GOSA TRANSACTIONS

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Volume I, 1989

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**The Geyser Observation
and Study Association**

(continued on inside back cover)

(continued from outside back cover)

Geysers Active in 1988
Yellowstone National Park

compiled by T. Scott Bryan

On the following pages is a list of the geysers known to be active during 1988. The sources of this information are varied. Most is based on my own observations during July, but much information was garnered from the Visitor Center logbook and via verbal and written communications with others. I claim the compilation of the list only, and offer my thanks to all who contributed.

The list is organized geographically, by geyser basin and then by recognized group within each basin; within each group, the springs are listed in an approximate along-the-trail order.

Some of the names are followed by an asterisk (*). This indicates that some sort of new or unusual activity was noted in these springs, and that further information about this can be found in the pages following the list.

The number of geysers in Yellowstone is impressive. Many were surprised in 1987 when my list of active geysers reached 391, miscellaneous small backcountry areas not included. I was surprised, too, yet this year the number is 445 active geysers. Furthermore, this number must be taken as minimal, as a number of areas (notably West Thumb and Heart Lake) were not thoroughly observed because of the lack of time and the forest fire situation.

For comparison, the numbers are:

Area	1987	1988
Upper Geyser Basin	155	185
Midway Geyser Basin	18	17
Lower Geyser Basin	92	107
Norris Geyser Basin	22	29
Gibbon Geyser Basin	12	17
West Thumb Geyser Basin	12	8
Lone Star Geyser Basin	12	6
Shoshone Geyser Basin	34	42
Heart Lake Geyser Basin	34	(34 est.)
Annual Totals	391	445

Geysers Active in 1988

UPPER GEYSER BASIN

Old Faithful Group-- (2 geysers)

Old Faithful
UNNG "Teapot"

Geyser Hill Group-- (40 geysers)

Bronze Spring
Silver Spring
Cascade
Little Squirt
(Little) Anemone
(Big) Anemone
UNNG below Anemone*
Plume
Beehive's Indicator
Beehive
Depression
UNNG-GHG-3 (4 geysers)
Arrowhead Spring*
UNNG next Pot O' Gold*
Little Cub
Lion
North Goggles
UNNG east of Lion
UNNG-GHG-5
Beach Spring
Aurum
UNNG-GHG-6
UNNG-GHG-7
UNNG north of Doublet
Sponge
Pump
Plate
UNNG near Plate*
Vault
Giantess
Mottled Pool.
Dome
Model
UNNG near Model
Roof
UNNG-GHG-9
Solitary

Castle and Grand Groups-- (32 geysers)

Sprinkler
Castle
"Castle's Vent" ("Gizmo")
Tortoise Shell Spring
Crested Pool
Terra Cotta 'A'
Terra Cotta 'B'
Spanker
South Scalloped Spring*
Deleted Teakettle
UNNG near "Frog Pond"*
Churn
Uncertain
Sawmill
Tardy
"Twilight Spring"
Penta
Spasmodic
Oval Spring
Old Tardy
Crystal Spring Geyser
Bulger
Rift
West Triplet
Grand
Turban
Vent
Shoe Spring*
UNNG Bush area
UNNG "Upper Orange"
Pulsar Spouter
UNNG Orange Spr Gp

Giant Group-- (17 geysers minimum)

Oblong
Middle (East) Purple Pool
Giant*
Mastiff
Catfish
Bijou
"Platform Geysers" (10 geysers)
Giant Group #1 of Peale, 1878*

Round Spring Group-- (2 geysers)

UNNG-RSG-1
UNNG-RSG-2

Daisy Group-- (10 geysers)

Bank
UNNG-DSG-1
Radiator
"Bonita's Sputs"
Daisy
Comet
Brilliant Pool
Splendid
Mud Pool
Pyramid

Punch Bowl Group-- (2 geysers)

UNNG next Punch Bowl*
UNNG-PBG-2

Grotto Group-- (11 geysers)

UNNG-GRG-1 ("Variable Spring")*
Grotto
UNNG ("Central Vents")
Rocket
Indicator Spring*
Grotto Fountain
South Grotto Fountain
"South South Grotto Ftn"
Spa
UNNG ("Connector")*
Riverside

Chain Lakes Group-- (5 geysers)

Culvert
UNNG ("Persistent Spring")*
Square Spring
UNNG beyond Square Spring
Link (minor)

Morning Glory Group-- (3 geysers)

Fan
Mortar
(East) Sentinel

Cascade Group-- (6 geysers)

Artemisia*
Atomizer
Slide
Sprite Spring
Seismic's Satellite
UNNG-CDG-1 ("Ocherous")

"Westside Group"-- (5 geysers)

Fantail*
Ouzel
UNNG-WSG-1 ("Sideshot")
UNNG-WSG-2 ("Bigfoot")
USGS YM-210 (markers)

"Old Road Group", Biscuit Basin-- (8 geysers)

Cauliflower
UNNG-ORG-1 (2 geysers)
UNNG-ORG-2
UNNG-ORG-3 ("Demise")
UNNG-ORG-4 ("Mercuric")
Rusty
Island

"Main" or Soda Group, Biscuit Basin-- (11 geysers minimum)

Jewel
Shell Spring
Silver Globe Spring*
Silver Globe "Cave"
Silver Globe "Slit"
Silver Globe "Pool"
Avoca
West (washed areas)*
East Mustard Spring
UNNG-BBG-2
Coral (subt.)

Black Sand Basin-- (8 geysers)

Spouter
UNNG near Cucumber
UNNG-BSB-1 (trailhead)
UNNG-BSB-1a
Cliff
Handkerchief Geyser
UNNG-BSB-2 ("B'walk")
Sunset Lake

Pine Springs Group-- (1 geyser)

UNNG-PSG-1

Myriad Group-- (18 geysers minimum)

UNNG near Basin Spring*
UNNG in N. Sister (?Mugwump)
UNNG beyond 3 Sisters (2 gey.)
West Trail*
UNNG near Bell (4 geysers)
Bell
Pit
UNNG pool near Pit
Strata
White
Spectacle
Abuse*
Other UNNG (2)

Pipeline Meadows Group-- (4 geysers)

Dilapidated*
UNNG-PMG-2
Pipeline Meadows Geyser
UNNG-PMG-4

Upper River Areas-- (no active geysers)

Total Observed Active Geysers, Upper Geyser Basin, 1988 = 185

Unusual Geyser Activity
Upper Geyser Basin -- 1988

compiled by T. Scott Bryan

The following brief notes discuss the activity of those features noted by asterisks after their names in the table of geysers active in 1988. Unnamed geysers are designated by "UNNG"; any numbers are from Bryan's The Geysers of Yellowstone, 1986 edition.

UNNG below Anemone-- This is an old vent in which there has been minor activity during prior years. During July 1988 it was a small but frequent and regular geyser. The greatest height of 1 to 2 feet was reached for a few seconds every few minutes.

Arrowhead Spring-- Whether Arrowhead ever actually erupted is questionable, but it definitely performed as an intermittent spring. Times of increased overflow were enough to flood the southeast side of the cone, killing plants and carving small channels. This activity began before late-May and continued at least into August.

In the same vicinity, the small vent just east of Pot O' Gold erupted in late July, and Heart Spring increased its discharge substantially.

UNNG north of Doublet Pool-- This small bubbling vent was active as an almost perpetual spouter throughout the summer.

UNNG near Plate Geyser-- This geyser played from a ragged vent just a few feet southeast of Plate. The eruptions were small and erratic, occurring in the first few days following the July 8 eruption of Giantess.

South Scalloped Spring-- Sometime during the spring a baby bison fell into South Scalloped. This induced some eruptions. Much later, during July, it reactivated weakly, with episodes of brief heavy discharge, strong bubbling, and a few splashes up to 1 foot high.

UNNG near Frog Pond-- "Frog Pond" is the pool with the railing along the boardwalk between Sawmill and Geyser Hill. Across the walk from it is a small spring which began intermittent action (in 1986?), at the same time the water level dropped in Frog Pond. This year this spring became a small geyser, playing often at the times of high water. I saw one splash at least 3 feet high.

Shoe Spring-- We'd all seen this without realizing it had a name. Shoe Spring is the unimpressive double spring between Grand and Economic in which a small opening drains a small flow into a larger vent. As seen by Keller, Moss, and Koenig, it erupted on August 21. Only three eruptions were seen. The largest reached 10 feet high at an angle, so that the play reached over the boardwalk and beyond to a total distance of more than 20 feet.

Giant Geyser-- As reported more fully elsewhere in this volume, Giant erupted twice during 1988, on June 28 at 2155 and on September 12 at 1846. The interval of 75d 20h 51m is the shortest since 1955.

With this activity were related eruptions by Catfish, Mastiff, Bijou, and numerous additional vents.

Giant Group #1 of Peale (1878)-- This deep old vent lies near the boardwalk part of the way from Giant towards Grotto. In the 1870s it was reported as a full pool with a scalloped rim. In 1988 it was positively shown to be affected by activity in the Giant Group, and on July 29 I found evidence (killed plants and washed areas within the vent) to indicate a weak, subsurface eruption.

UNNG next to Punch Bowl-- This oval spring immediately at the east base of Punch Bowl's cone has been known as an intermittent spring, but on two occasions during July I saw it erupt. The play was splashing only a few inches high, but it was distinct eruption occurring during each episode of intermittent overflow.

UNNG-GRG-1-- Referred to as "Variable Spring" in my paper elsewhere in this volume, but apparently also having an historical name, this spring near Grotto erupts to variable degrees dependent on the activity elsewhere in the Grotto-Giant Complex. At its best, it erupts muddy water with superheated bursting, reaching 3 to 4 feet high from a water level 1 to 2 feet below overflow.

Indicator Spring-- Also known as Grotto's Indicator and Grotto's Drain, this was reported by Marler to have rare eruptions. On at least two occasions (one observed) during July, it erupted. The one eruption that was seen involved splashes several feet high from a water level two to three feet below the crater rim. It lasted several minutes.

UNNG "Connector Spring"-- This is the pool to the east of the paved trail between Spa and Riverside. Although known to be somewhat variable in its water level and to also sometimes bubble weakly, this proved to be a geyser following Giant's eruption on June 28 and some of Grotto's long-mode ("marathon") eruptions. The play was of long duration (1+ hour). Splashes several feet high came from a nerly drained crater.

UNNG "Persistent Spring"-- Near Culvert Geyser, this breakout evidently marks the site of the spring which also appeared in 1954, that time opening a crater large enough to swallow a car on the edge of the road. The play is a nearly steady, somewhat cyclic bursting reaching 1 to 2 feet high.

(East) Sentinel Geyser-- In a fashion infrequently reported in the past, Sentinel had a series of major eruptions during late August. The intervals were around 10 minutes, durations of 1 minute and heights to as much as 12 feet at a sharp angle to the south.

Artemisia Geyser-- Although its eruptive activity was essentially unchanged, with intervals around 10 hours sometimes interrupted by minor eruptions, Artemisia did show a significant change in its refilling period. Instead of the usual 2 hours, the time before first overflow was as long as 5 1/2 to 6 hours. It is intriguing that there can be this great a change in refilling without any observable corresponding change in interval or duration.

Fantail Geyser and Ouzel Geyser-- Via the use of markers, Fantail was known to have had eruptions during the winter and early spring of 1988. Then, on August 16 it played at least three times. One eruption was seen, and was reported to have been fully as strong as those of mid-summer 1986.

Ouzel was irregularly active throughout 1988. Several eruptions were seen during early July, some of them reaching over 10 feet high.

<u>USGS YM-210</u>-- This is the southernmost spring of the "Westside Group." Noted on the USGS maps as YM-210 and as a dormant geyser, this spring produced significant washing in its runoff channels sometime in early July. Markers were subsequently washed away on two later occasions in July. Whether it actually erupted is unknown.

<u>Silver Globe Complex</u>-- This entire complex of springs was active. Virtually no time was spent observing them, but Silver Globe Spring, "Cave", "Pool", and "Slit" were all observed.

<u>West Geyser</u>-- West was not seen in action by any known observer. It definitely had some episodes of heavy overflow, and some washing in the uphill direction indicated possible eruptions.

Nearby Seaweed Spring behaved as an intermittent spring.

<u>Myriad Group</u>-- Considerable change occurred within the Myriad Group during the winter of 1987-88, and some unusual action was still present this summer.

Near Basin Spring was a small geyser. Playing about 2 feet high from a muddy crater, it was persistent and showing signs of some permanence.

The water level dropped and the temperature rose in both Trail and West Trail Geysers. Only West Train erupted. Some of the early play apparently reached 6 feet high, but during the summer it was virtually perpetual and just 1 foot high.

In the vicinity of and including Bell, Pit, and Strata Geysers there was considerable action. A total of at least 8 geysers, mostly very small, were active during the winter. Strata was still active during July, and on July 11 I witnesses a single, first-known eruption from a small pool just south of Pit; it rreached about 4 feet for a duration of more than 30 seconds.

Spectacle had a few weak eruptions during the summer. Both it and Abuse had at least one major eruption in mid-winter.

<u>Dilapidated Geyser</u>-- One eruption by Dilapidated was seen by me on July 8. It was far weaker than those of 1980-82, reaching only 1 to 2 feet above the top of the cone and with minimal discharge. However, the use of markers indicated other, stronger eruptions both before and after this one. The active episode appeared to have ended by July 15.

MIDWAY GEYSER BASIN

Till	Pebble Spring	Rabbit Creek Geyser
UNNG-MGB-1	UNNG-MGB-4	UNNG NE Rabbit Creek
UNNG-MGB-2	(New) Catfish	UNNG Fracture area
UNNG-MGB-3	Flood	Opal Spring
River Spouter	West Flood	UNNG beyond West Flood (3 minimum)

Total Observed Active Geysers, Midway Geyser Basin, 1988 = 17

LOWER GEYSER BASIN

Great Fountain and White Creek Groups-- (12 geysers)

Firehole Spring	A-1*	Diamond Spring (?i.s.)
Great Fountain	A-2	UNNG-WCG-4
UNNG-GFG-1	Logbridge	Tuft/Crescent
A-0	Botryoidal	Spindle

White Dome Group-- (7 geysers)

White Dome	Crack	Tangled Creek area (1 geyser)
Gemini	Pebble	
UNNG near Gemini*	"Cave Spring"	

Pink Cone Group-- (9 geysers)

Pink Cone	Bead	Box Spring
Pink	Labial	UNNG below Labial
Narcissus	Labial's Satellites (2)	

Black Warrior (Firehole Lake) Group-- (5 geysers)

Steady	Artesia Spring
Young Hopeful	Primrose Spring (UNNG-FLG-1)
Gray Bulger	

Fountain Group-- (14 geysers)

UNNG-FTN-1	Fountain	UNNG-FTN-3*
UNNG south of Twig	Sub	UNNG-FTN-4 near FTN-3
Twig	Spasm	UNNG pool to west*
Jet	Clepsydra	UNNG near above
UNNG-FTN-2 ("Super F.P.")	New Bellefontaine	

Kaleidoscope Group-- (7 geysers)

Kaleidoscope*	Deep Blue	Honeycomb
UNNG-KLD-1 ('66 blowout)	"Deep Blue's Satellite"	Honey's Vent
(Kaleidoscope) Drain		

Sprinkler Group-- (13 geysers minimum)

Ferric	"New Angle"	Earthquake (minor)
Bridge	Sprinkler	UNNG (6 minimum)
"Vertical Angle"	West Sprinkler	

Thud Group-- (4 geysers)

Thud (?washed areas)	UNNG near Stirrup Spring (2 geysers)
Kidney Spring	

Culex Basin and Morning Mist Group*-- (12 geysers minimum)

Porcupine Hill Geyser	Culex Basin #19
Morning Mist	Culex Basin #26
Geyserlet	Culex Basin #32
Paperiello #10	Culex Basin #34
Paperiello #17	Culex Basin #38
Paperiello #35	Culex Basin #42

River Group-- (12 geysers minimum)

UNNG-RVG-4 near Azure	UNNG "Rocco's Slit"	UNNG ("Brain")
Bath Spring	UNNG "Rocco's Pool"	UNNG ("Blurple")
Pocket (Basin) Geyser	UNNG upper east area	UNNG-RVG-1
UNNG in meadow	Fortress	Mound

Fairy Creek Meadows Groups-- (5 geysers minimum)

Paperiello #18	Paperiello #27 ("Tremor Spring")
Paperiello #19	Paperiello #29 ("Rhinoceros Spring")
Locomotive Spring	

Imperial Group-- (2 geysers)

Imperial	Spray

Sentinel Meadows Group-- (5 geysers)

Iron Pot	Rosette
Steep Cone	UNNG (2 geysers)

Total Observed Active Geysers, Lower Geyser Basin, 1988 = 107

Unusual Geyser Activity
<u>Lower Geyser Basin -- 1988</u>

compiled by T. Scott Bryan

<u>A-1 Geyser</u>-- This spring might have had a brief active episode during May or early June. One eruption was reported by Bob Hoffman as being distinctly different from an eruption of A-2; he did not have a clear view from his position at Great Fountain, but this can probably be accepted as a reliable report. It would be the first activity by A-1 since the 1970s.

<u>UNNG near Gemini Geyser</u>-- Along with the cyclic activity by Gemini, Crack, and Pebble Geysers was action from a small hole a few feet east of Gemini. This has acted as a minor drain for some of Gemini's water in the past. During July 1988, during the interval between an eruption of Gemini and one of Crack, this vent sometimes (definitely not always) erupted. Whenever seen, the duration was only a few seconds. The height was about 2 feet of sputtering play.

<u>UNNG near Twig Geyser</u>-- The pair of vents between the boardwalk stairs and Twig were seen to simultaneously erupt on several occasions. There seemed to be no clear correspondence between this action and that occurring elsewhere within the Fountain Group.

<u>UNNG-FTN-3</u>-- This geyser on the valley floor south of the Fountain Group was frequently and vigorously active. Some of the intervals were as short as 12 minutes. The maximum height of 40 feet was held for only the first few seconds of a 1 minute eruption.

As has been suspected, there is a second geyser in this area. About 30 feet southwest of FTN-3, this "FTN-4" played less frequently with a bursting action reaching about 10 feet high.

<u>New UNNG west of Fountain Group</u>-- On July 24 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 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 around 20 seconds. the greatest height was probably 4 feet.

Kaleidoscope Group-- I hope, but doubt, that somebody will be in a position to write a detailed account of the 1988 activity in the Kaleidoscope Group. Every known geyser plus one new one was active.

Frequent and erratic exchanges took place between Kaleidoscope (40 feet), Drain (25 feet), and "1966 Blowout" (40 feet).

Deep Blue was active throughout the season. Some of its frequent bursts reached between 20 and 30 feet.

"Deep Blue's Satellite Vent" deserves a more proper name. Although mostly active apparently as a perpetual spouter, the fact that it did stop and restart several times indicates that it is a geyser. The eruption was steady jetting at an angle, reaching up to 50 feet high.

Honeycomb was known to have infrequent but tremendously powerful eruptions. The heights may have reached 100 feet. And Honey's Vent was nearly perpetual, but had some bursts to near 25 feet.

Culex Basin and Morning Mist Groups-- This area was examined carefully for geyser activity. Although most are very small, I am confident that at least five geyser in the Morning Mist Group and six geysers in Culex Basin were active during 1988.

NORRIS GEYSER BASIN

Porcelain Basin-- (12 geysers minimum)

UNNG behind Congress Pool	UNNG east of Sunday	Lava Pool Complex (1)
Blue	Little Whirligig	Dark Cavern
Iris Spring	(Big) Whirligig	Guardian
Primrose Springs (1)	Splutter Pot	Valentine

Back Basin-- (17 geysers)

Minute	UNNG near Double Bulger	Puff-N-Stuff
Palpitator Spring	Dabble	UNNG near Mud Spr.
Rubble	Orbicular	Echinus
Veteran	Hydrophane Springs (1)	Steamboat (minor)
UNNG below Tantalus bridge	Big Alcove Spring	Steamvalve Spring
Vixen	Medusa Spring	

Active Geysers, Minimum Total, Norris Geyser Basin, 1988 = 29

GIBBON GEYSER BASIN

Artists Paint Pots-- (1 geyser)

UNNG-GIB-2

Geyser Creek Springs-- (15 geysers)

UNNG ("Entry Pool")	UNNG blue mud pot	UNNG upper flat
UNNG large sinter pool	UNNG north of Bat Pool	Oblique
"Formicary" (ex-"Anthill")	Bat Pool	Big Bowl
UNNG lower flat (2 minimum)	Tiny	Other UNNG (3)

Gibbon Hill Groups-- (1 geyser)

Gibbon Hill Geyser

Total Observed Active Geysers, Gibbon Geyser Basin, 1988 = 17

SHOSHONE GEYSER BASIN
compilation by Rocco Paperiello

Little Giant Group-- (6 geysers)

Trail	UNNG N of Little Giant	Meander
"Horse Trail Spring"	Double (The Pirates)	Locomotive

Minute Man Group-- (10 geysers)

Spouter below Bl. Sulphur	Little Bulger (2 vents)	Shield
USGS #15	USGS #11	Minute Man
Soapkettle	USGS #12	Minute Man's Pool
	Gourd	

Orion Group-- (3 geysers)

Taurus	USGS #86	UNNG near USGS #86

Camp Group-- (2 geysers)

UNNG near USGS #119	Geyser Cone

Island, Lake and Shore Groups-- (no geysers seen)

West Group-- (4 geysers)

USGS #136 ("Pecten")	UNNG next to USGS #135
USGS #160	USGS ?162

South Group-- (3 geysers)

Outbreak	UNNG (?Wave Spring)	Flake Spring

North Group-- (14 geysers)

Fissure Spring	Velvet Spring	Frill Spring
USGS #58	Small	Lion
Yellow Sponge Spring	USGS #52	UNNG near Lion
Brown Sponge Spring	Knobby	Iron Conch
USGS #64	Mangled Crater Spring	

Total Observed Active Geysers, Shoshone Geyser Basin, 1988 = 42

OTHER GEYSER BASINS

The three remaining geyser basins either were not visited or were given only passing observation during 1988. Accordingly, the numbers of active geysers in each area is approximate and intended to be minimal.

Minimum Known Active Geysers, Lone Star Geyser Basin, 1988 = 6

Minimum Known Active Geysers, West Thumb Geyser Basin, 1988 = 8 (includes Potts Basin)

Total Presumed Active Geysers, Heart Lake Geyser Basin, 1988 = 34 minimum

Activity in the Spectacle/Round Complex, Winter 1988/1989
Myriad Group, Upper Geyser Basin, Yellowstone Park, Wyoming

Mike Keller

An increase in activity of some features in the Spectacle/Round complex of the Myriad Group was observed beginning in early January 1989. Four previously inactive geysers reactivated and 2 new features were formed. This reactivation is believed to have been caused by a series of minor earth tremors felt at the Old Faithful area on December 29, 1988.

The first observed change was noted on January 3, 1989. A new geyser, later unofficially nicknamed "Squirtgun", was seen erupting in the run-off channel from Abuse. It erupted perpetually to a height between 2 to 6 feet. Abuse Spring and Spectacle Geyser were both also active, perpetually erupting to 3 feet. An unnamed geyser (UNNG#1) [see map] was observed erupting to 2 feet high at intervals of 3 to 8 minutes.

Sometime during the night of January 3-4 the energy shifted completely to Spectacle. On the morning of the 4th Abuse was 15 inches below overflow, Spectacle was surging and "Squirtgun" was erupting. During an increase in surging Spectacle erupted. The eruption lasted just over 2 minutes and reached between 15 and 20 feet high. After this eruption Spectacle completely drained but "Squirtgun" continued to erupt. A second eruption of Spectacle occurred after an interval of 3 hours and 2 minutes. It was similar to the previous eruption.

Spectacle, UNNG#1, and "Squirtgun" were still active on the morning of January 5. On the south side of "Squirtgun" two small geysers and other patches of hot ground were forming. Ground temperatures varied from 152°F to 187°F. The activity of Spectacle had not changed, UNNG#1 continued to erupt every 5 to 10 minutes up to 5 feet and "Squirtgun" remained active. There was no change in their activity until January 11.

When I arrived in the Myriad Group on January 11 the energy had shifted. Both Spectacle and "Squirtgun" were not erupting, and had cooled to below boiling. The unnamed spring between Round Geyser and Abuse Spring (UNNS#1) [see map], however, had increased in temperature. Round Geyser was having more powerful boiling within its crater then previously. Later that evening, from the service road, I witnessed an eruption of Round Geyser. The play was no higher than 20 feet, and lasted less than a minute. Due to the eruption on Round UNNS#1 became murky white from washed in gravel. UNNG#1 continued to be active. Round had one more eruption during the night of January 11 to 12. On January 12 the energy had shifted back to Spectacle. UNNS#1 declined in temperature by 10°F and remained murky. Except for January 15 Spectacle was active again until January 18.

From January 19 to 21 Round was again active. The play was similar to the previous active cycle. UNNS#1 rose in temperature again by 7°F and Spectacle, Squirtgun and Abuse cooled by 4°F. Another unnamed feature (UNNS#2), with a history of eruptive activity, located between Round and Myriad had up until this time showed an increase in temperature. During this cycle of activity from Round, however, its temperature dropped when Round was active and rose again when Spectacle was active. Furthermore, UNNG#1 became inactive when the energy shifted from Round to Spectacle. During the inactive periods the temperature of Round did not change, but the pool level fell about 3 feet.

Spectacle was active from January 23 to 27. Intervals and durations during this cycle were longer than in previous cycles. Intervals between eruptions averaged 3 hours 40 minutes and eruptions were 4 minutes in duration. The play was 10 to 15 feet high. UNNG#1 was active for a single day on January 26. On January 27 Spectacle was still active but "Squirtgun" stopped erupting and cooled by 3°F. When Spectacle was active without "Squirtgun" the hot ground behind "Squirtgun" also cooled.

Round had another active series from January 28 to February 1, with a break on January 30 when Spectacle was active. The same heat changes were observed in UNNS#1 near Abuse and UNNS#2 near UNNG#1, when the temperature of the first increased, and that of the second decreased. Between February 1 and March 19 Round was active only on February 7, 20, and March 8. Spectacle was not active on all the other days. During these times nothing is active except for "Squirtgun."

UNNG#1 had one more active cycle on February 10 and 11. The cycle was much weaker than previous cycles. Intervals were 22 to 38 minutes and the eruptions were no higher than 2 feet. All eruptions took place from a low water level. Since the dormancy of UNNG#1 a small feature has formed north of it. Its play is a small sizzling up to one foot high.

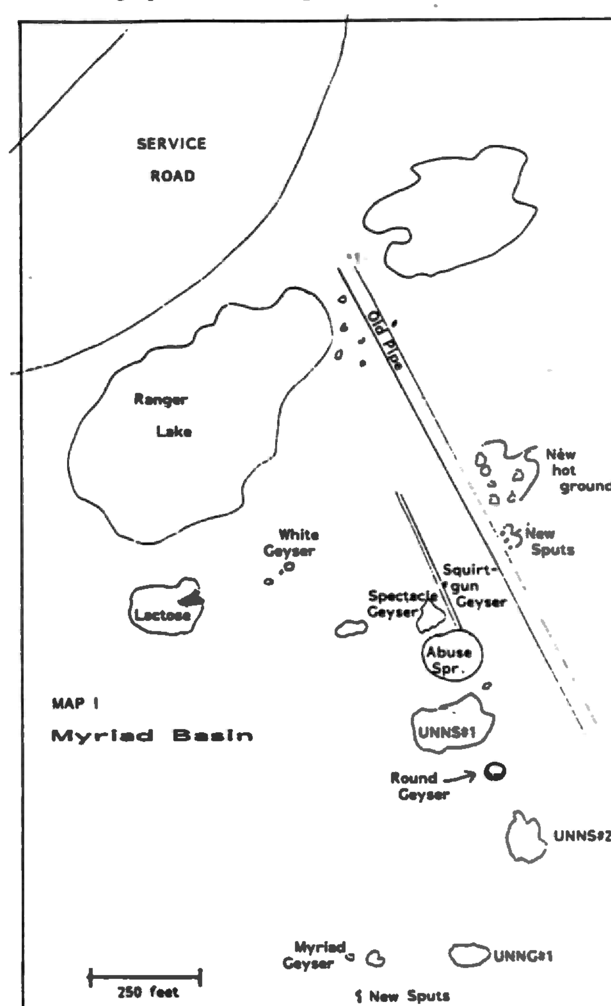

Table 1 - Myriad Group Temperatures
January 3 - March 16 1989

Date	Spect.	Squirt.	Abuse	Round	UNNS (1)	UNNS (2)	UNNG (1)
1/03	199 A	199 A	199 A	199	138	183	200 A
1/04	199 A	199 A	199 A	200	137	182	200 A
1/05	199 A	201 A	199 A	200	138	182	200 A
1/06	199 A	199 A	196	199	138	182	200 A
1/07	199 A	199 A	197	199	137	183	200 A
1/08	199 A	199 A	195	200	135	183	200 A
1/09	199 A	199 A	195	199	138	183	200 A
1/10	199 A	199 A	195	199	138	183	200 A
1/11	196	199	194	199 A	142	184	200 A
1/12	199 A	199 A	198	199 A	132	185	200 A
1/13	199 A	199 A	195	199	134	184	200 A
1/14	199 A	199 A	196	199	135	186	200 A
1/15	198	200 A	196	199	135	185	200 A
1/16	199 A	199 A	196	199	137	185	200 A
1/17	199 A	196	197	200	137	179	200 A
1/18	199 A	195	196	200	138	178	200 A
1/19	197	193	196	201 A	145	178	200 A
1/20	197	192	196	201 A	141	180	200 A
1/21	197	196	196	200 A	142	180	200 A
1/22	198	198	197	200	136	177	200
1/23	199 A	198	197	200	137	178	200
1/24	199 A	199 A	197	200	137	177	200
1/25	199 A	199 A	196	200	138	177	200
1/26	199 A	199 A	193	199	138	176	200 A
1/27	199 A	196	195	200	140	177	200
1/28	197	192	196	202 A	144	177	200
1/29	198	193	196	201 A	148	177	200
1/30	199 A	198	197	199	141	177	200
1/31	197	198	197	200 A	144	176	200
2/01	197	199	197	201 A	145	175	200
2/02	198	199 A	197	200	140	176	200
2/03	199 A	199 A	197	200	138	173	200
2/04	199 A	200 A	196	200	137	174	200
2/05	199 A	200 A	196	200	137	175	200
2/06	199	200 A	196	200	137	170	200
2/07	199	200 A	196	201 A	142	168	200
2/08	199 A	200 A	197	200	139	170	200
2/09	199 A	200 A	196	200	136	174	200
2/10	199 A	200 A	195	200	138	173	200 A
2/11	199 A	200 A	196	200	138	179	200 A
2/12	199	199	193	200	138	180	200
2/13	198	195	192	200 A	144	177	200
2/14	-	-	-	-	-	-	-
2/15	-	-	-	-	-	-	-
2/16	- A?	- A?	-	-	-	-	-
2/17	199 A	200 A	194	201	138	170	200
2/18	199 A	199 A	195	199	139	171	200
2/19	199 A	199 A	193	199	137	172	200
2/20	199	200 A	195	199 A	146	174	200
2/21	199 A	200 A	192	199	154	163	200
2/22	199 A	199 A	191	199	150	170	200
2/23	199	199 A	192	200	147	171	200
2/24	198	199 A	194	200	144	174	200
2/25	199 A	197	193	200	140	175	200
2/26	199 A	196	194	199	140	177	200
2/27	199	200 A	192	200	139	176	200
2/28	199	199 A	194	200	139	175	200 A
2/29	199	199 A	194	200	139	175	200 A
3/01	199 A	199 A	195	200	140	174	200 A
3/02	199 A	199 A	195	200	141	176	200
3/03	199	199 A	193	200	143	171	200
3/04	199 A	199 A	194	200	144	172	200
3/05	199	199	194	200	144	173	200
3/06	199	199	195	200	146	173	200
3/07	199	199	195	200	147	175	200
3/08	199	199	194	200 A	149	170	200
3/09	199	199	195	200	132	171	200
3/10	199	199	195	200	133	172	200
3/11	199	199	192	199	134	175	200
3/12	199	199 A	192	200	134	177	201
3/13	199	199 A	194	200	135	177	201
3/14	199	199 A	195	200	134	176	201
3/15	199	199 A	196	200	135	176	201
3/16	199	199 A	197	200	135	178	200

All Temperatures are in degrees Fahrenheit.
"A" specifies that feature was active as a geyser on said date.

Diurnal Activity of Beehive Geyser

H.Koenig

Abstract: Since 1985, Beehive Geyser, located in the Upper Geyser Basin of Yellowstone National Park, has shown a remarkable tendency to only erupt during daylight hours. The observations of 1988 are discussed in detail, with a examination of the alternate hypothesis, that most nighttime eruptions were missed. Some speculation on the cause of this activity is given.

Location and Setting

Beehive Geyser is located on the southern side of Geyser Hill in the Upper Geyser Basin. Beehive is a cone-type geyser, about four feet (1.3m) high, sitting on a large, flat shield of sinter. With an altitude of ≈7342ft (2207m), it is the lowest spring on Geyser Hill [Muffler, et.al. 1982].

Activity during the 1980s

During 1981 through 1984, when Beehive's intervals were consistently regular, it was possible to infer missing eruptions by gaps in the data.

Table 2 shows the result of comparisons between the data for the years presented in *Table 1*. Listed are the probability values for the $\chi 2$ test results. The values in bold-face are those which could have occurred solely by chance: The smaller the number, the less likely the two years are similar. Because of a lack of data, comparisons with the years 1985-1988 used the grouped nighttime categories of *Table 1*.

The correlations in this table confirm what a simple visual inspection of *Table 1* shows: that the years can be divided into two distinct groups: 1981-1984 and 1985-1988.

The data for 1982 needs some remarks. During that year, the general feeling was that Beehive was erupting about twice a day, and that many nighttime eruptions were being missed. This was probably true, since the observed intervals and averages compare with the other years of its group. There is some evidence in the data, however, that may support the possibility that these eruptions did not occur, and that 1982, therefore, should be grouped with 1985-1988.

Detailed analysis of 1988

During the period of 01May1988 to 31Aug1988, the eruption intervals exhibited a remarkable bimodality resulted in nearly every observed eruption occuring between 11:00 and 18:00. There was very little tailing off, with only eight eruptions observed in the two hours preceding or following this interval.

The observed eruption intervals fall nicely into two distance classes: a "short" interval class and a "long" interval class. The shortest interval, of 15h07m, took place three days after an eruption of Giantess, and was probably an effect of that eruption[Marler 1973]. The second shortest interval was 20h05m.

The question arises then, is this tendency for daylight only eruptions an artifact of the data? Or is it because nighttime eruptions were not being observed?

It is well known that for several hours after an eruption of Beehive, the cone appears dry and whitish. Once Beehive begins splashing and surging, the wetted cone then turns gray. Between the hours of 06:00 until 21:00, it daylight and there are usually a few observers about. So if eruptions were not being observed, then they

Time of Day	1981	1982	1983	1984	1985	1986	1987	1988
0:00	6	5	6	7	0	0	0	1
1:00	2	1	7	9	1	4	0	0
2:00	4	2	3	2	0	1	0	0
3:00	1	4	4	11	1	3	0	0
4:00	3	1	3	10	0	0	0	0
5:00	4	2	4	6	0	2	0	0
6:00	5	2	8	9	0	1	0	0
7:00	7	8	7	17	1	1	0	0
8:00	5	3	9	12	1	2	1	0
9:00	11	7	13	7	2	6	1	2
10:00	10	19	8	8	6	14	4	10
11:00	18	12	12	14	14	16	5	10
12:00	11	21	10	10	10	13	8	10
13:00	6	8	12	11	14	12	5	13
14:00	12	12	6	10	14	13	4	16
15:00	9	11	15	16	15	7	4	17
16:00	9	8	10	14	6	8	5	7
17:00	11	6	6	10	2	8	1	4
18:00	10	5	7	6	1	6	1	2
19:00	8	8	7	7	0	0	0	1
20:00	4	2	3	12	1	2	0	0
21:00	6	1	4	7	1	2	1	1
22:00	3	2	5	10	0	0	0	1
23:00	4	7	3	9	1	0	1	0
Σ0-8	42	28	51	83	4	15	1	1
Σ18-23	35	25	29	51	4	10	3	5
Missed		≥26	≥62	≥34	≥13	≥3	≥9	

Beehive Eruptions By Time of Day
Table 1

	1981	1982	1983	1984	1985	1986	1987	1988
1981	—	0.464	0.8106	0.0724	<0.001	0.009	0.0012	<0.001
1982	0.464	—	0.1084	0.0011	<0.001	0.3235	0.1419	<0.001
1983	0.8106	0.1084	—	0.6863	<0.001	<0.001	0.0011	<0.001
1984	0.0724	0.0011	0.6863	—	<0.001	<0.001	<0.001	<0.001
1985	<0.001	<0.001	<0.001	<0.001	—	0.0638	0.8443	0.9201
1986	0.009	0.3235	<0.001	<0.001	0.0638	—	0.5739	0.0194
1987	0.0012	0.1419	0.0011	<0.001	0.8443	0.5739	—	0.841
1988	<0.001	<0.001	<0.001	<0.001	0.9201	0.0194	0.841	—

Probabilities Resulting from Contingency Analysis between Years
Table 2

should be occurring during the period between 21:00 to 06:00. Note that no explanation is given for the lack of observed eruptions between 06:00 and 11:00 as well as between 18:00 and 21:00. As the data shows, the number of observations, especially in the morning hours, drops abruptly.

If eruptions were missed, then how would this change the interval statistics? The average long interval was 43.6 hours. Assume that the missed eruptions must occur in the range of 22:00 to 06:00, when few observers wereon hand. There are two possible cases then: a longer than average "short" interval followed by a very short interval, or the reverse, the very short interval followed by the longer than average "short" interval. In either case, the shorter interval can be no longer than sixteen hours, otherwise the eruption would occur outside the supposed range. The longer interval would then be no shorter than 28 hours. This means that if a long interval is broken into two shorter intervals, both intervals fall well beyond the standard deviation from the mean for a "short" interval.

In addition, only one of these very short intervals was observed. If twenty very short intervals occurred only when an eruption took place during the early morning hours, then this too would be some sort of diurnal effect.

Several explanations for these observations can be offered, none of them more than speculation.

Year	n	Mean	sdev
1981	96	14h43m	1h55m
1982	80	15h21m	3h38m
1983	151	16h25m	3h28m
1984	222	14h52m	1h49m
1985	87	40h10m	34h41m
1986	117	27h44m	13h48m
1987	25	97h57m	79h08m
1988	76	29h26m	8h59m

Yearly Interval Averages
Table 3

It could be statistical coincidence. The mechanism that causes the bimodality may purely by chance cause all the eruptions to occur in daylight. That this could continue for four years seems unlikely. A season of nighttime only eruptions would, however, lend support to this hypothesis. It could be a wind effect on Giantess, which is known to be connected to Beehive [Marler 1973]. Generally it is calm until 10:00, and after dark. Its location as the lowest major spring (along with Depression Geyser) on Geyser Hill might make Beehive the most susceptible spring to any Giantess effects. Finding similar diurnal behavior in other springs on Geyser Hill connected to Giantess would lend support to this hypothesis. It could also be wind effects of Beehive itself. Beehive is reputed to be quite easy to induce, and the opening is quite small, so even slight changes in pressure might have an effect [Landis 1988].

References

Landis 1988 Landis, Phillip, suggested in personal communication.

Marler 1973 Marler, George D., *Inventoryof Thermal Features of the Firehole River Geyser Basins, and other Selected Areas of Yellowstone National Park. NTIS Pub. PB221289.*

Muffler, et.al. 1982 Muffler, L.P.J., White, D.E., Beeson, M.H., and Truesdell, A.H *Geologic Map of Upper Geyser Basin, Yellowstone National Park, Wyoming.* U.S.Geologic Survey, Map I-1371.

	Mean	St.Dev.	Count
Short	24h23m	2h41m	56
Long	43h36m	3h22m	20
All	29h26m	8h59m	76

Intervals - 1988
Table 4

The Lion Geyser Group
by
Allan Friedman

ABSTRACT

This paper deals with the relationships within the Lion Geyser Group, using data from observations in the years 1983, 1985, 1987 and 1988.

Based on these observations, the Lion complex can be seen as comprising of six geysers, all interrelated and all connected underground. This paper will discuss each geyser individually and explain the observed connections between them. Typical behavior and statistical information is included, as well as some speculative suggestions regarding the underground connections.

THE COMPLEX

The Lion Group is located approximately 1500 feet north-northwest of Old Faithful Geyser, on the northwestern edge of the large sinter expanse known as "Geyser Hill" (Figure 1). Four of the geysers in the complex, Lion, Lioness, Big Cub, and Little Cub, are perched on a small platform that rises about six feet above the surrounding flat terrain. For many years these four geysers were believed to be the sole members of the Lion Group [Marler, 1973]. The other two features, Goggles Spring and North Goggle, are situated about 70 feet northeast of Lion Geyser.

Each feature is described in detail, from south to north:

1) **Little Cub** is the most active geyser in the group. The fresh deposits surrounding its small cone indicate that its level of activity has not changed significantly in recent years.

2) **Lioness Geyser** was once considered a major geyser [Marler, 1973]. It has been dormant since 1952.

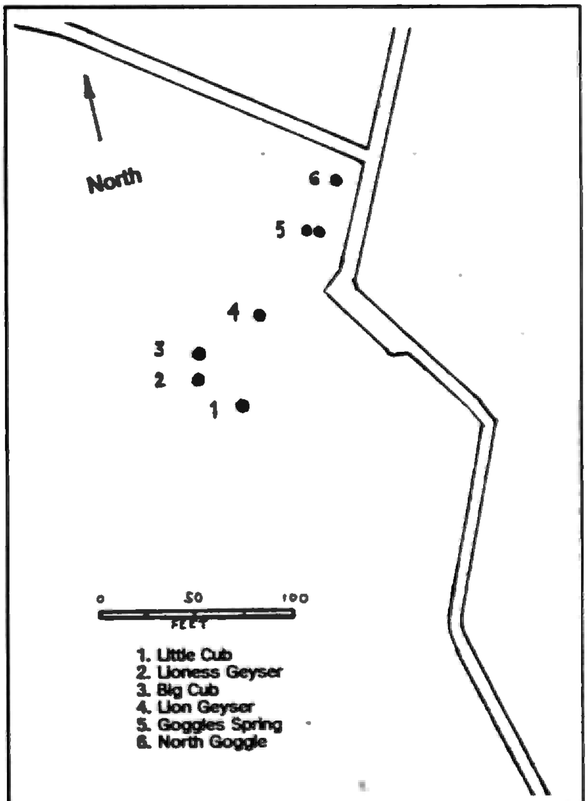

Figure 1. Map of the Lion Group.

3) **Big Cub** was, in the past, considered intimately connected with Lioness. An eruption of Big Cub in August 1987 was the first eruption recorded since 1952.

4) **Lion Geyser** is the largest geyser in the complex, both in terms of the size of its cone and its eruptions. The name of this geyser comes from the startling, noisy gushes of steam that precede some of its eruptions.

5) **Goggles Spring** is a very rare geyser and will probably only erupt during some of the rare North Goggle major eruptions.

6) **North Goggle** has infrequent major eruptions. Its minor activity is probably the most commonly observed activity in the group.

GENERAL BEHAVIOR

My interest in the Lion complex started in a routine fashion. In 1983, while waiting for an eruption of Lion, I observed patterns of behavior in Little Cub and North Goggle that led me to believe they were related and therefore connected underground. This casual beginning led to several years of observations that resulted in the following general conclusions. First and foremost, all six geysers must be recognized as part of the complex. Also, the activity of the group as a whole has increased since my observations began in 1983.

This group can be examined in three separate ways. All three are valid and all three demonstrate distinct characteristics of the group:

1) The features can be discussed as individual geysers with their own schedules;

2) The geysers can be paired, with each of the three pairs -- Lioness and Big Cub, Lion and Little Cub, North Goggle and Goggles Spring -- analyzed separately;

3) The group can be looked at as a whole, each geyser playing its part in affecting the rest of the group. This method is the most speculative and will be the last to be discussed.

The first method, discussing the individual geysers, has been dealt with to some extent already. In the discussion of the pairs of geysers the individual characteristics will be analyzed further.

Lioness and Big Cub

These features are currently the rarest performers in the group. In the past there were occasional reports of simultaneous eruptions. During their last active phase in 1952 many of their eruptions were simultaneous [Marler, 1973]. This sympathetic behavior manifests itself today; during their occasional episodes of splashing or heavy steaming the activity is simultaneous.

Both geysers have shown greater activity in recent years. Big Cub did erupt in August 1987 with no warning. The heavy splashing, boiling, and heavy steaming are becoming more common. I suspect there may be more eruptions from Big Cub in the near future and possibly activity from Lioness.

Lion and Little Cub

Little Cub is the most active eruptor in the group. It erupts in a pattern of activity that is reliable most of the time.

To understand its pattern of activity the three observed eruption types of Little Cub must be defined:

1) Minor eruptions. They are very short, with durations less than a minute. There is little ejected water; the eruptions are frequently heard as much as they are seen.

2) "Major Minor" eruptions. Their duration is about a minute, with continuous jetting of water to a height of one to two feet.

3) Major eruptions. With durations of 13 to 17 minutes and a water height of up to six feet, these eruptions are much more vigorous than the other two types.

To demonstrate the eruption pattern of Little Cub, the data from August 25, 1988 will be used. This data is typical.

1655- Little Cub (LC) Major ends.
1657- LC Minor (Interval=2m)
1702- LC Minor (I=5m)
1708- LC Minor (I=6m)
1716- LC Minor (I=8m)

1734- LC Major Minor (I=18m)
1751- LC Major Minor (I=17m)
1823- LC Major (I=32m, major interval=103m)
1823- LC Major ends (Duration=15m)

The above example is classic. After the end of the major, the geyser erupts in a series of minors with increasing durations and intervals until the next major eruption. There are many variations on this theme, but this is true of any thermal features which is part of a complex.

Lion Geyser, which was hardly active when I began to monitor this group, is now a geyser that averages more than one series of eruptions a day. Lion gets its name from the roaring gush of steam that precedes any eruption except for the first of a series.

Lion erupts in a series of two to four eruptions, each eruption separated by an interval of about an hour. Over the last few years the time between series has varied from seven hours to days. In 1988, the time between series varied from 7 to 13 hours.

Lion eruptions are quite impressive. In the first eruption of a series, Lion can erupt to a height of 60 to 80 feet with a duration of about 8 minutes. They are especially impressive because, like most geysers on Geyser Hill, the observer is very close to the eruption. This proximity has its disadvantages. Wind can affect the height; those on the "wrong" side of the wind can get soaked. During subsequent eruptions in the series the height will diminish somewhat; the duration of the subsequent eruptions averages three to four minutes.

As previously mentioned, a series of Lion eruptions consists of two to four events. There are two methods of determining if the series has ended. The first, and less accurate method, is observing a group of "roarlets" and minor eruptions over a period of a few minutes. This method is sometimes misleading because on occasion there is another eruption after this event. The second method, which is always accurate, is to observe water splashing out of Lion's cone. This indicates that the geyser is in the time period between series, and usually begins within an hour of the last eruption of a series.

Like other geysers, the splashing of water from Lion's cone will increase to large splashes, to occasional surges increasing in frequency, to finally one big surge that will start the first eruption of the next series.

Are Lion and Little Cub related?

I believe they are, because Lion usually begins a cycle near or during an eruption of Little Cub. Lion can begin either during or within a few minutes before the start of a Little Cub eruption. There are almost no examples of Lion beginning a series when Little Cub was neither erupting or imminent to erupting. Generally, if I were waiting for Lion to begin a series and Little Cub erupted and finished without an eruption of Lion, I could leave for about an hour and be confident that nothing would happen.

North Goggle and Goggles Spring

These two geysers act both as a unit and independently. They are located just a few feet from each other and their water levels can be seen rising, overflowing, and falling at the same time.

Goggles Spring almost never erupts. When it does, the events are short in both duration (seconds) and height (six feet).

North Goggle is a more frequent performer than its brother. Its most prolific recent activity was in 1985, when it had a large number of major eruptions. A major eruption of North Goggle can reach fifty feet and last five minutes.

North Goggle also has many minor eruptions, which can be divided into three types:

1) Following a long "extended overflow" (described later), a short-duration, six-foot eruption can take place from inside North Goggle's crater.

2) A "wild minor" eruption, which begins from a rise and boil. It also can reach a height of six feet.

3) Small minors, one to three feet in height, which occur during a rise and boil. These are the most common and take place within the regular pattern of activity, described next.

The Pattern. North Goggle and Goggle Spring follow the identical pattern of behavior, except during their eruptions. Over a period of 11 to 15 minutes, the water in both geysers rises in their vents, overflows for about one minute, then drains completely from sight. This activity, during which the water in both vents remains at the same level, is easily visible from the boardwalk. This pattern recurs repeatedly until it is broken up by an "extended overflow". An extended overflow, which can lead to either a major or a minor eruption, takes place when the water in both vents rises, overflows as usual, but does not drain. An extended overflow can last from a few minutes to over 100 minutes. The longer the period of overflow, the better the chance of an eruption.

During extended overflows the water in North Goggle appears to slowly heat up. At first, no bubbles are visible in the water. After about 40 minutes a few bubbles begin to appear. Their numbers slowly increase until the water is boiling. The boiling first begins in only one section of the cone, but slowly spreads throughout the visible water, finally resulting in a full boil. It is from this state that a major eruption can take off. Unfortunately, most of these events do not result in an eruption; instead, they terminate in Goggle rather unceremoniously draining from sight.

Fairly often there is a pattern to the amount of North Goggle boiling. The amount of boiling in each overflow episode will be stronger than the preceding overflow. After the boiling reaches a peak height of a few feet the boils will diminish with each overflow.

One other fact to note is that, although the two features rise and fall together, during the one time that temperatures were recorded in both features it was noted that North Goggle had a consistently higher temperature than Goggles Spring.

CHANGES IN THE COMPLEX

There have been some changes within the Lion Group in the last few years which should be noted here.

1) Following the October 23, 1983 Borah Peak earthquake, Lion Geyser was dormant for many months. Although there were a few rare eruptions in 1984, the group as a whole really reactivated in 1985. This was also the year that North Goggle had a large number of eruptions.

2) Since 1985, the intervals between Lion eruptions have increased, while the durations of the first eruption in a series have decreased.

3) In 1988, both the interval and duration of eruptions of Little Cub decreased significantly. The interval decreased by over 17 percent and the duration decreased by 20 percent.

4) Since 1985, the overflow-to-overflow period of North Goggle has decreased each year, from

15.25 minutes in 1985 to 10.91 minutes in 1988. This is a change of over 28 percent.

5) Lion eruptions have increased in frequency each year. By 1988 there could be three separate series in daylight hours.

In general, .these changes show a "heating up" of the complex: events are happening more often. If this trend continues it will be interesting to watch the group in the next few years. This may make 1989 a significant year, considering the great change in Little Cub's behavior in recent years.

THE LION GROUP AS A WHOLE

There are important relationships among members of the complex other than those discussed in the paired associations. These will be discussed next.

Little Cub's link to Lioness and Big Cub. Both Lioness and Big Cub will only splash water or boil strongly immediately before of during the early part of a major eruption of Little Cub. Big Cub sometimes ejects a "bucketful" of water with a discernable splash while at other times only ejects a few drops. Lioness rarely splashes water out of the cone, but will often splash water visibly inside the cone, either in a left-to-right or right-to-left direction. Since this activity of both Lioness and Big Cub is only seen just prior to the start or during an eruption of Little Cub, it can be used as an indicator or predictor for Little Cub.

This is especially interesting because of Lion's known exchange of function with Big Cub and Lioness: in the historical records, when Big Cub and Lioness are active, Lion is dormant.

Lion's association with North Goggle. The most important fact in this discussion is that North Goggle major eruptions take place almost exclusively within the Lion cycle and, with all probability, late in the cycle. [Bryan, 1985] discusses this fact, although he does not mention the time within the cycle that eruptions took place:

"Of the 31 major eruptions [of North Goggle], 23 definitely took place during an active phase of Lion. Three others probably had Lion active, or at least close enough to such activity to be considered as such. Only three eruptions occurred when Lion was definitely not active. There is one questionable eruption, and one for which there is no data. Thus, at an apparent minimum, about 84% of the major eruptions of North Goggle occurred when Lion was active."

Although North Goggle Geyser can have an extended overflow at any time, it was noted that the later in the Lion cycle, the longer the overflow; as mentioned earlier, the longer the overflow, the greater the chance of an eruption.

Another important factor in the relationship between these two geysers (and I believe that Goggles Spring can be included here) is the events that take place when Lion is approaching the first eruption of a series. There are two separate points to note:

First: apparently, when Lion is very close to its first eruption it seems to heat up and splash and surge more heavily at the time of a Goggle's overflow. This does not always take place, but it occurs often enough to be seriously noted.

Second is the evident temperature change in North Goggle Geyser after the last eruption of a Lion series. What happens (visually: I have never taken temperatures during this period) is: after the last eruption of the Lion series North Goggle begins to heat up, peaks, and then drops as Lion approaches the start of its next series. There are two consequences to this. It shows that North Goggle has its greatest chance of an eruption late in the Lion series. Also, it can be used as a predictor for a new Lion series.

Independence of Little Cub. In one sense, Little Cub is the most interesting geyser in the group. The data indicates that every other feature in the complex is affected by some other feature. Only Little Cub seems to act independently within the group, not changing behavior due to the influence of another member. Little Cub affects them, not the other way around.

The Lion Group and Giantess. I have often heard that an eruption of Giantess Geyser affected almost every geyser on Geyser Hill, including Lion. Because of Giantess' recent infrequent activity this has been a difficult relationship to either confirm or disprove. On August 28, 1988, I was fortunate to be on Geyser Hill at the start of a Giantess eruption -- an incredible experience -- at a time when I was collecting data on Lion. Three interesting facts emerged:

1) The Giantess eruption seemed to delay the start of the next Lion series. At about the time Lion should have erupted, which was 44 minutes after the start of Giantess, a Lion eruption took place that lasted for only one minute and rose only five to ten feet above the vent. After this minor (or "aborted" eruption) Lion did not erupt for over three hours. This is the only time I have seen or heard of such an event.

2) The Giantess eruption seemed to have produced longer series of Lion for the next day or two.

3) Little Cub behaved oddly before and after the Giantess eruption. When I began observing Little Cub in 1988, the intervals between its major eruptions were a fairly short 68 to 80 minutes. The intervals gradually lengthened until they were over 100 minutes (103, 105, etc.). After August 28, the intervals shortened. Could there be a connection between the eruption of Giantess and the changes in the interval of Little Cub? Is this a possible predictor for Giantess?

LION	1985	1987	1988
Intervals			
First to Second	71.3 Min.	78.78	82.5
Second to X	(above # is all intervals)	64	69.428
Durations			
First Eruption	9 Min.	8.125	7.83
Second, etc.	3.3	3.79	4.035

LITTLE CUB	1985	1987	1988
Interval	100.11 Min.	102.77	83.7
Duration	17	16.77	12.83

NORTH GOGGLE	1983	1985	1987	1988
Overflow to Overflow	13.3	15.24	11.95	10.91

The obvious changes in these comparisons are those in Little Cub from 1985 to 1987 and 1987 to 1988 (the shrinking of the interval and duration), and the changes in North Goggle (the shrinking of the interval). Also, the year that North Goggle was the most active (1985) was the year of its longest overflow to overflow period.

Examples of the range of numbers involved in the above averages include: in 1985, a range of 13 to 18 minutes in North Goggle's overflow-to overflow; also in 1985, a range of Little Cub intervals of 73 to 121 minutes.

In 1987, the range of Little Cub intervals was 82 to 117 minutes while their durations ranged from 14 to 19 minutes.

In 1987, the range of Lion data was: First to Second intervals varied from 69 to 91 minutes; duration of Lion firsts varied from 7 to 10 minutes; duration of Lion seconds and thirds varied from 3 to 4 minutes.

In 1987, the range of North Goggle overflow intervals was from 10.5 to 14 minutes.

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REFERENCES

Marler, George. Inventory of Thermal Features of the Firehole River Geyser Basins and Other Selected Areas of Yellowstone National Park. National Technical Information Service Publication #PB-221 289. 1973.

Bryan, T. Scott. Annual Summary of Geyser Activity, Yellowstone National Park, 1985. Unpublished. 1985.

Observations of Anemone Geysers, 1985-1988

OBSERVATIONS OF ANEMONE GEYSERS 1985-1988

by: Ralph C. Taylor Jr.

1 ABSTRACT

This paper discusses observations of the Anemone geysers made in the summer months of 1985, 1986, 1987, and 1988. The behavior of the Anemone geyser system shows a significant change in 1988 from that in the previous summers. Typical eruptions of both types are described, and observed eruption data is presented and analyzed for both patterns of activity. In 1985-87, the eruptions of both North and South Anemone were regular in interval and duration. In 1988, South Anemone became dominant, having long eruptions about once per hour. These affected the intervals of North Anemone, but not the duration.

2 INTRODUCTION

The Anemone geysers are familiar to most visitors to Geyser Hill, being frequent performers and close to the main boardwalk on Geyser Hill. Despite the frequency of eruption, however, relatively little attention appears to have been given this geyser group. This paper presents the results of studies of the eruption patterns of North and South Anemone Geysers over the years 1985, 1986, 1987, and 1988. The larger of the geysers, North Anemone, is regular in its eruptions in most years, and is frequent enough to allow a reasonable amount of data to be accumulated in a short time.

In the summers of 1985 through 1987, the Anemone geysers exhibited a constant, regular pattern of eruption. The duration and interval of North Anemone was constant and showed little variation from eruption to eruption or from day to day. South Anemone was also regular, although it often skipped eruptions. North Anemone geyser clearly dominated the pair with its more regular and larger eruptions. In 1988, a significant change in pattern occurred. South Anemone had become more dominant, showing a long eruption sequence about once an hour. This long eruption sequence was able to cause North Anemone to remain quiet, and to show a slow recovery.

In the remainder of this paper, Section 3 describes the Anemone geyser formation and the eruption patterns observed in the 1985-87 seasons and the changes in 1988. Section 4 describes the data collected and computed. It contains daily and annual mean and standard deviation data for North and South Anemone Geysers, as well as the full recorded observations. Section 5 discusses and analyzes the data. Section 6 describes plans for future research.

3 Description of the Anemone Geysers

In this section, the Anemone Geyser formation is described. The typical eruption pattern from the 1985-87 summers is described, followed by a description of the pattern seen in 1988.

3.1 Anemone Geyser Formation

The Anemone Geysers are located to the south and west of the west branch of the boardwalk loop around Geyser Hill, near the junction of the trail to the Firehole River bridge and Old Faithful Geyser. The walk makes a sharp turn to the west about 100 meters past the junction. The Anemone geyser craters are on the left (west) of the observer on the inside of the turn in the boardwalk. The Anemone Geyser consists of two related geysers. The larger crater, nearest the boardwalk, is referred to in this paper as "North Anemone" and the smaller crater to the south is referred to as "South Anemone". The latter geyser is labelled "Anemone Geyser" on the official USGS map, but common usage attaches the name "Anemone Geyser" to the larger feature. To avoid confusion, the names "North Anemone" and "South Anemone" are used throughout this paper.

North Anemone Geyser has a symmetrical crater about 1.5 meters in diameter. The formation is covered with spiny sinter, colored by minerals and bacteria. The formation has a vent about 10 cm in diameter, with a gradual funnel shaped curve. The formation is generally flat, with a slight sinter rim and concentric circles of sinter sloping gently to the vent. The sinter at the edges of the formation is colored a reddish brown by bacteria; that nearer the center is a yellow color. The spiny sinter bears a slight resemblance to the texture of a sea anemone, giving the geyser its name. Well defined runoff channels lead from the boardwalk edge of North Anemone down the slope of Geyser Hill toward Plume Geyser.

South Anemone is located about 3 meters southwest of North Anemone, and has a considerably smaller crater. The shape of South Anemone's crater is similar to that of North Anemone. The formation is surrounded by geyserite gravel with no defined runoff channels.

Marler [Marler 1973] describes Anemone as consisting of three vents on a north-south line. Apparently, during the continuous eruptions of the south vent and the dormancy of the north and central vents following the 1959 Hebgen Lake earthquake, the north vent described by Marler was filled and cemented. A small depression, now filled with loose gravel, is still visible on the northern shoulder of North Anemone Geyser in 1988. There was no sign of activity from this vent during the period covered by this paper.

3.2 Anemone Geyser Eruptions, 1985-87

The observed eruptions of the Anemone Geysers in 1985-87 all followed the same pattern. This pattern differs somewhat from the pattern described by Bryan. The observed eruptions all fit into the pattern suggested by "...but during some periods an eruption of one will invariably follow that of the other." [Bryan 1986] The pattern is similar to that described by Marler [Marler 1973] for the pre-1959 earthquake activity, but with only two vents active.

Most of the observed eruptions consist of an eruption of North Anemone followed by an eruption of South Anemone. Typically, the sequence begins with a rise in the water in South Anemone. The water reaches a point 2-4 cm. below the outer formation, so that a pool 25 cm. to 40 cm. in diameter is formed. The pool is quiet, with little or no surging or bubbling. The level of water then drops. Within 10 to 20 seconds after the water drops in South Anemone, a gurgle is heard from North Anemone, followed by a sudden rising of the water. The vent fills, and water rises in the inner portion of the crater to a diameter of about a meter. The first burst of steam through the water follows almost immediately and marks the beginning of the eruption. The initial burst throws water a meter or so in the air; the eruption then rapidly builds to a height of 2 to 4 meters. Often the boardwalk to the south of the sharp bend is drenched. The eruption lasts for 25 to 45 seconds, and then suddenly stops. The water drains abruptly, with a loud gurgling sound. After North Anemone drains, a quiet interval of about one minute is followed by the filling of South Anemone, and usually by an eruption of South Anemone. Occasionally, South Anemone just fills and then drains, but usually an eruption of South Anemone occurs. These eruptions are similar in appearance to those of North Anemone, but on a smaller scale. The water is splashed to a height of 0.5 to 2 meters in height. South Anemone's eruptions are more variable in length and often longer than those of North Anemone. When South Anemone drains, a quiet interval ensues.

3.3 Anemone Geyser Activity in 1988

During the summer of 1988, a different pattern of activity was observed. South Anemone was considerably more active than before, and North Anemone had become relatively less active than in previous years. This was evident from the changes in the runoff channels. In previous years, South Anemone had little or no runoff, as shown by the lack of any perceptible runoff channels or sinter deposits. North Anemone, on the other hand, had considerable runoff and has established an extensive geyserite formation and pronounced runoff channels with substantial algal mats. In 1988 the bacterial mats in the runoff channel from North Anemone were dying and the channel had little water in it.

In 1988, the intervals of North Anemone were variable, and were influenced by the activity of South Anemone Geyser, which also exhibited a changed pattern of activity. About once an hour South Anemone would have a prolonged eruption sequence, lasting from 13 to 15 minutes. During these long eruptions, North Anemone remained quiet. South Anemone's long eruptions consisted of a typical South Anemone eruption of about one minute duration, followed by a brief quiet period. During the quiet period, instead of draining, the water remained near overflow. The quiet period was then followed by a continuation of the eruption. The continuation typically lasted 10 minutes, followed by a short quiet period, then one or two feeble, brief eruptive periods lasting a few seconds. During the last such period, steam bubbles could often be seen rising in the throat of the crater and collapsing before reaching the surface.

These long eruptions of South Anemone were accompanied by considerable overflow, with the water reaching the crest of the western slope of Geyser Hill about 30 meters beyond the crater. The runoff channel from South Anemone Geyser runs over geyserite gravel, and the water is mostly absorbed into the gravel.

A long eruption of South Anemone was invariably followed by an eruption of North Anemone within about four minutes. This first eruption of North Anemone following the long South Anemone eruption began from an empty crater, spraying water mixed with steam. As the eruption continued, the crater filled, so that the eruption ended with a full crater. The level of water was noticeably lower than in previous years, and little overflow occurred.

In the 1988 pattern of activity, South Anemone often skipped one eruption following a long eruption. The interval between North Anemone eruptions was reduced to five minutes following the long eruptions of South Anemone, with the interval increasing to 7 to 8 minutes over the next eight to ten eruptions. Despite the variability of the intervals of the eruptions of North Anemone, the durations were constant, though shorter than in previous years.

4 Observations of Anemone Geyser, 1985-1988

This section contains the data from observations made during the summers of 1985, 1986, 1987, and 1988. In general, observations were made for periods of about one hour in the earlier years. In 1988, longer periods were observed.

4.1 Definitions and Description of Observations

All times were recorded to the nearest second. The short intervals and durations make this resolution essential. The original data taken consist of the start and stop time of North Anemone and South Anemone geyser eruptions.

The start time of the North Anemone eruption is defined as the time of the first burst of water thrown by a bursting steam bubble. This is generally preceded by a rapid rise of water and some surging. The burst of the first bubble is easily noted and unambiguous.

The stop time of North Anemone is the end of the last burst of water. The bursting action of the eruption ceases rather quickly, followed by a rapid draining of the water. The stop time is defined as the time the last burst of water actually thrown into the air stops. Again, this time is relatively unambiguous.

The start time for South Anemone is defined as the time of the first burst of water thrown into the air. This becomes ambiguous when the eruption is not very vigorous. The eruption begins with a small surging, followed by gentle bubbling, followed usually by a more pronounced splashing. The doming and surging is not counted as part of the eruption.

The stop time for South Anemone is less well defined. Generally, the end of the eruption is marked by a gradual decline in the height and vigor of the bursts. The end is therefore relatively difficult to pinpoint.

On some occasions, South Anemone fills, the water surges and a few small bubbles burst, but no actual eruption ensues. In these cases, the times recorded in the following data reflect the approximate time the water became visible in the vent. The stop time is the time that the water drops from sight in the vent.

In 1988, following a long eruption of South Anemone, the next one or two eruptions often did not occur. In many of these cases, a distinct boiling could be heard coming from the vent, indicating that low water level prevented the filling or eruption. Some of these cases were recorded; the times are marked in the tables of data with a "u" for "underground boiling". The underground boiling could only be observed when the surroundings were quiet and there was not too much wind.

In the following tables, the observed start time and the computed durations for North Anemone and South Anemone geyser eruptions are shown. The duration is defined as the time between the start and end of the eruption.

The intervals for both North Anemone and South Anemone are also shown. In this paper the term <u>interval</u> is used to describe the time from the beginning of one eruption to the beginning of the next, in keeping with common usage. [Note: Bryan [Bryan

1986] defines the interval as "the period of time from the end of one eruption to the beginning of the next..." and period as "the interval plus the duration; that is, the span of time the start of one eruption to the start of the next." I have chosen to follow common usage and define interval as the time from the start of one eruption to the start of the next eruption.]

Most eruptions of North Anemone are followed by an eruption of South Anemone. The length of the quiet period between the eruptions, defined as the time from the end of the North Anemone eruption to the start of the South Anemone eruption, is also shown.

4.2 Notation

In general, times are shown in hh:mm:ss format. Some observations were made from a distance or were not possible to record accurately; these are shown as hh:mm:xx ~. Questionable observations, (generally cases where the observer was distracted or simultaneous events caused the start or stop of a particular eruption to be noted but uncertain) are shown as hh:mm:ss ?. Times for eruptions seen in progress are shown hh:mm:xx ie (in eruption). The computed data are also marked with these symbols. Basically, uncertainty in either of the two observations used to compute a value causes uncertainty in the result. If either value needed in a computation is unavailable, the result location is marked with dashes (----).

For each computed value, i.e., duration, interval, and time between North Anemone's eruption end and South Anemone's eruption start, a mean and standard deviation (S.D.) are computed for the day's observations. Computed values with any uncertainty are not used in the mean or Standard Deviation computations.

4.3 Summary of Observed Data

4.3.1 Anemone Geyser Duration and Interval Summary

Date	North Anemone				South Anemone					
	Duration		Interval		Duration		Interval		After North	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
3 August 1985	00:31.5	00:03.5	06:47.7	00:47.3	----	----	----	----	----	----
4 August 1985	00:34.0	00:03.6	06:10.0	00:57.5	00:32.5	00:12.8	09:44.0	----	00:48.8	00:10.7
7 August 1985	00:34.9	00:06.1	06:40.7	00:31.7	00:38.0	00:15.7	06:31.0	00:24.1	00:40.2	00:08.1
8 August 1985	00:38.9	00:05.9	07:44.0	04:53.2	02:56.8	04:55.3	11:30.2	05:59.7	03:38.7	06:15.6
All 1985	00:35.5	00:05.5	06:55.7	02:57.3	01:35.1	03:10.1	09:49.3	05:05.4	02:33.4	04:09.6
17 July 1986	00:39.9	00:02.4	08:24.0	00:11.7	00:28.3	00:10.9	08:26.5	00:19.6	00:59.3	00:15.4
18 July 1986	00:41.4	00:02.9	07:59.6	00:49.8	00:28.4	00:10.3	08:04.5	01:01.4	01:00.2	00:14.1
2 August 1986	00:41.2	00:01.6	08:02.5	00:06.7	00:24.0	00:04.2	08:04.3	00:16.2	01:06.8	00:07.3
3 August 1986	00:39.0	00:02.7	08:08.3	00:09.3	00:25.0	----	----	----	----	----
4 August 1986	00:41.4	00:02.1	08:04.5	00:05.3	00:24.7	00:08.5	08:07.8	00:22.8	01:11.4	00:13.6
5 August 1986	00:36.5	00:08.1	07:54.3	00:20.6	----	----	07:52.5	----	00:57.0	00:21.4
6 August 1986	00:40.1	00:02.7	08:07.4	00:05.4	00:29.0	00:10.9	08:03.9	00:20.5	01:03.3	00:13.3
All 1986	00:40.2	00:03.3	08:06.9	00:27.7	00:28.0	00:10.0	08:08.9	00:37.5	01:42.5	00:14.5
2 August 1987	00:38.1	00:04.5	06:44.7	00:19.9	00:27.3	00:05.2	06:48.7	00:20.2	00:48.9	00:08.4
3 August 1987	00:38.8	00:02.3	06:43.6	00:11.7	00:26.4	00:04.2	06:38.6	00:08.6	00:41.9	00:10.7
All 1987	00:38.4	00:03.7	06:44.3	00:16.9	00:27.0	00:04.7	06:44.3	00:16.8	01:24.1	00:09.8
5 August 1988	00:28.0	00:02.3	08:03.7	04:22.4	03:18.7	04:25.9	06:03.8	04:18.0	02:57.0	04:07.7
6 August 1988	00:28.5	00:03.5	06:36.4	01:17.1	02:00.8	01:23.2	06:49.6	02:18.1	00:34.2	00:51.2
8 August 1988	00:29.2	00:04.1	08:02.5	04:01.3	02:54.6	04:02.5	08:16.7	06:53.1	02:47.6	03:28.4
9 August 1988	00:28.3	00:03.0	08:43.8	04:15.8	01:55.2	02:53.2	05:33.6	03:43.1	02:51.9	04:22.6
10 August 1988	00:27.9	00:03.0	11:53.7	14:32.1	02:14.1	03:33.4	06:38.1	03:19.5	02:19.6	03:47.6
12 August 1988	00:29.3	00:02.8	08:36.2	04:34.4	02:34.5	03:57.0	07:50.0	08:20.2	04:33.4	05:55.8
13 August 1988	00:29.9	00:02.8	08:09.5	03:49.8	01:43.3	02:51.6	05:25.3	02:38.6	02:41.8	03:58.4
14 August 1988	00:28.0	00:02.0	08:52.5	04:56.7	03:12.8	04:31.3	07:21.6	06:23.3	02:05.6	03:10.9
16 August 1988	00:27.2	00:02.1	07:39.7	04:03.3	02:26.3	03:32.2	06:17.1	03:48.8	03:21.2	04:46.8
18 August 1988	00:27.3	00:02.6	09:25.2	05:46.2	01:46.4	03:25.0	07:00.1	03:55.2	04:29.3	06:12.4
All 1988	00:28.5	00:03.0	08:15.4	04:04.8	02:23.2	03:31.5	06:33.8	04:50.1	03:29.8	04:22.0

Observations of Anemone Geysers, 1985-1989

4.4 Detailed Data

Start(N)	Dur	Int	Start(S)	Dur	Int	After North
3 August 1985						
10:05:45	00:28	-----	----	---	---	---
10:12:01	00:29	06:16	10:13:00	01:23	---	00:30
10:19:43	00:35	07:42	----	---	---	---
10:26:08	00:34	06:25	----	---	---	---
4 August 1985						
13:27:20	00:29	---	----	---	---	---
13:34:30	00:34	07:10	----	---	---	---
13:40:48	00:35	06:18	13:42:27	00:22	---	01:04
13:47:04	00:37	06:16	13:48:21	00:34	05:54	00:40
13:54:23	00:37	07:19	----	---	---	---
14:00:28	00:39	06:05	14:01:55	00:50	13:34	00:48
15:42:20	00:35	---	----	---	---	---
15:46:51	00:29	04:31	----	---	---	---
15:52:22	00:31	05:31	15:53:36	00:24	---	00:43
7 August 1985						
10:05:23	00:39	06:xx	10:06:41	00:55	---	00:39
10:12:50	00:22	07:27	----	---	---	---
15:15:23	00:34	---	15:16:40	---	---	00:43
15:21:37	00:41	06:14	15:22:48	00:39	06:08	00:30
15:28:05	00:35	06:28	15:29:17	00:41	06:29	00:37
15:34:45	00:36	06:40	15:36:13	00:17	06:56	00:52
15:41:54	00:37	07:09	----	---	---	---
15:48:00	---	06:06	----	---	---	---
8 August 1985						
19:20:52	00:40	---	19:22:53	00:00	---	01:21
19:27:19	00:37	06:27	19:28:46	00:42	05:53	00:50
19:34:52	00:42	07:33	19:35:40	01:59	06:54	00:06
19:42:37	00:39	07:45	----	---	---	---
19:48:48	00:47	06:11	19:53:52	12:56	18:12	04:17
20:09:10	00:30	20:22	20:07:05	00:42	13:13	17:30
20:12:48	00:32	03:38	----	---	---	---
20:18:12	00:40	05:24	----	---	---	---
20:24:20	00:34	06:08	20:25:43	00:28	18:38	00:49
20:30:28	00:48	06:08	20:31:54	00:54	06:11	00:38
17 July 1986						
09:16:12	00:45	---	09:17:58	00:23	---	01:01
09:24:40	00:39	08:28	09:26:16	00:24	08:18	00:57
09:33:03	00:41	08:23	09:35:02	00:15	08:46	01:18
13:18:07	00:36	---	13:19:24	00:00	---	00:41
13:26:11	00:41	08:04	13:28:20	00:00	08:56	01:28
13:34:50	00:38	08:39	13:36:18	00:42	07:58	00:50
13:43:15	00:39	08:25	13:44:45	00:35	08:27	00:51
13:51:45	---	08:30	13:53:18	00:27	08:33	---
13:59:55	00:41	08:10	14:01:48	00:12	08:30	01:12
14:08:28	00:39	08:33	14:09:52	00:35	08:04	00:45
14:25:05	00:40	08:23 ?	14:26:35	00:42	08:xx ?	00:50
18 July 1986						
10:28:20	00:40	---	10:29:45	00:40	---	00:45
10:36:35	00:40	08:15	10:38:30	00:00	08:45	01:15
10:44:55	00:42	08:20	10:46:30	00:30	08:00	00:53
10:53:09	00:39	08:14	10:54:41	00:30	08:11	00:53
11:01:15	00:47	08:06	11:03:04	00:26	08:23	01:02
11:09:32	00:38	08:17	11:11:05	00:41	08:01	00:55
11:15:02	00:38	05:30	11:16:16	00:34	05:11	00:36
11:23:16	00:42	08:14	11:25:14	00:16	08:58	01:16
11:31:35	00:43	08:19	11:33:06	00:35	07:52	00:48
11:39:48	00:39	08:13	11:41:49	00:11	08:43	01:22
11:56:22	00:40	---	11:57:56	00:38	---	00:54
12:04:30	00:45	08:08	12:06:32	00:13	08:36	01:17
12:12:50	00:45	08:20	12:14:41	00:27	08:09	01:06
2 August 1986						
18:44:48	00:40	---	18:46:29	00:31	---	01:01

Observations of Anemone Geysers, 1985-1989

Start(N)	Dur	Int	Start(S)	Dur	Int	After North
2 August 1986 (Cont.)						
18:52:54	00:40	08:06	18:54:38	00:22	08:09	01:04
19:00:47	00:43	07:53	19:02:32	00:25	07:54	01:02
19:08:55	00:43	08:08	19:10:57	00:21	08:25	01:19
19:16:58	00:40	08:03	19:18:46	00:21	07:49	01:08
3 August 1986						
13:46:32	00:38	---	13:48:25 ie	---	---	01:xx
13:54:35	00:34	08:03	----	---	---	---
14:02:46	00:39	08:11	14:04:13	00:32	---	00:48
14:10:45	00:42	07:59	----	---	---	---
14:19:05	00:41	08:20	14:20:23 ?	---	---	00:37 ?
14:43:35 ?	---	08:xx ?	14:45:26	00:18	08:01 ?	---
14:51:40	00:38	08:05 ?	14:53:15 ?	00:23 ?	07:49 ?	00:57 ?
15:16:00	00:41	07:xx	----	---	---	---
4 August 1986						
11:29:20	00:40	---	11:31:14	00:00	---	01:14
11:37:28	00:39	08:08	11:39:17	00:28	08:03	01:10
11:45:28	00:41	08:00	11:47:30	00:00	08:13	01:21
11:53:38	00:43	08:10	11:55:10	00:31	07:40	00:49
12:01:38	00:44	08:00	12:03:45	00:15	08:35	01:23
5 August 1986						
15:40:17	00:37	---	15:42:15	00:00	---	01:21
15:48:27	00:43	08:10	15:49:50	00:50	07:35	00:40
15:56:29	00:41	08:02	15:58:00	00:00	08:10	00:50
16:04:00	00:25	07:31	----	---	---	---
6 August 1986						
08:03:01	00:36	---	08:04:55	00:24	---	01:18
08:11:08	00:41	08:07	08:12:51	00:27	07:56	01:02
08:19:20	00:43	08:12	08:20:53	00:32	08:02	00:50
08:27:20	00:42	08:00	08:29:06	00:25	08:13	01:04
08:35:32	00:41	08:12	08:37:29	00:11	08:23	01:16
08:43:41	00:36	08:09	08:45:07	00:41	07:38	00:50
08:51:41	00:40	08:00	08:53:40	00:00	08:33	01:19
08:59:53	00:42	08:12	09:01:22	00:43	07:42	00:47
2 August 1987						
10:06:10	00:25	---	10:07:26	00:22	---	00:51
10:12:50	00:40	06:40	10:14:23	00:24	06:57	00:53
10:19:48	00:37	06:58	10:21:20	00:00	06:57	00:55
10:27:00	00:38	07:12	10:28:16	00:34	06:56	00:38
10:33:52	00:41	06:52	10:35:35	00:00	07:19	01:02
10:40:21	00:39	06:29	10:41:50	00:33	06:15	00:50
10:46:44	00:43	06:23	10:48:12	00:29	06:22	00:45
10:53:36	00:42	06:52	----	---	---	---
10:59:36	00:38	06:00	11:01:00	00:25	---	00:46
11:06:27	00:36	06:51	11:07:51	00:26	06:51	00:48
11:13:11	00:41	06:44	11:14:46	00:18	06:55	00:54
11:19:34	00:34	06:23	11:21:10	00:00	06:24	01:02
11:26:34	00:41	07:00	11:27:57	00:30	06:47	00:42
11:33:27	00:41	06:53	11:34:40	00:00	06:43	00:32
11:40:36	00:35	07:09	11:41:58	00:32	07:18	00:47
3 August 1987						
09:09:34	00:42	---	09:11:06	00:30	---	00:50
09:16:30	00:40	06:56	09:17:40	00:00	06:34	00:30
09:23:02	00:38	06:32	09:24:31	00:25	06:51	00:51
09:30:05	00:37	07:03	09:31:00	00:00	06:29	00:18
11:11:03	00:42	---	11:12:27	00:20	---	00:42
11:17:47	00:38	06:44	11:19:07	00:00	06:40	00:42
11:24:25	00:36	06:38	11:25:53	00:30	06:46	00:52
11:31:13	00:37	06:48	11:32:40	00:00	06:47	00:50
11:37:44	00:38	06:31	11:39:05	00:00	06:25	00:43
11:44:14	00:37	06:30	11:45:40	00:27	06:35	00:49
11:51:04	00:42	06:50	11:52:20	00:00	06:40	00:34

5 August 1988

Start(N)	Dur	Int	Fill(S)	Start(S)	Drain	Dur	Int	After North
----	---	---	----	13:31:06	---	00:24	---	---
13:35:08	00:31	---	13:36:17	13:36:17	---	00:55	05:11	00:38
----	---	---	----	13:37:50	---	09:55	01:33	02:11
----	---	---	----	13:48:24	13:50:00	00:16	10:34	12:45

Observations of Anemone Geysers, 1985-1989

Start(N)	Dur	Int	Fill(S)	Start(S)	Drain	Dur	Int	After North
5 August 1988 (Cont.)								
13:52:13	00:29	17:05	----	----	---	---	---	---
13:56:51	00:27	04:38	----	13:58:15	---	00:27	---	00:57
14:02:10	00:28	05:19	----	14:03:15	---	00:33	05:00	00:37
14:08:25	00:31	06:15	14:09:40	14:09:40	14:20:49	09:43	06:25	00:44
14:23:57	00:26	15:32	----	14:28:00 u	---	---	18:20	03:37
14:28:45	00:29	04:48	----	14:29:56	---	00:19	01:56	00:42
14:34:23	00:23	05:38	----	14:34:42	---	01:30	04:46	??:??
14:41:40	---	07:17	----	----	---	---	---	---
15:09:58 ie	00:xx ~	---	----	15:09:58 ie	---	02:xx ~	---	??:??
----	---	---	----	15:17:11 u	---	---	07:xx ~	07:xx ~
15:18:11	00:29	08:xx ~	15:20:00	----	---	---	02:49	01:20
15:24:17	00:26	06:06	15:24:50	15:24:50	---	11:36	04:50	00:07
----	---	---	----	15:36:38	15:37:20	00:42	11:48	11:55
15:40:21	00:29	16:04	----	15:44:50 u	---	---	08:12	04:00
15:45:09	00:24	04:48	15:46:33	15:46:33	---	---	01:43	01:00
----	---	---	----	15:47:00 u	---	---	00:27	01:27
15:50:30	00:30	05:21	----	15:50:35	---	01:xx ?	03:35	??:??
----	---	---	----	15:57:20 u	---	---	06:45	06:20
15:59:10	00:27	08:40	----	16:00:55	---	00:55	03:35	01:18
16:05:11	00:29	06:01	----	16:05:52	---	01:34	04:57	00:12
16:12:35	00:30	07:24	16:14:04	16:14:04	---	10:12	08:12	00:59
----	---	---	----	16:24:41	16:25:20	00:39	10:37	11:36
6 August 1988								
11:49:25	00:30	---	----	----	---	---	---	---
11:54:09	00:23	04:44	----	----	---	---	---	---
11:59:20	00:25	05:11	----	12:00:02	---	01:13	---	00:17
12:05:53	00:34	06:33	12:07:10	----	12:08:15	---	07:08	00:43
12:12:40	00:31	06:47	----	12:14:54	---	00:33	07:44	01:43
12:19:00	00:30	06:20	----	12:19:00	---	03:37	04:06	??:??
12:27:13	00:27	08:13	12:29:00	----	12:29:40	---	10:00	01:20
12:33:50	00:28	06:37	----	12:34:10	---	02:40	05:10	??:??
12:42:16	00:19 ?	08:26		----	---	---	---	---
8 August 1988								
----	---	---	----	14:57:xx ie	----	---	---	---
15:25:51	00:32	---	15:26:38	15:26:38	----	10:18	29:xx ~	00:15
----	---	---	----	15:38:07	15:38:23	00:16	11:29	11:44
15:41:20	00:29	15:29	----	----	----	---	---	---
15:46:32	00:25	05:12	----	----	----	---	---	---
15:52:11	00:23	05:39	15:53:38	15:53:38	----	00:47	---	01:04
----	---	---	----	15:57:45	----	02:15	04:07	05:11
15:58:00	00:28	05:49	----	16:00:20	16:00:40	00:20	02:35	07:46
16:05:43	00:32	07:43	----	----	----	---	---	---
16:11:50	00:26	06:07	----	16:12:55	----	00:38	-----	00:39
16:18:25	00:36	06:35	16:18:00	16:18:00	----	02:48	05:05	??:??
----	---	---	----	16:21:19	16:21:43	00:24	03:19	02:18
16:28:00	00:31	09:35	----	16:30:13	----	00:21	08:54	01:42
16:33:56	00:28	05:56	----	16:34:30	----	02:30	04:17	00:06
16:42:34	00:22	08:38	16:43:22	16:44:23	----	01:07 ?	09:53	01:27
----	---	---	----	16:46:01	16:56:29	10:28	01:38	03:05
17:00:03	00:28	17:29	----	----	----	---	---	---
17:04:53	00:27	04:50	----	17:06:11	----	00:28	20:10	00:51
17:10:15	00:28	05:22	17:11:10	17:11:37	----	00:13	05:26	00:54
17:16:15	00:35	06:00	----	17:16:44	----	02:02	05:07	??:??
17:23:15	00:31	07:00	----	17:24:37	----	00:53	07:53	00:51
17:30:30	00:37	07:15	17:30:20	17:32:03	----	12:37	07:26	08:17
17:48:08	00:27	17:38	----	----	----	---	---	---
17:53:14	00:28	05:06	17:55:05	17:58:55	----	02:10	26:52	05:13
17:58:39	00:34	05:25	----	----	----	---	---	---
18:06:40	00:26	08:01	----	----	----	---	---	---
9 August 1988								
10:11:58	00:27	---	----	10:11:xx u	----	-----	-----	-----
----	---	---	----	10:13:10	----	00:34	02:xx ~	00:45
10:17:31	00:26	05:33	----	10:17:53	10:20:35	01:52	04:43	??:??
10:26:40	00:26	09:09	----	10:28:49	----	00:20	10:56	01:43
10:32:30	00:32	05:50	10:33:29	10:33:29	----	01:00	04:40	00:27
----	---	---	----	10:34:55	10:35:24	00:12	01:26	01:53
10:39:46	00:29	07:16	10:39:40	10:40:31	----	02:19	05:36	00:16
----	---	---	----	10:43:05	----	08:35	02:34	02:50
----	---	---	----	10:52:35	10:53:07	00:14	09:30	12:20
10:56:02	00:28	16:16	----	----	----	---	---	---
11:01:18	00:23	05:16	----	11:02:48	----	00:07	10:13	01:07

Observations of Anemone Geysers, 1985-1989

9 August 1988 (Cont.)

Start(N)	Dur	Int	Fill(S)	Start(S)	Drain	Dur	Int	After North
11:06:55	00:29	05:37	----	11:07:37	11:09:48	01:08	04:49	00:13
11:13:48	00:29	06:53	----	11:15:17	----	00:37	07:40	01:00
11:20:28	00:35	06:40	11:20:54	11:20:54	----	00:06	05:37	??:??
----	---	---	----	11:21:28	----	01:10	00:34	00:25
----	---	---	----	11:22:48	----	00:33	01:20	01:45
----	---	---	----	11:24:28	----	08:52	01:40	03:25
----	---	---	----	11:34:25	11:35:52	00:14	09:57	13:22
11:37:52 ?	00:30 ?	17:24 ?	----	----	----	---	---	---
11:42:40	00:29	04:48 ?	----	11:44:48	----	01:28	10:23	01:39
11:47:57	00:25	05:17	----	11:48:25	11:50:44	01:27	03:37	00:03
11:56:40	00:26	08:43	----	11:57:56	11:59:15	01:10	09:31	00:50
----	---	---	----	----	----	---	---	---
14:42:08 ie	00:xx -	---	----	14:43:43	14:44:19	00:25	-----	01:20
14:47:47	00:29	05:xx -	14:48:38	14:48:38	----	01:29	04:55	00:22
----	---	---	----	14:50:24	----	10:50	01:46	02:08
----	---	---	----	15:01:23	15:03:40	00:37	10:59	13:07
15:05:39	00:24	17:52	----	----	----	---	---	---
17:12:19	00:29	---	----	17:12:31	17:16:14	02:36	-----	??:??
17:22:11	00:29	09:52	----	17:23:58	17:24:46	00:41	11:27	01:18
17:28:06	00:30	05:55	17:28:50	17:29:20	17:31:00	01:06	05:22	00:44
17:35:09	00:30	07:03	17:35:05	17:36:05	17:38:40	01:55	06:45	00:26
17:42:56	00:34	07:47	17:43:20	17:43:40	----	01:10	07:35	00:10
----	---	---	----	17:45:25	----	00:25	01:45	01:55
----	---	---	----	17:46:18	----	09:05	00:53	02:48
----	---	---	----	17:55:30	----	00:20	09:12	12:00
----	---	---	----	17:56:52	17:57:32	00:19	01:22	13:22
18:00:21	00:26	17:25						

10 August 1988

Start(N)	Dur	Int	Fill(S)	Start(S)	Drain	Dur	Int	After North
10:25:15	00:25	---	10:25:32	10:26:04	10:27:36	00:48	-----	00:24
11:31:41	00:31	??:??	11:33:10	----	11:34:23	---	-----	-----
11:38:20	00:30	06:39	11:38:22	11:38:43	----	11:01	-----	??:??
----	---	---	----	11:50:54	11:51:32	00:09	12:11	12:04
11:54:00	00:26	15:40	----	----	----	---	---	---
11:59:46 ie	00:xx -	05:xx -	----	----	----	---	---	---
----	---	---	12:01:16	----	12:01:40	---	---	---
12:05:00	00:29	05:xx -	12:04:55	12:05:00	12:08:12	02:15	---	??:??
----	---	---	12:30:00	12:30:10	12:30:26	00:15	-----	-----
12:34:29	00:31	---	12:34:05	12:35:25	----	01:00	05:15	00:25
----	---	---	----	12:36:41	12:37:40	00:27	01:16	01:41
12:42:30	01:00 ?	08:01	12:44:04	----	12:44:53	-----	-----	-----
12:48:44	00:32	06:14	12:48:40	12:49:25	----	10:05	-----	00:09
----	---	---	----	12:59:42	13:01:46	00:23	10:17	10:26
13:04:23	00:25	15:39	----	13:05:20 u	----	-----	05:38	00:32
13:09:28	00:27	05:05	13:10:45	13:11:00	13:11:30	00:20	05:40	01:05
13:14:46	00:24	05:18	13:15:44	13:15:55	13:16:46	00:35	04:55	00:45
13:21:03	00:32	06:17	13:21:20	13:22:13	----	09:57	06:18	00:38
----	---	---	----	13:32:20	13:34:44	00:53	10:07	10:45
13:37:08	00:26	16:05	----	13:41:40 u	----	-----	09:20	04:06
13:44:04	00:25	06:56	13:45:35	13:45:50	13:46:42	00:40	04:10	01:21
13:49:45	00:25	05:41	13:49:57	13:50:22	----	01:12	04:32	00:12
----	---	---	----	13:51:45	13:52:54	00:23	01:23	01:35
13:58:26	00:27	08:41	14:00:04	14:00:19	14:00:50	00:26	08:34	01:26
14:04:26	00:24	06:00	14:04:40	14:05:29	14:07:06	00:57	05:10	00:39
14:11:28	00:28	07:02	14:12:27	----	14:13:52	-----	-----	-----
14:18:03	00:32	06:35	14:17:18	14:18:27	14:22:10	02:33	-----	??:??
14:27:57	00:31	09:54	14:29:37	14:29:50	14:30:22	00:23	11:23	01:22

12 August 1988

Start(N)	Dur	Int	Fill(S)	Start(S)	Drain	Dur	Int	After North
10:33:52	00:31	---	10:35:30	10:35:44	10:36:14	00:23	---	01:21
10:40:01	00:30	06:09	10:41:00	10:41:10	----	00:59	05:26	00:39
----	---	---	----	10:42:48	----	10:02	01:38	02:17
----	---	---	----	10:53:15	----	00:40	10:27	12:44
----	---	---	----	10:54:24	10:54:59	00:09	01:09	13:53
10:57:46	00:22	17:45	----	11:00:xx u	----	---	05:xx -	01:xx -
11:02:32	00:29	04:46	----	----	----	---	---	---
11:07:35	00:32	05:03	11:07:40	11:07:50	----	01:28	07:xx -	04:49
----	---	---	----	11:09:40	11:10:30	00:20	01:50	06:39
11:14:53	00:29	07:18	----	----	----	---	---	---
11:20:42	00:31	05:49	11:20:53	11:21:35	----	00:36	11:55	00:22
----	---	---	----	11:22:25	11:23:15	00:25	00:50	01:12
11:28:13	00:31	07:31	11:27:43	11:29:40	11:30:55	00:50	07:15	00:56

Observations of Anemone Geysers, 1985-1989

Start(N)	Dur	Int	Fill(S)	Start(S)	Drain	Dur	Int	After North
12 August 1988 (Cont.)								
11:35:02	00:31	06:49	11:35:16	11:36:19	----	01:11	06:39	00:46
----	---	---	----	11:37:40	----	09:20	01:21	02:07
----	---	---	----	11:47:30	11:49:15	00:18	09:50	11:57
11:51:38	00:26	16:36	----	----	----	---	---	---
11:58:44	00:27	07:06	12:00:00	12:00:20	12:01:20	00:xx ?	12:50	01:09
12:04:26	00:30	05:42	12:05:10	12:05:22	12:07:29	00:52	05:02	00:26
12:11:04	00:33	06:38	----	12:12:05 u	----	---	06:43	00:28
12:17:59	00:31	06:55	12:17:36	12:19:03	12:31:43	11:05	06:58	00:33
12:34:19	00:27	16:20	----	12:54:30 u	----	---	35:27	19:44
13 August 1988								
12:26:48	00:26	---	----	12:27:31 u	----	---	---	00:17
12:32:02 ?	00:30 ?	05:14 ?	----	----	----	---	---	---
12:37:20 ?	00:28 ?	05:18 ?	----	----	----	---	---	---
12:43:36 ?	00:26 ?	06:16 ?	----	----	----	---	---	---
12:52:35	00:33	08:59 ?	12:54:14	12:54:36	12:55:17	00:29	---	01:28
12:58:40	00:34	06:05	12:59:00	12:59:27	----	01:27	04:51	00:13
----	---	---	----	13:01:05	13:02:55	00:17	01:38	01:51
13:06:12	00:30	07:32	13:07:05	----	13:08:30	---	06:00	00:23
13:12:50	00:30	06:38	13:12:48	13:14:09	13:15:52	00:51	07:04	00:49
13:19:53	00:30	07:03	13:20:55	13:21:17	13:22:02	00:13	07:08	00:54
13:26:55	00:30	07:02	13:26:03	13:27:08	----	02:22	05:51	??:??
----	---	---	----	13:30:24	13:31:10	00:06	03:16	02:59
13:36:55	00:30	10:00	----	----	----	---	---	---
14:04:30 ?	00:24 ?	---	14:05:32	14:05:48	14:06:24	00:22 ?	---	00:54
14:09:35	00:27	05:05 ?	14:09:54	14:10:20	14:12:45	01:29	04:32	00:18
14:16:35	00:31	07:00	14:17:50	----	14:18:50	---	07:30	00:44
14:23:11	00:30	06:36	14:23:08	14:24:28	----	10:02	06:38	00:47
----	---	---	----	14:34:48	----	00:13	10:20	11:07
----	---	---	----	14:35:42	14:36:31	00:38	00:54	12:01
14:39:23	00:30	16:12	----	----	----	---	---	---
14:44:35	00:23	05:12	14:46:00	14:46:04	14:46:35	00:08	10:22	01:06
14:50:03	00:28	05:28	14:50:39	14:50:54	----	01:06	04:50	00:23
----	---	---	----	14:52:30	14:53:23	00:16	01:36	01:59
14:56:11	00:33	06:08	14:57:41	14:57:56	14:58:27	00:24	05:26	01:12
----	---	---	15:02:46	----	15:03:25	---	04:50	06:02
15:04:03	00:33	07:52	15:05:46	15:05:54	15:06:58	00:33	03:08	01:18
15:09:37	00:33	05:34	15:09:55	15:10:22	----	02:50	04:28	00:12
----	---	---	----	15:14:30	----	09:02	04:08	04:20
----	---	---	----	15:23:52	15:25:20	00:17	09:22	13:42
15:27:38	00:28	18:01	----	----	----	---	---	---
14 August 1988								
13:18:55	00:30	-----	13:20:29	13:20:57	13:21:35	00:28	---	01:32
13:25:03	00:32	06:08	13:25:25	13:26:08	----	11:47	05:11	00:33
----	---	---	----	13:38:35	13:39:27	00:17	12:27	13:00
13:41:56	00:27	16:53	----	----	----	---	---	---
13:46:34	00:27	04:38	----	13:49:xx u	----	---	10:xx ~	01:xx ~
13:52:01	00:30	05:27	13:52:20	13:52:23	13:55:25	01:55	03:xx ~	??:??
13:58:59	00:27	06:58	13:59:48	----	14:01:15	---	07:25	00:22
14:05:19	00:30	06:20	14:05:39	14:06:41	----	00:38	06:53	00:52
----	---	---	----	14:07:25	----	00:17	00:44	01:36
----	---	---	----	14:07:54	14:19:45	10:21	00:29	02:05
14:21:55	00:30 ?	16:36	----	----	----	---	---	---
14:27:10 ie	00:xx ~	05:xx ~	----	14:28:50 u	14:29:05	---	20:56	01:21
14:32:40 ie	00:xx ~	05:xx ~	----	14:32:40 ie	14:35:27	01:xx ~	03:xx ~	??:??
14:41:21	00:26	08:xx ~	14:42:50	14:43:06	14:43:35	00:14	10:xx ~	01:19
14:47:28	00:27	06:07	14:48:07	14:48:30	14:50:07	00:35	05:24	00:35
14:54:52	00:27	07:24	14:54:35	14:55:58	----	01:42	07:28	00:39
----	---	---	----	14:58:16	15:08:31	09:44	02:18	02:57
15:10:48	00:27	15:56	----	----	----	---	---	---
15:15:58	00:26	05:10	----	15:15:00 u	----	---	16:44	03:45
----	---	---	----	15:17:20	----	00:36	02:20	00:56
16 August 1988								
08:53:12	00:27	---	----	08:53:20 u	----	---	---	??:??
08:58:01	00:26	04:49	----	09:00:01 u	----	---	06:41 ?	01:34
09:03:21	00:27	05:20	09:03:45	09:03:50	09:06:17	01:30	03:49	00:02
09:09:59	00:29	06:38	09:11:50	----	09:12:15	---	08:00	01:22
09:16:25	00:29	06:26	09:16:20	09:17:35	----	01:05	05:45	00:41
----	---	---	----	09:19:10	----	09:40	01:35	02:16
----	---	---	----	09:29:07	09:30:23	00:13	09:57	12:13
09:32:51	00:26	16:26	----	09:39:06 u	----	---	09:59	05:49
----	---	---	09:41:20	09:41:30	09:42:50	01:15 ?	02:24	01:09

Observations of Anemone Geysers, 1985-1989

16 August 1988 (Cont.)

Start(N)	Dur	Int	Fill(S)	Start(S)	Drain	Dur	Int	After North
09:39:55	00:26	07:04	----	----	----	---	---	---
09:45:28	00:24	05:33	09:46:10	09:46:20	09:47:51	00:30	04:50	00:28
09:51:34	00:28	06:06	09:52:10	----	09:53:48	---	05:50	00:08
09:58:01	00:24	06:27	09:58:00	09:59:10	10:00:50	00:37	07:00	00:45
10:05:28	00:32	07:27	10:06:39	10:07:12	----	01:28	08:02	01:12
----	---	---	----	10:09:00	----	09:23	01:48	03:00
----	---	---	----	10:18:38	----	00:31	09:38	12:38
----	---	---	----	10:19:50	10:21:24	00:20	01:12	13:50
10:23:07	00:28	17:39	----	----	----	---	---	---
10:28:09	00:27	05:02	----	----	----	---	---	---
10:33:40	00:26	05:31	10:34:10	10:34:18	10:36:24	01:32	14:28	00:12
10:40:28	00:29	06:48						

18 August 1988

Start(N)	Dur	Int	Fill(S)	Start(S)	Drain	Dur	Int	After North
14:22:18	00:28	---	14:23:32	14:23:45	14:25:25	00:41	---	00:59
14:29:44	00:26	07:26	14:29:31	14:31:05	14:33:06	00:40	07:20	00:55
14:39:25	00:29	09:41	14:41:09	14:41:21	14:41:55	00:27	10:16	01:27
14:46:16	00:32	06:51	14:47:15	14:47:46	----	01:45	06:25	00:58
----	---	---	----	14:50:37	----	10:48	02:51	03:49
----	---	---	----	15:01:42	----	00:19	11:05	14:54
----	---	---	----	15:02:30	15:03:44	00:15	00:48	15:42
15:07:06	00:25	20:50	----	----	----	---	---	---
15:12:38	00:26	05:32	----	15:14:12	15:14:28	00:13	11:42	01:08
15:18:49	00:25	06:11	15:19:26	15:19:46	15:22:00	00:50	05:34	00:32

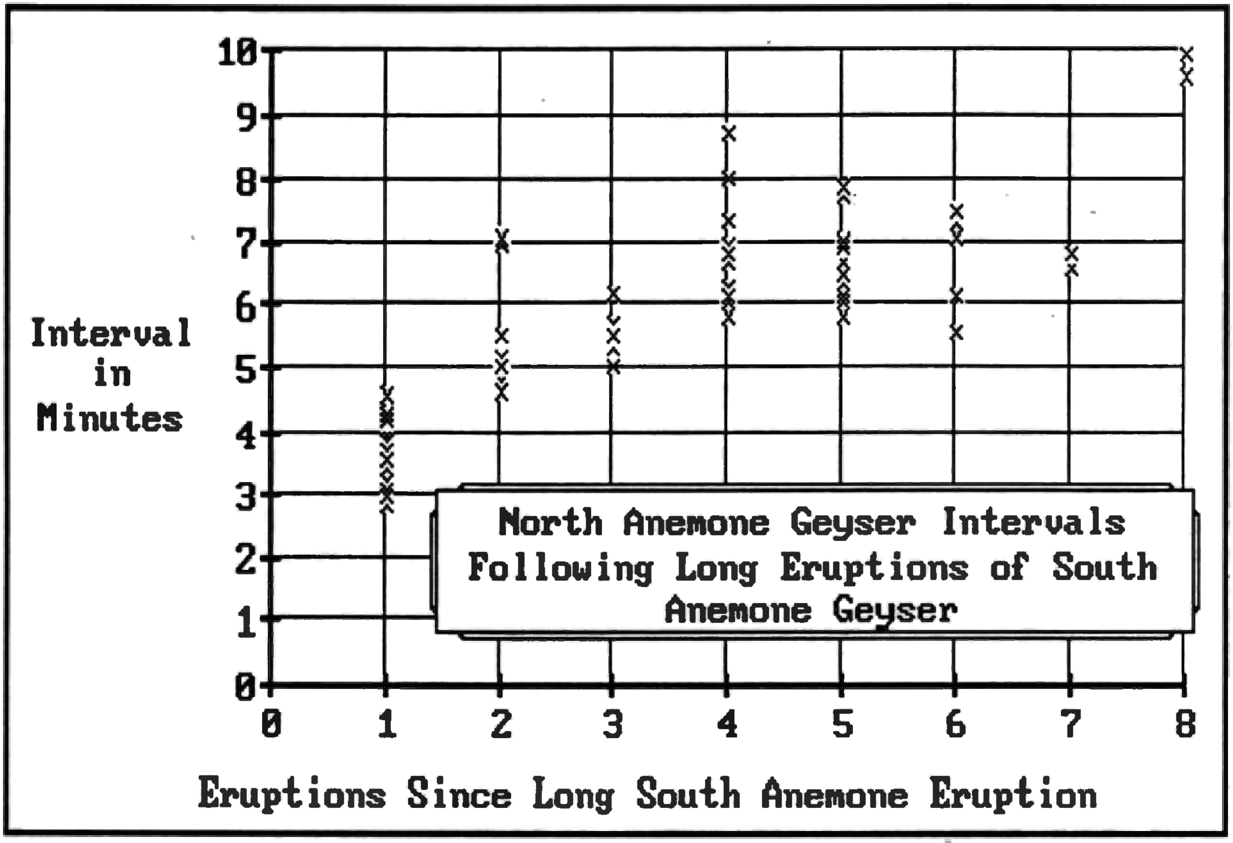


Figure 1

5 Discussion and Analysis

Examination of the summary data in section 4.3 shows that both North Anemone and South Anemone Geysers were very regular in both duration and interval in 1985, 1986, and 1987. During these years, the durations of the eruptions of both geysers were very consistent, showing little variation from day to day. The intervals show more variation, having standard deviations of a few seconds to just under a minute on mean intervals between six and eight minutes.

