. Similar conditions apparently



SKETCH MAP #2 **"LOGJAM THERMAL AREA"**

existed in 1884, and Hague [1887] at that time "regarded [it] as an active geyser."

Ochre Spring is a small pool lying just downstream and a bit farther from the creek than Whistler. It was named in 1888 by Walter Weed [1888] for its color. We did not examine it closely.

Rocco: "Broadside Geyser" lies on the west bank of Broad Creek and about 25 feet downstream from a small waterfall. It operated as a strongly cyclic spouter during our visit in 1992, but Lee was certain that it was periodic when he first saw it in 1976. The name of this geyser was suggested by Rick Hutchinson in his November, 1976 report "due to the fact that the geyser is by the side of Broad Creek and 'shoots a broadside'." This is also most likely the same feature called "Broad Creek Geyser" by Walter Weed [1888]. In 1962 the Majors [1962] party merely noted it as a "small hot spring in the creek bottom..." In 1976, Rick Hutchinson reported eruptions to a height of 9 - 12 feet lasting 30 to 40 seconds followed with intermittent surging to 3 to 6 feet which lasted about 15 minutes. An interval of 4 hours or less was reported. In 1978, Whittlesey reported heights of 4 - 15 feet for 5 to 6 minutes at intervals of 20 to 40 minutes. In 1992, activity appeared to be continuous but widely cyclic and with a steady copious discharge. Quiet periods only lasted from 1 to 5 seconds. These were interspersed with 2 to 4 foot surges. About every 5 minutes surging would suddenly increase to about 10 to 12 feet with a much wider plume of water, along with surging from a second vent. These eruptions were strongly angled, and would last only 4 to 7 seconds. A short period of quiet (about 5 to 10 seconds only) would follow.

The following day we hiked a hard 11 to 12 miles to Coffee Pot Hot Springs, on to "Fairyland Basin", and back to Josephs Coat. We started down Broad Creek for about a half mile, and then climbed up a difficult, sloping, deadfall-covered, high bench to Coffee Pot Hot Springs. The route taken was somewhat laborious. We had crossed Broad Creek on a small logjam at the upstream end of a very small thermal area along the banks of Broad Creek. We named the spot the "Logjam Thermal Area". It consisted largely of fumaroles in the steep slopes of the creek banks, but one discharging spring of thin gray mud was observed. A short distance downstream could be seen a small cave on the west bank, just a few yards above the creek. On our way back we were very fortunate to find a heavily traveled game trail just a short distance below Coffee Pot Hot Springs. This we followed most the way back to Broad Creek, saving quite a bit of time and effort. This trail ended in a small, narrow, marshy meadow. (See sketch map). About a hundred yards further we came out directly opposite the cave mentioned above.

Coffee Pot Hot Springs have been rarely visited. None of the early surveyors reached this area. Bob Christiansen of the USGS was there in the 1960's, and Rick Hutchinson in 1976. [Hutchinson 1976a] We found the area highly interesting, with much more water and discharge than one would expect considering its chemistry and elevation. It matched the description in Rick Hutchinson's 1976 report in every way. A wet green meadow lay between its lower and upper areas.

Lee: For over twenty years I had fostered dreams of visiting this place, and now I could hardly believe I was here.

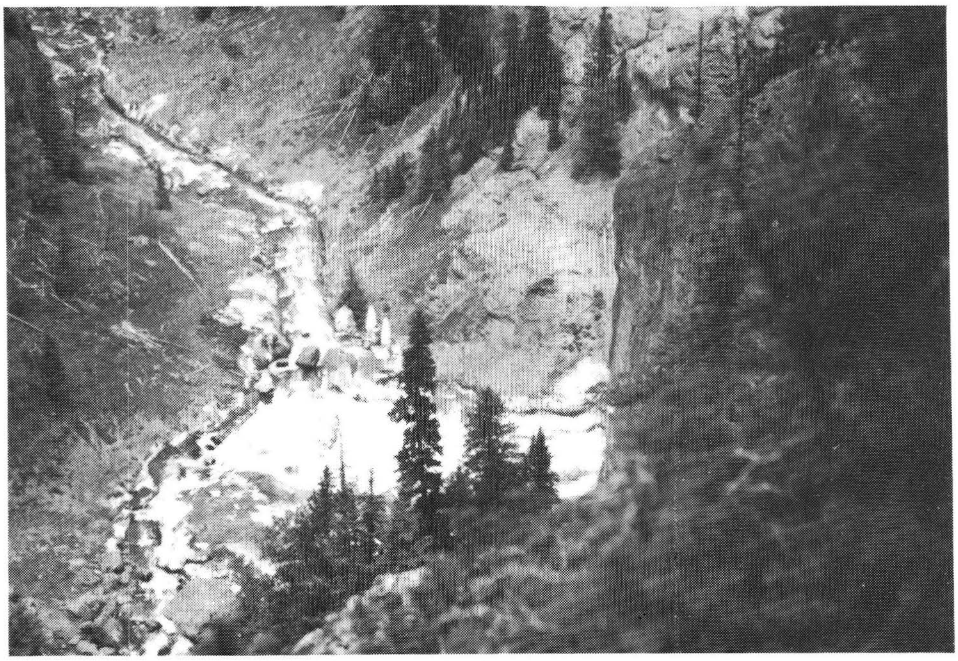
The lower (western) area of Coffee Pot Hot Springs contains numerous boiling muddy springs, frying pans, and small spouting vents. A few of these spouters emerge from sintered vents. No statement about the origin of this place name has been found; it first appeared on the 1959 USGS 15-minute quadrangle map of Tower Junction. [Whittlesey 1888] Perhaps the name of these springs had been suggested because of the presence of its numerous tiny spouters. These concentrate in a small central area from which a considerable discharge flows. The main starting point of this flow comes from an area of two strong spouters, one of which spouted at an angle to a height of about 5 feet during our visit. Because this unique spring emitted metallic pyrite it was dubbed by us "Pyrite Spring". In his 1976 report Rick Hutchinson noted the following:

> While the lower area of Coffee Pot Hot Springs is predominately oriented north-south, it also has a short section of intense alteration and weak fumaroles [and a few small spouters] that extend perpendicularly to the west. All of these trends represent very definite structural control. At the intersection of the two lower trends is located the most important feature of the whole thermal area. It is a continuous spouter nestled among a collection of black frying pans. The spouter ejects water horizontally as far as 2.1 meters [~7 feet] in a southeasterly direction from an outcrop of acid-altered boulders of Lava Creek welded ashflow tuff (Member B). It and the frying pans discharge a total of approximately 21 liters per minute (5.5 gpm) of turbid grayish-black sand and metallic pyrite flakes, gold in color. Water from this group drains west along the extension of the lower thermal zone, then down a steep ravine into Broad Creek Canyon. The spouter and frying pans temperature were all 91°C. To date no other thermal feature in the park is known to emit metallic pyrite. ...The pyrite appeared to be a very thin coating on the sand grains. [Hutchinson 1976a]

The upper area was also fascinating. Its main area contained a large group of spouters, "boiling" springs, frying pans, and steam vents lying in what appeared to be a long fracture zone. The temperature of a small clear water spouter in the main central area was measured at 188° F. Near the northwest edge of this main area was what we believed to be a superheated steam vent; its vapor was not visible until about a foot above the vent. A hundred feet or so to the southeast of this main area was a large mud pot and a large spouter emerging from a deep fracture. The black water of the spouter would at times reach more than 12 feet. Rick Hutchinson described this upper area as follows:

> The upper zone has the largest pools (3 in number) which are all turbid gray to buff tan in color and have little or no discharge... Good views reward the backpacker of Mount Washburn to the west and the Buffalo Plateau to the north. [Hutchinson 1976a]

From the upper (eastern) Coffee Pot area, we took a compass reading and walked three-quarters of a mile to another thermal area, just a waterless gas barren. On the way we descended a bit and traversed an



"GNOME GROUP" AT CONFLUENCE OF BROAD AND SHALLOW CREEKS **TEKIELA PHOTO**

area of heavy deadfall before following a dry water-course. We crossed over a very small divide, and dropped into the beginning of another drainage. This brought us right to the gas barren which was marked as "Hot Springs" on the 15-minute quadrangle map. Once past the deadfall, the travel through here was relatively easy.

From the gas-barren, we compassed northwest toward the confluence of Broad and Shallow Creeks. Unfortunately, we got much too far to the east and were forced to spend two hours fighting the steep, heavily deadfall-covered slope above Shallow Creek. We finally reached the high promontory on the south side of the confluence of the two creeks. We were 350 to 400 feet above the river junction.

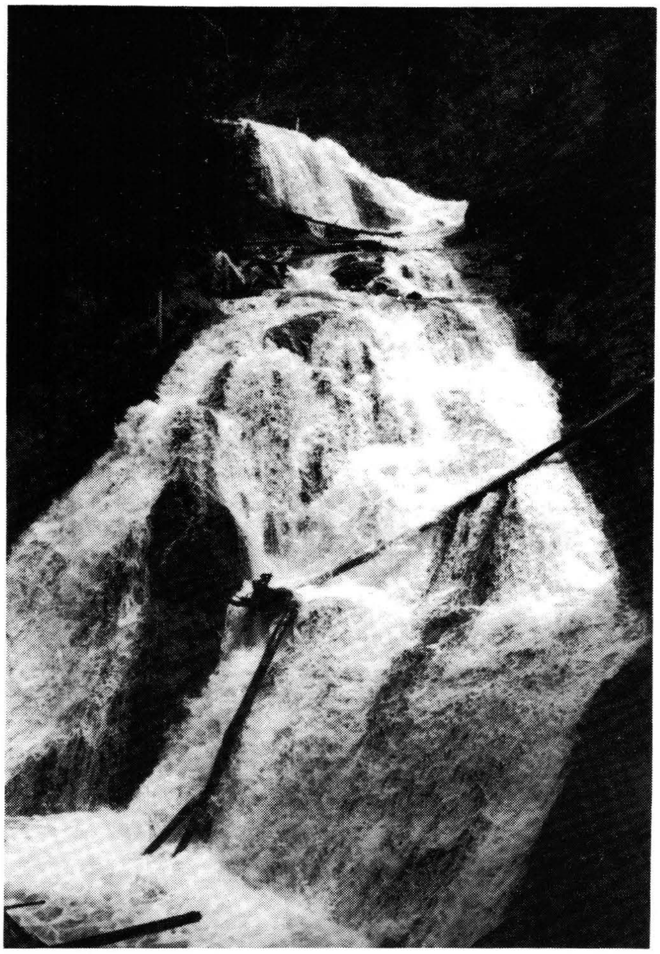
The canyon walls enclosing this area are largely vertical here and much higher. The cliffs above Broad Creek are as high as 1500 feet in places and are composed of a dark welded tuff. The creek beds themselves in this hardcore canyon country are composed of rhyolite and were frequently stained with a colorful orange mineral deposit.

Rocco: Last year Julie and I were part of a group who had attempted to reach the confluence of Broad and Shallow Creeks by traveling down first Wrong Creek and then Shallow Creek, starting from above Rainbow Hot Springs. The travel was difficult and we were forced to travel largely within the creek bed itself. As we neared the junction we had been forced to travel around or through a few small falls and cascades. We were then finally confronted with a much larger falls which twisted down between sheer cliffs. This was "Golden Fleece Falls". Without a belay, we were at an impasse. The steep climb out of the canyon was made in the rain, and was exhausting. When we finally got back to our camp a few miles above Rainbow Hot Springs, we all concluded this had been one of the most laborious hikes any of had undertaken. The hike on this day, however, was not as difficult. I was momentarily disappointed though when we broke out on the high promontory above Broad and Shallow Creeks. At first there seemed to be no way down, but Rick Hutchinson has said that this route was possible, so we continued to search for a way down. It was Julie who found it, following a game trail which descended from the east rim of the promontory, mostly following the wall of the cliff above Shallow Creek.

Lee: As we descended, John and Julie in the lead, I heard Julie yell, "I see it!", meaning Golden Fleece Falls. I was very impressed with my first view of it.

This waterfall was called "Golden Fleece Falls" a few years earlier by Rick Hutchinson [Whittlesey 1980] due to the golden-colored thermal bacteria on the canyon walls immediately by the falls. To this day this 100 foot high falls remains unmapped, and virtually unknown. It made a neat curve in the middle. We took lots of pictures of it from the best vantage point on the rocky slopes above Shallow Creek.

Rocco: I could see the spot on which we rested last year, unable to travel farther down the drainage. To think we had reached to within a quarter mile of our destination only to be thwarted. Just above the falls on the west bank is a small spring up on the side of the cliff. As the discharge runs down to the edge of the creek it spreads out in a cape-like manner and supports a growth of cyanobacteria. I suggested the name of "Golden Fleece Spring".

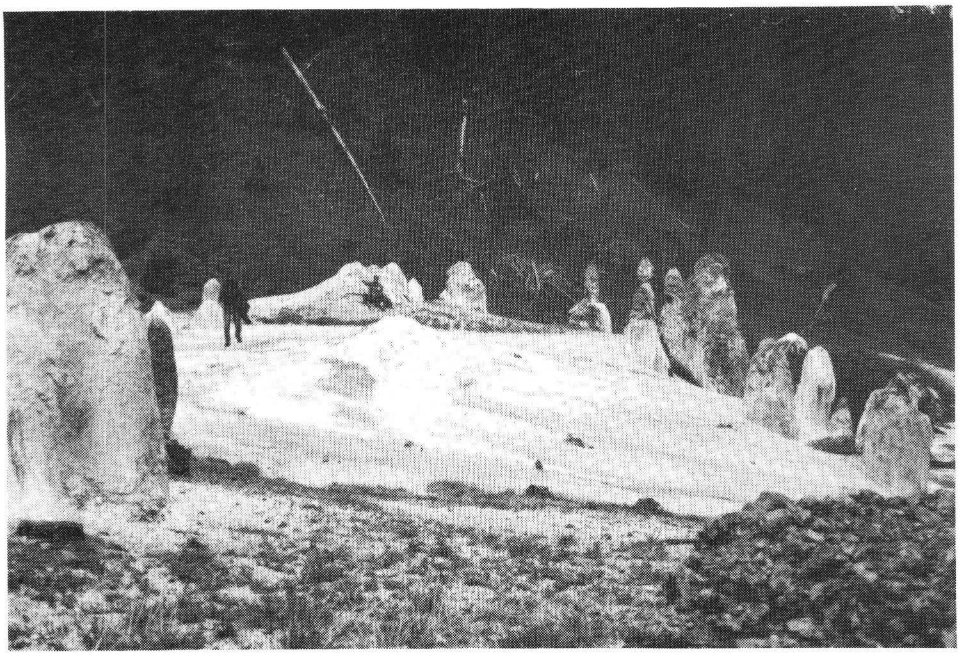


"GOLDEN FLEECE FALLS" **TEKIELA PHOTO**

Lee: Upon reaching the level of this heavily flowing creek, we ate lunch and drank in the surroundings. Thermal springs were breaking out everywhere along the banks. John proposed the name "Arch Spring" for a tiny hot spring lying directly below a noteworthy arch like those at Arches National Park in Utah. This 10 foot span appeared to be formed of sinter. For the group of springs both above and below the falls Rocco suggested the logical name of "Golden Fleece Group".

Rocco: The lighter colors of the bottom of the canyon contrasted greatly with the darker welded tuff of the higher elevations. There was a large cave opening on the east wall of the cliff just below the main falls. "Golden Fleece Falls", along with "Vest Falls" on Shallow Creek a short distance above its junction with Wrong Creek, was discovered a few years ago by members of the U.S. Fish and Wildlife Service who saw them both from the air. Rick Hutchinson later hiked in and visited "Golden Fleece Falls", giving it its name. In 1978, Lee and party hiked to "Vest Falls" and proposed that name. [Whittlesey 1980] (See "The Discovery of a Waterfall" by Lee Whittlesey, a manuscript in the YNP Research Library).

Lee: I finished my lunch near "Arch Spring", while John and Rocco walked north to the thermal area at the confluence of Broad and Shallow Creeks (also visited a few years ago by Rick Hutchinson). Rocco returned

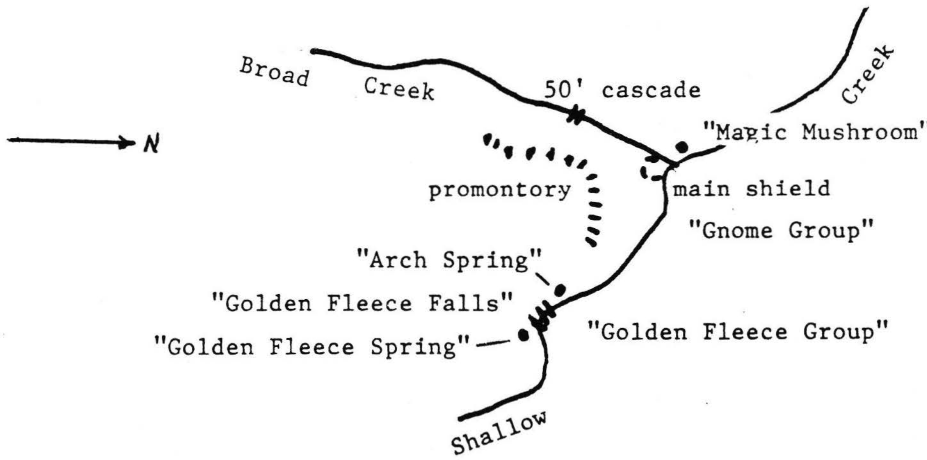


"FAIRYLAND BASIN": MAIN SHIELD OF "GNOME GROUP" **TEKIELA PHOTO**

in just a few minutes, yelling "you've got to see this!". As I crested a small hill with Rocco and got my first glimpse of the area, I was dumbstruck! John was standing in the midst of the strangest place I have ever seen. Around fifty tall, Liberty-Cap-like thermal cones were standing on a thermal shield of deposit in extent larger than the Mammoth Visitor Center. I immediately turned back to get Matt, to make sure he got to see the place and to soak up his first reaction to it. As he came up, he stopped abruptly to take pictures with Rocco who also was taking picture after picture. Our reactions were all of dumbstruck excitement.

This small thermal area was most puzzling. With almost no exception all the springs were comprised of tall, narrow cones from 2 to more than 10 feet high. These cones began about 150 yards above the junction of the two creeks along Shallow Creek and extended to just beyond the confluence. Although most of these cones were at the time dormant, they presented an aspect which was truly weird. A few were active with water flowing from them. John counted about fifty thermal cones on the shield, some only two feet high and others about fifteen feet high. The culmination of this weird aspect was a small circular (sinter/ travertine?) platform at the very junction of the two creeks on which were placed a dozen or so of these tall cones in a near circular pattern. Thoughts of Stonehenge occurred to more than one of us. In the middle of the platform were a few much more squat cones. Two small squat cones near the center showed evidence of very recent activity. They were thought to be either geysers or intermittent springs. The apparently new coating of (travertine/sinter?) surrounding them, along with the beading, gave them the look of having been formed by a periodic activity. The newer coating of deposit was very white. Both the cones and the new deposit looked more like travertine than sinter. A few additional cones bordered all four sides of both creeks just before their confluence, and a few more were present on the west side of Broad Creek just after the entry of Shallow Creek.

This thermal area is truly unique, and among the most interesting in the Park in our opinion. We feel strongly that the



SKETCH MAP #3 **"FAIRYLAND BASIN"**

deposits here are both sinter and travertine, but we did not prove it.

Rocco: The name of "Fairyland Basin" was suggested by Lee for the entire area. I suspected that the activity of the two central cones was possibly seasonal in nature. Only one open spring could be found during our hasty reconnaissance, and this was at the southwest edge of the circular platform and about 2 feet across; the water was quite hot but no temperatures were taken. A particularly beautiful cone -- fat, 15 feet high, and covered with algae/bacteria -- was located immediately north of the stream confluence point. Lee called it the "Magic Mushroom", for he said it resembled one. Two more cones stood as sentinels on both banks of Shallow Creek to the east. I made a fast run up along Broad Creek to investigate another fall which I had seen from the high promontory above. I found a cascade with probably about a 50 foot drop. Time was running short and I returned. Upon reaching the confluence, a rapidly approaching storm cloud hastened our departure. In a few minutes a period of heavy sleet had us seeking shelter.

The five of us agreed to refer to the place (from the falls to the confluence) by the provisional name "Fairyland Basin", the higher thermal group being the "Golden Fleece Group" and the lower (confluence) group being the "Gnome Group." Indeed, in the lower area we expected to see ancient druids, walking about priest-like, wearing long robes, so spiritual was the locale. Sketch maps of both Josephs Coat Springs, and "Fairyland Basin" are included with this report.

Lee: I should like to emphasize that this place is difficult to reach. Matt Tekiela severely injured his left knee in the deadfall in reaching it, and all of us were nearly spent in returning to our camp at Josephs Coat Springs. In our opinion, no one should attempt the feat who is not in excellent shape and proficient with a map and compass. This is trailess country.

Rocco: If you can obtain the new 7½-minute quadrangle maps, it would be a significant help. If you can find the game trail just above the "Logjam Thermal Area", this would also be a great help, and it would make getting to Coffee Pot Hot Springs substantially easier. It runs almost due northeast. Also, the importance of not falling into the drainage of Shallow Creek cannot be over emphasized. On the last compass heading from the small gas barren to the promontory, you must stay on the top of the ridge once it is gained. Staying near the edge of the cliffs above Broad Creek on our way back was by far the superior route. Also remember that from Josephs Coat Springs to the confluence of Broad and Shallow Creek (by way of Coffee Pot Hot Springs) there is a gain of over 500 feet then a drop of over 1300 feet -- and you have to come back!

We consider this area to be one of the most interesting, perhaps almost magical, places we have visited in Yellowstone National Park.

BRIEF RESUME OF NAMES:

Josephs Coat Springs - this name was given by Arnold Hague and Walter Weed [1884], and made official at a much later date. Other names given for these same springs:

> **Orange Rock Springs:** This name was given by Jones [1875] in 1873. This also was made an "official" name.

> **Wayside Group:** This name was given by Comstock also in 1873. [Jones 1875]

> **Orange Creek Springs:** This was the name given by Peale [1883], though he himself did not visit this area.

The Whistler - This was the name given by Arnold Hague [1886] to a roaring steam vent at Josephs Coat Springs. Unfortunately, the 1896 Geologic Altas (folio 30) of Yellowstone National Park labeled this vent "Whistler Geyser" and this latter name was eventually made "official".

Scorodite Spring - This name was given by Arnold Hague (or possibly Walter Weed) in 1884. [Weed 1884]

Ochre Spring - This name was given by Walter Weed in 1888 for the color of the spring. [Weed 1888]

"Broadside Geyser" - This name was suggested by Rick Hutchinson in his November, 1976 report "due to the fact that the geyser is by the <u>side</u> of Broad Creek and 'shoots a broadside'." This is also most likely the same feature named "Broad Creek Geyser" by Walter Weed [1888].