In 1988, however, the regularity was upset dramatically by a change in the pattern of eruption of South Anemone Geyser. Approximately every 45 minutes, South Anemone Geyser had a long eruption, lasting from 9 to 12 minutes (from the initial fill to the final drain). This long eruption always suppressed any activity from North Anemone Geyser. Once South Anemone Geyser stopped drained, North Anemone invariably erupted within 2m45s to 4m15s. North Anemone then erupted regularly, with intervals slowly increasing in length, as shown in Figure 1. By the fourth eruption, the intervals stabilized in the 6 to 8 minute range, which was near the 1985 and 1987 mean interval.

Figure 1 is a plot of the North Anemone Geyser interval vs. the eruption number following a long South Anemone Geyser eruption. This plot shows the almost linear trend of increasing interval following the long eruption as the system recovers energy.

Despite the irregularity of the interval, North Anemone Geyser maintained a very constant 28.5m duration, with a Standard Deviation of only 3.0s. This represents nearly a 10 second decline in duration from the 1985-87 activity, probably caused by the strong activity in South Anemone.

The intervals and durations of South Anemone Geyser, aside from the long eruptions, showed considerably more variation than in previous years. Missing eruptions, long eruptions, and eruptions before, instead of after, North Anemone Geyser, were all seen in 1988; there were even concerted eruptions on occasion.

5.1 North Anemone Geyser

In 1985, North Anemone had a mean duration of 35.5s, with a Standard Deviation of 5.5s. The daily means fluctuated from 31.5s to 38.9s. Most durations were between 29s and 39s. Intervals averaged 6m55s with a Standard Deviation of 2m57s. This high deviation was caused by one eruption of South Anemone that was in the 1988 pattern; a 12m56s duration eruption on 8 August that caused a North Anemone interval of 20m22s. The following intervals were short but lengthened in the 1988 pattern. The observed intervals on that day were near the mean.

In 1986, North Anemone lengthened its eruption duration to 40.2s, with a notably smaller Standard Deviation of only 3.3s for all observations that year. The daily means were all between 36.5s and 41.4s. On most days, the Standard Deviation was under 3 seconds. Most observed durations were between 36 and 45 seconds. Intervals averaged 8m7s for all of the observed eruptions. The Standard Deviation was just 27.7s. The intervals were constant from day to day, showing only a 30 second range. On most days, the Standard Deviation was under 10s. 18 July 1986 had a relatively high Standard Deviation, caused by one short (5m30s) interval; the rest of the intervals that day were all between 8m6s and 8m20s.

In 1987, observations were recorded for only two days, but more intervals were observed each day. The mean duration dropped to 38.4s, with a Standard Deviation of just 3.7s. Most observed durations were between 36s and 43s. Intervals in 1987 dropped to an average of 6m44s with a Standard Deviation of just 16.9s. 1987 had the lowest variability in interval of all years observed.

In 1988, the duration of the North Anemone eruptions dropped to an average of 28.5s, with a Standard Deviation of just 3.0s. The ten second drop in duration is clearly related to the increased activity of South Anemone Geyser, which overflowed much more than in previous years, leaving significantly less water available for North Anemone Geyser. It is interesting to note that in 1988 the durations for North Anemone Geyser were the most constant of any year observed, while the intervals and the behavior of South Anemone Geyser was much more variable.

The intervals of North Anemone Geyser were much more variable in 1988 than in the other years observed, but followed a distinct pattern (see section 3). The overall mean interval was 8m15.4s, near the 1986 average and longer than the 1985 and 1987 averages. However, the Standard Deviation was 4m4.8s, indicating the large variability. Typically, the intervals were 10 to 17 minutes during a long eruption of South Anemone Geyser.

The intervals dropped to 2m45s to 4m20s for the interval immediately following the long South Anemone Geyser eruption (this interval measured from the end of the South Anemone Geyser eruption). The first full interval between North Anemone Geyser eruptions following a long South Anemone Geyser eruption was between 4m40s and 5m20s; the second interval varied from 5m to 6m10s, with most intervals being between 5m20s and 5m45s. The third and subsequent intervals were between 6 and 8 minutes, approximating the mean interval seen in 1985-87. The scatter in interval increased after the third interval as well, probably because the influence of the long South Anemone Geyser eruption on the availability of water had diminished. The shortened duration following the long South Anemone Geyser eruption was apparently caused by a shortage of water rather than less energy, as the vigor of the eruption was not less than in 1985-87, and the beginning of the first eruptions following the long eruption began from an empty crater with a spray of steam and water changing to the typical full surges of water.

The variation between the daily means for North Anemone Geyser intervals is caused largely by a variation in the number of long South Anemone Geyser eruptions seen. These eruptions were relatively infrequent; some days none were observed (e.g., 6 August 1988). This was because of a relatively short observation period rather than a lack of long eruptions.

5.2 South Anemone Geyser

South Anemone Geyser exhibited a wider variation in its behavior than North Anemone Geyser. The duration of the eruptions of South Anemone Geyser has been relatively constant, but eruptions are often skipped, in the sense that the "normal" eruption of South Anemone Geyser following an eruption of North Anemone Geyser may not occur.

In 1985, the duration of South Anemone Geyser eruptions averaged 1m35.1s with a Standard Deviation of 3m10.1s. The largest variation was because of one very long eruption on 8 August. This eruption was much like those seen frequently in 1988. The daily Standard Deviations for 1985, ignoring the day with the long eruption, were 12.8s and 15.7s, much larger than those for North Anemone Geyser. The durations observed varied from 17 seconds to over 2 minutes. Some of this may be attributable to the difficulty in determining the precise beginning and end of the eruption.

The intervals for South Anemone Geyser in 1985 averaged 9m49.3s, but this is distorted by the long eruption on 8 August. The Standard Deviation was 5m5.4s, again distorted by the long eruption. The intervals for South Anemone Geyser are generally similar to those for North Anemone Geyser, since the eruptions follow those of North Anemone. The last columns in the South Anemone Geyser data show the time from the end of the North Anemone Geyser eruption to the start of the subsequent South Anemone Geyser eruption was computed. The mean time between the end of a North Anemone Geyser eruption and the subsequent South Anemone Geyser eruption start had a mean of 2m33.4s in 1985, with a 4m9.6s Standard Deviation. The Standard Deviation is typically in the 8 to 12 second range in the absence of long eruptions of South Anemone Geyser.

In 1986, South Anemone Geyser's duration averaged 28.0s with a 10s Standard Deviation. The range of durations was 11s to 45s. Some of the shorter eruptions are weak. The 1986 intervals averaged 8m8.9s with a Standard Deviation of 37.5s, and the eruptions of South Anemone Geyser followed those of North Anemone Geyser by an average of 1m42.5s with a Standard Deviation of 14.5s.

In 1987, South Anemone Geyser had an average duration of 27.0s with a Standard Deviation of 4.7s. The intervals averaged 6m44.3s, exactly the average for North Anemone Geyser that year. The Standard Deviations were within 0.1 second of each other as well. The lag of South Anemone Geyser from North Anemone Geyser was 1m24.1s with a Standard Deviation of 9.8s. When matched with the preceding North Anemone Geyser eruption, the intervals of South Anemone Geyser did not show such a close match.

In 1988, South Anemone Geyser's change in function is evident from the statistics. The mean duration was 2m23.2s, and the corresponding Standard Deviation was 3m31.5s. These averages are not very useful considering the pattern of eruption seen. The recorded times show the long eruptions to be a series of eruptions beginning with the filling of the crater and consisting of three to six distinct bursts of activity without the crater emptying. Usually one of the eruptions was much longer than the rest, in the range of 9 to 11 minutes in duration. The remainder of the eruptions lasted anywhere from 10 seconds to 2 or 3 minutes. The mean duration shown in the tables includes each of these individual episodes as a distinct duration. Taking the duration as the total time from the fill of the crater until the final drain, the durations are typically 13 minutes, with a range from 11 to just over 15 minutes.

The eruption following the long eruption of South Anemone Geyser was often only observed as a boiling heard from the crater. The next visible eruption did not appear to be unusually short, but the data do not include enough observations to support a general conclusion.

Table I - Long intervals of South Anemone Geyser

5 August 1988	33:23
	27:31
8 August 1988	46:58
9 August 1988	41:14
10 August 1988	32:40
12 August 1988	54:16
	42:20
13 August 1988	46:47
14 August 1988	40:14
	48:56
16 August 1988	50:19

The 1988 South Anemone Geyser intervals averaged 6m33.8s with a 4m50.1s Standard Deviation. The large deviations are caused by the periodic long eruptions. These long eruptions appear to occur at intervals of about 45 minutes (see Table 1) but this interval is based on relatively few closed intervals. There is one instance of an observed interval in excess of one hour with no long South Anemone Geyser eruption (from 13:21:20 until 14:29:37 on 10 August 1988). The intervals between the long eruptions range from 27m31s to 54m16s. The intervals on a given day tend to be similar, with more variation from day to day.

The time between the end of a North Anemone Geyser eruption and the subsequent start of South Anemone Geyser was also highly variable, with a mean of 3m29.8s and a Standard Deviation of 4m22.0s. The mean was significantly higher than in previous years. Perhaps more significantly, in 1988 South Anemone Geyser sometimes erupted before North Anemone Geyser, and on occasion the two geysers erupted together. This seemed to have no effect on the eruption of North Anemone Geyser; it proceeded at its normal time and with its normal duration. Sometimes these concerted eruptions were the start of a long South Anemone Geyser eruption, but not always.

The long South Anemone Geyser eruptions suggest that there has been a significant shift in energy from North Anemone Geyser to South Anemone Geyser. To test this hypothesis, the fraction of the time in eruption for each geyser was computed to determine whether there was such a shift. The results are shown in Table II. In 1985, both geysers were active about 8% of the time except for 8 August, when the single long eruption seen in 1985 changed the percentage. In 1986 North Anemone Geyser stayed at about 8% and South Anemone Geyser dropped to between 5% and 6%. In 1987, North Anemone Geyser was active about 9% of the time, and South Anemone Geyser was active 7% of the time. For all three of these years, the percentage of active time for South Anemone Geyser was computed from the start and stop times, which were measured as described in Section 4.

In 1988, North Anemone Geyser was active only 6% of the time, a result of the shorter durations and the long quiet periods during the extended South Anemone Geyser eruptions. To take into account South Anemone Geyser's new pattern of eruption, the percent active time for 1988 was computed from the fill time and drain time, as the full pool indicated the presence of thermal energy above the usual amount. Using this convention, which exaggerates the percentage somewhat, the increase in energy in South Anemone is clear. On most days, South Anemone was active 40% of the time or more.

The other thermal features in the vicinity did not appear to be significantly more powerful in 1988 than in previous years, so the increase in energy seen in South Anemone does not appear to be part of a general increase in the southwest part of Geyser Hill. All of the 1988 observations reported here were made between the Giantess Geyser eruptions on 8 July and 28 August [Bryan 88]. It would be interesting to know whether the behavior of the Anemone Geysers was affected by the 28 August eruption of Giantess Geyser, especially so as Bryan also reports that Beehive became much less frequent at about the same time.

Table II - Percent of Time Active North and South Anemone Geysers

Date	% of time active North	South
3 Aug 1985	8.0%	---
4 Aug 1985	9.3%	7.1%
7 Aug 1985	8.3%	8.2%
8 Aug 1985	8.3%	29.5%
All 1985:	8.5%	21.6%
17 July 1986	7.8%	5.4%
18 July 1986	8.6%	5.4%
2 Aug 1986	8.6%	4.5%
3 Aug 1986	7.9%	---
4 Aug 1986	8.6%	5.0%
5 Aug 1986	7.6%	10.9%
6 Aug 1986	8.3%	6.2%
All 1986:	8.3%	5.6%
2 Aug 1987	9.6%	6.9%
3 Aug 1987	9.4%	6.7%
All 1987:	9.5%	6.8%
5 Aug 1988	5.6%	40.1%
6 Aug 1988	7.4%	25.1%
8 Aug 1988	6.0%	34.8%
9 Aug 1988	5.4%	43.5%
10 Aug 1988	5.2%	35.2%
12 Aug 1988	5.6%	40.0%
13 Aug 1988	6.1%	44.4%
14 Aug 1988	5.7%	44.2%
16 Aug 1988	5.9%	43.9%
18 Aug 1988	4.8%	42.3%
All 1988:	5.7%	40.1%

6 Future Research

In analyzing the eruption data for the Anemone Geysers, it has become clear that longer runs of observations are needed. The geysers do not show substantial variation from day to day. However, in 1988 South Anemone Geyser showed a periodic long eruption cycle of about one hour in length.

If the Anemone Geysers revert to the older pattern, there is still a need for at least some full day, unbroken records of activity to determine whether the pattern was really as constant as it appeared or whether the long eruptions of South Anemone were just less frequent. The one long eruption of South Anemone Geyser seen on 8 August 1985, during a time when the durations and intervals were constant and the geyser showed no overt signs of the long South Anemone Geyser eruptions, suggest that these long eruptions can occur at any time.

A refinement in data taking also suggests itself. The author's raw data contain some indications of whether the South Anemone crater filled before the North Anemone Geyser eruption, but these notes are not included here as they were not recorded systematically. More intervals are needed, noting the fill and drain times for South Anemone Geyser (as shown in the later 1988 data) to determine which times are significant.

With more observations, it may become clearer whether the actual eruption cycles of South Anemone Geyser within the long eruptions are the most significant measure of the long eruptions, or whether the time from the initial filling of the crater to the final draining of the crater is more significant.

References

[Bryan 1986] The Geysers of Yellowstone, T. Scott Bryan, Colorado Associated University Press, 1986

[Bryan 1988] "Some News About Geysers", The Geyser Gazer SPUT Volume 2, Number 5, October 1988

[Marler 1973] Inventory of Thermal Features of the Firehole River Geyser Basins and Other Selected Areas of Yellowstone National Park, G. D. Marler, Geological Survey and National Park Service, Menlo Park, California June 1973

Cascade Geyser Reactivates

Mike Keller

During January of 1988 Cascade Geyser erupted. This was its first active cycle since the winter of 1983/84, and only its fifth historically documented eruptive sequence. Even though Cascade's eruptive activity lasted only three days, other nearby thermal features were effected.

The first eruption witnessed in this sequence was on January 20. Sandy Snell (a naturalist at Old Faithful) and I were on Geyser Hill when we noticed a geyser erupting that was unfamiliar. The play lasted around 2 minutes and reached a height between 8 and 12 feet. This activity continued at intervals of 11 to 36 minutes until I left Geyser Hill that evening.

The following day Cascade remained active without major changes from the previous day. When viewed from the vicinity of Chinaman Spring the eruption include a fair cascade of water into the Firehole river. Cascade erupted from a half full pool and overflow was not achieved until nearly 80 seconds into the eruption. Thumping could be felt to the south-west of the crater seconds prior to the eruption. By mid-afternoon the intervals began the lengthen to between 57 and 74 minutes. There was no change in durations.

By the morning of January 22 the intervals had increased to between 120 and 145 minutes, the height had decreased to 4 feet, and the quantity of water discharged decreased. No further eruptions were observed after January 22.

While Cascade was active other nearby geysers changed their activity. The most obviously effected was Beehive Geyser. Prior to January 20 it had been erupting every 1 to 4 days. From January 18 through 26 Beehive did not erupt. Its activity declined to the point that there was no boiling inside the cone on January 21. Similarly, Anemone's average interval increased from an 7 minutes to near 20 minutes, and Little Anemone became inactive. It was not until February 4 that Anemone recovered fully to its pre-Cascade activity. Finally, Little Squirt had its first eruption of the winter. This eruption began on January 19 and continued to February 1.

Table I
Known Eruptions of Cascade Geyser, 20-22 January 1988

Date	Time	Duration(sec)	Interval(min)	Height(ft)
1/20/89	1127	118	--	10
	1141	122	14	12
	1158	123	17	12
	1223	117	25	12
	1235	114	12	10
	1259	136	24	12
	1313	120	14	8
	1349	118	36	12
	1404	121	15	12
	1423	110	19	10
	1438	143	15	10
	1500	125	22	10
	1526	119	26	10
	1543	121	17	10
	1604	119	21	12
	1626	120	22	8
	1649	132	23	10
	1702	108	23	10
	1733	116	31	10
1/21/89	0950	122	--	10
	1022	117	32	12
	1043	118	21	12
	1100	121	17	12
	1121	11	21	12
	1153	134	32	12
	1214	99	21	12
	1242	116	28	8
	1319	128	36	8
	1345	117	26	10
	1412	126	27	10
	1506	107	54	10
	1603	142	57	10
	1709	117	66	10
	1823	124	74	10
1/22/89	0647	134	--	8
	0847	126	120	8
	1046	129	119	6
	1311	131	145	4
	1526	115	135	4
	1744	127	138	4

THE GRAND GEYSER COMPLEX, SUMMER 1978

by
Suzanne Strasser

ABSTRACT

From June 4 until July 8, 1978, an intensive effort was made to record data for 100 consecutive intervals (101 consecutive eruptions) of Grand Geyser. Data for several other geysers in the Grand Geyser Group were also collected. Purposes of the study were: 1) to determine the interrelationships among the various geysers in the group and to record their effect on the length of Grand's intervals; 2) to perform various statistical tests on parameters such as eruption duration, number of bursts, and intervals between eruptions; 3) to record changes in Grand's behavior during the period of study. The following paper summarizes the observations and data that were collected.

HISTORY

Since its discovery in 1871, Grand Geyser has been recognized as one of the most prominent geysers in Yellowstone. Records of its activity in the last century indicate that Grand was, at different periods, dormant, infrequent, or erupting at intervals ranging from hours to days.

Grand is a fountain geyser, erupting from a pool rather than from a cone. It differs from other fountain geysers in that its eruptions consist of a series of distinct and separate bursts, each characterized by hundreds of separate jets of water. The initial surge of water in any burst reaches the maximum height, which can range from 120 to nearly 200 feet. Between bursts, Grand shuts down completely for about a minute; the only indication that the eruption will continue is the presence of water in Grand's pool. The eight- to ten-minute duration of the first burst is much longer than any of the succeeding bursts, most of which have durations of less than one minute. When the eruption is over, the pool drains completely.

Other geysers will join with Grand in the display. Turban Geyser, intimately connected with Grand, will start its ragged eight-foot splashing eruption within moments of the start of Grand. The oblique water column of Vent Geyser joins the show a few minutes following the start.

Prior to an eruption, Grand gives little appearance of eruption potential. Its wide, shallow pool is often ignored by tourists, who see the lusty splashing of Turban every 20 minutes and assume that Turban is Grand. These Turban eruptions are significant, however, because Grand can only erupt when Turban is due.

Following its recovery from dormancy caused by the 1959 Hebgen Lake earthquake, Grand has become more regular. In most years its interval averages approximately 8-1/2 hours, varying from 7 to over 14. The most striking change in behavior in the last 30 years was the abrupt decline in number of bursts that occurred in 1969. Prior to that year there were routinely eight to twelve bursts in an eruption. Since then, nearly all eruptions consist of one to five bursts, although as many as eleven have rarely been seen.

Grand is not a separate and solitary feature. Surrounding it are numerous other geysers, most of which are connected underground with Grand. These include but are not limited to Turban, Vent, Rift, West Triplet, and "Percolator" geysers. The observed interrelationships of these geysers with Grand will be discussed.

ERUPTION CHARACTERISTICS OF GRAND, TURBAN, AND VENT GEYSERS

Grand Geyser

During the period of study, an average eruption of Grand Geyser had a duration of 12 minutes and 25 seconds, and contained 3 bursts (statistical average = 2.80). Each eruption was preceded by waves rippling outward from the center of Grand's pool, gradually becoming larger until water domed 3 to 4 feet from the orifice, marking the start of the eruption.

If the first burst duration was relatively short (6 to 8-1/2 minutes), there was a chance that Grand would have a four- or five-burst eruption. However, if the first burst duration was longer (10 to 12 minutes), a total of only one or two bursts could be expected.

Occasionally, when Grand had a short first burst, the second burst duration would be quite long, averaging 2 to 4 minutes. In those instances only a total of three bursts could be expected, due to the great depletion of energy in the long second burst.

Sometimes Grand had short 1- to 2-second pauses during a burst. Because the water never totally stopped jetting from the orifice, these were not considered to be true pauses between the end of one burst and the start of another. The longer duration first bursts tended to have one or two of these small pauses; on one occasion a second burst with a duration of 4 minutes was observed to have five of these "fake stops."

The total duration of Grand's eruption also depended upon the number of bursts. Five-burst eruptions usually had a total duration of 13 to 14 minutes, while one-burst eruptions normally lasted 11 to 12 minutes.

When the total duration of an eruption of Grand was longer than average, Turban and Vent Geysers would usually quit afterwards. In this case, Turban would drain immediately after Grand's eruption was finished, with Vent quitting one to two minutes afterwards. Five to twenty minutes later, Turban and Vent would start to erupt again, in what is commonly known as the "afterplay."

When Grand had a shorter than average total duration, Turban and Vent would usually continue into afterplay without stopping immediately after Grand. The afterplay normally lasted 1 to 2 hours. An unusually long afterplay could delay Grand's following eruption. One such afterplay continued 3 hours and 20 minutes after Grand. The next eruption came 6 hours and 20 minutes following the end of afterplay, causing Grand to have a 9 hour 47 minute interval.

An unusually long 10- to 11-hour interval between eruptions did not necessarily indicate that Grand would have a spectacular eruption. A one-burst eruption could occur after an 11-hour interval just as easily as a five-burst eruption could follow a 7-hour interval.

Turban and Vent Geysers

Turban Geyser usually began its eruption 30 to 70 seconds after the start of Grand. Occasionally, however, Turban would erupt first, with Grand following a few seconds to a minute later. Vent Geyser began its eruption approximately 2-1/2 minutes after the start of whichever geyser (Turban or Grand) happened to be the first to erupt. Thus, when Grand started before Turban, Vent would follow 2-1/2 minutes later. However, when Turban started first, Vent would follow the start of Grand after only about 2 minutes.

Occasionally Turban would erupt even before waves could be sighted on the surface of Grand's pool. This type of eruption was normally preceded by a low water level in Grand's pool; the ridges of rock near the front of the pool would be nearly, but not completely, covered.

However, after the start of Turban, the conditions would change abruptly: within 30 seconds the level of Grand's pool would rise at a very rapid rate. Waves would then follow, lasting only about 10 seconds before the start of Grand.

Another type of eruption occurred when the waves on Grand's pool would stop, only to start up again. The water level of Grand's pool dropped, Turban began its eruption, but Grand's pool then refilled extremely rapidly. The waves started again with little warning, and Grand began to erupt almost immediately afterwards. In such a case, an event known as "the 40-minute delay" (to be discussed later), was averted.

Delayed bursts

During the summer of 1978, five eruptions of Grand had an unusual feature known as a "delayed burst." Two occurred during the period of study; one was a fifth burst that had a 6 minute 1 second pause after the fourth burst. The other was a third burst that occurred approximately 20 minutes after the second burst. The other three delayed bursts had 6- to 8-minute pauses after the previous burst. In all five cases Turban and Vent continued into afterplay immediately after Grand.

The following describes the typical sequence of events that could result in a delayed burst. After the "normal" bursts, water would drain into Grand's crater as usual, supposedly indicating that Grand had completed its eruption. However, five minutes later, water could be seen splashing out of Grand's orifice. This splashing, normal during afterplay, would be more vigorous and higher than usual. The splashes would continue to build in height until enough pressure could be released for Grand to have one final burst. The delayed burst would always be smaller than normal (about 100 feet in height), and the duration would range from 30 to 45 seconds. Turban and Vent would continue their afterplay following the delayed burst.

CAUSES FOR INCREASES IN GRAND'S AVERAGE INTERVAL IN 1978

During June 1978, Grand continued to erupt at regular and predictable intervals, with the majority of its eruptions occurring every 7 to 9 hours. However, two factors caused the average interval of 8 hours and 17 minutes to increase above the 1977 average of 8 hours and 1 minute [Hutchinson, 1978].

In the first few weeks of June, Rift Geyser dominated the scene, causing delays as long as three hours in Grand's eruptions. If all of the Rift-delayed eruptions were omitted, Grand's average interval would decrease to 8 hours and 5 minutes. In addition, during the latter part of the month, there were numerous occasions when Grand had waves upon the surface of its pool but no eruption occurred immediately afterwards. In these instances the eruption would usually occur two cycles of Turban later, causing a 40-minute delay.

EARLY TO MID-JUNE: DELAYS CAUSED BY RIFT AND RELATED GEYSERS

Rift Geyser

Most geyser gazers regarded Rift Geyser, with its sputtering sounds and 3-foot splashes, to be a very unpopular feature in the Upper Geyser Basin. From June 7 until June 16, it erupted with greater frequency than had been recorded in recent years, averaging once a day. Prior to June 7, log book records [1978] showed that Rift had erupted fifteen times in 1978. At least two eruptions per month were observed from January through March, and four eruptions occurred in May. The increase in the number of eruptions of Rift, along with an increase in the activity of West Triplet and "Percolator" geysers, indicated that there was an energy shift away from Grand toward Rift and its vicinity.

Of the eleven observed eruptions of Rift during the period of study, seven significantly delayed Grand, while the other four had no apparent effect. The shortest interval between Rift eruptions was 17 hours and 57 minutes, occurring June 8-9. In this case, the two eruptions of Rift delayed <u>three</u> eruptions of Grand.

On average, Rift erupted once a day with a duration of approximately 2 hours. The longest observed interval between Rift eruptions was 42.5 hours from June 5 through June 7.

The longest delay that Rift had upon Grand's eruption was approximately 4 hours. The typical pattern was for Grand to erupt 3 hours after Rift finished its eruption. However, Grand occasionally erupted in concert with Rift. In the latter case, Rift usually stopped immediately after Grand finished its eruption.

An observer could not accurately predict the length of Grand's delay based upon Rift's duration or the time period between Grand's previous eruption and the start of Rift. One could only be certain that Grand would be unpredictable and that its eruption could be delayed anywhere from 0 to 4 hours.

<u>West Triplet Geyser</u>

An eruption of West Triplet started with heavy overflow accompanied by thumping noises. Water splashed 3 to 4 feet in height, with a duration ranging from a few seconds to 10 minutes. This activity most frequently occurred immediately before an eruption of Rift. On several occasions the geyser erupted vigorously for 10 to 15 minutes. Immediately after the eruption ended, Rift Geyser started, and the pool of West Triplet drained completely. On another occasion, Rift and West Triplet erupted together for 12 minutes before West Triplet drained. Two other times, West Triplet was observed in eruption <u>before</u> its pool had reached overflow level; the pool then gradually filled during the eruption, and overflow started after approximately one minute.

During an eruption of Rift, the pool of West Triplet would <u>always</u> drain. Several hours would pass before West Triplet's pool refilled and water began to overflow the crater.

<u>"Percolator" Geyser</u>

"Percolator" Geyser was active for about half of the eruptions observed until June 19. Its eruption, consisting of small, 2- to 3-foot splashes, usually preceded Rift. As Rift began erupting, Percolator changed into a noisy fumarole and then quieted down gradually, finally becoming inactive as Rift took total control of the scene.

CONDITIONS RETURN TO NORMAL: RIFT BECOMES INACTIVE

After June 16, the conditions in Rift, West Triplet, and Percolator changed. West Triplet was in a near-constant state of overflow; the eruptions accompanied by the thumping noises ceased. This continued throughout the summer. After mid-July, orange algae could be seen growing inside the crater. Percolator stopped all activity on June 19 and was quiet for the rest of the summer. Rift was also quiet. Only small amounts of steam occasionally welled out from the rock pile of Rift's crater, and gurgling noises could be heard at depth. Without the interference of Rift, Grand once again began having shorter intervals.

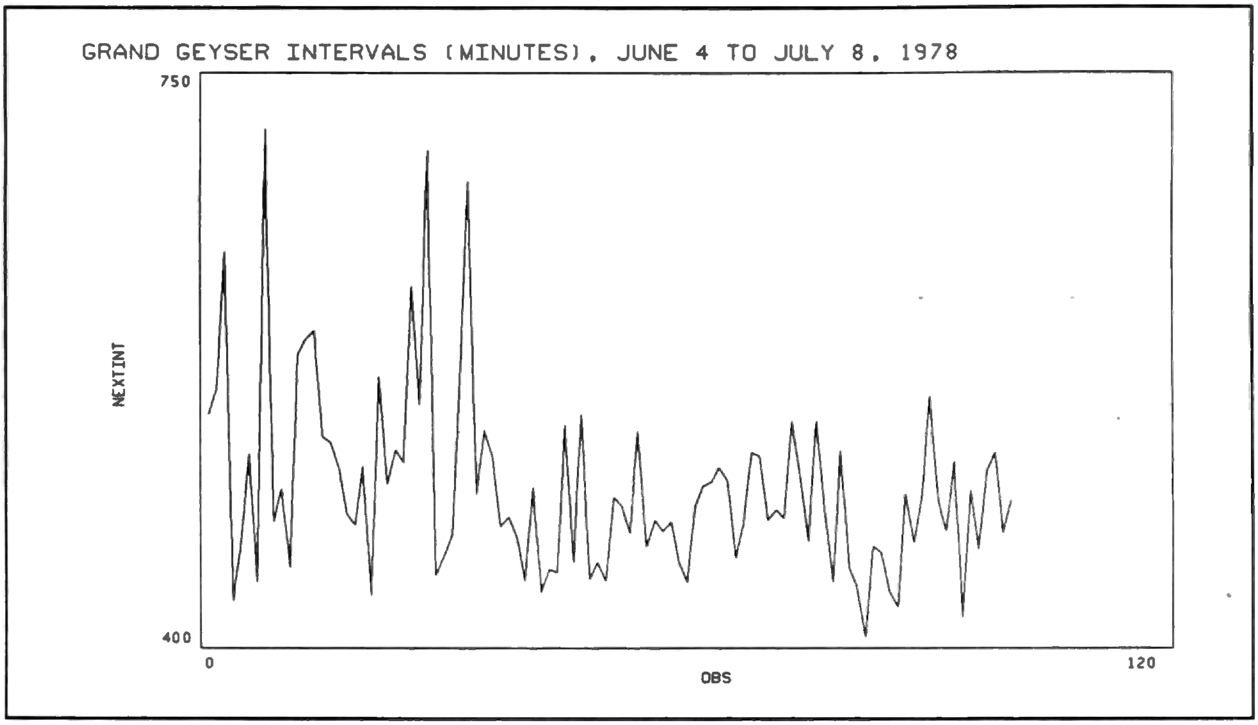


Figure 1. Grand Geyser Intervals.

Figure 1 above shows a time-series graph of all of Grand's intervals recorded during the period of study. The tall spikes on the left side of the graph show the long intervals caused by Rift's eruptions. The right side shows the shorter intervals of Grand which occurred after Rift became inactive. Rift had one more eruption during the summer: on July 16, after the study had ended. For a full seven hours it erupted, its longest duration of the summer. However, no delay on Grand's following eruption was observed.

THE 40-MINUTE DELAY

Seven and a half hours have passed since Grand's last eruption, and a crowd has already assembled for the next show. Suddenly small waves come rippling out from the center of Grand's pool. A murmur of excitement arises from those who have knowledge of Grand's indicator - the waves signify that Grand is due to erupt!

But what is happening? The small waves suddenly have dwindled into nothing, and small ridges of rock jut out ominously above the dropping level of Grand's pool. Turban is late - at least 4 minutes. Finally Turban erupts, and the disappointed crowd settles down for at least another 20-minute wait.

This type of activity characterized several of Grand's eruptions at the end of June and throughout July. Marler [1964] stated that these cases of "false waves" very rarely occurred. However, 7 of the 101 observed eruptions contained these false waves.

The "false waves" usually started 7 to 7-1/2 hours after

Grand's previous eruption. The waves were quite small and rarely reached the size of the "breakers" that develop about 10 seconds prior to Grand's eruption. The average duration of the waves was 3 to 4 minutes, considerably longer than the 96-second average duration of the "real waves" preceding an eruption. Soon the waves stopped altogether, and the level of Grand's pool began to drop. After a 3- to 4-minute period of quiet, Turban erupted, usually after a long interval of 24 to 27 minutes.

As late as 1979, it was believed that if waves were observed on Grand's pool without resulting in an eruption, Grand would erupt on the next Turban cycle [Bryan, 1979]. It was believed that the presence of waves on Grand's pool was an excellent indicator of an eruption either within seconds or in approximately twenty minutes.

The observations made during 1978 established that this theory was erroneous. Contrary to the belief, waves on the pool of Grand without a resulting eruption were actually an indicator that Grand would not erupt for at least two Turban cycles.

The "40-minute delay" was in progress. During the following cycle of Turban the level of Grand's pool rose only slightly; the ridges at the front of the pool continued to jut out and were never completely covered. Turban then erupted 2 to 3 minutes <u>early</u>, having only a 17- to 18-minute interval. Finally, two cycles of Turban after the false-indicator waves, Grand was once again ready to erupt. The pool completely filled, the waves started once again, and an eruption of Grand <u>usually</u> followed, almost a full 40 minutes after the false waves appeared.

Occasionally Grand's eruption was delayed not 40, but 60 minutes after the false waves. On one occasion Grand had two 40-minute delays in a row, creating a long and frustrating wait for many tourists.

On another occasion Grand was observed to have very large waves followed by water splashing 2 to 3 feet from the orifice, but no eruption occurred. In this case, the delay was 60 minutes.

There was only one time during the entire year when Grand was observed to erupt just 20 minutes after the false waves. Thus a person observing false waves could be fairly safe in assuming that he would have <u>at least</u> 40 minutes but <u>possibly</u> 60 minutes to wait before Grand's eruption.

<u>"Low pool waves"</u>

During the delay caused by an eruption of Rift Geyser, small waves on Grand's pool were commonly observed. At these times, Grand's pool was not at a full level. Instead, the water level would be at least a half inch below full, and these small waves, little more than ripples in the water, were often seen near the edge of the pool.

These "low pool waves" are not to be confused with the larger, more forceful waves associated with the start of the 40-minute delay. They most likely represent the recovery of Grand from the effects of the Rift eruption, a time when more energy than water was available to the plumbing system. There is no evidence that low pool waves are of any significance to the likelihood of an impending eruption.

STATISTICAL ANALYSIS

Tables 1-3 contain descriptive statistics for all of the variables measured during the study. Table 1 contains the statistics for all eruptions recorded during the period of study, while Tables 2 and 3 contain the means for eruptions with and without activity from Rift geyser, respectively. All statistics were computed using the NCSS microcomputer programs [Hintze, 1987].

Table 1. Statistical Summary
ALL ERUPTIONS*

Variable	Count	Mean	St.Dev	Min	Max
WAVES	60	96	54	12	260
ALL TURBAN STARTS	58	15	53	-143	129
TURBAN START AFTER GRAND	34	52	23	14	129
TURBAN START BEFORE GRAND	22	-42	35	-143	-4
VENT START AFTER GRAND	64	145	26	78	198
VENT AFTER TURBAN OR GRAND	53	159	23	109	221
BURST 1	101	9m 25	1m 19	6m 15	12m 01
BURST 2	96	62	43	23	240
BURST 3	65	44	20	23	150
BURST 4	18	44	10	29	62
BURST 5	1	35	--	35	35
PAUSE 1	96	41	18	19	168
PAUSE 2	65	54	16	25	127
PAUSE 3	18	59	11	34	83
PAUSE 4	1	75	--	75	75
NUMBER OF BURSTS (includes afterbursts)	101	2.80	0.84	1	5
NUMBER OF BURSTS (excludes afterbursts)	101	2.78	0.82	1	5
FIRST BURST DURATION:					
DURING A 1-BURST ERUPTION	5	11m 26	26	10m 54	12m 01
DURING A 2-BURST ERUPTION	30	10m 26	52	7m 51	11m 58
DURING A 3-BURST ERUPTION	48	9m 05	62	6m 15	11m 50
DURING A 4-BURST ERUPTION	16	8m 06	41	6m 53	9m 26
DURING A 5-BURST ERUPTION	2	7m 42	74	6m 50	8m 34
(includes afterbursts)					
ERUPTION DURATION	101	12m 25	48	10m 11	14m 10
WATER DURATION	101	11m 00	39	9m 22	12m 29
PAUSE DURATION	96	1m 29	37	25	3m 00
TOTAL DURATION:					
OF A 1-BURST ERUPTION	5	11m 26	26	10m 54	12m 01
OF A 2-BURST ERUPTION	31	12m 04	47	10m 11	13m 26
OF A 3-BURST ERUPTION	47	12m 33	39	11m 25	14m 03
OF A 4-BURST ERUPTION	17	12m 56	40	11m 10	14m 01
OF A 5-BURST ERUPTION	1	14m 10	--	14m 10	14m 10
(excludes afterbursts)					
TURBAN QUIT AFTER GRAND	37	71	34	39	199
VENT QUIT AFTER GRAND	36	156	30	117	246
VENT QUIT AFTER TURBAN	36	85	15	19	107
INTERVAL	100	8h 17	57m	6h 47	11h 56

*All times are given in seconds, unless noted otherwise.

Table 2. Statistical Summary
ERUPTIONS - RIFT ACTIVE*

Variable	Count	Mean	St.Dev	Min	Max
WAVES	4	125	65	62	198
ALL TURBAN STARTS	5	68	51	-4	129
TURBAN START AFTER GRAND	4	86	36	46	129
TURBAN START BEFORE GRAND	1	-4	--	-4	-4
VENT START AFTER GRAND	6	143	34	112	198
VENT AFTER TURBAN OR GRAND	5	150	33	119	198
BURST 1	11	8m 48	1m 31	6m 24	10m 40
BURST 2	11	57	34	29	147
BURST 3	8	68	36	33	150
BURST 4	3	32	4	29	37
BURST 5	1	35	--	35	35
PAUSE 1	11	38	12	20	56
PAUSE 2	8	54	31	32	127
PAUSE 3	3	49	6	43	55
PAUSE 4	1	75	--	75	75
NUMBER OF BURSTS (includes afterbursts)	11	3.09	0.94	2	5
NUMBER OF BURSTS (excludes afterbursts)	11	3.09	0.94	2	5
FIRST BURST DURATION:					
DURING A 1-BURST ERUPTION	0	--	--	--	--
DURING A 2-BURST ERUPTION	3	10m 34	6	10m 28	10m 40
DURING A 3-BURST ERUPTION	5	8m 36	74	6m 24	9m 17
DURING A 4-BURST ERUPTION	2	7m 35	32	7m 12	7m 57
DURING A 5-BURST ERUPTION	1	6m 50	--	6m 50	6m 50
(includes afterbursts)					
ERUPTION DURATION	11	12m 22	46	11m 10	14m 10
WATER DURATION	11	10m 45	43	9m 22	11m 31
PAUSE DURATION	11	1m 37	42	44	3m 00
TOTAL DURATION:					
OF A 1-BURST ERUPTION	0	--	--	--	--
OF A 2-BURST ERUPTION	3	12m 04	11	11m 53	12m 15
OF A 3-BURST ERUPTION	5	12m 25	26	12m 00	13m 04
OF A 4-BURST ERUPTION	2	11m 50	56	11m 10	12m 29
OF A 5-BURST ERUPTION	1	14m 10	--	14m 10	14m 10
(excludes afterbursts)					
TURBAN QUIT AFTER GRAND	4	73	10	59	83
VENT QUIT AFTER GRAND	4	153	23	128	175
VENT QUIT AFTER TURBAN	4	80	14	67	92
INTERVAL	11	9h 53	1h 27	7h 49	11h 56

*All times are given in seconds, unless noted otherwise.

Table 3. Statistical Summary
ERUPTIONS - RIFT NOT ACTIVE*

Variable	Count	Mean	St.Dev	Min	Max
WAVES	56	94	53	12	260
ALL TURBAN STARTS	53	10	51	-143	95
TURBAN START AFTER GRAND	30	48	17	14	95
TURBAN START BEFORE GRAND	21	-44	35	-143	-4
VENT START AFTER GRAND	58	145	25	78	197
VENT AFTER TURBAN OR GRAND	48	159	22	109	221
BURST 1	90	9m 30	1m 16	6m 15	12m 01
BURST 2	85	63	44	23	240
BURST 3	57	41	14	23	122
BURST 4	15	46	9	33	62
BURST 5	0	--	--	--	--
PAUSE 1	85	41	18	19	168
PAUSE 2	57	54	13	25	113
PAUSE 3	15	60	11	34	83
PAUSE 4	0	--	--	--	--
NUMBER OF BURSTS (includes afterbursts)	90	2.77	0.82	1	5
NUMBER OF BURSTS (excludes afterbursts)	90	2.74	0.80	1	4
FIRST BURST DURATION:					
DURING A 1-BURST ERUPTION	5	11m 26	26	10m 54	12m 01
DURING A 2-BURST ERUPTION	27	10m 25	54	7m 51	11m 58
DURING A 3-BURST ERUPTION	43	9m 08	60	6m 15	11m 50
DURING A 4-BURST ERUPTION	14	8m 10	41	6m 53	9m 26
DURING A 5-BURST ERUPTION	1	8m 34	--	8m 34	8m 34
(includes afterbursts)					
ERUPTION DURATION	90	12m 26	48	10m 11	14m 03
WATER DURATION	90	11m 03	38	9m 31	12m 29
PAUSE DURATION	85	1m 28	37	25	2m 48
TOTAL DURATION:					
OF A 1-BURST ERUPTION	5	11m 26	26	10m 54	12m 01
OF A 2-BURST ERUPTION	28	12m 04	49	10m 11	13m 26
OF A 3-BURST ERUPTION	42	12m 33	31	11m 25	14m 03
OF A 4-BURST ERUPTION	15	13m 05	30	12m 26	14m 01
OF A 5-BURST ERUPTION	0	--	--	--	--
(excludes afterbursts)					
TURBAN QUIT AFTER GRAND	33	70	36	39	199
VENT QUIT AFTER GRAND	32	156	31	117	246
VENT QUIT AFTER TURBAN	32	85	16	19	107
INTERVAL	89	8h 05	38m	6h 47	9h 48

*All times are given in seconds, unless noted otherwise.

Grand had the following burst distribution during the period of study (afterbursts included):

One	Two	Three	Four	Five	Total
5	30	48	16	2	101

EXPLANATION OF THE TESTS USED

Several causal effects in the Grand Group have been suggested or rejected among observers; the following "box plots" and results of statistical tests will deal with these.

Box plots

A box plot is a visual method of comparing the distribution of several groups of data. The box plots used herein are called "notched" box plots, which allow for quick visual estimation of possible statistical significance. The following statistics, from bottom to top of each box, are described:

small circles	- outliers
short horizontal line	- 10th percentile
box bottom	- 25th percentile
middle of notch	- median
box top	- 75th percentile
short horizontal line	- 90th percentile

If the notches in the two (or more) boxes do not overlap horizontally, we may assume that differences in the group medians are statistically significant. The box plots herein are selected for the 95% level of significance. For each box plot, the results of the appropriate statistical test are given.

T-tests

For tests with two groups, the two-sample T-test is used. In these cases, an F-test is first performed to determine if the two groups' variances are homogeneous. A probability level of less than 0.1 indicates that the hypothesis that the two group variances are equal should be rejected. The result of this test tells the reader which T-test (Equal or Unequal Variances) should be used. If the probability level from the resulting T-test is less than 0.05, the hypothesis that the two groups' means are the same can be rejected.

Analysis of variance

If there are more than two groups, a one-way analysis of variance is used. A probability level of less than 0.05 indicates that the hypothesis of no differences among any of the group means can be rejected.

If differences are found, contrasts among the group means are performed to determine which pairs of means are significantly different. If the groups are ordered in any particular way, only one contrast is fit. This special contrast is used to determine if a linear relationship exists between the groups and their means. A contrast probability level of less than 0.05 indicates a significant linear relationship.

In this paper, linear contrasts are used in the analyses relating Grand's total number of bursts to parameters such as total duration and first burst duration. The contrasts will determine if an increase in the total number of bursts corresponds to a linear increase in total duration or a linear decrease in the first burst duration.

RESULTS OF THE TESTS

Tests showing the effects of Rift. Two-sample T-tests were done to determine if Rift's activity had a significant effect upon the durations and intervals of Grand's eruptions as well as the durations of bursts and pauses.

Rift had a very significant effect upon Grand's interval. An unequal-variance T-test (Table 4) showed that Grand's average interval of 8 hours and 5 minutes without Rift was significantly shorter than the 9 hour 53 minute interval with Rift (p-value = 0.0019, with 10.6 DF). In addition, the 1 hour 27 minute standard deviation of Rift-related intervals was significantly higher than the 38 minute standard deviation of the non-Rift intervals. Thus, when Rift was in eruption, the time of Grand's next eruption was much more difficult to predict. These differences may be viewed graphically in the box plot shown in Figure 2 on the right.

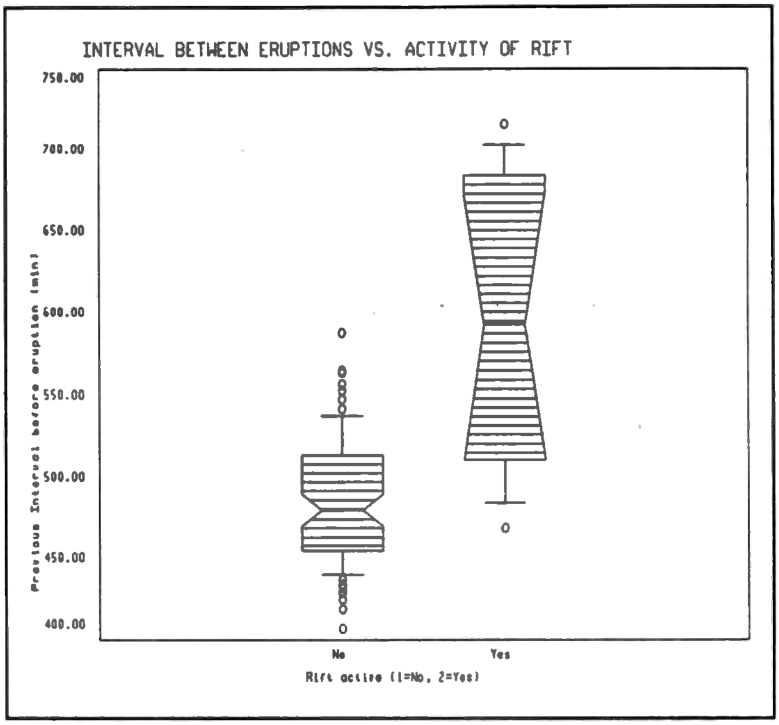


Figure 2. Rift's effect upon Grand's intervals.

Table 4. Two sample T-test of Rift's effect upon Grand's intervals.

Response: ERUPTION INTERVAL (minutes)

Group:	RIFT = No		RIFT = Yes	
Count - Mean	89	485.191	11	593.2727
95% C.L. of Mean	477.121	493.261	534.6381	651.9073
Std.Dev - Std.Error	38.30971	4.060821	87.31562	26.32665

	----- Equal Variances -----		----- Unequal Variances -----	
T Value - Prob.	-7.386945	0.0000	-4.057426	0.0019
Degrees of Freedom		98		10.57686
Diff. - Std. Error	-108.0817	14.63145	-108.0817	26.638
95% C.L. of Diff.	-137.1171	-79.04627	-166.9196	-49.24381

F-ratio testing group variances 5.194768 Prob. Level 0.0000

```
                         |407            95% Conf. Limit Plots              716|
RIFT=No                                <a->

RIFT=Yes                                           <---------a--------->
```

Rift also had an effect on the time in which Turban started its eruption before or after Grand. When Rift was not in eruption, Turban, on average, began its eruption 10 seconds after Grand. However, when Rift was active, Turban tended to begin its eruption much later, approximately 68 seconds after Grand.

Of the five observed Turban starts when Rift was active, only one occurred before Grand's start. Although it was more common for Turban to start after Grand, it had a greater capability of being the first geyser to erupt when Rift was not active (Figure 3 and Table 5).

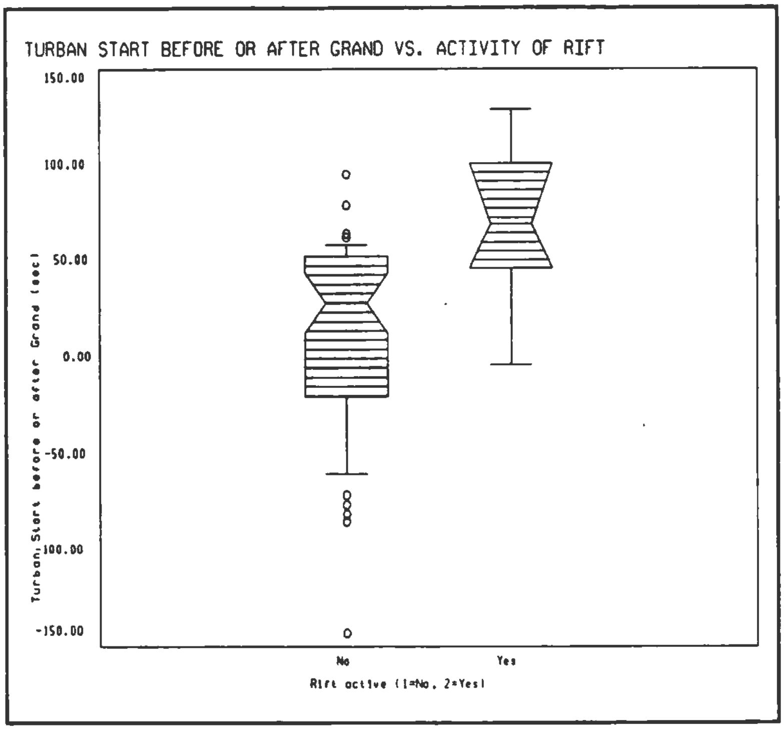


Figure 3. Rift's effect upon the start of Turban.

Table 5. Two sample T-test of Rift's effect upon the start of Turban.

Response: Start of Turban before or after Grand (seconds)

Group:	RIFT = No		RIFT = Yes	
Count - Mean	53	9.698113	5	68.2
95% C.L. of Mean	-4.405781	23.80201	4.720544	131.6794
Std.Dev - Std.Error	51.16887	7.028585	51.18301	22.88974

	----- Equal Variances -----		----- Unequal Variances -----	
T Value - Prob.	-2.443793	0.0177	-2.443224	0.0584
Degrees of Freedom		56		5.177701
Diff. - Std. Error	-58.50188	23.93897	-58.50188	23.94454
95% C.L. of Diff.	-106.4574	-10.54634	-119.9051	2.901333
F-ratio testing group variances		1.000553	Prob. Level	0.4157

```
                      |-143              95% Conf. Limit Plots         131.6794|
RIFT=No                                              <--a-->

RIFT=Yes                                              <-----------a---------->
```

Tests showing the effects of total duration, burst duration, and number of bursts.

A one-way analysis of variance performed on total duration vs. the total number of bursts in an eruption showed that with longer durations, more bursts could be expected. In this and succeeding analyses, four- and five-burst eruptions were grouped together to give a larger sample size. Afterbursts were not included in the analysis of total duration. The results of the contrast printout showed that total duration and total number of bursts were linearly related to each other (Figure 4 and Table 6).

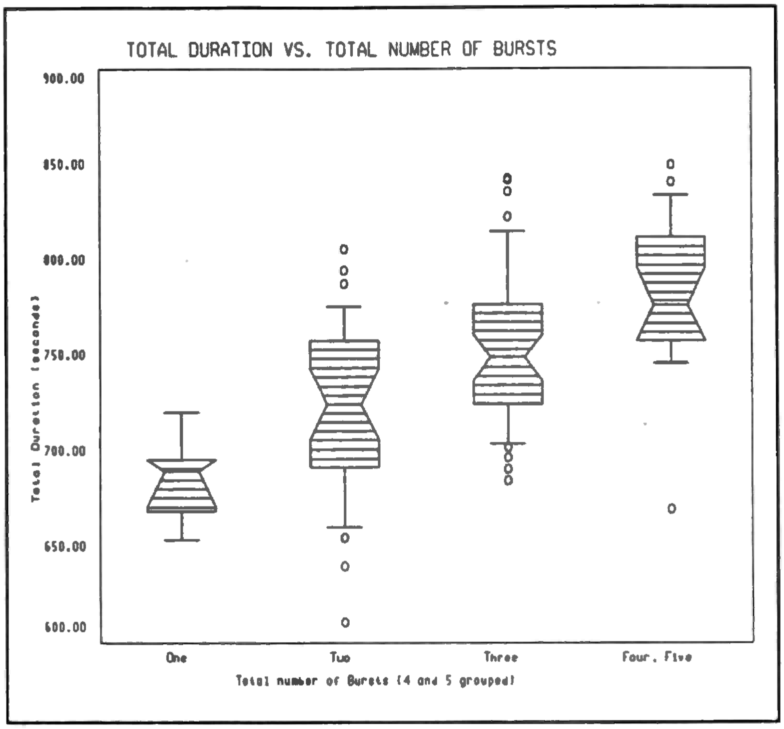


Figure 4. Total duration vs. number of bursts.

Table 6. Analysis of variance: total duration vs. number of bursts.

ANOVA Table for Response Variable: Total duration (seconds)

Source	DF	Sum-Squares	Mean Square	F-Ratio	Prob>F	Error Term
BURSTS	3	57051.56	19017.19	10.92	0.0000	ERROR
ERROR	97	169001.6	1742.285			
TOTAL(Adj)	100	226053.2				

Means & Standard Errors for Total duration (seconds)

Term	Count	Mean	Std.Error
ALL	101	735.6723	
BURSTS			
1	5	685.9999	18.667
2	31	723.5806	7.496848
3	47	752.5532	6.088504
4,5	18	780.5555	9.838373

Linear Contrast Report

Contrast Coefficients
-3 -1 1 3

Contrast Value	312.6394
Contrast T-Value	4.882293
Prob T=0	0.0000

Another one-way analysis of variance was done to determine if differences in first burst duration had a significant effect upon the total number of bursts. The analysis indicated that shorter duration first bursts usually resulted in a higher total number of bursts for the eruption. The contrast report indicated that the two variables were linearly related to each other. Afterbursts were included in this analysis (Figure 5 and Table 7).

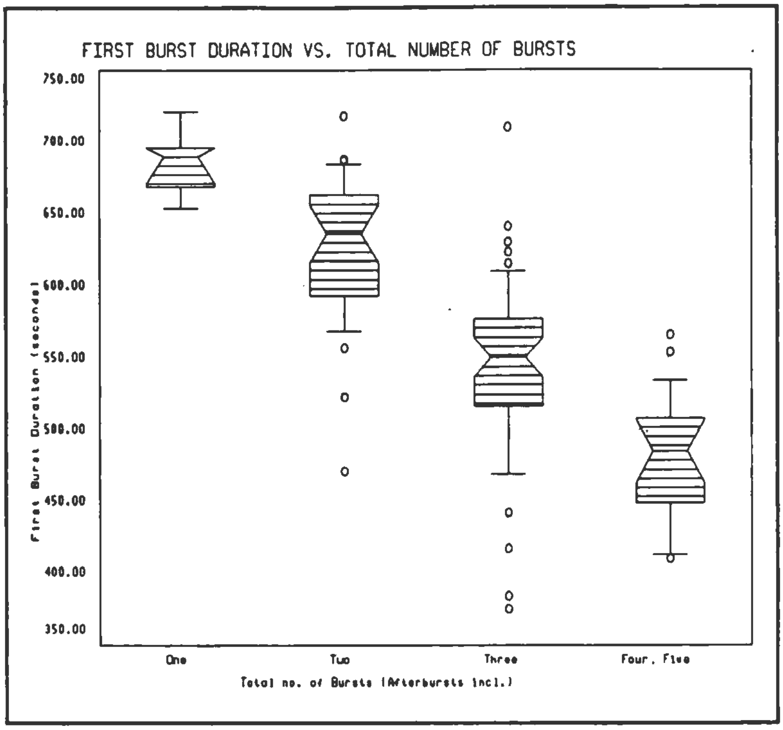


Figure 5. First burst duration vs. total number of bursts.

Table 7. Analysis of Variance: first burst duration vs. total number of bursts.

ANOVA Table for Response Variable: First burst duration (seconds)

Source	DF	Sum-Squares	Mean Square	F-Ratio	Prob>F	Error Term
BURSTS	3	324856.9	108285.6	35.99	0.0000	ERROR
ERROR	97	291889.9	3009.174			
TOTAL(Adj)	100	616746.8				

Means & Standard Errors for First burst duration (seconds)

Term	Count	Mean	Std.Error
ALL	101	585.0872	
BURSTS			
1	5	686	24.53232
2	30	626.1334	10.01528
3	48	544.9375	7.917773
4,5	18	483.2778	12.92967

Linear Contrast Report

Contrast Coefficients
-3 -1 1 3

Contrast Value	-689.3624
Contrast T-Value	8.190405
Prob T=0	0.0000

For eruptions containing two or more bursts, a test was performed to determine if the duration of the pause between the first and second bursts could be related to the total number of bursts (afterbursts included). The resulting analysis of variance and linear contrast showed that a decrease in first pause duration corresponded to a linear increase in the total number of bursts. Two-burst eruptions had an average pause of 52 seconds between bursts, while the average first pause duration for four- and five-burst eruptions was only 33 seconds.

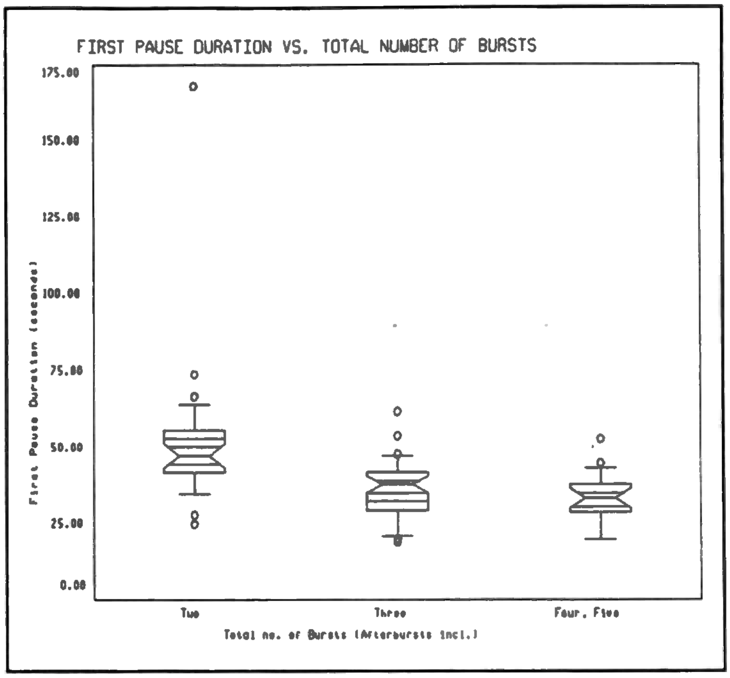


Figure 6. First pause duration vs. total number of bursts.

This result may be attributed to the amount of energy expended. A short pause indicates that Grand's energy reserves are still high, enough to produce two or more succeeding bursts. However, a long pause indicates that not much energy is left; only one more burst may be expected (Figure 6; Table 8).

Table 8. Analysis of variance: first pause duration vs. total number of bursts.

ANOVA Table for Response Variable: First pause duration (seconds)

Source	DF	Sum-Squares	Mean Square	F-Ratio	Prob>F	Error Term
BURSTS	2	5764.054	2882.027	11.36	0.0000	ERROR
ERROR	93	23600.45	253.7682			
TOTAL(Adj)	95	29364.5				

Means & Standard Errors for First pause duration (seconds)

Term	Count	Mean	Std.Error
ALL	96	40.45417	
BURSTS			
2	30	51.96667	2.908426
3	48	36.39583	2.299313
4,5	18	33	3.754762

Linear Contrast Report

Contrast Coefficients	-1 0 -1		
Contrast Value	-84.96667		
Contrast T-Value	17.88983	Prob T=0	0.0000

There were also differences in the duration of the second burst and the total number of bursts. Although the analysis of variance table showed significant differences among the group means, the linear contrast results were not significant. Two-burst eruptions had an average second burst duration of 43 seconds, three-burst eruptions averaged 75 seconds, but the average of the four- and five-burst eruptions decreased to 60 seconds.

The short second burst duration of the two-burst eruptions indicates that Grand did not have much energy left at the time of the start of the second burst. This next burst then depleted the energy reserves, resulting in the end of the eruption.

Since the eruptions with more than two bursts had more energy reserves at the time of the second burst, their second burst durations were longer. The difference in means between three-burst eruptions and four- or five-burst eruptions was analogous to the pattern observed for first burst durations: a decrease in second burst duration led to an increase in the total number of bursts (Figure 7; Table 9).

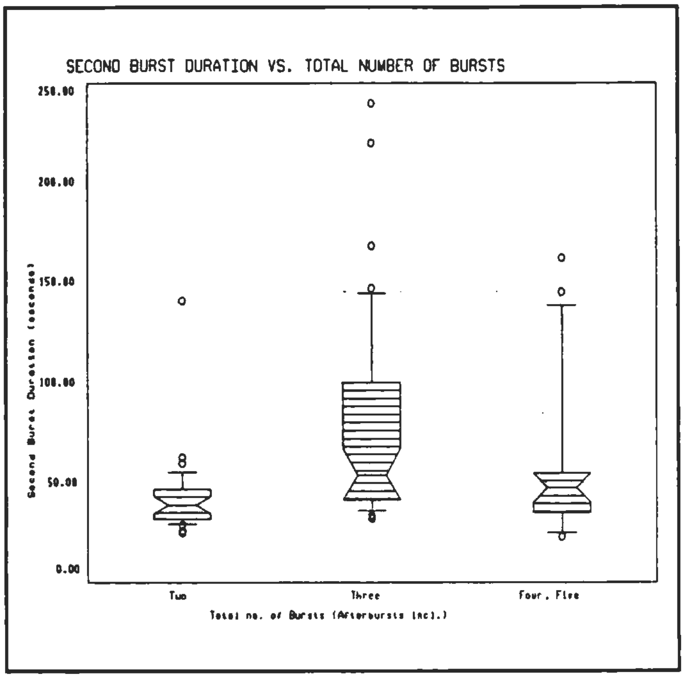


Figure 7. Second burst duration vs. total number of bursts.

Table 9. Analysis of variance: second burst duration vs. total number of bursts.

ANOVA Table for Response Variable: Second burst duration (seconds)

Source	DF	Sum-Squares	Mean Square	F-Ratio	Prob>F	Error Term
BURSTS	2	18954.7	9477.35	5.71	0.0046	ERROR
ERROR	93	154446	1660.709			
TOTAL(Adj)	95	173400.7				

Means & Standard Errors

Term	Count	Mean	Std.Error
ALL	96	59.24398	
BURSTS			
2	30	43.1	7.440227
3	48	75.02083	5.882016
4,5	18	59.61111	9.605291

Linear Contrast Report

Contrast Coefficients
-1 0 -1

Contrast Value	-102.7111
Contrast T-Value	8.453701
Prob T=0	0.0000

Total duration and its effect on the afterplay of Turban and Vent.

The total duration of an eruption of Grand had a significant effect upon whether or not Turban and Vent would continue to erupt after Grand finished. If the average total duration was approximately 12 minutes, Turban and Vent could be expected to continue their eruptions. However, total durations averaging 32 seconds longer (range: 10 to 53 seconds) resulted in Turban and Vent quitting shortly after Grand. This result is not surprising, since a longer total duration would be expected to expend more energy during Grand's eruption, leaving less energy available for Turban and Vent to continue their eruptions afterwards (Figure 8; Table 10).

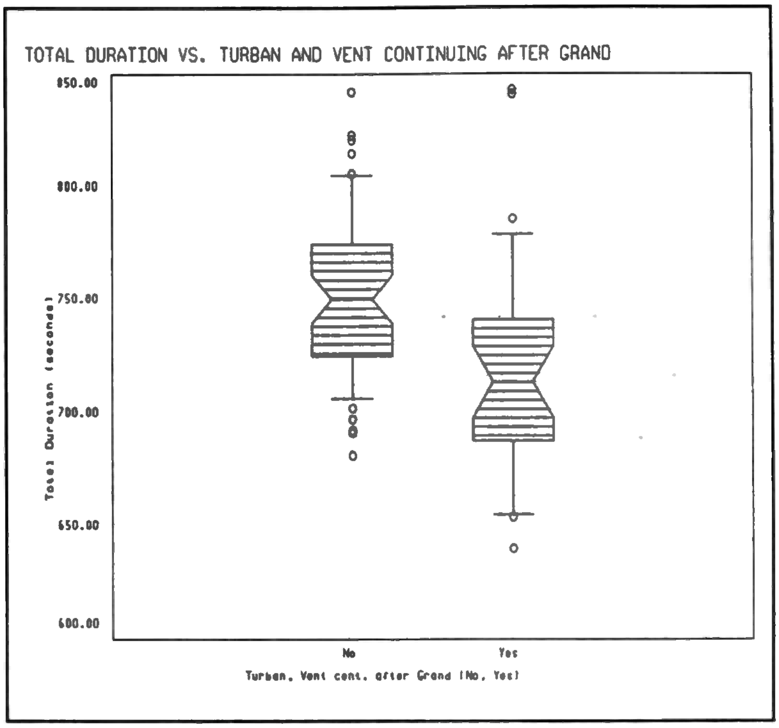


Figure 8. The effect of total duration on Turban and Vent's activity after Grand.

Table 10. Two sample T-test of the effect of total duration on Turban and Vent's activity after Grand.

Response: Total duration of Grand's eruption (seconds)

Group:	Turban, Vent cont. - No		Turban, Vent cont. - Yes	
Count - Mean	52	752.0577	28	720.2143
95% C.L. of Mean	741.9177	762.1977	700.7583	739.6703
Std.Dev - Std.Error	36.42258	5.050903	50.17846	9.482839

	----- Equal Variances -----		----- Unequal Variances -----	
T Value - Prob.	3.257685	0.0017	2.9638	0.0049
Degrees of Freedom		78		43.77296
Diff. - Std. Error	31.84338	9.774852	31.84338	10.74411
95% C.L. of Diff.	12.38338	51.30339	10.19006	53.4967

F-ratio testing group variances 1.897987 Prob. Level 0.0242

```
                     |640              95% Conf. Limit Plots               843|
Turban, Vent - No                                         <-a-->

Turban, Vent - Yes                           <-----a---->
```

CONCLUSION

The behavior of most geysers in Yellowstone will vary to some degree from year to year. The geysers in the Grand Complex are no exception. Some of the behavioral characteristics presented in this paper were common to the Grand Group only during 1978. Grand's behavior in the 1980's has become more erratic, with longer intervals, fewer bursts, and increased activity from Rift.

Some of the statistical tests performed herein may appear to new geyser gazers as "conventional wisdom." In the case of Grand, protracted studies, such as those conducted in the seventies [Wolf, 1977], were the basis for much of this knowledge. It is hoped that the observations and statistics presented in this paper will both demonstrate the type of analysis done at the time and be used as a basis for further studies of the Grand Group in years to come.

ACKNOWLEDGEMENTS

John Railey, Marie Wolf, Paul Strasser, and Dennis Hafen were invaluable in gathering eruption data when the author was working and unable to go out into the geyser basin. Without their aid, this study would not have been possible. Special thanks go to Paul Strasser, whose advice, encouragement, and companionship made this paper a reality.

REFERENCES

Bryan, T.S. The Geysers of Yellowstone. Colorado Associated University Press. 1979.

Hintze, J.L. Number Cruncher Statistical System, Version 5.01. Dr. Jerry L. Hintze. 1987.

Hintze, J.L. Number Cruncher Statistical System, Version 5.1 - Graphics. Dr. Jerry L. Hintze. 1987.

Hutchinson, R.A. Geothermal Activity in the Thermal Basin of Yellowstone National Park, 1977. Unpublished. 1978.

Marler, G. Studies of Geysers and Hot Springs along the Firehole River. Yellowstone Library and Museum Association. 1964. Revised with R.A. Hutchinson, 1978.

Old Faithful Visitor Center Log Book. Informal records. 1978.

Wolf, M. Grand Geyser reports. Informal records. 1977.

New Activity for Key Spring

Mike Keller

A new geyser, with no known history of eruptive activity, suddenly sprang to live on August 21, 1988. Located about 100 meters north of Grand Geyser and 20-30 meters south of the Economic Geysers, it has been known as "Key Spring" and also unofficially as "Hobart Geyser". The crater is roughly gourd shaped, 2½ meters long and 1 meter wide.

Prior to 1988, I have always observed it to be a cool, small, and algae filled spring. Its temperature as measured in January of 1988 was 70°C. There are two vents within the crater. The first is located on the south-eastern side of the crater. It usually overflowed into the other vent on the north-western edge of the crater. The only times I have observed the upper vent not overflowing into the lower was during the fall on 1977 and early winter of 1988. As the summer of 1988 progressed, the spring became gradually clearer and clearer. By late July no algae remained within the vent.

The first eruption I observed was at 1706 on August 21, 1988. There may have been one unobserved eruption on August 20. It was in eruption when I arrived. Three vents were erupting, two on the north-western side and the one vent on the south-eastern side. The highest was playing at an angle across the boardwalk in the direction of Grand's runoff channel to a height of between 2 and 4 meters. The other vents were playing 1 meter high. The eruption lasted at least 3 minutes, and stopped very abruptly. All the vents drained. For the next 70 minutes they gradually rose and fell, each rise being a little higher then the previous. At 1842 a second eruption took place. This eruption was not as tall as the first, 1 to 1½ meters from all vents, and lasted only 117 seconds. After this eruption the vents once again drained, and the rise and fall cycles were again observed. At 1931 a third eruption occurred. This eruption began from a lower water level and was the smallest of the three eruptions observed, with no vent reaching over 1 meter. The south-east vent only boiled. Its duration was 86 seconds. Only one other eruption is known to have occurred since August 21, 1988. Inferred from markers, it occurred between 2200 on August 23 and 0545 on August 24, 1988.

When the activity ceased the crater remained murky and had a foul smell. The eruptions never truly overflowed, though the pool rose high enough to kill some surrounding grass. Even by mid-October the water in the vent had only partially cleared. This eruptive activity had no obvious effect on any other nearby feature.

An interesting note about this feature when it was active is that the temperature remained very low until just prior to the eruption. The pool was only 62°C twelve minutes prior to the second observed eruption. The rise in pool temperature seemed only to occur as the pool began to surge at the start of an eruption.

The Grotto Geyser Group and Giant Geyser Group
Upper Geyser Basin, Yellowstone National Park, Wyoming

Activity and Relationships
June 28 -- July 28, 1988

by T. Scott Bryan

Section 1 -- Introduction

Despite the great long-standing interest in and known importance of the geysers of the Grotto Group, the sheer size and rarity of eruptions by the geysers of the Giant Group, and the established connective relationship between them, never in the 118 years of recorded Yellowstone history have these geysers received a detailed program of observational study. Marler (1973) notes the relationship between the groups and the resultant variations in the activity by the geysers, but he provides neither data nor substantial detail. Both Marler and Bryan (1986) provide general descriptions of the individual activities but, again, no further details.

A project such as this has, therefore, been needed for a long time. It has been suggested by many through the years-- by myself as early as 1976 and by Heinrich Koenig as recently as 1988-- but because of the relative isolation of the Grotto Group and the prospects of an observer having to sit through many long and lonely hours of rather boring action, none had tackled the study.

Because changes were known to be occurring among these groups starting with the eruption by Giant Geyser on September 12, 1987, I had already determined that I would attempt the project in 1988. The fact that Giant erupted again on June 28, the very day of my arrival in the Park, confirmed that this was a necessary and viable project.

Many positive findings have come from this study, and the behavior of the Grotto Group, especially, should be much easier to understand in the future. However, any concludions drawn here must be considered tentative and perhaps not truly representative of what Grotto "normally" does; remember that the period of study was the first 4 1/2 weeks following the eruption by Giant, and might therefore represent an aberrant, recovery performance.

The majority of the eruption times, durations, periods, and general observations recorded here, and all of the analyses and conclusions, are my own. However, many others contributed basic data and information, without which the project would have been far less complete. Especially included here are GOSA members John Muller, Jens Day, Lynn Stephens, Chris Kittell, Rick Lassen, Rocco Paperiello, Marie Wolf, Phil Landis, Mike Keller, Clark Murray, Herb Colin, Doug Simons, and the entire Johns, Hoppe, Goldberg, and Nelson families; and Old Faithful Naturalists Sam Holbrook, Ann Deutsch, and Tom Hougham. My sincere thanks go to all who contributed any amount of data. In total, this group spent literally hundreds of hours making this project a reality.

Section 2 -- Description of Individual Springs

Most of the individual hot spring units involved in this study are well-known and need no separate description in this report. Readers desiring more are referred to either Marler (1973) or Bryan (1986). However, some of the features are less well-known yet highly important, and so do merit some description here.

The features observed during this project are as follows; those receiving additional detailed descriptions are identified by asterisks (*):

A. The Grotto Geyser Group
1. Grotto Geyser
2. "Central Vents" (*)
3. Rocket Geyser
4. (Grotto's) Indicator Spring (*)
5. Grotto Fountain Geyser
6. South Grotto Fountain Geyser
7. "South South Grotto Fountain Geyser" (*)
8. "Frying Pan Vents" (*)
9. "Variable Spring" (Bryan, 1986, UNNG-GRG-1) (*)
10. Spa Geyser
11. "Connector Spring" (*)

B. The Giant Geyser Group
1. "Midway Pool" (Peale, 1878, Giant Group #1) (*)
2. Giant Geyser
3. Mastiff Geyser
4. Catfish Geyser
5. Bijou Geyser
6. Turtle Geyser
7. "Platform Geysers" (*)

C. Other Features
1. Oblong Geyser
2. The Purple Pools
3. "Persistent Geyser" (*)
4. Square Spring
5. Link Geyser
6. Riverside Geyser

For all intents and purposes, those features noted by the asterisks in the above list have not been previously described, especially in terms of eruptive activity. These springs are:

A.2. "Central Vents"

These small geysers play from openings located on the geyserite mound between the cones of Grotto and Rocket Geysers. They are ordinarily active only while Grotto and Rocket are in eruption, but on several occasions they were observed to erupt independently. Such eruptions proved significant.

All observed independent eruptions by the Central Vents occurred at the time of the first complete fill by Indicator Spring and, therefore too, at the time of the first significant boiling preplay by Grotto Fountain Geyser. The eruptions began abruptly, reaching up to 3 feet high with copious discharge. During the play both Grotto and Rocket would spill a little water and appeared to be in incipient eruptions. After a duration of 4 to 5 minutes, the play would gradually decline to an indistinct termination.

The independent eruptions by the Central Vents proved to be a delaying action for the Grotto Group as a whole. Whereas the preplay activity by Grotto Fountain normally recurs just two or three times on 10 to 20 minute intervals, here the independent eruptions were an unfailing herald of at least a 45 minute delay before further significant action would take place. On one occasion the delay was of more than 3 hours.

There is a single exception to the above statement. On July 26, as reported by Naturalist Deana Dulen, Grotto began eruption during the play by the Central Vents and without the usual precursor eruption by Grotto Fountain. The eruption began slowly, requiring several minutes to build into normal force. Adding to the unusual nature of this event is the fact that Spa Geyser was also in eruption at the time. This type of action probably accounts for the few uncertain reports of eruptions by Grotto without Grotto Fountain during May, 1988.

Independent eruptions by the Central Vents were observed only while Grotto was operating on its short-mode (see Section 3, Part A).

A.4. Indicator Spring

Also known as "Grotto's Indicator" and "Grotto's Drain", Indicator Spring behaved in an entirely normal fashion except on July 5 and July 27. On both of those dates its water was found to be murky. The occurrence on July 5 was a few hours following the 53+ minute duration by Grotto Fountain (see Section 3, Part B). That of July 27 occurred about 2 hours after a major hot period by Giant. On both occasions, then, something "unusual" had happened elsewhere within the system not long before.

The direct cause of the murkiness was observed on July 27. Indicator Spring erupted. The play rose above a pool level fully 2 1/2 feet below the rim, yet some of the splashes reached 4 feet above the rim. The play was vigorous and rather violent but also mostly confined by the crater. The roiling water thoroughly stirred the sediment in the bottom of the crater, causing the murkiness that was still evident at dark, more than 2 hours later. The duration of the eruption was roughly 4 minutes. The subsequent activity by Grotto Fountain and Grotto did not appear to be altered in any way.

A.7. "South South Grotto Fountain Geyser"

This geyser plays from three small vents within the sinter shoulders on the south and southwest sides of South Grotto Fountain Geyser. In past seasons it has been known to have strong (to 15 feet) eruptions independent of the other Grotto Fountains, but these are rare. It has also been observed to jet weakly during eruptions by South Grotto Fountain, and intermittently throughout

 Grotto's play.

This year, South South Grotto Fountain unfailingly played, to as high as 8 feet, as a precursor to the eruption by Grotto Fountain, leading that play by about an hour. This was a reliable enough indicator to serve as a warning for the impending end of a long-mode interval. It also preceeded the short-mode eruptions. The reliablility failed only when there was independent activity by the "Central Vents".

South South also played consistently to 15 to 20 feet high throughout the 53+ minute duration by Grotto Fountain on July 5.

A. 8. The "Frying Pan Vents"

These five vents made their first known appearance either at the time of or shortly after Grotto Fountain Geyser's 53+ minute duration on July 5. They were then seen in action from time to time throughout the remainder of the study period. They have not been previously reported, and extensive discussions with other gazers revealed none who can remember the slightest indication of activity at this site.

The Frying Pan vents are located almost exactly half-way between Indicator Spring and South Grotto Fountain Geyser. The steaming, sputtering patches of ground are confined to a 2-foot diameter area of sinter gravel. On most occasions their action is slight but several times, always shortly after Grotto Fountain concluded, they sputtered water several inches high with a sound loud enough to be distinctly heard from the trail (this with Grotto in full eruption!).

On July 16 and July 28, the Frying Pan vents were observed active fully an hour before Grotto Fountain erupted, starting the play at about the same time as did "South South Grotto Fountain."

A. 9. "Variable Spring"

I identified this spring as unnamed geyser UNNG-GRG-1 in Bryan (1986). I now name it Variable Spring because it serves as a clear "barometer" for the entire Grotto-Giant system. On any occasion when some form of more-or-less unusual behavior occurs within the complex-- for examples, eruption or major hot periods by Giant, long-mode eruptions by Grotto, and the long duration by Grotto Fountain-- this feature exhibited some degree of change.

Its normal state is full, or nearly so, bubbling gently through clear water. When affected by the outside influences, it would lower its water level to as much as -2 feet, become murky to outright muddy gray-brown, and erupt with superheated bursting as much as 3 feet high. Full recovery required as long as 12 hours, which was more than enough to allow an observer to detect the unusual behavior during a night with no observations.

A few feet north of Variable is a narrow vent surrounded by a grassy-weedy area. In the bottom of this is a perpetual spouter. Although this was never observed to cease its action, its force, water level and clarity did vary in accord with that in Variable Spring.

A. 11. "Connector Spring"

This name, invented for this report, was chosen to reflect my belief that this spring is part of a connecting trend between the Grotto Group and Riverside Geyser. This is the pool to the right of the trail as one approaches Riverside from Spa Geyser.

Previously known to be somewhat variable in its water level and degree of bubbling, on June 29 (the day following Giant's eruption), July 11 (after a duration by Grotto of 16h 07m), and July 27 (following Grotto's 22+ hour duration), this spring nearly emptied its crater and erupted 3 to 4 feet high. Other long-mode action by Grotto had a lesser effect. Grotto's short-modes and Giant's major hot periods had no observable effect.

Note that the intermittent spring across the trail from Connector was not affected by any of these events.

B.1. "Midway Pool"

Evidently the same as Peale's (1878) "Giant Group #1", at which time it was a full and overflowing spring, Midway Pool exhibited its relationship to the Giant Group in a fashion similar to that of Variable Spring. The variations here were much less extreme, however. Although empty the day following Giant's eruption, it otherwise altered its water level by only a few inches, dropping at the times of major hot periods by Giant. Its water was clear on all observed occasions. Overall, this does not seem to be a significant indicator of system activity.

On July 28 I noted some evidence of washing within the crater walls. Some tufts of grass appeared to be dying and sand had been smoothed and rilled. Since this was a time with no significant rainfall, I conclude that some sort of eruption took place at about that date. Note that this time corresponds to the episode of frequent major hot periods by Giant.

B.7. Giant's "Platform Geysers"

These are the numerous small openings on the sinter platform of the Giant Group. They are mostly confined to two separate groups of vents, one immediately west of Giant's cone and the other further to the southwest. In total there are at least 13 openings, 10 of which have been observed to erupt at the time of a major hot period. With one exception, they are not active at any other time, and even then not all of them are necessarily active. Most of these Platform Geysers do little more than sputter a little water 1 to 2 feet high, but one member of each group is significantly larger.

The exception which does play at times other than major hot periods is the largest of these geysers, the so-called "Posthole Geyser". As reported by Mike Keller, starting in August (and so after the primary time span of this report), it behaved as a small perpetual spouter during Grotto's long-mode durations.

For a further description of the action by the Platform Geysers, see Section 4, Part D.

C.3. "Persistent Geyser"

This geyser/spouter is the "new" breakout near Culvert Geyser. The name was suggested by Phil Landis because this spring is evidently the same as that which caused the famous 1954 collapse on the shoulder of the old highway. At that time the opening was large enough to swallow a car. Now its crater measures only about 4 X 6 feet and is just 1 to 2 feet deep. Since its initial development on June 24 and attainment of the present size by June 26, it has been quite stable and shows little indication of further significant growth. The eruption is a nearly constant splashing reaching a maximum of 2 feet high.

The development of this spring was monitored closely because of its historical significance, the ongoing changes within the Grotto-Giant Complex, and evidence of a linear trend including this and the Grotto Group. But while the development of Persistent Geyser is likely related to the changes across the trail, there is no indication that its activity is affected by action elsewhere.

Section 3 -- The Activity of the Grotto Geyser Group

A. General Cycle

The general nature of a Grotto Group eruptive cycle is well known. Its onset is most often noted with the first refilling by Indicator Spring and accompanying boiling preplay by Grotto Fountain Geyser. Perhaps more realistically, the priming of the group is seen sooner as brief but significant eruptions by South Grotto Fountain Geyser and/or play by "South South Grotto Fountain Geyser."

Once Indicator Spring has filled, it will usually ebb and refill several times. Each high water level is accompanied by the boiling in Grotto Fountain. On infrequent occasions, Grotto Fountain will erupt on the first fill. More commonly the fill-drop-fill cycle repeats a number of times, each requiring 10 to 20 minutes to complete. Occasionally, too, will be independent eruptions by the "Central Vents," a sure sign of a 45 minute or longer delay in the onset of eruptions.

An eruption per se by the Grotto Group begins with Grotto Fountain. Its boiling action will wax and wane a number of times, but once this grows into jetting several feet high the eruption is triggered. The maximum height may fall anywhere in the range of 30 to 70 feet. It is reached quickly and then held until very near the termination of the eruption. Grotto Fountain shows considerable variation in its duration, ranging from 7 to 53 minutes.

Following the start by Grotto Fountain, there will be a delay ranging from about 2 to 13 minutes before Grotto (with Rocket Geyser) begins to play. In most cases, the longer this delay then the higher will be both Grotto Fountain and the initial surge by Grotto.

The activity by Grotto during July proved to be strongly bimodal. In terms of sheer frequency, most eruptions were of the short-mode, but long-mode activity (also known as "marathons") actually occupied a greater total amount of time. There was surprisingly little variation in either period or duration within each mode. (Note: in this paper I do make the technical distinction between "interval" and "period" when it applies. Period is equal to duration plus interval.) It was quickly found that the duration of an eruption strongly controlled the length of the subsequent interval. This was mostly recorded as period since eruption start times were far easier to come by than eruption termination times.

Eruptions of the short-mode had durations in the range of 1h15m to 4h38m. The average was 2h32m with a standard deviation of only 45m. These durations resulted in predictable periods ranging from 6h33m to 9h28m. Here the average was 7h29m with a small standard deviation of 46m. Short mode eruptions by Grotto were normally accompanied by short duration eruptions by Grotto Fountain, major eruptions by Rocket Geyser (when the duration was in excess of 2 hours), nearly complete inactivity by Spa Geyser, and no significant drawdown effects in related springs. Short-mode action always terminated a long-mode period, and then usually occurred as a series.

Eruptions of the long-mode showed somewhat more variation; but then, too, it was more difficult to obtain the start and stop times for them. It seems that all such durations were in excess of 16 hours long, and one definitely exceeded 22 hours. The resutant periods were in the observed range of 26h28m to 40h50m. Included in this data, however, are periods of "only" 16h24m and 17h36m; these may be aberrant and not properly part of this population. When all are taken, the average period is 26h51m with a standard deviation of 7h37m. Long-mode eruptions are clearly different from those of the short-mode. There are severe drawdown effects in related springs, such as Variable and Connector, Rocket only rarely had major eruptions, and Spa played quite frequently. Excepting the period prior to July 5, no two long-mode periods ever followed one another consecutively.

The first short-mode eruption following a long-mode period was also all but invariable. Its duration would be excessively short, and its force and volume weak. At the same time, the precursor eruption by Grotto Fountain would be strong and of long duration, and sometimes of the "steam break" variety (see Section 3, Part B).

Exceptions to this bimodal pattern occurred prior to July 5. Even then the bimodality was evident, but the pattern was different with long-mode action being dominant. The single event marking the transition into true bimodal activity was the 53+ minute, steam break eruption by Grotto Fountain. I believe that, beyond question, this marks the Grotto-Giant system's recovery from Giant's June 28 eruption. There were no clear exceptions after this time.

The Grotto Fountain-Grotto eruption data can be seen in Table I. A summary of the Period-Duration data is shown in Table II.

B. Grotto Fountain Geyser and Its "Steam Break" Eruptions

Eruptions by Grotto Fountain Geyser preceeded all eruptions by Grotto, as has been the norm since 1971, with the sole exception of July 26 at 0750 when Grotto was triggered by an eruption of the "Central Vents." In accord with the bimodal activity by Grotto, Grotto Fountain was also bimodal in its durations. In essence, short-mode periods resulted in short durations and long followed long. There was not a great difference in the lengths of these two modes-- the short durations ranged from about 7 to 11 minutes while the longs were 13 minutes and greater-- but the distinction between them was definite; no Grotto Fountain duration fell in the range of 11 to 13 minutes.

On four occasions, most notably on July 5 at 1230 but also on July 12 at 0903, July 20 at 1229, and July 24 at 1815, Grotto Fountain erupted in a fashion never before recorded. These eruptions, for reasons that are immediately obvious when the action is seen, I call "steam break" eruptions.

Grotto Fountain Geyser is a cone-type geyser. Once the eruption has started, the play is a steady jet of water, continuous from start to finish. It is only at the very termination of an eruption that any form of bursting, more typical of the fountain-type geyser, is seen. The total duration is commonly between 13 and 22 minutes, as noted by Marler (1973) and all other recent observers. In only one season was there notable exception to this. In 1957, most eruptions had durations in the range of 40 to 65 minutes. In that case, however, Marler makes no mention of any intermittent interruptions during the play, as was the case during steam break eruptions.

The first of the observed steam break eruptions (that of July 5 at 1230) began in seemingly normal fashion. It occurred at the end of a long-mode period of 29h18m. As usual for such timing, the play by Grotto Fountain was stronger than average, being fully 50 feet high, and the delay before Grotto started was a long 9 minutes.

Differences from the normal became apparent immediately, however. A 9 minute delay would usually result in an exceptionally strong (30-40 feet) initial surge by Grotto, but in this case Grotto probably did not even reach 20 feet. It was so weak, in fact, that it received disappointed comment at the time. Also immediately apparent was the fact that everything about the eruptions by Grotto and Rocket were "dry." The southernmost runoff channel was entirely unused and there was little more than a trickle in the others, splashing by Rocket was weak and infrequent, and the "Central Vents" and other openings at the bases of the cones were virtually inactive.

In short order, Grotto Fountain was joined by South Grotto Fountain, which proceeded to have an unusual eruption consisting of steady jetting fully 15 feet high; this continued unabated until well after Grotto Fountain finally ceased. "South South Grotto Fountain" also participated by playing consistently 15 to 20 feet high throughout the duration.

The play by Grotto Fountain was continuous until 1305, a full 35 minutes after it began. It then ceased abruptly, not with the usual few weak closing bursts but with a strong gush of steam. This steam phase was the first "steam break." Within seconds, renewed bursting grew into steady jetting, reaching fully 50 feet again. These steam breaks continued, recurring at least eleven times over the next 17 minutes. Each renewed eruption reached a height equal to all the others, but in general each had a shorter duration as the successive breaks lasted longer.

Finally, starting at about 1322, the action declined into a series of bursts. Though more persistent than usual, these had all the appearance of the normal closing bursts. The last of these, and the end of the eruption, was noted at 1323:36.

Although the precise start of this eruption was not seen (the observers were at Fan and Mortar Geysers), it was noted in progress at 1230. Thus, the eruption had a total duration in excess of 53 minutes, and might have been one or two minutes longer.

For the record, the time-line of this eruption was:

1230	Grotto Fountain i.e.; I = 29h11m
1239	Grotto starts; delay about 9m
1305	First observed steam break, but details not recorded until...
1316:14-16:49	Steam break eruption; D=35s
1317:10-17:28	I=21s; D=18s
1317:45-18:08	I=17s; D=23s
1318:40-18:53	I=32s; D=13s
1319:21-19:39	I=28s; D=18s
1320:11-20:30	I=32s; D=19s
1321:06-21:20	I=36s; D=14s; last steam break
1322:10-23:36	I=50s; concluding bursting

Given the highly unusual nature of this eruption, it is fortunate that it was seen by so many people. GOSA members present for all or part of the eruption were Scott Bryan, Lynn Stephens, Jens Day, Chris Kittell, and Rick Lassen.

Similar but weaker steam break eruptions were seen on three other occasions. That at 0903 on July 12 had a duration of 15m40s and involved one steam break; that at 1229 on July 20 had a duration of 20m44s and again involved one steam break; and that at 1815 on July 24 had a duration in excess of 26m and included three steam breaks. Reported in August by Mike Keller was an additional eruption probably of the steam break variety; it had an "interrupted" duration of more than 22m.

Although the steam break eruptions cannot be predicted, they can be somewhat anticipated. All four of those recorded during July occurred at the end of a Grotto long-mode period. It appears, then, that they can take place only under those circumstances, but then not always. Also of note is that all four of these eruptions were associated with exceptionally short durations by Grotto; respectively, they were of 1h15m, 2h06m, 1h36m, and 1h25m. This probably results from the excessive discharge of energy via Grotto Fountain.