Coffee Pot Hot Springs - This name first appeared on the 1959 USGS 15-minute quadrangle map of Tower Junction. It was apparently given by the USGS but no other information on its origin is currently available. [Whittlesey 1988]

"Pyrite Spring" - A name suggested by Rocco Paperiello in 1992 for the unique spring in the Coffee Pot Hot Springs which was emitting metallic pyrite.

"Vest Falls" - A name suggested by Lee Whittlesey [1980] after his trip to this falls in 1978. This is a two-tiered, 200 foot waterfall on Shallow Creek about ¼ mile upstream from its junction with Wrong Creek.

"Golden Fleece Falls" - A name suggested by Rick Hutchinson for a 100 foot falls on Shallow Creek about ¼ mile before its junction with Broad Creek. He might very well have been the first person to visit this falls. [Whittlesey 1980]

"Fairyland Basin" - A name suggested by Lee Whittlesey in 1992 for the small thermal area stretching from the junction of Broad and Shallow Creeks to just above "Golden Fleece Falls", about a quarter mile distant.

"Golden Fleece Group" - A name suggested in 1992 for the small group of springs along the banks of Shallow Creek from just above "Golden Fleece Falls" to about 50 yards below the falls.

"Golden Fleece Spring" - A discharging spring which breaks out in the steep hillside just to west of and slightly above "Golden Fleece Falls".

"Arch Spring" - A name suggested by John Richardson in 1992 for a small spring in the "Golden Fleece Group", emerging from the ground immediately below the middle of a small arch about 10 feet long.

"Gnome Group" - A name suggested for the group of springs (consisting almost entirely of slender cones) found near the junction of Broad and Shallow Creeks and stretching about 100 yards up Shallow Creek.

"Magic Mushroom" - A large active cone at the confluence of Broad and Shallow Creeks, on the west bank. This name was suggested by lee Whittlesey.

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Visitors to Yellowstone Hot Springs Before 1870

Lee H. Whittlesey

Abstract

An analysis of diverse literature shows that Yellowstone was quite frequently visited during at least the 65 years prior to the so-called discovery by the Langford-Washburn-Doane Expedition of 1870. This chronology is confined to pre-1870 visits known to have seen and commented upon the thermal areas.

Introduction

The following chronology represents the known visits by man to Yellowstone thermal areas prior to 1870. I have omitted known visits to Yellowstone where thermal areas were not specifically mentioned. Note that several of the 1860s visits were not known prior to the author's studies which culminated with the publication of *Wonderland Nomenclature* [Whittlesey, 1988]. A highly edited version of this chronology appeared in *The Geyser Gazer SPUT* newsletter (Volume 3, Number 4, August 1989).

1805—

James Wilkinson received information from Indians on what is currently the earliest known reference to Yellowstone thermal features. Someone visited an area on the Yellowstone River (probably Crater Hills or Mud Volcano) and Wilkinson forewarded a letter on it to President Thomas Jefferson with a sketch made by the Indians on a buffalo pelt:

> "This rude sketch... exposes the location of several important Objects and may point the way to useful inquiry— among other things a little incredible, a Volcano is distinctly described on yellow Stone River..." [Carter, 1948]

1819—

Fur trader Alexander Ross, who chronicled a trip through a portion of Yellowstone by Donald McKenzie, mentioned that "boiling fountains having different degrees of temperature were very numerous; one or two were so very hot as to boil meat" [Ross, 1855].McKenzie's trip, as reconstructed by Rocco Paperiello, would place him in the Yellowstone area in August of 1819, and not in 1818 as given by other authors. Paperiello notes that this gives greater significance to the inscription on a tree, "J.O.R. August 19, 1819", found by Park superintendent P.W. Norris above the Grand Canyon. We are now searching for one of McKenzie's men who had the initials "J.O.R.", and he may well be the J.O. Roch postulated by Aubrey Haines [Paperiello, 1993; Haines, 1974].

1824—

E.S. Topping says Baptiste Ducharme (to whom Topping talked) went to the head of the Yellowstone River, then crossed west to the Firehole and went down it, passing through the geyser basins [Topping, 1888].

1826—

Topping says that Ducharme made the same trip that he had done in 1824, this time possibly (but not known for sure) with Sublette and Potts. Topping says: "Each time he saw the geysers and can yet describe them quite accurately" [Topping, 1888].

1826—

Daniel Potts, a member of the Sublette party of fur trappers, wrote a letter to his brother (dated July 8, 1827, about his 1826 trip) in which he gave the first detailed description of Yellowstone thermal features. The description probably refers to the West Thumb Geyser Basin (though not necessarily specifically to that portion of West thumb now known as the Potts Hot Spring Basin):

> "...on the south borders of this Lake is a number of hot and boiling springs some of water and others of most beautiful fine clay and resembles that of a mush pot and throws its particles to the immense height of from twenty to thirty feet in height The Clay is white and of a pink and water appears fathomless as it appears to be entirely hollow under neath. There is

> also a number of places where the pure suphor is sent forth in abundance one of our men Visited one of those wilst taking his recreation there at an instan the earth began a tremendious trembling and he with dificulty made his escape when an explosion took place resembling that of thunder. During our stay in that quarter I heard it every day. [Potts, 1827]

1829–30 (Fall and Winter)—

Fur trapper Joe Meek visited the Park from its north side and possibly saw Norris Geyser Basin (Aubrey Haines' belief). Meek told Frances Victor of the account and her version follows. Victor said that Meek

> "...ascended a low mountain in the neighborhood of his camp— and behold! the whole country beyond was smoking with the vapor from boiling springs, and burning with gasses, issuing from small craters, each of which was emitting a sharp whistling sound. When the first surprise of this astonishing scene had passed, Joe began to admire its effect in an artistic point of view. The morning being clear, with a sharp frost, he thought himself reminded of the city of Pittsburg, as he had beheld it on a winter morning a couple of years before. This, however, related only to the rising smoke and vapor; for the extent of the volcanic region was immense, reaching far out of sight. The general face of the country was smooth and rolling, being a level plain, dotted with cone-shaped mounds. On the summits of these mounds were small craters from four to eight feet in diameter. Interspersed among these, on the level plain, were larger craters, some of them from four to six miles across. Out of these craters issued blue flames and molten brimstone.
>
> For some minutes Joe gazed and wondered. Curious thoughts came into his head, about hell and the day of doom. With that natural tendency to reckless gayety and humorous absurdities which some temperaments are sensible of in times of great excitement, he began to soliloquize. Said he, to himself, "I have been told that the sun would be blown out and the earth burnt up. If this infernal wind keeps up, I shouldn't be surprized if the sun war blown out. If the Earth is *not* burning up over thar, then it is that place the old Methodist preacher used to threaten me with. Any way it suits me to go and see what it's like."
>
> On descending to the plain described, the earth was found to have a hollow sound, and seemed threatening to break through. But Joe found the warmth of the place most delightful, after the freezing cold of the mountains, and remarked to himself again, that "if it war hell, it war a more agreeable climate than he had been in for some time" [Victor, 1870].

Rocco Paperiello believes that Meek was on the Mirror Plateau rather than at Norris, because of the location of the Yellowstone River in the Victor account.

1832–37—

During the period 1832–37, according to his grandson's recently–donated references, Aaron (or James A.) Campbell visited Yellowstone with a party of fur trappers. While the account is admittedly third hand, it puts a little more meat on the bare bones of fur trade history in Yellowstone and makes an interesting comment about Indians there (although *which* Indians are not known):

> "Grandpa said... his grandfather [Aaron or James A.] told him when they were on their long seven year hunt at the upper end of the Missouri River, they heard of an area called by the Indians as 'Devil Country', and thought they ought to go look at it. He reported that about every few minutes, or even seconds, there would be spouting hot water and steam out of the earth. There were hot mud ponds that they saw a ground squirrel run into and immediately... killed, cooked completely, and many... peculiar formations. Grandpa [Harvey Campbell] thought his grandpa [Aaron or James A.] was lying like a horse thief, and didn't believe these stories. However... (years later) he had occasion to visit his son, Roy, in Montana, and... (they) went to Yellowstone Park. He (Grandpa) saw Old Faithful and the other geysers, the hot mud ponds, and the other peculiarities of the thermal area his grandfather had reported. Then Grandpa realized the old man [Aaron or James A.] had actually seen the things that he had told him (about earlier)..." [Campbell, 1988]

1833—

The party of trapper Manuel Alvarez saw "remarkable boiling springs... on the sources of the Madison" and gave accounts to Warren Ferris that were "astonishing" (see following citation).

1834—

Warren Ferris, having heard accounts of the hot springs at Rendezvous in 1833 from Alvarez's party, determined to visit them himself. With two Indians, he headed east from the Henry's Lake area through "Piny Woods" (the Madison Plateau) and entered the present Upper Geyser Basin, probably by descending the Little Firehole River or the outlet of Summit Lake. Ferris has been called "the first tourist to Yellowstone" because his visit was curiosity rather than business, and he was the first to apply the word *geyser* to Yellowstone thermal features as well as the first to provide an adequate description of a Yellowstone geyser. Ferris wrote:

> We regaled ourselves with a cup of coffee, the materials for making which, we had brought with us, and immediately after supper, lay down to rest, sleepy and much fatigued. The continual roaring of the springs, however, (which was distinctly heard,) for some time prevented my going to sleep, and excited an impatient curiosity to examine them, which I was obliged to defer the gratification of, until morning, and filled my slumbers with visions of waterspouts, cataracts, fountains, jets d'eau of immense dimensions, etc. etc.
>
> When I arose in the morning, clouds of vapour seemed like a dense fog to overhang the springs, from which frequent reports or explosions of different loudness, constantly assailed our ears. I immediately proceeded to inspect them, and might have exclaimed with the Queen of Sheba, when their full reality of dimensions and novelty burst upon my view, "the half was not told me."
>
> From the surface of a rocky plain or table, burst forth columns of water of various dimensions, projected high in the air, and sulphurous vapors, which were highly disagreeable to the smell. The rock from which these springs burst forth, was calcareous, and probably extends some distance from them, beneath the soil. The largest of these wonderful fountains, projects a column of boiling water several feet in diameter, to the height of more than one hundred and fifty feet, in my opinion; but the party of Alvarez, who discovered it, persist in declaring that it could not be less than four times that distance in height— accompanied with a tremendous noise. These explosions and discharges occur at intervals of about two hours. After having witnessed three of them, I ventured near enough to put my hand into the water of its basin, but withdrew it instantly, for the heat of the water in this immense chauldron [*sic*], was altogether too great for my comfort; and the agitation of the water, the disagreeable effluvium continually exuding, and the hollow unearthly rumbling under the rock on which I stood, so ill accorded with my notions of personal safety, that I retreated back precipitately, to a respectful distance. The Indians, who were with me, were quite appalled, and could not by any means be induced to approach them. They seemed astonished at my presumption, in advancing up to the large one, and when I safely returned, congratulated me on my "*narrow escape.*" They believed them to be supernatural, and supposed them to be the production of the Evil Spirit. One of them remarked that hell, of which he had heard from the whites, must be in that vicinity. The diameter of the basin into which the waters of the largest jet principally fall, and from the center of which, through a hole in the rock about nine or ten feet in diameter, the water spouts up as above related, may be about thirty feet. There are many other smaller fountains, that did not throw their water up so high, but occurred at shorter intervals. In some instances, the volumes were projected obliquely upwards, and fell into the neighboring fountains, or on the rock or prairie. But their ascent was generally perpendicular, falling in and about their own basins or apertures. these wonderful productions of nature, are situated near the centre of a small valley, surrounded by pine-crowned hills, through which a small fork of the Madison flows.
>
> From several trappers who had recently returned from the Yellow Stone, I received an account of boiling springs, that differ from those seen on Salt river only in magnitude, being on a vastly larger scale; some of their cones are from twenty to thirty feet high, and forty to fifty paces in circumference. Those which have ceased to emit boiling, vapour, Etc., of which there were several, are full of shelving cavities, even some fathoms in extent, which give them, inside, an appearance of honey-comb. The ground for several acres extent in vicinity of the springs is evidently hollow, and constantly exhales a hot steam or vapour of disagreeable odor, and a character entirely to prevent vegetation. They are situated in the valley at the head of that river, near the lake, which constitutes its source. [Ferris, 1842]

Aubrey Haines believes Ferris saw Splendid Geyser in action, with the reference to other geysers "projected obliquely upwards" being to Daisy Geyser. Others may disagree, but it is notable that, given the amount of time Ferris spent among these geysers, he evidently did *not* witness Old Faithful Geyser.

1836—

Trapper Osborne Russell visited present Steamboat Point and wrote about the Steamboat Springs there:

> Near these was an opening in the ground about 8 inches in diameter from which steam issues continually with a noise similar to that made by the steam issuing from a safety valve of an engine and can be heard 5 or 6 Mls. distant. I should think the steam issued with sufficient force to work an engine of 30 horse power. [Russell, 1965]

1839—

Russell visited Shoshone Geyser Basin, "Hour Spring", and Castle or Lone Star Geysers. He described Grand Prismatic Spring in the earliest known description of a Yellowstone thermal feature that is definitely identifiable. Crossing east to Hayden Valley, Russell travelled up river to Yellowstone Lake and around the north side of the lake where he tried to shoot a swimming deer at West Thumb Geyser Basin. Russell then went south to Heart Lake, mentioning the hot springs there, and then west to Falls River. Russell was impressed with the springs at Shoshone and Upper Basins, noting that at the latter the "kettle is always ready and boiling."

Russell described the "hour Spring" at Shoshone Geyser Basin as follows:

> ...the first thing that attracts the attention is a hole about 15 inches in diameter in which the water is boiling slowly about 4 inches below the surface at length it begins to boil and bubble violently and the water commences raising and shooting upwards until the column arises to the height of sixty feet from whence it falls to the ground in drops on a circle of about 30 feet in diameter being perfectly cold when it strikes the ground. It continues shooting up in this manner five or six minutes and then sinks back to its former state of Slowly boiling for an hour and then shoots forth as before My Comrade Said he had watched the motions of this Spring for one whole day and part of the night the year previous and found no irregularity whatever in its movements [Russell, 1965].

The description of Grand Prismatic Spring is noteworthy for being almost poetic:

> At length we came to a boiling Lake about 300 ft in diameter forming a nearly complete circle as we approached on the South side. The steam which arose from it was of three distinct Colors from the west side for one third of the diameter it was white, in the middle it was pale red, and the remaining third on the east light sky blue. Whether it was something peculiar in the state of the atmosphere the day being cloudy or whether it was some Chemical properties contained in the water which produced this phenomenon. I am unable to say and shall leave the explanation to some scientific tourist who may have the Curiosity to visit this place at some future period— The water was of deep indigo blue boiling like an immense cauldron running over the white rock which had formed [round] the edges to the height of 4 or 5 feet from the surface of the earth sloping gradually for 60 or 70 feet. What a field of speculation this presents for chemist and geologist [Russell, 1965].

1839—

A party of forty [40!] men including Baptiste Ducharme and Louis Anderson saw and orally described to Bill Hamilton "the hot springs at the upper end of the lake [West Thumb Geyser Basin]; Steamboat Springs on the south [east] side... They also told about the sulphur mountains... and the mud geysers..." Bill Hamilton noted that he "listened with rapt attention when they described the wonderful springs at the Lower Basin, especially the one situated on the bank of the river called Fire Hole." [Hamilton, 1905]

[Note: at this point, the editor of *The Transactions* will contend that this "one situated on the bank of the river called Fire Hole" and Russell's "boiling Lake" equated by others with the modern Grand Prismatic Spring are one and the same, *and* that this feature is *not* Grand Prismatic. Rather, given a location on the river bank and that Russell's pool was surrounded by "edges to the height of 4 or 5 feet", he feels this to be the earliest notation of a young, evolving Excelsior Geyser. But as author Whittlesey replies, "Maybe so but maybe not."]

1839—

Trapper E. Willard Smith travelled to Wind River Mountains with Louis Vasquez. Vasquez told Smith of visiting the Yellowstone country either earlier that year or the year before. According to Vasquez, the country was filled with "mounds emitting smoke and vapor... There are volcanoes, volcanic productions and carbonated springs." Smith wrote "that he [Vasquez] went to the top of one of these volcanoes, the crater of which was filled with pure water, forming quite a large lake." [Smith, 1913]

1843—

Did William Sublette guide Sir William Drummond Stewart through the Yellowstone region this year? Kennerly [1948] talks of throwing things into "Old Steam Boat Geyser". However, although Stewart was in the American West in 1843, neither of his two books of fiction nor Mae Reed Porter's *Scotsman in Buckskin* contains any hint of a Yellowstone visit. Kennerly's account is considered fiction by historians.

1846—

Trapper James Gemmell accompanied Jim Bridger from Jackson Hole to Yellowstone Lake, thence to the Upper and Lower Geyser Basins, and finally to Mammoth Hot Springs. According to Olin Wheeler, Gemmell said:

In 1846 I started from Fort Bridger in company with old Jim Bridger on a trading expedition to the Crows and Sioux. We left in August with a large and complete outfit, went up Green River and camped for a time near the Three Tetons, and then followed the trail over the divide between Snake River and the streams which flow north into Yellowstone Lake. We camped for a time near the west arm of the lake and here Bridger proposed to show me the wonderful spouting springs on the head of the Madison. Leaving our main camp, with a small and select party we took the trail by Snake Lake (now called Shoshone Lake) and visited what of late years have become so famous as the Upper and Lower Geyser Basins. There we spent a week and then returned to our camp, whence we resumed our journey, skirted the Yellowstone Lake along its west side, visited the Upper and Lower Falls, and the Mammoth Hot Springs, which appeared as wonderful to us as had the geysers. Here we camped several days to enjoy the baths and to recuperate our animals, for we had had hard work in getting around the lake and down the river, because of so much fallen timber which had to be removed. We then worked our way down the Yellowstone and camped again for a few days' rest on what is now the [Crow Indian] reservation, opposite to where Benson's landing now is. [Wheeler, 1896]

1850—

E.S. Topping [1888] has stated:

Kit Carson, Jim Bridger, Lou Anderson, Soos, and about twenty others on a prospecting trip, came from St. Louis, overland, to the Bannock Indian camp on Green River, late in the fall of 1849. They fixed up winter quarters and stayed with these Indians till spring. Then they went up the river and as soon as the snow permitted crossed the mountains to the Yellowstone and down it to the lake and falls; then across the divide to the Madison river. They saw the geysers of the lower basin and named the river that drains them the Fire Hole. Vague reports of this wonderful country had been made before. They had not been credited, but had been considered trapper's tales (more imagination than fact).

1853—

Captain John Mullan appears to have seen thermals in Yellowstone after hearing of them from Indians:

As early as the winter of 1853, which I spent in these mountains, my attention was called to the mild open region lying between the Deer Lodge Valley and Fort Laramie... Upon investigating the peculiarities of the country, I learned from the Indians, and afterwards confirmed by my own explorations, the fact of the existence of an infinite number of hot springs at the headwaters of the Missouri, Columbia, and Yellowstone rivers, and that hot geysers, similar to those in California, existed at the head of the Yellowstone... [Mullan, 1863]

1859—

According to Ellis Dunklee, his great uncle, Frank Sheldon of Morengo, Illinois, joined a group of horse traders and drove horses west from Illinois to Salt Lake City for sale. East of the Great Salt Lake, they met Jim Bridger

...who spoke of the "Yallerstone" country where there were springs of great color, pools of hot water, and places where the water squirted out of the ground with great force.

The group was so impressed they decided upon a visit through the country on their way home.

...they made their way up by the Tetons, into the Lake area where they saw the West Thumb thermal area; made their way around and down the river to the canyon, then over to the Madison... [Replogle, 1958]

Although I am suspicious of this account, I include it here for completeness. It was told to Ranger Wayne Replogle by Ellis Dunklee in 1958.

1863—

A large party under Walter W. DeLacy saw hot springs on Snake River, Shoshone Geyser Basin ("some of which were geysers, which my men saw in action, spouting up the water to a great height."), and Lower Geyser Basin. About Lower Basin, DeLacy wrote that he

...soon entered a valley or basin, through which the stream meandered, and which was occupied on every side by hot springs. They were so thick and close that we had to dismount and lead our horses, winding in and out between them as best we could. The ground sounded hollow beneath our feet, and we were in great fear of breaking through, and proceeded with great caution. The water of these springs was intensely hot, of a beautiful ultramarine blue, some boiling up in the middle, and many of them of very large size, being at least twenty feet in diameter and as deep. There were hundreds of these springs, and in the distance we could see and hear others, which would eject a column of steam with a loud noise. These were probably geysers, and the boys called them "steamboat springs." No one in the company had ever seen or heard of anything like this region, and we were all delighted with what we saw. This was what was afterward called the "Lower Geyser Basin" of the Madison, by Prof. Hayden. [DeLacy, 1876]

In 1869, DeLacy wrote further: "At the head of the South Snake, and also on the south fork of the Madison, there are hundreds of hot springs, many of which are 'Geysers.'" [Raymond, 1869]

1864—

Rocco Paperiello has found an important newspaper account of a visit to the Park in 1864 by Montanan George A. Bruffey, who later wrote the book *Eighty–One Years in the West* (1925), and his friend, T.B. Sacket. Bruffey reported that on September 16, 1864, while near present Eagle Nest Rock,

> we saw a man emerge from the willows. The trail was trackless, so where was he from? I was soon by Sacket's side. We motioned the man to come on... He said the was a free trapper from the south fork of Snake River, and that he was looking for a more abundant field of fur... He told us of the Jackson lake, the country around Yellowstone lake, and of what he termed water volcanoes. His descriptions could only daze a person. He had evidently only seen some of the flowing springs. He said one came up to the top five or six feet and then sunk back. He had crept up and peered down into the smoking mouth. He said there was one like that quite nearby.[Bruffey, undated]

At that point, the man invited Bruffey and Sacket to accompany him to see the "water volcanoes." They set out eagerly, then became afraid he would waylay them, and managed to lose him.

> We never saw our volcano friend again, but we wished in after years that we had followed him.