C. Rocket Geyser, Major Eruptions

The observed major eruption activity by Rocket Geyser is shown in Table III. It is certain that not all major eruptions were seen and/or recorded, but the data is nonetheless revealing. All but two (perhaps three) eruptive episodes by Rocket took place during short-mode eruptions by Grotto. Only twice for certain-- on July 15 and July 21-- did they occur during Grotto's long-mode durations. During the short-mode play, Rocket did not always have major eruptions, and in fact, they were seen only roughly 60% of the time.

This mode distinction is, I think, a very important one. Although it might seem that the long-mode eruptions by Grotto should provide more opportunity for Rocket to erupt, it does so only rarely. While on the short-mode, Rocket's eruptions happened almost exclusively near the end of the eruptive activity by the group, as a finishing touch, so to speak. It seem clear, therefore, that the long-mode and the short-mode eruptions are very different things, involving something more than simple extended play. Discussed more elsewhere in this paper, I feel that the short-mode involves eruptive activity by the Grotto Group alone, and that the long-mode eruptions involve not just the Grotto Group but the Giant Group as well; e.g., the entire system. Mechanically, Grotto behaves as two different geysers, and so does Rocket.

When it did occur, the major action by Rocket was quite consistent with previous findings. The eruptions occurred on average 2h06m after the start of Grotto; the standard deviation of only 19m shows that this is a very regular event (when it occurs). Furthermore, these eruptions (with two exceptions, see below) always took place within 1h, and on average just 29m, before the end of Grotto's eruption.

There were two occasions when Rocket's major eruption occurred more than two hours before the end of the activity (specifically 2h11m and 3h36m). Grotto was operating on its short-mode each time, but involving two of the longest such durations. This deviation from the usual may be explainable by activity in Giant. In one case this happened on the last Grotto-Rocket before a Giant major hot period, and the other happened the day following that same major hot period.

There were just two certain examples of Rocket having major activity during Grotto long-modes. With both of these, a first Rocket occurred about 2h after Grotto's start. Then a second Rocket took place approximately 2h after the first. By comparison to all the other contrary data, these two pairs of eruptions during long-modes are without clear explanation. Again, however, they might be explained via activity in Giant, where a major hot period occurred about 4h prior to the example of July 21. The other case happened roughly 6h following the M4 Borah Peak, Idaho earthquake of July 15. So, as is the case with most other uncommon system events, both of these "abnormal" events can be related to outside influences.

There were numerous short-mode eruptions by Grotto (about 40%) which were not accompanied by major eruptions in Rocket, even though the duration was adequate. Signs of that activity were present, however. At about the "right time", Rocket would surge heavily, but so would Grotto and the "Central Vents." After two or three minutes of this the play would abruptly decline into the usual splashing by Grotto, largely without Rocket. It seems here that perhaps the major eruption of Rocket did take place, but that the force was somehow distributed among many vents rather than just Rocket-- result, unspectacular.

D. Spa Geyser Eruptive Episodes

Spa was very irregular in its activity. Given that there were some very short, observed active phases, it is likely that the record falls far short of representing all of the performances. The existing record is given as Table IV.

To at least some extent, the relationship between Grotto and Spa is the inverse of that between Grotto and Rocket, and I suspect that there is a real physical cause in this.

Most active episodes by Spa occurred while Grotto was operating on the long-mode, just the opposite as for Rocket. This fits past history when it has been noted that Spa fills slowly during Grotto's eruption, usually requiring about 3h to become full. Only when full, or nearly so, would Spa erupt, but even then not usually. Instead, after a brief period of overflow the water level would drop to about -4 feet. If Grotto continued to play, this cycle would repeat. Throughout most long-mode eruptions, this happened repeatedly.

On three occasions (July 11, 17, and 23) Spa began its eruption when Grotto was not in eruption. All three of these events occurred shortly after Grotto had quit, twice on the short-mode and once on the long-mode. All three of these eruptions were of extremely short durations (33m, 09m, and <30m). All three played from a low pool level. Finally during each of these, the frequency and power of the bursts was remarkable, repeatedly reaching over 30 feet high every few seconds.

In a very loose way, the eruptive episode by Spa relate to Giant: the considerable majority of these events took place shortly (that is, within 2 days) of either eruption or major hot period in Giant. This compares to Marler's statement that Spa would have exceptional eruptions following Giant.

Lastly, the eruption of July 26 must be noted. It began an unknown time before Grotto did, on the same occasion when Grotto began to play with the "Central Vents" rather than Grotto Fountain as a precursor. This eruption had a duration in excess of 8h, playing strongly from a full pool throughout.

Section 4 -- The Activity of the Giant Geyser Group

A. "Normal" Activity

The "normal" (or perhaps, "usual") activity shown by the geysers of the Giant Group is virtually identical to that seen during the past many years. Giant itself occasionally jets upwards at an angle, strongly enough for the water to reach halfway up the inside of the cone. Mastiff boils at a water level of near -4 feet, enough that some spray reaches slightly above the rim of the craters of either or both vents but with inconsequential discharge. Catfish jets a little water 2 to 4 feet above its rim, most such play accompanying stronger action by Bijou. Bijou is otherwise nearly constant in its action, pausing or weakening briefly every 10 to 25 minutes for about 1 minute.

If there is any difference between this activity and that of past seasons it is that the jetting in Giant is a bit more forceful and frequent. What is now a perfectly ordinary surge would have caused some excitement a few years ago.

Long-mode eruptions by Grotto visibly enervate the entire Giant Group to the extent that even Bijou virtually ceases for as long as several hours. Recovery at these times is slow, being essentially identical to that of the Grotto Group.

B. The "Mastiff Hot Period" Activity

Not previously described by any known observer, this is the weakest variety of Giant Group hot period. A Mastiff hot period was characterized by persistent boiling and strong intermittent jetting/bursting, some of the play reaching 10 and even 20 feet above the crater rims. The greatest play is from the vent nearest the river, where there is enough discharge to form a considerable stream. The vent nearer the boardwalk is much weaker, but still may form some trickling runoff across the front of the platform.

Curiously, a Mastiff hot period seems to have essentially no effect on the other members of the group, Giant included. At best, Giant may have a few jets to near the top of the cone, but they are still uniformly weaker than those seen during the other types of hot period. The water level is not visibly higher in Mastiff or any other feature.

Mastiff hot periods were only observed while in progress, and their terminations were indistinct. Evidently, with waxing and waning, their duration is as long as 2+ hours.

Reporting from August 5, Mike Keller has described an "active cycle" of Mastiff. Although its duration was of little more than an hour and its action apparently more distinctly intermittent and stronger, I believe this event is best applied as a Mastiff hot period rather than as a truly independent eruptive phase.

C. The "Minor Hot Period" Activity

The minor hot period is the commonest sort. Its frequency seems to relate somewhat to the Grotto cycles, being most often seen during a short-mode or early (and never late) within a long-mode duration. This pattern might be a function of observing time.

Minor hot periods were commonly irregular and rather infrequent, taking place perhaps two or three times per day. At two times, however, they were recorded as a series of regular and frequent events. Both of these may be of significance, since the first case was the day prior to Giant's June 28 eruption and the other the day prior to the onset of Giant's frequent and regular series of major hot periods (see below). Note, however, that other similar but shorter series were also recorded.

A minor hot period is characterized most notably by very strong jetting in Giant. These jets are more vertical and more voluminous than the usual, and quite frequently reach above the top of the cone. Discharge is rather slight, most water falling within the cone, but there is often enough flow over the south and southeast sides of the cone to wash away markers and produce minor amounts of standing water on the platform near the cone. (Note here for the sake of interest that minor hot periods tend to discharge more water from Giant than do the major hot periods, and that there is almost never <u>any</u> discharge from the open front (west) side of the cone during <u>any</u> hot period!)

While this is happening within Giant, there is only a slight increase in the activity elsewhere in the group. Their water levels do rise, by perhaps 1 foot. What increased activity is present seems to occur in either Mastiff or Catfish, but not in both simultaneously, and in any case the increase is slight. Also, there is more visible water and louder boiling in the "Platform Geysers."

Minor hot periods typically last from 2 to 7 minutes but timing them is difficult as they have neither a distinct beginning nor end.

D. The "Major Hot Period" Activity

This is the notable, encouraging, and famous type of hot period action. Unfortunately, it is rather uncommon and irregular in its occurrence. Nevertheless, a good record of the major hot periods has been obtained via the use of markers and diligent, fortuitous observations. Most of the statements here are based on my personal witness of the hot period of July 9 and the follow-up actions on July 19, 21, 23, and 27, and on discussions with John Muller, Jon Nelson, the Goldberg family, and Mike Keller, who among them saw all or part of the hot periods on July 23, 25, 27, 29 and 30 and August 1, 6 and 8.

A major hot period began abruptly. If one was familiar with what to look for, then there were some slight indications that the action was about to happen, but this was always uncertain. These indications included pauses by Bijou, some increased action in Giant along with a "different" quality to its sound, and some louder boiling noises from the "Platform Geysers."

The first distinct event was a rise in the water level in Mastiff. This falls contrary to Marler's statement that an overflow from a side vent of Turtle should be the first event. Very quickly, the Platform Geysers would activate, first those immediately in front of Giant's cone, then those to the southwest, and finally the "Posthole" and other vents nearer the boardwalk. Their combined water discharge was prodigous. As of this time there was little visible difference in the activity by Giant, Catfish, or Bijou. Turtle Geyser overflowed to the southeast, and surged strongly enough to bulge the water a foot or so above the vent. Mastiff presented the most remarkable sight, becoming a large, full, and overflowing pool, beautiful to behold, discharging copiously in all directions and doming superheated water 2 to 4 feet above each vent.

Arbitrarily, I have numbered the Platform Geysers; for reference, see sketch Map A. Their major hot period activity was as follows:

#1. "Posthole" Geyser is artificial, being the hole drilled into the platform to hold the long-gone Giant Geyser sign. Phillips (1927, in Marler) states: "The iron pipe bearing the sign steams vigorously on these occasions and water is thrown out of the drilled hole in the sinter in which it is set." This was the most impressive of the Platform Geysers, playing a steady stream of water to at least 10 feet high. Apparently, too, it was one of the two vents active during all major hot periods.

fp. Immediately to the left of #1 is a small depression, filled with gravel, which acted as a frying pan while #1 was erupting. It was progressively clearing itself of the rubble and could become open and active as a geyser.

#2. A small geyser, active with #1, sputtering 1 to 2 feet high.

#3. A geyser reaching 1 to 4 feet high. On July 9 this was both the first and last geyser to be active.

#4. A significant geyser reaching up to 6 feet high at a slight angle to the west. Despite the fact that this is the closest geyser to Giant itself, it was active during only the most forceful of hot periods.

#5. A small sputtering geyser, 1 foot high, active with #4.

#6. A geyser, 2 to 4 feet high, apparently active during all but the very weakest of hot periods.

#7. A geyser similar to #6, but with a larger vent and greater discharge.

#8. A weak geyser, spraying 1 foot high at best, and inactive during most hot periods.

#9. The second most important Platform Geyser, this played at a low angle toward the southwest, only 2 to 3 feet high but outwards as far as 12 feet. Discharge was great. With #1, this was one of the two vents active during all major hot periods.

#10. A spring, not observed to erupt, but which did fill and boil during major hot periods. The open vent allows one to check the water level within the platform at any time.

#11. A steam vent until July 24(?), when it entirely cleared its vent of rubble-- notably not during a hot period! Subsequently, it filled and boiled during major hot periods but was not seen to actually erupt.

sv. A steam vent which hissed noisily during major hot periods.

Listed above are 9 geysers. Marler notes nine Platform Geysers, and these nine were all active during the forceful major hot period action on July 9 and 27. Mike Keller notes 10 active vents during one other hot period, but I am uncertain as to which added vent this is. It is important to note that most major hot periods do <u>not</u> involve action by all of the Platform Geysers. Most commonly only 5 or 6 are active, and on some occasions only two (#1 and #9) have played.

Prior to the June 28 eruption of Giant, the duration of the Platform Geyser's activity ranged from 3m47s to 8m34s. This play was evidently without pause. All major hot periods since June 28 have been quite different, including a complete pause in the action. Here the Platform Geysers erupted for 4 to 6 minutes, and this was when they were of greatest numbers and force. Then they abruptly paused for 1 to 4 minutes. Finally the play resumed, but by fewer vents and with distinctly less force. With this, the total durations were as long as 12.5 minutes.

At about the time the eruptions by the Platform Geysers either ceased or paused, the water level in Mastiff dropped. It would not recover after the pause. Simultaneously, Catfish jetted briefly but strongly to over 20 feet as Bijou entered a similarly brief but loud steam phase. Both Catfish and Bijou then quickly returned to their more normal activity.

It was at this time, <u>after</u> the drop in water level, that Giant had its strongest surges. Giant did have surging earlier during the hot period, but they were no more than equal to those of the minor hot periods. These later surges were tremendous. Large volumes of water filled the cone, with much being spilled over the east and south sides, and considerable spray reached as far as 20 feet above the top of the cone. The noise was great and the whole scene violent. This action alone was enough to make Giant a very impressive geyser.

It seems clear that this is the point at which a full eruption by Giant will begin. Paul Strasser has wondered if major hot periods might actually be aborted major eruptions. I believe that this is, indeed, the case, or that major hot periods should be considered as minor eruptions. Of course, the terminology should not be changed after all these years.

Whatever the case, there are some questions here. Marler states that major hot periods last between 4 and 11 minutes. Those figures are in accord with the observed durations of the Platform Geysers, but when the heavy surging by Giant was added the entire hot period was shown to last as long as 32 minutes. Marler implies that Giant's eruptions start while the Platform Geysers are still active, but here the great surging was afterwards. Marler does not make it clear whether or not Mastiff was ever a full pool, but the implication is that it is full, and again, the heavy surging follows the drop in water level by Mastiff. Finally, Marler described action by Turtle on a pattern different from what has been seen now. The only conclusion I can make from this is that while major hot periods are largely the same now as they were during the 1950s, there are some clearly different relationships, too. Perhaps the system has undergone some slight physical change in these thirty years; but perhaps also Giant will stabilize in time with a renewal of the historical activity.

The strong post-Platform Geyser surging in Giant occurred in company with little else. It only slowly subsided and the exact termination of the hot period was impossible to judge. Commonly, however, the total duration from the initial rise by Mastiff to the last observed significant surging was in the vicinity of 30 minutes.

A summary of the known major hot periods by the Giant Group since the eruption of September 12, 1987 is found in Table V. This data is mostly the work of Mary Ann Moss and Mike Keller, with input by many others.

E. The Eruption of Giant Geyser on June 28, 1988

Giant erupted at 2155 on June 28, 1988. Because of that time in late twilight, few observers were near and none were at Giant. Therefore, rather little definite can be said about the eruption. Apparently the closest gazer was Amy Recker, who was new to Yellowstone in 1988 and did not fully realize the significance of the activity at the time.

Grotto began eruption at about 2145, just 10 minutes before Giant. While Marler notes that eruptions by Grotto would usually delay Giant by several hours during the 1950s, there were occasions then when Grotto started just a few minutes before Giant. Therefore, there is precedent for this. However, whether Giant was undergoing a major hot period (or, indeed, any kind of hot period) at the time will never be known. Note that this interval by Grotto was of approximately 15h, fitting into neither the short- nor long-mode categories. The eruption was still in progress at 0130 but had ended by dawn on June 29, yielding a duration of something between about 4 and 8 hours, again fitting neither mode.

Giant probably had a maximum height between 150 and 200 feet and a total water phase duration of about 1 hour. The better part of a full day was required for the system to recover. Bijou began having weak jetting after 15 hours, but truly normal water levels and actions were not present until about 1830 on June 29, 21 hours after the start of the eruption.

The majority of Grotto's eruptions in the succeeding days were long-mode. The July 5 steam break, 53+ minute duration eruption by Grotto Fountain Geyser appears to mark the onset of the first true bimodal activity by Grotto and therefore probably also marks the time required for full recovery by the system. Giant definitely did not have another major hot period until July 9.

Section 5 -- Activity by The Purple Pools

Insofar as this study goes, there is relatively little to be said about the Purple Pools. They are positively known to be connected with the Giant Group, and their water levels were low on June 29.

Following their eruptive episode in the Fall of 1987, about which I have essentially no data, the Purple Pools were evidently quiet. The only known eruption of any sort was observed by me on July 17. This involved Middle (or East) Purple Pool only. As viewed from Giant, this eruption was a lazy splashing, one burst every few seconds reaching 3 feet above the crater rim, and so actually about 5 feet high. Markers were not washed away. The play persisted for around 3 minutes after it was first seen, but the total duration is unknown since the initial sighting was upon arrival. A quick check a few minutes later showed the water levels of all three Purple Pools to be down only slightly, and the south pool continued some overflow.

It may be important to note that this eruption occurred 2 days before the first of Giant's seven successive major hot periods, which also had intervals of about 2 days. Is it possible for activity among the Purple Pools to replace that of the Giant Group proper?

Section 6 -- Activity by Oblong Geyser

Oblong Geyser presents something of a mystery. A check of the historical record (primarily Phillips (1927, in Marler), and Marler) makes it seem quite clear that there is a relationship between Oblong and Giant. This has appeared especially in the form of irregular and relatively infrequent eruptions by Oblong whenever Giant is active. Oblong is certainly erratic in its performances now.

Via the use of markers as a check on nighttime activity, it is known that during July Oblong had intervals ranging from 15h54m to 47h30m. The average of 13 intervals was 30h58m with the whopping standard deviation of 8h44m. The basic data recorded for Oblong during July is shown in Table VI.

As first seen during 1986, Oblong may have a series of eruptions rather than a single isolated play. During July such series were recorded five times (but with data recordable for just four of them). The geyser is extremely regular within these series. The first intervals (those from the first to the second eruption) were 2h14m, 2h14m, 2h04m, and 2h05m. Only one second interval, of 33m, was recorded. These values in each case are entirely in accord with the observations of 1986-87.

These five series are believed to be the only ones to have occurred during July, and their dates are significant. The four well recorded were on July 3, 19, 21, and 22. The first of these occurred while the entire system was still rrecovering from the June 28 eruption, and the other three all took place amid Giant's series of regular major hot periods. The last occasion, on July 25, was also during the hot period series, but statistical data was not recorded.

It seems, then, that the roots of this geothermal system are wide indeed, and that eruptive series by Oblong can be related to events as far afield as the Grotto Group. Do note, however, that these series are as follow-up activity, and are of no predictive value.

Section 7 -- Some Discourse on the Relationships Between the Grotto Group and the Giant Group

Much of what will be said here is a summary of the material in the preceeding pages. I will attempt to make some logical inferences and surmises about the activity of the Grotto Group, of the Giant Group, and the relationship between the two groups. All is subjective, based on the observations of June 28-July 28, 1988.

1. Grotto Geyser is strongly bimodal in its activity.

The period of the eruptive activity (that is, duration plus interval) was dependent on the previous duration and, evidently, on nothing else. A long-mode duration invariably produced a long-mode period, and short-mode lead to short-mode.

2. The short-mode equated with minimal discharge from the system

Although the short-mode eruptions were the more common in terms of sheer frequency, the net water/energy discharge from the system was relatively small. The average short-mode period was 7h29m and the average duration was 2h32m. Thus, during the short-mode activity, Grotto was actually in eruption 33.85% of the time.

3. The long-mode equated with maximum discharge from the system.

Although the long-mode eruptions were comparitively few in number, they occupied a greater total time span than did the short-mode, and the the net discharge by the system was very much greater. Here the average period of 26h51m compares to an average duration of 18h29m. Thus, during the long-mode activity, Grotto was actually in eruption 68.84% of the time.

4. Eruptions of the two modes were greatly different events.

The difference between the in-eruption values indicates that the two modes of function were more than simple extended play. Grotto in the long-mode was in actual eruption about 2.03 times as much of a total time span as when it was in the short-mode, and it must therefore have expended that much more water and energy in equal blocks of time.

Marler derived a discharge value of 470 gallons per minute for Grotto's eruptions. Using that figure, and standardizing the two modes, during a 24 hour span of time Grotto discharged about 465,000 gallons of boiling water during the long-mode activity, but only about 230,000 gallons during a corresponding span of short-mode activity. This is a great difference, and must have a source.

5. Eruptions of the two modes had very different effects on related springs.

Entirely aside from the difference in in-eruption times shown above, the two modes had dramatically different effects on related features within the system.

Eruptions of the short-mode were in company with short-duration eruptions by Grotto Fountain, relatively frequent major eruptions by Rocket, rare activity by Spa, and no observable drawdown or enervation of connecting units or the Giant Group.

Eruptions of the long-mode were accompanied by infrequent major activity by Rocket, common play by Spa, more extensive activity by the Grotto Fountain cluster, severe drawdown effects in connecting features, and enervation at Giant.

6. Very different plumbing was involved in the two modes.

Clearly, water was in limited supply during the short-mode eruptions by Grotto and very much more abundant during the long-modes. In essence, short-mode eruptions were play by the Grotto Group alone whereas those of the long-mode involves not only the Grotto Group, but the Giant Group as well.

7. Activity by the Giant Group served as the trigger from short-mode to long-mode.

The observational evidence was that Grotto would normally operate on the short-mode only, and that some external action was required to cause the long-mode activity. There were several examples of Grotto virtually ceasing its eruption after two to three hours, and then rejuvenating into a long-mode eruption. I believe this trigger to be action by the Giant Group.

Although most of the long-mode eruptions of Grotto did not correspond to observed performances at Giant, enough were to allow the surmise that all Grotto long-modes were caused by something happening within the Giant Group. This was not necessarily an immediate effect, as some long-modes began as long as two short-modes after witnessed activity at Giant.

There is evidence that the Giant Group may have hot period activity other than the types described in this paper. These are entirely subsurface in nature but could nevertheless have a significant effect on the system.

8. Eruptive or hot period activity by the Giant Group was most likely during Grotto's short-mode.

Because the short-mode activity by Grotto involves minimal system discharge, it is then that there is the least impact on the Giant Group. It was therefore then that Giant was most likely to undergo a major hot period or full eruption.

9. Major hot periods by Giant took place when Grotto was not in eruption.

Major hot periods require a full system. Given that any eruption by Grotto does discharge water from the system, activity by Giant was most likely to occur when Grotto was in the process of recovering from a prior eruption. Without known exception, all major hot periods during July occurred with Grotto not in eruption, but well into recovery.

It is clearly possible for Giant to erupt or have a major hot period within the first few minutes of a Grotto eruption, as happened on June 28, but such action is from a fully primed system and before there has been any opportunity for Grotto to have produced significant drawdown.

10. Short-mode activity was the key to predicting Giant's hot periods.

Not only were major hot periods by Giant related to Grotto's short-mode, but they generally occurred following a series of several consecutive short-mode eruptions. Combined with point 9 above, then the best time to watch for Giant was when Grotto was well into recovery towards a next eruption of the short mode.

11. Giant has entered an active cycle.

Given the persistence of major hot period activity, Giant must be considered to be an active geyser. The fact that its long dormancy is over is illustrated by the hot periods, which did not occur in the months following the previous eruptions of 1978, 1982, 1984, and 1986, or prior to that of 1987.

12. An eruption by Giant might occur at any time.

Since Giant is active and since major hot periods can occur only when the system is fully primed in terms of both water and energy, any major hot period is capable of producing an eruption. Recall that it might be fully correct to consider the major hot periods as either minor or aborted eruptions. The difference between playing and not playing is probably only a matter of one or two additional strong surges, the surging starting earlier within a hot period, more of the Platform Geysers playing or perhaps not pausing, greater bursting by Mastiff, or some other seemingly minor event.

Section 8 -- On the Physical Nature of the Connections Between the Grotto Group and Other Features

On June 15, prior to my 1988 visit to Yellowstone, I wrote and distributed a short paper titled "Exchange of Function Along the Grotto-Giant Trend." This section is a shorter, revised version of that speculative paper.

A. Basic Information

That the geysers of the Grotto Group are connected with those of the Giant Group has been inferred since the early 1950s, when Marler noted eruptive relationships between the two groups. It is also known that the Purple Pools are connected with the Giant Group, and there is inferential data showing a probable connection between Oblong Geyser and the Giant Group. Connections with the Daisy Group have been suggested, too.

To my knowledge, nobody has previously suggested a relationship between the Grotto Group and features to the northwest of Spa, or in the direction of Riverside Geyser. Indications are that such connections do exist and that, in fact, these are a vital part of the entire Grotto-Giant system. If this is so, then there are relationships among the geysers and other features extending all the way from Link Geyser on the northwest to Oblong Geyser and the Purple Pools on the southeast, making this one of the most far-flung complexes of springs in Yellowstone.

B. The "Grotto-Giant Trend"

Considerable change has taken place within the entire general vicinity of Grotto Geyser during the months since Giant Geyser's eruption of September 12, 1987. Included, of course, are the actions of the Grotto Group, the eruption and continuing major hot periods by the Giant Group, the erratic activity by Oblong Geyser, and the Fall, 1987 eruptive episode of the Purple Pools, all of which are described elsewhere in this paper. Not previously described, however, are ongoing changes to the north and northwest of the Grotto Group.

Near the west side of the trail to the northwest of Spa Geyser is a cluster of springs and small geysers. Culvert Geyser, Square Spring, some small unnamed features, and the "new" Persistent Geyser have generally been considered as part of the Chain Lakes Group of springs, which includes Link Geyser. This "Culvert Group" should probably be considered to be a separate unit, within which substantial change has occurred.

Sometime during the late winter-early spring of 1988, Culvert Geyser began to erupt. The play was small but notable in that such action had not been observed in many years. As a probable precursor to this was the minor eruptive activity of Square Spring, seen during the summer of 1987 for the first time since the 1950s. At about the same time that Culvert activated, several gravelled areas on the shoulder of the trail south of Culvert began to steam. While the Park Service erected a portable barricade around Culvert, the steaming ground was left undisturbed. As described in Section 2 of this paper, one of the steaming spots developed into "Persistent Geyser" starting on June 24. Through July, the area seemed to have stabilized. Culvert became quiet with the new development, but Square Spring continued to act as an intermittent spring with infrequent 1-foot eruptions.

Meanwhile, Link Geyser had changed somewhat, too. This was evident only to experienced observers, primarily in the guise of greater discharge and perhaps longer durations of the minor eruptions.

By taking copies of the USGS Thermal Map series, drafted about 1968, it is easy to see that the cause of these changes is likely the same as that causing changes in Grotto and Giant Groups. There is an obvious alignment of thermal features along a straight line. This trend runs directly through Giant Geyser, "Variable Spring", Indicator Spring, Spa Geyser, Culvert Geyser, and Link Geyser, and therefore also very near to "Midway Spring", Grotto-Rocket, and the Grotto Fountains. This trend, which has a geographical strike of N 28 W, is shown on Map B, a copy of the Thermal Maps. Extended beyond the map, this trend could also include West Sentinel Geyser and Green Star Spring.

Note also two other alignments which also strike near N 28 W. One runs through the Purple Pools; the other marks the base of the hillside west of the Chain Lakes.

It is abundantly clear that an exchange of function has taken place in this area. I believe that this is a matter of water being differently distributed along a fracture system or fault on this trend. Clearly, too, this exchange is not simply a shift from Grotto to Giant but rather one from Grotto to elsewhere. Giant is evidently a partial recipient but not the sole beneficiary.

The future of this exchange will be dependent on both how extreme the shift becomes, and on the direction along the trend that the shift follows. It would not necessarily be in the direction of Giant, however, and further increases in the activity of the Culvert and Chain Lakes Groups might be detrimental to Giant. There is one point, though, which argues against that happening.

Marler notes that of all the features of the Grotto Group, perhaps the one which is most strongly affected by the Giant Group is Spa Geyser. Spa, of course, is the Grotto Group member furthest to the northwest, and furthest from Giant. So perhaps the increased action at Culvert and Link is, in fact, a direct function of the increased action at Giant. In other words, although Giant is geographically southeast of Grotto, perhaps the route of the geological connection between them starts to the northwest.

This is all surmise, of course, but I feel that continued close observations of the Culvert and Chain Lakes Groups might be worthwhile and revealing of further eruptive relationships.

C. Additional Connections With the N 28 W Grotto-Giant Trend

Many have surmised about several other group connections in this area. One of note is that between Giant and Daisy. Marler believed in this, but did not describe his reasons. At the time of the June eruption and July major hot periods by Giant, there appeared to have been some change in Daisy Geyser's interval, the average becoming somewhat shorter from (roughly) 88 minutes to 83 minutes. Given the complexity of the Daisy Group, however, any conclusions based strictly on interval data would have to be considered tentative, at best.

There has also been some discussion about a connection between Link Geyser and Fan & Mortar Geysers. Data is sparse and its evidence may be coincidental. Nonetheless, the N 28 W trend runs quite near Fan & Mortar and could easily connect with the Fan fracture across the river.

D. Possible Connection Between the Grotto Group and Riverside Geyser

There is also a proposed connection between Riverside Geyser and the Grotto Group. I have inferred this in past seasons, when there simply seemed to be "too many" eruptions of Grotto Fountain and Riverside with nearly simultaneous starts. A similar relationship was evident at times during 1988.

Riverside this year had a longer average interval than has been seen in some time. The basic cause was a near total lack of short-mode (Riverside) intervals, especially prior to Giant's June 28 eruption. However, when the Grotto Group had recovered from that eruption, the short-mode of Riverside became dominant for several days. On July 5-6, several consecutive eruptions of Grotto Fountain Geyser began within minutes of Riverside. One of these occurred during the first preplay episode and before Indicator Spring had filled for the first time.

Physical evidence for this connection is present as "Connector Spring", described in Section 2 of this report. It showed a clear relationship to the Grotto Group, and another line drawn on the map from Riverside through Connector reaches the Grotto Group near Indicator Spring.

I must emphasize the very tentative nature of this conclusion, but feel it is another matter worth further investigation.

References

Marler, G. D., 1973, *Inventory of thermal features of the Firehole River Geyser Basins and other selected areas of Yellowstone National Park*. National Technical Information Service (NTIS), Publication Number PB-221289.

Bryan, T. S., 1986, *The Geysers of Yellowstone*. Colorado Associated University Press, Boulder.

ADDENDUM
Further Notes About Giant Major Hot Periods
August - September, 1988

People who were in the geyser basins throughout August and early September, 1988 continued close observations of Giant and its hot period activity, and of their relationship to activity by Grotto. Table V presents a list of all known major hot periods for the period ending on September 5; most of the data is courtesy of Mike Keller. A summary of this data follows.

Giant's major hot periods were predictable on the basis of Grotto's action. This was true to a great enough extent that essentially no hot periods were missed during this time. Hot periods occurred only when the following conditions were satisfied:

1. All observed major hot periods, or a series thereof, began 4 to 5 hours after any Grotto start. This could be either short-mode (in which case Grotto was quiet, having already ended eruption) or long-mode (in which case Grotto was still in eruption). OR

2. Major hot periods which did not begin per the above took place 8 to 10 hours after the end of Grotto's long-mode play, and thus well into system recovery. PROVIDED

3. Either of the above cases could apply only if it had been at least 18 hours since the previous major hot period.

4. Furthermore, it also appeared that major hot periods could occur only within 1 or 2 minutes of a Daisy eruption start.

So, the key to predicting Giant major hot periods lay in monitoring the activity of Grotto and Daisy. Grotto appeared to control the system, and it is likely that long-mode eruptions often prevented or delayed hot periods. Daisy appeared to trigger the system, when it was properly primed.

Consistent data apparently ended on September 5 due to the forest fire situation. This is unfortunate, because Giant erupted at 1846 on September 12, 1988. The interval of 75d 20h 51m is the shortest since 1955.

TABLE I

GROTTO GEYSER -- JULY 1988

Date	Grotto Fntn Start	Grotto Fntn Duration	Grotto Start	Grotto End	Grotto Period	Grotto Inferred Period	Grotto Duration	Data for Inference
7/01	ie0730	----	ie0730	1924		8h15m X 2	~12h	
7/02	0740	15m	n.r.	n.r.		24h10m	~2½h	Rocket major @0931
	1459	15m	n.r.	n.r.	7h 19m			
7/03	1320	13m	1345	----		7h27m X 3	>8h 15m	
7/04	0719	13m	0721	----	17h 36m		>14h 09m	Still i.e. 2130
7/05	1230	<u>>53m</u>*	1239	1354	29h 18m		1h 15m	Period from markers
	1935	13m	1940	----	7h 01m		~2h	i.e. 2100; not i.e. 220
7/06	0302	9m	0305	0524	7h 25m		2h 19m	
	0951	10m40s	0953	1211	6h 48m		2h 18m	
	1651	8m27s	1654	1925	7h 01m		2h 31m	
7/07	0848	8m	0850	1147		7h53m X 2	2h 57m	
7/08	No observations made, due action by Giantess; Grotto i.e. 2045							
7/09	0922	8m	0922	~1400			~4h 38m	i.e. 1350;not i.e. 142
	<u>(1606 -- GIANT MAJOR HOT PERIOD)</u>							
	1801	7m07s	1802	2146	8h 39m		3h 45m	
7/10	1023	11m	1025	----	16h 24m		>5½h	"weakly" i.e. 1550
	1715	10m	1718	below	6h 52m			still i.e. 2255
7/11	end of 7/10@1718 eruption--0925						16h 07m	Obs + severe drawdown

TABLE I, continued

7/12	0903	15m40s*	0908	1114	40h 50m		2h 06m	Markers
	1618	13m50s	1622	1858	7h 14m		2h 36m	
7/13	0816	15m27s	0820	~0040,7/14		7h59m X 2	~16h 20m	
7/14	1359	13m	1410	1530	29h 50m		1h 20m	Obs + markers
	2039	14m22s	2043	2325	6h 33m		2h 42m	Giant minor h.p. @2100
7/15	0358	8m	0401	0630	7h 22m		2h 30m	
	1107	8m49s	1110		7h 09m		>10h	still i.e. 2145
7/16	1335	13m30s	1338	1601	26h 28m		2h 23m	
	2108	14m20s	2112		7h 34m		<3h	not i.e. 0100,7/17,v.r.
7/17			----	0640				unobserved start~0400
	1033	8m03s	1036	1406		6h42m X 2	3h 30m	
	1937	7m57s	1940	2213	9h 04m		2h 33m	
7/18	1129	7m36s	1131	1350		8h25m X 2	2h 29m	
	1851	7m42s	1855	2222	7h 24m		3h 27m	
7/19	(est. 0300 -- GIANT MAJOR HOT PERIOD)							
			~0500	----		~10h	>18h	still i.e. 2300
7/20	1229	20m44s*	1239	1415		~31h	1h 36m	
	2009	15m26s	2014		7h 35m		<2½h	not i.e. 2230
7/21								active during night
	(~0700 -- GIANT MAJOR HOT PERIOD)							
			~1100	below				still i.e. 2200
7/22	end of 7/21@1100 eruption			~0500			~18h	
	1411	n.r.	1414	1656		~27h	2h 42m	
	2229	n.r.	2236	----	8h 22m			

TABLE I, continued

7/23	(0732 -- GIANT MAJOR HOT PERIOD)							
	0804	n.r.	0807	1034	9h 28m		2h 27m	
	1453	9m09s	1456	below	6h 49m			
7/24	end of 7/23@1456 eruption ~0600						~15h	
	1815	26m*	1825	1950	27h 29m		1h 25m	
7/25	0830	9m	0834	1110		7h04m X 2	2h 36m	
	(1409 -- GIANT MAJOR HOT PERIOD)							
	1542	12m58s	1545	1810	7h 11m		2h 25m	
7/26	did not erupt		0750	below		8h02m X 2		i.e. 1940
7/27	end of 7/26@0750 eruption ~0600						>22h	
	(1725 -- GIANT MAJOR HOT PERIOD)							No Grotto as of 2100
7/28	(early am -- weak GIANT MAJOR HOT PERIOD)							
	1108	13m18s	1111	1318		?? >51h	2h 07m	
	1755	9m	1758		6h 47m			

end of study

* Asterisks and underlining in "Grotto Fountain Duration" column indicate "steam break" eruptions.

TABLE I, continued

7/23	(0732 -- GIANT MAJOR HOT PERIOD)							
	0804	n.r.	0807	1034	9h 28m		2h 27m	
	1453	9m09s	1456	below	6h 49m			
7/24	end of 7/23@1456 eruption ~0600						~15h	
	1815	26m*	1825	1950	27h 29m		1h 25m	
7/25	0830	9m	0834	1110		7h04m X 2	2h 36m	
	(1409 -- GIANT MAJOR HOT PERIOD)							
	1542	12m58s	1545	1810	7h 11m		2h 25m	
7/26	did not erupt		0750	below		8h02m X 2		i.e. 1940
7/27	end of 7/26@0750 eruption ~0600						>22h	
	(1725 -- GIANT MAJOR HOT PERIOD)							No Grotto as of 2100
7/28	(early am -- weak GIANT MAJOR HOT PERIOD)							
	1108	13m18s	1111	1318		?? >51h	2h 07m	
	1755	9m	1758		6h 47m			

end of study

* Asterisks and underlining in "Grotto Fountain Duration" column indicate "steam break" eruptions.

TABLE II

A Summary of Periods and Durations
GROTTO GEYSER -- JULY 1988

Note: The data in this table is that used for the inferences discussed in Sections 3 and 7 of this paper. Inferred periods and durations are not included; some approximations believed correct within a few minutes are included.

Short-Mode		Long-Mode	
Period	Duration	Period	Duration
7h 19m	1h 15m	17h 36m	16h 07m
7h 01m	2h 19m	29h 18m	16h 20m
7h 25m	2h 18m	16h 24m	19h 30m
6h 48m	2h 31m	40h 50m	22h 00m
7h 01m	2h 57m	29h 50m	
8h 39m	4h 38m	26h 28m	
6h 52m	3h 45m	27h 29m	
7h 14m	2h 06m		
6h 33m	2h 36m		
7h 22m	1h 20m		
7h 09m	2h 42m		
7h 34m	2h 30m		
9h 04m	2h 23m		
7h 24m	3h 30m		
7h 35m	2h 33m		
8h 22m	2h 29m		
9h 28m	3h 27m		
6h 49m	1h 36m		
7h 11m	2h 42m		
6h 47m	2h 27m		
	1h 25m		
	2h 36m		
	2h 25m		
	2h 07m		
n = 20	n = 24	n = 7	n = 4
$\bar{x}$ = 7h 29m	$\bar{x}$ = 2h 32m	$\bar{x}$ = 26h 51m	$\bar{x}$ = 18h 29m
σ = 46m 29s	σ = 45m 12s	σ = 7h 37m	σ = 2h 26m

TABLE III

THE GROTTO-ROCKET RELATIONSHIP, JULY 1988

Date	Grotto Start	Grotto Mode	Rocket Start	Interval of Rkt after Gto	Rocket Duration	Rocket Before Grotto End
6/07	1355	unk	1530	1h 38m	n.r.	
6/22	0835	unk	1055	2h 20m	n.r.	
7/02	0740	short?	0931	1h 51m	5m	
	1459	short	1705	2h 06m	7m	
7/06	0305	short	0506	2h 01m	n.r.	18m
	0953	short	1134	1h 41m	2m	37m
	1654	short	1908	2h 14m	3m	17m
7/09	0922	short	1149	2h 27m	n.r.	2h 11m
	1801	short	2015	2h 14m	10m	31m
7/10	1025	short	1214	1h 49m	6m	3h 36m
7/14	2043	short	2243ie	~2h 00m	~8m	42m
7/15	0401	short	0603	2h 02m	n.r.	30m
	1110	long	1347	2h 37m	12m	---
			1542	[4h 32m]	7m	---
7/16	1338	short	1541	2h 03m	6m	20m
7/17	1036	short	1309	2h 33m	6m	57m
7/18	1855	short	2148	2h 53m	12m	34m
7/21	~1100	long	missed			
			1450	[3h 50m]	n.r.	---
7/23	0807	short	1002	1h 51m	4m	32m
7/28	1111	short	1256	1h 45m	9m	22m
	1758	short	1956	1h 58m	6m	n.r.
				$n = 19$		$n = 9$
				$\bar{x} = 2h\ 06m$		$\bar{x} = 29m\ 47s$
				$\sigma = 19m\ 44s$		$\sigma = 11m\ 54s$

TABLE IV

THE GROTTO-SPA RELATIONSHIP, JULY 1988

Date	Spa Start	Grotto Mode	Grotto State*	Spa Water Level	Spa Duration	Spa Max. Height(ft)
7/01	1006	long	i.e.	full pool	4h 44m	30
7/07	2045ie	short?	i.e.	not record.	not. rec.	--
7/09	2135ie	short	i.e.	not record.	long	20
7/10	1322	short	i.e.	full pool	2h 28m	40+
7/11	0954	long	not i.e.	very low pool	33m	35
7/15	1514	long	i.e.	full pool	38m	30
7/17	1420	short	not i.e.	low pool	09m	25
7/19	0840	long	i.e.	full pool	4h 50m	50 (many)
7/21	1500ie	long	i.e.	full pool	>6h	40
7/23	1120ie	short	not i.e.	low pool	<30m	20
	~1840	long	i.e.	full pool	>3h	25
7/26	0813ie	long	?not i.e.	full pool	>8h	25

* "i.e." is an abbreviation meaning "in eruption".

TABLE V

Known Eruptions and Major Hot Periods
GIANT GEYSER, SEPTEMBER 11, 1987 - SEPTEMBER 4, 1988

Date	Time	Grotto Active	Number Of Active Vents	Duration Platform Vents	Interval
9/11	afternoon				
9/12/87	1358	-- ERUPTION BY GIANT GEYSER			~ 1d
10/08					~26d
10/11					~ 3d
10/20					~ 9d
10/22					~ 2d
10/30					~ 8d
10/31/87-01/16/88	-- No concerted observations; major hot periods reportedly not occurring.				
1/16/88	0900-1650		4		
2/01	1313	x	5	7m 18s	~16d
2/03	1556		3	3m 47s	2d 02h 43m
2/17	night		2		~13 1/2d
3/14	0947		6	8m 34s	~26 1/4d
3/15/88-4/28/88	-- No observations; at least one major hot period shown by markers.				
4/29-30	2100-1300		4		
5/03	1513		2	7m 16s	~ 3 1/2d
5/16	1904		8	5m 14s	13d 03h 51m
5/22-23	1700-0800		5		~ 6 1/2d
6/01	0919		1	9m 43s	~10d
6/03	2014		3	3m 23s	2d 10h 55m
6/06-07	1500-0540		2		~ 3d
6/14	1606		9	6m 03s	~ 7 1/2d
6/15	0908	x	7	7m 09s	0d 17h 02m
6/20	1043		10	8m 37s	5d 01h 35m
6/24	0900-1500		1		~ 4 1/4d
6/28	1400 v.r.		--		~ 4d
6/28/88	2155	x	-- ERUPTION BY GIANT GEYSER		
7/09	1606		9	12 1/2m	10d 18h 11m
7/17	0845ie		Eruption by Middle Purple Pool		~ 7d 16h 39m
7/19	~0300		7		~ 1d 18h
7/21	~0700		7		~ 2d 04h
7/23	0732		6		2d 00h 32m
7/25	1409		7	~10m	2d 06h 37m
7/27	1725		9	~12m	2d 03h 16m
7/28	early am ?		2		~ 0d 10h
7/29	2345		9		~ 2d
7/30	0750		1		0d 08h 05m

8/01	~1000		8		~ ~2d 02h 10m
	1130ie		2		~ 0d 01h 30m
8/06	1034		8		4d 23h 04m
	1827		2	4m 27s	0d 07h 53m
8/08	2013	x	1	47s	2d 01h 46m
	2208	x	3		0d 01h 55m
8/10	1200-1800		10		~ 1d 17h
8/12	0700ie		8	>8m	~ 1d 16h
	1336	x	1	2m 03s	~ 0d 06h 36m
	1753		5	7m 06s	0d 04h 17m
8/13	~ 0600		7		~ 0d 12h
8/14	1149	x	10	9m 14s	~ 1d 05h 19m
8/15	1848ie		1	>30m	~ 1d 06h 59m
8/16	1420		13	12m 26s	~ 0d 19h 32m
8/18	1440ie	x	10	>8m	~ 2d 00h 20m
	2208	x	2	5m 26s	~ 0d 07h 28m
8/19	0920		2	4m 43s	0d 11h 12m
8/20	1830ie	x	9		uncertain
8/21	1440ie		9		~ 0d 20h 10m
	1930		2	16m 42s	~ 0d 04h 50m
8/23	1133	x	8	6m 51s	1d 16h 03m
8/24	1234		11	11m 16s	1d 01h 01m
8/27	0237ie		2	>4m	2d 14h 03m
	0330-0830		8		~ 0d 3 1/2h
8/28	0927		10	9m 41s	~ 1d 03h
8/29	1547		8	~ 23m	1d 06h 20m
8/30	1604		9	16m 36s	1d 00h 17m
9/01	0805		8		1d 16h 01m
	1125ie		2	>4m	~ 0d 03h 20m
	1557ie	x	2	>7m	~ 0d 04h 32m
	1703	x	1	5m 01s	~ 0d 01h 06m
9/02	0304		3	5m 29s	0d 10h 01m
	1656		12	19m 56s	0d 13h 52m
9/04	1533		11	13m 47s	1d 22h 37m
	2050	x	2	>6m	0d 05h 17m
9/06	0838		9	13m 03s	1d 11h 48m
9/07	~0530		7		~ 0d 21h
9/08	early am		7		~ 0d 20h
9/09	0700		7		~ 1d 05h
9/10	1119		3		~ 1d 4h
	1852		7	~ 17m	0d 07h 33m
9/12/88	1846 -- ERUPTION BY GIANT GEYSER				1d 23h 54m
9/20	0200		7		~ 7d 07h

End of Data for This Report

Thanks to Mike Keller and, indirectly via Keller, Phil Landis and Lynn Stephens for providing the data from August 1 through September 20.

Sketch Map A

THE GIANT GEYSER GROUP

This map is a sketch only, and is not intended to represent a high degree of accuracy. It is loosely based on map work done by both Mike Keller and Scott Bryan during 1988.

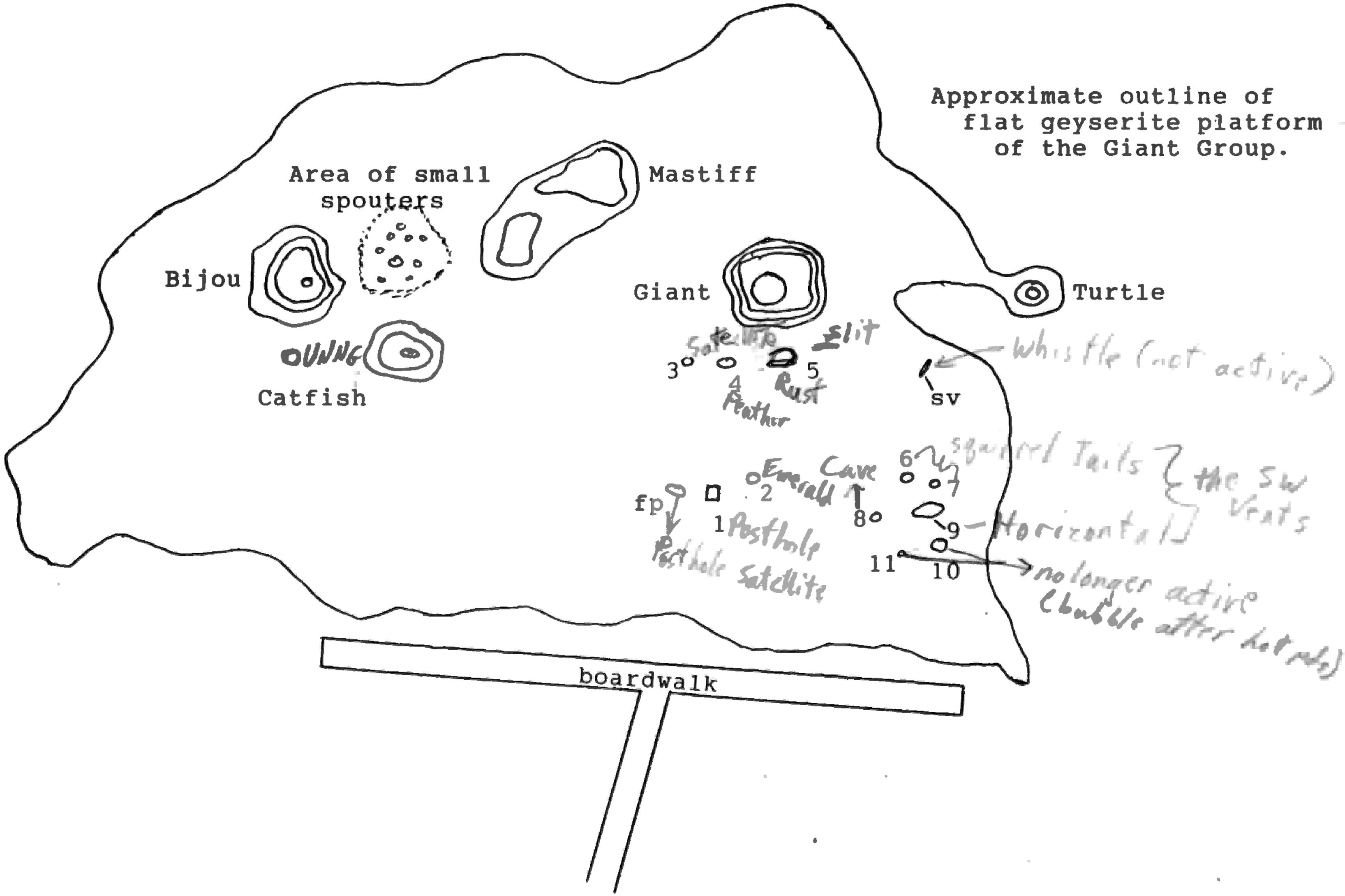
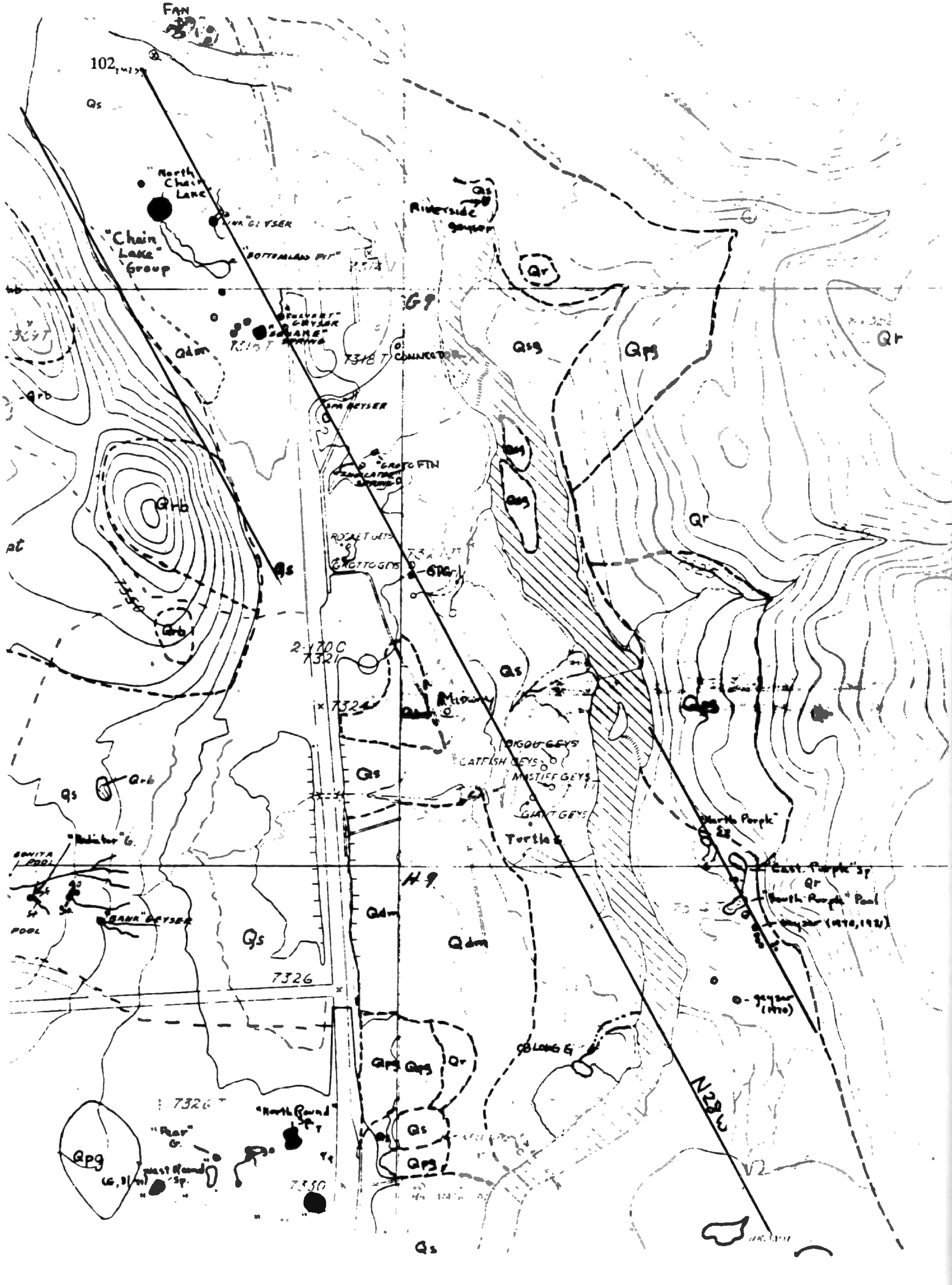


TABLE VI

OBLONG GEYSER -- JULY 1988

Date	Time	Solo Interval	First Series Interval	Second Series Interval
7/02	1333	-------		
7/03	1123	21h 50m		
	1337		2h 14m	none
7/04	1940	30h 03m		
7/06	0757	36h 17m ?		
7/07	1145ie	27h 48m		
7/10	1008			
7/11	~1230	~26h 22m		
7/13	0801	43h 31m		
7/14	0755	23h 54m		
7/15	1825	34h 30m		
7/17	night	(30+h)		
7/18	0803	~30h		
7/19	1545	31h 42m		
	1759		2h 14m	
	1832			33m
7/21	1802	47h 30m		
	2006		2h 04m	none
7/22	~1200	~15h 54m		
	1405		~2h 05m	none
7/25	missed			
	1529		<3h	none
7/26	1514ie	23h 45m		
7/27	0650ie	39h 36m		



FAN
102
Qs
"North Chain Lake"
"Chain Lake" Group
Riverside geyser
Qr
G9
Qsg
Qpg
Qdm
Qrb
7318 T CONNECTOR
SPA GEYSER
"GROTTO FTN
ROSETTE GEYS
GROTTO GEYS
2-170C
7321
7324
BIJOU GEYS
CATFISH GEYS
MASTIFF GEYS
GIANT GEYS
Turtle G
"North Purple" Sp
"East Purple" Sp
"South Purple" Pool
H9
"Radiator" G
BONITA POOL
"BANK" GEYSER
7326
OBLONG G
"North Round" Sp
"Pear" G
"West Round" Sp
7330
N28W

Description of Giant Geyser Eruption
September 12, 1988
Yellowstone National Park, Wyoming

Lynn Stephens

Abstract

Giant Geyser erupted on September 12, 1988, at 1846. This paper describes the eruption, including the hot period preceding the eruption.

In checking the water levels in various pools around the Giant area the morning after the eruption, it was noted that the pool between Grotto Fountain and Riverside, on the east side of the paved trail and south of the Riverside prediction board, was almost empty. Subsequent observations revealed that the water level in the pool fluctuates in response to marathon eruptions of Grotto.

Introduction

The objective of this paper is to describe the Giant eruption of September 12, 1988. The time of Giant Hot Periods for September 6 through September 20 are summarized in Table 1. A chronological listing of the observations made prior to and during the eruption is provided in Table 2. Eruptions of Daisy, Grotto Fountain, Grotto, Oblong, Riverside, and Rocket for the day of the eruption are listed in Table 3. Table 4 contains information on the Bijou pauses for September 11 and 12. Grotto's activity for September 6 through September 18 is summarized in Table 5.

Hot Period Preceding the Eruption

Bijou pauses had been occurring approximately every 24 minutes the afternoon of the eruption. At 1833.20 Bijou paused and resumed activity at 1834.59. At this point the water level in the platform vent known as "Posthole" (or "West") was checked to determine if the eruption of Grotto was causing the water level to decline. The water level in "Posthole" appeared unchanged from earlier that day at approximately 2 inches full.

At 1838.10, Bijou was off again. The 4m 50s interval was the first short interval noted that day, although earlier that afternoon Mary Ann Moss had mentioned that sometimes pauses occurred at 5 minute intervals.

The water level in Mastiff rose quite suddenly. The water level in the west side was rising rapidly at 1839.25, seven minutes before the start of Giant's eruptive activity. 1841:07 Mastiff was boiling to a height of 3 to 4 feet from the east side and the west side was overflowing.

The overflow from Mastiff was strong, and by 1842.13 it was flowing steadily over the ledges of the platform. The runoff formed and inverted V pattern when viewed from the boardwalk, running off the ledge in front of Mastiff, and over toward Giant's cone and off the platform at the south end of the V. Less than at minute later at 1843.02--about 3 minutes from the start of the hot period--Mastiff's runoff was "akin to a Great Fountain wave." The water appeared to be at least 2 inches deep in the runoff areas.

Some of the platform vents had started erupting by 1839.44. North #2 was the first vent, but it was immediately joined by three of the vents in the southwest group. Rusty (East #1) started erupting 10 seconds later at 1839.54. At this time the north vent was erupting approximately 6 feet high.

The first time Turtle was checked, at 1841.16, it was overflowing. The only action from Turtle during the hot period was overflow. No eruptive activity from Turtle was noted and the stop time of Turtle's overflow was not determined.

Posthole began to bubble at 1841.52. No action other than the slight above ground bubbling was noted from Posthole.

Catfish gave several 5 to 8 foot splashes about 2 minutes into the hot period.

Activity in the platform vents began to decline about 3 minutes into the hot period. The north vent had decreased to the height of 2 to 3 feet. One of the vents in the southwest area had ceased erupting. At this point North #2, Horizontal, two other vents in the southwest group, and Rusty were still erupting. Activity in the southwest area continued to decline and by 1843.21 only one vent in the area was erupting, probably the vent called "Blowout". At 4 minutes into the hot period, 1843.50, Horizontal, North #2, and Rusty (East #1) were the only vents erupting. The overflow from Mastiff had covered the south end of the platform by this time and at was impossible to determine any overflow action from vents that were not actually erupting.

At this point in the hot period, Mastiff began to erupt. At 1844.13, 4m 38s into the hot period, the east side of Mastiff was erupting. The was surging to about 12 feet in a wide column. The height of these surges continued to increase. At 1844.57 they were estimated at 30 feet and at 1845.22 Mastiff was conservatively estimated at 50 feet.

Approximately 2 minutes before Giant erupted, at 1844.57, while Mastiff was surging, the platform started to "pound". The vibrations could be felt in the boardwalk and the noise was clearly audible. Thirty seconds later there was a loud "roaring" sound from the Catfish/Bijou area of the platform. The sound was a combination roar/whistle, quite unlike any other geyser sound previously heard by the observer.

Activity of the platform vents during the last two minutes of the hot period prior to Giant's eruption was not determined.

Activity of Giant

On Sunday, September 11, 1988, the day before Giant erupted, Giant was relatively quite. At 1819 that evening there were not many splashes from Giant, but the splashes that were occurring were vertical.

Giant was exhibiting more activity on the following day. At 0854, 0914, and 0915 several vertical splashes were observed, some of which reached the top of the "bite" on the south inside of the cone. That afternoon, form 2 to 2 hours before the eruption, some splashes were observed from the right side of the cone, followed by vertical splashing.

It was not until immediately preceding the eruption that Giant indicated it was going to erupt. During most of the hot period preceding the eruption, Giant's splashes were not of unusual height or volume. Only one splash out the front of the cone was noted, 5 minutes before the eruption at 1841.16. After Mastiff started erupting, Giant began splashing more vigorously, with splashes filling about two-thirds of the cone.

At 1846.20 Giant gave a splash that completely filled the cone, both in width and height, and water splashed out the front. At 1846.49 the column of water from Giant lifted in what seemed to be one continuous motion, without exhibiting surges.

An estimate of the height was not made until about 4 minutes into the eruption. The estimate was made while standing at the 200 foot marker from Giant, between Giant and Oblong. The angle to the top of the column was estimated at between 40 and 42 degrees. A minute later the top of the column was estimated at 45 degrees, or approximately 200 feet. By ten minutes into the eruption the top of the main column had declined sightly, but some spikes of water were still reaching 200 feet. At 26 minutes into the eruption the top of the column had dropped to about 100 feet.

The water phase continued for about 35 minutes. At 1921 Giant had started to exchange steam with water, with the water portion reaching heights between 20 and 40 feet. Within about 3 minutes, at 1924, the action changed to "rushing"--a series of steam bursts mixed with some water rather than continuous action. At this point the steam bursts were only seconds apart.

The eruption changed to only steam at the 41 minute mark. The frequency of the steam bursts declined over the next 7 minutes, and it appeared that the eruption was dying out about 47 minutes after it had started.

Giant continued to have water splashes and steam rushes until 63 minutes after the eruption began. In the final minutes of the eruption, the frequency of the steam bursts declined rapidly. The eruption was deemed finished at 1958--71 minutes from the start--when the steam bursts terminated.

The next day, September 13, Giant appeared dead, as did the platform. It was not until September 14 that Giant resumed its customary splashes.

Activity of Bijou, Catfish, Mastiff, and Platform Vents during the Eruption

Bijou and Catfish exhibited very little action during Giant's eruption. As previously noted, Catfish had some strong splashes 4 to 5 minutes before Giant erupted. No other activity from Bijou or Catfish was noted. Eleven minutes into the eruption, Bijou and Catfish were clearly visible. At that time there was no eruptive activity of any type from them. Both remained off during the remainder of Giant's eruption.

Once Giant started erupting, the view of Mastiff was somewhat obscured by the water and vapor from Giant. During the first few minutes it appeared that Mastiff continued its eruption. Although it was difficult to tell what was water erupting from Mastiff and what was water coming down from Giant's eruption, photographs taken during the first 10 minutes of Giant's eruption appear to show Mastiff erupting to a height close to Giant's.

Mastiff was clearly visible at 24 minutes into the eruption. At that time it was off, and remained off during the remainder of Giant's eruption.

About 7 minutes into the eruption some platform vents were still erupting, though their exact identities area not known. Photographs taken during the first 5 minutes show the southwest vents erupting at that time. At 11 minutes the southwest vents were steaming vigorously but not erupting. By 20 minutes into the eruption the platform vents were quite.

The platform vents resumed activity at some point in time as Giant's activity was decreasing. At 1938, 51 minutes into Giant's eruption, Posthole, North #2, and some of the southwest vents were splashing. Posthole continued splashing until 1943.25, the last eruptive activity from the platform vents that was noted. The other vents had declined to steam by 1939.30.

Giant Indicator Pool

The Giant Indicator Pool, locate between Grotto and Giant on the east side of the boardwalk in a small group of trees, was not checked until 1926. It was completely empty at that time. There were indications that it had been full. The grass at the top of the west side of the crater was pulled down, wet, and warm. The sinter area on the west side of the crater was wet, and the boardwalk was damp. Sharon Roe indicated that the area had been wet and steamy when she came from Grotto to Giant about 10 to 15 minutes after the eruption started. The gravel around the pool, however, did not appear to be washed.

Activity of Grotto and Rocket

Giant's eruption began 2 hours and 33 minutes after Grotto started a marathon eruption. Grotto's activity for several days before and after the eruption is summarized in Table 4.

On September 12 Grotto started at 0943 and stopped at 1214. No Rocket major was observed in connection with this eruption. Grotto turned on again at 1613, and Rocket had a major eruption at 1819, with a duration of 8 minutes.

As noted by Phil Landis, Grotto's pattern of marathon activity had changed in the days preceding Giant's eruption. The time between two consecutive beginnings of Grotto marathon eruptions had lengthened from around 48 hours to a range between 60 and 72 hours. Following the Giant eruption, the time between the next two marathon eruptions decreased back to the 48 hour range.

When Grotto resumed activity on September 14, the intervals were shorter than average. The one known interval was 5 hours and 18 minutes. When first observed that morning at 0909 Grotto appeared to have recently completed an eruption because the runoff area was still steamy and water in the north runoff channels was still warm. Water in the pools in front of Grotto was also still warm and steamy but observations indicate that it stays warm much longer that does the runoff channel. If Grotto had turned off at 0900 and had erupted for 2 hours then an approximate start time would be 0630. This would give Grotto a 5h 15m interval preceding the 5h 18m interval.

Giant Hot Periods for September 6 - 13

As noted by Phil Landis, Giant increased its hot period activity a few days prior to the eruption. Hot periods occurred on September 7,8,9, and 10 at approximately 25 hour intervals. Hot period activity for September 6 - 20 is summarized in Table 5.

Pools near ~~Riverside Geyser~~

The pools between Grotto and Riverside were checked on September 13. The water levels of Square Spring and Culvert did not appear to have been affected by the eruption.

North of Grotto Fountain there is a clear, round pool on the east side of the pavement leading to Riverside. There are two large rocks at the north end of this pool. On the morning following Giant's eruption, this pool was observed at 0822. At this time the pool was nearly empty, with a water level at least 2 feet below the edge. This pool was checked periodically over the next few days. The water level appears to be independent of Riverside. At the beginning of Riverside's eruptions the pool has been observed to be both full and empty.

The water level remained down on September 13. On September 14 at 0914 the pool was full. It was full on September 15 at 0752, but the water level had dropped about 18 inches by 1857 that afternoon. The drop in water level corresponded to a Grotto marathon. On September 16, following the marathon and 1 hour before the start of the next Grotto eruption, the pool was down about 12 inches.

Subsequent observations during September and October confirmed the sympathetic relationship between the water level in this pool and marathon eruptions of Grotto Geyser.

Three pools on the west side of the pavement were also observed--two pools across from the pool with the two large rocks, and the pool behind the Riverside benches. The water level in these pools had not changed following either the Giant eruption or the two succeeding Grotto marathons.

Recovery of Giant

The day after the eruption, all the units of Giant's platform looked dead. It was 1530 that afternoon before any water was seen from Catfish. About 10 minutes later Bijou exhibited a few drops of water. The first visible drops of water from Giant did not appear until 1552, about 21 hours after the eruption. There was no gurgling sound from the area where the southwest vents are located.

By the next morning, September 14, Bijou had recovered, gurgling sounds could be heard from the southwest vents, mastiff's west vent would occasionally shoot up a few drops of water, and giant had resumed its normal periodic splashing. Bijou had recovered sufficiently to time pauses. The pauses that day lasted from 1 to 1.5 minutes at intervals that were generally about every 20 minutes.

Giant did not give indications that it was ready to have another hot period until the morning of September 18. At 1000 that morning there was a long Bijou pause and the water level in Mastiff started rising. The author went to observe the Giant Indicator Pool while Mary Ann Moss watched the platform. At 1002 the water level in the indicator pool reached its maximum at 6-8 inches below ground level. Then the hot period aborted and the water level dropped to about 3 inches above the top of the gravel bar.

Mary Ann Moss reported that the first Giant hot period after the eruption occurred during the night of September 19-20, one week after the eruption.

[Editor's note: For a general background and description of terms for the Giant/Grotto Group please see: Bryan, T.S., "The Grotto Geyser Group and Giant Geyser Group, Upper Geyser Basin, Yellowstone National Park, Wyoming," in this issue.]

Table 1

Times of Giant Hot Periods

September 6 - September 20, 1988

Date	Notes/Comments
September 6	Hot period at 0838
September 7	Hot period in progress at 0540
September 8	Markers placed the previous day had been washed when first checked at 1015
September 9	When first checked at 0732 the water puddles on the platform were still warm from a very recent hot period. Mastiff was splashing up 3 to 4 feet, Bijou was strong with wide bursts reaching 8 to 10 feet. Giant was still exhibiting strong left to right splashing as late as 0740.
September 10	Markers placed the previous day had been washed when first checked at about 1000.
September 10	Hot period at 1872. Heavy overflow from Mastiff, not much splashing from Giant.
September 11	No hot periods occurred.
September 12	Bijou pause at 1838, followed by a hot period and Giant Geyser eruption at 1846.
September 13-17	No hot periods during this time.
September 18	At 1000 Bijou paused long enough for the water level to rise in both Mastiff and the Giant Indicator Pool, but the hot period aborted before any vents erupted.
September 19/20	The first hot period following the eruption occurred, possibly during the late night the 19th.

Table 2

Giant Eruption -- September 12, 1988
Chronological Listing of Observations

Time	Observation	Time before or after eruption
1610.45-1612	Bijou Shutdown, 1m15s.	2h36m
1611 -1618	Grotto Fountain, 8m.	2h35m
1613	Grotto marathon start.	2h33m
1633.10-1634.45	Bijou shutdown, 1m35s.	2h13m
1633.40	Giant, C splash.	2h13m
1639.55	Giant, C splash.	2h07m
1641.10	Giant, C splash.	2h05m
1644.55	Giant, B splash.	2h02m
1645.50	Giant, B splash.	2h00m
1647.25	Giant, B splash.	1h59m
1650.40	Giant, A splash to top of bite.	1h57m
1657.00-1658.35	Bijou shutdown, 1m35s.	1h49m
1720.00-1721.00	Bijou shutdown, 1m00s.	1h26m
1745.40-1746.40	Bijou shutdown, 1m00s.	1h01m
1809.05-1810.05	Bijou shutdown, 1m00s.	0h37m
1833.20-1835.00	Bijou shutdown, 1m40s.	0h13m
1838.10	Bijou shutdown.	8m39s
1839.25	Water level rising in Mastiff, both Mastiff vents boiling.	7m24s
1839.44	North #2 and three vents in the southwest group start erupting.	7m05s
1839.54	North #2 erupting to about 6 feet; Rusty (East #1) has started.	6m55s
1840.02	Horizontal vent has started; erupting to about 3-4 feet.	6m29s
1841.07	Mastiff boiling up 3 to 4 feet and overflowing.	5m42s
1841.16	Giant B splash out the front. Splash was wide, filling the cone, and reached into bite area. Turtle overflowing.	5m33s
1841.52	Posthole started bubbling.	4m57s
1842.00	Catfish splashing 5 to 8 feet.	4m49s
1842.13	Mastiff heavy overflow over the platform ledge by boardwalk.	4m36s
1842.29	Catfish still splashing 5 to 8 feet	4m20s
1842.40	North #2 erupting 2-3 feet, horizontal plus two of southwest vents and Rusty still erupting.	4m09s
1843.02	Mastiff overflow heavy enough to look like a "Great Fountain wave."	3m47s
1843.21	Activity in southwest vents has declined. Only one vent, either Blowout or Southwest #5, is erupting.	3m28s
1843.50	Horizontal, North #2, Rusty (East #1) still erupting. Mastiff wave all over the platform.	2m59s
1844.13	Mastiff erupting about 12 feet high from the east vent.	2m36s
1844.57	Mastiff to 30 feet	1m52s
1845.22	Mastiff 50 ft, pounding from platform	1m27s
1845.54	Pounding continues, roars from Bijou area of platform.	00m55s
1846.20	Giant B splash filling entire cone and splashing out the front.	00m29s
1846.49	Giant column lifted.	00m00s
1851	Height estimation from 200 foot marker between Giant and Oblong, without an inclinometer. Angle to top of column estimated at 40-42 degrees.	0h4m
1852	Some spikes from top of column well above 45 degree angle from 200 foot marker.	05m
1853.30	Some platform vents appear to still be erupting, but steam and falling water make it difficult to be certain.	06m
1856	Some spikes still reaching 200 feet.	09m
1857.48	Southwest vents steaming.	11m
1858	Bijou and Catfish doing nothing	12m
1907	Platform vents are off	20m
1911	Mastiff is off	24m
1912	Giant height estimated at 100 feet	25m
1921	Giant now steam mixed with water; water ejected 20-40 feet high.	34m
1924	Giant eruption no longer continuous, but consists of steam rushes mixed with water.	37m
1926	Checked Giant Indicator Pool. It is empty, grass at top of vent is pulled down, wet, and warm. Boardwalk damp.	39m
1927	Giant eruption consists of steam.	40m
1934	Steam phase of Giant eruption is dying out.	47m
1938	Platform vents have resumed splashing. Posthole and North #2 are erupting. Other vents are steaming.	51m
1940.31	Giant ejects water bursts	53m
1941.05	Giant ejects water bursts	54m
1942.28	Giant ejects water burst.	55m
1941.40-1943.25	Posthole splashing	54m
1946	Giant having occasional steam rushes.	59m
1947	Giant eruption water mixed w/ steam	1h00m
1950	Giant still having steam rushes and water splashes.	1h03m
1953	Giant only occasional steam.	1h06m
1958	Giant completely off.	1h09m
2000	Grotto still erupting. Variable springs still full.	1h13m

Table 3

Eruptions of other geysers in the Giant Area
September 12, 1988

Geyser	Time	Interval
Daisy	0945	
	1108	83 minutes
	1228	80 minutes
	1347	79 minutes
	1502	75 minutes
	1622	80 minutes
	1744	82 minutes
	1910	86 minutes
Grotto Fountain	0941 - 0948	
	1611 - 1618	6 hrs. 30 min.
Grotto	0943 - 1214	
	1613 - unknown	6 hrs. 30 min.
Oblong	1713(ie) - 1718.40 (no second eruption)	
Riverside	1347	
Rocket major	1819.02 - 1827.02	

Table 4

Times and Durations of Bijou Pauses

September 11, 1988

Bijou off	Bijou on	Duration	Interval
1701.00	1701.50	00m50s	
1711.00	1712.50	01m50s	10m
1733	1736	03m	22m
1759.30	1800.50	01m20s	26m30s
1819.20	1821.55	02m35s	19m50s
1847.25	1848.45	01m20s	28m05s
1907.40	1909.40	02m00s	20m15s
1933.25	1935.05	01m40s	25m45s
1958.10	1959.30	01m20s	24m45s

September 12, 1988

Bijou off	Bijou on	Duration	Interval
0851.40	0852.40	01m00s	
0914.00	0915.50	01m50s	22m20s
0937	0939.55	01m+	23m

*Grotto turned on at 0943 and Bijou pauses became difficult to determine.

Bijou off	Bijou on	Duration	Interval
1413.20	1414.25	01m05s	
1436	1437.30	01m	23m
1500.10	1501.15	01m05s	24m
1522.15	1522.50	00m35s	22m10s
1544.35	1546.30	00m55s	22m20s
1610.45	1612.00	01m15s	26m10s
1633.10	1634.45	01m15s	22m25s
1657.00	1658.35	01m35s	23m50s
1720.00	1721.00	01m00s	23m00s
1745.40	1746.40	01m00s	25m40s
1809.05	1810.05	01m00s	23m25s
1833.20	1835.00	01m40s	24m15s
1838.10			04m50s

Table 5

Activity of Grotto Geyser
September 6 - September 18, 1988

Date	Start	Stop	Comments
9/06			0945 Grotto is off.
9/06	1411	1615	
9/07	0618	und.	Marathon; Grotto still on when burned out of basin at 1601.
9/08			0955 Grotto is off.
9/08	1208	1319	
9/08	1819	und.	
9/09			0723 Grotto is off.
9/09	0856	1058	
9/09	1505	und.	Marathon occurred based on Grotto being off all day 9/10.
9/10			Grotto off all day.
9/11			0900 Grotto is off.
9/11	1237	1503	
9/11	2009	und.	
9/12			0820 Grotto is off.
9/12	0943	1214	
9/12	1613	und.	Marathon based on the fact that it was still erupting at 2000 and decreased water level in Variable Springs the next morning.
9/13			Grotto off all day.
9/14			0909 Grotto recently turned off. Runoff area steamy and water in north runoff warm.
9/14	1145	1340	
9/14	1703	1923	Interval 5 hours 18 minutes.
9/15			Marathon. Grotto on at 0700 and still on at 1940.
9/16			0757 Grotto is off.
9/16	0911	1133	
9/16	1802	und.	
9/17			Marathon. Grotto on at 0727 and remains on all day.
9/18			0725 Grotto is off.
9/18	1055	1205	Probably first Grotto since marathon based on short duration and 27 minute long Grotto Fountain.

und. = undetermined

Activity of Link Geyser during 1983

H.Koenig

Abstract: During 13-18 October 1983, Link Geyser had an unprecedented series of eruptions. At least 40 eruptions were observed or inferred, and as many as 20 more may have occurred. In each of the five years since this activity, changes have occurred in the springs around Link.

Activity prior to 1983

Little has been recorded about Link, mostly because it is so infrequently active. There is also circumstantial evidence which indicates it may be a relatively new feature.

A description of the Chain Lakes can be found in the section on the Grotto Group in [Peale 1883] under No.17—The Bottomless Pit. The description of these springs matches their typical appearance today. The table of springs includes Square Spring and the three small nearby springs are described under No.16. Neither the map of the Upper Geyser Basin, nor the text, however, has any spring that would match the present day Link in either location or description. Peale does state, however, that the maps and text were prepared separately.

The map of the central portion of the Upper Geyser Basin in [Hague 1904] also shows the springs of the Chain Lakes area. The location and shape of these springs closely matches those in *Map 1* of this paper, with the exception of Link. On Hague's map, there are two springs located northeast of the Chain Lakes. Both of these springs are oblong, with their long axis pointing in a northwest direction. They fit in with the location of the present Link Geyser, except that Link, although it does have a constriction in the middle, does not consist of two distinct pools.

The first known and reported eruptive activity from Link took place in 1936. A report on this activity, [Douglass 1936], gives a description of the activity that year. Link erupted every few days. Between eruptions, the pool remained full. Douglass also describes what seems to have been the one meter high minor eruptions characteristic of Link for the last few decades. Only the Chain Lake referred to in the present paper as M1 showed a sympathy great enough to be reported. Its activity only consisted of draining during an eruption of Link Geyser. Activity in Link continued into 1937 [Marler 1973].

Documented activity in North Chain Lake Geyser took place in July 1958, the only other recorded activity was in response to the 1959 Hebgen Lake earthquake[Marler 1973]. At that time, eruptions lasted about 2 minutes, and were of the fountain type.

The next known activity of Link Geyser began in 1954. As reported in [Marler 1973], there were a few eruptions in 1954, eight eruptions in 1955, and six reported for 1956. In 1957, Link began to have series of eruptions, with the intervals between eruptions averaging about three hours apart, with the entire series lasting about a day or two. During a series, the water in the Chain Lakes would drop to about 1-½ meters by the end of the series. This activity ended by autumn, with only minor activity, eruptions about one meter high and occurring every few hours, taking place during the winter of 1957-58. During the spring of 1958 there were occasional major eruptions. Starting on 07 July 1958, Link had a nearly two day long series of major eruptions. By the end of this series, the water level in the Chain Lakes had dropped down to about 2.6 meters.

Following this last series of eruptions, the temperature of the Bottomless Pit rose from 141°F to 198°F. Marler records no more activity in this area until 19 September 1968. He gives no details, other than that there were two eruptions that day, and that they possibly were in response to a local earthquake.

Over the next few years, there were occasional reports of activity in the Chain Lakes Group (see Table 1). Some of these reported eruptions may have been nothing more than a minor eruption from Link Geyser.

The next series of eruptions took place on 29 August 1974. There were at least eight, and most likely nine eruptions in this series. Except for the first interval, which is not known for certain, the length of each interval was longer than the preceding interval. [Martinez 1974] reports that there was a small spring which acted as an indicator to activity. This spring seems to correspond to the N1 of this report. Also, during this series of eruptions, the water levels in the Chain Lakes dropped after each eruption [Bryan 1986].

Since this series of eruptions, and until 1983, only one major eruption of Link has been reported, on 11 October 1981 [NPS Log Books]. No details were given.

In 1983, a solo eruption of Link Geyser took place at 19:35 on 4 September. The only observer to witness this eruption was John Wegel. Based on discussions with

Date	Time	Spring(s)	Comments
01 Sep 68	≈08:45	"Bottomless Pit Group"	
08 Sep 69	15:50	Link Geyser	Minor (no details given)
15 Oct 69	10:00	Link Geyser	"
18 Oct 69	10:24	Link Geyser	"
19 Oct 69	17:28	Link Geyser	"
23 Oct 69	17:08	Link Geyser	"
18 Oct 70	17:10	Link Geyser	Probably a minor
22 Aug 71	19:29	Link Geyser	
25 Aug 71	07:25	Link Geyser	
04 Sep 72	early am	Link & Bottomless Pit	
16 Jul 73	late pm	Link & Bottomless Pit	[Wolf 1983]
24 Aug 73	late pm	Bottomless Pit	[Wolf 1983]
26 Aug 73	late pm	Bottomless Pit	[Wolf 1983]
24 Feb 74		N2 Chain Lake	Approx date, [Wolf 1983]

Activity in the Chain Lakes Group 1968-1974
Table 1
(sources: [NPS Log Books])

him, my observations the next day, and my observations of the October series of eruptions, the following is known, or can be said with confidence about this eruption:

The eruption lasted about 1m10s, and was about 15 to 20 meters high. The amount of wash was relatively moderate, in that it was not enough to reach the paved trail, unlike eruptions in the 1974 [Wolf 1983], or October 1983 series. This eruption did scour clean the algae which was in the runoff channel shared by Link and Culvert. Wegel described this eruption as being "wet, without any jetting." He also said that from his location behind Riverside Geyser, he did not see any water, and a moderate wind did not allow a very high steam cloud. This, combined with the short length of the eruption, as compared with the later eruptions, leads to the conclusion that this eruption did not include the powerful steam jetting phase which was typical of the end of the October eruptions.

The next day, while waiting for an eruption of Fan and Mortar Geysers, I saw at least three of the heavy boiling minor eruptions. As was typical of Link's activity during the summer of 1983, these lasted about ten minutes, and had intervals of about four hours. Although no detailed survey was made, there seemed to be no easily recognized changes among the Chain Lakes, and the water overflowing from Link did not seem to be cloudy.

Activity on 13 October

After reconstructing the events of this series of eruptions, it is believed that the first eruption of the series took place at about 13:30 on 13 October 1983.Mary Ann Moss came to this area around 13:00 to check on markers that had been placed near Fan and Mortar Geysers. She did not notice anything unusual in or about the area. At about 13:30, while waiting at Grand Geyser, she and other observers noticed a large steam cloud at the northern end of the Upper Basin, in the vicinity of Grotto Geyser. As the cloud lasted only a minute or two, and because Grotto was in eruption at the time, they assumed that they had just seen a major eruption of Rocket.

At about 14:30, Marie Wolf and a friend were near Artemisia Geyser, and heading south, when they noticed a large cloud of steam beyond the trees. At first they assumed that they were seeing the start of an eruption of Fan and Mortar. But when the steam ended a minute or so later, they concluded that it was from something else. By the time they arrived at the bridge next to Fan and Mortar, they had forgotten about the steam cloud. Passing by the Chain Lakes Group, they noticed a distinct fishy smell. Wolf commented at the time: "It smells like it did after Link erupted in '74." At that time, there was no evidence of fresh wash on or near the paved trail.

Date	Time	Interval
29 Aug 74	06:00–09:15	
	11:32	2h15m–5h15m
	14:16	1h18m
	15:43	1h26m
	17:30	1h47m
	19:53	2h23m
	22:59	3h06m
30 Aug 74	06:30–07:00	≈7 1/2h

Eruption Series of August 1974
Table 2
(Sources: [NPS Log Books] and [Martinez 1974])

From the first steam cloud seen at 13:30, and until she left the vicinity of Grand Geyser at about 19:30, Moss noticed at least six of these steam clouds. Because of her interest in the activity of the Grand Group, and due to nightfall, she never made it down the basin to investigate these puffs of steam. These clouds averaged about one hour apart, but no exact times were noted. The day was cool and cloudy, so all the springs in the basin were giving off large amounts of vapor.

The next morning (14 October), at 09:41, Ranger-Naturalist J.Selleck jogged up to the aftermath of an eruption. He saw a large amount of water running off of the sinter formations surrounding Link, and sinter fragments washed up onto the paved trail.

From the above observations, and from the observations of the later eruptions, some assumptions can be made about the nature of these first few eruptions. The last few eruptions of the series were much larger than the first eruptions that I observed on 14 October, which were near the start of the series. These later eruptions were still ripping out sheets of sinter, but most of the loose material had been cleaned out before my observations began. Also, the deep runoff channels helped keep the water off the trail and slow the rate of erosion. So the fact that during the mid-afternoon of 13 October the area near the trail did not look different would seem to indicate that the first eruptions were not as powerful as later eruptions. Perhaps they were only three to ten meters high, with only moderate wash. Like the eruption in September, there may not have been a powerful steam phase that was a part of the later eruptions.

Between 13:00, 13 October and 14:00, 14 October, there were at least seven eruptions of Link, and if the eruptions were averaging one hour apart, there may have been as many as 25 eruptions during this time. A major portion of the erosion around Link took place during this period. Much of the loose debris that had accumulated over the years had been removed by the eruption of 4 September, what had remained was removed by these subsequent eruptions.

For about one week before 13 October, there were a number of minor earthquakes that registered on the helicorder in the Old Faithful Visitor Center. The largest of this swarm measured about 3.0 Richter magnitude, and occurred at about 03:30 on 13 October. This was the last quake of any significant size for the next day or so. Also of interest is the fact that Splendid Geyser erupted sometime between the afternoon of 13 October and early in the morning of 16 October. Markers that had been in place for years disappeared during this period. These eruptions of both Link and Splendid in possible response to earthquake activity is similar to the activity of 19 September 1968, as described in [Marler 1973]. On that date there were at least sixteen known tremors, and a number of springs erupted that night.

Description of Activity by Link

The crater of Link resembles a long trapezoid with irregular sides. The base of the trapezoid lies on the southwest, and is about three meters wide, while the top lies on the northeast, and is a little over a meter wide. The sides of the trapezoid are indented, giving Link the appearance of being a mini-Chain Lakes. The sides of the crater itself are also irregular, being made up of many laminations that have been broken off into ragged shelves. The overall direction of the vent is downward toward the west from the southern end of the crater. About five meters down, the vent opens into a huge cavity, described as being "the size of a garage." [Hutchinson 1983]

The rim of the crater is only a centimeter or two high. It is broken in only two places, where the overflow during Link's more common minor eruptions occurs. The gap on the north is about one-half meter wide, while that on the southeast is close to two meters wide. Overall, the appearance of Link's vent is one of recent formation, quite angular, and with little smoothness and few delicate formations.

The eruptive activity by Link and the Chain Lakes could be grouped together into a set of series with three types of eruptions. A series consisted of from one to several eruptions, and lasted as much as 7-1/2 hours. If there was more than one eruption in a series, then the first and last eruptions were distinctly different from each other, as well as from the eruptions that occurred between them. If there was just one eruption in a series, it behaved like the first eruption of a series, but at the end behaved like the last eruption of a series. In addition, the last observed eruption was different from all the preceding eruptions.

In keeping with my tendency for creative naming, I have referred to these three types of eruptions simply as the First Eruption, Second Eruption and the Last Eruption.

Table 3 is a list of all the eruptions of Link Geyser for which exact times are known. The column labeled Drop shows the depth to which Link's water level dropped after an eruption. The column labeled N1 before shows the activity before an eruption that was observed in the Chain Lake vent called N1. A gap in the table signifies that at least one eruption occurred while Link was not being observed.

Date	Time	Drop after	N1 before	Interval	Comments
14 Oct	14:23:46	3m			
	16:49:01	2m	overflow,boiling	2:25:25	
	18:28:50	?	overflow	1:39:49	
15 Oct	08:26:19	4m?	erupting,h=2m		First
	08:59:23	4-1/2m	?	0:33:04	
	09:30:11	5m	down,2m?	0:30:48	
	10:00:18	2-1/2m	down,2-1/2m	0:30:07	Minor
	14:43:59	5m	erupting,h=1m	4:43:41	First
	15:27:36	5-1/2m	down,1-3/4m	0:43:37	
	16:00:04	3-1/2m	down,2-1/2m	0:32:28	Minor
	20:34:51	?	erupting,h=1m	4:34:47	First
16 Oct	07:42	2m			seen from Oblong
	11:01:47	6m	erupting,h=1/2m	3:20:–	First
	12:00:55	5m	down,1m	0:59:08	
	12:43:18	5-1/2m	down,1m	0:42:23	
	13:22:11	6m	down,1-1/2m	0:38:53	
	14:07:20	6m	down,2m	0:45:09	
	14:55:07	6m	down,2m	0:47:47	
	15:44:08	5-1/2m	down,2-1/2m	0:49:01	
	16:52:58	5m	?	1:08:50	Chain Lakes drop
	17:28:01	5m	down,2m	0:35:03	
	18:04:08	5m	drained	0:36:07	
	18:40:53	3m	drained	0:36:45	Minor
17 Oct	07:49:07	4-1/2m	erupting,h=1m	13:08:14	First
	08:49:16	5m	overflow	1:00:09	
	09:51:57	5m	down,1m	1:02:41	
	10:34:13	5m	down,0.1m	0:42:16	
	11:12:14	5-1/2m	down,2m	0:38:01	
	11:50:08	5-1/2m	down,3m	0:37:54	
	12:27:18	5m	down,2m	0:37:10	
	13:03:29	5m	?	0:36:11	
	13:38:26	3m	drained	0:34:57	Minor
18 Oct	04:46:02	5m	erupting,h=1m	15:07:36	First
	05:29:37	6m	erupting,h=1m	0:43:35	
	06:11:54	6m	dn,0.2m	0:42:17	
	07:03:09	6m	dn,1-1/2m	0:51:25	
	08:58:06	8-10m	dn,1-1/2m	1:54:57	

Observed Eruptions of Link Geyser
Table 3

Description of First Eruptions

Before the first eruption in a series, there would be a slow rise in the water level in some of the Chain Lakes, especially N1, M1, and M. M would slowly rise to a depth of about one-half meter, when it would begin to overflow first into M2, and then on into the Bottomless Pit. M1 would start boiling over its vent, while slowly rising to a depth of about twenty centimeters. Meanwhile, N1 would first rise to overflow, then it would begin boiling, and finally start to erupt. This eruption would start small, but after a while, it would reach a height of between one and two meters. Meanwhile, the water level in Link would slowly rise, while boiling violently along the southern and western edges of the crater. Then, with perhaps only a few seconds warning, the boiling in Link would turn into surging throughout the entire southern end of the crater. This was the start of an eruption.

When the water level in the pool was low, as in the later portions of an eruption series, it could be seen that this surging comes from the southwestern part of the crater. The surging rapidly raises the level of the water, but the size of the surges do not exceed three meters until the water level is above the rim. At times, when the water level was low, this surging could take as long as 45 seconds to reach the point of overflow.

The water then began to pour out of Link's crater, a wave ten to twenty centimeters deep, ripping up some sheets of algae and sinter. The eruption at this point was an Oblong Geyser-like boiling, while the height rapidly rose to ten to twelve meters. This portion of the eruption

Number	26
Minimum	1m54s
Maximum	2m32s
Average	2m15s
Std. Dev.	0m08s

Eruption Durations
Table 4

lasted from thirty seconds to one minute, during which time the massive flood of water occurred.

Just before the eruption of Link began, N1's eruption could reach three meters. With the start of surging in Link, the bursting suddenly stopped, and the crater rapidly drained. For ten to fifteen seconds M1 would pour a massive quantity of water into M. Then the water level in M1 began to drop. About 30 to 40 seconds after the start of Link's eruption, the water had dropped about one meter, and was below a shelf in the vent. Then M1 began to erupt, while its water level continued to rapidly drop.

After a minute of surging and pouring out massive quantity of water, Link would begin to throw jets of water at a sharp angle to the southeast. These jets appeared to come from the southern end of the crater, from the same area as the surging. The jets were inclined about 30° to 45° from the horizontal, yet could reach as much as twenty to thirty meters high. While the flow of water was continuous, there was a distinct pulsing which seemed to throw the water just a little farther. By this time the area surrounding the crater was shrouded in steam, which made both observations and photography difficult.

After about thirty seconds of these water jets, the eruption turned into a series of quick, powerful steam bursts. These were comparable to steam bursts from Giantess Geyser during the transition from water to steam. With these steam bursts there were some thumps, which were felt best in the central part of the triangle formed by the vents of Link Geyser, N1 and M1. They felt as if you were standing on a concrete slab, and someone was underneath, hitting this slab with an iron pipe. The thumps were not as powerful as those produced by Artemisia, Giantess or Oblong.

Number	26
Minimum	0h 29m 07s
Maximum	1h 08m 50s
Average	0h 42m 55s
Std.Dev	0h 10m 16s

Does not include intervals between series, or between solo eruptions.

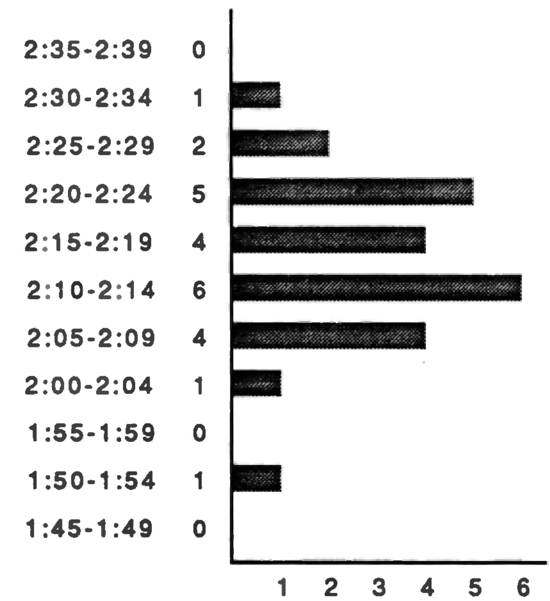
Intervals Between Eruptions
Table 5

These jets rapidly died down, and turned to surging below the rim. In foggy weather, or in the dark, it was sometimes difficult to tell exactly when an eruption ended. Measured durations, however, were quite consistent, as *Table 4* and *Table 6* show. During the steam bursts, a fair amount of water ran back into the crater, only to be blown out with the next burst.

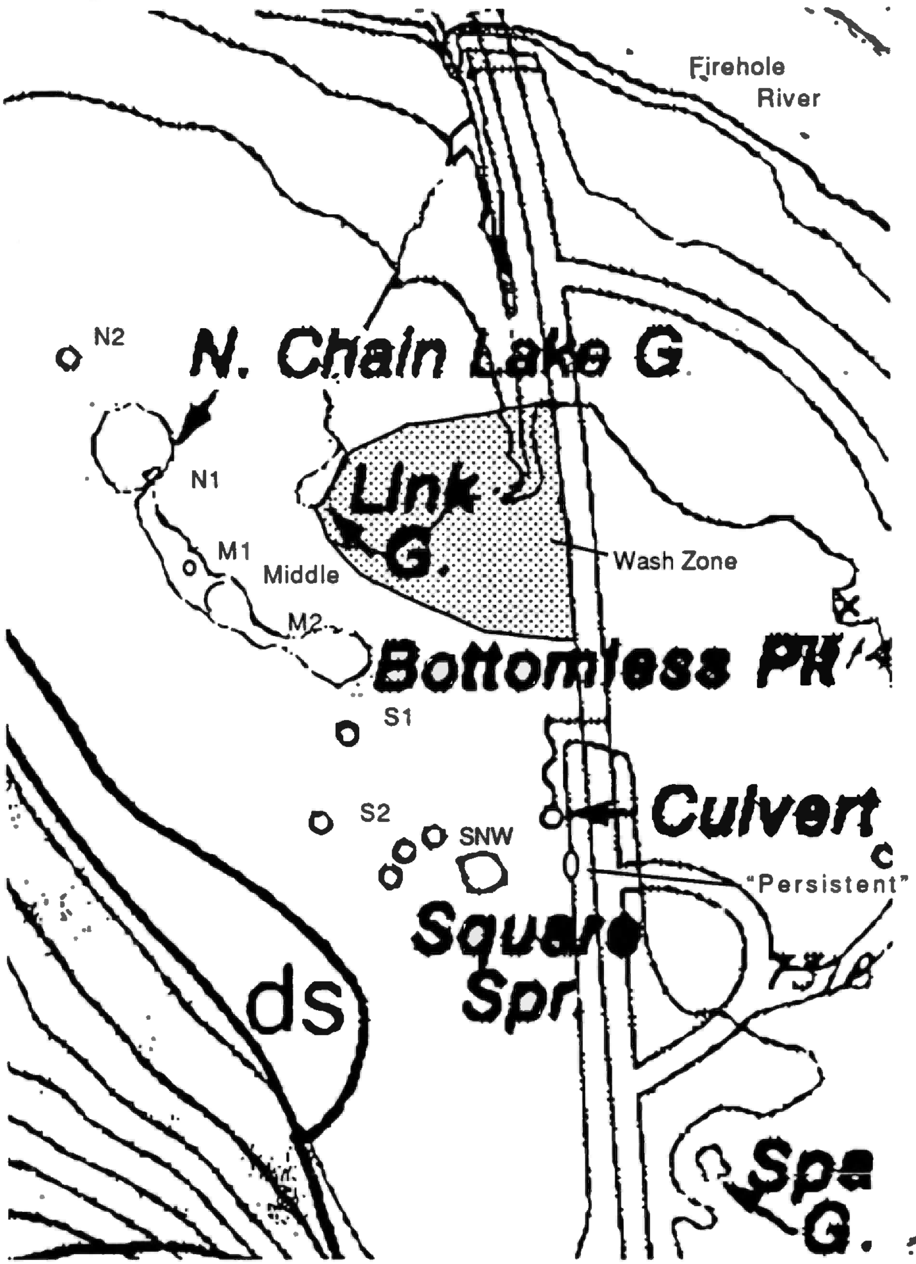
Description of Second (Middle) Eruptions

After an eruption of Link, the water level in its crater dropped. A deep drop, four to six meters, was a reliable indication that the series had not ended. Also after the eruption both M1 and N1 would be drained (their water levels would be below 3-1/2 meters and out of sight).