1864—

Prospector John C. Davis noted:

> We came into the park just above the lake, and immediately found ourselves in the midst of the wonders of this enchanted land. The boiling springs and geysers were all around us, and, accustomed as we were to the marvels of Western scenery, we hardly knew what to think of the phenomena. Having visited this place the preceding year [with DeLacy] I was, however, less surprized than the others. [Davis, 1884]

1864—

Charles Howell wrote in 1883 that "an old mountaineer who lives in the vacinity said it [Old Faithful] had not missed [an eruption] once to his knowledge in the last nineteen years." This would place this old man's first look at Old Faithful in 1864. [Whittlesey, 1988]

1864—

Superintendent Norris stated in 1881 that prospector George Huston and his party saw the geysers of Upper Geyser Basin and probably even saw Giantess Geyser in eruption:

> Later in the same season George Huston and party ascended the main Fire Hole River, and from the marvelous eruption of the Giantess and other geysers, and the suffocating fumes of brimstone, fearing they were nearing the infernal regions, hastily decamped. [Norris, 1881; per Topping, 1888, the date of this visit could be 1866]

1864-65—

Mrs. George Cowan, at age ten, heard stories from the lips of the man we probably now know as Gilman Sawtell, who had visited the geysers sometime earlier. The date of 1864-65 is when Mrs. Cowan was told the story, so the date of Sawtell's visit is unknown but probably before that time:

> In Virginia City, where we lived the first year in Montana, 1864-5, my father one day brought home an old man whose name I cannot recall, who told us some very marvelous stories. He had been in the West for years, and was living at that time at Henry Lake, trapping and hunting, and during the winter season marketing fish from the lake. My father termed them fish stories. However, I enjoyed them immensely. My fairy books could not equal such wonderful tales. Fountains of boiling water, crystal clear, thrown hundreds of feet in the air, only to fall into cups of their own forming; pools of water within whose limpid depths tints of the rainbow were reflected; mounds and terraces of gaily colored sand— these and many others were the tales unfolded. [Cowan, 1903]

1864–65—

George Harvey Bacon made two trips into the Park during these years. His letter, quoted in Whittlesey [1988] for its early reference to Old Faithful, is reproduced here in full for its first publication:

> George Harvey Bacon went west from Boreau [probably Bureau] Co Illinois in about 1864 with [the] gold rush and lived in Virginia City Montana for several years. Part of [the] time he was with bands of men who fought Indians[,] scout & guide at times; tracked— worked as butchers assistant and was on[e]

> of the Vigilanties who destroyed the Henry Plummer gang by hanging or running out of the territory. He with others heard through the Indians of the queer noises and steam coming out of the ground. He went with a friendly bands of Indians through this district and spoke of a geyser which was regular in its eruption and [which] later was called Old Faithful. He spoke of a place where he could boil and egg in hot water and without ch[ang]ing his track reach water that was very cold. He later took a group of white men through this region [a second trip]. He claimed he lead the first white group of men through this district. He spent from 1864 to 1873 in this district. Died in 1917 in Peoria, Ill. [Bocern, undated; all *sic*]

The signature on this letter is that of Dr. J.H. Bocern.

1865—

The George H. Bacon trip of "1864–69" above could possibly have occurred in 1865, as per Aubrey Haines. [Haines, 1977]

1865—

Father Francis Kuppens saw "hot and cold geysers" and other items of scenery in Yellowstone. [Kuppens, 1962]

1865—

In 1933, the *Livingston Enterprise* newspaper ran a special issue devoted to the history of the Yellowstone Park–Paradise Valley–Livingston areas. In an article entitled "Park Becomes Real Tourist Mecca in 1883", the reporter interviewed Newton Seward, of Kentucky and then a resident of Paradise Valley. Seward came to Montana Territory in 1864 and was touted as one of the discoverers of the Clark's Fork mines at Cooke City. He says he joined a party of 19 men who left Virginia City on a prospecting expedition in 1865. They entered present Yellowstone and camped in "an open space of queer formations." Says Seward:

> None of us had ever heard of geysers. Our amazement and fear can be imagined when a vast rumbling and bubbling in the middle of our camp was followed by a stream of hot water that rose high into the air. Conjecturing that we were on a volcanic ground that might at any moment erupt disastrously, we gathered our equipment and beat a very hasty retreat until we were out of sight of the geysers. [*Livingston Enterprise* newspaper, June 20, 1933]

1866—

E.S. Topping claims that a party under George Huston went up the Madison and Firehole Rivers "to the geysers":

> They stayed at the Upper Basin for several days, and were probably the first, besides the early trappers, to see the great geysers. [Topping, 1888]

This party also saw the Mud Volcano area and probably the Heart Lake geysers and West Thumb springs. Rocco Paperiello believes that this trip may have been the same as the 1864 trip of Huston as reported above.

1866—

An 1877 tourist party that visited Great Fountain Geyser reported that they found hundreds of names written in pencil on its formation, some dating back to 1866, thus proving that white men (probably prospectors) visited the area those years. Astonishingly, one of these early visitors was a woman, as her name "Miss Ella Aylesworth" was one of the names found written. [Whittlesey, 1988]

Miss Aylesworth is now known, from her reminiscence, to have visited Yellowstone Park in 1876.

1867—

Dr. James Dunlevy and a small party appears to have visited Mammoth Hot Springs from Montana. [*Montana Post* newspaper, August 24, 1867; also Curtiss, in Topping, 1968]

1867—

A group of prospectors called the "Bear Gulch Stampeders", including A.H. Hubbell, Lou Anderson, George Reese, and Caldwell, spent at least eight days travelling through the Yellowstone "volcanic country." They saw thermal features, probably those of Crater Hills, Mud Volcano, and other areas. [*Montana Post* newspaper, August 31, 1867] This account is quoted in Haines [1974].

1867—

Uncle Joe Brown was one of the earliest residents of the Yellowstone country, arriving there in the fall of 1866. He spent the winter of 1866-67 prospecting at Bear Gulch. In 1909, Brown recalled a trip into the Park for the *Livingston Enterprise* newspaper:

> In 1867 we all went through the park. An old trapper named Lou Anderson who had a Snake Indian squaw, came down and told of what is now the Upper Geyser Basin. Anderson had been in the country since 1836 and had been over most all of it. Our party went into the Park and up to the east fork of the Yellowstone, crossed over to the lake, and then came down to what is now the Upper Geyser Basin, which Anderson called a Fire Hole. We spend about two months in there prospecting, but didn't find anything. That was in 1867, and I have never been back to the basin since. I never got so tired of hot springs in my life. There were lots of geysers then in all directions, but many of them have since dried up. Up on the east fork where there were many, I have found on different trips since [then] that a lot of them have dried up. [*Livingston Enterprise* newspaper, December 18, 1909]

Here Brown confirmed that the long dead thermal area just west of Mount Norris (also described as active by A. Bart Henderson) was in fact quite active in 1867. Paul Schullery and I have discussed the activity of this thermal area in early Park days in our book [Schullery and Whittlesey, 1992].

1867—

Prospector A. Bart Henderson visited Butte Springs and Beach Springs on Yellowstone Lake, the Washburn Hot Springs, and other thermal areas. Henderson thought that Washburn Hot Springs would "be a very great wonder in the course of time." [Henderson, 1964]

1868—

There were probably some trips into the Yellowstone country during this year, for stories appeared in *Frontier Index, Helena Weekly Herald* and other newspapers. Actual details are yet to be discovered.

1869—

William Marshall wrote in 1880:

> How long it [Old Faithful] has thus spouted we do not know, but I do know that in 1869 my friend Mr. Ira Livermore strayed into this region with a mining partner, on a 'prospecting trip', and found it thus regular, as have parties in each of the ten summers since." [Whittlesey, 1988]

1869—

The Folsom-Cook-Peterson party saw a number of thermal areas in Yellowstone, excluding Mammoth Hot Springs and Upper Geyser Basin, but including Lower Geyser Basin where they watched an eruption of Great Fountain Geyser.

Conclusion

When all the above is summarized, it is evident that something considerably greater than 100 people visited the Yellowstone thermal areas prior to 1870. This figure reflects only those visits known from published accounts, for each of which there could well have been (and probably were) numerous additional visits. The Langford-Washburn-Doane Expedition of 1870 might well be the most famous Yellowstone exploration and was responsible for much of the publicity that resulted in the creation of the national park, but in no way can that party be credited with anything but the final, or formal, discovery of the Yellowstone geysers.

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Mickey Hot Springs
Harney County, Oregon
Observations of March 27–29, 1992

Jeff Cross

Abstract
Mickey Hot Springs in southeastern Oregon is the site of a small geyser among about two dozen hot springs. This thermal area is described and mapped here. The cyclical activity shown by the geyser during three days in March 27-29, 1992 is included.

Introduction

Mickey Hot Springs lies on land administered by the Bureau of Land Management in southeastern Oregon's Harney County, approximately 35 miles via dirt roads south from paved Highway 78 at a point 26 miles northwest of Burns Junction. The area has gotten considerable attention from people interested in hot springs for recreational bathing purposes, but the existence of either boiling or spouting springs there was largely unpublicized until 1990, when the BLM became interested in better protecting and interpreting the area. The visit on which this paper is based took place on March 27-29, 1992.

The thermal features of Mickey Hot Springs are strewn about on a hillside, adjacent to and below a parking area. The upper portion of the thermal area consists of old sinter mounds and formations, some of which contain within themselves active vents. However, only one spring (#1) in this upper area overflows. At a lower elevation to the south are found the most active features. Mud pots and steam vents are at very slightly higher elevations than the flowing springs. A number of the steam vents were superheated, boiling at this elevation being ≤96°C. Discharge from the lower area exits the immediate vicinity via a hot stream, which flows a short distance before disappearing into a brackish swamp. The total discharge of the area is approximately 115 liters per minute. A white mineral deposit, probably transported into the area by winds from nearby dry lake beds, covers significant portions of the area.

It is possible that most of the flow from the area once issued from the upper area through the now relatively inactive craters there, and then, at some time not too long ago, shifted to the newer

The geyser at **Mickey Hot Springs**, in full 1½ meter eruption on May 18, 1991. Photo by Bob Berger.

looking vents in the lower area.

Immediately southwest of the lower area is a low semicircular formation ("V" on Map B) which may be part of the rim of an explosion crater, centered near springs #17 and #18.

The siliceous sinter deposited in the Mickey Hot Springs area appears to be of a variety less dense than that of the major geyser basins of Yellowstone National Park; at Mickey, some deposits are quite porous, somewhat resembling pumice. This is especially obvious around the rim of spring #2.

An old deposit probably of sinter was also located on the west side of the hill west of the springs, indicating either a different locus of or more extensive thermal activity in past times.

Spring Descriptions

The features marked on the maps are identified in one of two ways. Those with numbers exhibited obvious thermal activity (the presence of hot water or steam). Other structures and sinter formations are labeled with letters. There is no definite scale to the maps, and Map A is at a slightly larger scale ratio than Map B. The features were mapped by observation and not actual measurement. The general direction of north is indicated. More accurate maps might be available from the BLM's Burns District Office.

Descriptions and data on the marked features follow. Temperatures are given in degrees Celsius (°C), followed by an approximate pH (if measured). The temperature data represents the highest temperature measured in that feature on the morning of March 29, 1992, at which time the air temperature was 14°C. Overflow was present only at those springs where it is indicated.

A-C, E-H, and N: old sinter mounds.

D: a large flat-bottomed crater approximately 15 to 20 meters across, with broken sinter blocks on the southeast margin; three small hot springs (#3) are located in the northeast quadrant.

I: a cave penetrating sinter.

J: small holes.

K: three wide craters aligned toward 'D'; origin not obvious.

L: a hole.

M: the rim of an old sinter shield.

P: a collecting basin in the runoff channel from spring #1; used for bathing by visitors, and probably carved out by humans for this purpose some time in the past; about 3 by 1.5 by 0.5 meters.

Q, R: shallow hot spring craters atop sinter mounds.

S: a small hole.

T, U: old shallow craters.