With the water level of Link down four to six meters, the temperature in the pool would be relatively low, from 190°F to 200°F, as compared to 204°F to 206°F obtained at other times. This low water temperature might be due to the water which was draining back into Link in the few minutes after the end of an eruption. Although the water level was quite low after an eruption, the level rose rapidly until around it had reached the two meter level. During this rise, M1 and N1 were also rising, although they never reached the same level as they had before the First Eruption. There



Distribution of Durations
Table 6



Map 1
adapted from [Muffler, et.al. 1982]

also seemed to be a relationship between the pool water levels, and the duration of the series. The later an eruption in a series, the lower the water level in the pools.

Compared with the activity recorded for previous years, the intervals between eruptions were very short. It also seemed that there was a tendency for the longer intervals to occur early in a series. This was reflected by the fact that early in a series, the water levels in the Chain Lakes reaches greater heights than later in the series. Also, the amount of rise in Link decreased with each eruption in the Series.

The size and duration of the Second Eruptions were comparable with the size and duration of the First Eruptions. It did seem, however, that as the entire activity progressed, the later eruptions were larger than the preceding eruptions. The first eruptions observed on 14 October seemed to be only 15 meters high. By 16

October, observers were estimating the heights to be in the range of 25 to 30 meters. And the last eruptions on 17 & 18 October were as high as 35 meters. M.Wolf says that to her these last eruptions of Link appeared comparable in height to an eruption of Daisy when erupting in concert with Splendid. At these times, the height of Daisy has been measured as high as 38 meters [Wolf 1983].

Description of the Final Eruptions

The events leading up to the Last Eruption of a series were no different than those which preceded the previous eruptions. The Final Eruption could not be predicted by the activity leading up to the eruption. But once the eruption started, it was obvious that it was different.

First, the surging lasted longer than during any earlier eruption in the series, but this could be explained by the very low level in the pool (three to four meters down). Little water was thrown out during the eruption, and it was not thrown with any force. The height of the eruption was low, only eight to ten meters high. Finally, the steam jetting was completely absent. It was a weak eruption, almost a minor, when compared to the eruption that had preceded it.

After the eruption, the water level in Link was nearly the same as it was at the start of the eruption: down three to four meters. Unfortunately, no temperatures were taken right after a Final Eruption, so it is not known if this was any different. All of the pools in the Chain Lakes were at their lowest level in the series, and began to slowly recover as their water levels rose.

The recovery time between series ranged from as short as 3-1/2 hours, to over 15 hours. These longer intervals are known for certain, as markers (pine cones and small piles of pine needles) were placed in the runoff channels it indicate activity when no observers were present.

When there was only one eruption in a series, it appeared the same as any other First Eruption. But the pool level in Link would only drop about two to three meters, as it would do after Final Eruption. These solo series were only recorded on 14 October, early in the activity.

The last eruption of the five day period of activity was unique. The interval was longer than any other recorded in a series. Before this last eruption, the water levels in the Chain Lakes dropped, reaching new low levels. M.Wolf described the last eruption as being the largest eruption she had seen yet, and just as powerful. Following the eruption, the water levels in all the pools of the Chain Lakes, including Link, dropped even farther than before. The depths were comparable to those described by [Marler 1973] during the eruption series of the late 1950s. Link's water level was over eight meters down, and beyond the reach of the thermometer cord. With this draining, it was concluded that the activity had ended.

Description of the Chain Lakes

The eruptive activity of Link had a profound effect on most of the springs in the Chain Lakes Group. Unless noted otherwise, all the springs described in this section showed the following characteristics:

- The water was a turbid, greenish-white color. Visibility through the water was nil, a few centimeters at most. The color or turbidity did not change during the eruptive series.
- All were lined with a five to ten centimeter thick layer of clay-like mud. In some areas, the mud had a thin, dark green layer of algae covering it. Sticks and rocks were embedded deep within some of the craters.
- All showed temperatures that were much higher than those measured during the summer (see Table 7).

Since most of the pools in the Chain Lakes Group are not named, it was necessary to develop a method of referring to the pools. The three largest of the Chain Lakes are called: N for North, M for Middle, and S for South (also officially known as the Bottomless Pit). Smaller features are then referenced in relation to the nearest large or named feature by adding either a number of direction postfix (e.g.: N2 or SqNW). Also, refer to Map 1 for information as to the specific location of the features of the area.

North Chain Lake #2 N2 The name "Clasp" is suggested by [Bryan 1986] as a name for this spring, in keeping with the names in the group. This pool erupted in late February 1974 [Wolf 1983]. It was the only pool in the area which showed a sympathy to Link but in which the water stayed clear. It is a funnel shaped pool, about three meters in diameter, and about 3-1/2 meters deep. For at least the last decade (and perhaps longer, see [Peale 1883]) it has been lined with a thick, green algae, and its temperature is in the range of 110°F. The rise in temperature, and the drop in water level caused the algae to spall off the sides, and collect in a thick mat in the bottom of the funnel, blocking the vent. The areas thus exposed revealed some of the clay or mud similar to that in the other Chain Lakes.

North Chain Lake #1 N1 This is a satellite vent which lies within the outer rim enclosing North Chain Lake Geyser (N). The shoulder separating N1 and N lies about 40 centimeters below the rim. On the west shoulder there are two or three small sputs, which were obvious only when they were erupting. N1 itself is an irregularly shaped trapezoid, with the narrow side on the northeast. It is about 3-1/2 meters deep, and the vent angles off toward the east, in the direction of Link.

This spring has erupted before, and in 1974 was referred to as "Link's Indicator." [Martinez 1974] This the 1983 activity, an eruption could take place shortly before an eruption of Link. The eruption began as an overflow into N across the low shoulder separating the two. If the coming eruption was a Second Eruption or a Final Eruption in a series, then this overflow is all that took place. Later in a series, the water level would not rise as high as before, and may not even have reached overflow.

Before the First Eruption of Link Geyser in a series, however, this overflow would increase, and boiling would begin. This boiling was continuous, and slowly increased in strength until water began to be thrown into the air. A few minutes before the eruption of Link, this play could be from one-half to two meters high. Less than a minute before Link's eruption, the sputs might begin to play to a height of a few centimeters. Suddenly, N1 would burst up to three meters high, and Link would begin its eruption.

Within seconds, N1 began to drain, and by the end of Link's eruption, the water in N1 would be out of sight. The temperature of N1 seemed to vary with the water level, with higher temperatures measured when the water level was high. But it was almost always in the 185°F to 200°F range.

North Chain Lake Geyser N This pool is about eight meters in diameter. For the first meter or so, the walls are vertical, but they quickly flatten out, so that except over the vent, the maximum depth of the pool at overflow is only about two meters. The vent is located in the northwest, while on the southeast, within the rim, is located the vent of N1. This pool seemed a bit clearer than the other Chain Lakes, and was distinctly bluish in color, rather than greenish. Most of the time the water level was down about 1-1/4 to 1-1/2 meters, so that a large portion of the bottom was visible. The water level might have been much lower, except for overflow coming in from N1.

Middle Chain Lake #1 M1 In the report on the 1936 activity of Link, [Douglass 1936] described this pool, and its relationship with Link at that time. This narrow, triangular shaped opening, with the apex of the triangle pointing toward the northwest appears exactly as it does

Date & Time	Link	N	N1	N2	M	M1	S	S1
June	†	157°		112°	150°	167°	140°	183°
July	†	156°		111°	148°	173°	137°	181°
August	†	158°		126°	149°	175°	142°	186°
15 Oct 08:53	204°		196°		182°			
09:07		168°	202°				140°	202°/202°
09:47							141°	
10:17	203°				189°	203°		
10:55	204°							
11:10	205°							
12:00	206°		191°			204°		
13:02	206°		194°			205°		
13:52	207°		203°			206°	142°	
16 Oct 10:28			204°		186°	200°		
11:32	204°		198°			204°		
12:06	190°							
12:13	202°							
12:23	205°		192°			204°		
12:42	205°							
12:47	201°					204°		
12:58	205°					203°		
13:08	205°		189°			204°		
13:21	205°							
13:26	202°					202°		
13:37	204°					204°		
13:49	205°		175°			204°		
14:01	206°		188°			202°		
14:11	196°					195°		
14:58	202°					203°		
15:48	201°					203°		
18 Oct 04:10	207°	184°	199°	161°	188°	206°	146°	200°/203°
04:48	192°	184°		163°	191°	203°	154°	
05:08	205°	184°	195°		192°	204°	153°	
05:18	205°		201°			204°		
05:32	200°	185°			196°		162°	
05:50	200°	185°	190°	157°	196°	204°	161°	
06:10	205°		200°			204°		
06:15	196°	186°			199°	194°	166°	
06:35	205°	186°			196°	203°	166°	
06:55	206°	186°	189°		193°	204°	166°	
07:07	188°	188°			201°	190°	169°	
07:30	203°	189°			202°	201°	171°	
18 Oct 07:50	205°	189°			202°	201°	171°	
08:10	206°	189°	189°		202°	205°	173°	
08:30	206°	189°			202°	205°	170°	203°/200°
08:50	207°	187°	190°		203°	206°	170°	202°/200°
09:02	192°	191°				187°	184°	
09:20	203°	191°			204°	204°	184°	
09:40	204°	188°			204°	203°	180°	203°/201°
10:00	204°	186°			204°	203°	180°	202°/201°
10:45	204°	184°	190°		204°	203°	180°	
14:00	206°	180°	188°		193°	206°	172°	201°/199°
19 Oct 10:04	205°	161°	170°	122°	169°	187°	178°	194°/196°
10:18	205°							
20 Oct 15:45	207°	160°	168°	121°	165°	182°	167°	174°/178°
21 Oct 16:00	200°	155°	168°	112°	173°	184°	189°	188°/199°
23 Oct 13:12	191°	134°	141°	103°	178°		200°	
24 Oct	199°	141°	163°	104°	189°	188°	200°	189°/192°
25 Oct 19:30	203°	136°	160°	103°	184°	186°	184°	181°/192°
22:00	200°						201°	
26 Oct 09:00	199°	133°	160°	103°	185°		200°	180°/192°
18:45	204°						185°	
22:00	198°						200°	
28 Oct 10:00	199°	133°	160°	106°	168°	177°	200°	181°/192°
17:00	198°						201°	
21:00	199°						200°	
4 Nov 16:17	170°	116°	121°	102°	167°	160°	196°	
25 Nov	167°							
February 1984		139°						
25 Mar 1984, am		136°	190°		119°	152°	145°	165°

† No temperature taken, but frequent periods of boiling.

[Lenertz 1983]

All temperatures are in °F, and are near the pool surface.

Pool Temperatures
Table 7

in photographs included in Douglass' report. The sides of the pool slope downward for about one meter, the depth at which the vent itself is located. The vent is also narrow and triangular, about one meter long. Below this opening, the vent widens out, especially near the point. This creates a shelf, or constriction in the vent.

Like the activity in 1936, this pool shoed the most sympathy to the activity in Link. Both in 1936 and recently, it drained completely during an eruption of Link Geyser. With the recent activity, however, once the pool dropped down to the shelf in the vent, an eruption would begin. At the start of an eruption series of Link, the water level in **M1** was about 15 to 20 centimeters below overflow. As the eruption of Link started, the water would immediately rise up, and overflow through a well defined, muddy channel into **M**. By the end of this eruptive series of Link, it seemed that this channel was much deeper than it was at the start of the series. After a few seconds of heavy overflow, the water level would begin to drop rapidly. About 20 to 30 seconds after the start of Link's eruption, the water level would drop below the shelf in the vent and an eruption of **M1** would begin.

The height of the eruption was only 1/2 to 1 meter above the dropping water level. The eruption did not have a distinct end, but the noise of splashing and boiling out of sight at depth would slowly die out as the pool refilled. If the pool did not refill to the shelf in the vent by the start of the next eruption of Link, it would not erupt, although there could be some heavy boiling.

Usually eruptions would take place only with the first few eruptions of Link in the series. Before the start of subsequent eruptions in the series, **M1** would not rise as much as before the previous eruption. After six to eight eruptions of Link, water could not be seen in the vent at the start of an eruption of Link Geyser.

No reference to activity in this vent during the 1974 activity of Link Geyser can be found.

Middle Chain Lake M This pool is approximately five meters deep, with steep sides near the top, gradually sloping down as a funnel at the bottom. There are two channels breaking the rim of the pool. From the northwest it receives runoff from **M1**. To the southeast is a channel about 1/2 meter deep, in which water from **M** runs off into **M2**, and then eventually into the Bottomless Pit.

The center of the pool showed a feeble convection most of the time during the recent activity. This area of convection widened, and increased in intensity as the water level dropped. When the water level dropped to about four meters, and the pool was only 1-1/2 to 2 meters in diameter, water began to be thrown into the air about 1/2 meters high. This constituted the eruption.

The water level tended to slowly drop overall during a series of eruptions of Link. It would slowly rise up before an eruption of Link, and then after drop to a level lower than before. The rate of rise and fall is slow. The water level never dropped out of sight until the very end of the activity.

Middle Chain Lake #2 M2 This pool is little more than a widening and deepening in the channel that connects **M** and the Bottomless Pit. It seemed to be filled by runoff from **M**, and then slowly dropped back to its previous level. This water level always seemed to drop to the same level as the level in the Bottomless Pit.

Bottomless Pit S It isn't. Instead it is a wide pool with nearly vertical sides for the three to four meters that could be observed. For most of the recent activity of Link, the water level was down about 1-1/2 to 2 meters. Then suddenly, toward the end of a long series, and between eruptions of Link, the water level quickly dropped down to three or four meters deep. This drop coincided with a similar drop in **N**.

Also, until the last eruption sub-series, the temperature in the Bottomless Pit was basically the same as had been recorded during the summer: 141°F (see Table 7). The rise in temperature during the last eruption sub-series will be treated later.

South Chain Lake #1 S1 This spring is only about three meters wide in a east-west direction, and about 1-1/2 meter north-south. There are two vents, each about the same size and depth, each which appears to be about two meters deep. The vents may be independent, as the measured temperatures were usually different. The water level seemed to be similar to that seen in the Bottomless Pit.

South Chain Lake #2 S2 This is a small shallow pool, in which the water level was down a few centimeters. The water was not quite as opaque as the Chain Lakes, but murky.

Square Spring Satellites SqN, SqNW, SqW These are three small springs near Square Spring. Except for a slight turbidity, I could not see any effects upon them.

Square Spring This spring showed no effects from the activity in Link Geyser. The water level would fluctuate from full to ebbing about two or three centimeters. This activity seems to be the norm for this spring.

Culvert Geyser There seemed to be no effects on this spring. It was a clear blue, and in a constant state of boiling, which were typical of its activity during 1983.

The End of the Recent Activity

There were some good indications that the last eruption series might be the last for a long time. This was because of the changes in the activity and temperatures in N, M, and the Bottomless Pit.

Throughout the summer of 1983, these three pools all showed temperatures within the range of 137°F to 158°F. (The higher temperature of N may be due to the connection that N1 has with Link, and water flowing in from there). After the start of activity in Link, the temperature of N rose about ten degrees, M about forty, while the Bottomless Pit stayed about the same. This was the case early in the morning of 18 October.

But during this series of eruptions, the temperatures in these three springs rose as their water levels dropped. After the next to last eruption, M began to erupt from an extremely low pool. The temperature in the Bottomless Pit peaked at a temperature of 173°F, while N had risen a few degrees to 189°F.

After the last eruption of Link, and for the next few days, the temperatures in the Chain Lakes, with the exception of Link and the Bottomless Pit, slowly dropped. The temperature in the Bottomless Pit was usually 200°F, with heavy convection along a line in the eastern half of the pool. The temperature of Link was 199°F. There were times when Link would show an exchange of function with the Bottomless Pit. At these times the temperatures would be about 203°F for Link, and 185°F in the Bottomless Pit. The water levels in all the pools slowly rose, so that they within a week they had risen to within a few centimeters of their height before the activity began. Link was first observed to overflow on 22 October.

During the first ten days after the last eruption, boiling was observed in Link only during those time when the temperature in the Bottomless Pit dropped to about 185°F. By 04 November, it was obvious that the runoff from Link Geyser was nearly continuous, as was indicated by the thickening algae which was beginning to line the two runoff channels. The algae reached nearly into the crater of Link Geyser, and the temperature near the surface was only 170°F. The temperature continued to drop, so that by mid-February 1984, [Hutchinson 1983] noted that there was algae deep within the crater of Link. At the same time, he reported that the heavy convection in the Bottomless Pit was continuing, while the other Chain Lakes showed low temperatures.

Spring Name	Height	Duration
Link Geyser	10m - 30m	1m-2 1/4m
North Chain Lake (N)	8m - 12m	2m - 2 1/2m
N1	1 - 3m	1m - >2h
N2	several meters	unknown
M1	1/4m - 1m	1/2m-3/4m
Middle Chain Lake (M)	boil - 1/2m	hours
Bottomless Pit	~5m - 10m?	unknown
Culvert Geyser	boil - 1m	minutes-hours

Geysers of the Chain Lakes Group
Table 8

Connections with Link

Based on this latest series of eruptions, there are a number of certain, or suspected connections. A direct connection is defined as an obvious, sympathetic relationship. An indirect connection is one in which changes occur, but which were not directly correlated with Link's activity.

All of the Chain Lakes proper showed signs of at least an indirect connection to Link. At the southern end of the group, the connections, if any, are tenuous at best. Riverside Geyser did not show any effects to the eruptions, however, after the activity of 4 September, J.Wegel mentioned that he had obtained some unusual data on Riverside's activity later that night. What sort of data, he did not disclose.

During the summer season of 1983, other geyser gazers and I studied Fan and Mortar Geysers, in an attempt to find some indicator for future eruptions. One of the possibilities that has been discussed is a connection to Link Geyser, and correlation between Link Geyser's and Fan and Mortar Geysers' minor activity (for a full description of Fan & Mortar's minor cycle, see [Strasser and Strasser 1983] and [Strasser 1989]). Some

North Chain Lake #2	Probable, through N?
North Chain Lake #1	Certain, direct
North Chain Lake Geyser	Certain, indirect
Middle Chain Lake #1	Certain, direct
Middle Chain Lake	Certain, indirect
Middle Chain Lake #2	Unknown, possibly with S
Bottomless Pit	Certain, direct
South Chain Lake #1	Possible, indirect
South Chain Lake #2	Unlikely
Square Spring	Probably not
Culvert Geyser	Probably not
Riverside Geyser	Unknown
Fan and Mortar Geysers	(see text)
Spiteful Geyser	(see text)

Status of Connections to Link
Table 9

interesting coincidences were observed, but never anything conclusive.

The three eruptions of Link Geyser that I witnessed on 14 October, and the first two seen on the morning of 15 October all came at the same stage in Fan and Mortar's minor (or hot period) cycle. This was between the start of activity in Mortar's Crack vent, and the end of activity in that same vent. This is also the stage in the cycle when an eruption of Fan and Mortar usually starts. By that time, I was beginning to take a greater interest in a possible connection.

I was unable to pursue this further, as an eruption of Fan and Mortar took place at 10:58 on 15 October. The activity of Fan and Mortar leading up to this eruption was typical of the pre-eruption symptoms observed throughout the summer of 1983, and of those symptoms reported by [Strasser and Strasser 1983]. At the start of this eruption, it seemed to both M.Wolf and myself that the boiling in Link Geyser increased substantially over what we had observed a few minutes earlier. At this time Link Geyser was in the middle of recovering from a Last Eruption of a sub-series.

During this eruption of Fan & Mortar Geysers, the water in Spiteful Geyser became turbid, and the water level dropped several centimeters, enough to stop all overflow. This is the only time known of the water in Spiteful Geyser becoming turbid. In 1974, [Martinez 1974] reports that the two eruptions of Link that he witnessed were preceded by eruptions of Spiteful Geyser that occurred twenty minutes or less before Link's eruption. Spiteful is believed to be connected with Fan & Mortar.

So there are a number of interesting coincidences between Link and Fan and Mortar, but at this time, there is nothing to justify the conclusion that they are connected. Perhaps if the frequent activity of Fan and Mortar continues, an opportunity to study this problem will appear.

Area Activity Since 1983

The activity in the area for the next few months was minimal. Link was relatively cool, considering the activity the previous fall. The vent was lined with dark-green algae to a considerable depth, while the amount of overflow was nearly constant. The Chain Lakes showed no signs of activity, with the temperatures in all of them slowly dropping.

On 25 Mar 1984, there was an eruption of North Chain Lake Geyser (N) [Hutchinson 1984]. The night before, there had been a moderate snowfall in the Upper Basin area, with a few centimeters new accumulation. The next morning, it was noticed that this snow was missing from parts of the old runoff channels leading from North Chain Lake. There was also noticeable turbidity in the Chain Lakes and in Link.

The eruption of North Chain Lake Geyser was observed at 10:29. The duration was 2m27s, and the height of the eruption estimated at ten to twelve meters high. The style of eruption was similar to that of Fountain Geyser. After the eruption, the water level in North Chain Lake dropped about 40 centimeters, and a cascade of water flowed in from the Middle Chain Lake, through a shallow channel connecting the two (see Map 1). Also, at that time, the water level in Link dropped about 15 centimeters, enough to stop overflow.

It is interesting that Link showed an immediate response to the eruption of North Chain Lake, whereas no response was seen in North Chain Lakes during Link's activity.

By means of markers, it is known that at least one, but probably no more than two, eruptions occurred between 17:30 that night and 10:00 the next morning, 26 March. Another eruption may have occurred between 27 March and 04 April.

No further eruptions of North Chain Lake occurred. For the remainder of the summer [1984] and into the next winter, North Chain Lake overflowed continuously, with temperatures in the 80°-93°C range. At the same time, all other features in the Chain Lakes, as well as Link, were cool, 55°-60°C and lined with red leathery algae. Link did not overflow during this period.

On 11 March 1985 an exchange of function occurred. Within 24 hours, the temperature in Link rose above 75°C, killing the algae lining, while at the same time North Chain Lake ceased overflow. By 16:00 12 March, the water level in North Chain Lake was down 30cm (1ft). Minor activity in Link was first noted on 25 March 1985. It should be noted that Fan & Mortar went dormant sometime in April, and did not erupt again until August 1986.

Sometime in the Spring of 1987 Square Spring rose, flooding the surrounding grass, and began to have minor eruptions. This activity was quite regular, consisting of alternating periods of overflow, and overflow coupled with 30cm high splashing at the southern end of the vent.

About five minutes after an eruption, the pool would rise up about 2cm and overflow over the entire rim. This overflow lasted a little over a minute. About 2m30s after this overflow ended (3m30s after the start), Square would begin to overflow again. Rather than drop after a minute, this time the next eruption would begin.

The intervals between eruptions was regular, with a mean interval of 9m57s, and a standard deviation of only 7sec. The eruptions lasted a mean of 50s, with a standard deviation of 5s. While not timed, this sort of activity was observed during August 1988.

In the Spring of 1988, the main center of boiling in Culvert Geyser shifted south, to the slot next to the abutment. At around the same time, a portion of the trail shoulder to the south began steaming. On 24 June, this area of steaming ground collapsed, forming a spouter/geyser referred to as "Persistent Geyser" [Bryan 1989]. Around this time Culvert ceased to overflow, causing the demise to the large bed of stromatolite-like algae to the north. By August 1988, "Persistent" had enlarged to about 1m x 2m, and was about 50cm deep.

Acknowledgements

I would like to thank a number of people who helped in either the observations of this eruption series, or in the preparation of this report:

Mary Ann Moss and Marie Wolf deserve the greatest share, for gathering of data when I was unable to be in the area. Rick Hutchinson, Geothermal Research Specialist, kept me informed about the activity in that area during the following winter.

* * * * *

As described in the original editon of this report, a *sput* is a very small geyser. The height of its eruption is usually less than 20 centimeters, and the vent may only be a crack less than a centimeter wide. The small perforations to the south of Splendid Geyser, or the individual vents of Rift Geyser are examples of sputs. The term was originally used in connection with the perforations near Bonita Pool by Wolf, but the term now is generally used for any small erupting vent that is so small as to make the term 'geyser' inapplicable.

* * * * *

Originally this report was written and distributed to a few friends, and a copy was sent to the Yellowstone Park Research Library in the Spring of 1984. It has been revised and rewritten for the *GOSA Transactions*, including the addition of new material on activity in the area since the first report was written. It was prepared using Fullwrite™ and AppleScan™ on a Apple Macintosh™ computer.

References

Most unpublished reports are available in the Yellowstone Park Library.

Bryan 1986 Bryan, T.S. *The Geysers of Yellowstone*, Revised Edition, Boulder, Colorado Associated University Press.

Bryan 1989 Bryan, T.S. *The Grotto Geyser Group and Giant Giant Group, Upper Geyser Basin, YNP, Wyo.: Activity and Relationships - 28June-28July 1988*. GOSA Transactions.

Douglass 1936 Douglass, E.B., *The Chain Lake Geyser*. Unpublished report. (Notation on copy indicating that it was published in May 1937 *Yellowstone Nature Notes*)

Hague 1904 Hague, Arnold., *Atlas to Accompany Monograph 27 on the Geology of the Yellowstone National Park, Wyo.*, U.S. Geologic Survey. Topography Sheet XXV.

Hutchinson 1983 Hutchinson, Roderick A., Personal communication.

Hutchinson 1984 Hutchinson, Roderick A., *Geologic & Thermal Hilights of Yellowstone: 1983-1984*. Unpublished.

Lenertz 1983 Lenertz, James., *Thermal Observations, June-August 1983*. Unpublished.

Marler 1973 Marler, George D., *Inventory of Thermal Features of the Firehole River Geyser Basins, and other Selected Areas of Yellowstone National Park*. NTIS Pub. PB221289, pp. 88-92.

Martinez 1974 Martinez, Samuel. *Hot Spring Activity in the Geyser Basins of the Firehole River, August 1974*. Unpublished. pp. 4-5.

Muffler, et.al. 1982 Muffler, L.P.J.; White, D.E.; Beeson, M.H.; Truesdell, A.H., *Geologic Map of Upper Geyser Basin, Yellowstone National Park*, U.S. Geologic Survey, Miscellaneous Investigations Map I-1371, scale 1:4800.)

NPS Log Books *National Park Service Geyser Log Books.*, Unpublished. 1969-1976.

Peale 1883 Peale, A.C., *Thermal Springs (of Yellowstone National Park)*, U.S. Geologic and Geographic Survey (Hayden), v.12, part 2. pp. 189-190, 192-193 and map of Upper Basin.

Strasser 1989 Strasser, Paul, "Fan and Mortar Geysers", *GOSA Transactions*, vol 1., 1989.

Strasser and Strasser 1983 Strasser, Paul and Strasser, Suzanne *Eruption Characteristics of Fan and Mortar Geysers (1979-1982)*. Unpublished.

Wolf 1983 Wolf, Marie, Personal communication and unpublished notes.

FAN AND MORTAR GEYSERS
by
Paul Strasser

ABSTRACT: During the last decade investigations into the behavior of Fan and Mortar Geysers have significantly improved our knowledge of this geothermal complex. The discoveries include an understanding of their cyclical minor activity and its relationship to major eruptions, the bimodal temperature curve of the minor cycle, short-cycle energy shifts within the complex, unique long-term cyclical behavior, and the unusual underground connections among the members of this geothermal unit.

In the eyes of geyser gazers Fan and Mortar Geysers have always been considered a single unit. They are intimately connected and in recent years and nearly all of their activity has been directly related to each other.

Fan and Mortar are among the most spectacular geysers in the world. No geysers anywhere start their eruptions with the punch and abruptness of these two, reaching full height and power in less than five seconds. They are certainly among the most favorite of the geyser gazers, who will frequently spend hours and days waiting for the next eruption.

Starting in 1979, Fan and Mortar were systematically studied by the author and in later years by several other geyser gazers. The results of these studies will be discussed below.

THE COMPLEX. Fan is a collection of cracks and vents along a prehistoric fracture (figure 1). The zone of fracture extends both to the east and west; the western end extends under the Firehole River while the east end continues towards and possibly beyond Spiteful Geyser, whose ragged, deep crater was probably formed by a thermal explosion long ago. It is quite possible that both Fan Geyser and Spiteful Geyser were caused by the same tremendous earthquake hundreds of years in the past.

When first studying Fan's activity in 1979 and logging the behavior of its individual vents, I gave them descriptive names to better separate their data. In the ensuing years these names have become standard, if not semi-official. From East to West they are:

1) The East Vent. Clever name. This is the largest vent in the Fan complex. A sizable portion of Spiteful's run-off trickles quietly into the East vent. When in full eruption, the East Vent throws water at a very low angle towards the east. This vent has no minor activity at all.

Beginning in 1987, some observers began to use the nickname "The Grand Canyon" to describe the East Vent, primarily in reference to a rare but spectacular type of major eruption. This will be described in detail later in the paper.

2) The Main Vent. This is the V-shaped vent at the "peak" of Fan's rift. It is called the Main Vent because the principal large water column(s) emanate from it. Due to obstructions inside the Main Vent, water is thrown in several directions from this one hole: vertically; towards the east; towards the river; and towards the north. These water columns are the largest associated with full eruptions of Fan. The water that clears the asphalt trail comes from this vent.

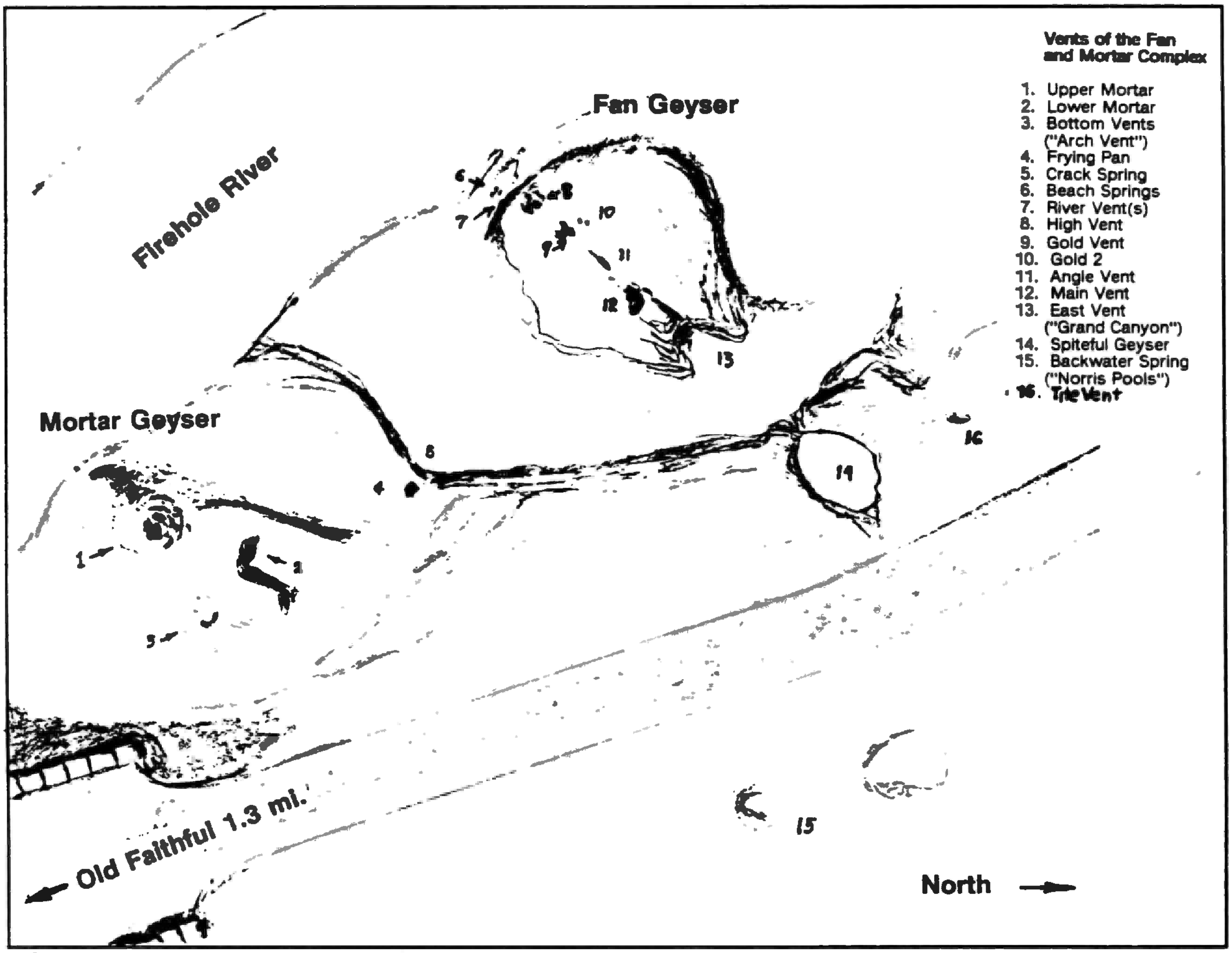


Figure 1. Map of Fan and Mortar complex.

There has been some confusion about this activity in the past. George Marler [1973, p.77] specifically states that the principal arcing water came from the East Vent. This is clearly not the case. Since Marler's prowess as a geyser gazer is unquestioned, it seems surprising that he would miss such a simple observation as this. It is therefore a possibility that, sometime in the last twenty years, Fan's eruption behavior has changed. It would be of great interest to see photographs of eruptions prior to 1970 in order to help answer this question.

The Main Vent rarely plays any water during the minor activity, and on these occasions the water, which amounts to a few droplets barely rising above the sinter, seems to have little bearing on the time of the next eruption.

3) The Angle Vent. A narrow slit, the Angle Vent is one of four that are the principle focal points of study during minor play. It was dubbed "Angle" because its minor activity shoots at an angle to the east. Its major activity is nearly vertical and impressive, reaching a height of over 40 feet in the first moments of a major eruption, but is overshadowed by the extraordinary display of its neighbor, the Main Vent.

4) The Gold Vent. The sinter surrounding this vent is golden-hued, hence the name. Gold has the most

vigorous visible minor activity of any vent of Fan. Its lusty splashing frequently has viewers excited about the possibility of an impending major eruption. Most of this minor activity only teases the observer. Data to help the reader tell the difference will be provided later.

Gold's major eruption activity is simply a part of the apparent unbroken curtain of Fan's water. Its water column and that of the Angle Vent's can criss-cross about ten feet above the ground, which is entertaining but often ignored.

5) The High Vent. This vent, named because it is perched on a small sinter hillock above Gold Vent, can pour an impressive amount of water down its brown-tinged slopes during minor activity.

6) The River Vent. The River Vent is a collection of cracks a foot or so above the high-water mark of the Firehole River. The River Vent is very unusual in one respect: It might be the only upside-down geyser vent in the world. Its water is ejected, under some force, downward as opposed to the more traditional vertical or the slightly iconoclastic oblique angle demonstrated in the rest of the geyser world.

During a major eruption the River Vent ejects steam under high pressure at a slightly less unusual angle: horizontal, nearly spanning the river.

There are a few other vents in Fan's immediate neighborhood. The Beach Springs are a small collection of seeps on the Firehole's bank directly under the River Vent. They are only above water when the Firehole River is low. The Beach Springs may be independent from Fan entirely; there is no evidence that they demonstrate any change in activity before, during, or after a major eruption. They are, however, the focus of one theory relating to Fan and Mortar's long-term behavior.

Another feature is known as "Gold 2." It is a compact group of little vents located about 12 inches north of the Gold Vent. They are so difficult to see that their occasional gurgles may have little meaning. They do take part in the major eruptions, during which they spray mixed steam and water six to eight feet high.

One last feature is known as "Tile Geyser" or, alternately, as the Tile Vent. It is an old, desiccated tile-lined culvert that juts out of the black and gray gravel along the incline about ten feet north of Spiteful's outlet. In 1983 Koenig noted that a mist of steam and water, under some pressure, was ejected from this culvert during a major eruption of Fan. It was with some interest that we saw Tile Geyser's discharge wax and wane along with the discharge from Fan's vents. This behavior has been observed several times since.

This leads to some disconcerting thoughts. It is clear that somewhere under the old Loop roadbed lies the vent of a major geyser trying vainly to break out. It is also clear that the people who laid the roadbed thought enough of this little vent to give it its very own culvert to remove the pressure and water.

Early road engineers were often very strong-willed in their determination to put down the road where they wanted it, ignoring the presence of obstacles like geysers or hot springs. It would be very interesting and exhilarating to have this old roadbed removed down to the original terrain, if for no other reason than to free this poor vent from its asphalt prison.

One other possible vent of Fan Geyser should be mentioned. Marler (1973) discusses a possible vent of Fan on the opposite side of the Firehole River:

> "During eruptions I witnessed in 1938 and 1939 a small steam vent located midway on the high embankment across the river jetted steam in

> a horizontal direction, which nearly spanned the river. Steam ejection would last fully two hours. During 1969 and 1970 this vent was inactive."

No trace of this vent has been observed in recent years.

Mortar Geyser is comprised of two large vents, predictably known as the Upper and Lower vents. Both can show water during the minor activity, but at different times and with different consequences. The major activity of Mortar is in many ways more intimidating than that of Fan, whose eruptions are merely spectacular and impressive. Mortar's play is a deep-throated, chaotic rumbling steam exhibition, preceded by vertical water that can approach 100 feet high.

In 1983 Koenig noted slight wisps of steam emanating from the loose sinter east of the Lower Vent. By 1987 two small vents formed at this spot. Koenig originally called them the "Bottom Vents" of Mortar. Later, not knowing of the original name, other observers dubbed them the Arch Vent (singular, not knowing there were two vents), named, most likely, because of an arch of loose rock above them. That rock arch has since nearly disintegrated, and the original "Bottom Vents" is suggested as the appropriate name.

When quiet, the Bottom Vents are nearly impossible to see from the road due to their location under a pile of loose sinter blocks. In 1988 they were first observed to erupt in conjunction with a major eruption of Fan and Mortar, attaining a height of 3 to 6 feet. Their recent creation demonstrates the general erosion seen throughout the entire complex over the last decade.

The Bottom Vents are unique in Yellowstone. They are the only new vents of an original major geyser since the Park's creation in 1872. As will be discussed later, there is reason to believe that they will increase in activity in the coming years.

Spiteful Geyser was a frequent performer in the 1970's. Its pool would empty following its 20-foot high eruptions and refill very slowly over a period of a few hours. The crack on the eastern side of Spiteful that shoots water a few feet high has been active for a few decades at least, despite its fresh appearance. Spiteful 's activity used to be considered a principal clue to the possibility of a major eruption of Fan and Mortar, but the hypothesis that linked their eruptions is no longer evident. It will be discussed at length later in this paper.

The other features in the Complex include the Frying Pan, a rubble-filled little spring on the northwest side of Mortar's Lower vent; nearby Crack Spring is a nearly invisible slit at the base of the incline between Mortar and Fan. Crack seems to be an indicator for the Frying Pan. It is located directly beneath the Frying Pan; its discharge is seen trickling down the old run-off channel between Fan and Mortar a few minutes prior to the start of the Frying Pan.

Also in this area are a few other small frying-pan-type springs around Lower Mortar, and, finally, two of the most motley looking springs in the entire Upper Basin, located on the eastern side of the asphalt trail. It was suggested that the southern of the two be named "Backwater Spring" by Martinez (1980) due to its observed relationship to Spiteful Geyser in 1974. Both of these features are often called "Norris Pools" for their resemblance, both visually and olfactorally, to many such features at Norris Geyser Basin. The connection to Spiteful will be discussed later.

MINOR CYCLICAL ACTIVITY OF FAN AND MORTAR

In 1979 the first report of an eruption of Fan and Mortar in nearly two years was the impetus to intensely study the complex. Within a few days of observation and recordkeeping I noticed a pattern to the low splashing and steaming that is the most common activity seen by most visitors (Figure 2).

This pattern of minor activity has proved to be the most important single factor in the analysis of the complex. It was discovered that the vast majority of all major eruptions occur in only one part of the cycle. A classic minor cycle, which lasts anywhere from 25 to over 130 minutes, is discussed in detail, as well as observed variations:

THE CLASSIC CYCLE: The logical starting point of the cycle is the first activity after a period of quiet. This is splashing deep within Mortar's lower vent, a boiling and surging that is sometimes very impressive, with some droplets landing ten feet or so to the north of the vent. Most of the time, however, the Lower Mortar activity consists of a churning motion a few feet high commonly referred to as "fuzzballs."

After a period of anywhere from five to twenty minutes of solo Lower Mortar splashing, the River Vent of Fan will heat up. Gentle wisps of vapor will turn into a roiling cloud of steam that is easily visible from all along the trail. The best view is from the bridge over the Firehole; from this vantage one can see the River Vent's water surging downward.

Since this cloud is so easily visible, it is frequently used as the benchmark for the "start" of a Cycle. The Lower Mortar splashing, it is often argued, doesn't start with the suddenness nor is as easily seen from so many places as the start of the River Vent. As long as the viewer is consistent in his or her data collection, either activity is acceptable for use as a starting point. From a purist's point of view, though, a "start" is logically defined as the beginning of activity following a period of inactivity, hence the theoretical preference for Lower Mortar activity signaling the start of a cycle.

The next stage in this typical cycle is the initiation of activity in the High and Gold Vents of Fan, which usually starts two to fifteen minutes after the River Vent. The first water seen is commonly overflow and small splashing from High, followed by heavy two to four foot splashing out of Gold.

This activity of the Gold Vent is the most visually impressive part of the minor cycle. Its discharge immediately

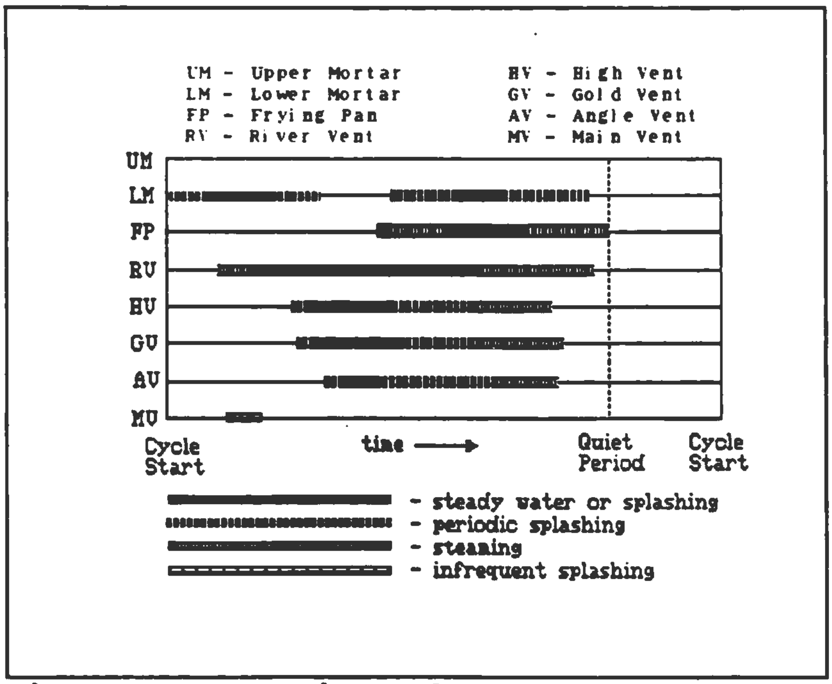


Figure 2. Classic cycle of Fan and Mortar.

after it begins is usually impressive enough to get onlookers excited about the possibility of a major eruption. Unfortunately, its activity at this stage in the cycle is irrelevant to the likelihood of a major eruption. At about the same time that the High and Gold Vents start, the activity within Lower Mortar wanes considerably. The lessened activity is accompanied by a drop in temperature and water level.

Following the Gold Vent's start, the Angle Vent begins its jetting motion to the east. This activity usually starts within 5 to 20 minutes of the Gold Vent's start, although it can occasionally start almost immediately after Gold.

Typically, the next activity is a resumption of churning within Lower Mortar. Its water level has risen again, although to a level lower by at least a foot from its height at the start of the cycle. Then, the Frying Pan starts steaming and gurgling, taking a few minutes to build up to its maximum activity.

At this point, activity begins to wane. Gold, High and Angle Vent, who started a slow change to steam intermixed with water at the time of the start of the Frying Pan, slowly ebb in force. Lower Mortar gets weaker and weaker, and the vigorous gurgling of the Frying Pan changes to steam as well. A few minutes later all is quiet. The quiet period before Lower Mortar begins splashing has varied from as short as 3 to over 25 minutes.

VARIATIONS TO MINOR CYCLES. The variations seen in a classic cycle are considerable, but nearly every cycle will display a tendency towards the typical one. Some of the variations include:

NO FRYING PAN. During periods of dormancy the Frying Pan is infrequently seen.

MINOR SPLASHING FROM UPPER MORTAR. Usually seen at about the time of Lower Mortar's mid-cycle resumption of activity, such behavior is of little consequence. During 1987 Upper Mortar sometimes splashed during the preliminary stages of a cycle; this elicited considerable excitement from the assembled throng but nothing else unique happened.

VERY HEAVY PRELIMINARY SPLASHING FROM GOLD AND HIGH. It is important to remember that, no matter how strong the first activity is from these vents, the first splashing does not matter. In fact, the most visually impressive starts of Gold and High took place during dormant years.

SPLASHING FROM THE MAIN VENT. This was first seen in 1987. The splashes were little more than droplets. This behavior appears to be random.

CYCLICAL ACTIVITY AFTER A MAJOR ERUPTION. Following a major eruption, the whole complex is quiet for four to eight hours. During this time the sinter within Lower Mortar's visible chamber dries out; its color changes from a dark brownish-gray to a very light gray color. The first minor activity after a major eruption is a very weak, short-duration cycle that only slightly resembles the classic cycle discussed above. After approximately 18 to 24 hours the cycles again resemble the classic cycle.

In the period of weak activity the Frying Pan is not an active participant in the play. The cycles at this time are from 24 to 35 minutes in length, and the changes in activity of the classic cycle are not as evident. A possible reason for this behavior is discussed later in the paper.

SIGNIFICANT VARIATIONS TO MINOR CYCLES. Of much greater interest are those cycles that vary tremendously from a classic cycle. The most common variations are discussed in the following:

RIVER VENT PAUSE CYCLE. This variation looks like a classic cycle until the start of the River Vent. Instead of the High or Gold Vent starting a few minutes later, the River Vent keeps steaming on its own, gradually getting weaker, until the whole complex is dead. This brief period of quiet lasts anywhere from 10 to 20 minutes, whereupon Lower Mortar starts splashing in conjunction with the restart of the River Vent. The remainder of the cycle starts a little quicker and tends to be more forceful than the classic cycle.

Frequently, one of two phenomena occur during a River Vent Pause eruption. Either Upper Mortar will splash or there will be a major eruption. Most onlookers prefer the latter.

On rare occasions <u>two</u> pauses in the same cycle have been observed. However, there is no apparent relationship between this occurrence and a major eruption.

REJUVENATION CYCLE. This cycle follows the Classic Cycle until the Gold, Angle and High vents turn to steam. The steam will weaken, then abruptly revert to water. Occasionally a Major eruption will take place. The object lesson of the Rejuvenation Cycle is that the true end of a cycle is when all activity ceases, not when the Gold and High Vents turn to steam, which is when most observers feel the chance for a major eruption has ended. During most cycles observers are correct; nevertheless, it only takes once to miss a major eruption.

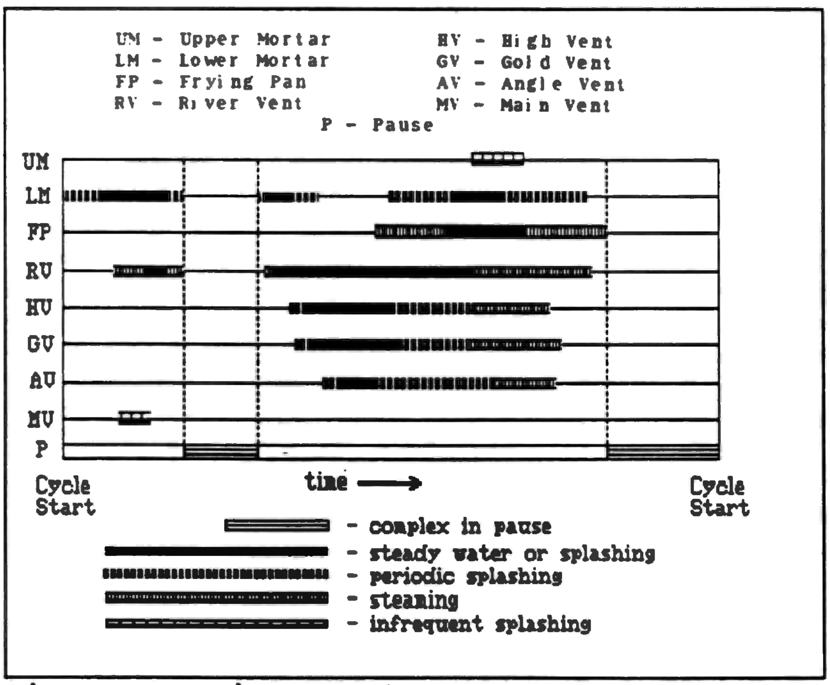


Figure 3. River Vent Pause cycle of Fan and Mortar.

WATER TEMPERATURE VARIATIONS THROUGHOUT THE CYCLE

In 1979, as a Thermal Volunteer for the National Park Service, I received permission to undertake off-trail work in the Fan and Mortar complex. I attempted to record the water temperatures and levels of the vents in every portion of the cycle. With the data collected from a few days of monitoring it became clear that the temperature of the complex is bi-modal throughout the length of the minor cycle.

The modes corresponded to the maximum splashing within Lower Mortar. At this time the water temperature was 204° F. When the River Vent began steaming the water temperature within Lower Mortar began dropping until it reached 197° F. When Lower Mortar began splashing again at about the time of the Frying Pan's start, its temperature rose again to 204°. In the period between the end of activity and the resumption of Lower Mortar splashing, the temperature dropped to 192°.

Temperature readings within Fan Geyser were more difficult to take than in Lower Mortar.

During most of the cycle there is no water visible even at depth in Fan's vents. The data the author was able to collect was from the Main Vent, where water rises to a variable level, three to six feet below the surface, at the time of the first Lower Mortar splashing. It then drops to a point where readings are unobtainable for the rest of the cycle. The only other water available for temperature reading is that which erupts from the Gold, River, High and Angle vents during their normal activity described earlier.

This temperature change, when examined in conjunction with the surface activity within the complex, led me to conclude that there is a heat flow in a minor cycle that shifts from Mortar to Fan and back to Mortar. When a major eruption takes place, the shift in energy back from Fan to Mortar is either interrupted or reverts back to Fan. This second shift takes place at the time when the Frying Pan begins steaming; the simple bubbling and steaming of the Frying Pan is the manifestation of the most critical time in the cycle. It is the time when the behavior of the complex changes, when the observer can normally first see that a major eruption may be imminent. It is important to note that the Frying Pan, in and of itself, is not necessarily the determinator. Its activity is the surface expression of the changes occurring underground.

This will be described in the following. As might be expected, there are variations to the start of a major eruption also; these will be examined closely, both in how they relate to the energy shift and how the observer can best determine what is occurring in the complex.

MAJOR ERUPTIONS AND THEIR RELATIONSHIP TO MINOR CYCLES

THE CLASSIC START. A minor cycle that results in an eruption is different in many respects from the preceding cycles. The most notable difference is in the behavior of the High and Gold Vents during their minor play. Ten to twenty minutes after their start they begin splashing water continuously and voluminously. This increase in activity takes place within a few minutes, before or after, of the anticipated start of the Frying Pan. The Frying Pan does not have to be steaming when this activity picks up. This relationship is somewhat similar to that between Grand and Turban Geysers. Grand can erupt either before or after the start of Turban in the same manner that the Gold and High Vents can start voluminous splashing either before or after the start of the Frying Pan. In the case of Fan Geyser, this period can be as much as ten minutes before or after the start of Frying Pan.

The continuous splashing looks different, as if the water level inside their vents is much higher. During non-major eruption cycles, the water ejected from these two vents looks more like the very top of a surge that started several feet below ground level. The difference is obvious to the observer who has endured several hours of waiting through uneventful minor cycles.

There is usually a 5- to 15-minute period of certainty that a major eruption is about to start. This is when the Gold and High Vents are splashing steadily and continuously, their height and power slowly increasing, accompanied by heavy surging from Angle Vent. As the Angle Vent gets stronger its water column slowly changes to vertical. When they are all going full tilt, erupting to a height of 4 to 8 feet, the eruption is imminent.

Usually the first play of a major eruption is a welling of water within Lower Mortar's vent, its deep blue water surging up several feet in a massive display. Within five seconds, Fan's Main Vent surges at first vertically, then unleashes a bolt of water that can reach the trail on the fly. It ranks among the most exciting, sudden and surprising starts of any geyser in the world.

Meanwhile, Mortar's two vents slowly rise. In some eruptions, Mortar is more impressive than Fan. The Upper and Lower vents can easily hit 100 and 60 feet respectively. Upper Mortar's column is a perfect vertical obelisk of water, while Lower Mortar frequently plays in a ragged, fountain-type display obliquely to the north. The differing water columns appear as if they are not playing from the same plumbing system.

While this is occurring, Fan is playing water from as many as a dozen different sources. The Main Vent is the most dramatic; a noisy, erratic display that waxes and wanes in conjunction with Mortar. Some Fan surges have landed over 130 feet east of the vent, over fifty feet beyond the trail. Four distinct water columns emerge from the Main Vent. One is shot at an angle towards the river. The second is massive and vertical, the third is the large arcing water jet, and the fourth, often unnoticed, splashes water to the north. The East Vent is also playing water toward the east, but its column is so oblique that it does not land very far from the vent. The Gold, High and Angle Vents are squirting nearly vertically, their interesting narrow water columns eclipsed by the Main Vent. The River Vent is pushing a forceful steam display horizontally across the Firehole River.

After a few minutes, Mortar changes to steam and the eruption is at its most impressive. Its steam pulses and pounds in eerie symmetry with Fan's water display. Occasionally Mortar will revert to water briefly, only to change quickly back to steam. This steam display is one of the finest in Yellowstone.

Most guidebooks state Fan's height as "125 feet" and Mortar's as "60 feet" [Scharff, 1967; Bryan, 1979]. Although no height measurements have been taken in recent years, personal observation leads me to accept the Mortar height as generally accurate. The Fan estimate of 125 feet seems high.

Most Fan eruptions appear to be in the 90-100 foot range, although the arcing water column and erratic display give it a much larger appearance. It should also be noted that Fan will occasionally have a much more powerful than average eruption. On one occasion I estimated the height at no less than 140 feet.

In some eruptions, Mortar is the dominant force. At these times the water from the Upper Vent will approach 90 to 100 feet while Fan is reaching, at best, 80 feet. There is no apparent correlation between powerful Mortar eruptions and any other factor.

The most commonly used measuring tool for the eruptive force of Fan is to see where its water column is falling beyond the asphalt trail. During most windless eruptions the ground is soaked approximately 6 feet beyond the eastern edge of the asphalt.

The entire performance slowly wanes in power. Approximately fifteen minutes after the start, the eruption suddenly quits entirely. This pause is generally the end of the most impressive part of the show. Within one minute Fan and Mortar will both come back to life but they seem exhausted. They will ebb and die, splash and quit for the next 30 to 50 minutes. The entire eruption lasts about an hour on average. But the best part, the culmination of the hours and days of waiting, is that first astonishing surge from Fan and the thrilling sensory assault of the eruption.

OBSERVED VARIATIONS IN THE START OF MAJOR ERUPTIONS

What was described above can be considered a normal start. Fan and Mortar are not stereotyped, and several variations have been observed. They are described as follows:

RIVER VENT PAUSE STARTS. Described earlier, these occur when the minor cycle briefly pauses after the start of the River Vent. Except for the short break in the cycle, these starts are essentially the same as normal starts. Of greatest interest is that in some years, such as 1987, over half of all observed major eruptions were preceded by River Vent Pause cycles. Since these account for less than 15% of all minor cycles, an observer should pay particular attention at these times.

The first energy shift from Mortar to Fan seems to be interrupted at the point when the water temperature in Lower Mortar begins to drop. After a few minutes, the cycle resumes as if there had been no interruption at all. From this point on to the start of the major eruption the River Vent Pause Start closely resembles the Classic Start.

One unique event should be mentioned. On July 2, 1987, Koenig (1989) witnessed what he described as a Lower Mortar Minor. He describes it as follows:

> "I arrived in the area at 13:02, while Fan and Mortar were in the quiet phase between hot periods. Soon after, the River Vent of Fan began to splash, signaling the start of activity [Koenig uses the River Vent as the start of the cycle]. The splashing from River and High lasted about 15 minutes. The activity was never really strong, and I did not see any activity from Gold. After this pause continued over fifteen minutes I saw what I thought was a large splash from Lower Mortar. This splash kept building, and within a few seconds had built to a small-scale eruption. The depression north of Lower Mortar's vent filled with water, and began to trickle through the saddle between the trail and Mortar. The maximum height was estimated to be about 1.5 meters above the high back rim of the vent. The play resembled the classic start of a major eruption. Suddenly the activity quit and the pool that had formed drained back into the vent.
>
> "The pause ended about a minute later when the River Vent restarted. At this point, the activity of Fan proceeded as expected for a Pause that results in an eruption, with no further unusual activity. There was nothing unusual about the major eruption.
>
> "Later that summer I remember talking to someone who claimed to have seen similar activity that did not result in a major eruption. I do not remember who this person was, so the credibility of the report should not be automatically assumed."

Despite the existence of only one datum point for this behavior, its very uniqueness leads me to believe that this is a distinct form of start, and not two independent actions -- unusual behavior in Lower Mortar and a major eruption - occurring coincidentally.

THE REJUVENATION START. In this start, the Frying Pan steams and splashes, the High and Gold Vents turn to steam. It looks as if the energy shift from Fan to Mortar is complete. In this variation, the energy suddenly shifts back to Fan. Gold and High change back to heavy water, and a major eruption becomes likely.

In many ways this is a more interesting start. The energy shift back to Mortar was either interrupted or was incomplete. The principal difficulty with this start is that the shift back to Mortar is frequently only delayed.

GRAND CANYON STARTS. This variation is very rare. Only four have been observed, all in 1988. Although somewhat similar to a Rejuvenation Start in that it occurs after the Gold and High vents revert to steam, both the timeframe of heavy minor activity and the actual start of the eruption are fundamentally different.

A Grand Canyon start at first resembles the Rejuvenation Start: The Gold and High Vents turn to steam at the time the Frying Pan begins to play. Their steaming action gets very weak; except for the continued activity of the Frying Pan an observer may believe that the minor cycle has ended.

Quite unexpectedly, Gold and High resume splashing. Instead of the slow increase in their play found in the Rejuvenation Start, the Grand Canyon Start changes from weak Gold and High steam to lusty splashing to imminent eruption in less than two minutes.

The start of the eruption is quite different also. The first visible water in the major eruption is a large surge from the East Vent. This first blast of water lands about twenty feet from the vent, inundating the area near Spiteful Geyser. On the two occasions where the beginning of the Grand Canyon Start was relayed to me [Bryan, 1988], there were two separate, distinct surges from the East Vent. It was only after these surges that the other vents of Fan started rising. This rise was much slower than the abrupt start of Classic eruptions, an almost leisurely twenty seconds required from the first East Vent surge for Fan to be fully in eruption.

The fact that all observed Grand Canyon starts took place in 1988 might indicate a change in the internal structure of Fan. This start may become more common in the future.

MORTAR MAJOR STARTS. These are extremely rare. Only three have been seen in the last ten years, and only one was from the immediate vicinity.

In 1983, Koenig witnessed a Mortar Major Start. He described it as follows:

> "The eruption of September 6 was unlike any that I have seen or heard about. I was not in the area to see the start of the River Vent, so I don't know its status prior to that time. I returned at about 17:55, and saw that it was active. The Gold Vent did not start until about 18:15. The activity proceeded normally until about 18:30, when Upper Mortar started splashing. At this time, Fan's minor activity was no more vigorous than during any of the other hot periods I had seen that day. On the sixth or seventh splash of Upper Mortar the water played up to about 1/2 meter, when it

> suddenly rose to about five to eight meters high. I glanced over to Fan whose minor play was unchanged, and I thought I was going to see a solo eruption of Upper Mortar. This lasted for about five seconds, when at 18:39:43, Fan suddenly began to throw water from all vents. There was still no activity in Lower Mortar, not even steam. This was dusk, when the slightest steam could have been seen coming from it. Lower Mortar finally began to erupt at 18:46:15. It did throw out water, but for only a few seconds. There seemed to be no change in the activity of either Upper Mortar or Fan when Lower Mortar started. There was no further unusual activity."

In many ways, the Mortar Major Start is more in keeping with behavior in the complex seen in the 1960's and mid-1970's. This change in activity will be discussed later.

It is clear that, although Fan and Mortar behave in a relatively predictable manner, they can occasionally surprise even the most experienced geyser gazer.

WAITING FOR FAN AND MORTAR: USING THIS INFORMATION TO KEEP YOUR WAIT AS PAINLESS AS POSSIBLE

Trying to see Fan and Mortar can be a long, discouraging sit. At best, the wait will be broken up into discrete sections, each lasting the length of a cycle. It is only during about fifteen minutes or so of the cycle that very close attention must be given to the minor activity. If the cycles are in the 90 to 120-minute range, as was the case in 1984, that gives the observers plenty of time to entertain themselves in other ways. In 1987 and 1988 the average cycle length was 55-65 minutes.

Unfortunately, despite the great efforts of a host of gazers, there is still no way of pinning down the eruption to a particular cycle or time frame, other than the rough estimate of using Fan and Mortar's current behavior pattern to calculate average intervals and standard deviations thereof.

There has been considerable effort in the years since 1979 to try and find a method of narrowing down the time of major eruptions within the window period between major eruptions. In most active years this window is from 3 to 5 days following the last major eruption. All of these efforts have proven futile to this date. In 1980 and 1981, I noted that the minor cycle periods lengthened as the eruption grew nearer, and many gazers speculated that there might be a critical cycle period that must be attained before an eruption is possible.

In some respects, this is true. However, all data gathered has concluded that this critical point is attained prior to the shortest observed major eruption intervals, so it is of little value, except to know when further waiting on some days is completely pointless. As an example, in 1987 all observed eruptions took place when minor cycles were at least 55 minutes in length. This cycle length was normally attained approximately 24 hours following the last major eruption. That year, however, the shortest observed interval between majors was 51 hours. The only advantage that this information gave the observer in 1987 was that if all minor cycles were below the 55-minute period, no eruption was remotely likely because the last eruption took place within the last 24 hours.

In most summers the time of the last eruption is known either by observation or the use of markers. Markers will normally provide the observer with a possible window of plus or minus 3 hours. The only time when the above hypothesis is of any value is after a long period in which neither observations nor markers were employed. In this event, if the minor cycles are very short the observer can assume that a major eruption occurred recently.

Even this broad generality has its limits. In 1977, for example, intervals as short as 25 hours were recorded. In 1988, observed intervals varied from 3 to 15 days.

There have been a few other speculative suggestions to try and pin down the major eruption. In some years, notably 1987 and 1988, observers have noted that not all minor cycles are of the same intensity, that after cycles of voluminous discharge or unusual events, such as large Upper Mortar splashing, the following 2, 3, or 4 minor cycles are weak. Geyser gazers were thinking that something similar to what is seen in Grand and Turban geysers might be occurring at Fan and Mortar. In the case of Grand and Turban, an unusually long Turban interval accompanied by heavy overflow and waving on Grand's pool is inevitably followed by from 1 to 4 sub-par Turban cycles, during which Grand has almost no chance to erupt.

If this were to hold true at Fan and Mortar, then observers would have confidence that an eruption was not likely for several hours following the impressive minor cycle.

There are several difficulties with this hypothesis. The concept of an impressive minor cycle is very subjective. What may appear as unusually strong discharge to one observer may appear only average to another. This is different at Turban and Grand, where the criteria for determining a delay is objective: waves on a full pool of Grand, a Turban interval of 25, 30 or more minutes, and no eruption.

In addition, the proponents of this hypothesis acknowledge that they have observed major eruptions that have taken place during theoretically "poor" cycles.

The method that will give the observer the best opportunity to see an eruption is to examine the recent eruptive history and simply be patient. When first approaching the area, the observer should determine Fan and Mortar's current cyclical stage. This is not as automatic as it seems. For instance, if the whole complex is dead, they are either in the period between cycles or the pause in the River Vent Pause Cycle. If it is simply assumed that the next cycle has not yet started one might leave the area believing that there is no chance for an eruption in the next 40 minutes. It would be a rude surprise to return only to see the waning activity of a major eruption.

After a while the observer will be able to make some reasonable assumptions about their upcoming action. The most important data to collect is the time of the start of the cycle. As discussed earlier, either the start of the Lower Mortar Splashing or the start of the River Vent Steaming can be used as the beginning of the cycle. It is important that those with whom this data is shared are aware of the chosen starting activity.

The important time to watch the complex during the cycle is about ten minutes after the start of the High and Gold Vents. Activity before then, no matter how impressive, is irrelevant. At this point interest among observers increases. If these vents are intermittent it is not a good sign. Steady, forceful play is worth close attention.

In essence, all of the data collection and study is designed to let one know when the next High and Gold activity will start and when the Frying Pan's activity will start. If the vents weaken, turn to steam and die out, the observer will know that the opportunity for a major eruption in this cycle is waning. Rarely, a Rejuvenation Start may take place. In most cases the observer must endure the time span until the next start of Gold and High Vents, when interest once again increases and attention will again be given to the complex.

One of the great thrills of geyser gazing is when Fan and Mortar are a lock: High and Gold are stronger and stronger, Angle is getting vertical, and gazers know It's Coming. Onlookers scurry giddily about, covering their packs and equipment with their ponchos, figuring out the wind direction's affect on viewing, and telling the unaware and uninitiated about the astonishing event that will soon take place.

THEORIES CONCERNING FAN AND MORTAR'S UNDERGROUND CONNECTIONS

Fan and Mortar. The principal connection in the complex is that between Fan and Mortar. Geyser gazers of the 1980's routinely consider them as "Fanandmortar", as if they are essentially one and the same geyser. However, if considered historically they are separate units, intimately connected but nevertheless with different personalities and occasionally different eruptive agendas.

They are reminiscent of Daisy and Splendid in some respects. When the barometer is low and these two geysers are active they are frequently considered two vents of the same geyser system. When the barometer is high, Splendid is not relevant and is often ignored.

When this allegory is applied to Fan and Mortar, the whole of the 1980's can be considered as a continuous "low barometer" period. Much of their earlier history was more in keeping with high barometer behavior in the Daisy complex, with the resulting independent behavior.

Some of their current behavioral patterns demonstrate the subtle nature of their independence. For example, their first minor activity following a major eruption is very different from the classic minor cycles discussed earlier. Both geysers display cyclical behavior, *but they are not meshed properly*. One will observe Mortar splashing and then waning, and Fan's River Vent starting followed by the Gold and High Vents, followed by a waning of activity, but the two operate at distinctly different time rates. Mortar's cycle is about 30% faster than Fan's. In addition, the Frying Pan is not active during this time.

About 24 hours following the major eruption most of this disjointed behavior vanishes; the Frying Pan starts bubbling at the proper time and both Fan and Mortar adhere to the same "proper" schedule. It is the author's hypothesis that during those first hours of activity the two units are essentially independent. It is only at about the time when the Frying Pan starts that Fan and Mortar get on the same schedule.

Since the start of the normal cyclical behavior coincides with the resumption of activity of the Frying Pan, which was previously mentioned as the principal indicator of the energy shift between Fan and Mortar within the minor cycle, it is reasonable to expect Frying Pan's activity to start at the time when Fan and Mortar's behavior coincides. Prior to that point the energy shift, as well as clear dependent behavior, is diluted in strength and appearance.

Such subtle changes in behavior do not lend themselves to obvious conclusions. What exactly is occurring underground? It is possible that whatever connections do exist cannot fully manifest themselves when the separate plumbing systems are depleted; at these times their independence shows itself only to disappear when the entire complex is "recharged". It is also possible that the fissures that are the actual physical connections between the two plumbing systems have changed during the last decade. There has been an obvious increase in surface erosion (discussed later) and it takes little imagination to believe that erosion has taken place underground and that the connections, once subtle, are now more pronounced. If this is correct, signs of independent action will diminish.

One reason why this observation was not discussed in detail in the past is that geyser gazers tend to ignore the complex for the first few days following a major eruption. Any close examination of the minor activity at such a time was normally very short in duration, frequently only long enough to confirm that a major eruption had recently occurred. Since many observers often have only a few weeks each year to enjoy the geysers, it is quite understandable that little time was spent observing Fan and Mortar when there was zero chance to see a major eruption. If there is anything to learn from this it is that observations during quiet, dormant periods or recovery times may elsewhere ultimately prove of some significance.

Close inspection of early records demonstrate that independent activity has occurred almost as far back as written records extend. In one case, Marler [1973] quotes the report of the Norton party of 1873 as an example of the enthusiasm at seeing an eruption of Fan and Mortar. However, a close reading of the report indicates that these witnesses observed a Mortar Major solo eruption, not an eruption of Fan and Mortar:

> " [We] arrived just in time to see 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 - on 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."

It is difficult to imagine that these observers would have written such a precise description of a Mortar eruption without also describing the spectacular activity of Fan Geyser only a few feet away. The conclusion is that this was a solo Mortar eruption. Since Mortar Geyser was not named until 1883, the observers believed they were seeing nearby Fan Geyser, named three years earlier and known to exist in the vicinity; they were so certain that they were seeing Fan that they attempted to reconcile the descriptive name "Fan" with the un-fanlike eruption they were witnessing.

Additional evidence of independent major activity will be discussed in the following section.

Spiteful Geyser. This discussion suggests that there is no specific evidence of any direct subterranean link between Fan and Spiteful. This may be a surprise, considering they are situated on the same fissure. This is even more perplexing when one considers the activity, previously discussed, of the Tile Vent. The actual Tile Vent, buried somewhere under the old roadbed <u>east</u> of Spiteful, erupts in symmetry with Fan Geyser. It would appear that the tentacles of Fan's plumbing system emerge on both sides of Spiteful without affecting it! Please note that the author is simply noting the lack of <u>evidence</u> of subterranean connections and not that the connections do not exist.

Nevertheless, observations clearly show a Mortar-Spiteful connection and not a Fan-Spiteful connection, at least underground. Above ground, a large amount of Spiteful's nearly continuous discharge flows into Fan's Main Vent. Since the mid-1970's, the only evidence of subterranean connections to Mortar Geyser is the lowering of Spiteful's water level following some, but not all, of Fan and Mortar's major eruptions. In the early to mid-70's the subterranean connections were much more obvious, although this information is not commonly known to today's gazers.

This connection was best recorded by former Park Service employee and thermal volunteer Sam Martinez [1980]. In his July 1973 report to the Old Faithful Sub-District Naturalist, he wrote,

> "Sometime during the winter Fan and Mortar became dormant and the nearby Spiteful Geyser began having eruptions of spectacular character. The maximum height of the eruption is reached in the first minute of play and averaged between 25 and 30 feet. About a minute after Spiteful initiated activity, Mortar's lower vent would quickly fill and erupt 10 to 15 feet high. Both geysers would play for about 5 minutes, Spiteful ceasing first with great suddenness. During some eruptions the lower vent of Mortar would be inactive or pause soon after it began and continue or restart sometime later. When this occurred the eruption of Spiteful also became less vigorous and would usually drop below 10 feet in height."

During that time, Spiteful was erupting every 5-1/2 to 7-1/2 hours. By the start of the next month, Fan and Mortar had rejuvenated and Spiteful was erupting in series. The series would start a few hours prior to an eruption of Fan and Mortar. At the time, this appeared to be the result of the subterranean connections made evident in the preceding month.

Observations later in the decade, notably in 1976 and 1977, indicated that the relationship between the start of a Spiteful eruption series and the subsequent major eruption of Fan and Mortar was more likely the result of the cessation of Spiteful's overflow into Fan's East Vent. From June 1974 onward, only the first eruption of Spiteful was from a full pool; all following eruptions were from an empty crater.

By 1977, geyser gazers, notably Martinez and Jamie Espy, determined that all observed major eruptions of Fan and Mortar took place only after an eruption of Spiteful, regardless of whether Spiteful's eruption was a solo number or the first in a series. In either event, the ingress of cooler discharge water from Spiteful into Fan's East Vent ceased for several hours. These two gazers speculated that this cessation was required for the Fan complex to "heat up" sufficiently to permit the major eruption to take place. Once Spiteful filled and overflow started, there were a few scant minutes before the chances for a major eruption dropped to nil.

The principal difficulty with this hypothesis is that events of the 1980's have completely negated it. Spiteful has overflowed for over 99% of the time this decade. Ironically, the only time that Spiteful stops overflowing now is immediately following some major eruptions of Fan and Mortar. There have also been two full Spiteful eruptions reported, both in the winter of 1983-84. These are now extremely rare.

Nevertheless, this hypothesis is intriguing. It does make some sense: the incoming water of Spiteful cooling Fan's plumbing to a point where an eruption is not possible, only to have them eventually erupt during one of Spiteful's lulls.

Assuming the data collected in the 1970's was valid (the observers were very experienced), how is it reconciled with the events of the 1980's? Since the water entering Fan from Spiteful is at a lower temperature than the water entering its plumbing system underground, it seems likely that if Spiteful had continued overflowing in the 1970's unabated for several days, a major eruption would have occurred anyway. Fan easily overcomes the effects of it now, and probably could have then also. It is not unrealistic to recognize that Fan was much more likely to erupt during these lulls than any other time. If the complex was that near to an eruption, a cessation of the ingress of cooler water was most likely all that was required for an eruption to take place. It is also interesting to note that the shortest reliable intervals for Fan and Mortar on record occurred in 1977. Several were in the 24-hour range.

Backwater Spring ("Norris Pools"). Further evidence of subterranean connections with Spiteful were noted in Martinez's July 1974 report:

> "The large spring across the trail from Spiteful shows definite connection to it, because whenever Spiteful enters an active cycle that pool slowly begins to drain and remains empty until Spiteful once again fills to overflowing."

The Beach Springs. Another hypothesis that had a certain amount of acceptance among geyser gazers concerns the water level of the Firehole River. When the Firehole is high its water lies several inches above the level of the Beach Springs, which are commonly thought to be part of the complex. It is logical to assume that the drenching effect of a continuous stream of cold water would certainly have some effect on Fan.

Originally, the hypothesis was paraphrased as follows: as long as the Firehole was covering the Beach Springs, Fan would not erupt. Events of the early 1980's led to a change in the hypothesis, when Fan and Mortar erupted several times while the Firehole River was at a near flood level.

The theory is still compelling. In most years of activity the average interval between major eruptions, as well as the standard deviation, is normally much shorter at the end of the summer than at the beginning, which corresponds to the varying levels of the Firehole throughout the summer season. Is this variation caused by the Firehole? Perhaps.

If a clear connection could be established between the Beach Springs and the remainder of the Fan complex this notion would be more tenable. As of now, there is no evidence of any connection, despite their close proximity. Suffice to say that, for whatever reason, when August and September arrive Fan gets more regular and more frequent.

It should also be noted that in 1988, the driest summer in Yellowstone's history, this theory was invalid. In August and September of that year major eruption intervals increased from a 104-hour average in July to over 130 hours. In October it decreased to 90. The Beach Spring connection theory alone does not account for this behavior.

Morning Glory Pool. It is quite common for Morning Glory Pool to appear much hotter in the early months of the summer season (May-June) than later in the summer. In May and June the algae is frequently absent from the pool's depths; occasionally the algae retreats to a thin band of orange within a foot or so of the pool's edge. By August, Morning Glory Pool reverts to its more normal appearance in recent decades, characterized with heavy algae as far down as the eye can see. At these times there is almost no inkling of the lovely blue color for which this pool was formerly renowned.

This is mentioned in light of Fan and Mortar's decreased activity in the early season months. As noted above, in years of greatest eruptive frequency Fan and Mortar are more infrequent and irregular in May and June than in August and September.

Although there is no evidence of any connection between the Fan and Mortar complex and Morning Glory, it must be mentioned that Morning Glory is the only thermal feature known to have an increase in activity (in this case, water temperature) during times when Fan and Mortar are more irregular. There is no evidence of any change of behavior in Morning Glory in reaction to major eruptions of Fan and Mortar. If such changes were limited to temperature fluctuations in Morning Glory they should not be too difficult to uncover. This might be an interesting long-term project for interested geyser gazers, assuming necessary permission was obtained.

Link Geyser. Link is located about 320 feet south of the Fan and Mortar complex. Its most common activity is low, boiling eruptions every three to four hours. These eruptions are noted for their high volume of discharge. A large waterfall of hot water from Link is visible cascading into the Firehole from the trail near Mortar Geyser.

Rarely, Link Geyser has displayed much greater geyser activity. At these times Link ranks as one of Yellowstone's premier thermal features. In 1983, Link entered a period of major activity on October 14. This behavior lasted for four days; during that time several experienced gazers, including Koenig, Moss, and Wolf, intensely studied the activity.

Concerning a possible Link-Fan complex connection, Koenig [1984] wrote:

> "The three eruptions of Link Geyser that I saw on 14 October, and the first two seen on the morning of 15 October, all came at the same stage in Fan and Mortar Geysers' minor (or hot period) cycle. This was between the start of activity in Mortar's Crack Vent [Frying Pan], and the end of activity there. This is also the stage in the cycle when an eruption of Fan and Mortar Geysers usually starts. By that time, I was beginning to take a greater interest

in a possible connection.

"But I was unable to pursue this further, as an eruption of Fan and Mortar Geysers took place at 10:58 on 15 October. The activity of Fan and Mortar Geysers leading up to this eruption was typical of the pre-eruption symptoms observed throughout the summer of 1983, and those reported by P. Strasser and S. Strasser. At the start of this eruption, it seemed to both M. Wolf and myself that the boiling in Link Geyser increased substantially over what we had observed a few minutes earlier. At this time Link Geyser was in the middle of recovering from a Last Eruption of a subseries."

If there is a connection to Link during its few rare major eruption episodes, would this connection also manifest itself during its more common periods of minor eruptions? This would be a good project for all interested gazers to work on together. By noting Link's activity during the long wait for Fan and Mortar such a "Link link" might be uncovered.

Riverside Geyser. Geyser gazer Dave Leeking believed he saw a connection between Riverside and the Fan and Mortar complex. He was led to believe that Fan and Mortar did not erupt during the two hours immediately preceding an eruption of Riverside. This idea was then discovered to be a mere hole in the data; further data collection dismissed this specific connection. If any connection between Riverside and Fan and Mortar exists, it has escaped discovery. Leeking's "non-connection" is noted because an attempt to discover subterranean connections with negative results is more significant than if no effort had been made at all.

In summary, the subterranean connections between members of the complex are not nearly as obvious as they first appear. Fan and Mortar, although operating in a very sympathetic manner in recent years, have demonstrated past behavior suggesting far more independence than the modern observer is accustomed to seeing. Any sudden appearance of independent activity in the future should come as no surprise.

LONG-PERIOD VARIATIONS IN ACTIVITY OF FAN AND MORTAR

One of the most interesting and perplexing discoveries of Fan and Mortar's eruption history is their long-term cyclical behavior. This behavior is best shown in Figure 4 on the following page.

Fan and Mortar behave in the following manner: After approximately two years of consistent activity, during which summertime intervals are commonly in the 2 to 10 day range, the complex abruptly shuts down. The complex remains dormant for about 18 months, during which time the average minor cycle duration is in the 25 to 40 minute range.

During some long-term cycles the resumption of activity is abrupt, as in 1976. At the start of the two most recent cycles major eruptions were at first irregular and unpredictable. It took nearly a year in both instances for major eruptions to occur at relatively regular intervals.

This summary is based on less than complete records. For several months of every year the complex is not under any observation; during most winters geyser observations are, at best, scanty. The lack of constant data is only a limit to specific knowledge of the number of

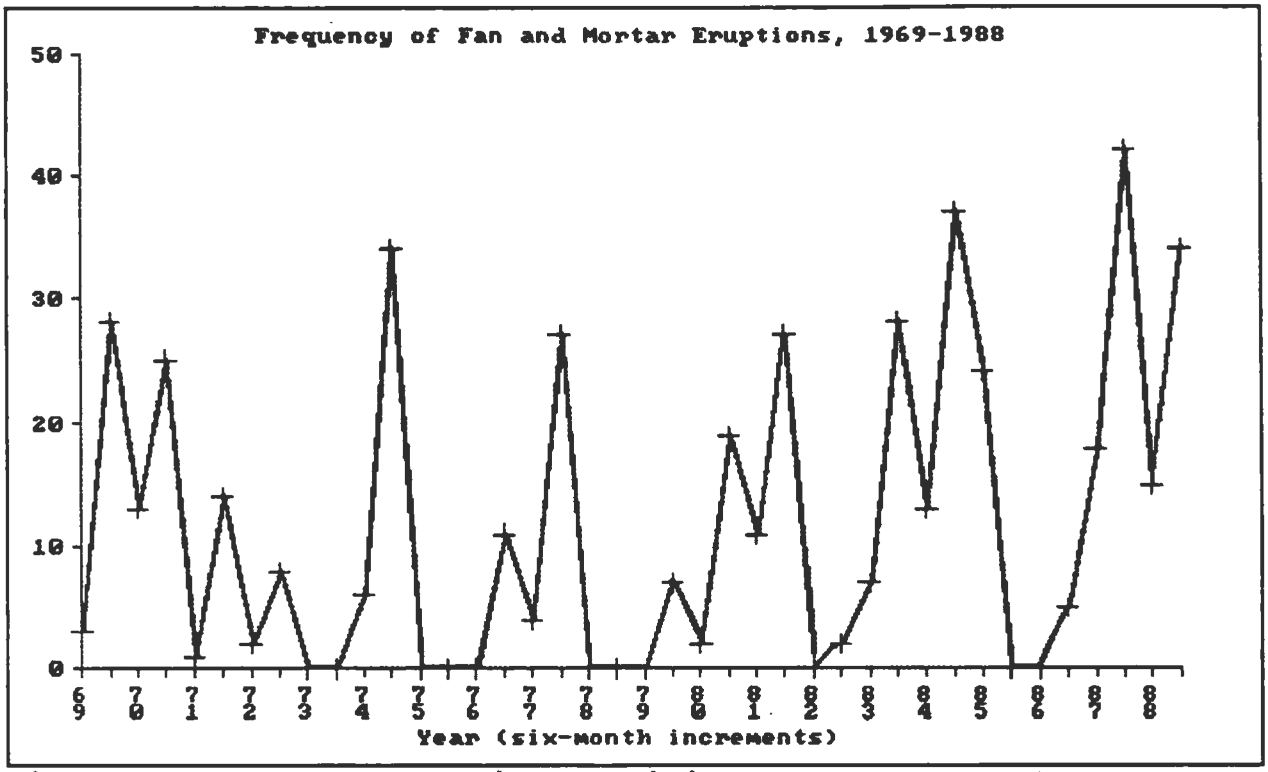


Figure 4. Long-term cyclical activity of Fan and Mortar.

eruptions that took place. It does not limit our knowledge of the length of dormant cycles. A marker placed in October and unmoved in April is an excellent indicator of dormancy.

Evidence points to an abrupt cessation of major eruptions at the end of an active cycle. The first example was in the winter of 1984-85, when a few interested naturalists and volunteers were working at Old Faithful. They kept close scrutiny of Fan and Mortar's behavior throughout the winter, mainly through the use of markers. Fan and Mortar erupted with unusual frequency and regularity throughout the summer and autumn of 1984 and, based on the nature of their long-term cyclical behavior they were expected to be dormant in the summer of 1985.

For most of the winter season the observers noted that eruptions were still taking place with remarkable frequency; the intervals were anywhere from 3 to 5 days. In the middle of March, when the observers left the Park, Fan and Mortar were still going strong. They were not under observation for the next few weeks.

When geyser gazers returned in April, Fan and Mortar were dormant. If there was a slowdown in activity it took place in a relatively short period of time.

Based on the long-term cycle, observers were anticipating the onset of a dormant period in the winter or spring of 1988-89. A close watch was kept on the Fan and Mortar complex during this time, looking for any indications of an impending dormancy. Major eruptions took place with routine frequency in December and January. On January 22, 1989, a major eruption took place after a seven-day interval. This was the last eruption observed through the writing of this section (late March 1989). Again, the onset of dormancy was abrupt.

POSSIBLE CAUSES FOR LONG-PERIOD CYCLICAL VARIATIONS

Long-term variations in geyser activity are common in Yellowstone. In fact, the list of geysers that do not vary from year to year is much shorter. In the geyser basins of the Firehole, nearly every instance of variation in activity is attributed to a geyser's connection with other thermal features nearby. This causal relationship among thermal features is known as "exchange of function". Examples include Bonita Pool and Daisy Geyser, Grotto Geyser and Giant Geyser, and Fountain and Geyser and Morning Geyser. In all these instances, the activity of the former reduces the latter to near or total dormancy.

In some geyser groups, such as the Grand Group and Geyser Hill, the changes in behavior are very complex. In the Grand Group, the behavior of Rift, West Triplet, East Triplet, the Percolator, and even Economic Geyser can affect Grand. Geyser Hill is even more complex than this. Many connections are known or surmised for Geyser Hill, but a complete theory detailing these connections has yet to be offered.

The behavior of Fan and Mortar is markedly different, so much so that it can be considered unique. Since, as mentioned earlier, Fan and Mortar have few known subterranean connections with other thermal features, their long-term cyclical behavior is most likely the result of changes within their own small complex. The long-term cycle cannot be explained using classical theories that adequately explain behavior changes elsewhere. "Exchange of Function" is difficult to apply in cases where there is no other feature with which to exchange water or energy.

As of this writing, there is no theory that adequately explains the long- term cycle. Some suggested ideas follow:

Perhaps the long-term cycle is simply a glitch in the data: there really is no cycle, but the activity of the last few decades gives the impression of order and pattern. The main difficulty with this idea is the fact that all the available data fits into the cycle. There comes a point where the data force the observer to accept that a pattern exists, despite no suggested explanation for its existence.

The only observed outside forces that affect Fan and Mortar are Spiteful Geyser and the Firehole River. Is it possible that one or both of these are a factor in the long-term cycle?

With regard to the Firehole, such a connection would be possible if the long-term cycle's period matched the seasonal variations in the level of the Firehole. The river rises and falls annually, somewhat matching the variations in eruption frequency. An entire cycle is up to three to four times longer. There is only circumstantial evidence that the river in any way is the cause of the cycle.

Spiteful Geyser is not a likely candidate for the cause of dormancy. Its occasional periods of activity occurred during both active and dormant periods of Fan and Mortar. There is no evidence that Spiteful's nearly continuous discharge is variable, although many gazers agree that the volume is less now than in the late 1970's.

A possible hypothesis is discussed next. Let us assume that every dormancy starts during a period in which the Firehole River's water level rises. In most years this would be in March-April, in other years, notably after drought years, a water rise could first occur in January or February. This initial rise of the Firehole River causes its water to flow over the Beach Springs. Can this assumption help us devise a long-cycle theory?

It is reasonable to assume that following several years of frequent activity the fissures and cavities of their plumbing systems would be both wider (from internal erosion) and clean of surface debris. Major eruptions are very violent; it is common to see small rocks, many with a beautiful white luster created only beneath the surface, hurled out with tremendous force. Eventually the near-surface fissures are wider than at any time previously. It may be easier for new debris to percolate downward rapidly. This could occur when the Firehole rises in the spring.

A full cycle is described: after a period of dormancy some of Fan's fissures are choked by debris and the ingress of cooling water. The minor cycles are short and relatively insubstantial. These shorter cycles do not last long enough to allow for the build-up of energy sufficient to initiate a major eruption within the clogged plumbing system.

After sufficient time, and triggered by a drop in the Firehole River, the minor cycles can finally last long enough, to the point where a major eruption takes place. The first major eruption following a dormancy begins the process of breakdown in the overlying debris. During some years, such as 1971 and 1974, this breakdown is immediate. In other years, such as 1982 or 1986, the breakdown takes longer and the first eruptions in the cycle are irregular and unpredictable. Eventually the activity reaches a point where major eruptions are relatively common. The removal of debris and internal erosion are at their highest levels.

It is only after many months of this type of activity that Fan is as close to internally clean as is possible. The fissures are wide open, ready to accept the incoming water and silt during the next rise of the Firehole. Thus, it is only after a period of great frequency and regularity that the Firehole can affect Fan. It is at this time that the fissures are open enough to allow penetration of water to the points within Fan that cause dormancy.

If the Beach Springs are accepted as critical in the long cycle of Fan and Mortar, one logical conclusion of this argument is readily apparent: if the Beach Springs were to remain uncovered by the Firehole, the dormancy would not start. The only natural way for this conclusion to be tested is for a severe drought year to coincide with the anticipated start of dormancy. If the Firehole never rose enough to cover the Beach Springs, would Fan and Mortar stay active? Even the most ardent geyser fan may not wish to see such a natural experiment take place. The results of the drought of 1988 are still etched in our memories.

The principal difficulty I have with this entire scenario is the assumption of a direct physical link between the Beach Springs and Fan. The Beach Springs are not gaping holes, but little more than bubbling seeps. They do not erupt during an eruption of Fan. Are such insignificant features the possible source of sufficient inflow to result in the dormancy of Fan and Mortar?

In addition, the period of Fan and Mortar's greatest activity usually lasts for two summers. During the intervening winter and spring, the Firehole rises and the Beach Springs are submerged, but dormancy does not occur. As noted earlier, Fan and Mortar are less regular and more infrequent in May and June than later in the season, but irregularity and dormancy are two distinctly different conditions.

One other possibility is that the rift in the sinter that contain both Fan and Spiteful may continue under the Firehole, and that the river water enters Fan's system from there. There is some evidence to support this; reports from the 1930's told of a steam vent on the other side of the river erupting in concert with Fan. The difficulty with this idea is that the ingress of water into Fan's system would not occur only during flood stage, but would continue throughout the year. Thus, fluctuations in the Firehole's water level would be irrelevant and could not affect Fan in the manner observed. It would be of great interest to inspect the riverbed in this area for signs of any egress points of hot water. It might be possible that Fan Geyser not only has a very rare upside-down geyser, but also an underwater geyser as well.

Another similar hypothesis is based on the local water table. Fan Geyser is located only a few feet above the average level of the river. Since Fan and Mortar are situated in a narrow river valley, the local water table most likely rises close to the surface in this area, close enough that Fan's plumbing system, and most likely Mortar's as well, intersects the local water table very close to the surface. It is possible that seasonal changes in the level and temperature of the local water table could have an effect on the eruption potential of these geysers.

Again, the principal difficulty with this idea is that the cyclical changes in the water table occur annually while the length of the active period in Fan and Mortar's long-term cycle is at least double that in length.

There is no one hypothesis that adequately explains the long-term cyclical behavior patterns of Fan and Mortar. Suggested ideas, including those presented here, are not completely satisfactory.

RECENT EROSION IN THE COMPLEX AS AN INDICATOR OF FUTURE ACTIVITY

Since 1978 the natural erosion of the sinter in the Fan and Mortar complex has been considerably greater than in any similar period since the Park's creation. What used to be a massive cone surrounding the vent of Upper Mortar now appears to be little more than a poorly stacked rockpile. The area at the base of Mortar nearest the asphalt walkway is crumbling away from both above and below. The Bottom Vent is a result of the internal erosion.

The Main Vent of Fan used to be buttressed by a large, square mass of sinter. It is now almost completely gone (Figure 5). Most dramatically, the East Vent of Fan used to be invisible from the trail. In the past few years erosion has been so extensive that a deep, dark cavern is now visible, hence the use of the nickname "The Grand Canyon". Such a

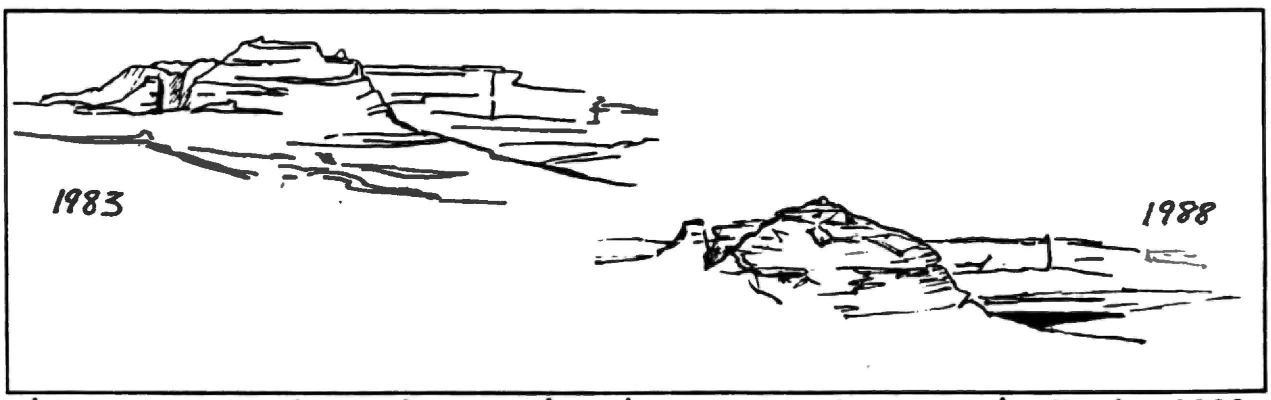


Figure 5. Surface changes in sinter near Fan's Main Vent, 1983-1988.

nickname a few years ago would have made no sense.

Based on this evidence, Fan and Mortar's activity during the last decade is unprecedented. Park Service records validate this fact: For most of the past 116 years, Fan and Mortar were considered dormant.

It is generally accepted that the increase in Fan and Mortar's activity took place in 1969. Between that date and 1978 they exhibited the start of the long-term cyclical activity mentioned earlier, but the total number of eruptions was smaller than in recent active years. This first decade of activity must have contributed somewhat to the erosion of the area, but the changes have dramatically accelerated in the past few years.

Assuming the rate of erosion continues unabated, will the nature of the eruptions change as well?

Externally, the principal erosion in Fan is that which surrounds the Main and East Vents. Based on recent erosion patterns, the water column of the East Vent will get more vertical as the erosion of the arch of sinter increases; the water will eventually land farther from the vent and contribute more to the fan shape of the entire display. The Main Vent's water column(s) will no doubt widen slightly, allowing for an even more spectacular display, but perhaps not hitting as great a height.

The other vents of Fan have been little affected by erosion and there should be no expected changes in their eruption behavior.

The case for Mortar is different. The entire cone seems to be eroding at a rapid rate. The nozzling effect of the Upper vent has been reduced since 1980; if this continues there will be a lessening of the height but widening of the column. The Lower vent will be less affected from outside erosion, but internal erosion is another matter.

As mentioned earlier, the east side of the cone is crumbling rapidly; since 1983, the Bottom Vents have formed in this area. It was not surprising when these small pools eventually began to take part in the major eruptions in 1988. The results could be very interesting. The rate of erosion will surely accelerate under such circumstances, significantly altering the appearance of Mortar's eruptions. During the next active cycle, observers should carefully note the changes in appearance to the display. It is possible that within the next decade the sight of Mortar having only two water columns will be only a memory.

There is one other form of erosion that must be mentioned. This is the disintegration of the asphalt trail itself. Every year a large amount of black, sticky asphalt breaks off the side of the trail and slowly edges its way downhill towards the Fan and Mortar complex. Cleanup of this is almost impossible owing to the numerical quantity of small particles. Of principal concern is the effect of this material when it eventually makes its way into a few of the vents. Those vents most susceptible to such artificial ingress of material are Spiteful, Fan's East Vent, and Lower Mortar. Spiteful is of particular concern. There is an impressive amount of black granules surrounding its satellite vents.

Even if this material will not appreciably affect the behavior of the geysers, it is very unsightly. Since the ground on which the asphalt sits is quite warm, keeping the asphalt soft and pliable, it is likely that this erosion will continue unabated.

A wide wooden boardwalk would be much preferred to the current crumbling trail. It should extend from the north end of the Firehole Bridge to the pine trees to the south of Morning Glory Pool. The side asphalt spur to the outhouse could stay; since the terrain at this spot is flat any erosion of this asphalt would essentially stay in place. Those visitors who ride their bikes could easily park their vehicles on the wide Firehole Bridge and walk the last hundred yards to Morning Glory Pool.

In addition to this laudable end, the removal of the asphalt trail and old roadbed could allow the Tile Vent of Fan to erupt from its original source. The results will benefit both the Park Service and the geysers themselves.

ACKNOWLEDGMENTS: Thanks go to the late Jamie Espy, who was the first to show me that geyser gazing could be more than simply running from eruption to eruption; to Heinrich Koenig, whose methodology and meticulous data collection were of tremendous help; to Sam Martinez, whose records are the only available source of information from the early 1970's on the geysers' activity; to the newer members of the geyser gazing world, including Mike Keller, Jens Day, and Lynn Stephens, whose enthusiasm and record keeping in 1987 and 1988 kept the rest of us abreast of current trends; to Suzanne Strasser, whose assistance and companionship made this report possible; to the National Park Service staff, notably R. Hutchinson, whose support and encouragement through the years has been of enormous value.

REFERENCES:

Bryan, T. S., personal communication. 1988.

Bryan, T. S., The Geysers of Yellowstone. Colorado Associated University Press. 225 pages. 1979.

Koenig, H., The Activity of Link Geyser during 1983. Unpublished paper. 1984.

Koenig, H., personal communication. 1984, 1989.

Martinez, S., Reports to the Sub-District Naturalist, 1973-1976. Unpublished. 1980.

Marler, G., Inventory of Thermal Features of the Firehole River Geyser Basins and Other Selected Areas of Yellowstone National Park. NTIS Publication #PB-221 289. 1973.

Roe, S., personal communication. 1989.

Scharff, R., Yellowstone and Grand Teton National Parks. David McKay Company. 1967.

Strasser, P., and S. Strasser, Eruption Characteristics of Fan and Mortar Geysers, 1979-1982. Unpublished. 1982.

Strasser, P., S. Strasser, and H. Koenig, Further Studies of Fan and Mortar Geysers, 1983-1984. Unpublished. 1985.

Unpublished papers are on file at the Yellowstone Library, Mammoth Hot Springs, WY or at the Old Faithful Visitor Center.