V: a berm of undetermined composition; perhaps related to the possible explosion focus near spring #s 17 and 18.

W: a large brackish pond in the drainage area. It may or may not have its own water source, and it appears to occupy a portion of another possible hydrothermal explosion crater.

#1: a large hot spring; 53°C; pH 8.4. The overflow runs through a trench (probably human cut) and disappears on the side of the hill after passing through the collecting basin ('P'); dimensions are approximately 9 by 9 meters.

#2: a deep crater atop a prominent mound; crater dimensions approximately 3 by 4 meters. A cavernous conduit drops straight down for several meters, and water could be seen in the very lowest visible portion of the tube (a mirror was used to reflect sunlight into the lower recesses; otherwise, the water would not have been visible).

#3: three small holes within feature 'D' containing hot water. The water in one of the holes was measured at 93°C.

#4: old hot spring crater, with two small hot springs under a ledge on the crater's north side. The eastern spring measured 39°C, pH 7.8; the western spring was 58°C, pH 7.6.

#5: a small hot spring in a hole; 42°C, pH 6.7.

#6: a small hot spring in a hole; 34°C, pH 8.0.

#7: a small hot spring in a hole; 35°C, pH 8.4.

#8: a small hot spring in a crack at the base of the inside wall of a dry hot spring crater; not easily accessible, so no data was taken.

#9: a hot spring; 54°C, pH 8.8. Slight overflow disappears into the side of the old hot spring crater immediately to the north.

#10: a steam vent in the southern portion of a crater; 92°C.

#11: a steam vent; no temperature measured.

#12: a steam vent in the northern portion of a crater; 70°C.

#13: a steam vent/mud pot complex; 96.6°C.

#14: a cloudy hot spring, gas bubbles rising from a vent; 57.2°C, pH 6.8.

#15: a mud pot; 88°C.

#16: a mud pot; 96.8°C.

#17: a hot spring; 68°C.

#18: a hot spring, 60°C, pH 9.0, approximately 2 meters across and with gas bubbles rising from the vent. Springs #17 and #18 share a common pool surface. Together, the pair's overflow constitutes a significant portion of the area's hot water discharge.

#19: a small hole containing water, nearly invisible in the grass.

#20: a hot spring, very obviously controlled in shape by two intersecting fracture systems, one of which is the spring's long axis (approximately 4 to 5 meters long); the other (3 meters long) is located at the spring's northern end and is angled between 15 and 25 degrees from the perpendicular to the long axis. Gas bubbles rise from many of the vents within the crater; one of a number of small holes at the south end of the spring pulsed constantly— it is unknown whether this action resulted from subsurface boiling activity or not, as the temperature above the hole was not significantly higher than the temperature of the rest of the spring. Spring #20 as a whole accounts for another significant portion of the area's hot water discharge. Temperature 77°C along the long axis, 86°C at the northwest end of the shorter fracture, 87°C at the intersection of the fractures, and 85°C at the southeast end of the shorter fracture; pH 8.6.

#21: a steam vent; no temperature measured.

#22: a collection of steam vents; temperatures in the respective vents were a, 91°C; b, 93°C; c, 97°C; d and e, 98°C. Conditions about vent a first hinted of a blowout, but further investigation revealed a probably human or bovine aid, as the steam issued not from a crater, but from a gouged area. The decomposed rock of the gouged area was of a bright red color. Between vent a and vents b and c is a low depression; vents b and c were but different points of steam emission within a shallow common crater.

#23, "Mickey Hot Springs Geyser*": temperature boiling, pH 9.1.

This is the "controversial" geyser (*, see footnote, next page). During this period of observation, it failed to behave as a true, intermittent geyser in that the eruptive action never stopped for any length of time sufficient to call an interval. However, the degree of activity was definitely periodic in terms of both height and overflow. The maximum eruption height was about 1 meter, and individual eruptive bursts of water occurred at a rate of 1 to 3 per second. The maximum overflow was around 1 liter per second for several seconds at a stretch.

The crater is roughly triangular; the long axis (and the longest side of the quasi-triangle) runs southeast-northwest, and is approximately 60 centimeters in length. The other axis is approximately 25 centimeters in length. The crater configuration appears to be controlled by a fracture passing through the crater and paralleling the long axis. A steam vent is located a few centimeters past the crater's northwestern point, on the same apparent fracture. Heat flow from the ground northwest of the crater is relatively high. On occasion, subsurface activity causes a slight jarring of the ground that can be felt within two meters of the crater, and a thumping that can be heard at slightly greater distances.

A well-cut runoff channel serves to drain the overflow. The vent itself is in what appears to be an older sinter deposit; atop this sinter is a loose accumulation of such material as would wash off the hillside above during episodes of precipitation. This upper deposit has been significantly eroded and washed out by the geyser's activity, and it is probable that some of the debris has washed into the vent. The older sinter is washed clean for about 0.5 meters around the vent, and the deposit on top of it is eroded for another meter beyond that.

Data on the activity was gathered on March 28, 1992, and this is presented as Table 1. Times are recorded as hour:minute/second. The following activity indicators are used:

"Pause"—a very short cessation of bursting activity, never more than one second in length.

"ovf"— Overflow.

"down"— the ceasing of overflow and/or a drop in water level.

"int"— Intermittent rising and falling of the water level without a change in the flow status (the feature is either overflowing or it is not).

* — An asterisk indicates more powerful activity during that overflow period.

In observing the variations in overflow and power of activity, the following was noted:

Episodes of more powerful activity (referred to as "major activity"), stronger overflow, and usually longer overflow durations generally occurred once roughly every 7 to 12 minutes. During the first half hour of observation, a second cycle was obvious, being manifest half way through the major cycle intervals.

There was a notable lack of major activity between 14:27 and 14:44 for which I have no suitable explanation.

After this quieter spell, major activity recurred on shorter intervals than before, and the activity between 14:57 and 14:58 appeared to be a single major episode with a pause partway through. The earlier minor cycle was not again obvious until after the 14:58 activity, and it again disappeared after 15:15.

Another long period of no major activity, from 15:18 to 15:43, was filled with recurrent overflows. The cycle of major activity might timorously have been in evidence with two longer overflows, one at 15:27 and the other at 15:37.

Major activity returned to the scene at 15:43 and 15:54, then disappeared again until 16:13. During this disappearance, the major cycle again might have been present, but if so was well disguised.

The next major activity began at 16:13. This time, there were two sets of such action, three major activity periods to each set. One more conventional period of major activity ended the recorded data.

#24: a steam vent, associated with the geyser.

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* This spring is known to have been eruptive more often than not since at least 1985, usually as a perpetual spouter, much as was seen during this report's observations. It first(?) began having truly periodic geyser eruptions around 1988, when a hot spring enthusiast's publication, *The Hot Springs Gazette*, described a "boiling geyser" at Mickey's (the same publication had noted only "whooshing steam vents and a few hot pools" in 1982). The action was quite weak when seen during 1990. In May, 1991, it was a strong and vigorous geyser, with intervals of a few minutes, durations about 2 minutes, and heights up to 2+ meters.

The Mickey Hot Springs are under study by a graduate student at the University of Oregon. Early results indicate that the geyser is highly changeable as a result of only slightly variable ground water levels— active as a perpetual spouter when levels are high, as a geyser when the levels are low (as was the case during the 1988-1991 drought).— T. Scott Bryan

TABLE 1
The Activity of "Mickey Hot Springs Geyser"
March 28, 1992

13:46/24	ovf*
13:47/00	down
13:47/35	pause
13:48/25	pause
int	
13:50/43	ovf
13:52/??	down
13:52/43	ovf
13:53/??	down
13:53/50	pause
13:54/02	pause
13:54/26	pause
int	
13:55/27	pause
13:56/31	ovf*
13:59/30	down
14:00/40	pause
14:01/35	pause
int	
14:03/06	ovf
14:03/26	down
14:04/??	ovf
14:05/50	down
14:05/55	short ovf
int	
14:10/45	ovf*
14:13/15	down
int	
14:15/43	pause
14:16/07	ovf
14:17/00	down
int	
14:18/00	ovf
14:18/18	down, pause
int	
14:19/18	ovf*
14:21/30	down
int	
14:24/00	pause
14:25/20	ovf*
14:27/00	short cessation of ovf
int	
14:30/44	pause
14:33/36	pause
14:36/00	ovf
14:36/35	down
??:??/??	up
14:38/00	down
14:39/47	ovf
14:41/00	down
14:44/00	ovf*
14:48/13	down
int	
14:50/04	pause
14:50/45	ovf*
14:54/00	down
int	
14:57/18	ovf*
14:57/45	down, pause
14:58/34	ovf*
14:59/??	down
int	
15:01/06	ovf
15:02/50	down
15:04/00	pause
int	
15:04/59	ovf*
15:06/00	down
15:06/51	short ovf
int	
15:08/43	ovf
15:09/30	down
int	
15:10/16	pause
15:10/56	ovf*
15:12/45	down
15:13/54	pause
int	
15:15/26	ovf*
15:18/20	down
int	
15:20/47	short ovf
15:22/00	short ovf
15:22/59	pause
15:23/50	short ovf
int	
15:27/00	short ovf
15:28/20	ovf
15:29/00	donw
15:30/00	ovf
15:30/50	down
15:31/20	ovf
15:33/10	down
15:34/02	ovf
15:35/00	down
15:36/11	ovf
15:36/30	down
15:37/50	ovf
15:39/50	down
15:40/06	ovf
15:41/14	down
int	
15:43/53	ovf*
15:45/20	down
int	
15:46/36	pause
15:47/40	ovf*
15:50/35	down
15:51/23	pause
15:52/10	ovf
15:53/24	down
15:54/06	pause
15:54/34	short ovf
15:54/55	ovf*
15:56/20	down
15:56/50	ovf
15:57/30	down
int	
15:59/50	ovf
16:00/25	down
int	
16:02/17	pause
16:03/13	ovf
16:05/00	down
16:05/50	short ovf
16:07/11	short ovf
16:08/15	ovf
16:09/00	down
16:09/50	ovf
16:10/25	down
int	
16:11/50	ovf
16:12/30	down
16:13/20	ovf*
16:15/30	down
16:17/12	ovf*
int	
16:18/20	pause
16:19/18	ovf*
16:22/00	down
16:22/35	short ovf
16:25/00	ovf
16:25/40	down
16:26/00	pause
16:27/10	ovf*
16:29/00	down
16:30/17	ovf*
16:31/00	down
16:32/21	ovf*
16:34/00	down
16:35/38	ovf
16:36/40	down
16:37/10	ovf
16:37/40	down
int	
16:39/45	ovf*
16:41/40	down
16:42/05	short ovf
16:44/15	ovf
16:44/30	down
16:46/00	pause

#25: a hot spring, approximately 3 by 1 meters; two vents, 65°C at the south vent and 91°C at the north vent; pH 9.2. Gas bubbles rise from the north vent.

#26: a hot spring; 82°C; pH 9.1. This was the third significant source of hot water discharge at Mickey Hot Springs' lower group.