Fan and Mortar Geysers in 1988
Upper Geyser Basin, Yellowstone National Park, Wyoming

Jens Day

Abstract

During 1988 the author witnessed nine eruptions of Fan and Mortar and the later half of another. In addition, a great deal of time was spent noting the geysers' behavior between other eruptions, sometimes missing the actual play by only a few minutes. This paper will cover changes or phenomenon not commonly noted or discussed.

Introduction

This report will be broken into four parts:

I. Changes noted during 1988

II. The Characteristics of "energy surges"

III. Indications of an impending eruption

IV. Conclusions

The various eruptive vents of Fan and Mortar Geysers are referred to throughout this paper according to the following informal names:

River Vent: A series of vents along a nearly horizontal fracture on the steep side of Fan's geyserite mound nearest the Firehole River;

Top or High Vent: the small vent on top of Fan's mound nearest the river and the River Vent;

Gold Vent: the vent next in line along the fracture on top of Fan's mound, northeast of the Top Vent;

Angle Vent: the next vent along the fracture line, to the northeast of Gold Vent, named because it tends to jet water at a sharp northeastward angle;

Fan Main Vent: the source of Fan's strongest jet of water during eruptions, this vent is less than obvious at other times;

North or Grand Canyon Vent: the vent furthest northeast along the fracture and nearest to Spiteful Geyser, this is sometimes called the Grand Canyon Vent because of its similarity in appearance. Although this is the largest of Fan's openings, it plays a relatively minor role during eruptions and no role during normal hot periods. It receives some of the water runoff from Spiteful Geyser;

Upper Mortar: the large cone vent adjacent to the Firehole River;

Lower Mortar: the more open, eroded vent on the opposite side of the cone from the river and nearer to the trail;

Frying Pan: the several vents in the low area between Fan and Mortar, specifically the one vent which sizzles, sputters, and throws small droplets of water into the air when active.

I. Changes Noted During 1988

During 1988, Fan and Mortar exhibited a number of changes from what had been noted in previous years. The following are some of the more important of these changes which I noted during my studies.

Fan Dominated vs. Mortar Dominated Eruptions: I have been told that during other years most eruptions were dominated by Fan; only on rare occasions was an eruption dominated by Mortar. On these occasions, Mortar would usually start playing 1 to 2 minutes before Fan, in what is called a "Mortar induced eruption."

For some reason, most 1988 eruptions were Mortar dominated although only one was known to be Mortar induced. In the August 15 eruption, observed by Lynn Stephens, Mortar began well before Fan started.

The only Fan dominated eruption I saw was on July 20. At the peak of the eruption, Fan was throwing water several feet beyond the "Norris Pools." During the other eruptions, Fan reached only a few feet past the trail. In both situations, the lateral throw of these eruptions was as much as 100 feet less than some that have been observed in earlier years.

Though Mortar was very strong during most eruptions, some were clearly stronger than others. In one eruption, the height of Upper Mortar approached 100 feet. In addition, there were a couple of eruptions where neither Fan nor Mortar seemed to dominate.

Shorter Hot Periods: Other geyser gazers told me that during 1987 the intervals, (from start to start) between Fan and Mortar's hot periods would typically reach 90 to 120 minutes in length before an eruption. During 1988 these intervals were considerably reduced. At the beginning of the summer the average interval before an eruption was 80 to 90 minutes; by the end of the season the average was down to only 60 minutes, and some interval of less than 40 minutes occurred.

Starting vent: 1988 was unusual in that almost any vent could begin the eruption. As in past years, most eruptions started by nearly simultaneous bursting and jetting by Lower Mortar and Fan's Main Vent. However, while in most previous years of simmilar sctivity it was Lower Mortar begining slightly before Fan's Main Vent, this year Fan sometimes started a fraction of a second ahead of Mortar or there was no perceptible interval between the them.

Several of the 1988 eruptions were called "Grand Canyon starts." In these the North Vent would begin playing several seconds before any others. In one of these, Spiteful Geyser was inundated by a flood of water while the other Fan vents were barely jetting. This type of start seems to be a new mode. It usually occurred after a late pause in hot period jetting and when some geyser gazers had concluded that no eruption was about to occur.

At least one eruption was observed to start with a 30 foot jet of water from High Vent. Except for the one Mortar induced eruption, all the various other vents of Fan and Mortar would begin to erupt within a few seconds of the initial start.

Eruption Intervals: Fan and Mortar's spring disturbance (presumed by some to be caused by high water levels in the Firehole River) was a little late in 1988, occurring from mid-May though mid-June. During this time there were just two eruptions.

From mid-June to mid-July, the eruptions were fairly regular. Herbert Simmons [personal communication] noted that the intervals differed according to a 16 hour pattern. Eruptions occurred on intervals of about 74, 90, 106, or 122 hours. No eruptions occurred on intervals substantially different from these, and the standard deviation of the six intervals between June 20 and July 10 was only 37 minutes.

Beginning in mid-July and continuing through September, however, the geysers were erupting at erratic intervals, and the earlier pattern had entirely disappeared. Then, however, during October and early November the intervals were again fairly regular. A summary of intervals is included in Table I.

Earthquakes: There was a minor earthquake in mid-July, just before the erratic intervals began. Another occurred in the latter part of August, just prior to the period of greatest irregularity. Yet another small earthquake, this one felt in the Old Faithful area on October 5, occurred at the start of a 200+ hour interval, the longest of the year.

Whether the timing of these earthquakes was coincidental or not cannot be demonstrarted. However, if the changes in activity are not coincidental, it appears that the activity of Fan and Mortar can be dramatically affected by even small and distant tremors.

II. The Characteristics of "Energy Surges"

Perhaps one of the most interesting patterns learned about Fan and Mortar in 1988 was what I call "energy surges." These are patterns of activity that repeat every 16 to 24 hours, and are distinct from hot period cycles.

If Fan and Mortar are erupting every 3 to 4 days, then the energy surges occur about every 16 hours. The time between surges increases as the interval increases, so that this period between surges reaches around 20 hours when intervals between eruptions are 5 to 6 days, and is over 24 hours when the intervals are a week or more long.

Each energy surge lasts about 5 hours. Progressing toward an eruption, each subsequent surge is usually stronger than the preceding one. Following are some of the characteristics of these energy surges.

Length of Hot Periods: The durations and intervals of the hot periods increase in length when an energy surge begins. For example, hot periods that have been occurring every 45 minutes suddenly increase their intervals to 60 minutes. After the energy surge, the hot period intervals may or may not decrease back to their pre-energy surge length.

High water levels: During an energy surge, the water level in the various vents will rise to 4 or 5 inches higher than normal. This results in standing water readily visible in Lower Mortar, and may also allow some otherwise rare visible jetting to occur inside the Main Vent of Fan. Between the energy surges, isolated hot periods may have similar high water levels, but during a surge this will be true in each of several consecutive hot periods.

Upper Mortar Surging: One of the striking features of these energy surges is a bursting and jetting of water from Upper Mortar. This occurs at the end of a hot period. With considerable rumbling and thrashing, the Upper Mortar vent spits water into the air. Most of these events do little more than dampen the cone, but some may discharge enough water to produce some runoff. The Upper Mortar surging lasts about 20 seconds followed by a 30 second pause. The entire episode lasts about 10 minutes.

The height of the water may only reach to the top of the cone and barely be visible, but I have seen it reach up to 8 feet high with small droplets going much higher. John Muller [Personal Communication] reports one occasion of surging repeatedly reaching 30 feet high.

At the beginning of hot periods, Upper Mortar frequently boils in a similar routine, but the water is much farther down in the cone and the action is much less vigorous. At the end of many hot periods between the energy surges there is a similar but subdued action, always substantially reduced from that during an energy surge.

The energy surge hot periods that end with Upper Mortar surging almost always come in sets of three, each separated by a normal or shortened hot period interval. Occasionally, there will be a fourth such hot period. Listed below in Table 1 is a typical example showing the hot period intervals during an energy surge:

Table 1

45 min	non-energy surge
44 min	non-energy surge
62 min	energy surge, Upper Mortar surging to 3 ft.
30-60 min	energy surge, no Upper Mortar
65 min	energy surge, Upper Mortar surging to rim
30-60 min	energy surge, no Upper Mortar
63 min	energy surge, Upper Mortar surging to 1 ft.
59 min	end of energy surge
61 min	non-energy surge

During 1988, Fan and Mortar would typically begin to erupt when an energy surge was due to start; however, some eruptions came during or near the end of an energy surge. Two eruptions also began midway between energy surges.

Conclusion: The energy surges seem to be some sort of eruptive activity into the plumbing system. Resulting water levels stand higher, and more water and energy are discharged. Perhaps they are similar to the minor eruptions seen in many geysers preceding a major eruption.

Energy surges are of only limited use in forecasting an eruption, however. Data collection can be difficult because of the long time spans and many hours which must be expended to collect the necessary data.

When the data does exit, the energy surges can be useful for showing trends. The October 14 eruption occurred after an interval of over 200 hours. For the first five days of that interval the energy surges repeated on relatively long cycles. When I noted that they had dropped to 16 hours, I correctly surmised that the next eruption would happen fairly soon. In fact, it came after an interval of about 75 hours.

III. Indications of an Impending Eruption

Pauses: Most geyser gazers who spend time at Fan and Mortar are familiar with the pre-eruption pause. The pause is when all Fan vents, including the River Vent, cease their jetting and overflowing for approximately 8 to 15 minutes about halfway through the hot period duration.

The pause is not a perfect indicator. Whereas in some years it has been a nearly invariable sign that an eruption would occur at the end of that same hot period, (after a re-start), it can fail. In 1988, there would often be as many as 3 or 4 hot periods with a pause during the interval between eruptions. Although about 50% of the 1988 eruptions followed pauses, most pauses did not result in an eruption.

Another aspect of the pause was seen during 1988, apparently for the first time. All involved "Grand Canyon" starts. In these, the hot period activity proceeded in an apparently normal fashion. Frying Pan began its sizzling and surging could be renewed in Lower Mortar as the jetting by Fan's vents declined to little or nothing. Then, after pausing for as long a 4 minutes, Fan very abruptly renewed its jetting on a much stronger scale. The eruption was triggered by massive bursting from the Grand Canyon Vent only seconds later. On one occasion the time from the renewed jetting to full eruption was less than 15 seconds.

Late Gold Vent Start: Most observers mark the beginning of a hot period as the time when River Vent begins to overflow and jet water into the river. Gold vent typically begins jetting 1 to 10 minutes later. However, during the last 24 hours before an eruption Gold will often take as long as 10 to 14 minutes to begin venting water. During the final hot period before an eruption, the delay before Gold starts can be as long as 16 to 22 minutes. During 1988, only twice did Gold delay for more than 14 minutes (14½ and 16¼) when not followed by an eruption.

Frying Pan start before Angle Vent: During a hot period, Angle usually starts its activity 5 to 10 minutes after Gold has started. On infrequent occasions, Angle will start before Gold, but it will usually quit and restart again at the more usual time. Frying Pan usually starts its hissing and sputtering approximately 4 minutes after the start of Angle. Frying Pan generally takes several minutes of many starts and stops to attain its full, vigorous activity.

Preceding about half of the eruptions, Frying Pan started several minutes before Angle during the final hot period. These Frying Pan starts were rapid and very strong. The eruptions of Fan and Mortar began 5 to 12 minutes later. During non-eruptive hot periods it is rare to have Frying Pan start before Angle. Then it happens just a few seconds before Angle and with a normal, weak and slow start.

Extended hot period durations: Fan and Mortar's hot periods usually follow a set routine and time sequence. If a hot period extends its duration beyond the normal, and more specifically if Fan renews its jetting after Upper Mortar has begun to surge, then an eruption is likely.

An example of this is the activity of September 22, 1988. The hot periods were lasting about 30 minutes on intervals of about 60 minutes. The hot period which began at 16:42 progressed through the usual sequence of events in the course of half an hour. Upper Mortar was surging 2 to 4 feet above the top of the cone, and the hot period appeared to be about over. However, instead of quitting, Fan's vents renewed their activity for an additional 16 minutes, continuing for 8 minutes beyond when Upper Mortar quit surging.

It is possible that this event was a "near miss" that might well have resulted in a "Grand Canyon" start. Instead, the geysers waited for the next hot period, which did not begin until 18:14, an interval of 92 minutes. The eruption of Fan and Mortar began at 19:14.

High Water Levels: Earlier, I mentioned that during energy surges the water level rises higher than normal just before a hot period begins. Frequently, just prior to the final hot period, the water rises even higher by several inches. Unfortunately, this is difficult to judge because of the pulsating water surface in Lower Mortar. It is easier to see this rise in Fan's Main Vent, but this cannot be viewed from the trail and therefore is out of reach of most observers.

Rumbling: On one occasion, I noted a deep rumbling sound gradually building in intensity about 15 minutes before an eruption. I presume this was caused by an increased boiling at depth in the various vents. It was roughly halfway through this rumbling that Fan's vents began their strong pre-eruptive buildup of jetting activity.

Lower Mortar continuous boiling: Between hot periods, Lower Mortar usually boils for about 20 seconds, then quits for another 20 seconds, then boils again, and so on. Prior to the final hot period, Lower Mortar will sometimes boil almost continuously. On at least one occasion I noticed this to be very striking. However, between other hot periods, Lower Mortar will occasionally boil continuously for several minutes only to revert to its normal behavior. Hence, this is a difficult and unreliable indicator.

Summary

Fan and Mortar exhibited several striking changes during 1988. Of particular note were the shorter hot period intervals before the eruption, the Mortar dominated activity, and the Grand Canyon starts.

Energy surges recurring every 16 to 24 hours can be helpful in predicting eruptions, and future study of them may reveal some interesting characteristics about the geysers. This, however, is a project that requires a commitment to spending long spans of mostly boring and unproductive time.

Other effects, such as pauses in hot period action, extended hot period durations, high water levels, and continuous boiling and rumbling noises were frequently noted to indicate an approaching eruption. The one extended hot period that was observed, gave a two hour warning before the eruption that began during the next hot period. When Frying Pan started before Angle, this was often a 5 to 10 minute warning. Gold Vent taking about 20 minutes to begin activity after the start of River Vent was frequently observed a half-hour before eruptions.

In spite of the considerable time that I spent at Fan and Mortar during 1988, some eruptions gave very little warning. Some eruptions were missed because the hot period action appeared to be "not right." Late in the year, although I was carefully studying the hot periods, I did not realize that an eruption was about to occur until only one minute before it began.

Whether some of these changes and effects will continue to be manifested in the future remains to be seen. Since the current cycle of Fan and Mortar's major eruptive activity appears to have ended during January 1989, it may be some time before this can be further investigated.

Notes on Slide Geyser

Cascade Group, Upper Geyser Basin, Yellowstone National Park, Wyoming

Lynn Stephens

Introduction

Slide Geyser is located in the Cascade Group of the Upper Geyser Basin. It is not included in The Inventory of Thermal Features [Marler, 1973], but it is referenced in The Geysers of Yellowstone [Bryan, 1986].

When observations were taken from the west bank of the Firehole river, looking east towards Slide, the start and stop times were determined based on when water became visible. When standing on the east side of the river on the hill above Slide, the start of the eruption is evidenced by splashing that does not quite reach the lip of the crater, and therefore is not visible from the west side of the river.

Observed durations were about 45 seconds to one minute, and intervals were about 15 minutes long. The observed durations and intervals are consistent with Slide's historical pattern of activity as reported by Bryan.

Data on observed eruptions is presented in Table 1.

Description of Slide Geyser

The crater of Slide Geyser is located on the hillside below Atomizer. The crater is somewhat L-shaped, with the long axis directed horizontally on the hillside. The short axis is at the south end of the long axis, directed vertically from the end of that axis toward the river. There are two small holes on the hillside above the main axis of the crater. The water from an eruption appears to be forced from the crater, and slides down the "slide" to the river. There is no algae on the slide. About one-third of the way down on the north side and 5/8 of the was down on the south side of the slide, brown algae appears on the extreme edges of the slide. The lower quarter of the slide has a hoof-shaped pattern. The south portion of the hoof has orange colored algae on it.

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

Approximately 20 feet to the north of the base of the slide, at the very edge of the river, is a vent with red, orange, and brown algae that constantly hisses and periodically ejects water.

References

Bryan, T. Scott, 1986. *The Geysers of Yellowstone*, revised edition. Boulder: Colorado Associated University Press.

Marler, George D., 1973. *Inventory of Thermal Features of the Firehole River Geyser Basins and other selected areas of Yellowstone National Park.* Springfield: NTIS Publication No. PB-221289.

Table 1
Observations of Slide Geyser

Start	Stop	Duration	Interval
September 3, 1988. Recorded from west side.			
0940.30	0941.18	48s	
0955.20	0956.02	42s	14m40s
1010.37	1011.18	41s	15m17s
1025.40	1026.21	41s	15m03s
1256.12	1256.55	43s	
1310.53	1311.42	49s	14m41s
1326.05	1326.55	50s	15m12s
1341.15	1342.02	47s	15m10s
September 4, 1988. Recorded from east side.			
1813.54	1814.59	66s	
1828.52	1829.55	63s	14m58s
September 5, 1988. Recorded from west side.			
1854.50	1855.55	65s	
1909.48	1910.45	57s	14m58s
1924.28	1925.24	56s	14m40s
September 6, 1988. Recorded from east side.			
1039.27	1040.30	63s	
1054.00	1055.05	65s	14m27s

Report on Fantail Geyser and Ouzel Geyser

Marie Wolf

Abstract: This report describes new activity in 1986 in the Cascade Group of the Upper Geyser Basin, Yellowstone National Park, Wyo. An overview of previous ephemeral activity is discussed, then a detailed description of the activity and evolution of "Fantail" Geyser and "Ouzel" Geyser is presented. Particular attention is given to speculation about the origins of such ephemeral activity in this area.

Introduction

The Cascade Group — which includes all the springs from Artemisia Geyser to Cauliflower Geyser — has been known to produce evanescent geyser activity about every ten to twelve years. Whole tracts of ground heat up suddenly, killing even full-grown trees, spawning numerous temporary geysers. Many of these geysers last only a single summer season. Among such ephemeral features are Hillside Geyser, Baby Daisy Geyser and Biscuit Basin Geyser. Hillside activated in 1948 for no apparent reason, and the latter two springs activated in 1952, four years later. Baby Daisy and Biscuit Basin Geyser began eruptive activity in response to a general heating of the ground around them. Both lasted about a year. Baby Daisy reactivated briefly after the Hebgen Lake earthquake of 1959 — but Biscuit Basin Geyser did not respond at all [Marler 1973]. In early 1962, Seismic Geyser was born. In the early 1970's at least two unnamed features south of Cauliflower were known to be active.

On the west bank of the Firehole River, numerous springs became geysers in response to the Hebgen Lake earthquake. Almost nothing has been recorded about this area. The USGS maps of the area, [USGS 1966] and [Muffler, et. al. 1982], mark three features as geysers, but no documentation of activity before 1983 can be found.

When Seismic Geyser was born, George Marler speculated that many, if not most, geysers originated by earthquake-induced explosions [Marler & White 1975].But geysers can also originate from the evolution of calm pools over a long period of time [Marler 1956]. Castle Geyser is a prime example of this type of formation: thick horizontal layers form the base of Castle's immense platform, indicating a very long period of quiet flowing before the geyser activity began. Old Faithful also appears to have begun as a flowing spring; in this case, the pool became dormant to the point where trees grew on the mound [Marler 1974]. It could be argued that the rejuvenation was fulminous—but its is more likely that a fracture formed first, maybe as the result of a tremor, and was abraded by splashing water into the elongated vent seen today.

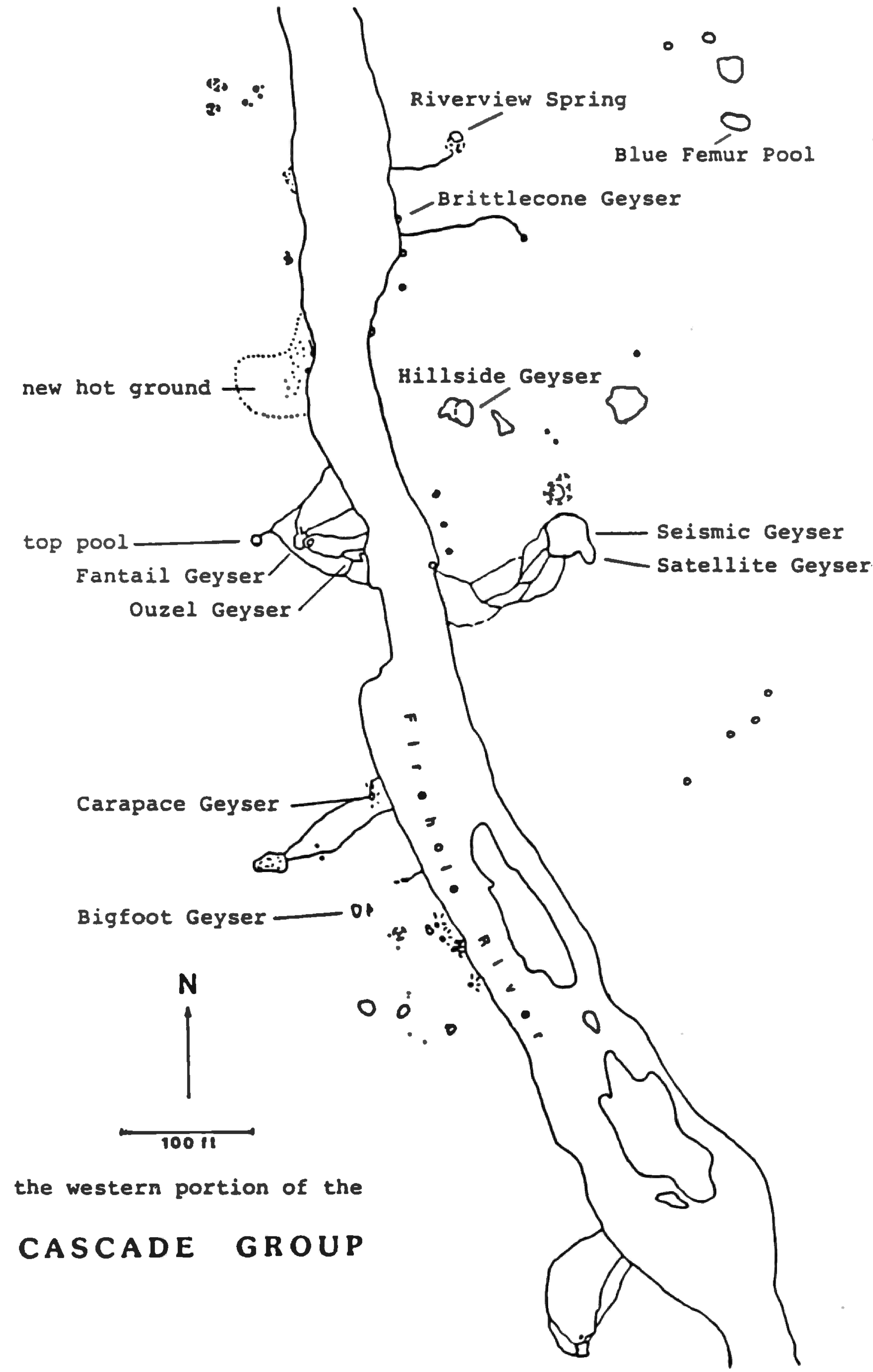
In the western Cascade Group, however, there is considerable evidence of explosions that were probably initiated by the Hebgen Lake earthquake: hot, surging springs that are filled with broken chunks of sinter only recently cemented. Even Carapace Geyser—on an obviously mature mound— shows signs of recent upheaval.

The entire Cascade Group is mercurial and volatile. The springs are sensitive to tremors, and patches of hot ground come and go approximately every ten years. As of now (1989) there is a tract of hot ground developing just northwest of Fantail. This hot ground is destroying everything around it—possibly including Fantail and Ouzel.

Just prior to Fantail's discovery, the Park had been jiggled repeatedly by swarms of small tremors; this activity had been occurring periodically for several months. Since the fracture-riddled Cascade Group seems sensitive to seismic disturbances, it is not surprising that there was a response to this persistent rattling.

While considerable time and effort went into the gathering of data which is presented in this report, additional important information was gathered by several others, in particular: Ed Herel, Bob Hoffman and Mary Ann Moss. In addition, Rocco Paperiello accompanied me on numerous occasions in order to catch middle of the night activity.

Since this report was written, Fantail has had occasional periods of activity. By the placement of markers, it was ascertained that activity came in spurts: over a period of about three weeks, the markers were consistently found to be missing; then a month or more would go by with no activity. An eruption in August 1988 was witnessed: it was an aborted type, about 50 feet high and about 3-1/2 minutes long. There were two known plays in January 1989. Through 1987 and 1988 Ouzel was brequently seen erupting to 4-5 feet.


Riverview Spring
Blue Femur Pool
Brittlecone Geyser
Hillside Geyser
new hot ground
top pool
Fantail Geyser
Ouzel Geyser
Seismic Geyser
Satellite Geyser
Firehole River
Carapace Geyser
Bigfoot Geyser
N
100 ft
the western portion of the
CASCADE GROUP

General Overview of the Western Cascade Group

This area is a mystery, despite being located in the most heavily-visited geyser basin in the Park. Eleven or more temporary geysers were reported here immediately after the Hebgen Lake earthquake [Marler 1964], [Marler 1973].Three geysers are marked on the USGS maps, but only one published reference to them can be found [Bryan 1986]. Many of the springs here show signs of recent birth, or rebirth, by quite explosive means, and are hot and violently surging.

The structure of the western Cascade Group, in general, is similar to that of the River Group of the Lower Geyser Basin: springs of successive ages lying beside one another, and much evidence of ancient, possibly extinct, vents being reactivated by a recent disturbance. More evidence of violence exists in the Cascade Group, however, for the western part of the group shows wide-spread evidence of explosions—in addition to the formation of Seismic Geyser on the Firehole River's east bank.

As with the River Group, springs of the western Cascade Group are oriented southeast to northwest along a fracture system that is cross-hatched by shorter, shallower cracks running generally east to west. Where the cross-hatches intersect the main fracture is where the deepest, hottest springs lie. This arrangement is, on the west side of the river, very compact and restricted, appearing to consist of one or two main northwest-southeast fractures and a few shorter parallel segments on either side. All of the springs lie in a narrow band that extends from right at the river's edge to no more than 40 feet up the bank to the west. The activity in this narrow strip is intense: only two pools and a clutch of very small vents are cool enough to harbor algae.

As mentioned earlier, the hot spouters of the western Cascade Group are probably lying at the junctures of east-west cross-hatches and the main northwest-southeast fracture. Extensions of the cracks to either side of these intersections are sometimes marked by collapse holes, steaming vents, and shallow pools that, while not boiling, are yet too hot for algae growth. These lesser features are a marked contrast to the churning, rubble-littered superheated spouters. Some of the collapse features come in small clusters; but most of the pools and steaming vents lie right beside the spouters so they could easily connect with radiating fractures. The collapse vents come at frequent enough intervals in places that the course of cracks beneath them can be inferred.

Any springs seeming to mark short north-south fissures running parallel to the main fracture are small, shallow and cool; and there are few of them. There are only two major springs lying off the main sequence. One is the "top pool" of the Fantail complex, which will be discussed in the following section; this spouter appears to lie at the upper end of an east-west cross-hatch—with the violent lower spouter, Ouzel, marking the main north-south fracture.

In spite of the incredible heat-flow of the area, discharge is quite low. It will be mentioned in the discussion of the Fantail group that the flow from these pools is exceptional. And it is true that most of the overflowing springs in this area are the older, well-established features, and these show a considerable diminution of discharge over that of former years. The levels of most of the vigorous spouters are well below overflow, some by as much as 18 inches; and old sinter sheets and dry runoff extend from some of these, indicating that overflowing springs had once existed in their places.

At one time, this whole area must have been dying out, with water, if not heat, dropping out from under the surface vents and leaving them dry and at the mercy of eroding elements. Recent seismic activity then jarred old, debris-clogged fractures and reopened choked spring plumbing. Since there wasn't much water available, the sudden increase in heat vaporized most of the liquid that was there, causing numerous explosions. The blasts cleared plugged fractures and opened new passages, and allowed a new influx of water; thus, the new springs violently supplanted the old.

The confined intensity of this area is reminiscent of the Daisy Group, only not so intensely linear. The main fracture here appears to meander quite a bit, and may actually be split in one place. The region of activity is nevertheless quite confined. This fact may account for much of the violence seen here, in the present activity, and in the ample evidence of widespread explosive altering of many of the springs in the not-so-distant past. It is unfortunate that this area was not given more attention after the Hebgen Lake earthquake.

Development of the Hot Ground North of Fantail Geyser

On the western side of the Firehole River an ancient sinter sheet covers the entire bank; in places it is nearly obliterated. Where the small springs lie to the north, this lichen, moss and grass covered sinter is exposed. Farther south lie patches of newer sinter, most of these old and weathered, but not ancient, and quite thick. This is where the hot, young-looking springs begin to appear, in the rubble of these old, weathered sinter patches.

The farthest north of these new springs has been adversely affected by the formation of an area of hot ground between it and the Fantail group. This area appears to have experienced heat-surges in the past: dead trees and rotting logs dot the ground, indicating increases in heat close enough to the surface to affect shallow-rooted lodgepoles. The ancient sinter sheeting forming this slope has been reduced to soil and clay from weathering and heat, until the only portion of it left intact protrudes from beneath a grass cover right on the riverbank. Yet the fractures giving life to the spouters to either side of this area certainly run beneath this zone as well.

All the springs to the north of this ground have shown some effect from the expanding heat. A spouter to the north dropped its temperature over ten degrees and its water level a couple of feet and ceased all spouting. A pool to the northwest used to be 100°F and full of algae, and it drained in late 1984, jumping in temperature to 198°F. Most of the small springs and river vents to the north jumped wildly in temperature from 1983. As the hot ground has expanded and intensified, all of these springs have once again dropped in temperature and dried up; the river vents can no longer even be found.

Even the Fantail complex, then unnamed spouters and pools, reacted with lower water levels and tiny sputs appearing on the north edge of Fantail's west pool, facing the hot ground. That the west pool of Fantail was also in 1985 displaying geyser tendencies may or may not be connected to the growth of the hot ground.

The development of this heated area began on a very small scale on August 9, 1984, when I thought someone's illegal campfire had been left smoldering. What I found on closer inspection was a simmering patch of ground partly under an old stump; the ground itself was black and pitchy and smelled strongly of burning vegetation. I also found several more patches of earth nearby in a similar condition.

This area now has expanded and extended north and east. It now encompasses an area of about 1900 square yards and is oblong in configuration. At the northwest extremity and the northeastern edge, small frying pan tracts have begun to form. This area will have to be watched, for it may be the birthing-ground of a new spring.

Overview of Fantail Complex

The pools of the Fantail group appear to be older the farther they lie from the river. The top, westernmost pool is obviously the oldest, with soft, decaying formations and a small tree stump lying beside its vent. Fantail's pools lie below this and are obviously mature, but not ancient; they used to possess weathered borders of scalloped sinter that indicated a steady water level over a long period of time. Ouzel was, it those days, a vigorous spouter; it appears to be an entirely new feature recently broken out in old, heat-leached formations.

The top pool was obviously dormant or extinct until quite recently, since the very old "biscuit" formations around it are decayed and only lightly recemented with fresh sinter. The stump now lying within the spring had no doubt been growing in or near the old crater for a considerable length of time, and was killed by a resurgence of activity. At one time, this spring was probably laying down the sinter base in which the younger springs below have formed.

Fantail appears to have been born in the sinter sheet formed by the top pool, possibly once having served as the older pool's successor. Originally, Fantail had a rounded sinter shoulder around six inches thick completely surrounding both pools; the inner edges of this shoulder tapered down to scalloped trim that overhung the water. Whatever disturbance reactivated the old pool and created Ouzel did not apparently alter Fantail: the original formations indicated a near-constant water level, right where it was through 1985, over most of its long life. Its steady overflow no doubt helped build up the thickness of sinter in which Ouzel was born.

Ouzel has three sections—upper, middle, and lower—placid, violent, and unsettled—with the lower, unsettled part lying barely above the water level of the river; it was submerged in May and June. Ouzel, like many spouters in this vigorous area, appears very young, and its present activity may have been a product of the Hebgen Lake earthquake. The much older deposits in which Ouzel has formed are very thick, but filled with holes and overhangs, which are indicative of heat-leaching that must have been going on for possibly decades before the active vents finally broke through.

This group of springs, more than nay others, displays parallel fracturing and cross-hatching. The top pool may lie on the end of an east-west cross-hatch, as it has only a single, relatively small, roundish vent. Fantail in those days gave away the presence of a north-south fissure by a string of small satellite vents lying north of the main pool. The vents of Ouzel are arrayed in parallel northwest-southeast strips of intense linearity; activity in the two of these nearest the river (violent middle and unsettled lower) appears at points along these strips, indicative of fairly open cracks supplying the energy.

Evidence points to wide-spread heat-leaching playing a major role in the formation of this group long before the present violent activity manifested itself. While Fantail's pools were reaching maturity, the thick formations of the old top pool, and the lower portion of its overflow shield, were being chewed away by damp heat radiating up through buried cracks.

This rather isolated system would appear to be riddled with very open fissures: the crack-vents of Ouzel running parallel to the river almost certainly mark the course of the main north-south fracture, or fracture system, on which most of the hot spouters on the west bank lie; it would connect with the now-defunct northern spouter on one side, and Carapace Geyser to the southeast. The fracturing is especially deep and prolific at Ouzel; this was very likely why heat-leaching of the sinter sheet that once covered them so extensive.

This sinter shield was probably built up by overflow from both the top pool, and later Fantail, over a period of many centuries; it is thus very thick, and probably concealed the lower fractures quite effectively. It could not stop the heat rising from those fractures. By the time of the disturbance that explosively brought water and increased heat to those fissures, the overlying formations were rotted to the consistency of sponge-cake. The horseshoe shaped alcove occupied by Ouzel had probably slumped and collapsed into a sizable depression riddled with steaming holes.

The leaching at the top pool could not have gone on as long as that near the river, or no decorative formations around the old crater could have survived. As it was, those formations were softened and partially destroyed, but not obliterated. This lesser destruction was also due to a lesser amount of fracturing *beneath* the old pool. The spring appears to lie on the upper end of a cross-hatch fissure, and does not connect with any north-south fractures; the heat thus rose from one spot, and one spot only, keeping the leaching effects of that heat quite restricted.

The heat that had sustained the top pool apparently shifted away, possibly to the pre-Fantail pools. The area cooled enough to support the growth of trees. Then the energy shifted back, and apparently in increased quantity.

Heat-leaching probably went on beneath the zone that now houses Ouzel for many decades before the present spring broke out. After a long period of this quiet leaching, a recent seismic event then allowed the fulminous entry of superheated water and steam into the weakened tracts, forming the current spring. Plumbing of the old top pool may have been torn open at the same time.

The amount of heat and water being poured from this triad of springs is phenomenal for this area. All of the pools are quite large and overflow copiously; since the geyser activity began, this discharge has vastly increased, as have the temperatures of the individual units. Fracturing in this narrow system is visibly open, and activity has been going on in one or the other of the pools for perhaps hundreds of years. A prediction in 1984 that this group would warrant study in the event of increased seismic activity has proved to be correct.

Discussion of the Individual Units Prior to 1985

Top (old) Pool—USGS #YM254b:

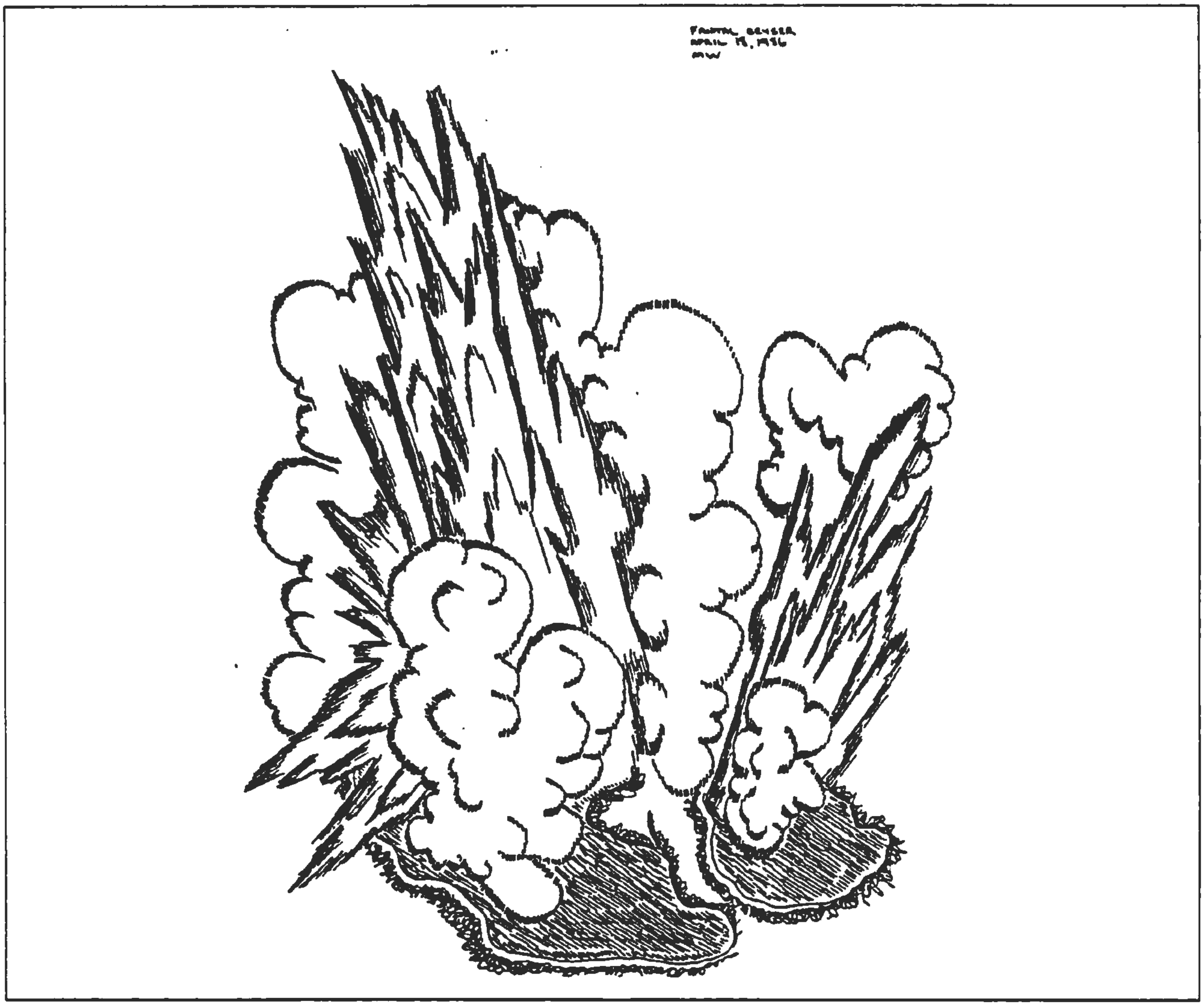
> "The vigorous perpetual spouter YM254b is located 14.3m [47 feet] west of Fantail and is eroded into the Quatenary sands and gravels as a circular pool approximately 2m [6-1/2 feet] in diameter and about 40cm [18 inches] deep. It has an old small sinter-lined runoff channel leading down to Fantail Geyser, but currently discharges less than two liters [1/2 gallon] per minute" [Hutchinson 1986]

It is old and beat up, but this spring is fascinating. Activity had at one time died down enough to allow a tree to grow right in the crater; the roots of this tree now fringe an active vent. The lightness of fresh deposition indicates recent origin for the present activity.

The pool is located in a low-sided amphitheater made up of soil and gravel. This horseshoe shape opens toward the river, and the series of springs—the two pools of Fantail and the depression Ouzel—progresses in stages downward from there. The top spring is oval, and its aged formations are some of the most interesting in the area. While not as ancient as the overgrown and age-darkened sinter sheet in the area, these rounded masses are weathered and decayed and obviously very old; they probably once marked the site of an extinct crater in the not-so-distant past. The clusters of "biscuits" are nevertheless thick, indicating that activity had persisted here for many decades; and said activity may have consisted of occasional eruptions of a low, splashing type that helped build the formations into rounded globules fist-sized and large, rather than into the smoothly-tapering shoulders formed by placid pools.

Present activity consists of splashing from a vent about a foot across. Until Fantail began erupting, the splashing was 3 to 8 inches high, and the temperature was 192°F; after April 1986, the temperature jumped to 204°F, and splashing got as high as 2 feet.

The condition of the formations seems to point to a more violent rebirth than present activity would indicate. The globular clumps of biscuits appear to have recently been torn away in big chunks. The remaining masses look as though they have been undermined, their lower works ripped out so that they now overhang the water; the somewhat awkward, top-heavy appearance of the overhanging sections should discourage the idea that they originally formed this way. The masses look fragile and crumbly, rather than brittle, and this would explain the absence of sharp-edge slabs, shelves or splinters around and in the pool, which one would expect to find after fulminous action.



Heat-leaching would explain the soft consistency of the sinter. Heat seeping up through these formations long before the springs's actual rebirth would have killed the tree and gradually leached the firmness from the heavy sinter. When the pool was rejuvenated—possibly as a result of the Hebgen Lake earthquake—the softened, now clay-like underlayers of these formations were torn away. Subsequent abrasion and collapse, as the crater refilled with water, would have dissolved, not re-cemented, the crumbly debris produced by the violence; in 1966 the water of this spring was still cloudy. All rough edges around the spring's vent and outer border would thus have been rapidly smoothed and rounded.

There has been some fresh deposition on the lower portions of these old, undermined formations—but it is like a layer of enamel paint over broken bread crust. What deposition has occurred looks fresh. But the upper portions of the biscuits, which do not touch water, look much like dried stale bread, making their descriptions *as* biscuits that much more appropriate.

"Fantail" Geyser—USGS #YM254a:

"Fantail Geyser has two oval sinter-lined pools which are separated by an irregular sinter arch-like partition which is only around 45cm [18 inches] wide at its narrowest point and approximately 110cm [3-1/2 feet] thick vertically. The main pool tapers to the east as a rough asymmetrical funnel from 4.67m by 2.84m [15'4" by 9'4"] at the top of its ornate sinter rim down to an estimated 50cm by 30cm [20 inch by 12 inch] vent at a point 2.60m [8-1/2 feet] below the surface. A 3.3m [10'10"] long lodgepole tree trunk is cemented into the sinter sheet west of the pool crater and juts over its margin by 0.66m [26 inches]. Fantail Geyser's smaller pool tapers also as an asymmetrical funnel, but towards the west through the partition arch. Its surface dimensions are 2.59m by 1.52m [8'6" by 5'1"]. Both pools have thin overhanging sinter rims which are a product of one or more long periods of stable water levels and quiescence. Later jetting below

> the shared vent suggests that there may be a subsurface cavity of unknown extent offset to the northwest [Hutchinson 1986].

Up until April 1986, Fantail's pools appeared to have remained placid and stable while instability and explosive change went on above and below them. It is believed that the top spring was active by itself for decades, maybe centuries, then died; the water receded and even the heat shifted away; vegetation took over. After a time the thermal energy gradually returned—but about 45 feet northeast of the old center of activity; the present two pools of Fantail then probably formed in a heat-leached section of the old pool's overflow deposits.

There is now evidence that the consistent pre-Fantail pools either shifted their overflow at some point in their history, or ceased discharge altogether for a time: erosion caused by the recent geyser activity has revealed beneath the top quarter-inch of sinter, on the main platform, a zone of dirt and sinter gravel overgrown with moss and stubby grass; this zone appears suddenly, as though the shift in flow had occurred abruptly. This may have happened as short a time ago as the Hebgen Lake earthquake in 1959; but the chances are better that the plant growth was inundated some time ago; the moss appears fresh in places— but the sinter covering it looks to be older and weathered. It poses a neat little puzzle.

In 1984 the new hot ground broke out. Fantail had broken out new spouters to the northwest of the present pool borders. It also began to display periodic boil-ups to 12 to 18 inches, making it an incipient geyser. Its temperature jumped from 196°F to 204°F in 1985.

In mid-1985 Scott Bryan reported that the water in Fantail was murky, and wash extended some distance around the crater, killing grass on the south edge. From this it was inferred that periodic boil-ups were occurring to as high as 10 feet; unfortunately the activity creating this tantalizing evidence was never witnessed. In January 1986, Jennifer Hutchinson reported seeing members of this group quiet and ringed with algae; whatever activity had caused the wash was no longer occurring.

Before the present activity broke out, Fantail's pools had to have remained stringently consistent in water level and behavior. The scalloped-edged shoulders surrounding both pools were at least 6 inches thick and smooth; the water level through 1985 lay right beneath the fringed border of these formations. Apparently the reactivation of the top pool and the birth of Ouzel had little effect on Fantail, other than perhaps changing the direction of overflow.

The large Hebgen Lake earthquake of 1959 and the Norris earthquake of 1975 appear to have not affected Fantail. The presence of hot ground indicated an increase in heat flow in the immediate area in 1984. This heat flow may have been further increased by the swarms of small tremors that hit the Park in late 1985 and early 1986. The surge of heat, however, may only have been temporary: the Cascade group as a whole abounds in temporary geyser phenomena—Baby Daisy, Biscuit Basin Geyser, Hillside and Seismic; three known unnamed features have also erupted briefly and then gone dormant. Thus it is possible that Fantail Geyser may also be ephemeral.

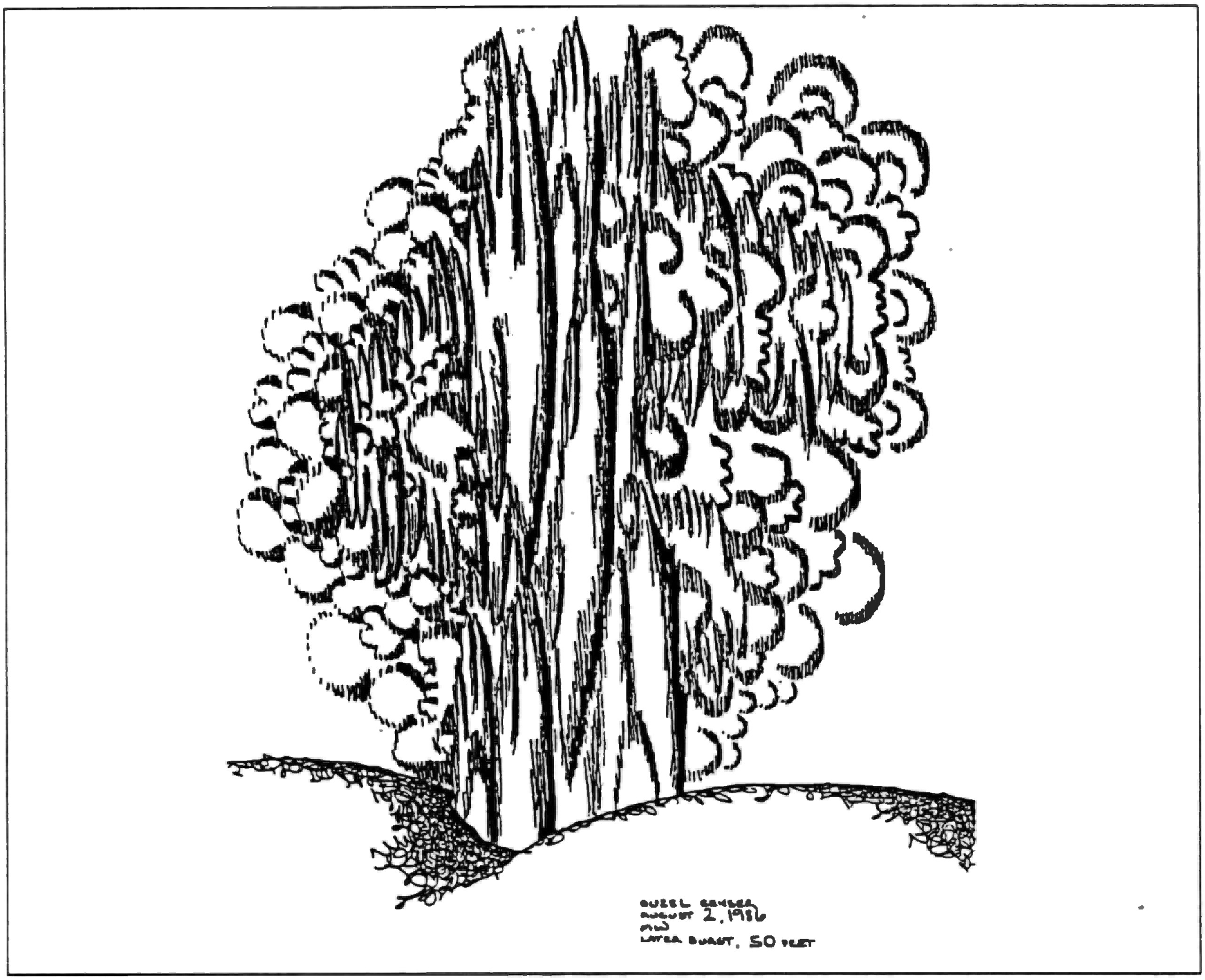
"Ouzel" Geyser— USGS #YM254:

> Ouzel Geyser is a roughly trapezoidal shallow collection of three pit and fissure-shaped vents extending 3.7m [12ft] from the Firehole River's edge to an overhung indentation in the sinter stalactites. Maximum dimensions and depth of Ouzel Geyser are about 3.7m [12'2"] by 3.0m [9'7"] and 2.0m [6'8"] respectively" [Hutchinson 1986].

Before it manifested geyser action, Ouzel was the largest spouter on the west bank, in overall area as well as activity. During the early autumn, the easternmost fracture vent lies approximately 1 inch above the level of the river; only a vigorous outflow of hot water, and a 4 to 6 inch high sinter dam with one narrow opening, prevent an inflow of cold river water. In late spring and early summer, when the river is swollen with snowmelt, Ouzel is submerged. The pool lies at such a low level, apparently because the thick sinter sheet in which it formed was leached away from beneath by rising heat, creating a big depression. Fulminous activity then blew out the present vents in the already-eroded basin.

The sinter banks rising to either side of Ouzel are quite high and steep. The sinter is undercut and honeycombed with holes and indentations created by heat-leaching; this partially-intact sheeting has the same crumbly, breadcrust appearance as the top pool's biscuits. The western vent of Ouzel is a calm pool so deep that it appears black; this broad strip-like vent is overhung by two gravelly ledges that are about 18 inches thick in places, each pierced by a hole that looks like a porthole down into the pool. Heat-leaching appears to have been occurring for a very long time, completely undermining the ancient sinter sheet, before the present spring was explosively born.

The vigorous middle vent of Ouzel, whose temperature is 206°F in the center, probably marks the course of the main northwest-southeast fracture that runs through this area on the west riverbank. The thickness of the overlying sinter sheet, plus a one-time lack of water, may have been the reasons for this spring not breaking out long ago. The disturbance of a large tremor would then have opened clogged passages, letting steam



expand explosively—which would have further opened restricted and buried fractures to allow the ingress of long-absent water, forming the new spouter.

Again, the clay-like consistency of the heat-softened older formations allowed no jagged edges or splintery debris to form during explosions. The hot water and vigorous boiling of the new vents have helped construct masses of fresh, beaded sinter in the lower portions of the basin. These fresh formations are a muted yellow-orange in place, no doubt from oxide compounds.

When the hot ground broke out in 1984, Ouzel's water level dropped nearly 6 inches, causing an increase in surging activity. This surging also stopped occasionally, making this spring a nascent geyser.

April 18 to August 20

Overview of Activity — Fantail Geyser

The discovery of Fantail Geyser occurred on April 6, 1986. As the Park Geologist, Rick Hutchinson, and his wife Jennifer, were driving by on the Grand Loop road, they noticed a huge steam cloud where no known geyser activity had previously occurred. They stopped the car and got out to discover a formerly quiet pool erupting to 30 to 40 feet; lateral bursts extended nearly 50 feet up a soil embankment to the south. The sinter platform discussed in the last section was being deeply eroded. Evidence in wash around the crater and dying grass on the south bank indicated that activity here had probably been going on for only a week or two.

The height of early eruptions of Fantail were well under 50 feet. Yet the powerful steam phase—such an outstanding characteristic of the eruptions during the first two-thirds of the summer—was as vigorous then as it would be for later, much larger, eruptions. The same was true for the first eruption I witnessed on April 18, which was only 30 to 40 feet high, yet very vigorous.

The size of eruptions gradually increased, peaking in July: the average eruption then was about 70 feet, and some plays reached as high as 90 feet. By early to mid-August, the height decreased to an average of about 50 feet. The last eruption of Fantail of the steam phase type was witnessed on August 20.

An Overview of the Steam-type Eruption Sequence: After an eruption the crater was completely emptied. In the first hour after the eruption, filling was slow—an inch or so every 15 minutes. During this time there was still a vigorous ejection of spray going on as part of the post-eruption activity. By the time the level was to the top of the vent—70 to 72 inches down—the rate of filling increased to 5 to 12 inches per quarter-hour. The post-eruption steam phase gradually changed to 6 to 8 foot splashes as water entered the bowl. These surges, gradually dying, continued well into the refill stage. By the time both craters were full there was only bubbling, if that. Refill was consistent at from 3-1/4 to 3-1/2 hours.

The most common refill pattern was for the pools to gradually and steadily fill, and for surging and spraying to gradually decline. Once overflow was reached, there would be periods of increasing and decreasing overflow, and surging would again pick up.

There was one occasion when another, less common mode of refill was observed. In this mode the water level began fluctuating when the pool was only half full. The level would rise about three inches and drop back one inch in these cycles.

In August Fantail began palpitating when the main crater was about half full; this activity continued well into overflow. On one occasion the pulsations were massive, rising and falling six to twelve inches. No explanation for this activity is known.

After initial overflow there was a period of about two hours when massive overflow stopped and started, but no boiling or surging occurred. Normal overflow came over the back (west) edge of the crater and at a point at the north end. This mostly stopped after especially vigorous surging. But in the middle of May, overflow was stopping completely every cycle; this only lasted a couple of days.

Massive overflow covered the entire pool border with flowing water, and this occurred in cycles. The length of time between initial overflow and initial *massive* flow varied from under two minutes to over eight minutes; massive flow almost always followed initial flow without any cessation.

In the early season, overflow in the initial stages of the interval was very massive, even without any surging or boiling. This copious discharge actually tapered off before the eruption. It doesn't seem to make sense, but a number of other geysers (for example, Grand Geyser) display this phenomenon. At this time, periods of massive flow lasted five to nine minutes.

Later in the season, the early massive flow was less copious— but the duration of the flow increased, ranging from 15 to 55 minutes. The pauses between these periods of massive flow ranged from 3 to 17 minutes. The pauses between flow-periods actually grew shorter as the flow-periods grew longer.

"Hot periods" began when sizzling and boiling started during periods of massive overflow; this usually began around 5 to 5-1/2 hours into the interval. After 30 to 90 seconds of massive overflow there was an abrupt surge in boiling activity; this surge was usually to about a foot, but could be as much as three feet. After about two or three minutes, this activity either died down to sizzling or picked up to very heavy surging or a false-start burst; then this heavier activity tapered down to sizzling, and massive overflow stopped. If the surging reached six to ten feet and did *not* die down, then the eruption ensued.

Just after hot period boiling began, there was often a temperature difference of 3°F or 4°F between the hot period and the pause. Later in the cycle there was near-continuous boiling and sizzling *between* hot periods, and the temperature stabilized at 204°F to 206°F. The only distinguishing feature between hot periods and pauses was the height of the surging and the occurrence of massive overflow.

Pauses between hot periods ranged from two to nine minutes and lasted anywhere from four to sixteen minutes; yet the duration of heavy surging, three feet or more, remained at about three minutes. During the longer hot periods, surging remained at about a foot until nearly the end, when three foot surging or false starts began; even then the total amount of heavy surging remained at around three minutes; when it lasted more than that the eruption usually followed.

"False starts" are actually minor or aborted major eruptions. They most often occurred late in the interval and rose six to ten feet. Sometimes there was more than one false start in a single hot period, but this was not common. One notable exception was on July 5, when five false start surges came in rapid succession in one hot period; one surge heaved up to 15 feet and came out of both craters; the major eruption was delayed 1-1/2 hours by this activity.

Usually Fantail died down gradually from a false start. Later, in August, hot period activity and massive overflow ceased the instant the false start dropped.

When an eruption was imminent, surging rose six to ten feet and did not die down in a few seconds. Sometimes eruptions came two or three minutes into hot periods, and sometimes the eruptions didn't come until nine to sixteen minutes into the hot period; the former was more common. The latter happened during a stretch in early August that lasted a few days. As rare as the long hot periods were, exceptionally short hot periods were even more rare: only one known eruption occurred in less than a minute from the start of the hot period.

Very rarely hot periods built steadily and gradually in sequence from light surging, to heavy surging, to eruption. Another mode of build-up was also rare, lasting for only two or three days; in this the heaviest surging came in the middle of the interval, then actually tapered off some before the eruption; these early false starts were actually masses of water to three or four feet with occasional spikes to five to ten feet.

In another mode of hot period build-up there was a single false start at about five hours into the interval; this, too, occurred on one or two days and was not observed again. Sometimes the eruption came in the next hot period after a false start, and sometimes a long recovery of two to four hot periods was needed.

Usually, if there was more than one six-plus foot surge in one hot period, the second was the eruption. As mentioned before, however, there was the rare occasion when repeated false starts came in one hot period, and the eruption was long-delayed as a result.

In late July and early August, Fantail developed an odd habit of having repeated false starts in consecutive hot periods. This would seem to indicate an over-abundance of energy—a situation that was to have a drastic effect on Fantail in late August.

The most common mode of pre-eruption build-up was for heavy and light surging to mix seemingly at random. False starts appeared to come where they may.

A Description of the Eruptions: The play of Fantail is typical of fountain-type geysers: masses of water are lifted, and the higher bursts arc up out of the mass from fifty to eighty feet. Fantail was a slow starter. When the height reached twelve to fifteen feet, the roiling boil changed to arching jets; maximum height was reached in 60 seconds or more and was maintained for two to five minutes.

The main crater has been probed to seven feet; the vent is about 12 to 14 inches high and enters the bowl horizontally from the north The water comes into the bowl horizontally and strikes the opposite wall. Such is the force of the entry that the water shoots upward. It then strikes the partition separating the two craters, and the mass is split in twain. Some of the water rushing into the main bowl is then deflected by an overhang on the surface and jets out horizontally up to 60 feet. All of this gives the eruption the appearance of twin rooster-tails arcing out in opposite directions. In large eruptions the small crater jets as high, or higher, than the main crater, sometimes arching over half-way across the Firehole River. In small and medium-sized plays the main crater dominated.

In the early eruptions rocks appeared after about a minute of play. Two to six minutes into the eruption a loud roar was heard, marking the powerful entry of steam. About ten to fourteen minutes into the play steam and spray predominated, and the steam phase was officially entered.

Once the crater was emptied of water the horizontal jetting of steam and spray became very evident. This was when the most prominent lateral jets occurred on the surface. Fantail had very wet steam phases in the early season. By mid-season that had changed: by the time the water began collecting in the bottom of the crater the discharge was blown to a fine mist; this steam was still wetter than the steam phases of cone geysers like Castle Geyser or Lion Geyser, yet drier than its own earlier spray-filled steam discharges. As more water collected in the bottom of the basin the discharge again became more watery. This soon died to splashing below the crater rim, which gradually died to bubbling as the basin filled.

Intervals in April and early May ranged from eight to ten hours. Afterwards they ranged from 5-1/4 to 8 hours. Changing from short to long and short and back was a gradual process.

Durations of water and steam phases were quite consistent. Water phases lasted 8 to 12 minutes. Steam phases were considered ended when water was seen collecting in the crater bottom; this usually took 12 to 17 minutes. Exact durations for eruptions were hard to determine because surging and splashing continued for almost two hours, into the refill stage.

Journal of Observations of Activity of Fantail — May 15 through August 17

May 15: The amount of water discharged by this geyser is phenomenal. Its overflow cycles, or hot periods, go on at intervals for three to six hours before an eruption occurs, and the discharge during a single hot period is massive. Then the eruption itself heaves quantities of liquid equal to the discharge of Oblong Geyser during an eruption. Yet even with this the water remains nearly opaque.

May 16: Fantail's behavior has changed since yesterday. Before the morning eruption I noticed that Fantail was dropping below overflow entirely between hot periods. Previously, overflow merely lessened between hot periods to runoff in only the main channel; now it is stopping completely. Before the afternoon play, massive surges began occurring *during* hot periods, starting only 4-1/2 hours into the interval. These four to six foot surges were the largest that I had seen that did not result immediately in an eruption. Such activity actually calmed down before the eruption, until seconds before the major play took off.

May 17: Up until recently, hot periods of Fantail have been quite ordinary: overflow increases to very massive, and the pool foams up over the vent with steadily-increasing vigor; between hot periods, overflow decreases to light but does not stop, and surging dies to sizzling and boiling.

Some of Fantail's behavior has been a mystery, since no one has taken the time to wait through an entire interval to note the progression of events. For instance, it is not known if, in the early stages of the interval, the pool dropped below overflow at some point in its cycle; initial overflow started and then became massive, but it is not known if normal overflow ceased after massive flow had stopped.

The pool now drops several inches after the initial hot period; it is not known if this behavior is new. What is *known* to be new is Fantail ceasing overflow after *every* hot period, right up to the eruption.

May 25: By the 24th, Ouzel was submerged under about a foot of water by the Firehole River. It may be significant that Fantail has begun playing higher and at shorter intervals. It is too early to tell if Ouzel had anything to do with it, but it would be wise to keep this in mind.

On the 22nd, when a log of continuous observations were kept through an entire interval of Fantail, it was discovered that Ouzel apparently played on its own cycle, which was independent of Fantail: some of Ouzel's eruptions came between hot periods—but some came right in the middle of Fantail's heaviest activity. There may be less connection between these two geysers than was earlier supposed. Further data will need to be gathered when the river drops.

Fantail itself is cutting down the length of its eruptions. The initial roar of steam is coming now about 2 to 2-1/2 minutes into the eruption, where earlier it was coming four to seven minutes into the play. Initial steam phase is also coming earlier into the eruptions.

Fantail's intervals are shortening now that Ouzel is under water, and eruptions are starting to get higher. It will be interesting to see where it ends in a few weeks, when Ouzel peeks out of the river and begins renewed activity.

Previously, when data was taken through entire Fantail intervals, it had become habit for the pool to drop below overflow between hot periods. Massive surging also occurred early into hot periods, well before the eruptions. On May 22 the pattern was slightly different: there was only one five foot boil-up without an eruption, and the pool dropped below overflow only toward the end of the interval. Later still, on May 24, Fantail did not drop below overflow at all, and massive surging over four feet occurred only in hot periods immediately preceding eruptions.

June 6: Fantail's average eruptions have gone from 40 feet to 50 to 60 feet high; the intervals have shortened to between just over seven hours to as little as 6-1/2 hours. In the last three days, the rocks thrown by Fantail have begun to get larger again. It remains to be seen if this increase in Fantail's activity is or is not due to Ouzel's recent dormancy. It is my present feeling that Ouzel and Fantail may *not* be as directly connected as had first been surmised.

June 15 This last week Fantail has been having longer intervals; most of these were between 7-1/2 and 8 hours, the most common being 7h45m. No reason has been put forth to explain this. The river is down a good six inches from last week, but water still completely inundates Ouzel. It is doubtful that the river is cooling Fantail from below, through Ouzel's vents and plumbing: Ouzel and Fantail are almost certainly less closely connected than was first thought. Also, Fantail was *shortening* its interval while the river was at its seasonal high.

One possible solution to this conundrum is that Fantail's "average" eruptions are again slightly larger. The "normal" eruption is now the same size as a *big* eruption of just a month ago; this just might be using up more energy. The duration of water play and the violence of the steam are about the same as last week.

So far, no definitive proof exists that Fantail has direct underground connections with any other spring. When Ouzel was active, it played on its own schedule; the activity, or lack of it, of Ouzel appeared to have no known effect on whatever activity Fantail was having. The same appears to be true for the possibility of a connection to Hillside Geyser, across the river, as well: it has a unique pattern of rise-and-fall and has no known sympathetic reaction to Fantail's hot periods or eruptions.

June 29: Interesting differences may be seen between this complete interval and that taken on June 12. The eruptions this time are larger. Now the water is used up more quickly, initiating earlier steam phases.

Fantail's vent appears to have been enlarged, both lengthened and widened. This might help to explain why the water now comes out seemingly all at once to initiate large plays. The fact remains that the eruptions are higher and run out of water more quickly. At a time when steam and spray last week were jetting to thirty feet, they now reach less than half that height at the same point in the eruption. By the time water begins to collect in the crater bottom, spray now reaches six feet, compared to 15 feet on June 12.

In both cases the crater filled in 3-1/4 hours, and hot periods did not begin until the pool had been overflowing for some time. This, at least, remained consistent. Boiling did not begin until the pool had risen to massive overflow and dropped back several times.

On June 12, the hot periods were mixed: periods of vigorous three foot surging were randomly sprinkled among periods of one foot boil-ups; a false start also occurred at about the five hour mark. Today was a distinct contrast: only one period of three foot surging was noted, and this came early; the rest of the hot periods were extremely weak, barely boiling up one foot. The eruption today sprang up as a surprise amid this lackadaisical activity. The interval on June 12, with a false start, was a half-hour longer than the interval on June 29 *without* this activity. Also, temperatures during hot periods were 2°F hotter than today, until the hot period of the eruption.

July 5: The relationship between Ouzel and Fantail is again the center of controversy. It appears, as surmised before, that there is very little relationship between the activity of the two geysers. The false starts appear to come where they may during Fantail's intervals, no matter what Ouzel is doing. The heavier activity in Ouzel sometimes falls at or near the time of Fantail's false starts—but usually Ouzel's activity has diminished considerably by that late in Fantail's interval.

This appears to be the only sympathy these geysers display toward each other: early in Fantail's intervals, before really vigorous hot periods start, Ouzel's eruptions are vigorous and sometimes over five feet high; as Fantail's interval progresses toward the next eruption, Ouzel calms considerably, playing only a couple of feet, with long pauses of total inactivity. This became especially evident during the full interval observed, where Ouzel was witnessed to have major eruptions to five feet or more at and near Fantail's time of initial overflow; this died to almost no activity toward the time of Fantail's second eruption.

Amid this activity come the anomalous eruptions of Ouzel that occasionally occur late in Fantail's interval; usually they are rather large, rising four feet in the boiling vents. Most of the time these plays come immediately before Fantail's eruptions: yet Fantail appears totally unaffected by this activity. Only once did this climactic activity occur before a false start, and that was before some odd activity in Fantail.

The unusual activity of Fantail on the morning of July 5 deserves further comment: Ouzel had just finished a vigorous play, and Fantail attempted to erupt; repeated false starts continued until quite late into the hot period. The false starts came in a sequence with individual surges 15 to 45 seconds apart. This was the most vigorous activity ever recorded that did not result in an eruption; during the fifteen foot surge, water even heaved up in both craters. Between surges, the pool dropped below overflow, and activity died to sizzling and boiling. Imagining a vicious tug-of-war between Ouzel and Fantail is tempting; but Ouzel's heavy activity had already ceased, before Fantail began surging. It simply appeared that Fantail was delaying itself.

These false starts could be classed as minor eruptions. Yet that does not answer the primary question in all of this: what *causes* false starts?

Only one possible answer comes readily to mind. When Fantail is having vigorous hot periods, the surface temperature runs about 206°F; it is on a hair-trigger. If conditions shift even slightly in favor of an eruption, the chain-reaction would be set off. If, however, enough weight is thrown off to stabilize the system, the incipient eruption would abruptly cease. On short intervals this activity *would* result in an eruption; on long intervals it would result in a big false start.

Fantail appears to run in cycles of shorter, followed by longer, intervals. During intervals greater than 7-1/2 hours, false starts usually occur; typically, the false starts would occur at about the same point in the interval that an eruption would come in a short interval. On some shorter intervals false starts come early enough that an eruption would be almost impossible. This happened on the days when Fantail had false starts at about five hours into the interval. Fantail still had enough time to recover, and still erupt with a 7-1/4 hour interval.

What remains puzzling are the times on May 17 when false starts were common in the middle of the interval. In fact, these were not even "normal" false starts: the roiling and boiling maintained at one to three feet, then would be periodically spiked with bursts four to six feet high; this would continue for four to eight minutes. Such activity came too early in the interval to initiate eruptions. The intervals recorded during this activity ran a bit longer, in the 8-1/2 hour range.

There were some differences between this latest observed interval and the complete interval taken on June 29. One significant change was in the overflow pattern before hot periods began. On June 29, the lengths of flow and ebb were the same as during hot periods, eleven minutes being the longest. On July 5, however, flow periods lasted over thirty minutes; the pauses themselves were still around five minutes. This narrowed down to more normal levels as hot period boiling and churning began.

Another difference was the amount of quiet period sizzling and boiling that occurred. On June 29, there was quite a bit of this activity. By July 5, there was a dead period between every two hot periods, and the temperature rose and fell 4°F right up to the time of the eruption.

The length of time until first overflow was nearly the same on both June 29 and July 5, being 3 hours, 19 minutes, and 3 hours, 24 minutes respectively. The increased length of the last filling was hardly significant in magnitude—but it may nevertheless have resulted from the exceptional size of the preceding eruption (≈90 feet). It is interesting to note that every observed event in the July 5 interval occurred about ten minutes later than in the June 29 interval—yet the length of both intervals was very nearly the same, being 7 hours, 16 minutes, and 7 hours, 19 minutes respectively. This remained true in spite of the false start spiking the June 29 interval.

In the past, Fantail erupted five to eight minutes into its hot periods, which is late compared to the present. In fact, on June 30, one play came 38 seconds into the hot period; it just overflowed, roiled up, and then erupted. Most present eruptions occur about three or four minutes into the hot periods; this invalidates the theory that heavy surging must continue for over three minutes before the eruption can occur.

The size of the eruptions has increased. More plays estimated to be 70 feet or more have been seen, and a new estimated maximum of 90 feet has been established. The jets appeared to be more vertical than previously observed. The latter might be due to the vent enlargement noticed last week.

The amount of rocks being thrown is varying considerably. Some eruptions toss out dozens, while others hardly throw out any at all.

July 31: The intervals have become erratic, ranging from 5-1/2 to 7-1/2 hours. Jumps of well over an hour have been recorded. In the past, Fantail's intervals changed gradually between long and short.

August 3: Fantail's duration of filling to initial overflow remains remarkably consistent at about 3-1/4 hours. The sequence of events is almost identical in each of the total intervals recorded. Fantail continues to boil, churn and splash in spite of the huge eruptions of Ouzel seen lately (20 to 50 feet). Refilling is the only action of Fantail to have remained consistent since April. During the initial periods of Fantail's massive flow—before hot periods begin— the lengths of flow are quite variable. The pauses between these flow-periods have grown very short, most lasting only a couple of minutes. But this, too, is variable. Flow-periods last eight to over twenty minutes, and pauses last anywhere from two to over fifteen minutes. At no time in these intervals was the extraordinary discharge seen, as it had been in the past; in fact, at times, massive discharge was maintained only by the narrowest of margins.

Hot periods have also become longer, and the pauses between them shorter. As with initial overflow, the hot periods last anywhere from five to over twenty minutes, and pauses last anywhere from two to fifteen minutes. Sometimes, when the pool is pulsing, it is hard to discern pauses at all. Another quirk has developed as well, this being a brief lapse in massive overflow right in the middle of a hot period. These lapses, occurring twice on August 2, last a minute or less and did not appear as decisive as a real pause.

In addition to longer hot periods there has been a change in the occurrence of general surging, false starts and even eruptions. In the longer hot periods, good surging sometimes does not begin until ten minutes into massive overflow. This is especially noticeable after a vigorous false start: the hot period immediately following this activity usually starts out flat; but after ten minutes or so, surging can begin suddenly and mount quickly into an eruption. On a couple of occasions repeated false starts were seen to occur in consecutive hot periods: this in itself was remarkable; but most of them also occurred about eight minutes into the massive overflow. One of the eruptions came *sixteen* minutes into the hot period. Until August 1 the longest time of an eruption into a hot period was nine minutes, and that had stood out as uncommon.

Consecutive false starts* were reported by Scott Bryan. This type of behavior is new. In May, a modified version of this occurred in very early hot periods, well before eruptions were even possible. Lately the established pattern is for there to be a substantial recovery time after a false start. Also there has been rarely more than one; the false starts on the morning of July 5—when five surges occurred in one hot period—were a distinct anomaly. Yet reports of repeated false start surges came in late July, and such activity was witnessed on August 2 and 3. No matter how vigorous the surges, another false start would come along right behind them, and there was no quieting-down of this activity before eruptions.

This abundance of false starts may or may not have been responsible for Fantail's abrupt decrease in eruption size. I doubt that Ouzel had anything to do with it, but Fantail may be somehow using up energy in some other activity than eruptions. The shorter intervals pick up some of the slack, as do false starts. Eruptions of Fantail now reach only 50 or 60 feet, with the occasional 70-footer thrown in. Yet these plays use up the water just as quickly as the larger ones did.

Probably because of the decrease in eruption size, almost no rocks are being thrown. Those we have seen are sinter from the surface formations, and so possess little threat to Fantail's overall health.

In spite of the lack of rocks being thrown by Fantail,there have been plays in which quantities of silt and obsidian sand have been ejected. Since this began at about the same time as Ouzel's huge, sand-filled eruptions, they may result from a similar cause. We believe that all of the sand and silt is coming primarily from Ouzel, from the days when the river was washing this material into Ouzel; that might explain why cold river-water in May and June did not cycle up into Fantail. Interestingly, nearly all of the sand from Fantail is ejected exclusively from the east crater, even though there is only one vent for both craters.

As mentioned before, intervals during the last three weeks of July were rather erratic. They became more regular during the first days of August: the intervals at first were around six hours or slightly less, and they gradually lengthened to 6-1/2, then seven. This gradual transition is more typical of early Fantail than drastic jumps from long to short and back. If intervals lengthen to near eight hours it will be interesting to see if eruption sizes increase.

August 9: The length of Fantail overflow periods, before hot periods began, varied considerably between the two total intervals observed the last week: during the first full interval of August 9 the overflow periods lasted between one and twelve minutes; during the second interval the overflow lasted 8 to 30 minutes. Due to this change, hot periods began an hour and five minutes after initial overflow; in the second interval it was almost two hours after initial overflow that hot periods began. Yet the second interval was shorter than the first by nearly half an hour; after boiling started, surging built rapidly to three, then six feet.

Hot period durations this week have been shorter than those of last week. The third eruption of August 9 was preceded by a hot period ten minutes long, the longest hot period recorded during the week. The rest have been four to seven minutes. The pauses between overflow and hot periods have remained short at two to six minutes. Also observed this week have been those brief one minute pauses where massive overflow ceased but surging did not. One such pause divided the hot period immediately before the third August 9 eruption.

Since the hot periods have become shorter, false starts and eruptions have been coming earlier. Once again, heavy to massive surging comes about three minutes into the hot period and lasts about three minutes. Only the third eruption of August 9 provided an exception: in this case, the hot period was about ten minutes long and ended with the eruption.

A new development this week involves false starts. Usually when a false start occurs, three-foot surging resumes afterward; this gradually tapers down to boiling and sizzling. There have been exceptions, of course, but few of them. This week the exception has become the rule: massive overflow ceases the moment the false start drops, ending the hot period. An unusual event occurred before the second eruption of August 9, a false start *began* very suddenly, jumping from one to six feet in a split-second.

The eruptions themselves have continued to be of only average size; and the water is running out at the end like last week's plays. One new development in this scenario is a very watery discharge from the east crater that continues even after the main crater is ejecting pure steam. Since both craters eject from a single shared vent, this presents a bit of a conundrum.

Again, there was one eruption that ejected quite a bit of sand and silt; and again, the ejection of this material came exclusively from the east crater.

The intervals during this last week were remarkably consistent. All were under seven hours. The average was 6 hours, 41 minutes, the longest being 6 hours, 58 minutes, and the shortest 6 hours, 18 minutes.

August 17 A few changes have occurred since last week. The overall average interval was 7 hours, 24 minutes, somewhat longer than last week. Unfortunately, the eruptions have not become longer or larger as a result. One smallish play was measured at 47 feet, so estimates of 50 feet have been fairly accurate. In addition, Scott Bryan measured an eruption in July at 78 feet, when the average height was higher.

Before hot periods began, the periods of quiet overflow were incredibly long. In both total intervals observed, these overflow periods lasted nearly an hour. They lasted so long, in fact, sizzling and boiling and the first surge to a foot all came in the latter part of the second overflow period. In contrast, actual hot periods lasted five to twelve minutes.

The first full interval was marked by a single six foot false start; but this did not significantly lengthen the interval. During the second total interval observed, no hot period surging reached over a foot, until the actual eruption; the eruption came as a surprise after such unimpressive activity.

The massive pulsations during the second total interval observed were quite novel. Only a steady, very light palpitation had been seen previously. The massive pulsations were so vigorous, I half expected the pool to explode. Unlike the light pulsing, massive palpitations occurred only during hot periods.

There were almost no rocks thrown out this week.

Overview of Activity of "Ouzel" Geyser

It is not known whether or not Ouzel became active as a geyser at the same time Fantail did but it is probable; they were discovered to be active on the same day. Ouzel, however, had been displaying some geyser proclivities last summer, when its incessant boiling was seen to pause occasionally for several seconds at a time.

Eruptions of Ouzel began in two different ways. The most common was for boiling to begin from a flat pool and gradually build to surging a foot or more. The second type of start was more dramatic, involving massive overflow and vigorous palpitations with the pool rising and falling as much as six inches; sometimes thumps accompanied this activity, and the following eruption was often large.

Sometimes Ouzel could be classified as a spouter, as it boiled and fluctuated in vigor for hours without complete cessation. This type of activity was seen on May 17, when two total intervals of Fantail were observed: Ouzel simply boiled and fluctuated up and down, only stopping for five minutes or so immediately following eruptions of Fantail. Later, distinct pauses occurred near the end of Fantail's intervals and right after Fantail's eruptions. Activity early in the interval could almost have been called one continuous eruption with variations in size.

Unlike Fantail, Ouzel did not empty its shallow basin during eruptions. The moderate overflow continued steadily before, during and after eruptive activity. Only the freak main vent majors of early August caused a significant drop in water level.

Most plays of Ouzel consisted of roiling and boiling to a foot or more; the level rose and fell, but the activity was fairly constant. During the major plays the boiling rose from the middle vents to four to five feet, and a narrow stream arced up in a vent in the southeast corner of the crater; this stream could jet as far out as fifteen feet, while the main vent roiled up as high as ten feet. These large plays were known to come from both a flat pool and one already agitated by minor activity. They usually came early in Fantail's interval and around the time of Fantail's first overflow. Some majors, however, came right before Fantail's eruptions.

In the first week of August, Ouzel had some freakish major activity. Ouzel's entire behavior changed: the pool would abruptly swell into a brown hemisphere seething with black sand, and this would suddenly explode. Individual bursts heaved great masses of brown water twenty to fifty feet in the air. When it ended, the water dropped a foot or two down into the vents. Unfortunately, this exciting activity only lasted for three days—long enough to clear river-silt out of the plumbing.

Intervals were highly irregular. Most varied from 25 to 45 minutes, but extremes of 10 to 55 minutes were not uncommon. When Ouzel was having majors, matters became rather confusing. Majors could come singly or in clusters where individual surges were seconds apart. Clusters came thirteen minutes to two hours apart; but minor activity stopped and started between majors. This was also true when Ouzel was having the huge main vent majors.

For the most part, Ouzel was overshadowed by its larger companion. Yet it presented its own share of mystery and excitement.

Ouzel's major activity, like Fantail's stopped somewhere in the vicinity of August 20. The following description covers activity up to that time.

Journal of Observations—May 15 through August 17

May 16: Ouzel Geyser has been reported to affect Fantail's overflow and surging. However, the river has been flooding Ouzel's crater during the last two weeks; in fact, its behavior lately is not much different than that of last year when it was still classed as a spouter. I have found no evidence to indicate that this activity is affecting Fantail's hot periods or eruptions. In fact, Fantail has been playing on relatively short intervals in spite of the cold river water flooding Ouzel.

This afternoon a rather surprising play of Ouzel occurred. First, there was a quick series of jarring thumps. Then there was a sudden rise in water level, causing a small tidal wave over the eastern formations. Within seconds, the middle vent began surging up four to six feet, while the southeast vent shot a narrow arc of water up onto the bank fifteen feet away.

During this activity, Fantail began surging vigorously. Rather than being dropped or delayed by Ouzel's play, Fantail appeared to be given a boost of energy. After some unusual behavior of its own, Fantail proceeded to erupt on a 7 hour, 40 minute interval.

May 17: None of the spectacular plays of Ouzel have been seen. In fact, Ouzel has been a more of a spouter than a true geyser, much as it had been in the past seasons. There has been near-constant one to two foot surging, with short pauses of boiling and sizzling. Fantail's unusual behavior continues, in spite of what Ouzel is doing.

July 5: The majors observed on July 5 have occurred in the middle of average boiling-type eruptions; all have been heralded by sudden and dramatic increase in the perpetual overflow. There have been, however, no thumps before any of the plays. This constitutes relatively new activity since the river has dropped below the level of Ouzel's crater.

August 3: Ouzel has been a puzzle lately. When visitors reported twenty foot eruptions, it was thought that what was meant were twenty foot narrow arcs from the southeast vent. Eruptions that were witnessed instead have thrown a twenty foot mass of muddy water and gravel from the main vent. It does seem odd that no previous mention was made of the mud and gravel. There is a good chance that these huge main vent eruptions are new activity.

These major plays are all heralded by a sudden rise in water level and huge palpitations that send deluging waves of water over the front formations. In general, the larger plays come after the more massive discharge. Also, larger plays dome up and explode while the pool is still pulsing—while smaller plays come rather belatedly after the pulsations have stopped and three foot boiling is already under way.

The twenty foot eruption on the morning of August 1 came as a total surprise. Ouzel's eruption came about two hours after Fantail's play and after a small eruption of its own and the following pause. When vigorous palpitations began, we expected a 15 to 20 foot eruption of the southeast vent. Suddenly the whole pool pulsed upward and swelled into a big dome, a "brown bubble" seething with dark sand.

This activity was so impressive that observers returned two hours after the next Fantail eruption to see what Ouzel would do. It had a major play, but only to a disappointing 15 feet. The following day, August 2, another complete interval of Fantail was observed. The first series of Ouzel eruptions consisted of "typical" majors dominated by the narrow southeast vent. Then, shortly after Fantail's first overflow, the surprises began.

A gush of steam from Ouzel was observed at a point when Ouzel had been completely quiet for almost fifty minutes, which in itself was unusual. Suddenly, a deluging overflow began. Then the pool abruptly domed up and exploded to about thirty feet. Again, the water was dark with sand. The first burst began to descend, when the second burst shot up through it. By the fourth burst, muddy water was reaching fifty feet; they just kept getting bigger. Some of the bursts shot off to the side, and several dumped water and sand into Fantail.

The level of the pool dropped about two feet afterward, and the water churned violently down in the vents. After nearly four minutes, the level rose, and Ouzel began to have "normal" major eruptions on the southeast function. After two of these the level rose abruptly and water gushed over the formations. Again, the pool exploded, and Ouzel had a thirty foot play. After the level dropped to six inches down, it began boiling up three feet. This diminished rapidly, however, and the pool was flat within twenty minutes.

This pause lasted almost an hour. Then loud thumps were heard. The pool rose in immense pulsations and deluged over the formations. The first play was an unremarkable fifteen feet; at this point the erupted water was the normal white of foam. A second eruption was even less impressive at eight feet. Then, suddenly, sand and mud were regurgitated, and the pool fulminated into a dark tower fifty feet high. Bursts came even faster than during the first large series, and were accompanied by thumping similar to the collapsing steam bubbles of Sawmill Geyser. This was followed by a play "merely" twenty feet high. Then it was almost half an hour before Ouzel was able to have a single, lone play to eight feet on the south east function. This was the last activity from Ouzel until Fantail erupted an hour later.

Two facts were salient after this fantastic activity: one was the distinct change in the water for the largest major plays. During major eruptions on the southeast function, the water was in its usual barely opaque state, and the erupted water appeared the usual white. For the large major plays on the main vent function, the water would abruptly become muddy brown and dark gray with suspended obsidian sand. This would actually manifest itself as the pool domed for the initial burst, the sand rising in a palpable cloud to the surface.

The second difference between majors of the southeast function and those of the main vent function, aside from sheer volume, was the manner of ejection. During plays of the southeast function, the main vent roils and boils up to five to ten feet in a kind of continuous surging, and the southeast vent arcs out to the side in rapid jets. On main vent function, the main vent erupts in sharp bursts that often jet up through one another, and the southeast vent surges up ten or fifteen feet in a continuous stream that is entirely vertical.

Why did Ouzel suddenly being having these big, dirty eruptions? Apparently, Ouzel's plumbing was choked with dirt and sand—and probably most of this material was washed into Ouzel's vents while they were under the river. This debris acted as a plug. While the river was flowing over it, Ouzel was cooled down below eruption temperature and so could do nothing to clear away this blockage, allowing silt and sand to accumulate. Then, when minor eruptions began, this load of debris circulated down into the upper plumbing. Then it began clogging narrow passages necessary for the eruption process. Pressure began to build. At first the smaller eruptions bled off some of this pressure—but the point was finally reached where this process became insufficient: the smaller openings through the debris simply could not release the steam fast enough to relieve the excess pressure mounting beneath them. Suddenly, huge steam bubbles forced their way up the narrow passages, shoving the silt and sand upward ahead of them. This explains the abrupt clouding of the water with black sand as the pool domed for the first burst of the eruption. The uncommon force of the eruption then thrusted sand and silt into the obstructed channel connecting Ouzel to Fantail.

The chances are quite good that the major eruptive processes of Ouzel occur at a rather shallow depth, while those of Fantail occur at greater depth. Cold river-water over the vent was able to quench Ouzel, where it does not in other geysers such as River Spouter in the

Midway Geyser Basin. Thus, the water in Ouzel must be flashing to steam in the upper part of the plumbing, and the river was able to prevent the conversion. Fantail, on the other hand, may have been receiving cold river-water through Ouzel into its upper plumbing. Yet it not only continued to erupt on relatively short intervals, it increased its size as well. Thus, the conversion of water to steam must occur at levels below the entry of the cold water.

On the day after the fifty foot plays, two eruptions were seen to thirty feet, and one to twenty. In the last cycle of the day, instead of a series of southeast function majors, Ouzel was having near-constant minor activity spiked with occasional lone main vent majors. It will be interesting to see, now that much clogging sand has been removed, how long main vent majors will continue.

August 9: A few rather mundane changes have occurred in Ouzel since last week.

Sudden massive or heavy overflow used to signify a series of vigorous eruptions on main vent or southeast function. On August 9, this was seen to occur during both of the complete intervals observed. This appears, however, to happen only thirty to forty-five minutes after an eruption of Fantail.

Major eruptions of Ouzel on August 9 never rose more than five feet; they were all preceded by massive overflow; and most of the massive or heavy overflows came with a simultaneous surge in boiling to three feet.

The main vent major eruptions have ceased. Apparently they occurred only to clear the river debris out of the plumbing, and now that this is done the larger eruptions have ceased. Southeast function major eruptions have also ceased. Ouzel is turning into a spouter, as pauses occur mostly during and immediately after Fantail eruptions.

August 17: Activity in Ouzel was much more promising than last week. While no main vent majors occurred, major eruptions on the southeast function did. From the main vent, some of these heights were ten feet. There was a dearth of sand or silt in these smaller plays; apparently the massive main vent majors occurred only to clear sand and silt from the plumbing; that process has now been completed, and the larger plays have ceased.

Now Ouzel behaves as a spouter, since it stops only during and after plays of Fantail.In the first complete interval, one half-hour pause was noted; none were recorded in the second total interval.

Overview of Activity of Fantail — August 20 to October 30

Aborted Eruptions: The steam phase eruptions have become a part of the past. The change was abrupt and total. At first it looked as though the new activity was due to an increase of energy. But as time passed the energy dwindled, and the intervals lengthened, became erratic, then lengthened again. By the end of October there were days between eruptions.

The eruptions were aborted, ceasing after only about four minutes. After an eruption the water level dropped only 20 to 27 inches. Yet filling was quite slow: even though the crater was over half full at the end of a play, refilling took 1-1/2 to 2 hours. With no steam phase, ten foot splashing simply died down gradually to bubbling.

Previously, initial overflow turned into massive flow without cessation. After the change, overflow sometimes ceased and restarted before massive flow began. Hot periods usually began early, even when the interval was over ten hours; the second rise of massive flow was generally when the first hot period occurred.

There was still a surge of boiling after massive flow to mark the hot periods, and it still came 30 to 90 seconds after massive flow began. There were numerous instances where surging jumped from zero to three feet; this was far more prominent than it was earlier in the season. For the most part, three foot surging and false starts continued to die down gradually—except for on October 18 and 19, when massive flow and surging dropped abruptly and simultaneously.

In late August there was only occasional surging between hot periods, and the temperature difference was usually about 2°F between hot periods and pauses; when overflow ceased, the temperature dropped as much as 6°F. Beginning on October 4, there was a lot of surging between hot periods—yet there was still a 2°F drop in temperature for pauses. On October 18, activity between hot periods was generally nil—and there was a 5°F drop in temperature for pauses.

As it was in the beginning of the summer, massive flow before these aborted eruptions was extraordinary. This flow, however, often slowed down after an initial gush, until it was barely coming over the edge that marked massive discharge; this often made it difficult to tell exactly when massive flow ceased.

During the time of the shortest three to four hour intervals, hot periods lasted two to five minutes, with pauses running five to seven minutes. In the week beginning on October 4, the length of hot periods extended to seven to fourteen minutes, with pauses at two to five minutes. On October 18 and 19, hot periods lasted only two to three minutes, with pauses running from 3-1/2 to 4-1/2 minutes.

In the steam phase sequence, three foot surging did not begin until 5 to 5-1/2 hours after the eruption. For the aborted eruption sequence, three foot surging came 2-1/2 to 3 hours after the previous play.

In late August, September and early October false starts were quite plentiful. During the very short intervals, false starts began occurring about three hours after the eruption; this compares with five hours for steam phase sequences. In August there were sometimes two false starts in one hot period; most of these were short—six to sixteen seconds. Some of them leaped from one foot surging up into the false start burst. In September the intervals were 5 to 5-1/2 hours, and false starts were more scattered; but there was only one burst per hot period. On October 18, there were numerous quick false starts to only four to five feet; all of these sprang from one foot surging.

On October 5 and 6 some unusual false start activity occurred: On the 5th there was activity in series. First there was a single false start that reached ten feet. Fifty-one minutes later there were three false starts in one hot period, one of these reaching ten feet.

On the 6th there was a "normal" false start in one hot period—then there were four false starts in the very next hot period. These were spaced out further than those of the day before; each time there was a surge, the water level dropped a little further; two of the bursts reached ten feet.

It was interesting to note that, until the 18th, there were no more known false starts, in spite of the intense study.

As usual, pre-eruption build-up was haphazard. In August the process was also rapid. Usually, false starts were followed by rest periods: both of the vigorous false starts on October 5 and 6 delayed eruptions for over an hour. But beyond that there were no set patterns: weak and heavy surging followed one another without rhyme or reason. The oddest build-up occurred on October 18 and 19: there were very many rapid hot periods, each about two minutes long, and all were about the same intensity; false starts were sprinkled about randomly, then one burst suddenly blossomed into the eruption.

In late August, eruptions came 1-1/2 to 4 minutes into the hot periods. During the week of October 4 through 11, the hot periods were longer, with eruptions occurring after five to eleven minutes. By October 18 it was necessary for Fantail to erupt in about two minutes.

The Beginning of the End

The eruptions lost a lot of vigor in their aborted form. The rise of the water into full eruption was slow: the time from three to fifteen feet remained about the same as before; but the climb from initial jetting, at about fifteen feet, to full height took longer. Even at full height, the water ejection appeared less vigorous than during steam phase plays; this was the first sign, when we viewed the first aborted play, that something was wrong.

Another difference was an almost total lack of water ejection from the east crater. Later, fortunately, this picked up again. Another loss that did not pick up was the roar of steam that previously kicked in after about two minutes; this phenomenon did not return.

After the gradual rise of the water, the end seemed abrupt: from nearly full height the water dropped suddenly to about 20 feet; from there the drop was to about 10 feet. After the height had dropped to six, then four, the decline was gradual.

Intervals at the beginning of the aborted cycles were short. This was a surprise at first, when it was assumed that the aborted play was merely a freak amid "normal" eruptions. Instead the next eruption came 3-1/2 hours later, and it was another aborted play. It was discovered that intervals were running 3-1/2 hours in length.

This presented an unusual problem: the aborted eruptions seemed to indicate a decrease in energy; yet the extremely short intervals seemed to indicate an excess of energy. After observing Fantail through a number of complete intervals, it seemed probable that the latter was correct. The eruptions, it appeared, were like large false starts. The water during the intervals was constantly agitated: in spite of the short intervals there were numerous false starts leading up to the eruptions. It was as if Fantail could not wait for pressure to build for steam phase eruptions, instead erupting prematurely.

This activity did not last. By late August, occasional intervals were well over four hours; by mid-September, intervals were over five hours, and in late September the interval length was between six and seven hours. Yet eruptions continued to be aborted, and false start activity died down considerably. In fact, in mid-September, Fantail was so weak it ceased overflow after every hot period.

From October 4 to October 11, an intense round-the-clock study was done on Fantail, with many complete intervals observed during the daylight hours. Intervals were extremely erratic, varying from 4-1/2 to 9-1/4 hours. Only twice were false starts seen—albeit these were of extraordinary vigor; the recovery period in each case was long, indicating growing weakness.

Only a week later the entire structure of hot periods had changed. By October 18, hot periods were only two minutes long. False starts or eruptions had to occur during the two minute time limit, and the false starts were quite weak. Intervals then were 10-1/4 and 13-1/4 hours. These were the longest recorded intervals up until that time.

Only seven days later, intervals had lengthened to days between eruptions. Markers were placed on Fantail's platform and checked twice a day. These markers remained in place for two days, being washed away sometime during the second night. That interval had to have been over 48 hours. The hot periods during that time were barely distinguishable, and surging remained at about one to two feet.

Journal of Observations of Activity in Fantail

August 29: The last known steam phase eruption of Fantail took place on August 20. Coincidentally, the same day Giant Geyser erupted for the first time in nearly two years.

By the 23rd, the water in the crater was clear enough so that it was possible to see 12 to 18 inches below the surface. Unlike earlier activity, water rose reluctantly into full eruption, and the maximum height was considerably less that earlier. At two minutes into the eruption there was no roaring steam.

This activity was somewhat perplexing, and raised a number of questions. How long would it be before the next eruption? How long would it take for the system to recharge from a nearly-full pool? It was assumed that there would be a five hour interval before the next eruption, but instead R.Hutchinson caught the next eruption 3-1/2 hours later, and it was another aborted eruption.

During cycles of steam phase eruptions there was usually a period after initial overflow when massive discharge occurred with no boiling or surging. In the new, short intervals, hot period surging began with the first massive overflow. Soon thereafter, heavy surging and false starts began, sometimes less than an hour after first overflow. Some intervals ran four to five hours, and heavy surging came a little later in the intervals on such occasions.

In the first months of the season, massive flow followed initial overflow without a pause; this happened without fail. Twice in this last week initial overflow ceased, and massive flow was not achieved until the second rise of water level.

Before August 20, hot periods built gradually from an initial surge of one foot, to three foot surging, into a false start or eruption; only once did a six foot false start spring suddenly from one foot surging. This week, however, it was not uncommon for the initial surge of the hot period to leap to three feet right away; and false starts sprang from one to two foot surging.

False starts in consecutive hot periods were not unheard of in late July and early August; this happened, oddly enough, in a time of intervals under seven hours. In spite of the much shorter intervals the past two weeks, it has begun occurring again. The situation looks now as though Fantail possesses an overabundance of energy, and cannot hold back eruptions until energy can build for steam phase plays. Heavy surging has begun to occur earlier in the interval, and false starts begin soon afterward; the situation finally peaks when Fantail is pushed into an early small eruption only 1-1/2 hours from initial overflow.

In mid-May, Fantail developed a habit of ceasing overflow after each hot period, weak or strong; as far as I know, this lasted only a couple of days; now it has begun occurring again, somewhat at random. Some of these pauses, however, lasted only a minute.

The eruptions themselves could be marked as peculiar almost from the beginning. In the past, there were only occasional instances where eruptions began is distinct steps, from three, to six, to ten, then to fifteen feet in stages. Now this has become the norm. The water seemed to "hang" for several seconds in each stage, even after roiling had become incipient jetting.

The next thing noticed to be "odd" was the almost total lack of jetting from the smaller east crater. During some of the large plays in June and July the east crater would actually dominate in height. This week, only weak splashing was emitted by this vent.

Heights of Fantail have varied considerably since the geyser's discovery. At one point, plays were averaging about seventy feet and occasionally reaching about ninety feet. In August, this tapered down to an average of about fifty feet, with occasional shots to seventy feet. When the aborted eruptions were first discovered, the heights were barely reaching forty feet; during the following week, the heights began to reach about fifty feet again. Generally, larger eruptions came after longer intervals.

The water ejection of a normal steam phase eruption usually lasted nine or ten minutes; this was one of the few characteristics of Fantail to be extremely consistent throughout the summer. This past week, however, the major part of the eruption lasted 2-1/2 to four minutes. Then the end was signaled by an abrupt drop from about forty feet to twenty feet. From twenty feet the water dropped suddenly again to half that. The drops were as distinct at various levels as the rise had been.

Previously steam phase plays totally emptied the main crater. This week, the level dropped twenty to twenty-six inches down and stayed there. Surging and splashing continued, steadily weakening, as the crater began to fill. Fantail's entire behavior pattern has suddenly changed. One possible explanation is a heat shift of some kind. Ouzel has reverted to being a steady spouter only one to three feet or so high; yet it remains as hot as ever at 206°F, so it can be discounted as the heat source Fantail is drawing upon. The top pool has remained as unperturbed as ever, in both temperature and behavior.