Access to Mickey Hot Springs

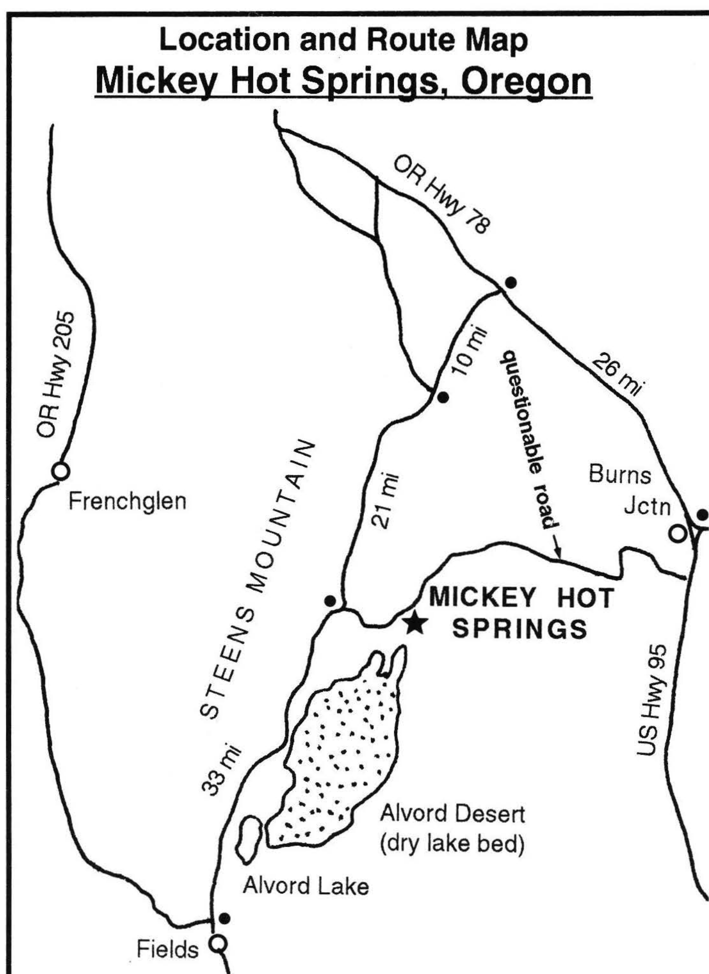
General directions for reaching Mickey Hot Springs appear on the map on the first page of this article. The junction of the road which passes Mickey Hot Springs with the Highway 78–Fields Road is 30.7 miles south of Highway 78. Previous directions indicated that there was a pine tree at or near this intersection. There is none. The hot springs lie approximately 5 miles east of this intersection.

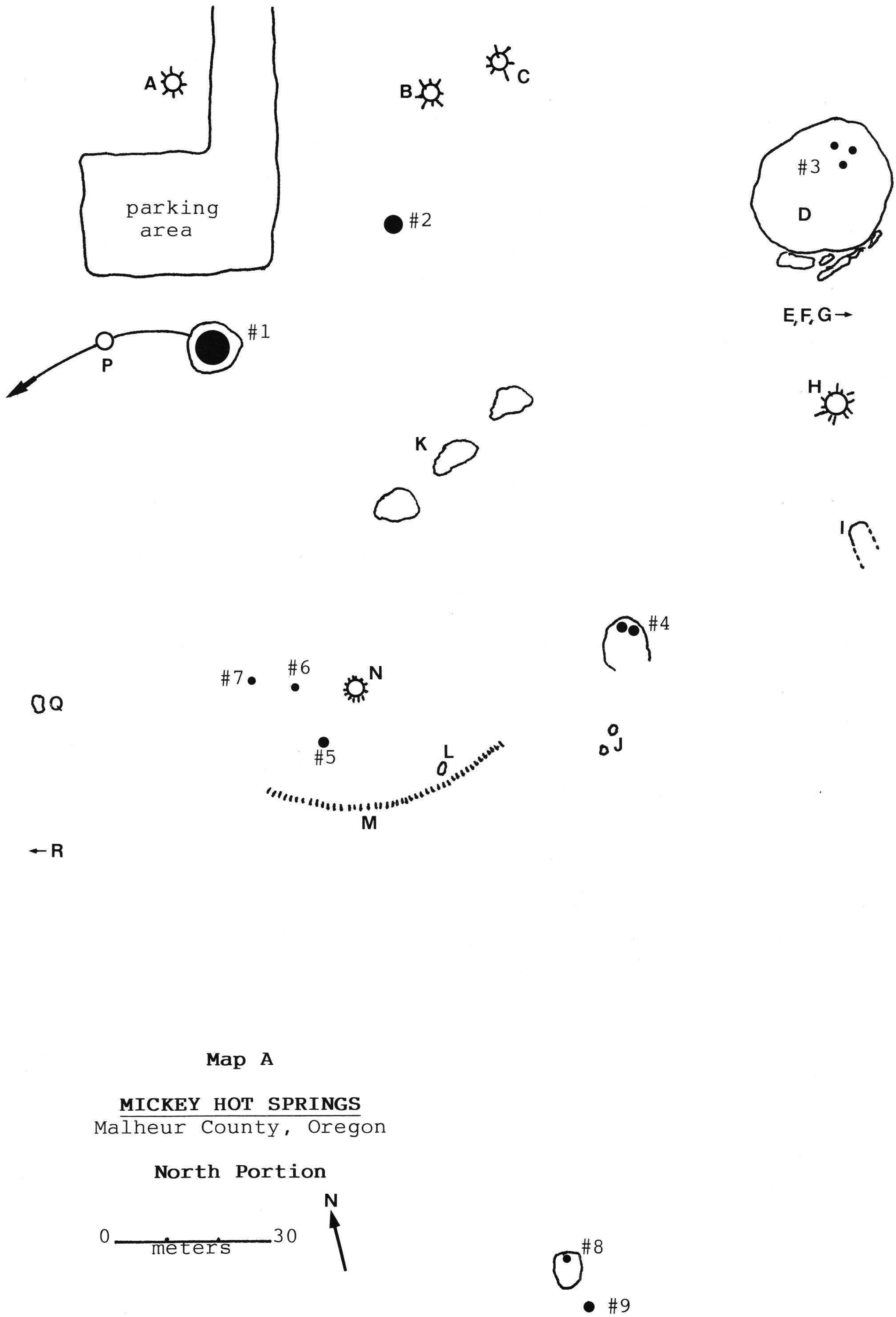
The county road continues south past the Alvord Desert and Alvord Lake, reaching the road to Frenchglen after another 33 miles. Still further south is the tiny settlement of Fields and then, just across the Nevada border, Denio.

The town of Frenchglen contains a few small service businesses such as a grocery and gas station, and it serves as the access point to the Steens Mountain region, a national scenic area proposed for national park status.

A complete spectrum of services is available in the city of Burns. The BLM's Burns District Offices (maps and other information available) are in Hines, adjacent to Burns.

Note that the map here and most highway maps indicate that the road which passes the Mickey Hot Springs continues eastward to an intersection with U.S. Highway 95 at a spot just three miles south of Burns Junction. Rumor has it that this is not a good route, but rather that a portion of it is exceedingly rough and distinctly four–wheel drive only.





Map A

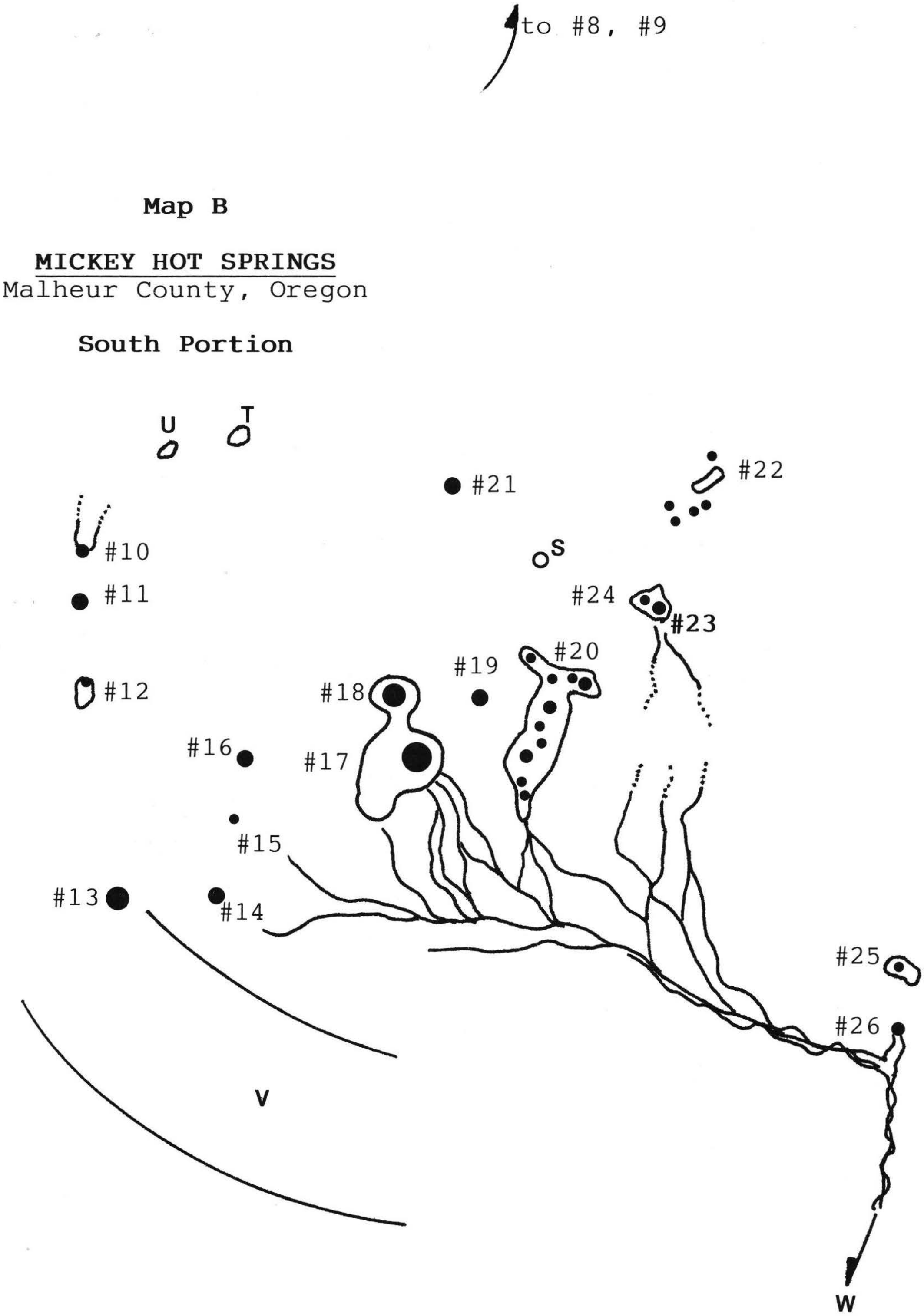
MICKEY HOT SPRINGS
Malheur County, Oregon

North Portion

Map B

MICKEY HOT SPRINGS
Malheur County, Oregon

South Portion



The Discovery of Kamchatka's "Valley of Geysers"

A Narrative By
Dr. Tatyana I. Ustinova

Introduction

The following narrative was prepared by Dr. Tatyana Ustinova in preparation for the talk she presented to a group of GOSA members in Yellowstone on July 25, 1992. The original hand–written text was rewritten and edited by T. Scott Bryan and then reviewed by Dr. Ustinova, who has given her permission for this publication.

I was the geologist in Kronotsky Nature Preserve. My husband and I arrived there in 1940.

It is hard to believe that at that time the Kamchatka Peninsula had no topographical maps. The shape of the peninsula was very well known, and its shoreline was accurately mapped for navigational needs. On the maps were shown the mouths of rivers, but not their routes. The positions and heights of volcanic mountain tops had been calculated and put on maps at the beginning of the century by a member of the big Russian Geographical Society expedition. At that time he was a university student and later became a member of the Academy of Sciences and the head of its geodesic laboratory.