One feature nearby that has shown distinct changes in heat flow is the hot ground to the north which has begun to intensify. In previous months, most of the actual activity and frying-pan springs had collected in a corner of the far northern edge of the warm tract. Now small, hot frying-pans have begun to break out along the eastern edge of the tract, and a hot strip has begun extending back toward Fantail. It cannot be known for certain, but this intensifying of heat to the north could have affected Fantail as well.

September 1: In just the last two days changes have again occurred. All cycles have sped up except for refilling, which has actually slowed down. It used to take 3-1/2 hours to completely fill a totally empty crater; now it takes 1-1/2 to 2 hours to fill a crater already three-fourths full. Generally the refilling process starts out extremely slowly at about one inch in fifteen minutes. After the first half-hour this picks up to four to six inches per quarter hours. Then, when the level reaches about six to eight inches below overflow the process again slows to a crawl. A notable exception came after the fourth play of the 31st: here the refill started off by gaining four inches each in the first two quarter hours; then only an inch was gained in the following two quarter hours; after this the next rate was 5-1/2 inches in fifteen minutes.

Overflow now takes two attempts before becoming massive. While this was never known to happen during the steam phase eruptions, it has become the norm now. Overflow reached massive on the first try in only two of the nine observed eruptions.

Hot periods have had consistent durations with consistent pauses: hot periods last three to six minutes and come six to ten minutes apart. Events progress fairly quickly, and each level of activity comes in a minute or less: the first one to two foot surge comes about a minute after massive flow, three foot surging comes a minute later, and false starts begin a minute after the first three foot surge. There are exceptions of course, especially before eruptions, but this pattern is generally followed.

When steam phase eruptions were occurring, false starts ran quite long, many well over a minute. Now 41 seconds is the longest, with many under 30 seconds. When there are two or three false starts in one hot period, they are 30 to 60 seconds apart. When five false starts occurred in a hot period on July 5, they were one minute, 40 seconds, 37 seconds, 43 seconds and 50 seconds apart.

During the time of the steam phase eruptions, it was rare for there to be more than one false start per hot period: July 5's events were extremely unusual; they have never been equaled. Two false starts in a single hot period, however, has become almost commonplace. This is anomalous considering how short these intervals are. Again, it appears that Fantail possesses an overabundance of energy.

Another odd quirk of behavior is how suddenly surging starts at the beginning of a hot period. In the past, a surge of about a foot or two preceded three foot surging, and three foot surging preceded false starts; sudden jumps of one to six feet or zero to three feet occurred but rarely. Now such jumps are happening once or twice a day. In fact, one leap from flat sizzling to a six foot false start was witnessed. Again, it seems that an overload of energy is creating such febrile behavior.

It has always been customary for overflow to stop completely for a pause after a false start or particularly heavy surging. Even now, this usually occurs; the pauses in overflow commonly last 1-1/2 to 5 minutes. In keeping with an overabundance of energy, however, there are occasions when overflow does not stop at all after a false start. Yet, there were two eruption cycles in which relatively long rest-periods were needed after false starts; during these rest-periods, overflow ceased after every hot period, no matter how weak.

In the past, overflow after a false start would stop three to seven minutes after the cessation of massive discharge. Now this takes only a minute or two. The entire sequence of hot periods and pauses has speeded up recently. The only time a really long hot period occurred was right before an eruption, when on one occasion the eruption ended a ten-minute hot period.

In May and early June, it was not uncommon for Fantail to take over a minute to climb to full eruption; in fact, one ascent took three minutes, 40 seconds. Most ascents, however, took between 11 and 50 seconds. After early June the really long climbs were no longer seen. The time of ascent since August 30 has remained about 25 to 45 seconds, in spite of the fact that they *seem* longer because of a general lack of vigor. It was mentioned in the last section that discharge from the small crater had all but ceased. In the last two days overflow has begun again. Sometimes the small crater can nearly equal the large crater in height and volume of discharge.

On the 30th a small steam vent was discovered in the northeastern corner of Fantail's main crater. This vent was active at times between 1983 through 1985, along with a string of satellite vents extending north from the edge of the crater. It was thought at the time that these were connected to the growth of the hot ground to the north. All of them ceased activity, however, when Fantail began to erupt. Now some of this activity has begun to reappear.

The hot ground itself has begun to intensify just since the last week. Steaming soil has actually broken into small frying-pans. The heat is also migrating east toward the river. If this continues unchecked it may well begin to rob energy from Fantail.

September 30: The intervals between Fantail's eruptions are gradually lengthening, and the eruptions have remained short. The intervals have lengthened from the occasional 4-1/2 hour to a consistent 5-1/2, then 6 hour, then 7 hour interval; yet the eruptions have stubbornly remained aborted. There has been a slight increase in height, but not in length or general vigor of play.

Other evidence of a general winding-down have also been present: on September 11 and 12 overflow ceased after almost every hot period. Especially on the 11th, overflow stopped after virtually all hot periods, vigorous or weak; and these pauses lasted three to five minutes. In fact, total pauses between hot periods lasted seven to ten minutes, as opposed to four to six minutes for the hot periods themselves.

Hot periods and pauses were almost even in length preceding the first play of September 12. Then during the total interval observed on September 12 pauses shortened to three minutes. Overflow ceased for only one to three minutes, when it stopped at all. This became especially true as the second eruption approached: the hot periods became less vigorous and closer together.

False starts were plentiful on September 11. Before the second September 12 play no false starts were seen at all; the surging looked weak.

An interesting pattern in the boil-ups in the east crater was observed by Mary Ann Moss: all of the east crater boil-ups either came right before the hot period began, or right afterward, before the first main crater surge. While the significance is unknown, this is still of interest.

October 6: Hot periods in the first three days of this week have lengthened considerably, to 15 to 20 minutes. Sometimes vigorous surging or false starts come rather late. Surging is most frequently extending through pauses, however, and through following hot periods for several hot periods in a row; this is the same type of activity seen at this time last year; this surging is sometimes only a foot, but can at times be from one to two feet high. The major difference this year is that it matters where on the pool the surging occurs: for the most part, hot period surging occurs out from the edge of the pool, extending toward the center; in the pauses *between* hot periods, boiling one to two feet occurs right along the east edge of the large crater, where last year's surges also occurred.

Massive flow is once again following initial overflow without a pause. During the 3-1/2 hour intervals surging also came right on the heels of initial overflow. In spite of the much longer intervals, surging and boiling still begin with the first overflow. Overflow now ceases only after false starts; it does not stop after every hot period as it did in late August.

During the three days of observation two eruptions have been preceded by massive false start activity. The occurrence of multiple false starts in a single hot period was exemplified best by the July 5 morning eruption. Late in August two false starts per hot period became quite frequent. But the type and magnitude of the false starts were entirely different: on July 5 were observed six foot to fifteen foot surges, and the pool dropped well below overflow afterward; in late August, the surges were four to six feet and had no effect on water level or delay of eruption.

Both false start sequences this weekend were extremely vigorous, and both resulted in intervals of over eight hours. In both cases, the actual surges were shorter than those on July 5 and much closer together. Again, overflow ceased entirely between the surges, then the pool dropped several inches when it was over. The eruption delay came when Fantail had to recover from this drop in water level, and this process caused the intervals to be over an hour longer than normal.

Despite this increase in unusual false start activity, the only consecutive false starts was for one surge to immediately precede the eruption-delaying sequence: this resulted in paltry two consecutive false start hot periods. False starts seem to be a rarity these days, and the two extraordinary series seen recently were actually rather freakish. There seems to be a general lack of enthusiasm in the hot period surging that made a distinct contrast to the febrile intensity of the surging seen in late August. This supports the suggestion that Fantail may be winding-down.

The only aspect of the eruptions which seems to have improved are the heights, which have been getting higher, and more water is coming from the east crater. The maximum height, however, is still attained slowly. The sizes of the eruptions vary from an estimated 45 to 75 feet. As a general rule, the larger plays come after the longer intervals; for instance, both of the eruptions delayed by false starts were about 75 feet high.

Post eruption activity is growing in complexity and is becoming more puzzling. On October 4, it was noted that there was boiling in the east crater, along the north edge, that appeared to be entirely independent of the boiling and surging in the main crater. It starts fifteen to twenty minutes after the eruption, while the crater is filling, and stops 30 to 40 minutes later. This has never been seen before. In addition to this, two tiny, spitting holes were discovered on the north shoulder of the east crater; they begin spitting when the water level is down about 18 inches and stop when there is an inch or two of water over them, about an hour later.

Another interesting development is the number of little, sputtering holes popping up along the edge of the main crater. On August 30, the 202°F renewed steam vent had been discovered. Now even more sputs are appearing in the northeast corner of the main crater, beside that first steam vent; all of these sputs extend north from the crater's edge.

The activity in the main crater was all seen last year at this time, then disappeared when Fantail became a geyser. Their reappearance indicates a northward shift of energy toward the hot ground. The hot ground itself is extending more and more east and south toward Fantail; and the activity is still intensifying; more frying pans are appearing almost daily. This might well end with a new spring sometime in the near future.

October 11: In both the long and the short intervals, surging still began after overflow. There were two known exceptions to this, both on October 9; on these occasions surging still started within three rises of massive flow, which is still early.

Early in the intervals pauses are hard to distinguish from hot periods; this is due to only slight drops in water level, and surging that continues through pauses. As the interval progresses, hot periods become more distinct, as water levels drop more between them. There is also a 2°F difference in pool temperature between pauses and hot periods. This remained true even when one to two foot surging continued through several pauses; the only change in surging was that hot period activity tended toward the center of the pool, and pause activity came up along the east edge of the main crater; then the only difference between hot periods and pauses was the amount of overflow and the temperature.

Once again there have been jumps from zero to three feet in hot period surging. This comes, however, amid generally weak hot period activity; no false starts have been witnessed since earlier in the week. The only vigor shown at this time have been periods of very heavy three foot surging.

Most hot periods are six to ten minutes long. Right after initial overflow hot periods can last thirty to fifty minutes. During the shorter hot periods, three foot surging begins quite soon after massive overflow; during the long hot periods three foot surging sometimes does not start until eight to ten minutes into the massive flow.

No matter how long or how short the hot periods are, nearly all pauses between them are 3 to 4-1/2 minutes.

Eruptions tend to occur late into the hot periods: twice, in fact, surging had died down toward the end of a hot period, then suddenly heaved up again and built into an eruption; most plays came eight to fifteen minutes into the hot periods; only a few eruptions came four to six minutes into the hot periods.

Eruptions are still generally higher than in late August; they are now about 50 to 75 feet high. With such erratic intervals, it has become obvious that large eruptions come after longer intervals, and the smaller plays come after short intervals. Following this, it is not surprising that the post eruption drop in water level is also governed by the size of the play: the larger the eruption, the farther the pool drops afterward; the maximum drop was 27 inches, the most common being 23 to 24 inches down.

Intervals this week were irregular: they ran anywhere from 4-1/2 to 7-1/2 hours; and they jumped about in erratic fashion. This is unlike earlier this season when the interval length varied gradually.

Post eruption activity has remained the same as that described on October 6. All of the sputter holes are still active. The hot ground has continued to expand, mostly toward the river—and it is still believed that this growth is related to Fantail's current activity. The sputtering holes are indicative of energy moving *away* from Fantail and *to* the hot ground.

There is further evidence of the hot ground drawing energy from other nearby springs: springs to the north and northwest, which had previously heated up, have in the last month dried up and lost their heat. Even springs right in the river have ceased activity. Everything in the vicinity appears to have sacrificed itself to the still growing hot ground; and it seems that Fantail is no exception.

October 19: In just one week, Fantail's entire mid-interval activity has changed. The longest known intervals have been recorded. Hot periods are hard to distinguish from pauses, and eruptions are coming ever father apart. All evidence points to Fantail's coming dormancy.

Hot period cycles have become rapid and shallow: it is difficult to tell pauses from hot periods; the latter are about two minutes long, pauses about four minutes; the rises and falls of the water level are slight, barely marking them from one another. Temperature, however, reveals a 2°F difference, and this remains true even when there is heavy surging during the pauses: hot period surging measures 205°F to 206°F, while boiling during pauses is only 204°F. Only once did the boiling during a pause, and the resultant 204°F temperature, continue through a period of massive overflow.

Previously, hot period surging occurred out toward the center of the pool, and surging during pauses came up along the main crater's east edge. This time all of the boiling, including that during pauses, occurred toward the center of the pool.

Most of the time, hot periods begin with massive overflow, and the first surge of boiling comes a minute or so later. On rare occasions, the first surge would come several seconds before the massive flow. The latter became commonplace in the middle of this last interval; it continued for several hot periods, then ceased.

Normally, three foot surging died down gradually to sizzling by the end of a hot period. This weekend the three to four foot surging just dropped abruptly, and massive flow dropped immediately afterward. Not once did surging die down gradually.

In late August, it was rather common for surging to suddenly leap from sizzling to three feet, or from one to six feet, without working up to it gradually. This was, at the time, considered a sign of increased energy. In contrast, a single jump from zero to three feet occurred during this last recorded full interval.

Unlike last week, there was this time very little surging between hot periods. This week, it began two thirds of the way through the interval and lasted for four hot periods; then it happened once more just before the eruption. The first time there was no change in surging between hot period and pause, and the temperature remained the same. Later, when surging reached three feet, there was a 2°F rise between pause and hot period. During the surging between hot periods, the one to two foot boiling began dying down about half-way through the pause, and was no more than sizzling by the time the next hot period began.

In 1985, there had been a moderate overflow and constant boiling; every minute or so surges up to three feet occurred above the general churning. When this happened these surges were false starts. This last recorded interval show numerous three to four foot false starts, and all of these came directly from one foot surging. Yet no six foot false starts occurred at all.

It seemed as though the hot period cycle was too fast to allow the larger false starts to build up; the hot periods were only two minutes long, and they did not lengthen to accommodate vigorous activity of any kind.

This was also true with the eruptions: when they finally came, they had to begin within the two minute limit; everything had to build quickly. This may be why eruptions have trouble getting started. In the past, quick starts were rare—so this is probably why eruptions are so few and far between.

As with last week, long intervals mean larger eruptions: all plays seen this week were in the range of 70 feet high.

For some reason the east crater post eruption activity has ceased entirely. The boiling independent of the main crater has ceased—and the two tiny spitting holes on the east crater's inner shoulder have disappeared; it is hard to tell, now, where the latter existed, without the activity to mark them.

As alluded to earlier, the two observed intervals are the longest on record for this geyser: the first was over ten hours, the second over thirteen hours. The eruptions themselves were still aborted, without steam phases.

Journal of Observations of Activity in Ouzel

September 30: Ouzel has remained a steady boiler, not reacting at all to Fantail except to cease activity entirely for about an hour after Fantail has played.

Bob Bohman observed Hillside Geyser during an eruption of Fantail to see if there was any reaction. The water level in Hillside was down about twelve feet and remained totally unperturbed by any eruptions of Fantail. Apparently, any earlier sympathy reported between these two springs was coincidental.

October 6: Ouzel has once again taken on geyser proclivities. It increases and decreases surging on a twenty to thirty minute cycle. First there is a sudden surge in boiling to three or four feet; this goes on for perhaps a minute, then begins to wane; by the time activity dies to sizzling, the cycle is ready to repeat. Then all activity ceases for about an hour after Fantail's play. This is about the only true geyser activity seen from Ouzel in quite some time.

References

Bryan 1986 Bryan, T.S., *The Geysers of Yellowstone.* Revised edition. Boulder, Col.: Colorado Associated University Press, 1986.

Hutchinson 1986 Hutchinson, Roderick A., "Rejuvenation of major geyser activity in the Cascade Group, Upper Geyser Basin.", unpublished memo dated April 21, 1986.

Marler 1956 Marler, George D., "How Old is Old Faithful Geyser?", *American Journal of Science*, vol. 254, p.615-622. October 1956.

Marler 1964 Marler, George D., "Effects of the Hebgen Lake Earthquake of August 17, 1959, on the Hot Springs of the Firehole Geyser Basin, Yellowstone National Park", U.S. Geological Survey Professional Paper 435-Q, 1964.

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

Marler 1974 Marler, George D., *The Story of Old Faithful*, Yellowstone Library and Museum Association., 1974.

Marler & White 1975 Marler, George D. and Donald E. White "Seismic Geyser and Its Bearing on the Origin and Evolution of Geysers and Hot Springs of Yellowstone National Park", *Geological Society of America Bulletin*, vol. 86, p.749-759. June 1975.

Muffler, et. al. 1982 Muffler, L.P.J., D.E.White, M.H.Beeson, A.H.Truesdell, *Geological Map of Upper Geyser Basin, Yellowstone National Park, Wyoming*, U.S.Geological Survey Miscellaneous Investigations Map I-1371. 1982.

USGS 1966 U.S. Geological Survey, Thermal Map Series of the Upper Geyser Basin, Yellowstone N.P. (circa 1966) with 1974 updates and names, sheet V.A.1. BISCUIT [Basin]. Unpublished on acetate, 1966.

A Possible Indication of the Internal Cavity Configuration of Fantail Geyser

by J. R. Hobart

Abstract: A curious phenomenon was observed during the late stages of Fantail Geyser eruptions. A cyclic pulsing would start about 30 to 40 minutes into the eruption when the pool had been emptied. A sound of outrushing steam and entrained water would be heard for several seconds, then quiet for a similar interval. The process would repeat ... over and over, like a cycling engine. A physical model for this phenomenon is proposed that could be used to determine one of its internal cavity dimensions.

Fantail Geyser began erupting in early 1986 with a fury that was awe-inspiring to all sufficiently fortunate to witness it.

Each eruption began slowly, the geyser working mightily to set up a circulation through the ten feet of water overlying the vent itself. After several minutes, the pool level began to lower. As a convective motion began, the full force of the eruption was directed obliquely across the pool to the base of a narrow rock bridge dividing the pool into two parts. As a result, the water and steam were deflected upward into a roiling, noisy "V" shape to hieghts of 40 feet or more with a fury unmatched by any geyser of comparable size (Figure 1). Sufficient force to propell an unimpeded column to 100 feet was probably present. After 10 minutes of unbridled fury, the eruption power began to diminish. Another 10 or 20 minutes was required to deplete the remaining water in the pool.

When the water supply was as far gone as most observers, a cyclic chugging would start. Each cycle would begin with a low frequency pounding sound signalling the outset of a "whoosh" of steam, ending with a second definite pounding sound. A pause followed. The sounds were clean, with no indication of any sloshing or mixing of steam and water.

Repetitive timing of a videotape showing eight cycles yielded a period of 6.53s consisting of a 3.58s steam phase followed by a 2.95s pause. The steam phase seemed more variable than the pauses.

One model for this phenomenon comes to mind. It consists of a superheated rock surface at depth with a water source above and to the side of the vent column as modeled in Figure 2.

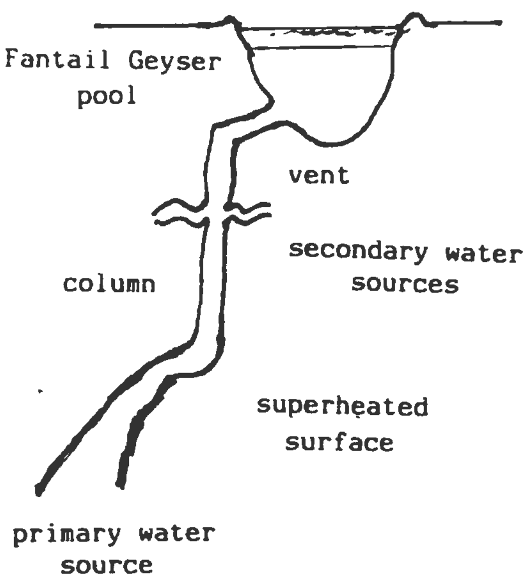
A small amount of entering water flashes to steam upon descending to make contact with the superheated surface. It expands upward, preventing entry of more water until the pressure is reduced via adiabatic expansion. This permits a small amount of water to again enter the column and fall to the superheated surface, flashing to steam and starting the cycle anew.

This cycle could be modeled as a thermal piston with appropriate mixed phase fluid, viscosity, and column surface drag parameters. In a vacuum, the free fall of this system would be 43m. With realistic flow field and boundary conditions, the true distance could be closer to 5m, but a detailed analysis has not yet been performed.

Several additional thoughts. If the column water source were the only one, an upper limit to incoming water flow could be determined by the rate of water rise in the pool once the steam phase has abated. On the other hand, the vent opening was not observed closely during cycling. It is possible that the water is simply falling from a cavity at the vent opening itself. In this case, the total column height could be determined. However, this does not appear to be the explanation, because cycling is nearly invariant with time for many minutes, suggestive of a constant water source.

Let's hope for renewed opportunities to obtain additional data to shed light on this interesting phenomenon.

See Plates for figure 1



POTENTIAL EVENT SEQUENCE

1. steam expands upward

2. pressure drops, allowing water to come together, creating the sound signalling the end of the steam phase

3. water falls in the column during the pause

4. water strikes the superheated surface, flashing to steam with a pounding slap to initiate the cycle

Figure 2. Fantail Geyser Model

Eruption Characteristics of Silver Globe Group Vents
Biscuit Basin, Yellowstone National Park, Wyoming

Grover Schrayer III and David Scheel

Abstract

The Silver Globe Group of geysers is located in the Biscuit Basin, approximately 2 miles north of Old Faithful. Within this small area of about 20 by 40 feet are 5 geysers that display sympathetic behavior. This short report details some of the characteristics of the group.

Introduction

A casual visit on September 5, 1988 to the Silver Globe Group of the Biscuit Basin was so interesting that the authors returned the following day for more detailed study. Further observation was planned; however the fire situation in the Old Faithful area became too serious.

Descriptions and Characteristics of the Silver Glove Vents

Figure 1 shows the relative positions of the five vents of the Silver Globe Group. These vents have been most recently described in [Bryan, 1986], though their activity changes from year to year.

"Cave" Vent

"Cave" is completely quiet only just following an eruption. Within ~~a~~ short time after an eruption splashing resumes as the water level rises in the crater. There was no way to tell how strong the splashing would become before the eruption ended abruptly and the water level dropped. The beginning of an eruption was not distinct, and an eruption could consist of anything from a series of 1 to 2 foot splashes to forceful angled jets hurled out to a distance approaching 40 feet. It was purely judgement as to what was "preplay," and what was a minor eruption. In all cases, however, eruptive activity ceased abruptly when the water level dropped. Durations noted were 10 to 30 seconds, intervals 9 to 47 minutes.

"Spring" vent

The eruptions of this little vent were little more than one or two quick splashes during times of high water level in the "Cave" vent. These splashes were at their highest 1 foot tall.

"Slit" vent

All the eruptions of "Slit" we observed were very similar. After a few seconds of overflow, "Slit" began steady jetting to 15 feet. It would maintain that height for most of the eruption, then slowly lose power and die, perhaps with a few last gasps. Durations observed were 1m26s to 2m18s, intervals were between 23 and 43 minutes.

"Pool" vent

Eruptions of the "Pool" consisted of ragged splashes 1 to 3 feet high. Between eruptions, the water level would rise and fall, and occasionally an isolated splash occurred during high water. The most forceful eruption that we observed was along with near-simultaneous eruptions from "Cave," "Spring," and the adjacent "Drain" vent.

"Drain" vent

We labeled this the "Drain" vent for its normal function, which was to swallow overflow from the "Slit" vent. On one occasion, however, "Drain" was observed to erupt along with "Cave," "Spring," and "Pool." The water level in "Pool" could be high while "Drain" was taking in water.

Reference

Bryan, T. Scott. *The Geysers of Yellowstone.* Boulder: Colorado Associated University Press, 1986. pp. 98-100.

Silver Globe Group
Biscuit Basin, Yellowstone National Park
Observations: September 5 - 6, 1988

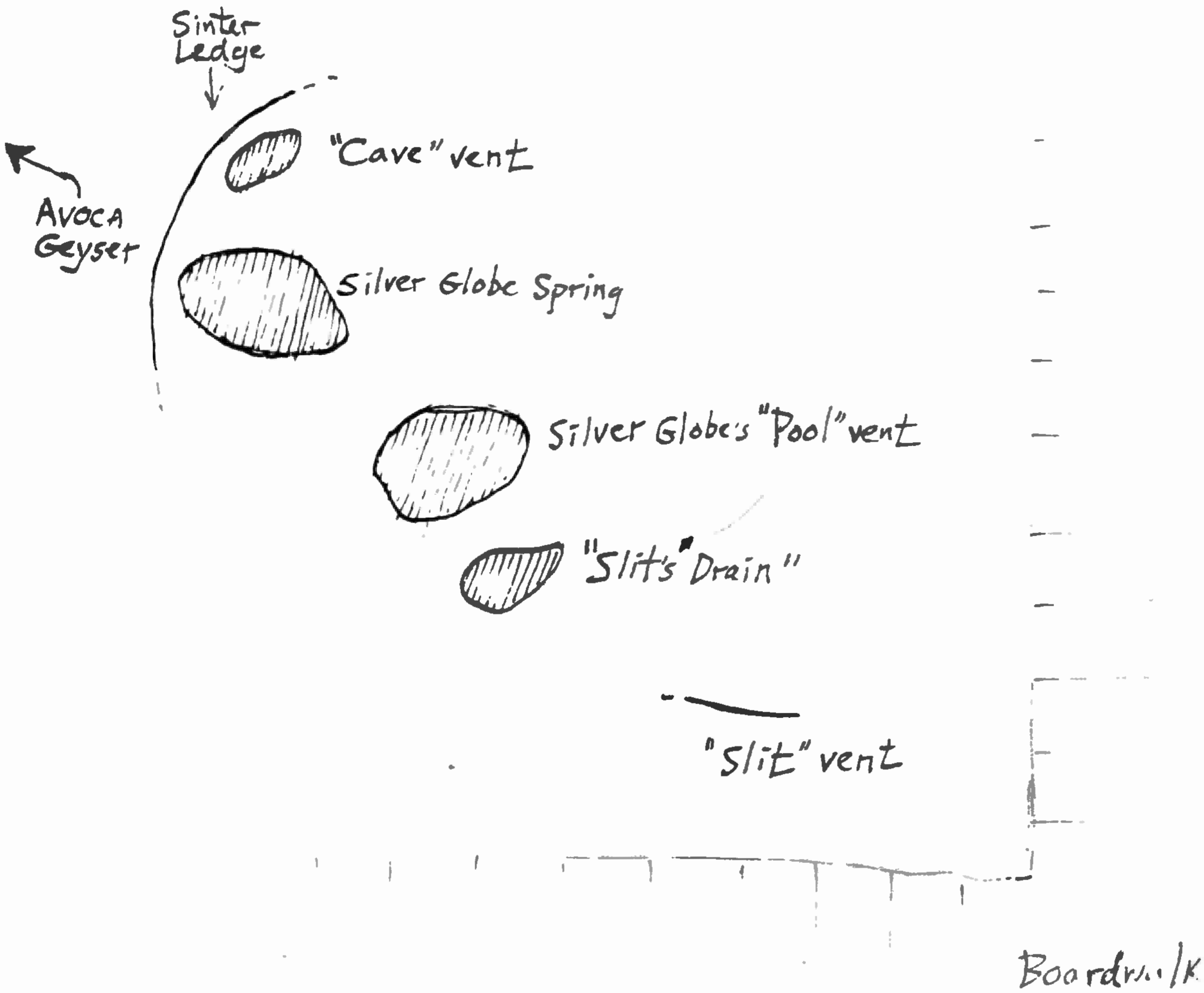
September 5, 1988

18:26 "Slit" vent erupts.
18:44 "Cave" vent minor eruption.
18:58 Avoca Spring erupts.
18:59 "Cave" vent major eruption. ("Pool" vent dropped prior to this.)
19:09 "Slit" vent erupts.
19:20 "Pool" vent splash.
19:27 "Avoca Spring erupts.
19:33 "Spring" vent erupts.
19:38 "Pool" vent splash.
19:42 "Pool" vent splash.
19:43 "Pool" vent splash.
19:46 "Cave" vent erupts, followed by "Spring", "Pool", and "Drain" vents.
19:47 "Slit" starts erupting as others die down.
19:49 "Slit" vent ends.

September 6, 1988

15:12:45 All quite.
15:17:04 "Slit" vents starts. Duration 01m26s. "Pool" vent calm, "Cave" had large splashes during "Slit" eruption.
15:24:50 "Cave" erupts. Duration 00m10s.
15:33:00 "Pool" filling to gray line.
15:33:31 "Pool" drops.
15:34:59 "Spring" vent erupts. Duration 00m10s.
15:35:00 "Cave" erupts. Duration 00m27s. "Pool" dropped 8" after "Spring" and "Cave" eruptions.
15:37:48 "Slit" overflows. Drops at 15:39.
15:40:56 "Slit" overflows and erupts. Duration 01m37s.
15:44:30 "Cave" vents splashes. "Pool" rising.
15:45:33 "Spring" vent splashes to 8".
15:51:00 "Drain" and "Pool" rising.
15:52:10 "Cave" splashes 3ft. "Pool" rising.
15:52:25 "Drain" and "Pool" drop 6".
15:53 "Drain" and "Pool" rising.
15:55:06 "Cave" splash.
15:56:10 "Cave" splashes. Water remains high.
15:57:05 "Spring" vent erupts.
15:57:07 "Cave" erupts. Duration 00m30s. "Pool" and "Drain" fill during "Cave" eruption.
15:59:20 "Pool" and "Drain" drop 8" and stop bubbling.
16:01:20 "Cave" resumes splashing and "Pool" bubbling.
16:05:26 "Spring" splashes to 6".
16:06 "Spring" and "Cave" erupt. Duration 00m30s.
16:10:55 "Cave" resumes splashing.
16:16:34 "Slit" overflows, drops at 16:17:09.
16:20:37 "Slit" overflows and erupts. Duration 02m18s. Three pauses during the eruption.
16:21:49 "Cave" erupts to 4ft. Ends at 16:22:06.
16:25:04 "Cave" resumes splashing.
16:31:58 Avoca Spring erupts.
16:32 "Cave" splashing heavily. "Spring" splashes 8".
16:37:05 "Cave" resumes splashing.
16:54:55 "Drain" rises and drops 3".
16:57:29 "Cave" erupts 5ft with "Spring" splashing to 8".
16:58:12 "Pool" splashes 3".
16:58:32 "Pool" splashes 3".
16:59 "Cave" resumes small splashes.
17:00:10 "Pool" splashes 4"

Silver Globe Group
from a sketch by Dave Scheel



Eruptive Behavior of Till Geyser

Lynn Stephens

Abstract

Till Geyser's pattern of activity is divided into five phases: a quite period, overflow, eruption, pause, and a cycle of minor activity. During the period of minor activity Till has steam bursts, or minor eruptions. The durations, intervals, and nature of these steam bursts follow a distinct pattern. This paper describes this activity and the pattern that it follows.

Introduction

Till geyser has steam bursts, or minor eruptions, following an eruption. Marler described these as "an occasional puff of steam with a little extrusion of water," and indicated that they continued "for a considerable period after an eruption." [Marler, 1973, p. 369]. The purpose of this paper is to describe this cycle of minor activity.

The following periods of activity were observed: Three complete periods of minor activity (September 2, 3, and 5, 1988); three partial cycles, one (September 1, 1988) with the preceding eruption, and two (September 3 and 5, 1988) with the succeeding eruption as reference points.

Till's common interval is in the range of 9 to 10 hours. Sometimes shorter intervals in the 5 to 7 hour range will occur. T. Vachuda [personal communication] indicated that when he observed Till's cycle of minor activity, the intervals seemed to vary depending upon the amount of minor activity following a major eruption. For each of the cycles I observed, the time between major eruptions was ≈9.5 hours. This is Till's more common interval, so my observations are only applicable to activity between the longer intervals.

Till's cycle of activity

Till's cycle of activity consisted of five segments:

1. Period of quiet
2. overflow
3. major eruption
4. pause before minor activity
5. cycle of minor activity

A typical cycle consisted of roughly 5 1/2 hours of quiet, 30 to 50 minutes of overflow, 30 minutes of major eruption, 15 minutes of pause, and 2 hours and 45 minutes of minor activity, all of which comprise the average interval of 9 hour 30 minutes to 9 hours 50 minutes. Details of each segment follow:

1. Quite Period

Two "quite" periods were observed -- one lasted 5 hours 19 minutes, the other lasted 5 hours 27 minutes. During the first 2 to 2 1/2 hours of this period, there was a small amount of water in the rocks at the bottom of the lower crater, occasional gurgling sound were heard. Approximately 2 hours before overflow occurred, the water level in the lower vent began to slowly rise. No water was visible in the upper vents prior to an eruption.

2. Overflow

After the lower vent filled, there was a period of overflow prior to the eruption. Three periods of overflow were observed, lasting 28, 43, and 47 minutes.

3. Eruption

The eruption was preceded by a sudden surge in the water level of the lower vent that flooded the platform and runoff channel. Eruptive activity began twenty to thirty seconds following the surge. Observed eruptions continued for thirty to thirty two minutes.

Water erupted from both the upper and lower vents during the eruption. The action of the upper vent was of a splashing nature, with some jets shooting up through the splashes. The water from the upper vent splashed west over a sinter-encrusted log about 10 feet from the vent. Several small vents to the south, east, and north of the upper vent played from 6 to 12 inches high.

The lower vent has a sinter ledge on the south end of the crater and a sinter shoulder that projects from south to north partially dividing the crater. Most of the action from the lower vent came from the east side of the shoulder. The sinter ledge deflected the water and caused the water that was erupted to be ejected horizontally.

About 20 minutes into the eruption action from the upper vent became intermittent, with pauses of 20 to 30 seconds. Action from the lower vent continued during these upper vent pauses. When the activity terminated it was quite sudden. On one of the upper vent pauses the lower vent also quit. The silence was noticeable. There was no visible water in the lower vent following the eruption.

<u>4. Pause</u>

Following the eruption, Till paused before beginning the minor activity. Two of the pauses were 16 minutes in length; the other was 17. No water was visible in either vent during the pause.

<u>5. Cycle of Minor Activity</u>

The durations of the minor activity cycle, measured from the beginning of the first burst to the end of the last burst, were 2 hours 44 minutes, 2 hours 42 minutes, and 2 hours 34 minutes. Despite the ten minute difference between the longest and shortest duration, each of the cycles consisted of exactly 18 separate minor eruptions.

The start of a steam burst was preceded by a noticeable increase in steam from the lower vent, small vents around the upper vent, and a vent on the north end of the sinter-encrusted log. The upper vent steamed lightly, with a slight increase just before the steam burst.

The actual start of the steam burst was a noisy "poofing" sound. The noise and subsequent water came from the upper vent. The lower vent steamed, as did several small vents around the upper vent.

Although the first two minor eruptions following a major eruption consisted of steam without visible water, in subsequent minor eruptions both steam and water were ejected. The bursts began with a five to ten second steam phase, followed by a water phase, and a 10 to 15 second steam phase at the end.

Small droplets of water were visible in the third, fourth, and fifth bursts. The size of these droplets increased until approximately the tenth burst, when they were marble sized. From approximately the tenth burst on, the activity consisted of two separate bursts of water, reaching 6 to 8 feet in height. The final three or four steam bursts consisted of three separate bursts.

The duration of the steam bursts followed a distinct pattern (Table 1), gradually decreasing from an average of 111 seconds for the first burst to 49 seconds for the eighth burst. After this point the average duration of each burst oscillated around 52 seconds.

The interval between the end of one steam burst and the beginning of the next steam burst also showed a definite pattern (Table 2). The interval gradually decreased until the sixth burst. The interval between the sixth and seventh burst increased. This increase continued such that the interval between the final two bursts averaged about 13 3/4 minutes. The pattern for the average period (start of one steam burst to the beginning of the next steam burst) showed the same pattern as the interval.

Reference

Marler, G.D. *Inventory of thermal features of the Firehole River Geyser Basins and other selected areas of Yellowstone National Park.* National Technical Information Service Publication Number PB-221289.

Table 1
Duration of Steam Bursts

Burst	Mean	Std. Dev. (sec)
1	111	3.3
2	91	6.0
3	89	5.7
4	77	1.9
5	73	2.5
6	63	1.4
7	55	3.3
8	49	3.3
9	54	1.6
10	56	6.5
11	47	2.5
12	54	6.2
13	54	6.6
14	51	2.2
15	48	3.1
16	52	1.3
17	53	1.9
18	52	12.7

Table 2
Interval/Period of Steam Bursts

	Interval		Period	
Bursts	Mean	Std. Dev.	Mean	Std. Dev.
1-2	6:49	5.9	8:43	5.0
2-3	6:29	5.7	8:00	9.5
3-4	6:20	8.2	7:49	9.4
4-5	6:14	9.9	7:31	10.6
5-6	5:55	5.7	7:07	4.7
6-7	6:00	8.2	7:03	6.8
7-8	6:16	24.0	7:08	20.2
8-9	6:33	15.9	7:25	13.1
9-10	7:14	12.4	8:08	11.9
10-11	7:35	15.5	8:31	9.3
11-12	7:58	5.4	8:44	5.3
12-13	8:58	31.7	9:52	28.2
13-14	9:29	61.0	10:20	56.8
14-15	11:39	71.8	12:30	69.8
15-16	11:11	20.1	11:59	19.0
16-17	13:09	118.6	14:01	117.5
17-18	13:35	15.1	14:28	16.4

Table 3 - Observations

September 1, 1988: Eruption 0832
Incomplete Cycle

Time	Duration	Interval	Period
0918.29*	1:55	6:42	8:37
0927.06	1:38	6:19	7:57
0935.03	1:26	6:04	7:30
0942.33	1:14	6:07	7:21
0949.54	1:07	6:05	7:12
0957.46	1:07		

*Initial steam burst

September 2, 1988: Overflow 1248
Eruption 1335
Complete Cycle

Time	Duration	Interval	Period
1420.56	1:47	6:51	8:38
1429.34	1:23	6:25	7:48
1437.22	1:22	6:16	7:38
1445.00	1:14	6:10	7:24
1452.24	1:10	5:54	7:04
1459.28	1:05	5:49	6:54
1506.22	:57	5:50	6:47
1513.09	:45	6:13	6:58
1520.07	:54	7:30	8:24
1528.31	1:04	7:19	8:23
1536.54	:50	7:54	8:44
1545.38	1:01	8:17	9:18
1554.56	1:02	9:14	10:16
1605.12	:54	10:37	11:31
1616.43	:51	10:43	11:34
1628.17	:52	11:16	12:08
1640.25	:52	13:14	14:06
1654.31	:50		

September 3, 1988: Incompl. Cycle
Succeeding eruption: 1502

Time	Duration	Interval	Period
0758.45	:45	10:15	11:10
0809.55	:49	10:12	12:01
0821.56	:56	12:09	13:05
0835.01	:49	14:16	15:05
0850.06*	1:02		

*Final steam burst

Table 3 continued next column.

September 3, 1988: Overflow 1426
Eruption 1502
Complete Cycle

Time	Duration	Interval	Period
1550.52	1:55	6:55	8:50
1559.42	1:34	6:37	8:11
1607.53	1:30	6:31	8:01
1615.54	1:18	6:28	7:46
1623.40	1:16	5:48	7:04
1630.44	1:02	6:04	7:06
1637.50	:50	6:11	7:01
1644.51	:48	6:52	7:40
1652.31	:52	7:11	8:03
1700.34	:48	7:56	8:44
1709.18	:46	7:51	8:37
1717.55	:46	9:07	9:53
1727.48	:46	8:26	9:12
1737.00	:48	13:20	14:08
1751.08	:50	11:30	12:20
1803.28	:53	12:19	13:12
1816.40	:56	13:49	14:45
1831.25	1:08		

September 5, 1988: Incompl. Cycle
Succeeding eruption 1354

Time	Duration	Interval	Period
0709.10	:52	12:23	13:15
0722.25	:46	11:20	12:06
0734.31	:52	12:18	13:10
0747.41	:49	17:45	18:34
0806.15*	1:00		

*Final steam burst

September 5, 1988: Overflow 1326
Eruption 1354
Complete Cycle

Time	Duration	Interval	Period
1441.21	1:51	6:41	8:42
1450.03	1:37	6:25	8:02
1458.05	1:36	6:12	7:48
1505.53	1:18	6:05	7:23
1513.16	1:12	6:02	7:14
1520.30	1:02	6:08	7:10
1527.40	:57	6:48	7:35
1535.15	:53	6:34	7:27
1542.42	:56	7:00	7:56
1550.38	:56	7:30	8:26
1559.04	:44	8:06	8:50
1607.54	:56	9:31	10:27
1618.21	:53	10:36	11:21
1629.50	:50	11:01	11:51
1641.41	:44	11:19	12:23
1653.44	:50	15:53	16:43
1710.27	:52	13:42	14:34
1725.01	:37		

Great Fountain Geyser - Eruption Patterns
Lower Geyser Basin, Yellowstone National Park, Wyoming

Tomáš J. Vachuda

Abstract

The cycles between, and patterns of, Great Fountain's eruptions are consistent and easily defined. A body of data has been accumulated, and a preliminary analysis of that data is presented. The characteristics of the quiet period, overflow, big boil, pause, eruption and interval are outlined. Of note is the geyser's apparent tendency to have shorter intervals preceding eruptions occurring during the day than those preceding eruptions occurring at night.

Introduction

The Great Fountain Geyser is located 7 miles north of the Old Faithful developed area, on the Firehole Lake drive. It erupts from a 5 by 7 meter pool that is surrounded by a sinter terrace 50 meters in diameter [Bryan, 1986; Allen and Day, 1935].

Great Fountain, one of the first geysers of the Yellowstone area to be studied and described, has been well documented over the past century. The pattern of Great Fountain's eruptions has remained consistent since it's discovery, even though there have been some significant variations in the average length of the eruption cycle. [Marler, 1973], presented a synopsis of historical reports, as well as of his studies of Great Fountain from 1938 to 1971. His reports showed that "prior to the [1959] Hebgen Lake earthquake, the intervals ranged between about 9 and 19 hours, with near a 12 hour average for most seasons." For example, Marler determined 174 intervals between April 1 and September 10, 1958. The average interval was 12 hours 24 minutes; the total range was from 9h15m to 15h15m. The Hebgen Lake earthquake resulted in a sudden decrease in the interval. The 1960 average interval was down to 7h25m. Great Fountain's average interval has steadily increased back towards pre-earthquake levels. By 1970 the average was up to 8h21m. In June, 1988 [Hoffman, 1988] collected 64 observed and inferred intervals, which yielded a range from 8h16m to 13h35m, and an average of 10h43m.

Eruptions vary greatly in their appearance and maximum height. The highest bursts in most eruptions fall between 30 and 40 meters, however some eruptions do not reach over 20 meters, and rare eruptions, observed no more than a handful of times a year, have been measured as high as 70 meters. At present, Great Fountain is one of the three highest active geysers in the world. When active, Steamboat Geyser, at the Norris Geyser Basin in Yellowstone, exceeds the height of Great Fountain. Giant Geyser, located in the Upper Geyser Basin near Old Faithful, also has the been observed to erupt higher than 70 meters.

Great Fountain is not known to be connected with other features. Observations of nearby springs have not revealed any sympathetic patterns. White Dome Geyser, the closest major geyser to Great Fountain, erupts at very irregular intervals, yet attempts to correlate these irregularities between White Dome and Great Fountain have been unsuccessful. A detailed study has not been conducted between Great Fountain and Surprise Pool, or with the nearby White Creek Group. If such a connection exists, the manifestation of it must be very slight.

The Eruption Cycle

Great Fountain follows a consistent pattern. With extremely few exceptions, one can expect to observe the same elements repeated between each eruption. Two of these anomalies, defined in [Marler, 1973], are periods of long overflow, and low ebb. Another irregularity, [Bryan, 1986], is known as the wild phase. A long overflow can last as long as two days, while during periods of low ebb the water remains well below the rim for several days. During a wild phase Great Fountain erupts continuously, though with much diminished strength, for hours or days. The normal eruptive pattern is reinstated within a day of the conclusion of one of these irregularities. In most recent years, no occurrences of these irregularities have been recorded.

Though the components are consistent, the time frames vary substantially. Eruptions in recent times have occurred on intervals as short as 7½ hours and as long as 14½ hours. Additional study is required on some aspects of this cycle, especially on the late stages of the eruption and on the hours immediately following the end of an eruption.

The Quiet Period

The quiet period between eruptions can be divided into two segments, and a clear understanding of this distinction is required in order to predict an eruption successfully. The pool refills within one to two hours after the end of an eruption. At this point the water is constantly boiling, around the edges and sometimes also in the middle. The water level, which fluctuates some, is often high enough to be easily visible, although it does not reach a point of overflow from the central pool onto the outer terrace. When the pool boils at a water level below overflow, an eruption has recently occurred. Several hours will elapse before another eruption takes place.

The second part of the quiet period is also characterized by fluctuations in the water level; however, no boiling occurs on the surface of the pool. The water level varies significantly, sometimes dropping entirely out of sight. Occasionally the water will remain unmovingly at one level for an hour or longer, while at other times there may be surges every 15 or 20 minutes. The presence of surging, in difference to a motionless pool or a very slow and gentle rise in water level, is a positive indication of an impending eruption. Such surging can, however, last a number of hours. Commonly, these surges will gradually reach higher and higher up the inside of the main pool. One of these fluctuations will reach high enough to breach the channels in the sinter surrounding this central pool. The point at which water first escapes onto the terrace is the start of overflow.

Overflow

In most cases there will be only one period of overflow immediately preceding the eruption. Exceptions are referred to as "false overflows." In such instances overflow is achieved; however, after 5 to 15 minutes, the pool again drops and overflow ceases. There is no visible difference between a false overflow and one that develops into an eruption until the pool begins to drop and overflow stops. Observations of false overflows tend to support the conclusion that the start of a false overflow is as vigorous as a true overflow. Some observers, who predict eruptions if Great Fountain regularly for the benefit of park visitors, have been embarrassed to post a firm prediction based on the start of overflow, only to watch the pool drop out of sight a few minutes later. Fortunately, false overflows are rare, and tend to occur in a series. There have been some instances in which, for a period of three to five days, a quarter to a half of all eruptions had two periods of overflow.

The case has been made, that if there are two periods of overflow then the duration of both of them combined will equal the standard length of a normal single overflow [H. Warren, 1984]. There is insufficient data either to demonstrate conclusively or to refute the truth of this observation. In the record of eruption times, the overflow duration is always that of the overflow that leads directly into the eruption.

The length of the overflow period, the interval between the start of overflow and the start of the eruption, varies from eruption to eruption. The annual average of overflow durations varies from year to year. The majority of these durations fall within the range of 55 to 80 minutes. The extremes, rarely observed, are between 45 and 50 minutes on the short side, and between 90 and 110 minutes on the long side.

During the period of overflow the pool gradually becomes more active. When overflow starts there is no boiling whatsoever. Roughly half-way through the overflow period boiling appears around the edges of the pool. The boiling increases in vigor, and moves around the pool. The boil is not steady but, rather, occurs in periods of greater activity separated by periods of calmer waters.

The Big Boil

The "Big Boil" is, by tradition, the start of the eruption. The big boil has been defined as a boil at least 1 meter high. It occurs when, during one of the periods of heavier boiling, the water reaches a height of 1 meter or more. Even though the geyser continues to overflow into the eruption itself, the duration of the overflow is recorded as ending with the big boil. The big boil itself might lead directly into the major bursts of the eruption, or it may end after 15 to 45 seconds.

The Pause

In the majority of cases, the pool returns to a quiet state after the big boil. The period between the big boil and resumption of activity culminating in the major bursts is referred to as "the pause." This pause can be as long as 10 minutes, or less than 1 minute. In a significant number of eruptions, there is not a period of quiet between the big boil and the initial major bursts, *infra*, in what is called a "no pause" eruption.

There is reason for concern regarding the consistency of pause measurements over the years. It has not been definitively determined whether the duration of the pause is timed from the start of the big boil to the initial major burst, from the end of the big boil to the resumption of doming in the pool, or from a mixture of these two possibilities. This question is significant, since the duration of the big boil itself usually exceeds half a minute, and sometimes lasts over a minute. The interval between the resumption of doming after the quiet period of the pause and the initial major burst varies from just a matter of seconds to a full two minutes.

It seems proper that the duration of the pause should represent the actual interval between the big boil, as the start of the eruption, and some other point. It is, therefore, logical to count the pause from the start, rather than from the end, of the big boil. More difficult to define is the correct end of the pause. A rational, though arguably arbitrary designation, would favour the initial major burst for two reasons. First, the initial burst is a more discreet event than the gradual increase in boiling that follows the quiet period of the pause. Second, the initial burst is a unique and spectacular point in the eruption, and is the moment in which most observers take the greatest interest.

Questions about the definition of the pause aside, there is also good reason to doubt the significance of the pause. Pause data has not been correlated with other aspects of the eruption or the interval. Popular tales, such as one proposing that a longer pause results in a stronger eruption, or similarly indicates a greater possibility of a superburst, *infra*, have not found any support in the data. There may, however, be some aspects of the pause worth further study. Of particular interest is a possible correlation between wind speed, wind direction, and air temperature on the pattern of boiling during the overflow.

The entire idea of a pause, as an actual pattern in the geyser's activity rather than an artifact resulting from an arbitrary designation formulated by observers, is suspect. The fact that a pause does not precede every eruption is not of itself meaningful. The circumstances of these "no pause" eruptions are, however, curious. Based upon hundreds of observations, it can safely be said that in instances where there is not a 1 meter high boil followed by a pause, there is a smaller boil, not noted as the big boil, that precedes the eruption by an interval similar to a standard pause. That observation suggests, it is probable that there are "big boils" that do not reach a meter and are indistinguishable from other boils that occur late in the overflow but are not immediately followed by an eruption. The 1 meter designation is arbitrary, but it cannot be lowered to include all boils that immediately precede an eruption because such an event is not always obvious at the time.

This problem also manifests itself in the start times and, therefore, the intervals. In the case of a meter high big boil the eruption will be logged to have started at the boil. In the case of a 90cm boil the eruption will be logged to have started perhaps 8 minutes later when, during the next round of surging, the geyser exceeds the requisite 1 meter and then proceeds into its major bursting without a pause. This inconsistency is no more than 2% of the interval, and should not be considered significant.

An 8 minute pause, on the other hand, represents over 10% of an entire standard overflow. Therefore, the length of overflow would be significantly different in the case of a 1 meter big boil followed by an 8 minute pause, vis a vis a 90 cm boil, followed 8 minutes later by a big boil that developed into the initial major bursts without a pause. This may be reflected by the fact that the average overflow duration preceding an eruption without a pause, is longer than the average overflow duration prior to a long pause. During the years 1983-1986, 129 overflow durations were recorded prior to eruptions with a pause of less than 3 minutes, with an average overflow length of 67.3 minutes. This is almost 5 minutes longer than the 63.6 minute average of overflow durations preceding eruptions with a pause of 6 minutes or longer.

The big boil and pause do, however, play a useful role in the observation of Great Fountain. I know of no instances in which a boil over a meter high was not followed, within 10 minutes, by the initial major bursts. Therefore, while the absence of such a boil does not speak definitively regarding the time of the initial major burst, its presence gives observers a positive indication.

In the majority of cases, the amount of overflow from the pool steadily increases up until the initial major bursts. There is some variation during the overflow period because of increased discharge during periods of heavier boiling followed by a subsidence of flow as the pool subsequently calms. One notable variation on this theme occurs on infrequent occasions immediately prior to the initial major bursts. In such a case, the pool boils up a few meters high, then quiets down. The water level in the pool sinks well below the overflow mark to a point where it is no longer visible from either the boardwalk or from the road.

It is rumored that such a drop of the water level increases the possibility of one of the spectacular eruption types described below. No data exists to support or refute that contention. A number of such occurrences have been observed to yield eruptions that were below average in power, while a number have been observed to yield spectacular eruptions.

The Eruptive Pattern

The eruption itself consists of alternating periods of activity and quiet. Within each of these periods of activity there are individual bursts of water punctuated by short moments of quiet. A typical series of bursts lasts approximately 10 minutes, a standard pause between series is roughly 7 minutes. During a typical eruption, Great Fountain has 4 to 7 periods of activity. Work is currently under way to further understand this pattern [H.R. Hoffman, 1989], and to produce additional quantifiable data on the subject. A recent theory, by Hoffman, suggesting that the number and duration of these periods of activity is closely related to the intervals between eruptions, will hopefully be the topic of a paper in the near future.

The initial major burst

The greatest volume discharge of water occurs at the beginning of the initial series of bursts. The highest known bursts from Great Fountain have also occurred during this time; however, in any given eruption, it is possible that the highest bursts occur later during the first series or, rarely, during a subsequent series.

The variability of the eruptions of Great Fountain results in a sense of anticipation even in dedicated observers. The initial bursts can take on a variety of mannerisms. Some of these characteristics are spectacular and named, others are less noteworthy but perhaps also significant.

The initial major bursts differ from all later bursts of the eruption by the fact that they ensue from a full pool. During this initial series the pool is emptied, and subsequent bursts originate from deep within the vent. This is responsible for the uniqueness of the first bursts. Because the discharge is sudden and massive, a series of waves of water cross the terrace, crashing down the various levels of the terrace.

At present, no quantified data exists for the diversity of eruptive patterns. Consequently, it is not possible to give percentages for certain occurrences. By defining these patterns in this article, I hope that observers in the future will be able to consistently characterize and record some of these occurrences. For now, observational impressions will need to suffice.

The big blue bubble

One of the two named and defined patterns of events during the initial series of bursts is known by the descriptive name of the blue bubble. This type of burst has been observed to occur only at the very start of the major bursts, and no more than one has been known to occur in a given eruption.

The blue bubble is, as the name suggests, a doming of water over the vent. The pool rises suddenly, without the surface tension of the water immediately breaking. The result is that the water from the pool is lifted, sometimes to a height of 10 meters or more, in a bubble that retains its blue colour. The blue tint of the water is best seen on bright but overcast afternoons when the air temperature is high enough to ensure steam does not obscure the water. Fewer than 10 bubbles are seen in most years. Some years almost none are reported.

The actual length of time that the bubble lasts has not been timed, but appears to vary depending on how quickly and how high the pool rises. A bubble in early 1989 was photographed through all of its phases with the help of a power winder. The bubble, from the moment the photographer recognized it and pressed the shutter to the moment it burst took up three frames with a winder rated at three frames per second. Half to 1½ seconds is probably the range of blue bubble durations.

When the bubble breaks, a number of things may happen. The most common is a 30 to 40 meter high massive burst. On less frequent occasions, the blue bubble develops into a short burst, perhaps 20 meters high and equally wide, spectacular in its massiveness. Another infrequent, although spectacular possibility, is for the bubble to explode into a superburst.

The superburst.

The term "superburst" has been used in a variety of contexts to describe very diverse phenomenon. While the term superburst, in the case of Great Fountain, represents the most powerful activity of this geyser, a "superburst" from Steamboat Geyser at Norris is a type of minor play, far removed from the best that Steamboat has to offer. Therefore, this use of the term "superburst" is, necessarily, only within the context of Great Fountain.

There is, unfortunately, some disagreement over the exact definition of a superburst. There is uncontended activity on either side of the spectrum: plays which clearly are superbursts and plays which clearly are not superbursts. The difficulty arises in characterizing activity which does not clearly fall into one of these categories. After discussing superbursts generally, I hope to provide a more precise definition.

Superbursts occur at a very particular time during the eruption, namely during the initial series of major bursts. Apparently, because of the quantity of water and the amount of energy required for such a massive and powerful burst, once the geyser has been erupting for a minute or so it has expended so much water and heat that superbursts are no longer possible.

The frequency of superbursts varies from month to month and year to year. For the summer of 1984, for example, there were a total of 13 observed superbursts. Of that number, none were observed in June, 6 in July, 3 in August, and 4 in September. While superbursts are never common, there are some months in which none are seen. There are also instances when four or five are observed within a single week.

There have been reports of two superbursts within a single eruption. In these cases two bursts occur within a few seconds of each other. Often the water has not stopped falling from the first when the second shoots up through it. Whether this should be considered two superbursts, or one with a very short pause, is really a mater of semantics.

In the broad sense a superburst is nothing more than an exceptionally high burst. Some superbursts are as low as 50 meters, others have been measured to exceed 70 meters. They are accompanied by a major discharge of water that produces cascading waves off of the terrace. Some of these waves are so powerful that they splash up onto the grass surrounding the terrace. Often some of the pieces of loose sinter on the terrace are moved by this rush of water. In exceptional cases plates of previously attached sinter are broken loose.

Superbursts can either be vertical, or angled in an easterly direction, toward the parking lot. Both types of superbursts have been observed at over 60 meters. The bursts that are angled toward the parking lot can deposit a substantial amount of water upon people as well as cars. People who were thus hit, at a distance of 50 meters from the vent, appeared as though they had fallen into a lake. Some observers, who had their vehicles parked in this lot for entire summers, eventually noticed on their windshields a build up of silica deposited from the water of these bursts.

The great superbursts differ from other bursts not only in height but also in the pattern of the water column. While typical bursts are splashes, which have little continuity, superbursts have been timed to last for 3 to 5 seconds, during which time the jetting is continuous. This activity is more in the pattern of a cone geyser than of a fountain geyser. A virtually identical pattern of activity has been observed in Morning Geyser, with the exception that there the very high, continuous, cone-like burst occurs towards the end of the eruption.

It is this distinction between the standard splashing and the longer jetting type burst that should be used as the demarkation between what should and what should not be considered a superburst. All bursts over 60 meters with which I am familiar did, in fact, follow this unique jetting pattern. In the 45 to 60 meter range, it is possible to have bursts fitting both patterns, of a splash or longer jetting. It does not seem that defining bursts as a superburst solely on the basis of height captures the spirit of the distinction, which is in fact a categorically different and unique manifestation of Great Fountain's eruptive potential.

While such a standard would decrease the number of superbursts noted each year, the arbitrary aspect of this category would be eliminated, and the data would refer more specifically to a unique phenomenon. In any case, the policy initiated by Hoffman of recording superbursts not only with the label but also with a height estimate is an excellent addition to the data.

The first series.
As mentioned above, each eruption consists of several series of bursts separated by periods of quiet. After the initial bursts the pool is empty. All subsequent activity comes from an empty pool. The first series, which lasts about 10 minutes, is stronger than the subsequent series. If the series starts with a superburst, then often the rest of the series is weaker than usual, presumably because of the water and energy already expended. While the most massive bursts occur early during the initial series, some of the highest bursts may occur 5 or more minutes into the series. These 30 to 40 meter high bursts tend to have little water, and, rather than a column of water, splash only droplets to that height.

As the first series draws to a close, the individual bursts grow smaller, have less water, and spread further apart. While at the start of the series there is substantial discharge of water, toward the end the bursts are generally not as wide, and much of the water falls back into the vent.

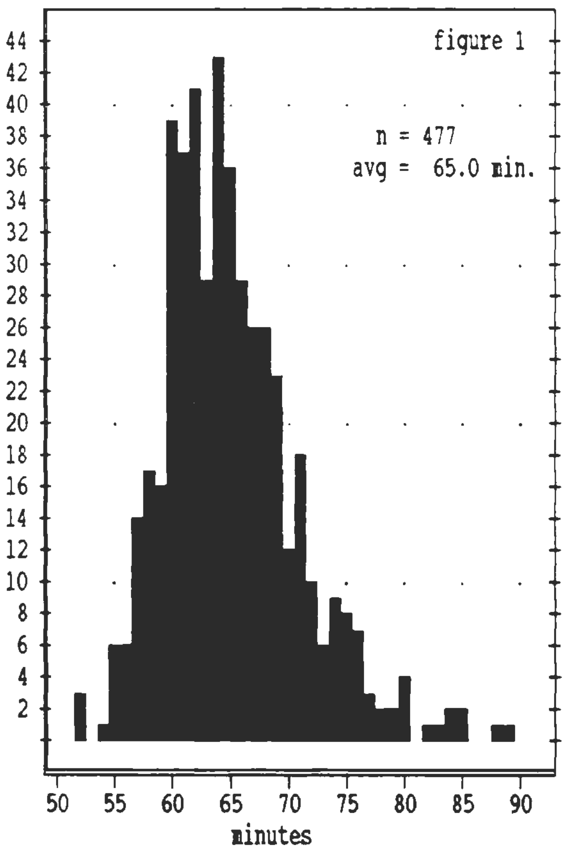
Subsequent series.
Subsequent series are similar to the initial one with a few exceptions. The pool does not refill between series, and the water discharge is much reduced from the initial series. In some cases, a small wave is produced by the first burst of a later series. The heights of individual bursts in the later series vary widely. Bursts as high as 40 meters have been observed, although there are many bursts under 10 meters and usually the highest burst in a later series is on the order of 15 to 25 meters.

Admittedly, there remains much more observational and analytical work to be attempted on the later portions of the eruption of Great Fountain. Based upon currently available data, there is no obvious difference between the second, third, and fourth series. Common belief, supported only by casual observational data, suggests that the third series is, on the average, slightly more powerful than the second or the fourth series. Sometimes there are series after the fourth, in which case the plays become progressively weaker. I hope that a paper on the later portions of Great Fountain's eruptions will be published in a future issue.

Interval Patterns

Overflow Duration
The period of the overflow, which of itself is around 10% of the interval, varies from eruption to eruption. The average and distribution differ from year to year. Figure 1 illustrates the range of overflow durations, in 1 minute increments, recorded over four years, 1983 - 1986. No pattern has been discovered that explains this variability in the duration of overflow. While a complete attempt at comparing overflow durations with the length of the interval has not yet been completed, preliminary results do not suggest a correlation.

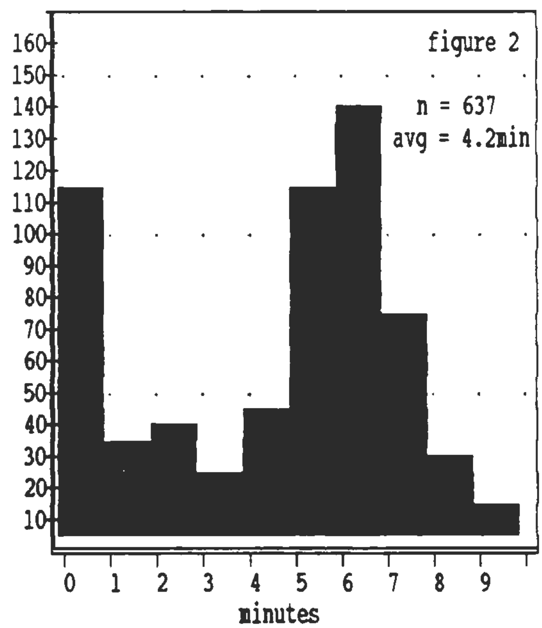
Frequency Distribution of Overflow Durations
1983 - 1986



Pause Duration
Despite the reservations mentioned above, there is a long tradition of recording the pause in field notes and, therefore, a wealth of pause data exists. As in the case of the overflow, attempts to correlate pause durations with the length of the interval have not proven fruitful.

Figure 2 gives the frequency distribution, in 1 minute increments, of 637 pauses timed during 1983-1986. From the time that Great Fountain reached a 1 meter boil, the initial major bursts followed, in every case, within 10 minutes. The average pause duration of 4.2 minutes is misleading, since that figure takes into account 110 eruptions that did not have a pause. The average pause duration of those 527 eruptions that actually had a pause was 5.1 minutes.

Frequency Distribution of Pause Durations
1983 - 1986



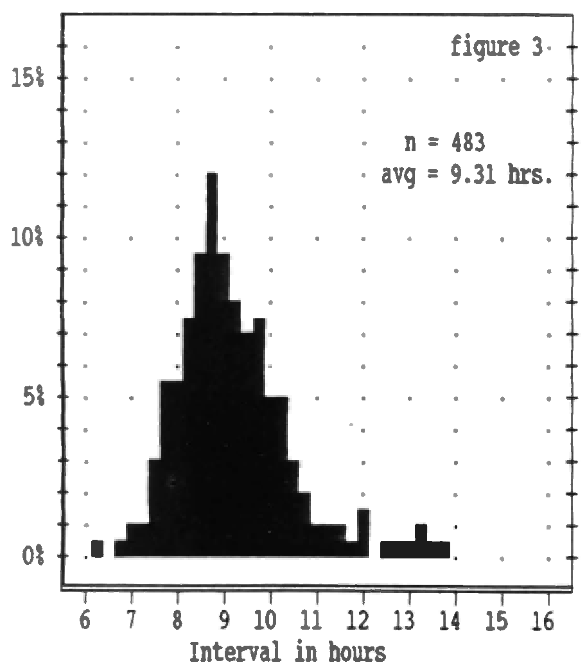
Interval
Because of its isolated location, 7 miles from the developed area, a significant number of Great

Fountain's eruptions are not seen. In some years, the majority of eruptions which occur between midnight and 0600 are inferred rather than observed. Therefore the distribution given may vary substantially from the actual distribution, since the intervals preceding eruptions occurring at night are significantly longer than those preceding eruptions during the day. Data points on the long end of the scale are, therefore, underrepresented.

In a similar vein, there are very few observations of Great Fountain during winter months. No intervals are recorded from some point in October until late April or May. There is no evidence that Great Fountain behaves differently in the winter than during the summer; however, such a conclusion is also far from being affirmatively demonstrated.

Figure 3 shows the distribution of all closed intervals recorded during 1983-1986. Each bar represents the percentage of the total number of intervals by quarter hour. Figures 4 and 5 similarly break down two subsets of intervals: Those preceding eruptions occurring during the

Distribution of known closed intervals, 1983-1986
Percentage by .25 hours



"day," between 1000 and 2159, and those preceding eruptions occurring at "night," between 2200 and 2159, respectively. The fact that there are 77 more datapoints in the "day" group is explained by a lack of observations during the nighttime hours.

The average interval between these two groups differs by 42 minutes. This disparity can be attributed chiefly to two observations. On the one hand, there are only 13 eruptions, or 4.6%, over 10h45m in the daytime group, while there are 34 eruptions, or 16.8%, over 10h45m in the nighttime group. On the other hand, the daytime set has 64 eruptions, or 22.9%, under 8h15m, while the nighttime set has only 15 eruptions, or 7.4%, under that length.

Distribution of known closed intervals, 1983-1986
Preceding eruptions between 1000 hrs. and 2159 hrs.
Percentage by .25 hours

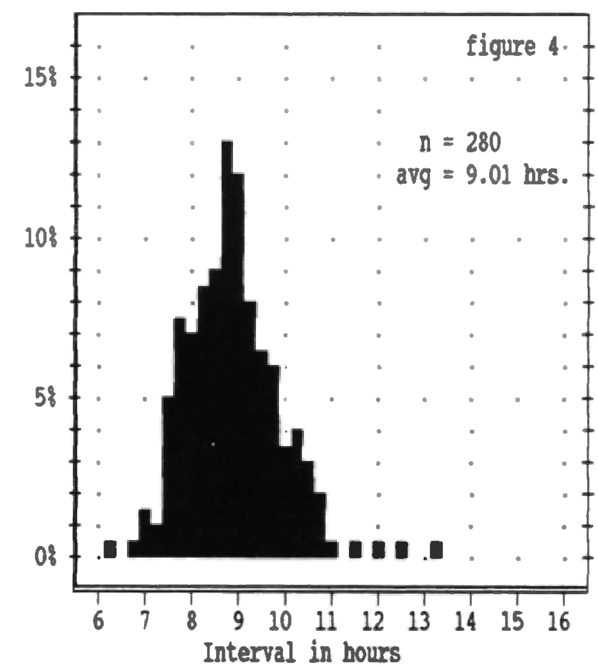
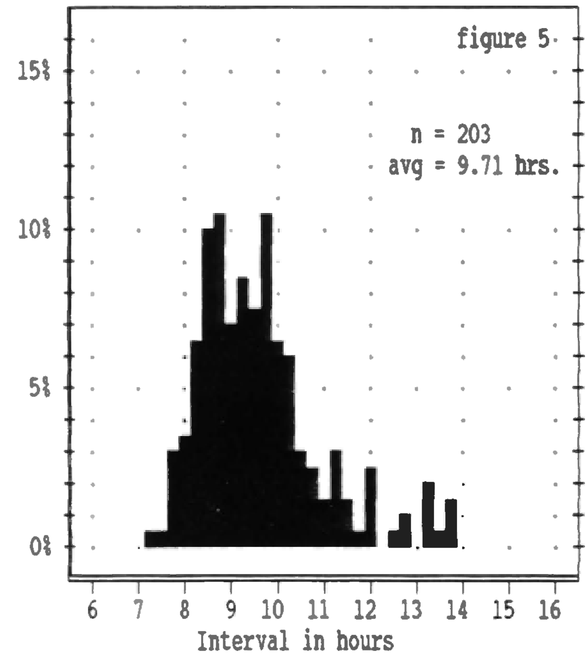
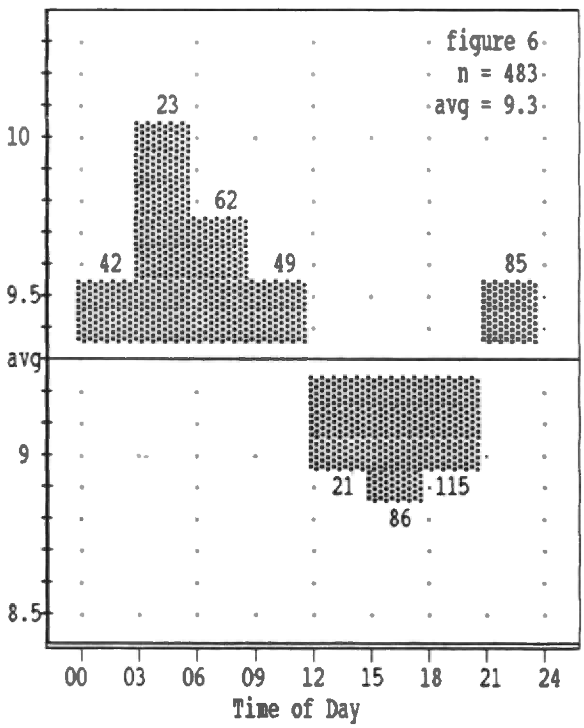


Figure 6 shows this same pattern in a different way, as a graph of averages by 3 hour blocks as compared to the overall average. Each bar represents the average length of all recorded intervals that preceded eruptions which occurred during that 3 hour period. This 3 hour average is graphed in comparison to the 9.3 hour overall average. The figure above or below each bar represents the number of data points averaged

Distribution of known closed intervals, 1983-1986
Preceding eruptions between 2200 and 0959 hrs.
Percentage by .25 hours



Closed intervals by time of day, 1983-1986
Averages by 3 hour blocks compared to overall average



together in each of these 3 hour periods. Here, the difference between the longest average of 10h03m, during 0300-0559, and the shortest average of 8h55m, during 1500-1759, is 68 minutes. This represents 12% of the average interval.

Why the difference between daytime and nighttime intervals of Great Fountain exists is puzzling, and no adequate explanation has been formulated. There are other instances in which time of day has be correlated with eruption patterns. Morning Geyser, in the Lower Geyser Basin, was so named because of its tendency to erupt in the morning. This pattern was explained by [Marler, 1973] as being caused by the effect of wind on Morning's pool, coupled with a tendency for calm winds during the morning. In the case of Morning, Marler suggested that the winds rippled the surface of the pool, increased discharge, and dissipated thermal energy. Clearly this explanation does not hold for Great Fountain, which erupts on shorter intervals during the late afternoon, a time of frequent winds. A similar wind-caused retardation pattern has long been established for Daisy Geyser [Bryan, 1986]. A somewhat analogous diurnal pattern has been proposed by [Koenig, 1989] for Beehive Geyser, though there is only speculation as to the cause.

In the case of Great Fountain, it is possible that climatic conditions play some role. Great Fountain's sizeable pool could perhaps be affected by wind speed, wind direction, air temperature, or barometric pressure. One major difference between night and day, namely sunlight itself, cannot be considered a serious candidate. Another option might be the effect of solar tides upon the plumbing system of the geyser, though it is difficult to explain why the solar pattern would be apparently dominant over the stronger lunar force. Yet another suggestion is that the hundreds of automobiles, campers, and buses that drive, during the day, along the edge of Great Fountain's terrace produce ground vibrations that somehow increase the energy or water flow.

Another way to approach the problem might be to look at the characteristics of the previous eruption. If [Hoffman, 1989] is correct and there is a relationship between the number of series in a Great Fountain eruption and the length of the subsequent interval, this may point to diurnal effects upon the length of the previous eruption as being the operative cause of the discrepancy in intervals.

An understanding of this diurnal pattern should significantly assist us in predicting Great Fountain's eruptions, thereby making it possible for more visitors to Yellowstone Park to see one of these spectacular displays. Additional data is being studied, and hopefully more data will be gathered in the coming few years, with the goal of developing a more accurate prediction formula which takes these patterns into account.

Acknowledgements

Much of the data that formed the basis for this article was collected by H.R. Hoffman, who also shared his observations and theories during numerous conversations while we waited for eruptions. H. Warren initially introduced me to the patterns of Great Fountain in 1981. H. Koenig assisted in the compilation of the data, and painstakingly extracted eruption times from various log books. C.A. Batchelor offered helpful suggestions on the text. I am grateful to R. A. Hutchinson, Yellowstone Park Geologist, for his support of this research.

References

Allen, E.T. and Arthur L. Day, *Hot Springs of the Yellowstone National Park*, pp. 274-275, Carnegie Institution of Washington, Publication No. 466, 1935.

Bryan, T. Scott, *The Geysers of Yellowstone*, pp. 123-125, Colorado Associated University Press, 1986.

Hoffman, H.R., *Great Fountain - June 1988*, unpublished, 1988.

Hoffman, H.R., personal communication, 1989.

Koenig, Heinrich, Diurnal Activity of Beehive Geyser, *GOSA Transactions*, this issue.

Marler, George D., *Inventory of Thermal Features of the Firehole River Geyser Basins and other selected areas of Yellowstone National Park*, pp. 399-421, 516-519, NTIS PB-221 289, 1973.

Warren H., personal communication, 1984.

The Gemini Geyser Complex

David Goldberg and Michael Goldberg

1. Introduction

Gemini, Crack, and Pebble Geysers are an interesting group of geysers across the road from White Dome Geyser on Firehole Lake Drive. In the summer of 1988, these small geysers erupted cyclically in a highly predictable sequence. Pebble, the feature closest to the road is a pool about 3 feet in diameter. Its eruption consists of a series of splashes from the right side of the pool, 1–3 feet high. To the left is Gemini. The main vent is in the bottom of a shallow depression. A second vent is a foot to the right. The eruption is a jetting 6–8 feet from both vents. The main vent jets mostly water and the other steam and spray. Crack is the farthest of the geysers from the road. Its main vent and many minor vents lie along a fissure in a level sinter platform. The pulsating water column reaches 10–12 feet at its strongest.

Two other vents are known to have erupted within this complex. The August 1988 issue of The Geyser Gazer Sput reports that on one occasion a small hole between Gemini and Crack was observed to spray to 2 feet. On July 26, 1987, the authors saw a shallow hole between Gemini and the road have a series of splashes sharply angled towards Pebble reaching half a foot high and 3 feet horizontally.

2. 1988 Observations

A typical cycle starts with Pebble Geyser beginning to splash from a low pool level. The water level rises slowly throughout the cycle. Next, the water in Gemini Geyser begins to rise and fall, going in and out of sight, getting higher each time. When the water from the left vent fills its overflow basin it begins to splash. The splashing soon grows into the eruption which lasts about a minute and a quarter. After the eruption Gemini's water level stays high and it continues to splash for about two minutes at which time it drains. 15–20 minutes after Gemini erupts, Crack erupts, preceded by increasingly heavy splashes from the main vent. The eruption lasts three and one half minutes. During the eruption Gemini fills and splashes but then drains. Also after Crack erupts Pebble drains down about two feet and stops splashing for about ten minutes. 35–40 minutes later Gemini erupts again as the cycle repeats itself.

Table 1 shows a series of observations of ten complete cycles taken on July 26, 1988. Table 2 is an analysis of this data showing intervals (start to start), durations, averages and standard deviations. The extreme regularity of the group is best illustrated by the fact that the standard deviations are only 4–5% of the average durations and intervals.

3. Previous Years

Prior to 1988, this group was also predictable, but it followed a very different pattern. In particular, When observed on August 9, 1986, Gemini was

Gemini			Crack			Pebble
start		stop	start		stop	restart
10:01:15	–	10:02:30	10:15:56	–	10:19:30	10:26:11
10:54:17	–	10:55:37	11:12:02	–	11:15:32	11:22:51
11:46:21	–	11:47:41	12:04:46	–	12:08:30	12:14:12
12:44:00	–	12:45:21	13:01:11	–	13:04:41	13:09:38
13:39:47	–	13:41:10	13:57:08	–	14:00:30	14:05:52
14:34:44	–	14:36:08	14:54:24	–	14:57:46	15:02:37
15:35:35	–	15:36:55	15:50:30	–	15:54:02	unrecorded
16:32:00	–	16:33:28	16:49:52	–	16:53:23	16:58:56
17:29:38	–	17:31:00	17:46:20	–	17:50:05	17:57:36
18:23:02	–	18:24:21	18:39:50	–	18:43:17	18:50:56
19:15:39	–	19:16:58	19:32:11	–	19:36:05	19:44:52

Table 1: Times of observed events, July 26, 1988.

Gemini			Crack			Pebble
duration	interval from Crack	cycle length	duration	interval from Gemini	cycle length	interval from Crack
0:01:15	—	—	0:03:34	0:14:41	—	0:10:15
0:01:20	0:38:21	0:53:02	0:03:30	0:17:45	0:56:06	0:10:49
0:01:20	0:34:19	0:52:04	0:03:44	0:18:25	0:52:44	0:09:26
0:01:21	0:39:14	0:57:39	0:03:30	0:17:11	0:56:25	0:08:27
0:01:23	0:38:36	0:55:47	0:03:22	0:17:21	0:55:57	0:08:44
0:01:24	0:37:36	0:54:57	0:03:22	0:19:40	0:57:16	0:08:13
0:01:20	0:41:11	1:00:51	0:03:32	0:14:55	0:56:06	unknown
0:01:28	0:41:30	0:56:25	0:03:31	0:17:52	0:59:22	0:09:04
0:01:22	0:39:46	0:57:38	0:03:45	0:16:42	0:56:28	0:11:16
0:01:19	0:36:42	0:53:24	0:03:27	0:16:48	0:53:30	0:11:06
0:01:19	0:35:49	0:52:37	0:03:54	0:16:32	0:52:21	0:12:41
averages						
0:01:21	0:38:18	0:55:26	0:03:34	0:17:05	0:55:38	0:10:00
standard deviations						
0:00:03	0:02:17	0:02:47	0:00:10	0:01:26	0:02:10	0:01:27

Table 2: Statistical analysis of observed data.

the only active member of the group; Crack and Pebble were both dormant. The following description is based on approximately 15 complete periods and 17 eruptions of Gemini Geyser observed by the authors.

During this time, Gemini erupted bimodally with intervals of either 5–7 minutes or 17–20 minutes. About 6 minutes before a long interval eruption, water would first be visible in the left vent. Four minutes before the eruption, it would begin to fill its overflow basin. The first overflow would leave the basin two minutes before the eruption. The right vent would discharge constantly into the basin just before the eruption. The left vent would begin surging half a foot high. When the right vent joined in, the eruption would begin. In half a minute, the eruption would reach the full hight of 8 feet and sustain it for up to one and a half minutes. The left vent would then lower to 1 foot as the right vent went into a steam phase. The entire play lasted no more than two and a half minutes.

After the eruption, the basin would begin to drain but it wouldn't finish. After a minute of sputtering, it would either drain completely in which case it would erupt 15–18 minutes later, or it would refill and erupt after only 3–5 minutes.

In 1987 the group continued on the same pattern. However, on July 26, 1987, following an eruption of Gemini, a shallow vent between Gemini and the road began gurgling loudly. The gurgling increased and, although the vent never filled, it had a series of splashes, the largest of which were half a foot high and three feet out towards Pebble Geyser. Gemini filled unusually slowly afterwards, and drained abruptly when the next eruption seemed ready to occur.

4. White Dome

During the same 10 hour period that we observed Gemini, Crack, and Pebble Geysers, we also recorded all activity in White Dome Geyser. Table 3 summarizes these observations. To test for the possibility that there might be a connection between White Dome and Gemini-Crack-Pebble, we converted these times to times after the most recent eruption of Crack, and plotted them in Figure 1. The "c" at the left represents the most recent Crack eruption and each tic mark represents 10 minutes. White Dome eruptions and splashes are represented by "w" and "s" respectively, and eruptions of Crack, Gemini, and Pebble are represented by "c", "g", and "p". While the Pebble, Gemini, and Crack eruption times are neatly clustered in this diagram, (as our previous analysis showed they would be), the times of White Dome activity are spread nearly uniformly throughout the cycle. A ten minute gap in White Dome activity was observed around the time of Gemini eruptions. However, with only 19 recorded events in a 56 minute cycle, under the assumption of

time	duration	interval	splash 1	interval	splash 2	interval
9:54:00	0:02:00	—	10:49:02	0:55:02	11:01:20	1:07:20
11:35:35	0:01:50	1:41:35				
12:06:25	0:01:57	0:30:50				
12:24:21	0:02:09	0:17:56	13:16:04	0:51:43		
13:27:41	0:02:02	1:03:20	14:06:06	0:38:25		
14:13:10	0:01:41	0:45:29				
15:50:02	0:01:54	1:36:52				
16:05:55	0:01:49	0:15:53				
16:34:25	0:01:54	0:28:30				
16:54:23	0:01:58	0:19:58				
17:14:52	0:01:57	0:20:29				
17:36:30	0:01:52	0:21:38				
18:07:15	0:01:50	0:30:45				
18:38:42	0:01:50	0:31:27				
19:04:41	0:01:59	0:25:59				
19:45:05	0:02:01	0:40:24				

Table 3. Activity in White Dome Geyser, July 26, 1988.

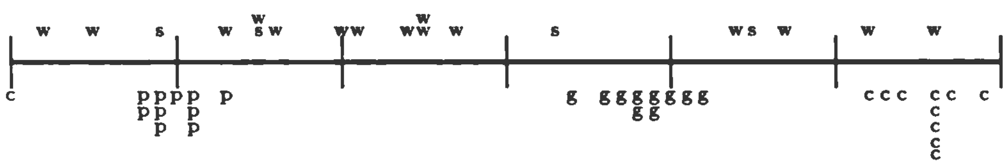


Figure 1. Activity in White Dome Geyser, and the Gemini-Crack-Pebble Geyser Group, plotted with respect to time after the previous eruption of Crack Geyser. Each tic represents 10 minutes.

a random distribution, there is about a 45% chance of a ten minute gap occuring somewhere in the cycle. Thus the observed distribution of the White Dome activity in this diagram is quite likely random and supports the conclusion that White Dome Geyser is not related to Gemini, Crack, or Pebble.

Treated independently, White Dome showed two kinds of activity patterns, an irregular mode in which intervals varied from 15 minutes to 2 hours, and a regular mode in which intervals gradually increased from 15 minutes. However, there is far too little data to draw any firm conclusions.

Norris Geyser Basin and Fall Disturbance
August, 1974
Yellowstone National Park, Wyoming

T. Scott Bryan

Abstract

The Norris Geyser Basin is known to have annual disturbances that cause substantial variation from otherwise common behavior of many thermal features. Some of these changes resulting from the disturbance that occurred during August of 1974 are described.

Introduction

From more than 14 years after the fact, recalling with any accurate detail just what events occurred during the August, 1974 disturbance event at Norris is difficult at best. However, I am writing at this time in order to partially clarify the record, having recently learned that the written reports prepared at that time have been lost.

The 1974 staff at Norris consisted of myself, Butch Bach, Jim Jones, George Algard, and Duane Cape. We made careful note of the disturbance and the geyser activity associated with it. A rather extensive report was prepared at the time. It was, admittedly, handwritten only, but it was comprehensive and detailed.

In any case, what follows is what I can recall from this report.

Early August, 1974

On reflection, it probably should have been obvious to us that something was happening in the Porcelain Basin in early August. In this observation there is the implication that maybe a disturbance does not begin at an abrupt moment, but rather that it can be somewhat progressive. What was observed was a slight but general increase in activity, especially within the central part of Porcelain Basin, in the general vicinity of Blue Geyser, Iris Spring, and Onyx Spring. Included were some large eruptions of "Norris" Geyser (informal name), and Green Apple Cider Spring, both of which changed from clear to murky water.

A few days before the disturbance occurred, a very remarkable change affected Congress Pool. Quite suddenly, its water level began to drop; as this happened the surging action became stronger and more intermittent. By the time of the disturbance itself, Congress was behaving as a true geyser with distinctly periodic eruptions at intervals of a few minutes. The eruptions lasted several minutes each, bursting fluid muddy water as much as 12 to 15 feet above the crater rim, and, therefore, fully 20 feet above the static water level. This activity persisted into early September when a gradual recovery of the water level returned Congress Pool to its more normal state.

August 13-14, 1974

While it is often stated that the 1974 disturbance event occurred on August 14, we were actually aware of it beginning on the evening of August 13. I have a recollection of being in the Back Basin myself, having taken in a sunset eruption of Echinus Geyser. Returning to the Museum via the long route, I observed several features to be muddied and eruptive, including "Hoddie's Hole Geyser" (now known as Dabble Geyser), and "Butch Geyser" (now Orby or Orbicular Geyser). Upon reaching the museum, others were noting changes taking place within the Porcelain Basin. It was not until the next morning, however, that any data or details were recorded.

On the morning of August 14 the entire Porcelain Basin seemed to be erupting. All known geysers were active as were numerous others. As examples, geysers such as Fan, Fireball, and Arsenic were in eruption the majority of the time and to much greater heights than are normal. Pinwheel Geyser seemed to be in constant incipient eruption, rolling its water and bubbling vigorously, sometimes breaking the surface with bursts up to 2 feet high. Several "unknown" geysers were observed. Most notable among these was "Geezer" Geyser, playing from a small irregular vent between Africa and Colloidal Pool. It was frequent and vigorous, reaching as much as 15 feet high. Springs on the hill above Pinwheel Geyser, never before or since known as geysers, were powerful. These "Ramjet Springs" were load enough to be heard from the Museum.

A check of the Back Basin also revealed considerable change. Echinus Geyser was erupting more frequently but more irregularly from a muddied and lower water level. Collapse Crater, Root Pool, Decker Island (Tantalus) Geyser, Dishwater Spring, and many other were muddy and surging, though not erupting. Mud pool, Mystic Spring, Blue Mud Spring, Dabble Geyser, Orby Geyser, "Dog's Leg Spring" ("Private Geyser"), and Palpitator Spring were all erupting frequently. New mud pots had developed near Black Hermit Cauldron and within the "Muddy Sneaker Complex." A large "explosion" crater had appeared on the open flat below Steamboat Geyser, and new muddy spouters were active beyond Fearless Geyser.

It was all very exciting. In accord with the disturbance, the Norris staff completely changed its activity schedule, an accumulated some extensive notes during these revised walks.

The effects of this disturbance lasted several days. As noted before and since, in relatively short order the volume of water decreased substantially. The decline in geyser activity was slower, but most features had returned to their pre-disturbance state within about one week. Some Back Basin action, most notably Dabble and Orbicular, persisted in their eruptions through September, still active when I departed the Park on September 25.

Other 1974 Activity

There were other significant events during 1974, a year that must rank as one of Norris' very best. This was the year when Ledge Geyser was predictably regular, 20 minute eruptions occurring every 14 hours, one of which threw its water laterally a measured 220 feet. Valentine was erratic but frequent. An unnamed feature in the 100 Springs Plain area erupted as a geyser several times, though none of the eruptions were observed. Arch Steam Vent erupted at least four times.

The most notable event, though, must be the reactivation of numerous vents immediately north and northwest of Emerald Spring. These features had been recorded at least during the 1930s. Unfortunately, I cannot recall the timing of this event except that it was pre-disturbance. The water in Emerald Spring was clear and remained so until the disturbance; the water in the new features was also clear. Appearing over the course of only an hour or so was a total of at least 12 vents, all of which acted as either spouters or geysers. The largest of these turned out to be the most persistent, with some activity continuing as late as September; its play reaching up to 10 feet high. As time went on, these features progressively decreased their activity. Perhaps, in part, their water was being confined to fewer vents. In any case, individually they progressed from erupting to calmly flowing, to standing water, to dry. Most of the vents had ceased action within a few days but some action continued for several weeks. The larger of these vents are still visible as depressions around the north edge of Emerald Spring.

TABLE 1

Geysers Active in 1974

The following is a list of the geysers which definitely were active during 1974; those with asterisks(*) following the name were active only during the disturbance.

Porcelain Basin:

Africa Geyser
Arsenic Geyser
Basin Geyser
Bear Den Geyser
Blue Geyser
Carnegie Drill Site
"Christmas Geyser"*
Colloidal Pool*
Congress Pool*
Constant Geyser
"Crackling Lake Geyser"
Dark Cavern Geyser
Ebony Geyser
Fan Geyser
Fireball Geyser
Feisty Geyser
"Geezer Geyser"*
Glacial Melt Geyser*
"Green Apple Cider Spring"*
Guardian Geyser
Harding Geyser
Iris Spring
"Junebug Geyser"
"Labial Geyser"*
Lava Pool Complex
Ledge Geyser
Little Whirligig Geyser
"Norris Geyser"*
Onyx Spring
Pinto Geyser*
Pinwheel Geyser*
Primrose Spring
"Ramjet Springs"*
UNNG 100 Spring Plain
UNNG near Cinder Pool
Valentine Geyser
Whirligig Geyser

Back Basin:

Arch Steam Vent
Blue Alcove Spring
Blue Mud Spring*
Corporal Geyser
Dabble Geyser*
Dog's Leg Spring
Double Bulger
"Downfall Geyser"
Echinus Geyser
Emerald Spring
Firecracker Spring
Minute Geyser
Mud Spring*
Mushroom Spring
Mystic Spring
Orbicular Geyser*
Palpitator Spring*
Pearl Geyser
Perpetual Spouter
Porkchop Geyser
"Puff-n-Stuff Geyser"
"Rediscovered Geyser
Rubble Geyser
"Son of Green Dragon Spring"*
Steamboat Geyser (minor)
UNNG near Cistern Spring
UNNG near Emerald Spring
Veteran Geyser
Vixen Geyser

This is an impressive list, totalling a minimum of 66 active geysers. The summer of 1974 was an active time for the Norris Geyser Basin, even without the disturbance events.

Activity in the Whirligig Complex, 1985
Norris Geyser Basin, Yellowstone National Park, Wyoming

Mike Keller

For most of the early 1980s the activity of the Whirligig Complex was dominated by Big Whirligig, Constant and Splutter Pot Geysers. Beginning in July of 1985 there were occasional shifts of energy towards Little Whirligig, during which times the activity of Big Whirligig, Constant, and Splutter Pot geysers changed.

Big Whirligig, Constant, and Splutter Pot were all very frequent and predictable geysers throughout 1984 and early 1985. Big Whirligig would erupt every 45 to 70 minutes, with a duration of 5 to 7 minutes, and play to a height of 5 to 15 feet. Constant had an eruptive series of 1 to 3 bursts, 10 to 20 feet high, every 90 to 115 minutes. Splutter Pot erupted every 5 minutes to a height of 5 feet. Little Whirligig was empty and only served as a drain for overflow from Constant. This regularity changed on July 16, 1985.

When I arrived at Big Whirligig on July 16th it had just finished an eruption. Splutter Pot's behavior was erratic, with intervals ranging form 4 to 18 minutes. 80 minutes after I arrived Big Whirligig was in heavy overflow and appeared within 5 minutes of erupting. Instead Splutter Pot stopped erupting and Little Whirligig started filling with water. Immediately, the water began to ebb in Big Whirligig. 14 minutes after Little Whirligig started filling it reached overflow, and continued to overflow for 35 minutes until Big Whirligig erupted. After Big Whirligig's eruption, both geysers drained. This same pattern was repeated 97 minutes later. During this behavior of Big and Little Whirligig the interval of Constant Geyser increased to near 150 minutes. This pattern of Activity continued until July 22, 1985.

Little Whirligig remained empty from July 22 through July 29. During the morning of July 30 it refilled. This time, however, it took Big Whirligig nearly 75 minutes to erupt after Little Whirligig filled. Splutter Pot was not active and Constant averaged 192 minutes between eruptions. On August 9 the energy shifted back to Big Whirligig. Little Whirligig had further overflow cycles on August 21 through August 26, September 5 through September 13, September 22 through October 1 and October 11 through October 18. During the last cycle Big Whirligig averaged 8½ hours between eruptions.

Despite the overflows, there was no know eruption of Little Whirligig in 1985. The pool temperature varied from 136°F to 144°F. The cooler temperature was always noted just prior to the drain. The overflow from Constant Geyser had little or no effect on the water level of Little Whirligig.

A Norris Explosion Crater Update

by J. R. Hobart

Abstract: The two 1987 hydrothermic explosion craters northwest of Norris Geyser Basin were visited in July 1987 and July 1988. Activity included mud explosions to 50 feet, termination of activity from the first crater, variability in explosive power, and toppling of trees into the enlarging active crater.

In January 1987, an explosion crater broke out on a wooded hill several miles northwest of Norris Geyser Basin near 44 deg 44.5 min N, 110 deg 44.6 min W. This crater was 40 to 50 feet deep and slightly larger in diameter. Its creation and early history must have been truly awesome for full-sized lodgepole pines were blown free of the crater and many others toppled within. Its activity apparently lasted for at least several months past the initial explosion for a large thickness of mud--exceeding 3 m in places--had accreted below the crater with virtually no evidence of secondary flow as would result from a short, massive deposition.

Around May 1987, thermal energy transferred nearly 100 m to the west, and a second, slightly smaller, yet similar crater opened. When visited in July 1987, it was about 10 m across. It's mud pool had a surface about 5 m below the rim although "level" could hardly be used to describe its surface.

A week before this visit, a group had been escorted in from Norris to view the phenomenon. At that time, the mud was reported to be quite fluid, splashing violently to about 2 m. A week later, a vastly different picture was presented. The mud level was 4 or 5 m below the high point of the rim, and large masses of wet mud were noisily being thrown above the rim. Fist-sized pieces were thrown as much as 10 m above the rim! The increased viscosity of the thickened mud enabled more thermal energy to be stored within. When finally released, far more energy went into kinetic energy of the departing mud rather than into steam formation, though it seemed like there would always be more than a necessary amount of steam present whenever picture-taking commenced. One phenomenon defying all physical principles was observed over and over again. No matter where one stood, boiling mud would be propelled precisely in that direction, forcing a deft maneuver or hasty retreat.

A lodgepole pine had fallen directly over the most energetic portion of the pool, taking the full force of the explosions, deflecting many to the side. Extending well beyond the rim, its top would thrash about with tremendous force with every explosion.

These explosions occurred every 2-5 seconds. Typical examples are shown as Figures 1 and 2, erupting to about 4 m. Mud was caked on the trees to 5 m above the rim, however amounts and distances were significantly less than observed around the original crater.

The original explosion crater was quiet, a small pool of water slightly steaming at the bottom. Figure 3, taken on a later visit, allows one to measure the crater depth in units of GOSA members Roz and Charlie Goldberg. From another angle, a 2 m opening could be seen below a rock ledge at the south edge of the crater floor, facing north. This could have been the energy conduit to the crater. Lodgepole "matchsticks" were scattered in and about both of the craters.

Another visit was made 4 days later, on the second day after an extensive intervening rainfall. At this time the mud was much more fluid, splashing

2 to 4 m above the pool. No mud was being thrown from the crater. On the other hand, several more trees had toppled into the crater since the last visit.

About 5 days later, a small group was led back to the crater. It included the Goldbergs: Charles, Roz, Dave, and Mike plus Blair Romer and Debbie Swenson. Nature's full fury had been reestablished to the same level as first observed. Apparently, the water influx rate was sufficiently low that the additional surface water had been completely evaporated in the meantime.

At times, kilogram-sized pieces of mud could be seen above the entire crater opening. A 30 kg mass was even hurled intact over the crater rim! The most apt description we could conjure up was that it was akin to the grand finale of a Fourth of July fireworks show.

In July 1988, a GOSA party made the trek over the sun-baked marshland to revisit the crater. Hopes were high that the dry weather would induce a real spectacle, that is if it were still active. Our group included the ever-present Goldbergs, Mike Keller, Mike Columbia, Phil Landis, and Scott Bryan. Arriving at the crater, we found, contrary to expectations, the crater had tapped a greater source of water so it was splashing vigorously to 2-5 m above its pool level which was about the same as it was the previous July.

Remarkably little physical change had taken place in the intervening 12 months. On the other hand, all of the trees that formerly extended in three directions from the center of the crater had disappeared. Therefore, some energetic eruptions must have occurred. Far more energy than in any observed eruptions would be required to displace or break up these trees.

The other crater had also changed. Material sloughing from its sides had filled in at least a quarter of the crater depth. The opening and rock ledge were buried beneath these deposits, but no signs of any intervening activity were present.

What is in store for the active crater? An adjacent stream and thermal lake indicate an elevated water table which being tapped to a greater degree. A pond such as those in the Mud Volcano area may result.

A large number of photographs of spectacular activity were taken during the 1987 visits. Many of these will be published by the author in a forthcoming book about exploding mudpots and related features.

See plates for photographs 1-3

The Heart Lake Geyser Basin:
Report and Investigation
Rocco Paperiello

Abstract: A catalog with detailed maps of the thermal features of the Heart Lake Geyser Basin, Yellowstone National Park. Previous designations noted whenever possible. Sources for names of features is also given.

Introduction

So long as you are not hoping to see many large geysers in eruption, your first visit through this basin is apt to provoke enthusiasm and interest. Unlike the other major thermal areas, the Heart Lake Geyser Basin consists of a number of large separate thermal tracts spread out over a distance. Most extend along the upper two-thirds of the Witch Creek drainage; these include the Upper, Fissure, Middle and Lower Groups. Also included are two small isolated groups to the south; these are the Rustic and an unnamed group. (See Map 1). The distance from the Upper Group to the Rustic Group is more than 2 1/2 miles.