At some places on the peninsula were oil expeditions. They made maps of comparatively small areas at a big scale. There were also such maps showing the areas around towns and the biggest settlements. But all the maps of the peninsula were drawn like a lace, with the rivers running straight, from the tops of the mountains to the ocean shores.

The territory of the Kronotsky Preserve had no map. My task was to make a list of all the interesting places in the preserve, and to show them on a map which I was to do myself. It wasn't truly a map, of course, but a sketch.

In that first summer, in 1940, we organized an expedition to the volcano Uzon. Famous volcanologist B. Peep had worked there in the Thirties. I had known his very interesting work and wanted to see this unusual place myself. Our expedition took 1 1/2 months.

Mount Uzon has a big caldera with many hot springs, mud pots, little mud volcanoes, and warm lakes, but it has no geysers. It also has a big lake, the remnant of a lake that once covered all of the caldera floor in the past. Now the water makes a way through the lowest wall of the caldera and forms a river. This river had no name and nobody knew its route to the Pacific Ocean. It was supposed that it was the river named Teekhaya (Slow).

The south border of the preserve was by the River Shumnaya (Noisy). On the sketch map made by Peep, it was shown between two volcanoes: Uzon and its southern neighbor Semyatchik. Thermal springs were supposed to be absent in this area, but I wondered. The Shumnaya never froze in the winter. Its water is very clear and has an unusual light blue-green color common to the mineral water of hot springs. I thought that maybe it began in the Caldera Uzon, or that it had some big hot springs somewhere in its valley. I decided to investigate the Shumnaya Valley in the spring, when the snow is harder than is the fresh snow of winter and it is better for a dog sledge. Also the thick spring snow covers the bushes which make it difficult to move on the mountain slopes, and the days are longer and give more time for work.

On this expedition I was with a preserve worker, Krupenin, a native man born on Kamchatka. He was a dog sledge driver and hunter. After this journey he became my true friend and good helper.

We started on April 7, 1941. We slowly moved along the ocean shore. First we discovered that between the Caldera Uzon and the ocean shore is a mountain range, and it is impossible for a river to flow from the caldera straight southward to reach the ocean. All the rivers on the flat area along the ocean began on the ocean side of this range, which is part of the Volcano Kikhpinich. The water of these rivers is not clean blue-green but muddy and brown.

Then we went to the Shumnaya. Near its mouth was a little hut where we left some of our load before going up the river. Movement in the valley's bottom became impossible very soon as the river flow shifted from one side to the other and left no room for us. We had to go up from the valley floor before the slopes would become too high for us.

We went up a gentle slope of the Volcano Semyatchik along the Shumnaya Valley and reached the place where the main valley turned northward to Caldera Uzon. This way took us all day long. We made a camp among low birch trees near the upper border of the forest. The next day, April 17th, we left our camp and the dogs, sledge and tent at 5 o'clock in the morning to investigate the Shumnaya Valley. We descended into the valley by a very steep slope about 300 meters or more high. We went by ski on the valley bottom until that was not possible, then left our skis and continued on foot. It was a very hard way. The snow was up to our knees and higher. We went by the steep snowy slope and below us were the waves of the rapid mountain river.

On the other side of the river we saw a little spot some meters long, without snow and with some little hot creeks. In the East Kamchatka we see such little hot springs in the river valleys very often. It wasn't what we looked for. Suddenly we saw a big cloud of steam farther up the valley behind a turn. We went as fast as we could, but after some turning we saw nothing new. There must be big hot springs, but where are they?

It was 2 o'clock. We had been away from camp for nine hours and had to return this day. We were tired and hungry. We had some biscuits and chocolate with us, so we decided to eat something before returning. With difficulty, we sat on the snowy slope to rest. In front of us on the other side of the river was a little light steaming area without snow and with a little hot creek. Very common. We found no big hot spring that could give a cloud of steam, and we felt very disappointed at our expectations.

Suddenly from the little warm spot across the river shot a column of boiling water with a cloud of steam. It roared loudly and shot right on us. We were terribly frightened and did not know what to think or where to run. You must understand— we were between two active volcanoes and maybe this was the last hour of our lives!

But as suddenly as it began, it ended. The roar stopped, the water column vanished, and only light steam rose above the little hot spot. It was like a mirage. And then I shouted: "It is a geyser!" I knew that there were no geysers on Kamchatka and in fact none on all of the Eurasian continent. But now we had seen one. It was fantastic and very exciting.

It was not easy to reach that hot spot. The Shumnaya was not a small river and it takes time to find a ford. Going to the hot place on the other side of the river, we crossed a little shallow river of warm water. It was 28°C in its mouth and of course must have had big hot springs in its valley. This was the river that I would later name the Geysernaya, but we had no time to investigate it on this trip. We went to our unexpected geyser.

We watched three cycles of the geyser's work (fountaining for 3 minutes and resting for 45 minutes), measured its temperature as 97°C, described what we had seen, drew a map of the area, and took some water for analysis. We were looking for hot springs, so we had sample bottles with us. It took us over two hours, and only about 4 o'clock did we begin our way back to camp.

The weather became worse. The sun hid and clouds covered the higher ridges of the valley. Our way back was faster. We found our skis and ran as we could, but when we clambered out of the valley onto its edge we saw that there was a snow storm.

We could not see more than three meters. In the wind and snow we lost any orientation. We knew that near to us was a precipice about 300 meters high, but we couldn't see it. What were we to do? We found a big snow hill, dug a cave into it with our skis, and hid there. At first it seemed warm after being in the severe wind, but not for long. We lay on our skis and shivered all night. We had only light dress because it had been a nice warm day.

When the next day broke, we crawled out of our cave and saw that the storm had not stopped. We couldn't find our camp. We went down the slope toward the ocean shore to find the hut at the mouth of the Shumnaya, and from there we would try to find our camp. Our descent was very hard. The fresh snow was soft and wet, and stuck to our skis. When we finally came to the hut we were exhausted, hungry and tired. We had left some of our food in the hut, so we could eat a little before falling to sleep.

After a little rest, Krupenin went out to try to find the dogs and camp. But he didn't. He came back at night. He was exhausted again and had injured his leg by falling into a creek hidden under the snow. All the next day, April 19th, we searched for the camp and dogs, and only finally found them in the evening. The dogs hadn't eaten for three days.

When we returned home from the expedition, I wrote a little article about our discovery for Kamchatka's paper.

In the summer of 1941, I and Krupenin went to investigate the warm river we had found near the geyser. We had one horse with our equipment and went by foot. The long, unknown and hard way to that river took us ten days. Now a helicopter flies the route in 20 minutes. First we couldn't descend the steep slopes into the valley with the horse, but finally we made a trail in the snow covered steeper upper slopes and cautiously led the horse down. Krupenin carried our equipment on his shoulders.

The valley turned out to be wonderful. We found 20 big geysers there along with an uncountable number of little ones, many hot springs and steam jets. We named the river the Geysernaya, the "Valley of Geysers" in English. We named all the main geysers, watched them, described them, and made a sketch map of the valley.

The snow on the slope above melted and became smaller every day. But we had to make our way out before the snow vanished because it was our trail, so we stayed in the valley for only four days. On the way home bad weather with thick fog trapped us in the mountains for a week without food. They were hard days, but not as hard as in April.

When we returned home we learned that the war [World War II] had begun. I was fired from my job at the preserve because of a lack of money. That was not the time to think of geographic discoveries, but I returned to work in the Kronotsky Preserve in 1946. After 1947, I was in the Valley of Geysers in 1951 and 1979.

Why were the geysers not found until 1941? The Valley of Geysers is a hidden part of the Kronotsky Preserve, which is a portion of the very rugged eastern volcanic mountain range of Kamchatka.

The preserve was known for many years as a place to hunt sable, little animals the size of a cat with precious fur. At the end of the 18th Century the amount of sable went down because of overhunting. The hunters then decided that the area around Kronotsky Lake, in the middle of the present preserve, had to become a protected place in order to save the sable. Nobody dared to hunt there. The law was a severe one: if a hunter was seen coming from the preserve with pelts, he was killed.

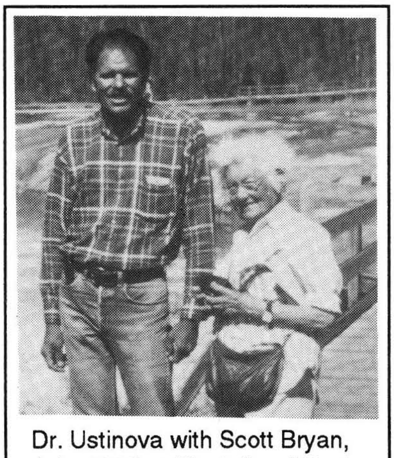
So the sable lived safely and increased in numbers. They started to leave the preserve where hunters could take them. Later, in this century, the sable's preserve became the Kronotsky National Nature Preserve.

Hunting sable is hard work. The hunting areas are far from any settlement. Hunters go into the area in the summer, carrying food for themselves and dogs by horseback. Then they return in the winter by dog sledge and hunt until spring, when they return home to sell the pelts.

Sable live in the forest. But near the Geysernaya River there is no forest. Nobody was curious enough to investigate the area in the middle of high mountains and deep valleys without forest. It was completely unexplored.

No scientific expedition had time to descend into the deep valley, either. The Geysernaya Valley cannot be seen from Caldera Uzon, where Peep had worked in the 1930s, so if somebody had seen the steam clouds that mount from the valley, they would have thought it was from a big fumarole at the foot of Volcano Kikhpinych. So the hidden valley stayed unknown until 1941. In 1943, a geodetic survey mapped Kamchatka at a scale of 1:200,000, and then of course the geysers would have been found.

Татьяна Устйнова
Tatyana Ustinova
July, 1992



Dr. Ustinova with Scott Bryan, July, 1992 at Black Sand Basin.

Anticipated Contents
The GOSA Transactions, Volume V, 1994

Volume V of *The GOSA Transactions* will be issued in early 1994. Works already known to be in progress for this volume include (with all titles and contents tentative at this time):

Plume Geyser— Comparisons Between the Activity in September, 1992 With That of 1993
Ralph C. Taylor

Observations on the Activity of the "Gizmo Geyser Complex"
Barry Schwarz

The Sawmill Geyser Complex
Mary Beth Schwarz

Fountain Group Activity During Summer, 1991— A Series of Related Articles:
- Fountain Geyser
- Jet Geyser
- UNNG–FTN–2 ("Super Frying Pan")
- Spasm Geyser
- Clepsydra Geyser
- Twig Geyser
- "Bearclaw" Geyser

Lynn Stephens

The Kaleidoscope Group— Activity from 1989 through 1991
Mike Keller

Veteran Geyser, Norris Geyser Basin
Ralph C. Taylor

The History and Current Activity of the Crystal and "Champagne" Cold–Water Geysers, Utah
Clark Murray

Geyser Activity at Nakama Springs, Savusavu, Vanua Levu, Fiji
T. Scott Bryan

Geyser Activity in New Zealand, 1993
T. Scott Bryan

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Researchers are encouraged to produce articles for *The GOSA Transactions* , Volume V. Please advise the Senior Editor as to article topic and anticipated length at the earliest possible date. The deadline for article submissions will be announced in "The Geyser Gazer SPUT" newsletter, but will not be later than December 1, 1993. Submissions received unannounced or late in the year may be delayed to Volume VI, the publication of which will probably not occur until 1995.

GOSA Transactions
Volume IV, 1993

The Geyser Observation and Study Association

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