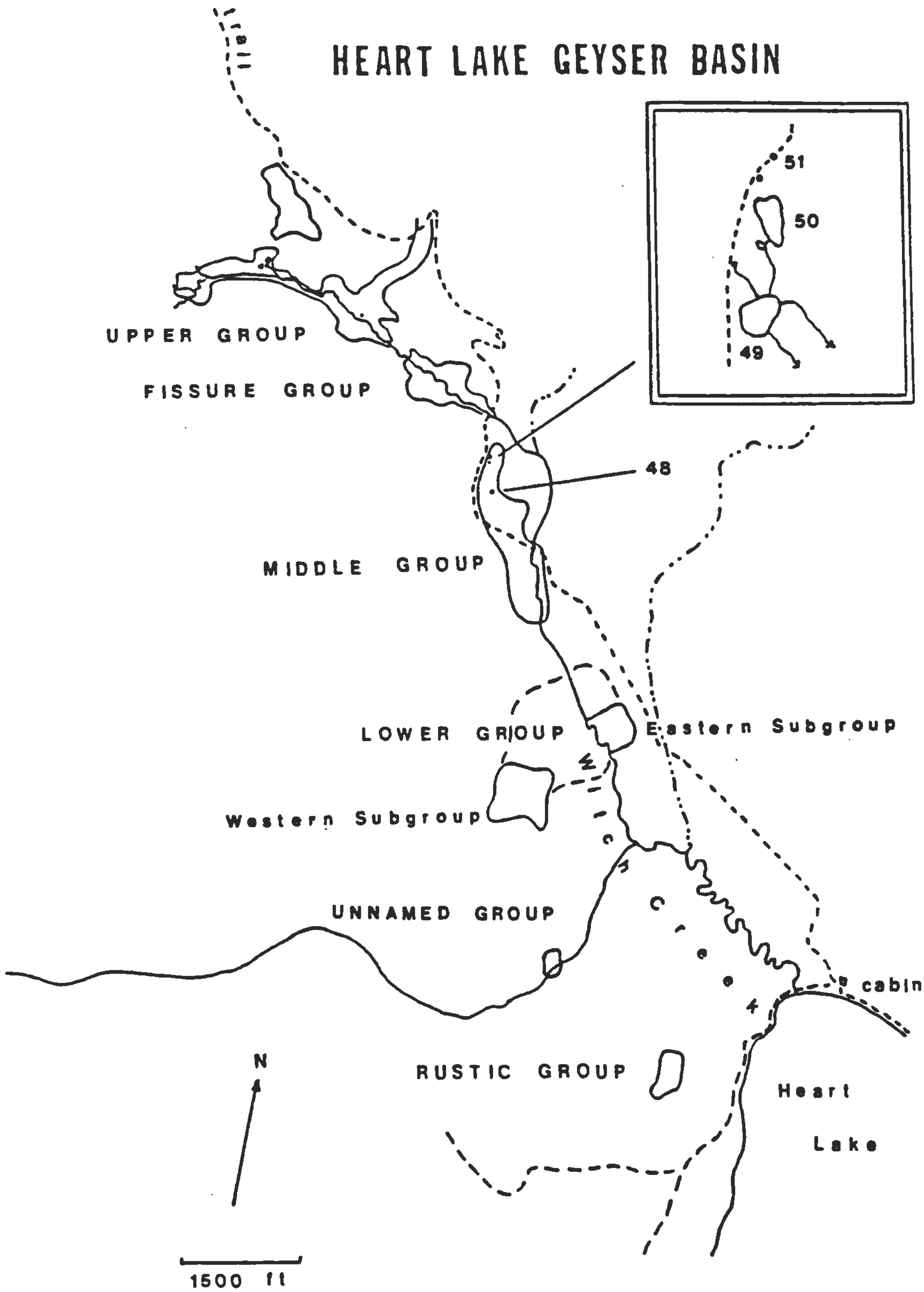
There are other characteristics which further differentiate this basin from other geyser basins in Yellowstone. Because of its setting alone, it deserves a visit. Some of the views seen from this basin are some of the prettiest in the Park. As Witch Creek passes through both the Upper and Fissure Groups, it tumbles over innumerable falls, cascades and rapids. In three places it is bridged by sinter — one of these bridges is fairly large. (Only three other sinter bridges are known in Yellowstone — two over the lower reaches of Violet Creek just before it reaches Alum Creek, and one over Alum Creek itself as it passes by a feature in the Glen Africa Basin called the "Flutter Wheel.") Although Heart Lake's thermal activity is not nearly so great as found elsewhere, some of its aspects are noteworthy. Though most are small, there are at least 48 geysers and numerous additional perpetual spouters in the Heart Lake Geyser Basin. The concentration of activity is extreme along the long "fissure" of the Fissure Group, where are located at least ten geysers and a few additional spouters. The majority of the larger geysers are found in the Rustic Group, notably Rustic Geyser itself. The tallest is Glade Geyser, found in the Fissure Group, it has been reported to have reached as high as 60 feet. Until recently Rustic Geyser was a regular and frequent performer. Since March 1985 it has been dormant, with an exchange of function to a geyser nearby.

Over the years comparatively little attention has been given to the Heart Lake Basin. In 1878 it was surveyed by Peale for the Hayden Survey, and a rough, almost unusable map was produced. A few years later, Walter Weed recorded further observations, but not until [Allen & Day 1935] described the area was anything further published about the Heart Lake Basin. Yet even here few individual features are described. It was not until 1973, when D.White and M.Nathanson of the U.S. Geological Survey mapped the areas and produced a substantial report. An excellent summary of the major geysers and some of the springs found in this basin can be found in [Bryan 1986].

Group	Number of Geysers: Definite	Number of Geysers: Possible	First Described in this Report	Number Active in 1986: Definite	Number Active in 1986: Possible	Number Active in 1987: Definite	Number Active in 1987: Possible
Upper	4	2	1	2	1	2	
Fissure	24	3	12	21	1	16	3
Middle	2		2	1		2	
Lower	10	4	8	8	4	9	2
Rustic	8		2	4		3	
Total	48	9	25	36	6	32	5

Geysers in the Heart Lake Geyser Basin
Table 1

map 1


HEART LAKE GEYSER BASIN
trail
51
50
49
48
UPPER GROUP
FISSURE GROUP
MIDDLE GROUP
LOWER GROUP
Eastern Subgroup
Western Subgroup
Witch Creek
UNNAMED GROUP
cabin
RUSTIC GROUP
Heart Lake
N
1500 ft

In the present work, an attempt has been made to collect and synthesize all of the previous known works on the area. These include [Barlow & Heap 1872], [Comstock 1875], [Peale 1883], [Allen & Day 1935], [Haynes —], [Majors 1961], [Sandborn 1965] and [Marler 1973]. More recent sources include: [Mebane 1959], [White 1973], [Sandborn 1975], [Martinez 1974], [Martinez 1976], [Martinez 1978], [Hutchinson 1978], [Hutchinson 1985], [Bryan 1986] and [Hutchinson 1986]. Personal visits in 1982, 1985, and especially 1986 and 1987 also gathered large amounts of information.

Upper Group

The Upper Group of the Heart Lake Geyser Basin lies along the upper reaches of the Witch Creek drainage. It was so named by Peale, and formed a portion of his Witch Creek Springs [Peale 1883]. Allen and Day include these springs, together with those of the Fissure Group, into their "Group 5" [Allen & Day 1935]. The bulk of the thermal activity lies along a narrow band on either side of Witch Creek. Its western extremity begins just as Witch Creek emerges from the steep forested hillside of Factory Hill and joins a similar tributary coming in from the northwest. This group continues along Witch Creek for about 3/4 of a mile where there is a small break in the thermal activity.

Two additional segments of the Upper Group branch off from above the main portion. One lies along the upper portion of an intermittent drainage called White Gulch [Peale 1883]. About this area Allen and Day write:

> "...over a small ridge... [lies] a little ravine with great scarcity of water, many diminutive springs, no sinter, but instead a reddish clay. Here and there abound tiny holes, the ground was bleached white, and occasionally a black spot, probably pyrite, appeared. At these gas holes faint tests for hydrogen sulphide were obtained with lead paper. Here we have very little water and a very small supply of sulphur coexisting. The result is that while no free acid remains, rock decomposition appears to be of the sulphate type" [Allen & Day 1935], pg. 326.

In this area are twenty or more mud cones up to two feet high. At times they appear to eject mud, mimicking miniature volcanoes [Map 2].

The second segment of thermal ground extends in a narrow band north from the lower end of the Upper Group; but along here there is almost no water. It is mostly a finger of hot ground, altered in places by steam leakage. [Map 1]

Within the main portion of the Upper Group, acid sulphate type activity predominates. The upper three-quarters of the group contains many frying-pans, mud-pots, small spouting springs, a few large, warm, acid-type pools, and two notable craters formed most likely from a short-lived but violent mud-flinging activity. Only the lower one hundred yards of so contain hard sinter line "alkaline"-type springs. Here is located Spike Geyser (a spouter), and Deluge Geyser. In addition to Deluge, at least three other small geysers are found in this area, plus two other possible geysers. [Maps 2 & 3].

Witch Creek, which travels through the heart of the Upper Group, descends through a series of narrow defiles, rapids and small cascades on its way toward Heart Lake. In his 1878 report Peale writes:

> "Witch Creek is the largest tributary of Heart Lake, and drains the northern slopes of Red Mountain [Factory Hill], which is the northern peak of the Red Mountain Range. It is a warm creek, deriving a large part of its water from the hot springs along its banks. It is about 4-1/2 miles in length, and at the lower end flows with a most torturous course through a march to the lake. [Its temperature was noted to be as high as 129°F in the midst of the Fissure Group]. At no point below the Upper Group did we find the water of the creek drinkable" [Peale 1883] Part II, pg. 290-291.

Fissure Group

This is perhaps the most intriguing of the groups which make up the Heart Lake Geyser Basin. The name comes from [Peale 1883], and is included in his Witch Creek Springs. Along with the Upper Group, [Allen & Day 1935] label this Group 5. Later, Marler names this the Crevice Group:

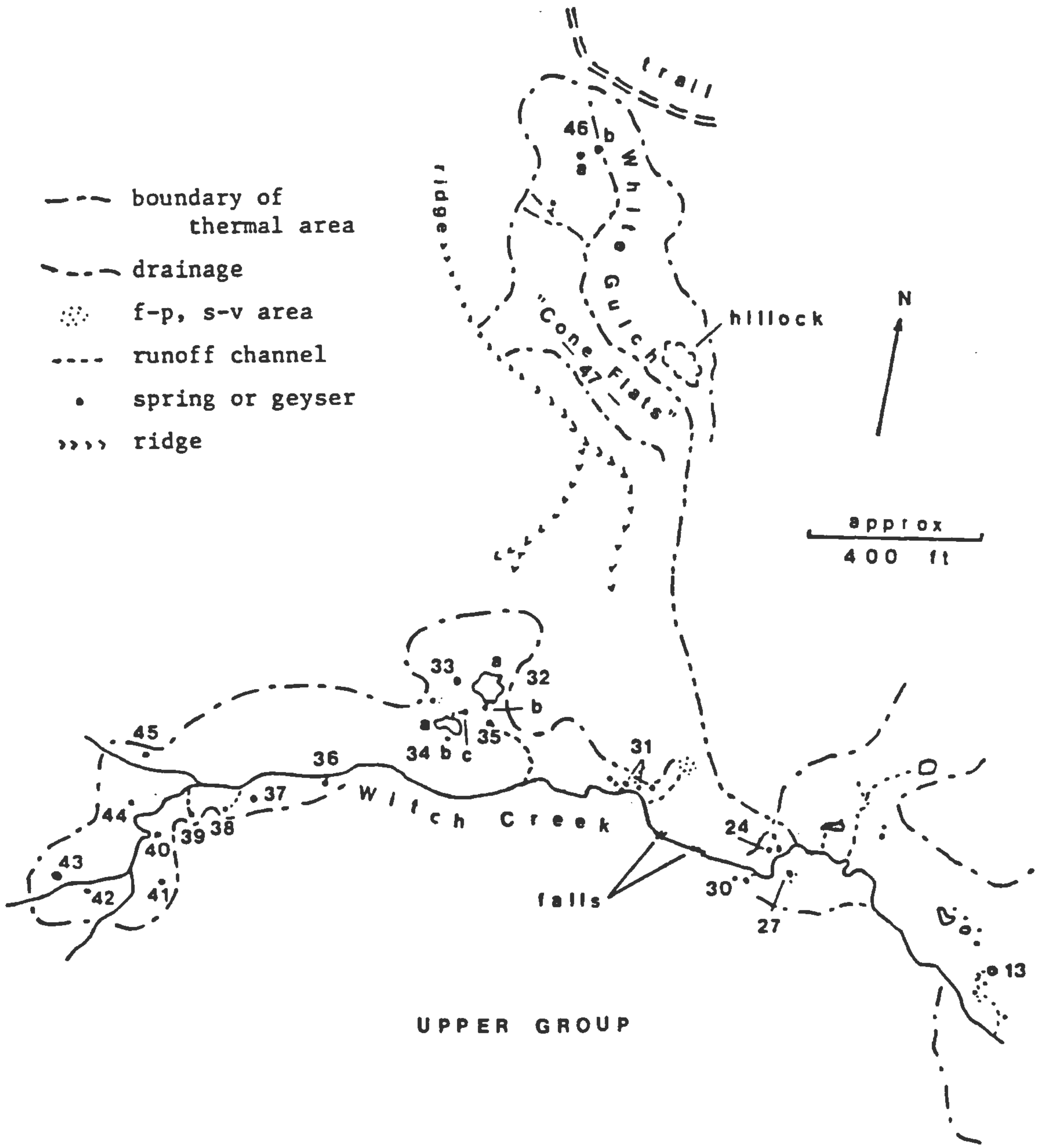
> "In the Crevice Group, or Group 5, Allen and Day found a greater thermal intensity than in any other section of the Witch Creek area. It is stated that on the sinter mound next to Factory Hill six geysers and six superheated springs were counted by Hanks in 1930" [Marler 1973], pg. 632.

S	Spring
PS	Perpetual Spouter
G	Geyser
FP	Frying Pan
MP	Mud Pot
B	Boiling Spring
SV	Steam Vent
IS	Intermittent Spring
•	Refered to by name

Abbreviations Used in Tables
Table 2

	(see map)
A - Upper Group	2 & 3
B - Fissure Group	4,5,& 6
C - Middle Group	7
D - Lower Group	
East Subgroup	8 & 9
West Subgroup	10
E - Rustic Group	11

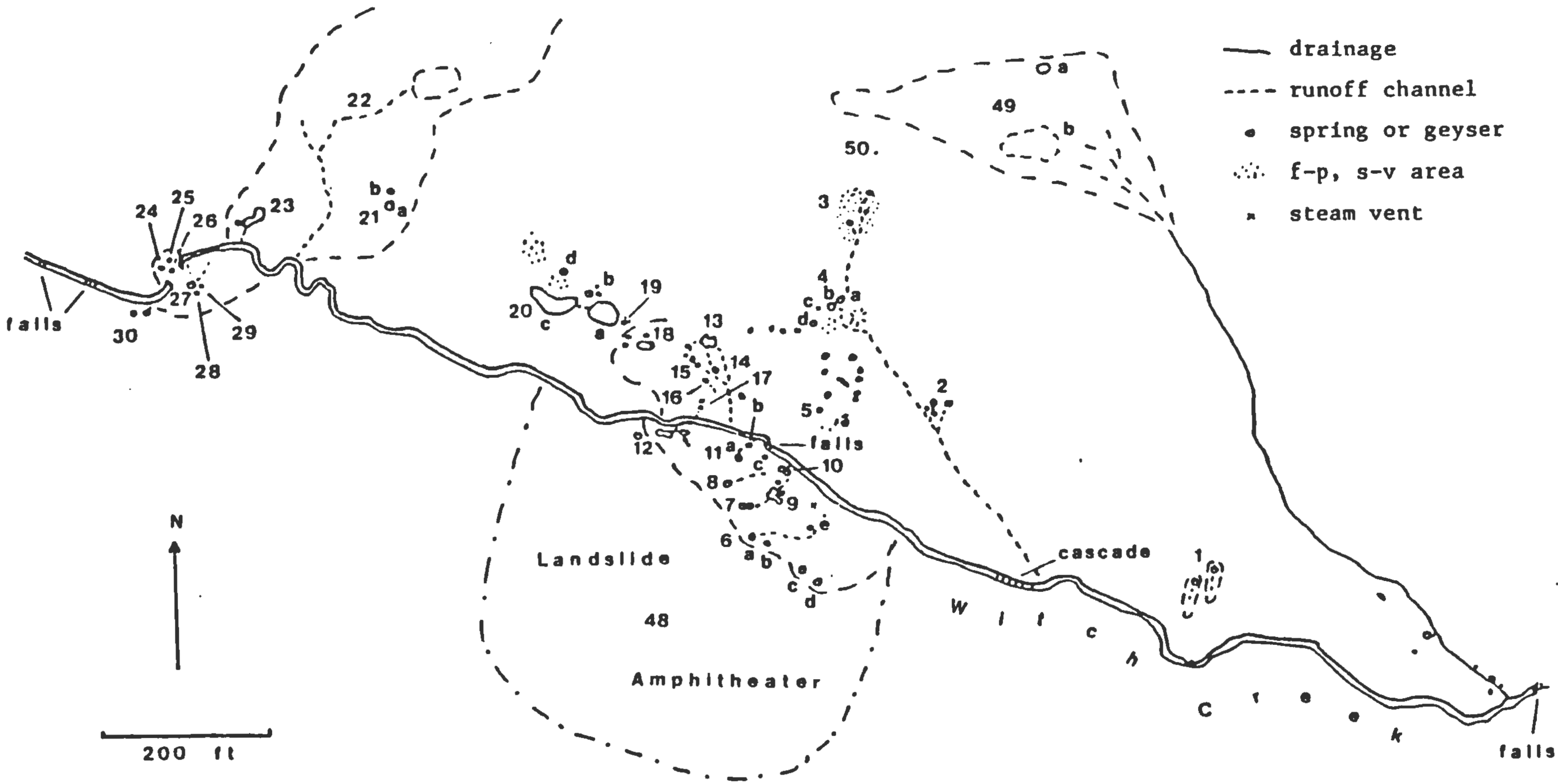
map 2



UPPER GROUP

map 3

UPPER GROUP

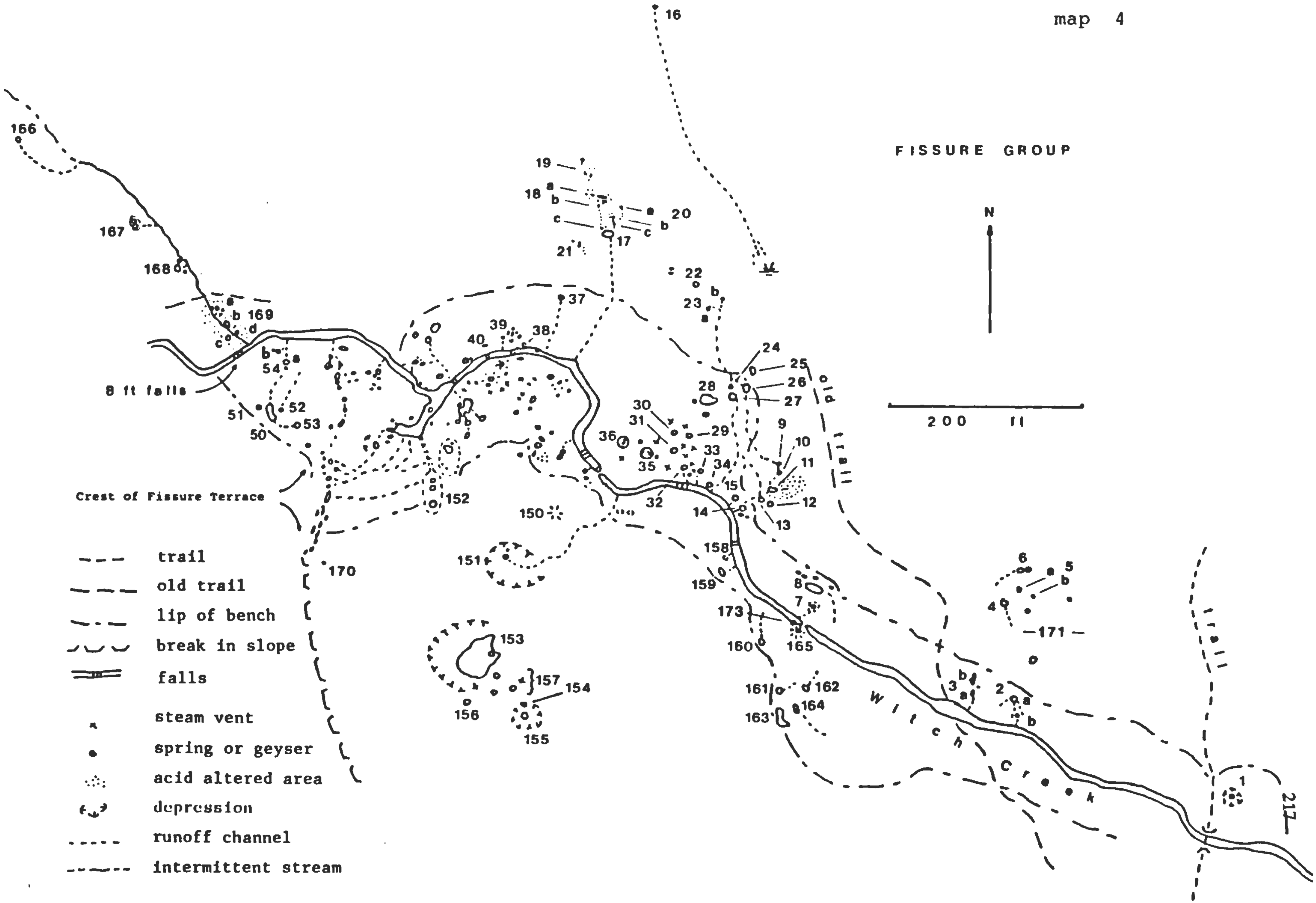


No. Name	Peale	White	Bryan	Function	Notes	Name by
1 - unnamed (2 springs)		shown		S	seep from fracture	
2 - unnamed(≥4 springs)		shown		PS		
3 - unnamed		shown		FP/PS/MP		
4a - unnamed		shown		MP	white	
b - unnamed		shown		S	scalloped	
c - unnamed				PS	small	
d - unnamed		shown		PS	through sand	
5 - unnamed		shown		S	deep chamber	
6a - unnamed		#19		S/B/PS		
b - unnamed		shown		S	flame effect	
c - unnamed		shown		S	milky	
d - unnamed		shown		S	clear	
e - unnamed		shown		sink	for #6a	
7 - unnamed (double spring)	11 ?	#16		S		
8 - unnamed		#16		S		
9 - unnamed	12 ?	#17		S	PS at east edge	
10 - unnamed (2 springs)		#18		PS/B	to 1', black	
11a - unnamed		shown		S		
b - unnamed (geyser?)			HLU-G1	G/PS		
c - unnamed				S		
12 - unnamed (5 springs)	9	#15		S	PS at east edge	
13 - Deluge Geyser	8	#1	•	G/IS	uncommon to 1', rare to 4'	Peale
14 - unnamed (2 vents)				IS	frequent	
15 - unnamed (≥4 vents)				S/PS		
16 - unnamed geyser		shown		G	connected to #13	
17 - unnamed				S		
18 - unnamed (3 others nearby)		#2		S	in old sinter	
19 - unnamed (2 springs)		shown		S	pulsates	
20a - unnamed		#3		S		
b - unnamed (3 springs)		shown		S	PS at edge	
c - unnamed		#4		S		
d - unnamed		shown		FP/PS		
21a - unnamed		shown		S	PS at east edge	
b - unnamed		shown		PS		
22 - acid-type area		#6			pool to northeast	
23 - unnamed		#7		S	PS at west edge	
24 - Spike Geyser	5a,b,c,d	#8	•	PS	has 2' cone	Peale
25 - unnamed	5i	shown		PS	1 vent	
26 - unnamed	5e,f	#9		PS	≥6 vents	
27 - "Yellow Funnel Spring"	6a	#11		S	yellow	White
28 - unnamed	6b	#12		S	bubbler	
29 - unnamed	6c ?			SV		
30 - unnamed (2 springs)		#10		PS	to 2'	
31 - unnamed (≥4 springs)				PS	1 from under rock	
32a - unnamed	4	#13		S	turquoise pond	
b - unnamed				sink	for #32a	
33 - unnamed				S		
34a - unnamed	3	#14		S	brown pond	
b - unnamed				sink	for #34a	
c - unnamed				MP	loud thumping	
35 - unnamed				S	outlet for #32 & #34 ?	
36 - unnamed				S	FP-type	
37 - unnamed				S	small, green	
38 - unnamed				PS	clear	
39 - unnamed				S/PS	FP-type	
40 - unnamed				PS		
41 - unnamed				PS		
42 - unnamed				PS		
43 - unnamed				PS	FP-type	
44 - unnamed				PS		
45 - unnamed				PS		
46a - "Red Mud Spring"	13b ?			B	sizzling red spr	Martinez
b - "White Mud Spring"	13c ?			MP	white	Martinez
47 - "Cone Flats"	14			MP/SV	mud volcanoes	Martinez
48 - "Landside Amphitheater"	10			S/FP/MP	area of acid springs & pools	White
49 - altered acid area		#5		S/FP/MP	area of acid springs & pools	
50 - unnamed				MP/SV	small mud cone	

Springs of the Upper Group, Heart Lake Geyser Basin

Table 3

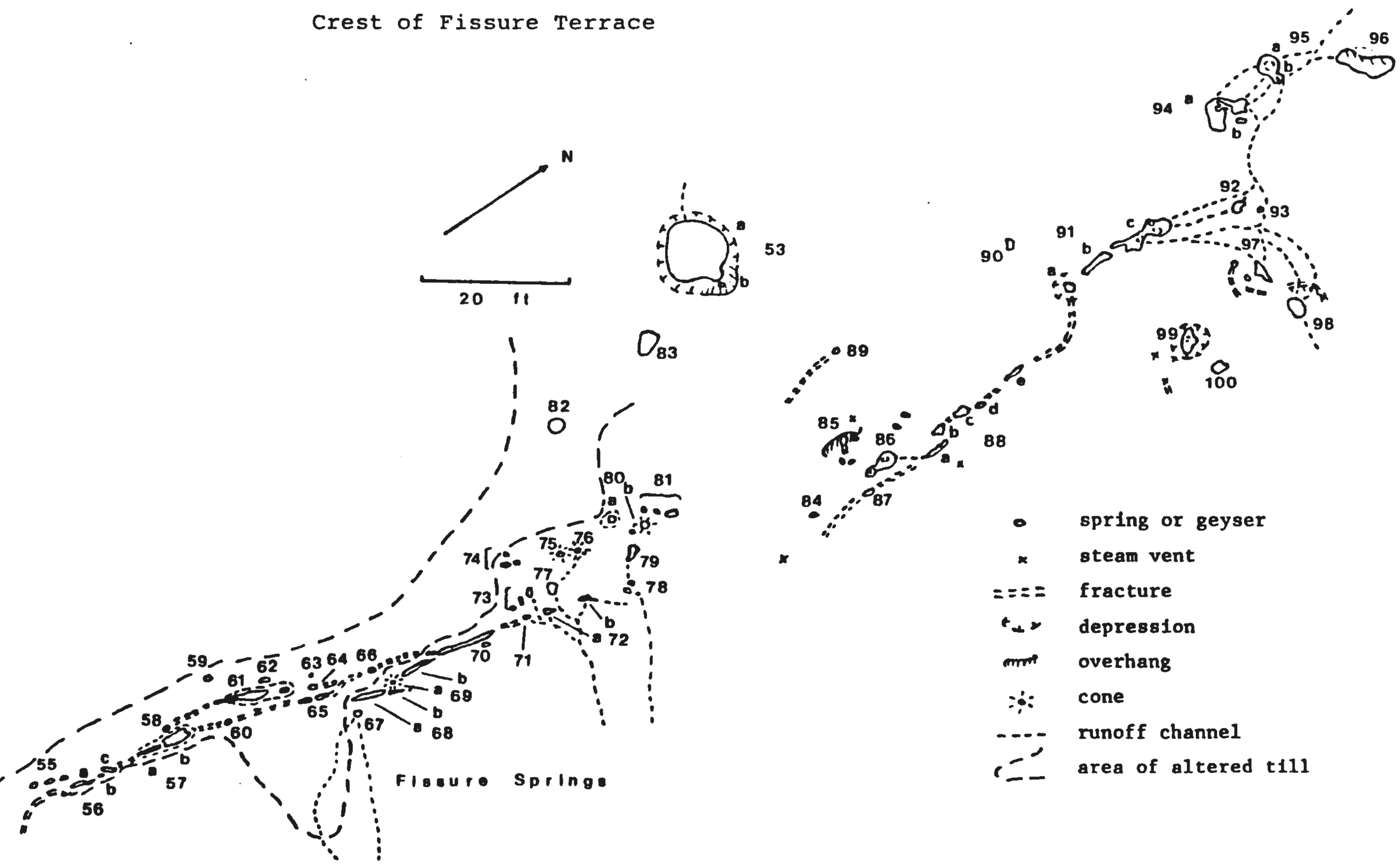
"Group 5 — The most interesting springs in the Heart Lake Basin are found in the Upper Witch Creek valley, perhaps a mile and a half from the lower end, where the narrow stream drops rapidly down in a series of foaming cascades. The creek on its southwest side closely skirts the base of a mountain called Factory Hill, almost as high as Mount Sheridan (9500 feet). Interest here centers in a sinter sheet clothing the base of the mountain and billowing out into a slope of gentler descent, again falling steeply to the edge of the creek. The summit of this sinter-encrusted mound was roughly estimated to be 40 or 50 feet above the level of the creek. Cutting the surface of the sheet, which is perforated by spring holes and surmounted by at least one hollow cone, all filled with clear blue water, runs a narrow fissure several hundred feet in length [according to [Peale 1883], 300ft], widening here and there into spring



map 4
FISSURE GROUP
N
200 ft
8 ft falls
Crest of Fissure Terrace
old trail
trail
Witch Creek
trail
old trail
lip of bench
break in slope
falls
steam vent
spring or geyser
acid altered area
depression
runoff channel
intermittent stream

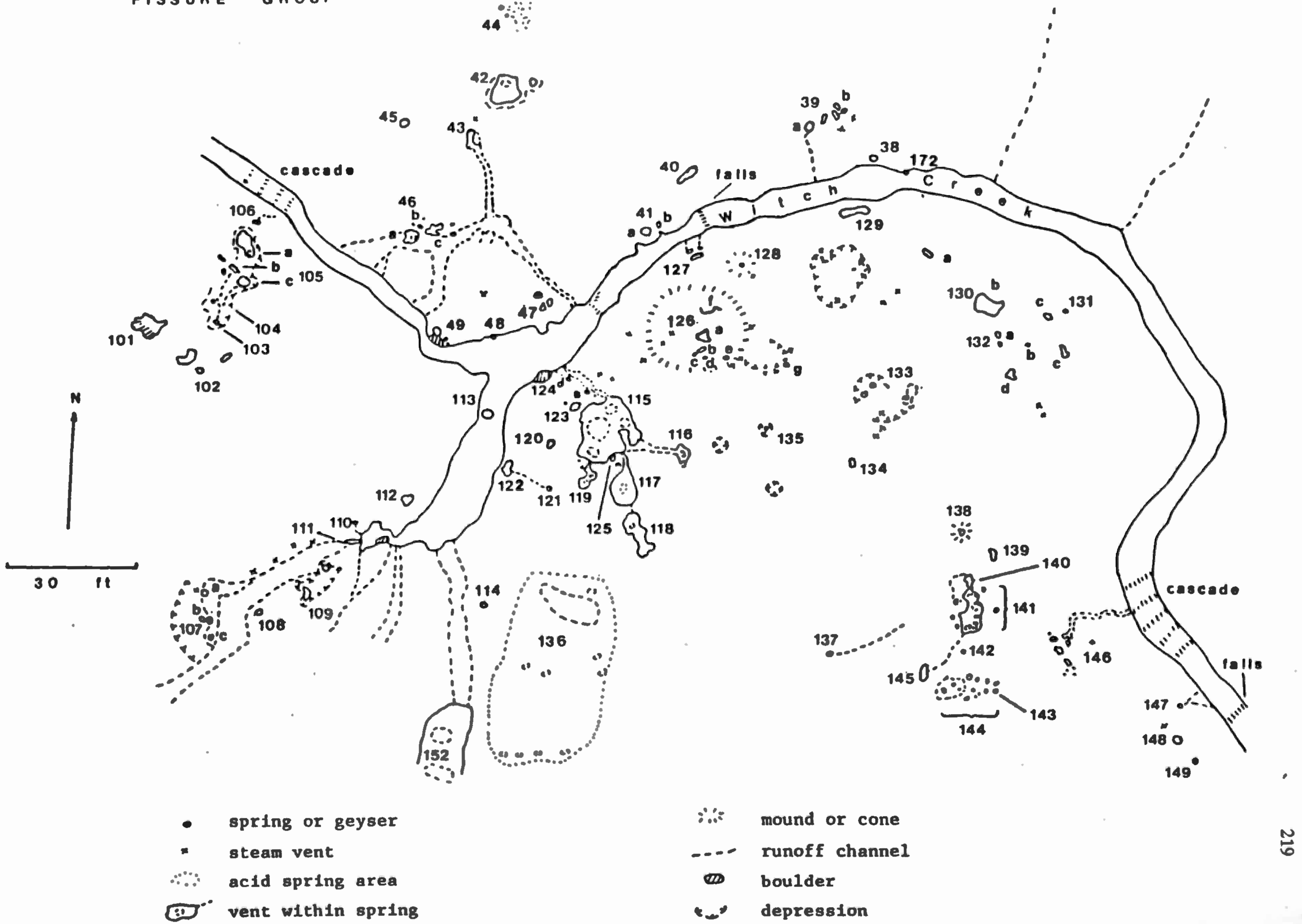
map 5

FISSURE GROUP



FISSURE GROUP

map 6



No. Name	Peale	White	Bryan	Function	Notes	name by
1 - unnamed		shown		S		
2a - unnamed		shown		S		
b - unnamed				S		
3a - unnamed		S#1		S	black precipitate	
b - unnamed				S/PS	occasional splash to 6"	
4 - unnamed (geyser ?)				G ?	2 vents; irreg. basin	
5a - unnamed			HLF-S1a	S	scalloped rim	
b - unnamed				S	small hole	
6 - unnamed (2 springs)				PS	both to 10"	
7 - unnamed geyser	33	S#2	HLF-S1	G	to 4',	
8 - unnamed	34	S#3		S	4 tiny springs nearby	
9 - unnamed				S		
10 - unnamed				PS	to 1-1/2'	
11 - unnamed		S#5		PS	to 1' through sand	
12 - unnamed				S	gassy	
13 - unnamed				S	milky-white	
14 - Sand Spring	23	S#4		PS	to 8", +2 adj. springs	Comstock*
15 - unnamed	25	S#6		PS	to 1-1/2'; triangular alcove	
16 - unnamed				S		
17 - unnamed (geyse r?)	17	S#8		B/G ?	ornate border	
18a - unnamed (3 springs)				FP/MP		
b - unnamed				S	bubbler; + spring above	
c - unnamed (2 springs)				PS	both to < 1'	
19 - unnamed (≥3 springs)				S	acid-altered area	
20a - unnamed				B	vigorous	
b - unnamed				FP	+1 in runoff channel	
c - unnamed				PS	spray to 1-1/2'	
21 - unnamed (3 springs)				S		
22 - unnamed				S	dying	
23a - unnamed				S		
b - unnamed				S		
24 - unnamed				S	sink hole	
25 - unnamed				S	dying	
26 - unnamed				S		
27 - unnamed				S		
28 - unnamed		shown		S	2 other springs nearby	
29 - unnamed		shown		S		
30 - unnamed		shown		B	water ≈5' down	
31 - unnamed		shown		B	water ≈3' down	
32 - unnamed		shown		S	+ small spring below	
33 - unnamed		shown		S		
34 - unnamed		shown		S	at edge of creek	
35 - unnamed geyser		G#9	HLF-G9	G	2 vents: one to 6', one to 7' laterally	
36a - unnamed	} 26	S#7	{	PS	sub from side vent	
b - unnamed geyser				G	sub to 4'	
37 - unnamed				S		
38 - unnamed		S#9		PS	to 1-1/2'	
39a - unnamed	}	S#10	{	S	discharge vent for 39b	
b - unnamed (4 pools)				PS	hits sinter bridge	
40 - unnamed	21	S#11		PS	gassy	
41a - unnamed		S#12	HLF-S12	PS	to 2'	
b - unnamed				SV ?		
42 - unnamed	15	S#13		B	"boiling" heavily	
43 - unnamed	14	shown		S	discharge vent for 42	
44 - unnamed (2 springs)				S	acid-altered area	
45 - unnamed	12	S#14		MP	pinkish-tan	
46a - unnamed				S	palpitates	
b - unnamed (2 holes)	} 13	S#15	{	B	sub	
c - unnamed (geyser ?)				S/PS/G ?	ornate sinter mass	
47 - unnamed		shown		S	bubbling; w/sinter bridge	
48 - unnamed				PS	tiny	
49 - unnamed				PS	to 6" + discharge vent	
50 - "Shelf Spring"	4	S#25		S	prominent shelves	White
51 - unnamed	4b	S#27	HLF-S27	PS	small cone	
52 - unnamed geyser	4a	S#26	HLF-S26	G/PS	small cone	
53a - unnamed		shown		S	in collapse	
b - unnamed				PS	under overhang	
54a - unnamed	9	S#24		PS	cyclic to 1'	
b - unnamed				S	2 vents	
55 - unnamed (3 holes)		shown		B	at depth ≈3'	
56a - unnamed geyser				G/PS	vertical slot; spouter/geyser	
b - unnamed	1a & b	S#37		S		
c - unnamed				S		
57a - "Fissure Springs Geyser"	1c	} S#36 {		G	to 12' (horiz to 15')	Paperiello
b - unnamed	1d			S		
58 - unnamed				SV		
59 - unnamed				SV	thumps	
60 - unnamed		shown		SV		
61 - unnamed	2 (in part)	shown		S	turbid, opaque	
62 - unnamed				SV		
63 - unnamed		shown		SV	small	
64 - unnamed		shown		SV		
65 - unnamed (2 vents)		shown		PS	subterranean	
66 - unnamed				SV		
67 - unnamed geyser	3a	G#5	HLF-G5	G	to 8'	
68 - unnamed geyser	3c	G#8	HLF-G8	G	to 4'	
69a - } unnamed geyser	{ 3d	S#35	} HLF-G6	G	to 4'	
b -	3f	G#6				

Springs of the Fissure Group, Heart Lake Geyser Basin

Table 4

* named applied to this spring by Peale

No.	Name	Peale	White	Bryan	Function	Notes	name by
70 -	unnamed geyser	3i	G#5	HLF-G4	G	to 5'	
71 -	unnamed		shown		IS	w/ eruption of 70	
72a -	unnamed		S#34		S	discharge varies w/ eruption of 70	
b -	unnamed		S#35		S	discharge varies w/ eruption of 70	
73 -	unnamed (3 springs)		shown		PS/S	south vent is PS	
74 -	unnamed (3 springs)		shown		S	west vent bubbles	
75 -	unnamed		shown		S	cone	
76 -	unnamed		shown		S	cone; discharge from tiny NE vent	
77 -	unnamed		S#32		S/IS		
78 -	unnamed (3 vents)		shown		PS		
79 -	unnamed		S#30		S		
80a -	} unnamed geyser		{ S #31 }		G	to 3', mostly sub	
b -			S#29				
81 -	unnamed (3 springs)		shown		S		
82 -	unnamed				SV	old dying spring	
83 -	unnamed				S	pool 1-1/2' below	
84 -	unnamed		shown		S	level at ≈-2'	
85 -	unnamed (4 vents)		shown		S/PS	W 2 vents spout, NE vent is sink	
86 -	unnamed (2 vents)		shown		PS	both to 10"	
87 -	unnamed		shown		PS	SV	
88a -	unnamed		shown		S	sink for 86	
b -	unnamed		shown		SV		
c -	unnamed		shown		PS	subterranean	
d -	unnamed		shown		PS	subterranean	
e -	unnamed		shown		SV		
89 -	unnamed				PS	tiny	
90 -	unnamed				S	water level ≈-4'	
91a -	unnamed geyser		shown		G	in "cave"	
b -	unnamed		shown		PS	cyclic	
c -	unnamed geyser		G#7	HLF-G7	G	to 2'	
92 -	unnamed		shown		S		
93 -	unnamed				S		
94a -	"Hooded Spring"	6a	S#28	•	PS	2 spouting vents to 2'	White
b -	unnamed	6b			PS	part of "Hooded Spring"	
95a -	unnamed	} 6c	shown	{	S	quiet	
b -	unnamed				PS	to 1-1/2'	
96 -	unnamed		shown		PS	3 spouting vents	
97 -	unnamed		shown		S	with fracture vents to S	
98 -	unnamed		shown		S		
99 -	unnamed geyser				G	sub in 6' depression	
100 -	unnamed				SV		
101 -	unnamed geyser				G	to 3'; partly hidden	
102 -	unnamed (3 holes)				SV		
103 -	unnamed geyser				G/IS	to 1-1/2' laterally	
104 -	unnamed				S		
105a -		8b	S#40			laterally to 18'	White
b -	} "Shell Geyser"	{ 8c		•'	} G {	to 1 1/2'	
c -						to 1'	
106 -	unnamed	8a			S (IS ?)	inactive in 1986	
107a -	unnamed				PS		
b -	unnamed (2 vents)		} shown {		S		
c -	unnamed				PS	frying pan-type	
108 -	unnamed				S	flame effect	
109 -	unnamed		shown		SV	2 deep vents	
110 -	unnamed		?		S	water at depth	
111 -	"Hot River"		S#38		S	≈900 gpm !	White
112 -	unnamed				S	water at depth	
113 -	unnamed				S	white flaming funnel in creek	
114 -	unnamed				S		
115 -	Splurger Geyser†	19	G#1	•†	G/PS	to 6'	Weed
116 -	unnamed geyser		G#3	HLF-G3	G	to 2'	
117 -	unnamed		S#21		S	bubbles	
118 -	unnamed				S	w/ upwelling sand	
119 -	unnamed		S#22		S	2 vents; bubbles	
120 -	unnamed				S		
121 -	unnamed				S		
122 -	unnamed				S		
123 -	unnamed				S		
123 -	unnamed				S		
124 -	unnamed				S		
125 -	unnamed				S		
126a -	Puffing Spring	20	S#20	HLF-S20	PS	to 2'	Comstock§
b -	unnamed				PS	subterranean	
c -	unnamed				PS	subterranean	
d -	unnamed				SV		
e -	unnamed				SV		
f -	unnamed				SV	fracture vent	
g -	unnamed				B	subterranean	
127 -	unnamed (3 vents)				PS/S	upper opening to 1-1/2' laterally	
128 -	unnamed	20a			S	old small cone - dry	
129 -	unnamed		?		S		
130a -	unnamed				S	cloudy	
b -	unnamed		shown		S	cloudy pale blue	
c -	unnamed				S		
131 -	unnamed				PS	tiny	

Springs of the Fissure Group, Heart Lake Geyser Basin

Table 4 cont.

* called "Shell Spring"

† called "Triple Bulger" by White and Bryan

§ name applied to this spring by Peale

No.	Name	Peale	White	Bryan	Function	Notes	name by
132a	unnamed (2 springs)				S		
b	unnamed				S		
c	unnamed				S		
d	unnamed				S	bubbler	
133	unnamed (3 springs)				B/S	SW spring sub boiler	
134	unnamed		shown		S/MP	opaque white; bubbler	
135	unnamed				S	in small depression	
136	unnamed				S	acid spring area many vents	
137	unnamed				S		
138	unnamed	22	shown		PS	sub in small cone	
139	unnamed				SV	deep hole	
140	unnamed geyser		shown		G	to 8"	
141	unnamed		shown		S	number of vents and springs	
142	unnamed				S		
143	unnamed geyser				G	to 1'	
144	unnamed (12 springs)				S	in old sinter area	
145	unnamed				S	algae filled	
146	unnamed (10 springs)		S#19		S		
147	unnamed		shown		S		
148	unnamed				S		
149	unnamed				S		
150	unnamed					dead cone	
151	"Glade Geyser"		G#2	•	G	to 30-40' (rare to 65')	Sandborn
152	unnamed	18	S#23		S	3 vents	
153	unnamed		S#39		S	large acid spring	
154	unnamed				SV		
155	unnamed		shown		SV		
156	unnamed		S#18		SV	large hole	
157	unnamed (3 depressions)		shown		SV		
158	unnamed		shown		S		
159	unnamed geyser		S#17		G	to 4"-6"	
160	unnamed		shown		S	tiny	
161	unnamed		shown		S		
162	unnamed		S#16		S		
163	unnamed		shown		S	in grass	
164	unnamed		shown		S		
165	unnamed				S	cone; above sinter bridge	
166	unnamed				S	intermittent thumping & increased discharge	
167	unnamed (2 vents)				PS	to 1' from lower vent	
168	unnamed (3 springs)		shown		S/PS	main spring bubbles; tiny spouter below	
169a	unnamed (≥3 springs)				PS		
b	unnamed	10 & 11	shown		PS	from under boulder	
c	unnamed		shown		PS	frying pan type	
d	unnamed				SV	violent with spray	
170	unnamed				S		
171	marshy area with a number of springs and seeps						
172	unnamed				PS	tiny	
173	unnamed geyser				G	2 vents	

Springs of the Fissure Group, Heart Lake Geyser Basin

Table 4 cont.

• possibly Comstock's Hissing Spring

basins several feet across. The climax of thermal activity is found along this fissure, the cause of which can only be surmised" [Allen & Day 1935], pg.324.

"I was impressed with the big rift in the Crevice Group, later ascribing it as having been due, in part at least, to seismic activity" [Marler 1973], pg.634.

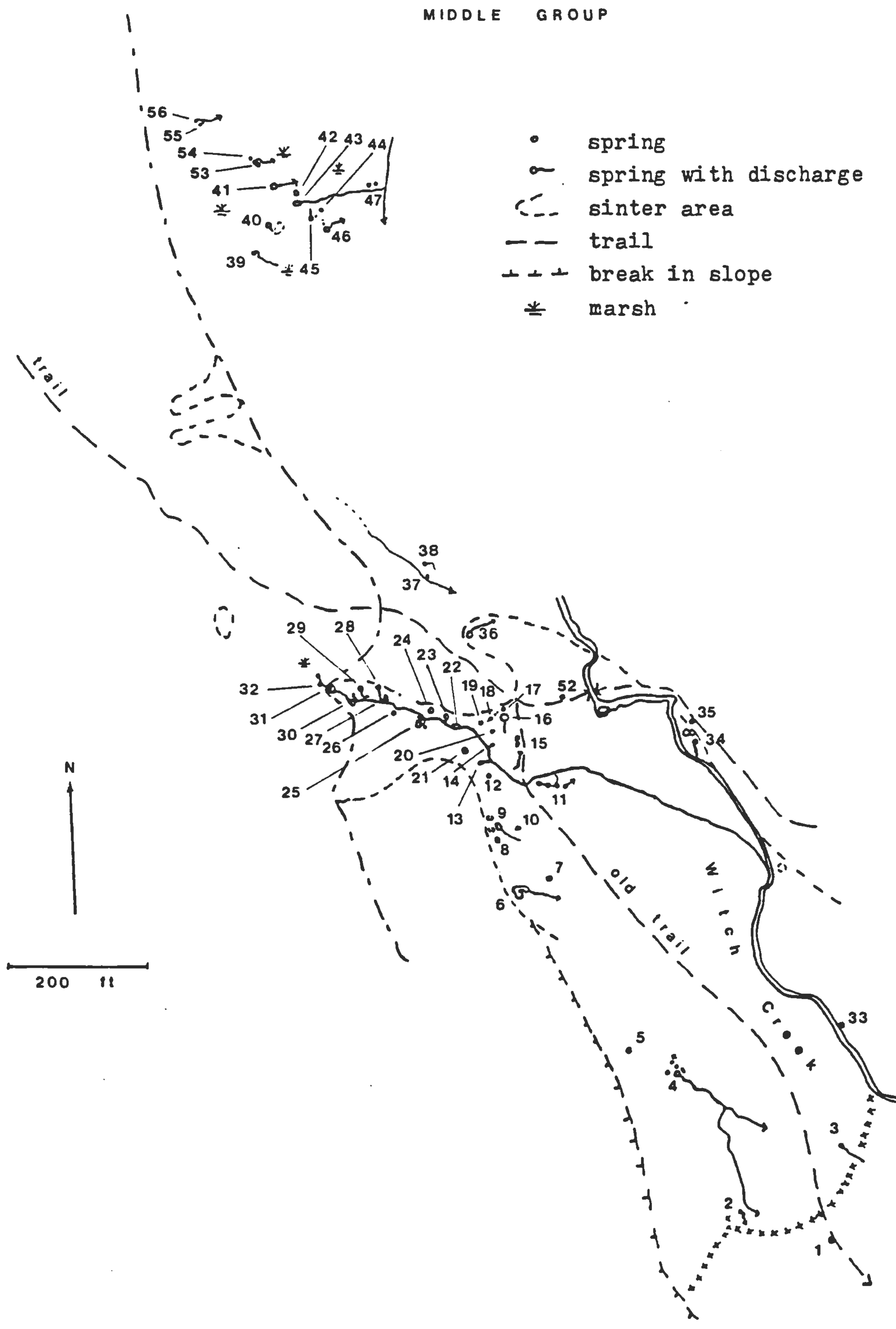
Along this fissure are at least ten geysers, and a number of spouting springs. There are also at least five other geysers on the slopes of this mound in close proximity to this fissure. One of these is the striking "Shell Geyser", named by White. This unique setting of numerous thermal features and contrasting color, through which Witch Creek drops in a series of falls and cascades, forms on of the more striking panoramas, not only in the Heart Lake Basin, but of any similar thermal area in the Park.

In all, there are at least 24 geysers, plus three other possible geysers, in the Fissure Group, 21 of which were active in 1986. The area of the Fissure Group extends down from the fissure along the Witch Creek drainage for another thousand feet. The trail to Heart Lake crosses Witch Creek at its eastern extremity. Included among the geysers of this group are Splurger Geyser ("Triple Bulger") and "Glade Geyser". This last is capable of erupting to sixty feet. Other named features of the Fissure Group include: "Shelf Spring", Fissure Springs (& "Fissure Springs Geyser"), Sand Spring, Puffing Spring, and "Hooded Spring".

Middle Group

This name was given by [Peale 1883] and was included in his Witch Creek Springs. As depicted on map 1, its area covers a lot of territory but only in its southern portion are there any significant concentrations of alkaline springs. (It is this portion in which

map 7


MIDDLE GROUP
spring
spring with discharge
sinter area
trail
break in slope
marsh
trail
old trail
Witch Creek
N
200 ft
1
2
3
4
5
6
7
8
9
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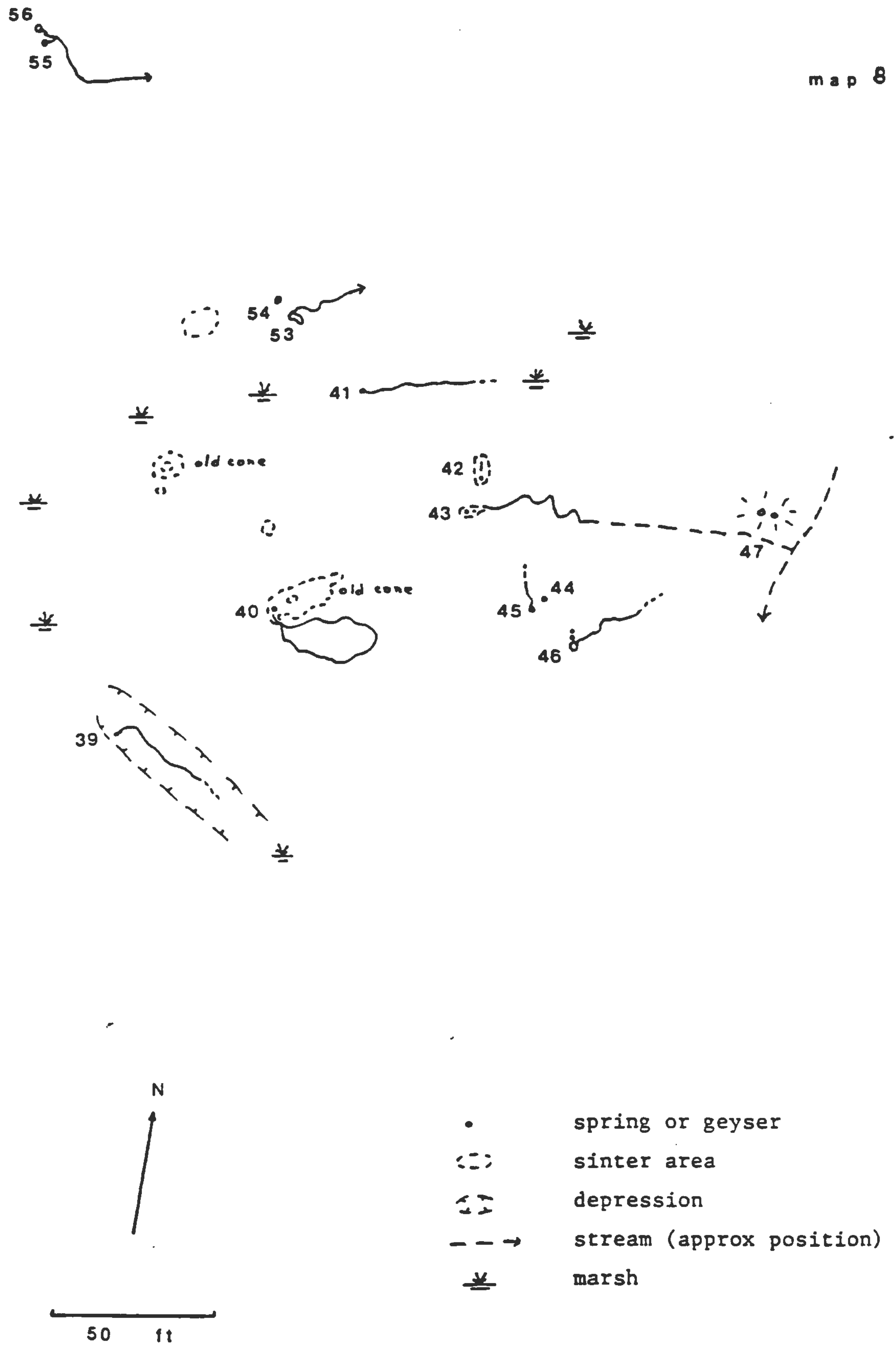


MIDDLE GROUP

No. Name	Peale	White	Bryan Function	Notes	Name by
1 - unnamed			S	series of small vents	
2 - unnamed			S	heavy discharge	
3 - unnamed		#6	S		
4 - unnamed (5 vents)	1	#7	S	hot & good discharge	
5 - unnamed	2	shown	S		
6 - unnamed	4 ?	#4	S	very deep pool	
7 - unnamed			S	warm	
8 - unnamed		shown	S	warm	
9 - unnamed	3 ?	#8	S		
10 - unnamed			S	muddy brown-gray	
11 - unnamed (4 vents)			S	good discharge	
12 - unnamed			S	seeping discharge	
13 - unnamed		shown	S	good discharge	
14 - unnamed		shown	S	scalloped edge	
15 - unnamed (6 vents)		#9	S	series of vents	
16 - unnamed	6a	#1	S	10' dia.	
17 - unnamed	6b		S		
18 - unnamed	6c	shown	S	tiny hole adjacent	
19 - unnamed		shown	-	dead vent in sinter	
20 - unnamed		shown	S	2 connected vents	
21 - unnamed		shown	S	deep vent	
22 - unnamed	9 ?	#10	S	very deep vent	
23 - unnamed		#12	S	warm & deep	
24 - unnamed		#12	S	heavy bubbling	
25 - "Double Spring"	5a & b	#2	S	2 large vents	White
26 - unnamed			S	seep	
27 - unnamed			S	at edge of stream	
28 - unnamed	7 ?	#11	S		
29 - unnamed	8 ?	#13	S		
30 - unnamed	10 ?	#14	S	in stream bed	
31 - unnamed		#14	S	upwelling and deep	
32 - unnamed			S	"boiling"	
33 - unnamed		#5	S		
34 - unnamed		#3	PS	to 6"	
35 - unnamed			S		
36 - unnamed		shown	S		
37 - unnamed			S		
38 - unnamed			S		
39 - unnamed	13 ?	#15	S		
40 - unnamed		#15	S		
41 - unnamed		#15	S		
42 - unnamed geyser	11 ?	#15	G	to 1-1/2'	
43 - unnamed		#15	S	very heavy discharge	
44 - unnamed		#15	S	on old mound	
45 - unnamed		#15	S		
46 - unnamed	12	#15	S		
47 - unnamed (2 springs)			S	on old mound	
48 - unnamed			S	very heavy discharge	
49 - unnamed	14	#16	S		
50 - unnamed		#17	S		
51 - unnamed			S	new, in trail	
52 - unnamed			S	algae filled	
53 - unnamed			S		
54 - unnamed			S		
55 - unnamed			S		
56 - unnamed geyser			G	to 1'	

Springs of the Middle Group, Heart Lake Geyser Basin
Table 5

[Allen & Day 1935] place their Group 3). Not much attention is usually given to this small collection of springs, only a few of which are at or near boiling. Until 1986, it was believed to contain no geysers; at that time, however, a small geyser was discovered within a small group of springs which lay well off the trail, separated from the rest of the group to the north (see map 7). A second small geyser was found in this same area in 1987.

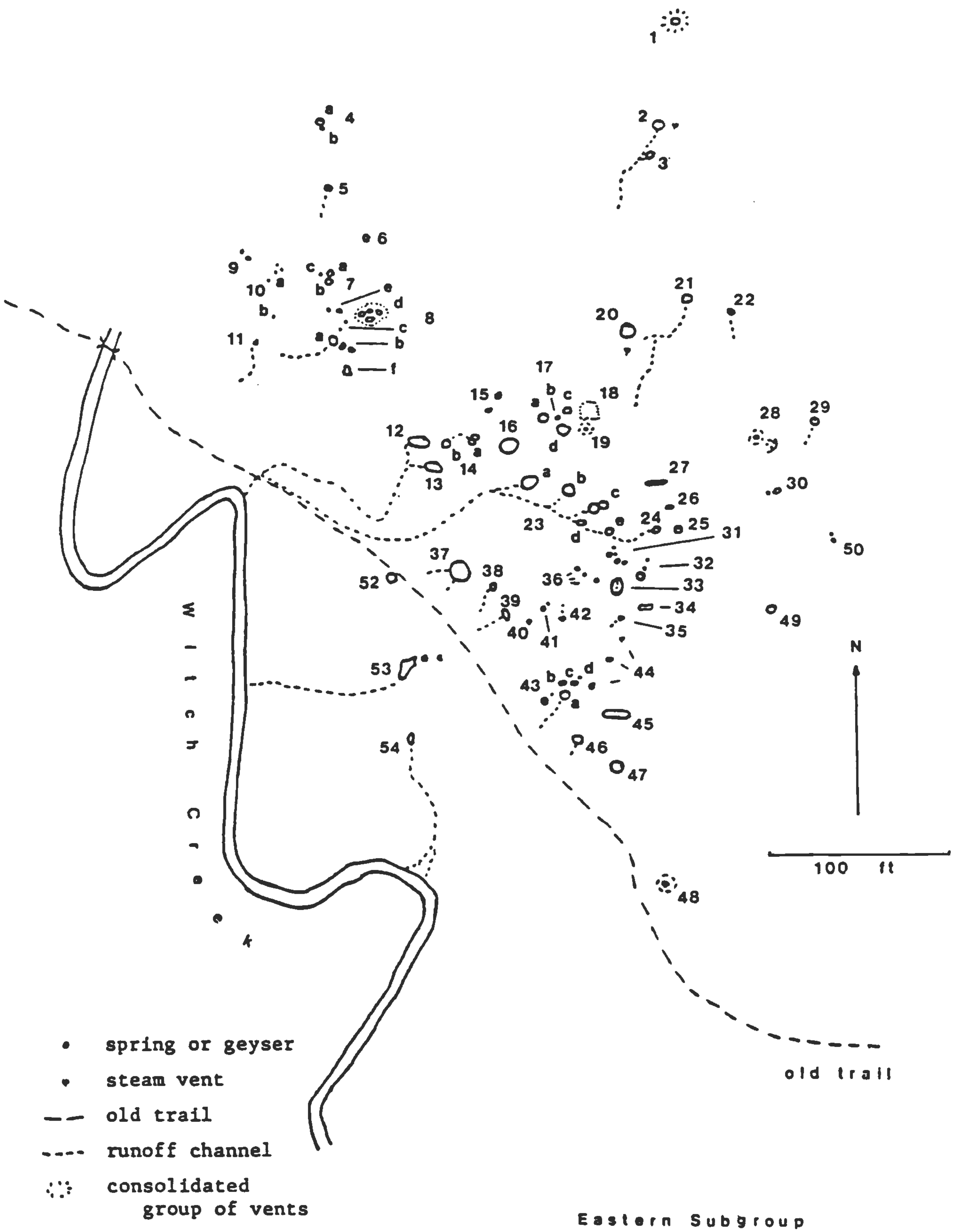
Stretching south from this area of concentrated activity is an old sinter shield, now mostly covered by gravel, grass, and trees. Only a few scattered springs appear here, most being on the periphery. To the north the conditions are a contrast to this, with a few dead relics of a more active past. Here the springs are all relatively cool, possessing no sinter. There are a few large, cool, typically acid pools with only small discharge. There is at least one spring which has an extremely high discharge, creating a boggy meadow below. A number of other springs discharge directly through the sod, again producing similar conditions. In addition, there are a few warm pools so overgrown with vegetation that they could become traps for the unwary.

Lower Group

This name was given by [Peale 1883] and it comprises the southeast portion of his Witch Creek Springs. Peale writes:

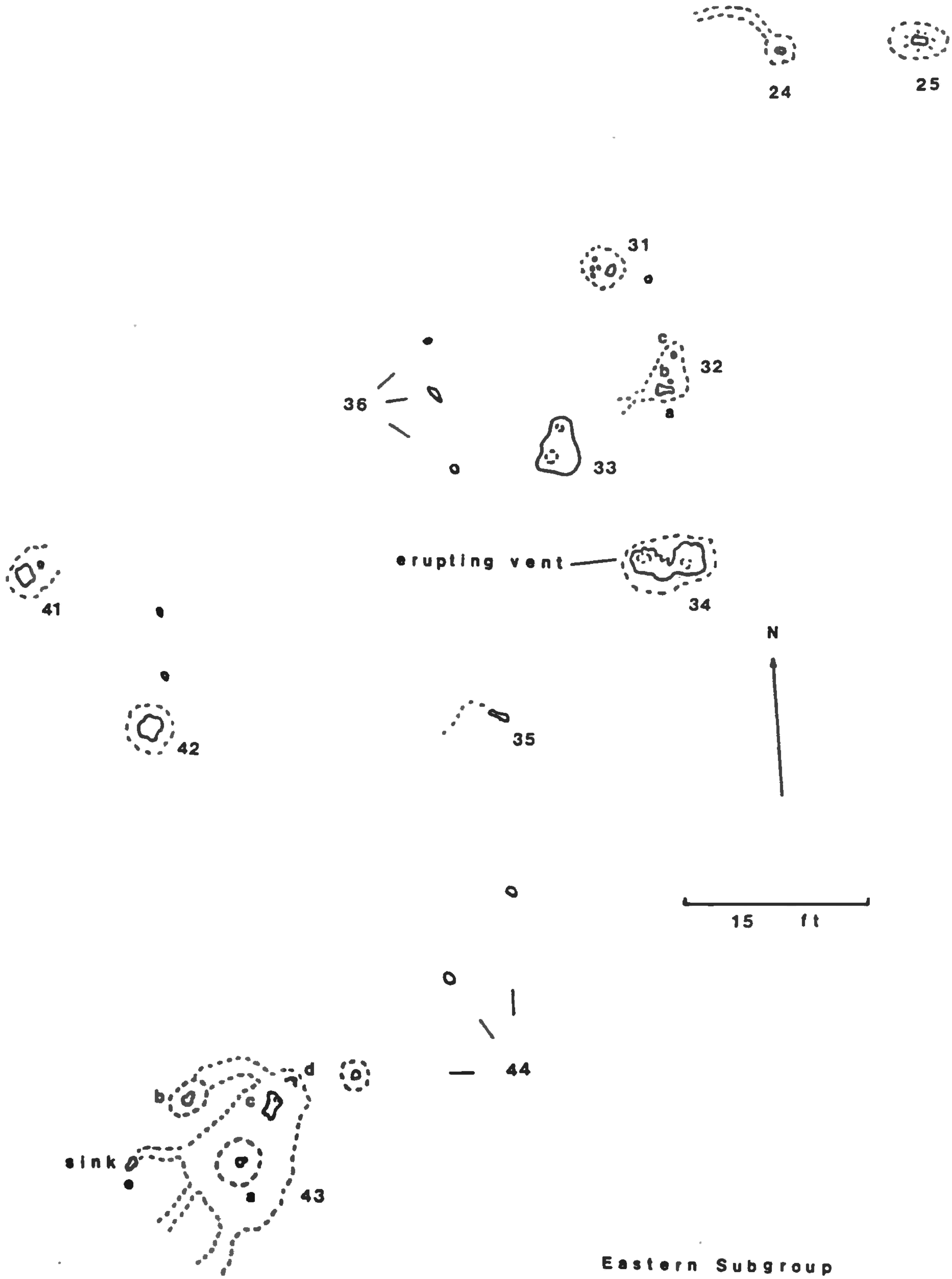
> "The Lower Group is near the upper margin of the swampy valley and consists of two subgroups. The first... is on the left bank of [the] creek on a wide flat which rises gently as the creek is left. The springs of this subgroup are partly on hard deposit and partly on marshy ground...

LOWER GROUP

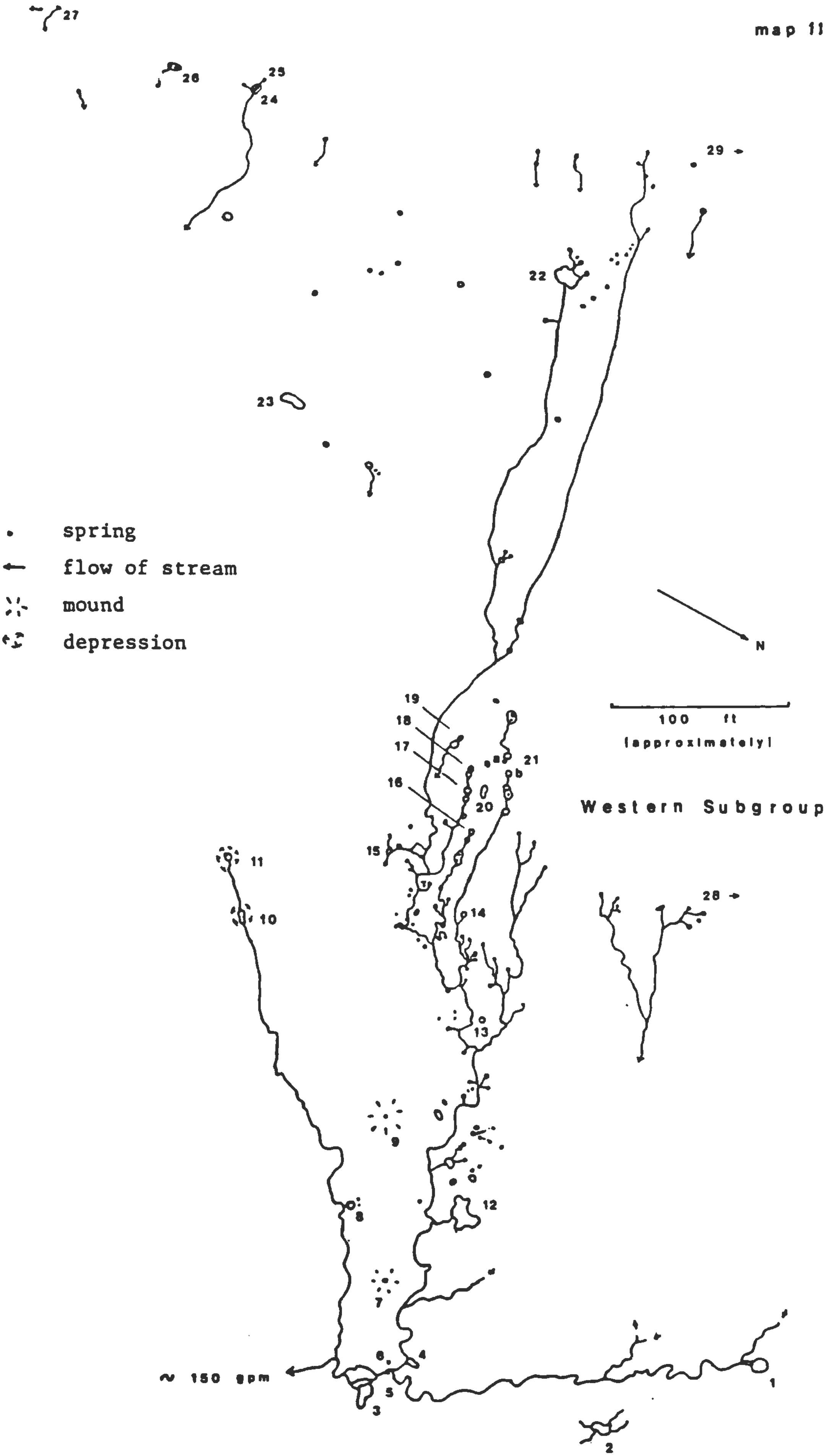


Eastern Subgroup

LOWER GROUP


24
25
31
c
b
32
a
36
33
erupting vent
34
41
N
42
35
15 ft
b
c
d
44
sink
a
43
Eastern Subgroup

map 11



LOWER GROUP

No. Name	Peale	White	Bryan Function	Notes	Name by
1 - unnamed geyser	31	W-1	G	12' diameter	
2 - unnamed	34	W-2	S	red algae	
3 - unnamed	33	W-3	S	handsome pool	
4 - unnamed			S	thumping, cavernous	
5 - unnamed			S	in streambed	
6 - unnamed			S	hot	
7 - unnamed		shown	S	on mound	
8 - unnamed			S	hot, thick sinter rim	
9 - unnamed			S	on mound	
10 - unnamed			S	warm	
11 - unnamed			S	underground stream flows into this spring; has small fish	
12 - unnamed	32	shown	S	large, in grass	
13 - unnamed			PS	3 tiny vents spout through sand	
14 - unnamed			S	pretty	
15 - unnamed			PS	superheated	
16 - unnamed			PS		
17 - unnamed			PS	in small alcove	
18 - unnamed			PS	in small alcove	
19 - unnamed			PS		
20 - unnamed			S	tan, opaque	
21a - unnamed			S	sink for discharge from above	
b - unnamed			S	discharge re-emerging from 21a	
22 - unnamed			S	large spring in old sinter	
23 - unnamed			S	red algal spring in grass	
24 - unnamed			S	sinter basin	
25 - unnamed			S	sinter basin	
26 - unnamed			S	2 bubbling vents in sinter basin	
27 - unnamed			B/PS	scalloped sinter rim	
28 - Long series of springs that continue to the NNW — majority are small, non-sintered, warm, discharge moderate to high; remain largely unmapped.					
29 - Series of spring similar to 29, not as extensive; remain largely unmapped.					

Springs of the Lower Group (Western Subgroup), Heart Lake Geyser Basin
Table 6

"The second subgroup contains a large number of springs on a small branch which joins the creek from the south or right side. The springs extend back as far as the base of the hills... The surface about most of them is marshy, and a number are merely oozing holes in the marsh" [Peale 1883], pg. 297.

Shown on Map 1, these have been labeled the Easter and Western Subgroups, respectively. These are the same designations given by [White 1973]. On the map dashed lines connect these two groups. Within this wide area, mostly a meadow, are a number of widely scattered springs. They are relatively cool, probably containing a large proportion of the surface water draining from the slopes of Factory Hill above. There are a few large, warm, murky pools sprinkled through the area, mostly toward the east. There are also numerous small springs typified by low temperatures, moderate to heavy discharge, and little or no sinter. Most of them are small holes which emerge directly from the meadow. These lie exclusively in the western portion of the meadow and up toward the base of the hill. Many form small rivulets which eventually flow into a small steam draining this western area. (Designated #28, #29 on Map 11). In addition, there are a number of seeping springs emerging directly into the sod, or in some spots, oozing out of small gravel areas. Toward the northwest "quaking-bogs", or "matress-meadows" can be encountered.

Only within the two main subgroups are any high temperatures found. The Eastern Subgroup was called Group 4 by Allen & Day:

"Group 4 — About a half mile above the Heart Lake Ranger Station is a small sinterclad flat sloping gently down to the northeast bank of Witch Creek. The area active today measures about 100 by 180 yards, but an older sinter deposit extends through the woods to the east. The ground is dotted with about 20 hot springs varying in size from 4 inches to 2-1/2 feet in diameter and relatively deep, among which Hanks counted five geysers, sputing to a height of 1 to 2 inches up to 18 inches... Several springs at that time seemed to be superheated... A peculiar type of sinter was noticed repeatedly at this little group of springs — rounded, mushroom-like masses a few inches across, with shallow scallops around the edges, attached to the ground by a very short stem.

"The creek opposite this area is considerably above normal temperature and shows a strong carbonate test. Extensive bars of sinter have been built up under the water in several places" [Allen & Day 1935], pp.323-324.

This small densely packed and vigorously active area is known to contain at least 10 geysers, with possibly three others. Eight of these geysers were active in 1986, but all were small, only one reaching as high as 4 to 7 feet.

The Western Subgroup has probably been rarely visited; a few of its myriad springs are interesting. Allen & Day labeled this area Group 2:

"Group 2 — A little more than a half mile to the northwest of the Rustic Group, and

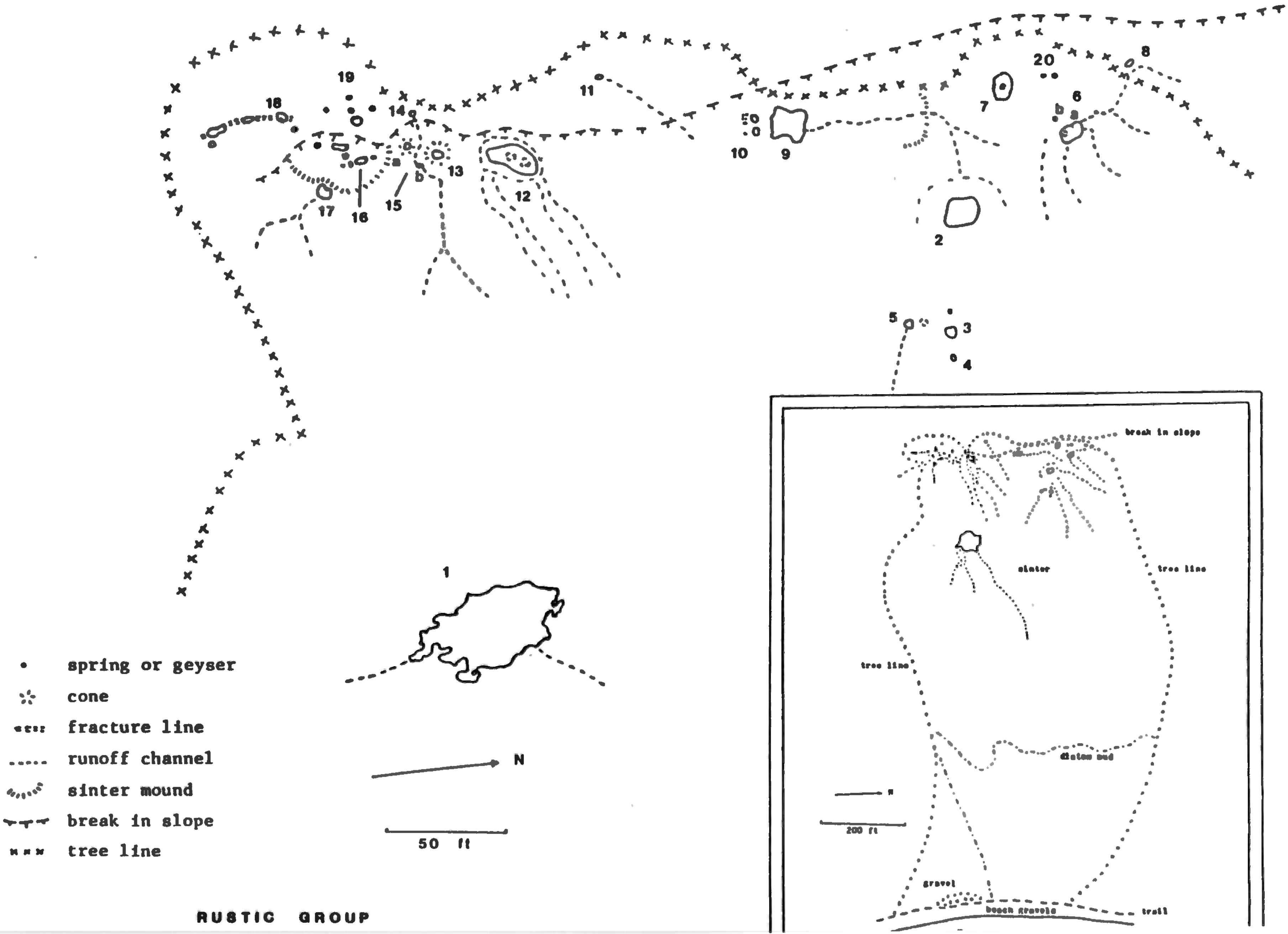
No. Name	Peale	White	Bryan	Function	Notes	Name by
1 - unnamed geyser	30	G#1	HLL-G1	G/PS	to 2-3' (rarely 10')	
2 - unnamed		S#13		S		
3 - unnamed		S#14		S		
4a - unnamed		S#12 ?		S	on sinter	
b - unnamed				PS	tiny	
5 - unnamed				S		
6 - unnamed				S		
7a - unnamed		S#16	HLL-S16	PS	to 1'	
b - unnamed				S	adjacent to 7a	
c - unnamed				S	small vent	
8a - unnamed geyser		S#15	HLL-S15	G/PS	cone on low mound	
b - unnamed (2 springs)				S		
c - unnamed (2 springs)				PS	each very small	
d - unnamed (4 openings)		shown		S	consolidated in basin	
e - unnamed (2 springs)				S		
f - unnamed				S	murky gray water	
9 - unnamed (double spring)		S#17		S	level fluctuates	
10a - unnamed (4 springs)				S	small non-discharging	
b - unnamed				S	small non-discharging	
11 - unnamed				S	scalloped rim in pool	
12 - unnamed		S#19		S		
13 - unnamed		S#18		S		
14a - unnamed				S	double pool	
b - unnamed				S	sink for 14a	
15 - unnamed (2 springs)				S	water down 1'	
16 - unnamed		S#10		S	large murky pool	
17a - unnamed		S#10		S		
b - unnamed		S#10		S		
c - unnamed		S#10		S		
d - unnamed		S#10		S		
18 - unnamed		S#10		S/B	cluster of hot vents in basin	
19 - unnamed geyser		G#3	HLL-G3	G	to 1'	
20 - unnamed		shown		S	large red pool	
21 - unnamed geyser		S#11		G	boiling eruptions to 1'	
22 - unnamed (geyser ?)				G ?	old cone	
23a - unnamed		S#9		S		
b - unnamed		S#9		S		
c - unnamed		S#9		S	double pool	
d - unnamed		S#9		S	in channel from 9e	
24 - unnamed geyser				G	to 8"	
25 - unnamed (geyser ?)		shown		G ?	small cone	
26 - unnamed				S		
27 - unnamed				S	recent collapse	
28a - unnamed		shown		B	decaying cone	
b - unnamed (4 openings)				B	in old sinter	
29 - unnamed		shown		S	on slight mound	
30 - unnamed (2 springs)		shown		S		
31 - unnamed (6 openings)		S#9 ?		S	5 vents in sinter	
32a -		S#8				
b - } unnamed geyser		{	} HLL-S8	G	PS in previous years	
c -						
33 - unnamed		shown		S	double vent	
34 - unnamed geyser		G#2	HLL-G2	G	to 2'	
35 - unnamed				S		
36 - unnamed (3 openings)				S		
37 - unnamed		S#20		S	large algal spring	
38 - unnamed				S		
39 - unnamed		S#22		S		
40 - unnamed				S		
41 - unnamed geyser (+1 tiny vent)				G	to 1'	
42 - unnamed (+2 other vents)				IS	intermittent bubbling	
43a - "Ivory Geyser"		S#6		G	to 7'	Paperiello
b - unnamed				S	empties with eruption of 43a	
c - unnamed				S	empties with eruption of 43a	
d - unnamed				SV	erupts with 43a at times	
e - unnamed				S	sink	
44 - unnamed (3 springs)				S		
45 - unnamed		S#5		S		
46 - unnamed		S#4		S		
47 - unnamed		S#3		S		
48 - unnamed		S#2		S	on small mound	
49 - unnamed		shown		S		
50 - unnamed (2 springs)		S#7		B		
51 - unnamed		S#1		S		
52 - unnamed		shown		S	bubbles	
53 - unnamed geyser		G#4	HLL-G4	G/B/S	to 2'	
54 - unnamed		S#21	HLL-S21	PS/IS	to 1' (remotely possible a geyser)	

Springs of the Lower Group (Eastern Subgroup) Heart Lake Geyser Basin
Table 7

separated from it by a stretch of of timber, is another hot area, of exclusively alkaline characteristics, containing about 25 springs. They range in diameter from 2 to 15 feet, some hot, clear, and sterile, others supporting an organic growth. Many gave a pronounce test for carbonate, others in which spring gases were seen rising gave none…

"Most of the springs lie in meadow ground and are drained by a little tributary of Witch

map 12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11
12
13
14
15
16
17
18
19
20
a
b
spring or geyser
cone
fracture line
runoff channel
sinter mound
break in slope
tree line
N
50 ft
RUSTIC GROUP

No. Name	Peale	White	Bryan	Function	Notes	Name by
1 - Columbia Spring	Columbia	S#1		S	53' x 48'	Gannett ?
2 - Rustic Geyser	Rustic	G#1	•	G	to 15' - 50'	Gannett ?
3 - unnamed geyser		G#3	HLR-G3	PS/G	to 10' as geyser, sub as spouter	
4 - unnamed		shown		S	in hole	
5 - unnamed	1	S#3		S		
6a - } unnamed geyser	2	S#2	HLR-S2	G {	rectangluar pool can errupt to 33'	
b -					small hole	
7 - unnamed geyser	3	G#2	HLR-G2	G	to 15' (laterally to 18')	
8 - unnamed				S	green algae	
9 - unnamed*	5	S#4		S	scalloped border	
10 - unnamed (6 springs)		shown		S	murky springs in grass	
11 - Prometheus Spring	Prometheus	S#5	•	G/PS/S	to 15'	Gannett ?
12 - unnamed geyser		S#6		G	2 vents - S erupts 4'-12' (rarely 20')	
13 - unnamed	6	S#7		S	old cone, now dormant	
14 - unnamed		shown		PS	to 8"	
15a - unnamed geyser		G#4	HLR-G4	G	to 1'	
b - unnamed		S#8		S	discharge vent for #15a	
16 - unnamed	7	shown		S	algal pool	
17 - unnamed geyser	8	S#9		G/S	infrequent geyser to ≈8"	
18 - unnamed		S#10		MP/FP/SV	along fracture	
19 - unnamed (many vents)		shown		SV	on hillside	
20 - unnamed				S	2 holes	

Springs of the Rustic Group, Heart Lake Geyser Basin

Table 8

* called "Square Spring" by A.Mebane, 1959.

Creek carrying only thermal water. The discharge just below the hot area was 0.55 cubic foot per second in 1930, and the temperature of the water was 60°C [140°F]. No geysers were found in this group" [Allen & Day 1935], pg.323.

In 1973, [White 1973] estimated the flow at this spot to be 150gpm (≈0.33 cubic feet per second). The only appreciable sinter deposition seen in this group lay along its southeast to northeast margins. Some new sinter appears in a few places; while underlying this portion is an expanse of thick old sinter. Some of its springs are still active and very hot. Only #1 is known to be a geyser. A number of small spouters emerge in the central portion of this group.

Rustic Group

The name of this group was given by the Peale survey crew [Peale 1883]; it no doubt comes from its most important geyser — Rustic. Exactly who gave the name to Rustic Geyser, and to the other named features of this group is open to speculation; I believe it was probably Henry Gannett or possibly William H. Holmes. [Whittlesey 1988] gives the following information from the 1878 diary of Geologist William H. Holmes:

> "...the name 'Stockade Geyser' was given simultaneously to this feature because of logs arranged about its opening. Holmes wrote: 'The basin rim that's surrounded by this curious sugar coated frame work suggested the name Rustic, which was for the time given to it.'"

This area is isolated and removed from the other groups of the Heart Lake Geyser Basin; it is distinct from what Peale labeled the Witch Creek Springs. It was labeled Group 1 by Allen and Day:

> "Group 1 — At the northwest corner of the Lake and at the very foot of Mount Sheridan is a small number of springs which Peale calls the Rustic Group. It is only a hundred yards in diameter, yet in this diminutive area the typical alkaline characteristics are well illustrated. Most of the individual springs are insignificant, but three measure from 6 to 12 feet, and one, the Columbia Spring, is 50 feet in diameter. ...of the six geysers, the Rustic is not only the ranking geyser of the group, but of the whole Heart Lake region, judged by present information. ...the slopes of Mount Sheridan supply this area with considerable water, expressed not only in springs, but in the marshy ground around them; in July 1930 the total discharge was 0.19 sec. ft. [≈87gpm], most of it flowing from the Columbia Spring. With one qualification all these springs carry alkaline water, often responding strongly to the carbonate test. None of the waters was acid... With the exception of ... [a] little chain of springs, practically all others in the Rustic Group are lined with siliceous sinter. As evidence of the hand of man at this spot long before 1870, it may be mentioned that the pool of Rustic Geyser, 8 by 9 feet, is bordered by logs in the form of a rectangle, much too carefully laid down to be the work of chance. In 1925 they were encrusted with sinter to a thickness of about half an inch. Peale says that the 'coating' on these logs was already thick and firmly attached to the surrounding deposit in 1878" [Allen & Day 1935], pp.320-321.

What Allen and Day wrote decades ago is still applicable today. This small but vigorously active group lies on a apron of graveled sinter which extends toward Heart Lake (see Map 12). Along with the mountains in the distance, this lake forms a beautiful backdrop for the springs and geysers of this group. It would be interesting to known which were the six active geysers of six decades ago, but unfortunately insufficient details are given. In 1986, of the eight known geysers, only four were active — Rustic was not one of them.

On admittedly little evidence, it would appear that at least some geysers of this group, including Rustic, #6 and #7, are affected by a seasonal change. "There is evidence that the length of [Rustic's] interval is dependent on the level and temperature of the subsurface water table. As the summer season progresses the level drops and the temperature rises, causing shorter intervals" [Bryan 1986], pg. 237.

Another named feature of this group, Prometheus Spring, has behaved at various times as a discharging spring, a perpetual spouter, and as a geyser. It has been dormant since 1978.

Unnamed Group

This thermal tract remains unnamed; it lies almost directly northwest of the Rustic Group, and not quite a half mile away. In elevation, it is about 100ft higher. Probably the easiest way to reach it is to traverse around to the northwest from the Rustic Group until reaching the unnamed drainage flowing down the flanks of the Red Mountain Range, between Mount Sheridan and Factory Hill. From there go up the drainage (see Map 1). I have not visited this area. The only-description known for this area comes from a Memorandum by Roderick Hutchinson.

> "During many previous trips into Heart Lake on occasional cloud of vapor has been observed rising from the drainage between Mount Sheridan and Factory Hill. The source of this heat has never been reported or described, and certainly rarely visited, because of its seclusion. Dense timber, heavy deadfall, and boggy conditions have discouraged or prevented earlier attempts to reach the area.
>
> "With snowpack covering most of the obstacles and cold weather making the thermal area more visible, M. Short and I were able to reach the thermal area late in the evening of the 27th [January 1977]. It was found to have two distinct parts: a grassy area of old pits and stagnant pools with low heat flow on a northeast facing slope, and 150 meters [≈500ft] to the south, a much hotter small area of thermal activity within the ravine of the main creek which flows year-round from the southwest. Based on topography, orientation of thermal features, and heatflow and vegetation patterns, the thermal area apparently follows a north-south trending normal fault, east side down-thrown.
>
> "The southern portion has only three features of interest:
>
> 1- One fumarole above the stream on the north bank; while moderately noisy and the main source of the vapor cloud visible from the patrol cabin, its activity is much subdued from previous years as shown by the alteration and erosion patterns.
> 2- Collection of vigorous frying-pans and small red pools. These are right at stream level and are grouped in a tight cluster about 10 meters [≈33ft] across. Most are no doubt flooded during the spring snow melt. No appreciable sinter deposition was noted.
> 3- Seeps. Located on south bank of stream, all have low to moderate temperature.
>
> "The legal description of the exact location of this thermal area is T50N, R113W, Section 19, NW1/4, SW1/4" [Hutchinson 1977].

References

Allen & Day 1935 Allen, E.T., and Arthur Day, *Hot Springs of the Yellowstone National Park*, Carnegie Institute of Washington, Publication No. 466, Baltimore, Md.: Waverly Press, 1935.

Barlow & Heap 1872 Barlow, John W. & David P. Heap, *Report of a Reconnaissance of the Basin of the Upper Yellowstone in 1871*, (42nd Cong., 2d Sess.; Senate Exec. Doc 66) Washington, D.C.: Govt. Printing Office, 1872.

Bryan 1986 Bryan, T.Scott, "Activity in Heart Lake Geyser Basin, Aug 4, 1986", (unpublished report dated Aug 6, 1986).

Bryan 1986 Bryan, T.S., *The Geysers of Yellowstone*. Revised edition. Boulder, Col.: Colorado Associated University Press, 1986.

Comstock 1875 Comstock, Theodore B., "Geological Report," in: Jones, WIlliam A. *Report upon the Reconnaissance of Northwestern Wyoming, including Yellowstone National Park, Made in the Summer of 1873*, Washing, D.C.: Gov't Printing Office, 1875.

Haynes — Haynes, Jack E., Vertical File in Special Collctions at Montana State University, Bozeman, Mont.

Hutchinson 1977 Hutchinson, R.A., Memorandum, Jan 29, 1977.

Hutchinson 1978 Hutchinson, Roderick, A. Notebook "Heart Lake Geyser Basin", Oct. 22 to Oct 23., 1978, 10 pages (unpublished).

Hutchinson 1985 Hutchinson, Roderick, A. Notebook (No title, but information on Heart Lake Geyser Basin), Mar. 6 and June 4, 1985 (unpublished).

Hutchinson 1986 Hutchinson, Roderick, A. Notebook (No title, but information on Heart Lake Geyser Basin), June 11 and June 13, 1985 (unpublished).

Majors 1961 Majors, Harry M., "The Thermal Areas and Thermal Features of Yellowstone National Park", (unpublished typescript and map), 1961.

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

Martinez 1974 Martinez, Sam, "Report on Hot Spring and Geyser Activity (in Yellowstone National Park) in 1974." (Unpublished).

Martinez 1976 Martinez, Sam, "Report of Hot Spring and Geyser Activity (in Yellowstone National Park) in 1976" (Unpublished).

Martinez 1978 Martinez, Sam, "Report of Hot Spring and Geyser Activity During the Field Trip of August 20 Through September 3, 1978 (in Yellowstone National Park)" (Unpublished).

Mebane 1959 Mebane, R.Alan, (and others), "Report on Heart Lake Geyser Basin, Oct 8 - 10, 1959", [Portion of report on the changes induced by the Hebgen Lake Earthquake of August 1959. Photographs included.]

Peale 1883 Peale, A.C., "The Thermal Springs of the Yellowstone National Park" in: Hayden, Ferdinand V., *Twelfth Annual Report of the United States Geological and Geographical Survey of the Territories: A Report of Progress of the Exploration in Wyoming and Idaho for the Year 1878*, Washington, D.C. : Gov't Printing Office, 1883.

Sandborn 1965 Sandborn, William B., Letter to Mr. George Marler, Yellowstone Park, Wyo. from San Francisco, Calif., dated Mar 17, 1965. (2pp typescript). At the YNP Reference Library, Mammoth, Wyo.

Sandborn 1975 Sandborn, William B., "The Discovery of Glade Geyser", *Gems and Minerals*, March 1975, pp 22-25, 51-52.

White 1973 White, Donald E., M. Nathanson, A.H.Truesdell, M.Thompson, & (Jo) White, (Untitled) Report on the Heart Lake Geyser Basin, Sept 10-23, 1973, 12 pages plus 7 maps.

Whittlesey 1988 Whittlesey, Lee H., "Wonderland Nomenclature: A History of the Place Names of Yellowstone National Park," (ms. on microfiche, available from the Montana Historical Society, Helena Mont.), 1988.

Hot Springs of the Northern Part of the Shoshone Geyser Basin, Yellowstone National Park

Rocco Paperiello

Abstract: A detailed set of tables and maps making up an inventory of hot springs and geysers of the northern portion of the Shoshone Geyser Basin.

S	Spring
PS	Perpetual Spouter
G	Geyser
FP	Frying Pan
MP	Mud Pot
B	Boiling Spring
SV	Steam Vent
IS	Intermittent Spring
•	Referred to by name
aka	also known as

Abbreviations Used in Tables
Table 1

The tables and maps of this report are part of a comprehensive report about the Shoshone Geyser Basin that is currently in progress. The tables attempt to correlate material from a number of important sources about the features of this basin. The first column gives the number of this spring within its group as shown on the maps. The next column gives a springs name, and if a spring has an official name, it is shown in boldface. The next three columns list the designations used in [Peale 1883], [USGS 1966], and [Bryan 1986] respectively.

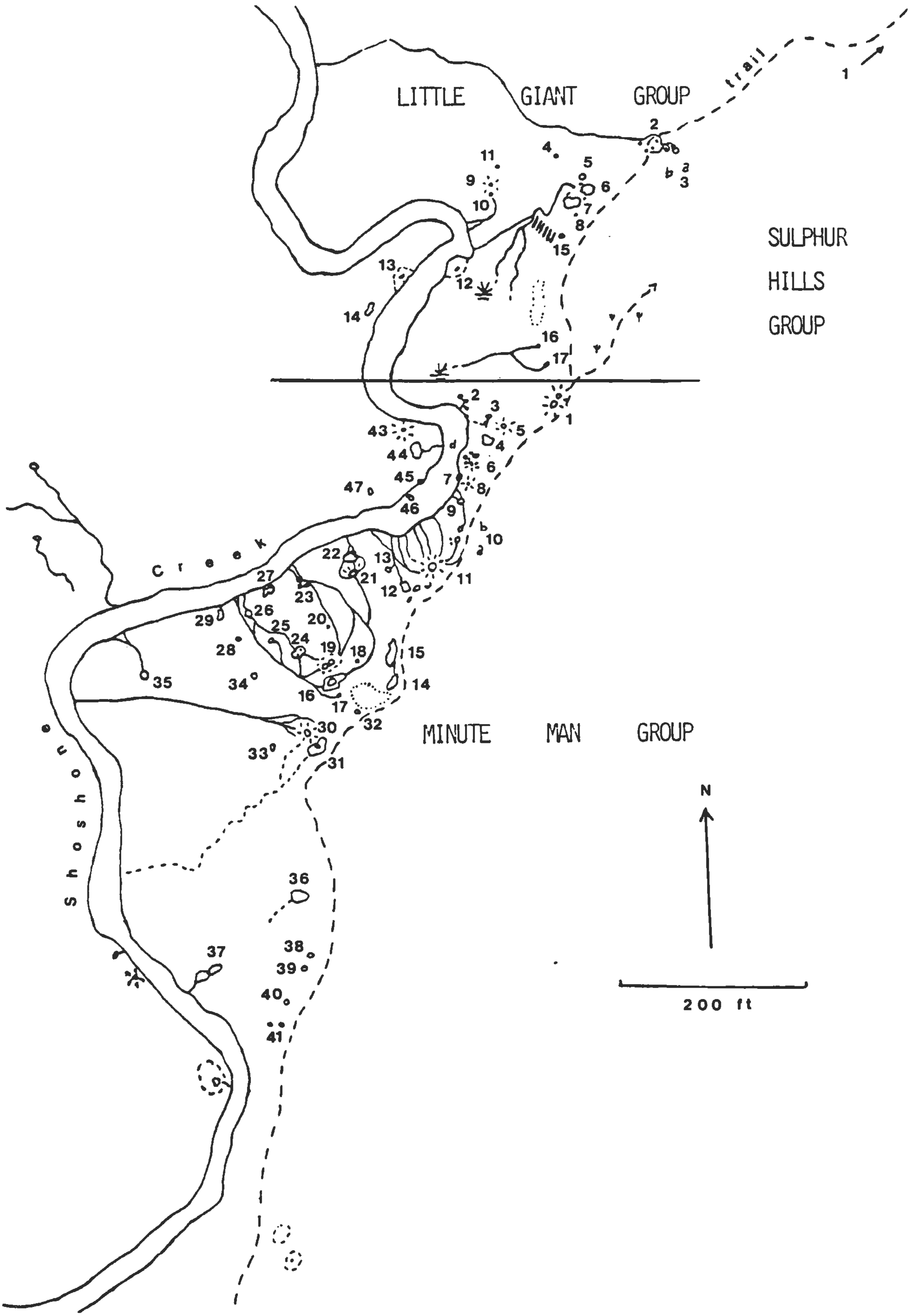
Some of the names presented in these tables are different from those of recent authorities. Recent research has properly located Frill Spring and Bead Geyser. Last minute changes in [Whittlesey 1988], the authoritative work on Park names, reflect this research. In some cases, old descriptions from the 19th century closely match those of today's features, while the locations do not. These discrepancies need to be resolved.

Summary of Geysers by Group

Group	Definite	Possible	Active in: 1987	Active in: 1988
Little Giant Group	8		7*	8*
Minute Man Group	12		9	9
Orion Group	15	1	1	2
Camp Group	2	1	2	2
North Group	23		17†	13†
South Group	8		4	3
Island Group		2	2§	0
Western Group	3		2	2
Shore Group	1		0	0
Yellow Crater Group		1	1§	1§
"Horse Camp Group"	2		2	2
"Swamp Lake Group"		1	1§	0
	74	7	44(48)	41(42)

* Including Little Giant minors.
† Velvet Spring—boiling minors in 1987, to 20' in 1988
§ May not have been periodic, but perpetual spouters

Table 2

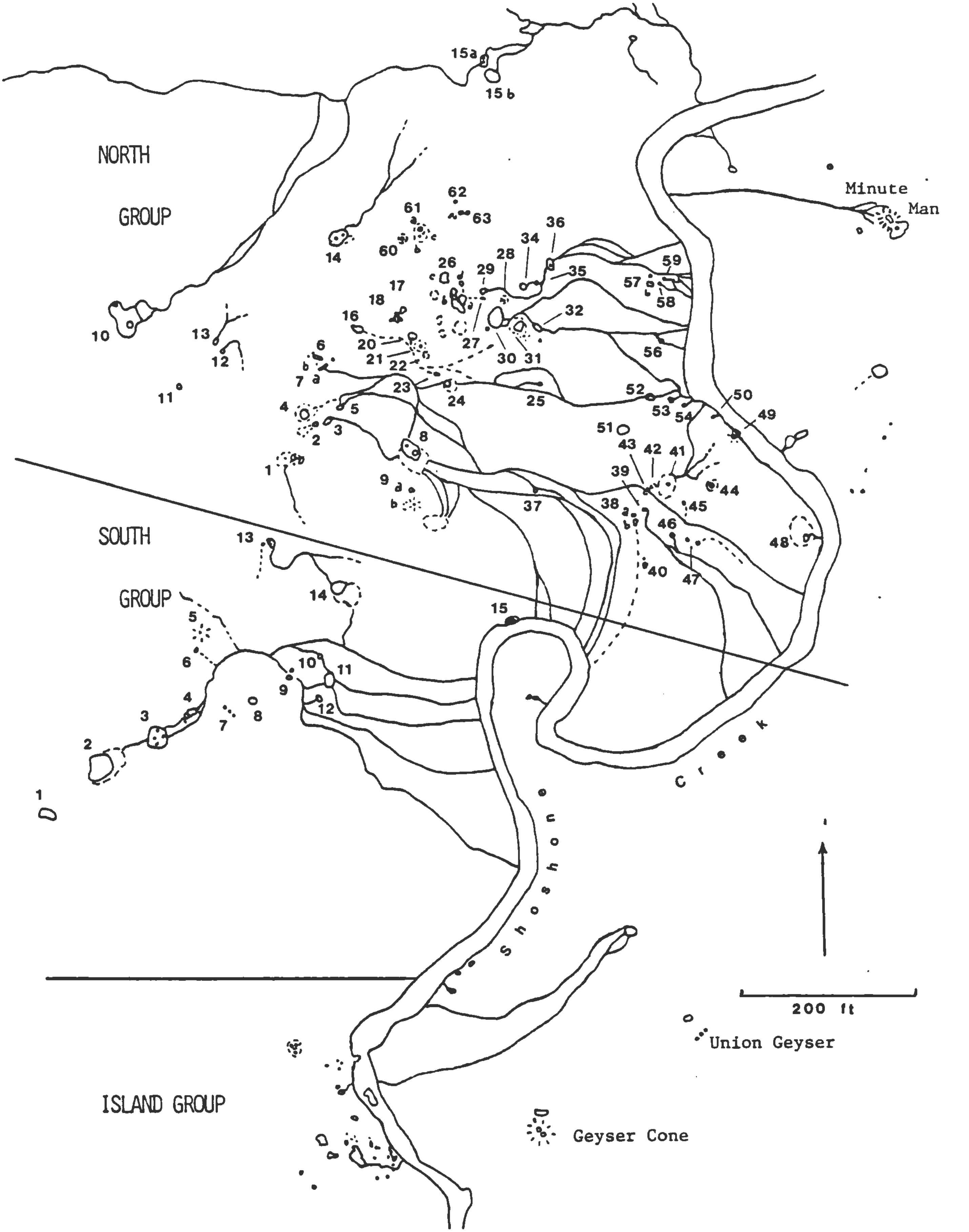

LITTLE GIANT GROUP
trail
SULPHUR HILLS GROUP
MINUTE MAN GROUP
Creek
Shoshone
N
200 ft

Map #	Name	Peale	USGS	Bryan	Func.	Notes	Name source
1 -	Sulphur Springs	15-21	shown		S	shown as "acid seeps" on USGS	[Bechler 1872]
2a -	"Trail Geyser"	13	32a		G	name found on old photo by Martinez	
				•		aka "Trailside Geyser"	[Bryan 1986]
b -					PS/S		
c -					PS/S		
d -					PS/S		
e -	unnamed geyser				G		
3 -	"Horse Trail Springs"	12	32		G	east spring is geyser	[Martinez 1976]
4 -		14 ?			S		
5 -		9 ?			S		
6 -		10 ?	31		S		
7 -		8 ?	30		IS		
8 -		11 ?			S		
9 -	**Little Giant Geyser**	•	29	•	G		[Bechler 1872]
						possibly "Hour Spring"	[Russell 1965]
10 -	"Double Geyser"	2 ?	28	•	G		[Bryan 1986]
						aka "The Pirates"	[Martinez 1976]
11 -		1			G	PS some years	
12 -	"Meander Geyser"	3	27	•	G/PS	can reach 8', numerous vents on platform	[Bryan 1979]
13 -	"Locomotive Geyser"		26	•	G	3"x5" vent	[Sanborn 1947]
						aka "Platform Geyser"	[Martinez 1974]
14 -			25		IS		
15 -		4			S		
16 -		5			S		
17 -		6			S		

Little Giant Group

Map #	Name	Peale	USGS	Bryan	Func.	Notes	Name source
1 -	The Twins	21	24		SV	decaying double cone	[Bradley 1872]
2 -		22	23		S	3 tiny vents + 1 at creek edge	
3 -		20	22		PS	number of vents along fracture	
4 -		19	21		S	boiling pool	
5 -		34 ?			S	old cone NE of 21	
6 -	**Black Sulphur Spring**			•		originally Black Sulphur Geyser	[Bradley 1872]
a -			19		PS		
b -			20		PS	subterranean	
c -					PS	2 collapses	
d -			18		PS	at 45° angle	
7 -					S	tiny cone	
8 -					S	tiny cone	
9 -		16	17		PS		
10 -	unnamed geyser						
a -		17	15		G		
b -			16		IS	discharge vent for 10a	
11 -	**Soap Kettle**	14	14	•	G		[Bradley 1872]
						aka "Crested Crater"	[Bechler 1872]
12 -	**Little Bulger Geyser**	15	13	•			[Peale 1883]
						aka "Bulging Spring"	[Bradley 1872]
a -	(original vent)				G		
b -	(east vent)				G	aka "Little Bulger's Parasite Vent"	[Bryan 1987]
13 -		18	12a		S		
14 -	Iron Spring		8		S		[Bechler 1872]
15 -	**Rosette Spring**	•	9	•	IS/S		[Bradley 1872]
16 -	**Shield Geyser**	•	3	•	G		[Bradley 1872]
17 -		2	3a		S		
18 -					S	small hole in sinter	
19 -	**Gourd Spring**	•	4	•	G	originally Gourd Geyser	[Peale 1883]
20 -					S (G?)	small hole in sinter	
21 -	unnamed geyser	4	11		IS/G	gushing discharge	
22 -	unnamed geyser	5	12		IS/G		
23 -	Five Crater Hot Spring	6	10		IS		[Bechler 1872]
24 -	**Square Spring**	3	5		S/IS/G		[Peale 1883]
25 -					S	sink	
26 -		8 ?	6a		S		
27 -	"Scout Spring"	7	7		G/IS/PS	geyser in 1976	[Ashland & McClelland 1965]
28 -					SV		
29 -		9 ?	6		PS		
30 -	**Minute Man Geyser**	•	1	•	G		[Bradley 1872]
						aka "Minute Geyser"	[Bechler 1872]
31 -	"Minute Man's Pool"	Pool		•	G	[Allen & Day 1935], pg 315 - photo in eruption	[Bryan 1986]
32 -		1	2		PS/S		
33 -		12			S		
34 -		13			?		
35 -		10	102		IS		
36 -	**White Crater Spring**	26	104		S	now red/shallow	[Bechler 1872]
37 -		27	103		S		
38 -	Mud Springs	28	105		MP/SV		[Peale 1883]
39 -	Mud Springs	28	106		MP/SV		[Peale 1883]
40 -		30	107		FP/SV		
41 -		30	108		FP/SV		
42 -		29			S	not located	
43 -		25	38		S	cone	
44 -		24	39		S	on fissure	
45 -					S	cone; Martinez #35	
46 -					PS	cone in river; Martinez #36	
47 -		23			S		
48 -					S	Martinez #37; not on map	
49 -					S	Martinez #38; 2 holes; not on map	
50 -					S	Martinez #39; not on map	
51 -		33			S	not on map	
52 -		32			S	not on map	
53 -		31			S	not on map	
54 -		11			S	not on map; can't be found	

Minute Man Group


NORTH GROUP
SOUTH GROUP
ISLAND GROUP
Minute Man
Union Geyser
Shoshone Creek
200 ft
Geyser Cone

Map #	Name	Peale	USGS	Bryan	Func.	Notes	Name source
1a -		1a	66		PS	at least 7 vents in complex, not "Fissure Spring"	
b -		1b	66		PS		
c -			66		PS		
d -			66		S		
e -			66		S		
2 -	Fissure Spring	2 (text)	61		G/PS	main vent + 3 holes	[Peale 1883]
3 -		3	60		PS	2 main vents; spouting vents along south margin	
4 -	unnamed geyser	4	62		G	funnel shaped	
5 -		2 (map)	59		PS	spouts from at least 6 vents	
6 -	**Yellow Sponge Spring**	8	57	•	G	originally named Yellow Sponge	[Peale 1883]
7 -	unnamed geyser	9	58		G		
a -						erupts from under 7-1/2' ledge	
b -						small cone	
c -						small hole (subterranean)	
8 -	**Velvet Spring**	11	68	•	G	2 vents, in past refered to as "Bead Geyser"	[Peale 1883]
9a -		10a	69		PS	main cone; 4 other cones	
b -		10c	69		S	pool	
10 -	**Glen Spring**	6	65	•	G		[Peale 1883]
						aka "Big Hot Basin"	[Bechler 1872]
11 -		5			S		
12 -	**Brown Sponge Spring**	7b	63	•	G	originally named Brown Sponge	[Peale 1883]
						aka "Brown Crater Spring"	[Bechler 1872]
13 -	unnamed geyser	7a	64		G		
14 -	"Spearhead Spring"	43	113		S	not "Funnel Spring"	[Martinez 1976]
15 -	**Funnel Spring**						[Bechler 1872]
a -		42a			S		
b -		42b	37		S	funnel shaped	
16 -	Small Geyser	15	55	•	G		[Peale 1883]
17 -		14 ?	50		PS	small vent is PS	
18 -	unnamed geyser	45 ?	51		PS/G	subterranean with sinter bridge	
19 -		46			S		
20 -	unnamed geyser	13a	52	Bead Geyser	IS/G	beautiful funnel spring	
21 -	Bead Geyser	13b	53		G	vent 13"x23" tapering to 15"x18" in shallow deteriorating basin	[Peale 1883]
22 -			54			shallow dead collapse	
23 -	unnamed geyser	12a			SV/G	deteriorating basin; vent barely discernable	
24 -	"Knobby Geyser"	12b	56	•	G	not "Frill Spring"	[Bryan 1986]
25 -		30	49		S	sink	
26 -	Mangled Crater Spring	39	45	SHO-5	G	not "Grotto Spring"	[Bechler 1872]
- a						main erupting vents	
- b							
- c						secondary basin also erupts	
- d						sink	
27 -	unnamed geyser				G	erupts with 26 (subterranean)	
28 -		37-1/2			S	fills with 26	
29 -		38 (W)	44		IS	discharge vent for 26	
30 -		31	46		S	not "Frill Spring"	
31 -	Frill Spring	32	47	SHO-6	G	tiny secondary vent to SE	[Peale 1883]
						aka "TB Geyser"	[Martinez 1974]
32 -	Pearl Spring	33	48	•	G	tiny secondary vent to S	[Peale 1883]
33 -		34				crack vent can no longer be found	
34 -	Grotto Spring	37	43		S		[Peale 1883]
35 -		35			S	in channel from 34	
36 -		38 (E)	42		S		
37 -		16 ?	109		S	sinter shelf over	
38a -		17a	77		S		
b -	**Bronze Geyser**	17b	77	•	G		[Peale 1883]
39 -		17e	78		S		
40 -		18 ?			S	2 openings	
41 -	Lion Geyser	20 ?	80	•	G	may not be original Lion Geyser	[Peale 1883]
42 -	unnamed geyser	21 ?	79		G	deteriorating	
43 -		21 ?			S	mostly dead small basin in channel from 42	
44 -		19 ?			S	old vent, boiling below	
45 -	unnamed geyser				G	small opening	
46 -	Iron Conch Geyser	22 ?	81	•	G		[Bradley 1872]
						aka "Red Crater Geyser"	[Martinez 1976]
						aka "Little Iron Geyser"	[Bryan 1979]
47 -		23 ?			S	only 2 separate holes seen	
48 -	mud springs	47			S	collection of springs in grass; sand bottoms in many	
49 -		48			S	2 small cones; one at water's edge discharges	
50 -					S		
51 -		24			PS	old crater, two vents deep within	
52 -		25	99		S	bluish opaque water	
53 -		26			S	2 small vents	
54 -					S	discharge from gravel	
55 -					S		
56 -		27	100		S		
57 -		28	101		S		
58 -		29	(101)		S	probably discharge vent for 57	
59 -					S		
60 -					SV	large dead crater	
61a -			41a		G	main vent discharges into sink	
b -	} unnamed geyser	40 {	41b			small sputterer	
c -			41c		SV		
62 -		41	40a		S		
63 -		44	40b		S	2 springs in shallow basin; small sputting vent nearby	

North Group

Map #	Name	Peale	USGS	Bryan	Func.	Notes	Name source
1 -					S	muddy spring	
2 -	**Coral Pool**	2	76		IS/G	geyser in 1987	[Bradley 1872]
3 -	Three Crater Spring	3,4	75		S/PS	4 vents seen	[Bechler 1872]
4 -		5	74		S/PS	tiny spouter just above	
5 -		6			S	cone	
6 -					S	bubbles	
7 -	"Outbreak Geyser"	(7 &) 8 ?	(73a)	•	G	possible rejuvenation	[Bryan 1986]
8 -					S	3 tiny holes	
9 -	unnamed geyser	9	(72a)		G	two shallow basins; location of original Wave Spring	
10 -	Wave Spring	10			G	although resembles the old description, probably NOT original	[Peale 1883]
11 -	**Flake Spring**	11	71		G	active in 1982	[Peale 1883]
12 -	unnamed geyser	1		SHO-7	G	active in 1982	
13 -	unnamed geyser	14	67		G	one spouting vent, one geyser vent	
14 -	**Blue Glass Spring**	12 & 13	70		G	west vent is geyser	[Peale 1883]
						aka Ornamental Spring	[Bechler 1872]
15 -		15	114		S	oval cone	

South Group

References

Allen & Day 1935 Allen, E.T., and Arthur Day, *Hot Springs of the Yellowstone National Park*, Carnegie Institute of Washington, Publication No. 466, Baltimore, Md.: Waverly Press, 1935.

Ashland & McClelland 1965 Ashland & McClelland, Reference Map of the Shoshone Geyser Basin (untitled), dated Feb, 1965, with additions and temperature data by Max Hancock, Ted Scott, and Terry Danforth, Mar 10, 1965, U.S. Dept. of Interior, NPS, Yellowstone National Park, 1965.

Bechler 1872 Bechler, Gustavus R., "Map of the Shoshone Geysers on the West Terminus of Shoshone Lake," [1872] in: Hayden, Ferdinand V., *Sixth Annual Report of the United States Geological Survey of the Territories, Embracing Portions of Montana, Idaho, Wyoming, and Utah: Being a Report of Progress of the Exploration for the Year 1872*, Washington, D.C.: Gov't Printing Office, 1872.

Bradley 1872 Bradley, Frank H., "Report of Frank H. Bradley", in: Hayden, Ferdinand V., *Sixth Annual Report *** for the Year 1872*, Washington D.C.: Gov't Printing Office, 1872.

Bryan 1979 Bryan, T.Scott, *The Geysers of Yellowstone*, Boulder, Col.: Colorado Associated University Press, 1979.

Bryan 1982 Bryan, T.Scott, Memorandum to Old Faithful Staff, [Yellowstone National Park], entitled "Thermal Observations, Shoshone Geyser Basin, Aug. 4-5, 1982", unpublished report dated August 10, 1982, (typescript, 6pp.)

Bryan 1986 Bryan, T.S., *The Geysers of Yellowstone*. Revised edition. Boulder, Col.: Colorado Associated University Press, 1986.

Bryan 1987 Bryan, T.Scott, "Geyser and Other Spouting/Intermittent Activity; Shoshone Geyser Basin", unpublished report dated Feb. 3, 1987, (typescript, 4pp).

Bryan, et.al. 1980 Bryan, T.Scott, Roderick Hutchinson, Lee Whittlesey and Sam Martinez, "Shoshone Geyser Basin — Spring Names and Numbers", unpublished report dated August 29, 1980, (typescript, 3pp.).

Bryan, et.al. 1986 Bryan, T.Scott, Roderick Hutchinson, Lee Whittlessey, and Sam Martinez (Aug 29, 1980), revised by Bryan, 1986, "Shoshone Geyser Basin — Spring Names and Numbers", unpublished report, (typescript, 5pp.)

Majors 1961 Majors, Harry M. "The Thermal Areas and Thermal Features of Yellowsonte National Park", (unpublished), typescript and map, 1961.

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

Martinez 1974 Martinez, Sam, Memorandum to Old Faithful Sub-District Naturalist [Yellowstone National Park], entitled "Report on Shoshone Geyser Basin Covering Trips Made June 16-17, July 7-8, and August 11-12, 1974", unpublished report dated Sept. 1974, (typescript, 6pp).

Martinez 1976 Martinez, Sam, "Report of Hot Spring and Geyser Activity in Yellowstone National Park in 1976", (unpublished), 1976.

Martinez 1978 Martinez, Sam, "Report of Hot Spring and Geyser Activity During the Field Trip of August 20 Through September 3, 1978 in Yellowstone National Park", (unpublished), 1978.

Peale 1883 Peale, A.C., "The Thermal Springs of the Yellowstone National Park" in: Hayden, Ferdinand V., *Twelfth Annual Report of the United States Geological and Geographical Survey of the Territories: A Report of Progress of the Exploration in Wyoming and Idaho for the Year 1878*, Part II, Washington, D.C. : Gov't Printing Office, 1883.

Russell 1965 Russell, Osborne, *Journal of a Trapper*, Aubrey L. Haines, Ed. Lincoln, Neb.: Univ. of Nebraska Press, 1965. (Journal of 1834-1843).

Sanborn 1947 Sanborn, William B., "Observations in Shoshone Geyser Basin", *Yellowstone Nature Notes*, Oct. 1947, vol 21, no 5, pp 58-59.

USGS 1966 U.S. Geological Survey "Yellowstone, Thermal, Wyoming, Shoshone Geyser Basin Area" (unpublished map, with revisions in later years).

Whittlesey 1988 Whittlesey, Lee H., "Wonderland Nomenclature: A History of the Place Names of Yellowstone National Park", (ms. on microfiche available from the Montana Historical Society, Helena, Mont.), 1988.

Recent Geyser Activity at Steamboat Springs, Nevada

H.Koenig

Abstract: During 1984 through 1987 eruptive activity at Steamboat Springs, Nevada, was observed in as many as twenty-one springs, despite repeated reports of the area's demise. This number of geysers means that Steamboat was the fourth or fifth largest geyser area in the world. Height of observed activity ranged from heavy overflow to approximately 15 meters. In 1987 a nearby geothermal powerplant, in conjunction with a regional drought, caused the end of all geyser activity to date.

Location and Setting

Steamboat Springs is located in southern Washoe County, Nevada. The thermal area is bisected by US 395, a four-lane highway that is the major north-south route east of the Sierra Nevada. From the Main Terrace, the casinos of downtown Reno are visible fifteen kilometers (9.5 miles) to the north.

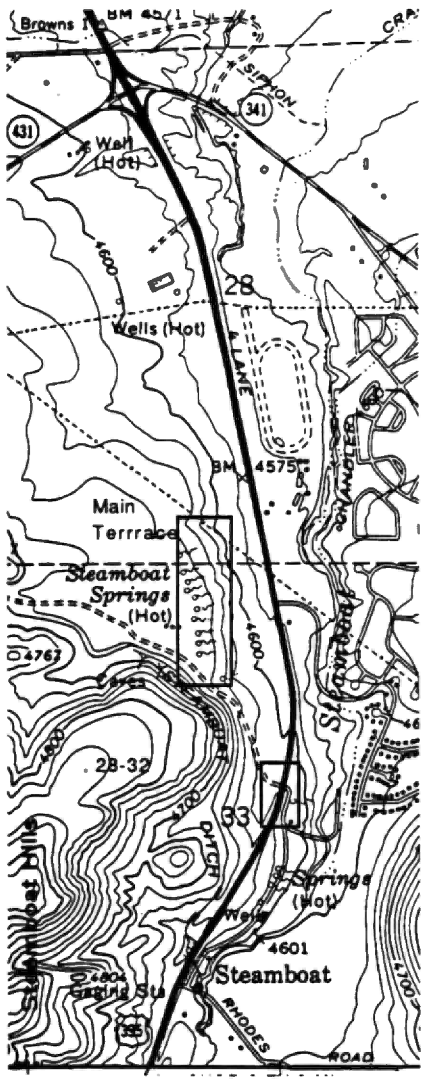
Most of the observed activity occurred on the crest of the Main Terrace, west of the highway. This sinter mound rises about 25 meters above Steamboat Creek to the east, and is about 750 meters in length. When compared to thermal areas in Yellowstone National Park, the most striking characteristics of the Main Terrace are the long fissures and cracks which run the length of the terrace. Most spring locations are controlled by these fissures.

Previous Work

The major reference on the geology, hydrology and geothermal activity at Steamboat are the U.S.G.S. Professional Survey Papers by [White 1968] and [White, Thompson & Sandberg 1964]. In addition, [White 1967] contains a description of Geyser 23n during the 1940s. The only later descriptions of individual springs are those in [Nehring 1980]. No geyser activity was observed, but Appendix 1 gives a description of each numbered spring during the dry summer of 1977.

Most popular works have described Steamboat Springs as an area that was destroyed by geothermal development. Until 1987, this was not the case. It seems that very few people have actually visited the area, but instead seem to have quoted this information from "the Final EIS on the Island Park Geothermal Area (pp. 111-112)...15 January 1980." [Schneider 1982] This report seems to be the ultimate source for many of these erroneous reports.

It is also interesting to note that some of these springs showed a response to the San Francisco earthquake of 1906. A section of the Carnegie Institute report on the earthquake discusses the minor geological effects on such features as hot springs. The last entry is about Steamboat Springs, and states that "for about 3 days after the earthquake, the volume was considerably increased, and the water became noticeably turbid with mud."[Lawson 1908]



Map 1
(from [USGS 1967])

Spring Names

Instead of using names, [White 1968] refers to observed springs by an arbitrary numbering scheme. These numbers have become the standard used by subsequent observers, and are also used in this report. In addition, activity has been observed in a number of vents previously unnumbered. In this report these have been given three digit numbers, starting with 100.

"Chicken Soup Spring", #33, is the only spring with a name [White 1968](pg.74). In addition, there has been some attempt to name some of the more spectacular geysers (for example, [Otto 1985]). Some proposed names are:

#24	Sluicebox Spring
#24e	Hillside Geyser
#41s	Saddle Geyser
#42w	Gunbarrel Geyser

Geyser Activity at Steamboat Springs

In Yellowstone, a spring which is observed to erupt for an extended period of time is not considered to be a geyser, but instead is called a "perpetual spouter". At Steamboat Springs, it was not unusual to find a spring that had been splashing a few inches high for over a year to suddenly quit. In the case of #39, eruptive activity as much as 4m high was observed over a period of four months. In all cases the activity was eventually observed to cease. Therefore for the purposes of this report these springs are considered geysers.

The Steamboat Hills Power Plant and Well 28-32

In January 1986, Chevron Resources and Yankee-Caithness began exploratory drilling of geothermal wells in the Steamboat Hills, about 2km southwest of the Main Terrace [BLM 1987]. Until May 1986, one of these wells, designated 28-32, was observed to be venting steam under considerable pressure. At times, the noise from this well could be heard on the Main Terrace, despite the distance. The effect of this activity on the thermal activity was devastating. Nearly every flowing spring ceased, and most non-flowing springs dropped anywhere from a few centimeters to over two meters. The springs that seemed to be least affected were #8 and #10.

After this venting ended, some springs immediately began to recover. By early September 1986, no specific effects could be found. That autumn saw the reactivation of #40 and #23n after several years of dormancy. The flowing springs (e.g. #2, #23, #19n, #34) reestablished their algae mats.

Description of Individual Springs

The following is a list of those springs which show activity of interest. Not being included in this list does not imply that the spring showed no activity during the period of the report. There are several small seeps north of Map 2 which flowed continuously except when dormant due to the activity in 28-32.

Spring	Height	Dur.	Int.
#1	0.1-0.25m	long	
#10	ovfl-0.5m	10s-3m	5m-hrs.
#12	ovfl-0.4m		hours
#14w	ovfl	≈1hr	
#15-#16	≈1m	days	
#19n	≈10cm	cont.	cont.
#23n	0.25-0.5m	15s-1m30s	15s-5m
#24	0.5-2m	secs	
#24e	≈2m		days?
#24sw	0.75m		
#26	≈30cm	cont.	cont.
#39	2-4m		
#40	2-4m	secs-cont.	
#41s	0.75m	months	
#42	0.5-3m		
#42w	1-15m	15s-5m	
#101	0.1m		
#102	0.5m		
#104	?		
#105	1m	days	
#113	10cm	1-3m	

Table 1
Summary of Observed Geyser Activity

#1 - Geyser

A set of three openings located immediately next to one of the access roads. The westernmost is the largest, about 61cm x 25cm. Located 1.6m to the east is a second opening, 38cm x 13cm, while the third located 56cm farther east and the smallest, 13cm x 30cm, and was stained yellow from sulfur. On several occasions tire tracks were observed running right through this spring.

On 28 December 1985 the eastern most vent was observed to be overflowing and continuously erupting about 10-15cm high. On 23 February 1986 the activity and overflow had shifted to the western vent, which was only bubbling heavily with occasional splashes breaking the surface.

#2 - Flowing Spring

A small opening with a broad shallow pool about one meter across, filled with long filamentous bacteria and algae. It was observed overflowing throughout 1984. A change was not noted until late April 1986, when in response to tests in Well 28-32, overflow ceased. Two weeks later it was completely dry.

#3- Flowing Spring

This spring appears similar to #2. Overflow from this spring decreased in May 1986. It was still overflowing slightly in June 1987. By September 1987 it had ceased flowing and was dry.

#4 - Non-flowing Spring

This spring is a circular vent about 1.75m in diameter, and only about 1m deep. Because of its location at the base of the southern end of the Terrace, thunderstorms have washed considerable gravel into the western end. Vandals have also contributed a number of large rocks. In 1984 an attempt to clean this spring by members of the Sierra Club, the Bureau of

Land Management and GOSA did cause the temperature to be raised from 170°F [77°C] to 203°F [95°C] (approximately boiling for the altitude of the Main Terrace).

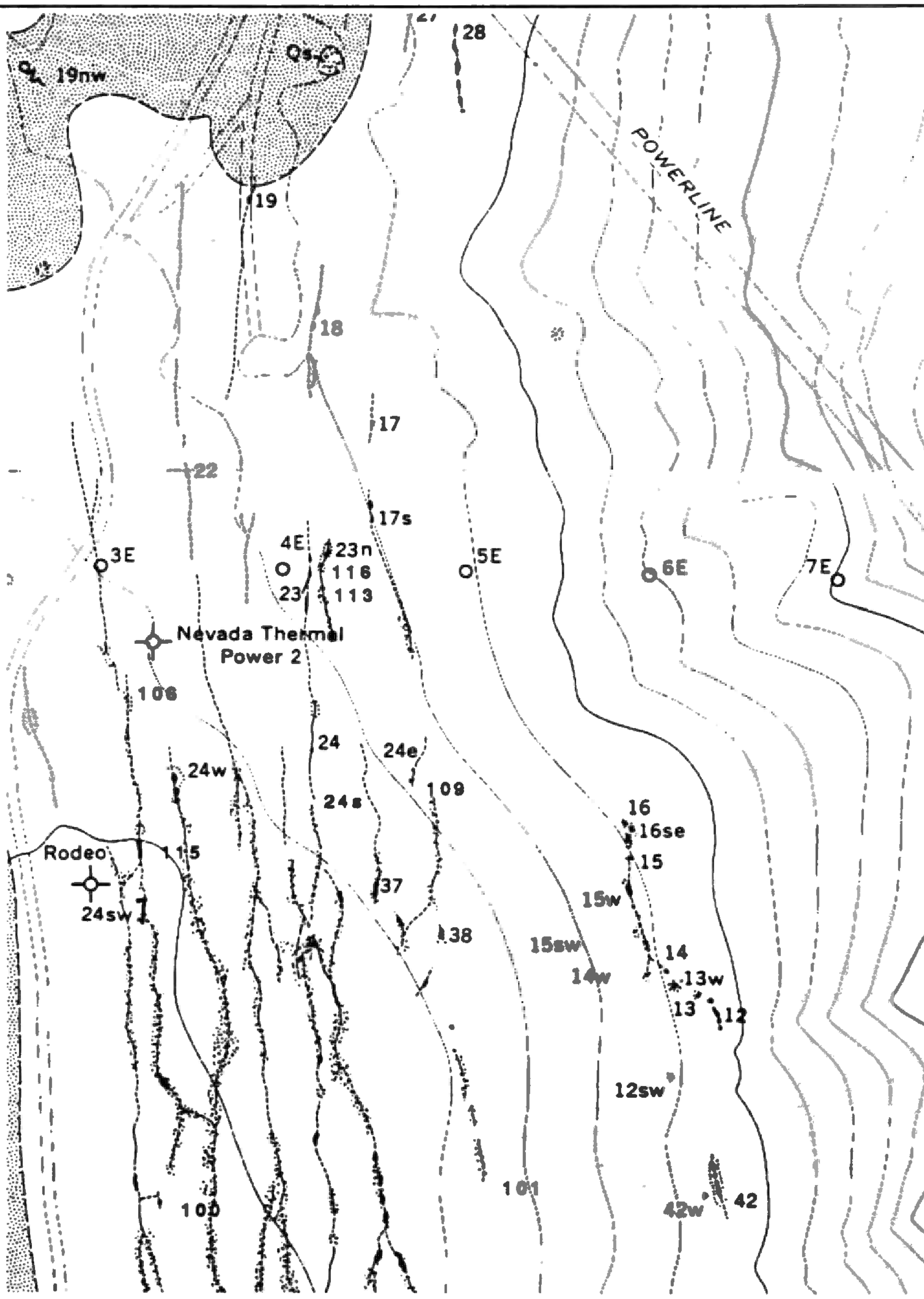
In response to the drilling tests at Well 28-32, this spring drained in late April 1986. In early June it was one of the first springs to show signs of recovery, and by the end of that month it was completely full and even showing signs of a slight trickle of overflow. In May 1987 it was again drained by Well 28-32.

#5 - Flowing Spring

Until it went dormant due to the powerplant, this wan an algae filled spring that quietly overflowed. It appeared similar to #2 and #2nw.

#6 - Intermittent Spring

A circular vent about 1.25m across and at least two meters deep heavily stained with black iron sulfides. Like #4, this spring was cleaned in 1984. Several hundred pounds of rocks,



Map 2
(from [White 1968] Plate 3)

cans and pipes were removed. The lowest spring of the Main Terrace proper, it is usually at or near boiling. The water level fluctuates about 2cm, and when high enough, a small trickle of water flows from a notch in the east side.

This activity was the norm until April 1986, when it dropped in response to activity in Well 28-32. By mid June, the water level had dropped about 45cm, while the temperature rose from 92°C to 95°C. By September, the water had risen back to overflow, with the temperature dropping to 93°C.

In May 1987, once again in response to activity in Well 28-32, the water level dropped about 50cm. The water level continued to drop, so that by March 1988, the water was down at least two meters.

#7

An irregularly shaped spring about 2.5m long that is almost certainly connected to #6. Usually water stands about a foot below the rim. When #6 was pumped out in an attempt to clean it, water dropped in this spring.

#8 - Flowing Spring

This is a small cone with a squarish vent about 28cm x 36cm across at the top. The water would stand just below the rim and the temperature was consistently between 180°F [82°C] and 184°F [84°C]. A small amount of bubbling was observed, while a trickle of discharge escaped through a small opening to the north. In September 1985 it was cleaned down to a depth of about 1 meter.

This spring was the last one to be affected by the geothermal power plant. In May 1987, when all other springs were dry, or nearly so, this spring still discharged a trickle. By December 1987, however, it too had dropped. Later it was reported that whenever the plant's wells were in operation, this spring dropped, while it would, in contrast, rise in response to a shutdown in operation [Knight and Strasser 1988].

#8nw- Non-flowing Spring

This is a rectangular shaped cone about 1/2 meter high, with an opening at the top about 76cm x 53cm. Until the autumn of 1985, this spring was filled to within 10cm of the rim with debris. A thermal cleanup effort removed several hundred kilograms of debris. After this effort, the vent was about three meters deep, and filled with boiling water. It may be connected to several seeps located to the west of it which dried up during the pumping operations.

#10 - Geyser

In [White 1968], this spring is referred to as a "gassy geyser" that overflowed intermittently. Most observed eruptions were little more than heavy overflow and boiling, but on occasions it was observed to throw water as much as one meter high. The activity varied considerably, with intervals ranging from about 15minutes to several hours. The durations were about one-half to two minutes.

During 1984 the intervals were several hours long, and the duration was only about 30seconds. This was also the case until the Summer of 1985, as while eruptions and wet runoff were observed, no intervals were recorded.

#11 - Flowing Spring

A small opening with a heavy deposit of yellow sulfur. It bubbles occasionally, but the temperature has never been measured above 40°C. It is probably connected underground with #10, as it dried up when #10 was pumped down for cleanup.

#12 - Geyser

This spring was reported by [White 1967] to have erupted as high as 25ft (7.6m). Several attempts were made to induce activity, but none were successful. Eruptive activity as high as 40cm has been observed from several of its vents. In addition, the water level fluctuated about 3cm.

During a visit of several hours, it was not unusual to note that this spring was overflowing, only to find it down about 2cm later. Or the reverse might be observed, with the spring below overflow, only to be seen overflowing later that day. Along with this fluctuation, the eruptive activity would start or cease. Sometimes the eruptions would take place during overflow, sometimes during the ebb.

#12sw - Flowing Spring

An opening about 30cm by 61cm and about 30cm deep with a slight yellow stain. The temperature was usually about 70°C. It is connected with #42 and #42w, as it would slowly drop after repeated eruptions of those geysers.

#13 - Non-flowing Spring

This is a low cone about 20cm high with a circular opening about 50cm in diameter. It is at least one meter deep. It is described in [White 1967] as being a geyser with eruptions as high as four meters, as well as exhibiting a relationship with the activity of #12.

The water level was usually about 30cm below the rim, and although the temperature was at or near boiling (200°F [93°C] to 204°F [95°C]), all attempts to induce it failed. On one occasion a rock the size of a basketball was removed.

Sum. 1984	Int - several hours, D ≈30s
Sum. 1985	active
14 Oct 1985	Int ≈1hr
19 Oct 1985	Int - 20m-1hr
30 Nov 1985	Int ≈10m
28 Dec 1985	Int - 20m - 30m
08 Feb 1986	Int - 15m-50m, D -1m-2m15s
23 Feb 1986	Int ≈45m, D ≈1m
04 Apr 1986	major - ≈45m, d≈1m minor - 3-6m, d-10-20s
19&26 Apr 1986	Int - 45m, d ≈2m
09 May 1986	Int ≈30m, D ≈2m
04 Jun 1986	Int 20-30m, d ≈2m30s
20 Sep 1986	Int ≈45m, d≈3m
25 Oct 1986	Int ≈45m
08 Nov 1986	Int 10-30m, D 1m30s-3m
10 Jan 1987	Int ≈30m
21 Feb 1987	Int ≈30m-1hr
02 May 1987	Int ≈45m-1hr
28 Jun 1987	minor Int≈3m major D ≈4m

Observation summary — #10

#14w - Intermittent Spring

This spring is a shallow, circular opening about 50cm in diameter on a shallow slope. Usually water was not observed in this shallow vent. The area downslope from the vent is a barren, gray-stained area washed clean of sinter gravel, indicating some sort of activity in the past. On 08 February 1986, the only instance of activity was observed, consisting of a quiet overflow which lasted about 35-45 minutes.

#15, #15w, #16, #16se - Geyser(s)

These springs are discussed as one, as they are located near each other. #15 is a circular opening about about 30cm across, which overflowed downslope to the east. #15w is three narrow cracks, with overflow to the east from the end of the southernmost opening. #16 is a long, wide crack only a few cm deep except at the north end. There it opens into a deep cavern. Located about 1.5m from this is #16se, a 10cm opening into this cavern.

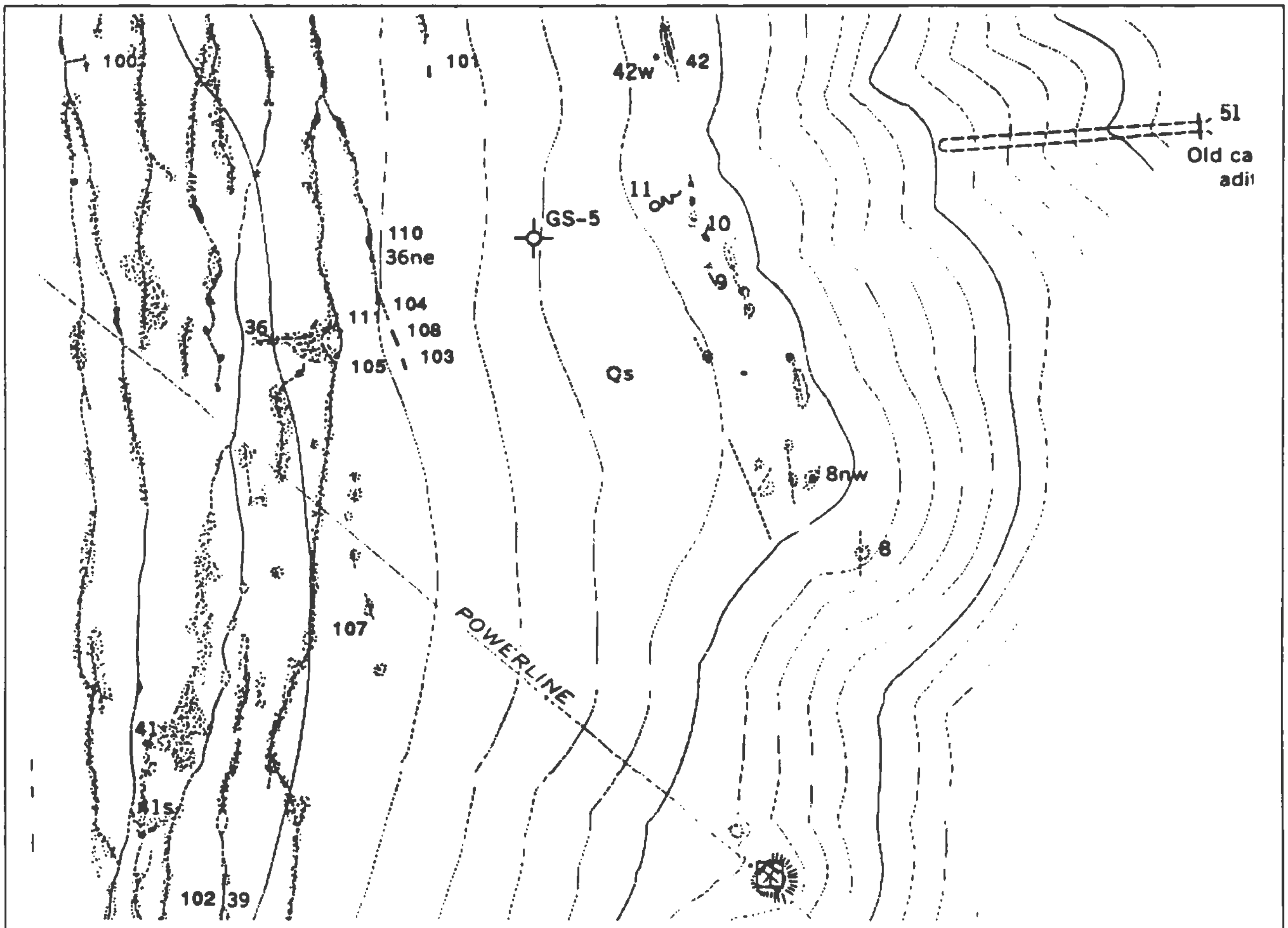
In November 1983, #15w was observed to be erupting continuously about 1m from two vents. The water from each vent was ejected toward the other so that the spray intersected. A thin coating of brilliant white sinter was being deposited over an older, nearly black layer. A colorful algae mat of reds and oranges enhanced the scene. A few weeks later this activity had ended, causing the drying of the algae mat, and the dulling of the sinter.

This group was first observed to cease overflow on 26 April 1986, when they had dropped about 1cm in response to tests in Well 28-32. This drop continued, so that on 09 May 1986 they were down about 14cm. After venting ceased, the group recovered, and was observed to only be about 2cm below overflow on 04 Jun 1986.

Through the winter, this group overflowed, and was not noted to change until production began at the Steamboat Hills power plant. On 02 May 1987, the group was down about 8cm, and was completely dry on 28 June 1987.

#19nw - Perpetual Spouter

This spring was never observed to change, except at the times of terrace-wide drainage by the operation of the Well 28-32 and Steamboat Hills power plant. When active, it was a small, shallow pool about 1/2m across which splashed about 10cm high. The outflow channel, like #2, was lined with thick, white filaments over a darker algae.



Map 3
(from [White 1968], Plate 3)

Nov 1983	H ≈10cm, Int ≈3-4min.
20 Sep 1986	H ≈50cm, Int ≈1m, D≈20s
25 Oct 1986	H ≈50cm, Int ≈5m
08 Nov 1986	major- Int ≈4m30s, D ≈1m20s minor- Int ≈1m30s, D ≈15
22 Nov1986	Int ≈50s, D ≈20s

Observation summary #23n

#23n - Geyser

This is a small opening about 20cm by 10cm, and only about 10cm deep. Eruptions are about 30cm to 1 meter high.

Its first observed activity was in November 1983 with a height of 1m and intervals around 3-4 minutes. It was subsequently dormant, filled by algae and debris washed in by the runoff from #106.

Even though runoff from #106 ceased around February 1986, no activity was observed until 08 September 1986, when activity consisted of eruptions about 1/2 meter high every minute and lasting about 20 seconds.

In the autumn of 1986, this spring was one of those which reactivated following the testing of the well 28-32. At first it was erupting regularly, while later, in November, it showed a relationship to nearby #113. This latter spring would cease erupting when #23n would erupt, then restart after #23n ended.

The eruption heights were unchanged, but the durations were now about 1m30s, and the interval was about 5 minutes. When #23n ceased erupting, #113 would then erupt, only ceasing when the next eruption of #23n began. On one occasion, there was a short (15sec) minor eruption about 1 minute before the major eruption of #23n.

Two weeks later the activity of #23n had again changed. This time it was having a series of major eruptions separated by from zero to two minor eruptions. The major eruptions lasted about 1m20s. A minor eruption only lasted about 15sec to 20sec. The interval from a major eruption to the next eruption ranged from 4m30s to 5m. If this eruption was a minor, then the interval was about 1m30s.

By the end of November it reverted to the activity observed in September, with durations around 20 seconds and intervals around 50 seconds.

By 10 January 1987 it had ceased erupting, but on 02 May 1987 it was induced to erupt several times. These eruptions lasted 40sec to 1m34s. The shortest interval between these eruptions was 8 minutes.

#24 - Geyser

This spring does not seem to have changed much since a photograph was taken of it around 1950 [White 1968], pg.20. It is a fissure at least 10m long, with the discharge taking place at the northern end. The built up ridges at the northern end, and the length of the spring suggests the name "Sluicebox Geyser." The actual vent seems to be buried among the collapsed walls of the southern end of the fissure. In October 1986 three distinct areas of boiling were observed. The play among the three vents varied, and no pattern was noted among them. The heights ranged from 15cm to 50cm.

A month later it was found that this spring could be induced to have an eruption about 2m high. This occurred after a half hour of foamy play about 50cm high.

Until Well 28-32, this spring flowed continuously, and had a large, wide algae mat running down slope. When dry, this area turned out to be stained gray by the considerable quantities of minerals in the water.

#24e - Geyser

This geyser was reported to be active during the winter of 1985. It has not been seen by any GOSA observer, but has been reported to erupt as high as 5m [Otto 1985]. It is a crack about 3m long located just south of the main runoff coming from #24. The vent is stained gray, and widens at the southern end. There is a wide area around the vent clear of gravel, a good sign of recent activity.

During the Winter of 1986, water was observed about 15-30cm below the vent. An attempt was unsuccessfully made to induce it.

#24sw - Geyser

A irregular, narrow slit about 15cm to 30cm wide and 4.5m long. On 22 July 1983 this spring was observed to erupt about 60cm high. Later, on 30 November 1985 it was again observed erupting about 60cm high. There was no runoff, although some water did disappear down another opening immediately to the north. The average duration was 48 seconds, and the interval was 2m30s.

#26 - Perpetual Spouter

Visits to the Lower Terrace, being farther south of the Main Terrace and across the highway, were uncommon. But whenever this area was visited, activity in this spring would be observed, the only activity in the Lower Terrace. This spouter would splash about 30cm out of its crack. This area was not checked, so the effects of Well 28-32 and the powerplant are not known.

#36ne

This opening is one of many along a crack near the crest of the Main Terrace. On 08 February 1986, the first of many new springs along this crack was observed. This activity slowly increased until the tests on Well 28-32 began, in preparation for the installation of the Steamboat Hills power plant.

By 22 March 1986, four new springs (#103, #104, #109, #110) were recorded along the crack, and two more to the west (#105, #111) were also noted. Until that day, #36ne was filled in with fragmented sinter and gravels. By that time, enough fragments had either been ejected or had been dropped deeper into the vent so that it was now a crack about 1m long, and splashing a few centimeters high.

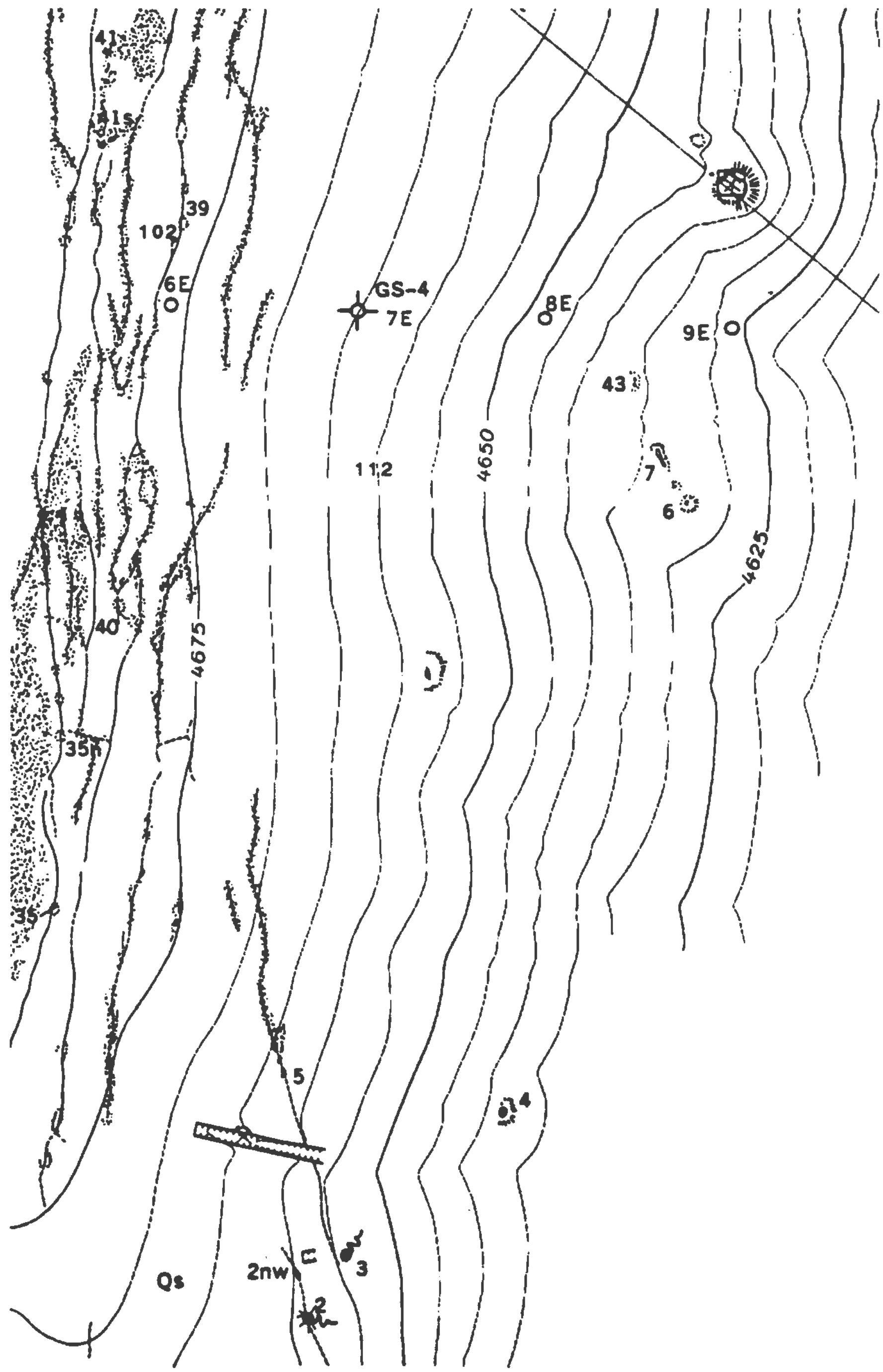
#39 - Geyser

This is a narrow crack, 6.7m long, located at the crest of the Main Terrace. It, along with #41s, and #102, were all first observed on 30 November 1985. Water is thrown at an acute angle, being ejected horizontally much farther than vertically. While active it was never observed to cease eruption. At first there was quite a bit of discharge, with the play about 1m high, and playing laterally to the east to about 2m. One impressive feature of this spring was the copious amount of material deposited by the runoff, which was a dull, greyish-black material, high in heavy metal content [Hudson 1986].

By 28 December 1985, the amount of discharge dropped dramatically, even though the height and vigor of the play did not seem to have decreased. There was some water thrown as much as 4m from the vent. On 08 February 1986, the activity was reduced, with only occasional droplets to 1.5m, and almost no discharge. This was also the case when observed on 23 February 1986.

#40 - Geyser

This geyser has a small, narrow irregularly shaped vent surrounded by a broad area of gray sinter deposited by activity.



Map 4
(from [White 1968] Plate 3)

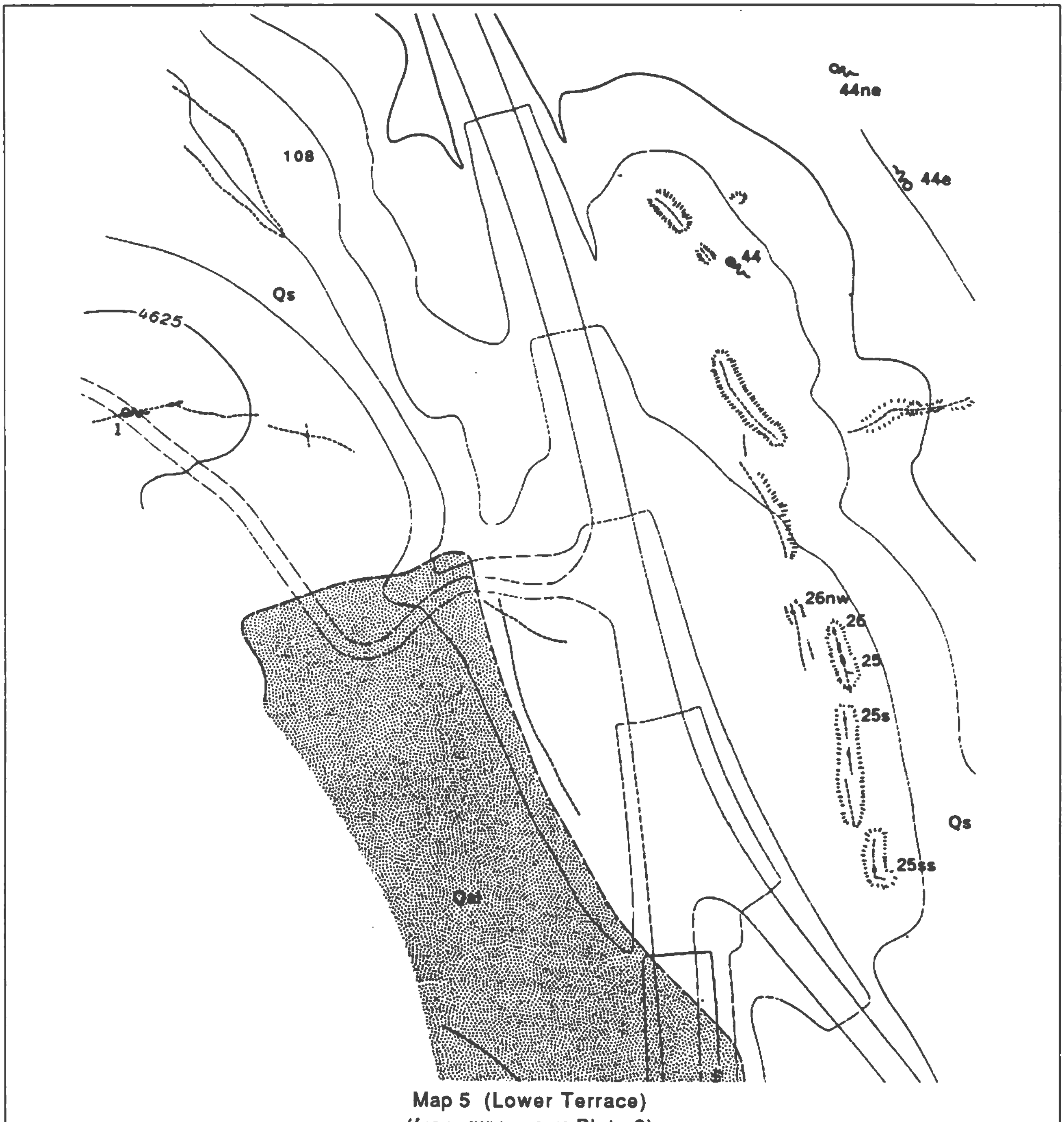
Sum. 1984	D≈30s, Int≈1m30s, H≈3-5m
08 Jun 1985	Subterranean activity
Sum. 1985-Sum. 1986	no activity
17 Sep 1986	D≈2m, Int ≈3m, H ≈3m
25 Oct 1986	Int ≈7m, D≈6m
22 Nov 1986	Nearly continuous
02 May 1987	Subterranean activity
28 Jun 1987	No activity

Observation summary - #40

Most of the overflow from this spring flows into two different cracks, one about 2m to the west, the other farther away and to the south.

Eruptions occurred as part of a series. After numerous frequent eruptions, the vent would drain, and there would be a period of quiet. In 1984 this period lasted about 6 to 8 minutes, while in 1986 this was only about 1 to 2 minutes.

The first observed eruptions took place during a general cleanup of the springs in 1984. It was noted that several large rocks, as much as 30cm across and estimated to weigh about



Map 5 (Lower Terrace)
(from [White 1968] Plate 3)

22 Sep 1984	major-1, d≥4m, h≈3m
28 Sep 1985	major-2, d=45s-3m23s, h≈5m
	minor-2, d≈1m10s, h≈1m
14 Oct 1985	major-1, d=1m42s, h≈3m (w/o #42w)
04 Apr 1986	minor-1, d=1m15s, h≈1m
08 Nov 1986	minor-1, d=15s, h≈2m

Observation summary - #42

30kg, were wedged deep in the vent. With considerable effort these were removed. "It was with some consternation that the eruptions following the cleanup were not as high as those preceding it. Those present mused that the rocks should be returned to their former resting place." [Strasser and Strasser 1989]

Around noon at the time of the summer solstice it was once noticed that a reflection of water could be seen a number of meters down in the vent.

#41

Until 23 February 1986, this spring was just a depression in the terrace just north of the trio of #41s, #39 and #102. On that day it was observed that the bottom had enlarged, and water was bubbling through the gravel in several places.

#41s - Geyser

This was the only geyser at Steamboat Springs which was observed to erupt from a distinct pool. It consists of two vents with a saddle-like ridge between them, hence the suggested name, "Saddle Geyser". The southern vent is the larger, measuring about 2m x 95cm, while the northern is about 1.22m x1.07cm. The total dimensions of the pool, which filled both vents, was 3.65m x 2.15m. Almost all overflow from this pool flowed a short distance north and drained into an opening about 84cm x 18cm. There was a small trickle toward the northern extension of the crack on which #39 is located.

This spring was first observed on 30 November 1985, erupting almost continuously to a height of about 1m.

By 28 December 1985, this spring was showing some periodicity. The southern vent was splashing continuously to about 30cm, while every 20-40sec the northern vent would burst about 75cm high. This activity seemed unchanged when observed on 08 and 23 February 1986.

Before the activity began, this spring was just a sinter filled depression at the top of the terrace. Because of this, it is interesting to note that according to [Hudson 1986], this spring was also active during the late 1970s and perhaps even the early 1980s.

#42 - Geyser

This geyser is a long crack with at least nine vents, widening to about 30cm wide at the southern end. These vents are designated with letters, starting with "A" at the southern end. Between Vents "C" and "D" there is a 5cm wide notch in the western rim. This spring is definitely connected with #42w.

When not active, and until the operation of Well 28-32 began, the water level in this spring sat about 1cm below overflow, with one or more of the vents functioning as perpetual spouters. Most times Vent "C" was active, but at times could be Vent "D" or Vent "B". Other times there would be an exchange of function between these vents every few minutes. Because of this, the flow of water within the crack between vents would reverse directions. This activity caused a noticeable increase in the deposition of spiny sinter around the vents, especially Vent "C". Unfortunately, the draining caused by Well 28-32 and the powerplant allowed these formations to crumble and disappear within a year.

The major activity took place at the southern end, in Vents "A", "B" and "C". Vent "B" is located at the neck where the crack narrows from 30cm to about 5cm. This vent played higher than the others, with Vent "A" only slightly smaller. The height of play diminished the farther north the vent, but even the northernmost could attain about 15cm from a small opening about 2cm in diameter.

The first known eruption of #42w was accompanied by an eruption of #42. Several other series of eruptions of #42w were observed that autumn, but not from the beginning, and #42 was not observed at those times. It was discovered that if particular attention was paid to #42 when attempting to induce #42w, then a concerted eruption could be produced. On one occasion only #42 erupted.

Occasionally the subsequent eruptions of #42w were accompanied by minor eruptions from a drained vent. In these cases the eruption began well after #42w began, and perhaps could even be considered a foamy steam phase-type eruption.

#42w - Geyser

The vent of #42w is a circular opening about 40cm in diameter at least four meters deep. It is usually filled with boiling water about 7.5cm below the rim. This is the tallest geyser observed at Steamboat Springs, with some eruptions at least 12m high. Yellowstone excluded, it may also be the tallest geyser in the Americas [Bryan 1986].

The first known eruption of this geyser took place on 22 September 1984, although there were reports of a new geyser earlier that month. "We were prepared to leave [the Main Terrace] when we saw not one, but two columns of water suddenly erupt. It was a very impressive sight: one column was vertical and over 25 feet [8 meters] high, the remaining water was ejected from a fissure a few feet away from the first water column. This water was almost an unbroken sheet about 15 feet [4.5 meters] long and ranged in height from less than 2 feet [60cm] to over 10 feet [3 meters] at the southern end. We raced to the geysers, and arrived before they had finished.

"We waited, and only 20 minutes later the single water column erupted again, this time higher than the first. It was a solo performance; the nearby fissure remained silent." [Strasser and Strasser 1989].

A number of series of eruptions were witnessed over the next few months, but never a full series from beginning to end. "Every time we visited the terrace we saw activity. We can conclude that a cycle was at least several hours long, and the interval between cycles was at least a few, but less than twelve, hours long. Sometime in November 1984 #42w became dormant. As far as we can tell, these were the only natural eruptions that have occurred." [Strasser and Strasser 1989]

With the approval of the Bureau of Land Management, members of GOSA have attempted to induce some hot springs in order to facilitate their cleaning. Over the years, several different techniques of inducing have been tried in order to see which method worked best. Beginning in July 1985, several attempts to induce #42w with granular soap, lye soap and PhotoFlo™ were tried, and none were successful. The first induced eruption on 21 September 1985 was by a combination of soap and lowering of the water level with a hand pump. It was later found that pumping air into the vent at depth, or dry ice also work well. The best method was a combination of liquid soap and dry ice.

#42w has been a popular place for debris. Most eruptions would eject a variety of trash: cans, bottles, a toothpaste tube, a shotgun shell, coins and many rocks. Once someone went to a considerable effort by stuffing a number of vents (including #8, #10, #12, #13 as well as #42 and #42w) with chunks of grass and sod removed from the terrace. Inducing #42w caused one of the largest eruptions seen, with brown water and lumps of grass ejected to over 12 meters high. Afterwards, about 50kg of grass clods, a pile almost a meter high, was cleaned out of the drained vents of #42.

See Plates

Photo 1
Geyser #42w (photo: P.Strasser)

The eruption itself consisted of a continuous jetting of water. Maximum height was reached in about 15 seconds. The water column stayed at this height for a while. Depending on the length of the eruption, this could have been for several minutes. Then the water column began to slowly drop. At times, it seemed that #42w would tap a second reservoir, and quickly climb back up to maximum height. In any event, the end of the eruption was not usually abrupt, but instead, the water column slowly dropped, sometimes staying about 1/2m high for twenty to thirty seconds before finally quitting. Even during these endings there was a considerable amount of water discharged.

After a major eruption, there could be a series of minor eruptions, about five to thirty minutes apart. At times these minor eruptions could be just as tall and just as powerful as the major eruptions.

After the conclusion of the last eruption of a series, #42w and #42 would begin to refill. This could take several hours, but once the water level reached a point about 30cm down from the rim, an attempt at a second inducement was often successful.

#100 - Non-flowing spring

A small vent about 56cm x 30cm. Boiling water was observed about 1m down during the winter of 1985-1986.

#101 - Geyser

This is a shallow pool about 1 meter by 3/4 meters. The vent itself is under the rim on the west edge and about 5cm x 8cm. The surrounding area slopes gradually to the east.

It was first observed in June 1985 when it was partly filled and bubbling. Over a period of several hours the level would rise and fall, but never enough to overflow.

On 22 November 1986, it was first observed in eruption. This activity consisted of splashing in the pool over the vent that occasionally reached 10cm.

On 21 February 1987, it was observed to overflow for about an hour.

#102 - Geyser

The total opening is about 7.3m long, with most of the activity coming from a 4' section near the center. There was never any discharge observed from this spring.

This spring was first observed on 30 November 1985, along with #39 and #41s. At that time is was erupting continuously to about 1/2m.

By 28 December 1985, most of the activity had ceased, although the vent was noisy, and occasional droplets were thrown from the vent.

#103 - Intermittent Spring

This small spring was first observed on 08 February 1986. A small triangular opening, from 25cm to 38cm on each side, it is located on the crack that includes #36ne.

By 22 March 1986, the spring was overflowing steadily. This activity immediately diminished at the same time as tests were being conducted with Well 28-32.

#104 - Geyser (?)

First observed on 08 February 1986, this spring consisted of a pair of vents about 8cm in diameters at the ends of a 61cm x 1.52m widening of the crack running through #36ne. At first water was observed bubbling in the bottom of each vent. By 22 March 1986, the vents had enlarged, with evidence of fresh sinter around the outer vent rim.

This activity immediately diminished at the same time as tests were being conducted with Well 28-32.

#105 - Geyser

Located at a forking of the fissure immediately between those of #36 and #36ne, this area began to show activity at the same time as the activity in #36ne increased. By 22 March 1986, this spring was splashing as much as 1 meter high.

Like #104, this activity immediately diminished at the same time the tests were being conducted with Well 28-32.

#106 - Flowing Spring

This spring was first observed in the spring of 1985. It is a narrow crack about 2cm across and about 3 meters long. A considerable amount of water flowed from this spring, forming a large algae mat over a number of springs, including #17s, #23, #23n and #113. This flow of water into these springs may have suppressed geyser activity in #23n and #113.

The overflow ceased around January 1986, although water could be observed in the vent until March 1986. After that, only occasional wisps of steam were observed.

22 Sep 1984	major-1, d≥4m, h≈5m
	minor-3, d≈2-2m30s, h≈5m, int=18m-31m
21 Sep 1985	major-3, d=1m30s-3m, h-9-12m
28 Sep 1985	major-2, d≈30s-45s, h≈4-5m
	minor-2, d≈30s-1m30s, h≈6m,int≈25m-50m
19 Oct 1985	major-1, d≈4m49s, h≈10m
30 Nov 1985	major-2, d≈30s-2m08s, h≈3-6m
23 Feb 1986	major-3, d≈38s-2m01s, h≈5-10m
04 Apr 1986	major-3, d=32s-1m50s, h≈1-3m
19 Apr 1986	major-2, d≈32s-2m27s, h≈4-5m
04 Jun 1986	major-2, d≈18s-24s, h≈3-4m
20 Sep 1986	major-3, d≈37s-3m03s, h≈6-9m
	minor-1, d≈1m52s, h≈6m, int≈33m
25 Oct 1986	major-3, d≈1m03s-3m21s, h≈5-10m
	minor-1, d≈10s, h≈1/2m, int≈18m
08 Nov 1986	major-2, d≈59s-1m36s, h≈6m-9m
	minor-1, d≈1m36s, h≈8m, int≈29m
22 Nov 1986	major-2, d≈1m33s-1m47s, h-6-8m
10 Jan 1987	major-1, d≈1m45s, h≈12m
	minor-2, d≈1m28s-2m11s, h≈5-8m, int≈3-17m
21 Feb 1987	major-1, d≈1m50s, h≈8m
	minor-3, d≈1m16s-1m56s, h≈4-5m, int≈3m-16m
02 May 1987	major-2, d≈1m14s-3m37s, h≈1-6m
	minor-1, d≈44s, h≈6m, int≈16m

Observation summary - 42w

#109 - Intermittent Spring (Geyser?)

A small pair of vents ≈8cm x 23cm and 1m apart in the crack on which #36ne is found, located midway between #104 and #103, first noted on 08 February 1986. By 22 March 1986, the area surrounding the vents had slumped, forming a rim around the vents that was about 2m long. There was also evidence of recent overflow.

#111

This is a small crack just north of #105 that was first observed steaming on 22 March 1986, when new activity was observed in several other fissures and opening in the immediate vicinity.

#112 - Flowing spring

This spring consists of a pair of openings at the top of the slope to the east of #6. When active in 1984, the overflow helped create a thick algae mat down the slope. The runoff itself ran around #6, and joined its runoff. This spring ceased flow during the winter of 1984-1985.

#113 - Geyser

A pair of small, ragged openings south of #23n, with which it is connected. The height of eruption was at most 10cm.

Nevada Thermal #1 - Artificial Geyser

This uncapped well lies due east of Main Terrace across from U.S. 395. An elbow pipe at the top prevents the play from being vertical, instead causing the water to fan out over a concrete enclosure. The eruptions would occur every few minutes, and only last for a few seconds. At times, water could be sprayed as much as 5m from the pipe. In response to the activity at Well 28-32, this well eventually ceased erupting. There were occasional puffs of steam that may have indicated eruptions at depth.

Acknowledgements

Foremost thanks must go to Paul and Suzanne Strasser. They accompanied me for most of the trips to Reno, as well as making numerous visits by themselves. They have also reviewed this report and made numerous contributions, comments and corrections. Without their help, most of this information would not have been gathered.

References

BLM 1987 Bureau of Land Management, *Environmental Assessment of Western States Geothermal Company's Steamboat Hills Geothermal Project*.Carson City, Nev.

Bryan 1986 Bryan, T.S., *The Geysers of Yellowstone*, Appendix: Geyser Fields of the World., Colorado Associated University Press.

Hudson 1986 Hudson, D., personal communication.

Knight and Strasser 1988 T.Knight, personal communication relayed by P.Strasser.

Lawson 1908 Lawson, Andrew C., Chairman, *The California Earthquake of April 18, 1906: Report of the State Earthquake Investigation Commission*. vol 1, part 1, page 409. Washington, D.C.

Nehring 1980 Nehring, Nancy L., Geochemistry of Steamboat Springs, Nevada., U.S.G.S. Open File Report 80-887.

Otto 1985 Otto, Chuck. *Steamboat Hot Springs Geyser Basin*, Your Public Lands (BLM), vol.34, #4, Autumn 1984., pp. 16-18.

Schneider 1982 Schneider, Bill, Yellowstone: The Incredible Shrinking Wilderness, *National Parks*, vol. 56, no.1-2, January/February 1982, pg. 26-27.

Strasser and Strasser 1989 Strasser, P. and Strasser, S., personal communication, 1989.

USGS 1967 Steamboat, Nev. 7.5' topographic quadrangle (photorevised 1982).

White 1967 White, Donald E., Some Principles of Geyser Activity, Mainly from Steamboat Springs, Nevada, *American Journal of Science*, vol. 265, October 1967, p. 641-684.

White 1968 White, Donald E., *Hydrology, Activity, and Heat Flow of the Steamboat Springs Thermal System, Washoe County Nevada*. U.S.G.S., Professional Paper 458-C, Washington

White, Thompson & Sandberg 1964 White, D.E, Thompson, G.A. and Sandberg, C.H., *Rocks, Structure and Geologic History of Steamboat Springs Thermal Area, Washoe County, Nevada.*, U.S.G.S. Professional Paper 458-B, Washington.

The Beowawe Geysers - An Historical Overview

Jan A. Roberts

ABSTRACT: The Beowawe Geysers, located in north-central Nevada, have been known to mankind for several thousand years. The nearby presence of a major water course (the Humboldt River) has provided a convenient route through extremely dry country for many travelers over the centuries. The roster of travelers includes Native Americans, white fur trappers, white explorers, California bound emigrants, and government surveyors. The first U.S. transcontinental railroad closely follows the course of the Humboldt River, as does a major highway (Interstate 80, and its predecessors). The end result has been that thousands of individuals have had the opportunity to view the geysers while the site was relatively undisturbed.

This overview will cover, in chronological order, known and potential sightings of the Beowawe Geysers area, coupled with reported levels of hot spring and geyser activity. Ownership of the area as pertinent to the attempts to establish first a National Monument and, later, a State Park will also be examined.

Included in this overview is a summary of environmental damage to the site by the initial geothermal energy explorations of 1959 to 1965. The article concludes with a brief look at the levels of thermal spring activity as observed by the writer in 1969, 1970, and 1988.

EARLY HUMANS - 6000(?) BC TO 900(?) AD

Archaeological surveys of north-central Nevada, primarily along the Humboldt River corridor, have revealed that humans may have utilized the area for roughly the last seven or eight thousand years. [1] Archaeological surveys in the vicinity of the Beowawe Geysers turned up several sites that contained a variety of stone tools and projectile points. At least one of these sites was judged to be a semi-permanent campsite, and is within clear view of the Geysers' sinter terrace [2]; winter occupancy of the Geysers' area in prehistoric (and more recent) times could not be excluded. [3] Utilization of the Geysers' area was stated to reflect "...more intensive food processing activities and a different orientation to the exploitation of hot springs, as opposed to riverine resources." [4]

The "riverine resources" is a reference to the Humboldt River, 6 to 8 miles distant from the Geysers' area. The river has been described by some as having provided "an easy, well-watered trail across the Great Basin" [5] in prehistoric times. This river continues to provide an "easy" means of travel across the Great Basin, in Nevada, as evidenced by thousands of California-bound emigrants, the first U.S. trans-continental railroad, and a major highway, (alternately named Victory, U.S. 40, and, currently, Interstate 80), all of which have traversed the area.

NEVADA INDIANS: 900(?) AD TO 1869(?) AD

According to one report on the archaeological surveys of the Beowawe Geysers' area, the inhabitants of the Beowawe area spoke a version of a language called "Central Numic," and may have moved into the area about a thousand years ago. [1] This language appears to be shared by the Native Americans who inhabit much of Nevada and the Great Basin, the Northern Paiute and Western Shoshone tribes in particular. [2]

Both Native American tribes are said to have utilized the Beowawe area. [3] A 1986 report on Great Basin Native American tribes indicates that the Geysers' area falls within the territory of the Western Shoshone. [4] One recent (1980's) newspaper article on the Beowawe Geysers stated that the Geysers' "...figure prominently in the creation story of the Western Shoshone tribe, who consider them sacred ground." [5] Others have indicated that Paiutes, and Northern Paiutes used the Beowawe area as a camping ground. [6]

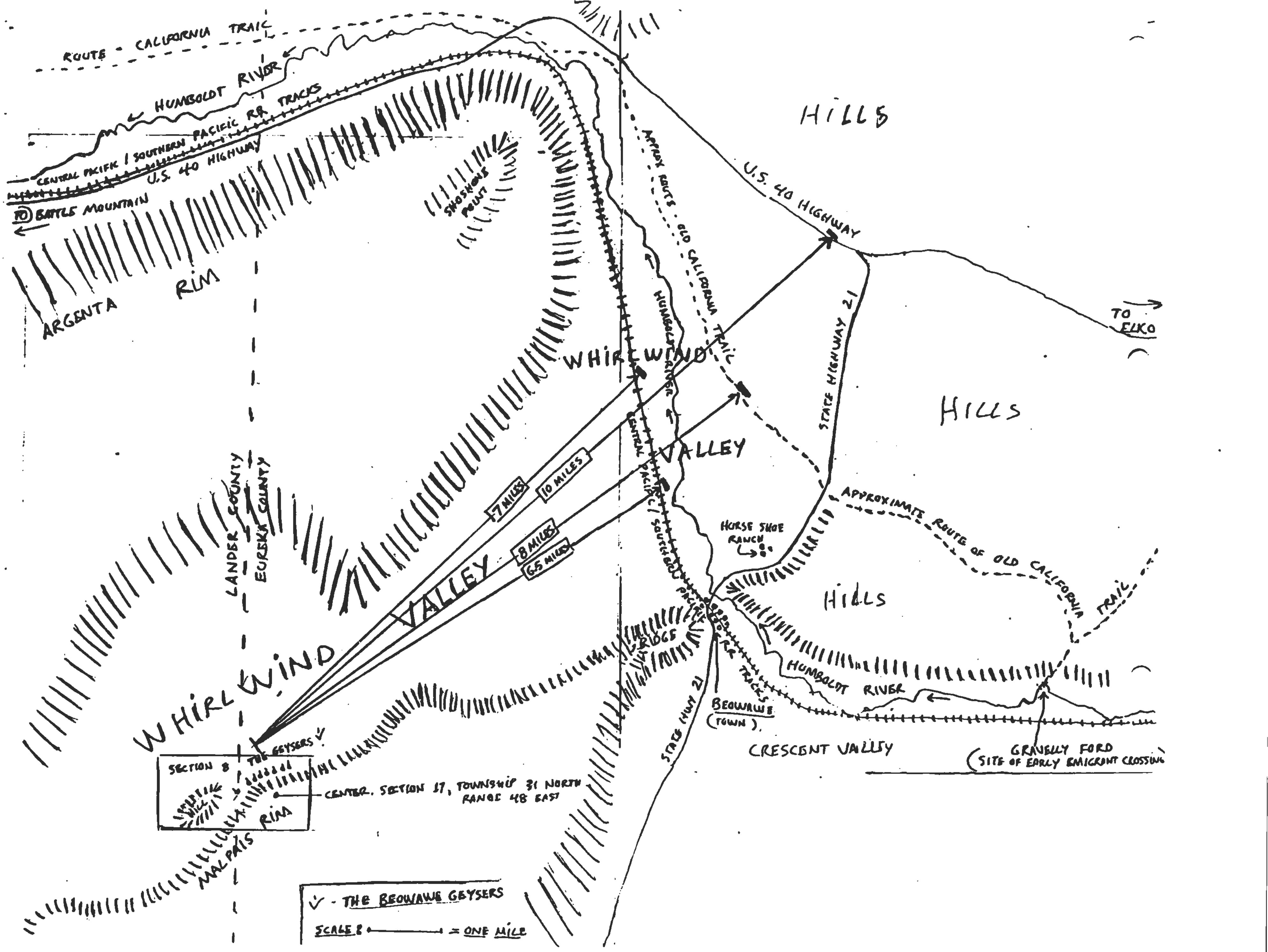
Trying to determine the territory of the Geysers' area by name origin has not proved effective. One authority on American place names stated, "Beowawe" probably means "gateway" or "pass" in the Shoshone language and possibly could mean "great posterior" [7]; and another source has said the name is Shoshone for "big wagon", in addition to the other definitions. [8] Others have said that the "Beowawe" name is Northern Paiute for "gate" and "great posterior". [9] Also, one writer has said that "Beowawe" is the name of a Moquis (Hopi) village in Arizona! [10] (The name "Beowawe", as applied to the Geysers' area, is a modern application; originally, the site was called "Volcano Springs". [11])

Also unclear is the relationship of an "old Indian battleground" that is shown on some Nevada road maps as being located south or southwest of the Geysers' area. [12] This "battlefield" has been described in at least two Nevada guide books as a site where Native American arrowheads, etc. have been found. One book states the "battlefield" was a Paiute camp-site. [13] The location of this "battlefield", as well as the Geysers' area, has been given as Crescent Valley, an error that is likely the result of faulty research. The Geysers' area is certainly not located here. [14] Another writer has placed said "battleground" in Whirlwind Valley, [15] which could mean the "battlefield" is one of the Native American camp-sites described in the archaeological report mentioned above. [16] If this "battlefield" is in Crescent Valley, it is apparently an unrecorded site. [17] It is an intriguing thought that Nevada Native Americans may have warred over the Geysers' area as one author has reported. [18]

The tribes may have used the thermal springs for bathing and curative purposes. Other Native American tribes have similarly utilized hot springs in other parts of the United States. One report on the Beowawe Geysers has stated that, because rocks located around geyser vents are not in a natural distribution, they may have been placed there by Native Americans. [19]

EARLY EXPLORATION OF THE BEOWAWE AREA BY NON-NATIVES

From 1828 to 1845, a number of explorations/journeys along the Humboldt River took place. The first appears to have been in 1828 by Peter S. Ogden, a British fur


ROUTE - CALIFORNIA TRAIL
HUMBOLDT RIVER
CENTRAL PACIFIC / SOUTHERN PACIFIC RR TRACKS
U.S. 40 HIGHWAY
TO BATTLE MOUNTAIN
SHOSHONE POINT
ARGENTA RIM
HILLS
APPROX ROUTE - OLD CALIFORNIA TRAIL
HUMBOLDT RIVER
U.S. 40 HIGHWAY
TO ELKO
WHIRLWIND VALLEY
STATE HIGHWAY 21
HILLS
7 MILES
10 MILES
8 MILES
6.5 MILES
LANDER COUNTY
EUREKA COUNTY
CENTRAL PACIFIC / SOUTHERN PACIFIC
HORSE SHOE RANCH
APPROXIMATE ROUTE OF OLD CALIFORNIA TRAIL
HILLS
RIDGE
RR TRACKS
HUMBOLDT RIVER
WHIRLWIND VALLEY
STATE HWY 21
BEOWAWE (TOWN)
CRESCENT VALLEY
GRAVELLY FORD (SITE OF EARLY EMIGRANT CROSSING
SECTION 8
THE GEYSERS ✓
CENTER. SECTION 17, TOWNSHIP 31 NORTH RANGE 48 EAST
RIM
MALPAIS
✓ - THE BEOWAWE GEYSERS
SCALE: = ONE MILE

trader/trapper, who was at the time employed by Hudson's Bay Company. [1] Ogden, with a small party of trappers, explored the Humboldt River in search of beaver, passing within 6 to 8 miles of the Beowawe Geysers. He and his men established a camp about 2 miles up stream from the present-day site of the community of Beowawe, Nevada. One of Ogden's trappers, Joseph Paul, had become very ill, so the 12-day lay-over at this camp-site was largely for the benefit of Paul's recovery. [2] Ogden's journal talks about the cold weather (it was mid-winter of 1828), Paul's illness (unspecified but possibly hypothermia), beaver, and the local Native's insistence that the cold weather was unusual and mild weather was expected. Ogden agreed with the Native American's assessment of the weather as not even they were appropriately dressed for the cold. [3] In the light of these entries in Ogden's journal, it is interesting to find not one mention of the Geysers at all. The steam from the Geysers should have been, in cold weather, quite visible to anyone in the area. Almost certainly, neither Ogden nor his men saw the Geysers, nor did the Natives Ogden was communicating with tell him about the site.

For Joseph Paul, ill and suffering from the severe cold weather, an unawareness of the Geysers' area proved to be fatal. He died and was buried near the present-day site of Carlin, [4] Nevada, a trek to which must have been far more arduous than that to the Geysers - 10 miles (or less) over flat land.

Ogden returned to the Humboldt River in 1829 but did not pass through the Beowawe area, choosing instead to explore the Maggie Creek to its head waters in search of beaver. [5] Ogden did not return to the Humboldt River after 1829, although the Hudson's Bay Company continued to send small parties of men into the region. [6] Little is known of these expeditions at this time

American guide/explorer, Joseph Walker, made at least three trips down the Humboldt River: one in 1833/34 [10], another leading a group of Captain Bonneville's party to California, apparently following the same route he used in 1833/34; and a third in 1845, leading a group of John C. Fremont's men. Fremont himself took a different route and thus did not, as some have claimed, pass through the Beowawe area. [7]

Walker lost his travel journal while crossing a stream so we have no idea as to what he saw on his trips down the Humboldt River. Walker's clerk, Zenas Leonard, on the 1833/34 trip did keep a travel journal but did not record seeing the Beowawe Geysers. [8] Likewise, Edward Kern, on the 1845 trip kept a journal but did not note that he, or anyone in their party of explorers, saw the Geysers' area. [9] Had Walker been aware of the Beowawe Geysers, it seems likely that he would have pointed the area out to Kern, in 1845, as a site worth looking at closely. Since that did not happen, it is reasonable to say that Walker was not aware of the Beowawe Geysers at that time (1845)

CALIFORNIA/HUMBOLDT RIVER TRAIL: 1841 TO 1869

There have been numerous trips to and from California via this route by emigrants, Mormons, government surveyors, explorers, and military units, cattle drivers, and mail/freight shippers. The job of researching the enormous amount of material concerning the history of travel over this particular trail constitutes an ongoing project. The following is a summary of results of research to date.

A recently published book on emigrant diaries/journals/letters, etc. lists over 2000 items regarding travel to California and Oregon, from the 1840's to the 1860's. [1] At least 300 (a conservative figure) of these diaries/journals describe the travel, and travails of travel, along the Humboldt River route, used by many to get to California. [2] I have examined 30 of these diaries/journals/maps dating from 1841 to 1863. This research includes the majority of the better diaries/journals which have been published. [3] At this time, only one diary/journal has been located which contains an entry that appears to be a description of one of the active hot springs at the Beowawe Geysers. [4] So far, no map of the California/Humboldt River trail prior to the 1870's has been found which shows the Geysers' area. [5]

The idea that California-bound emigrants saw the Beowawe Geysers, at least from a distance, appears to have originated from one writer who has suggested the very plausible scenario that "...gold rush pioneers of the 1850's saw the steam clouds and took them to be permanent dust devils". [6] As mentioned earlier, emigrant diary/journal entries that describe the Beowawe Geysers are exceedingly scarce. Furthermore, diary/journal entries describing dust devils/whirlwinds are also scarce. I have found less that six and none of these could be tied to the Beowawe Geysers area. [7] (The possible name origins of the Beowawe area, "Whirlwind Valley" will be covered in another section of this article.) As stated earlier, over 250 other emigrant writings and documents wait to be examined. It is, therefore, possible that something may turn up on this topic.

It is interesting to note from those who have studied the history of the California Trail and the Humboldt River, that there is little or no mention of the Beowawe Geysers as a trail "landmark". [8] Hot springs which did receive frequent mention in emigrant diaries/journals and histories of trail travel, include hot springs in the Thousand Springs Valley, N.E. of Elko, Nevada and in the Forty Mile Desert (Brady's Hot Springs), N.E. of the town of Fernley, Nevada. Many of the diary/journal descriptions say that steam plumes are seen rising from these hot springs; not a single entry could be found that mistakenly tied steam plumes to dust devils/whirlwinds.

Examination of related material concerning travel on the California/Humboldt River trail indicates that Mormons used the trail to and from their properties in western Nevada. What they might have observed in the Beowawe area has not been determined at this time. The same can be said concerning U.S. military units who were in the area in the 1850's and the 1860's, searching for Native Americans who had attacked emigrants at Gravelly Ford on the Humboldt River. [9] (Gravelley Ford is just a few miles east of the Beowawe area.)

At least two U.S. government survey teams followed the Humboldt River in the 1850's: Lt. E.G. Beckwith's Pacific Railroad survey [10], and the Pacific Wagon Roads project/survey, headed by A.H. Campbell. [11] Neither of these two surveys noticed, apparently, the Beowawe Geysers; however, the wagon road survey map of northern Nevada, the Humboldt River inclusive, does show the hot springs, mentioned above, that most emigrant diaries/journals describe. [12]

In closing it should be said that anyone who used the Humboldt River trail, from 1828 to 1869, had opportunity to see the Beowawe Geysers except during hot dry weather when steam plumes would not be visible. This trail saw heavy and multiple use by all kinds of people including cattle men, sheep men, Chorpenning's mail/freight service from Salt Lake City, Utah to Carson Valley, Nevada, etc. [13] Checking on this material is a very long, involved process...so stay tuned!

COMING OF THE RAILROAD: 1868 and onward

The need for a transcontinental railroad to California from the eastern United States was evident by the 1850's when the federal government authorized the Pacific Railroad Surveys. [1] The stories of construction of the Central and Union Pacific Railroad routes, linking at Promentory Point, Utah, have been well covered by other authors so that topic will not be researched here. [2]

By late 1868, the Central Pacific Railroad's tracks were advancing on the present-day site of Carlin, NV. [3] On November 9, 1868, author/journalist and retired (?) Colonel Albert S. Evans, serving on the staff of the Governor of California, prepared to leave the comforts of a Central Pacific Railroad camp near Argenta, Nv. to visit a geological curiosity, the "Volcano Springs", in "Whirlwind Valley". [4] A "Spanish lady" who is not named, had visited the "Volcano Springs" one day earlier and had described the site vividly to Evans. [5] Evans was apparently intrigued by the lady's description and decided to visit the area.

Evans' description of the "Volcano Springs" (aka "Beowawe Geysers") was printed in the February, 1869 issue of Bret Harte's *Overland Monthly* magazine under the title, "In Whirlwind Valley". [6] Despite some geographical errors and exaggerations, it would seem Evans describes in this article what we now call the "Beowawe Geysers". [7] (For those who seek details of Evans' description, the article has been reprinted recently.) Evans does make an interesting observation on viewing the Geysers' area from a distance: "...we saw a long table-land...white upon the top...with long ribbon-like streaks of blue and white running down from thence to the plain below. This has been designated as the locality of the Volcano Springs; but beyond the discolorations mentioned, there is nothing to attract the mention of the traveler, and one might pass the point a dozen times without being made aware of their existence." [8] This is an interesting statement which I checked myself while at the Geysers' area last October. Under certain lighting conditions, it would be possible to "see" the Geysers' area and not recognize it as a geyser site. Evans' statement may explain why the Geysers' area was not reported more often; no one knew what it was they were seeing. A close up view of the Geysers' area would have revealed the true nature of the site. Most emigrant parties did not, however, have the time to explore too far from the Humboldt River trail and the Geysers' area is at least 5 to 6 miles to the southwest of the trail. The primary concern for the emigrants was that of getting to California and delays on this trail often proved to be dangerous. Native American attacks upon and theft of livestock and food supplies, as well as snow in the passes of the Sierra Mountains are mentioned frequently in the diaries and journals as major trail problems. The Donner party disaster of 1846 was largely the result of trail delays, and served to spread the message to other emigrants that "delays were deadly".

Evans' article makes no claims/statements as to who first discovered the "Volcano Springs", the origin of the name, or the origin of the name "Whirlwind Valley". Whirlwinds can, however, be seen in this valley under certain atmospheric conditions during hot weather. In reading Evans' article, one gets the impression that both names antedated Evans' visit of 1868.

From 1869 onward, the Geysers' area received a fair amount of publicity in publications oriented to travel over the newly completed transcontinental railroad line. Much of this publicity is in the form of guide books on this new railroad line, written by a number of different people. [9] First and foremost is George A. Corfutt who set the standard for railroad guides with his series of guide books that are noted for their detail and accuracy. [10]

The Beowawe Geysers received a fair amount of description in most of Corfutt's R.R. guides, even though his earlier guides (1869 to 1876?) err in the location of the Geysers' area. [11] By the time his 1880 guide was issued, Corfutt had corrected his location error and had correctly placed the Geysers' area to the southwest of the community (and railroad station) of Beowawe, Nv. [12]

Corfutt's description of the Geysers' area and name(s) vary from guide to guide. The 1869 guide calls the site "Hot Spring Valley", a name he used consistently for the valley that had, since 1868, been officially called "Whirlwind Valley".[13] He also referred to the area as "Hot Springs" rather than "Volcano Springs". Corfutt's 1869 description is worth repeating: "If you do not behold the steam, and the springs are not always in active operation, you will behold a long yellowish line stretching for a full half mile around a barren hill-side. From this line, the sulphuric [sic] wash descends the hillside, desolating everything in its course, its water escaping through the bogs of the valley we now are crossing. From this line, around the hillside, escapes at intervals, columns of steam and, at times, of boiling muddy water, causing that reddish waste you see yonder. At times, all is quiet,; then come little puffs of steam, and then long and frequent jets which often shoot 30 feet high. And, oh!, aint [sic] the water hot? Woe to the unlucky hombre who kneels down to quench his thirst at one of these quiet harmless-looking springs. Phew, the skin of his mouth is gone, and oh, what a vast amount of energetic language is hurled at the smiling, placid spring, which suddenly resents the idea of being damned, and to show the utter absurdity of the attempt, suddenly sends a column of spray, steam and muddy sulphur water 20 or 30 feet into the air, and all is still again. There are about 100 of these bubbling curiosities around the hill...". [14] Discounting exaggerations and hyperbole, we have a fair description of the Beowawe Geysers. The "100" springs figure is interesting in that Donald E. White mapped 52 discharging or formerly discharging vents on the main sinter terrace, based on a 1951 map, as well as many vents with no water or steam. This constitutes about the same number that Corfutt said there were! [15]

Other railroad guidebooks that mention the Geysers' area in varying detail include *The Pacific Tourist* [16]; T. Nelson and Sons [17]; Stanley Wood's *Over the Range...* series [18]; and a certain few by the Southern Pacific Railroad Company [19]. Taken together, the publicity coverage spans minimally from 1869 to 1917.

Included in this roster, are two publications by the U.S. Geological Survey. One, dated 1883 and written by Dr. A.C. Peal, is a partial quote of Evans' 1869 article [20]. The second USGS publication is by W.T. Lee, et al., on the geology of the Overland Railroad route. [21] This 1915 guidebook describes the Geysers' area in just three sentences, indicating that the site was not inspected up close.

As a "final" word on this topic, let me mention two other well known names in American geology: F.V. Hayden and Clarence King.

Professor Hayden is well known for his studies of Yellowstone's hot springs and geysers, and may have known of the Beowawe Geysers. Hayden, in 1870, had authored the book, *Sun Pictures of Rocky Mountain Scenery*, which covered the geology of the eastern half (Union Pacific Railroad) of the then new transcontinental railroad. [22] Hayden had planned to do a companion volume that would have covered the western half (Central Pacific Railroad) of the railroad line [23], but this book apparently was not issued. Had he done this companion book as planned, it seems likely that he would have noticed the Beowawe Geysers. In 1870, Hayden became involved in the studies of Yellowstone's thermal springs, so he apparently was not able to do his planned book on the geology of the Central Pacific Railroad route.

Clarence King headed the massive 40th Parallel survey which, in the 1860's to 1870's, covered most of the Humboldt River corridor. Despite the fact that the survey included the geology of the Whirlwind Valley, the surveyors somehow failed to notice the Geysers' area. [24] Oddly, it appears that King and his field crew did not use binoculars, or their equivalents, to inspect the "Whirlwind Valley" area closely. Such an inspection would have revealed the Geysers' area.

MODERN KNOWLEDGE: 1917-1950's

After 1917, the Geysers' area apparently received little publicity in the form of railroad or other travel guides. [1] For example, the Automobile Blue Book for 1921, covers the Victory Highway route (U.S. Highway 40, now Interstate 80), through northern Nevada and does not mention the Beowawe Geysers. [2] Nor does the 1926 special touring issue of the Nevada Highway News mention the Geysers' area as one of Nevada's scenic features. [3]

The first description of the Geysers' area, after 1917, may be the biological paper by Charles T. Brues, published in 1928. [4] Professor Brues (and family) visited the Geysers in the summer of 1927 while on a survey project of fauna in hot springs in the western United States. [5] Brues reports observing several geysers erupting to heights of 15 to 20 feet at frequent intervals. [6] His wife's private diary gives more detail, "... within 45 minutes at least 10 of these [geysers] would play. The craters were very much like those of the geysers in Yellowstone Park, beautifully fashioned out of rough spongy-looking tinted geyserite." [7] From reading the Brues' accounts, there can be no doubt that they were describing the geyser activity that once existed on the sinter terrace at the Beowawe Geysers. The Brues' description of the Beowawe Geysers thus predates the 1934 report of Nolan and Anderson's by about seven years.

The Nolan and Anderson report on the Beowawe Geysers was published in 1934, in an issue of the American Journal of Science: their report notes the existence of five geysers that erupted frequently to heights of one to 12 feet. The report includes a map of the Geysers' area showing the major sites of thermal activity, plus several photos of the more active geysers and hot springs. [8] One photo shows the intermittently boiling spring that Don White (see ahead) calls "Frying Pan Geyser." Other photos show some of the smaller geysers in eruption. An unpublished photo by Nolan and Anderson, in White's Beowawe file, shows the vent of White's "Beowawe Geyser" (vent #29), except that it was not erupting when photographed by Nolan and Anderson. [9]

In the 1920's and 1930's, Drs. Eugene T. Allen and Arthur L Day, of the Carnegie Institutes Geophysical lab, in Washington, D.C., were preparing their huge book, *Hot Springs of the Yellowstone National Park.* [10] One of the authors mentions finding a description of the "Volcano Springs" in A.C. Peale's 1883 article. Dr. Allen (presumably) made unsuccessful inquiries of several sources, including the USGS. Finally, he found a couple of people in Nevada who were able to provide data on the Geysers area: a Professor S. C. Dinsmore, of the University of Nevada/Reno, and R.F. Garnett of Beowawe, Nv. [12], who provided "specimens and photographs that left no doubt to the true nature of these hot springs." [13] That is, true geysers did exist at that site.

Allen proceeded to inform T.B. Nolan about the Beowawe Geysers' area. Dr. Nolan, who was in Nevada at the time doing field work for the U.S. Geological Survey, contacted a friend of his, George H. Anderson. [14] The two men then proceeded to investigate the site for a few hours, in the summer of 1932, and this lead to their 1934 report. [15] Evans' 1869 visit/article on the Geysers' area turned out to be influential. Had Evans not been enthralled by the "Spanish" lady's description of the Volcano Springs...?

In the 1930's, additional publicity on the Beowawe Geysers' area appeared in a number of publications: Issues of *Nevada Highways and Parks*, a magazine that was published by the State of Nevada's Department of Highways [16]; a USGS publication, *Thermal Springs in the United States* [17]; WPA/FWP Nevada state guidebook (1940) [18]; and several Nevada road maps that date from the late 1930's. [19] A brief sampling of the comments from the above cited publications is presented below.

The 1930's *Nevada Highways and Parks* magazine articles on the Beowawe Geysers appear in the May, 1937 and March/April, 1939 issues; the Geysers are mentioned briefly as one of three or four areas of geyser activity in the U.S.A.; location of Geysers' area is given as "at Beowawe" and "east of the town [of Beowawe]". [20] Neither location is correct.

The 1937 USGS report on thermal spring locations in the United States briefly describes the Beowawe Geysers as "About 35 hot springs on tufa [sic] terrace for 3/4 mile along fault on hillside; 3 hot springs in low land nearby. Discharge varies according to season; 2 or 3 springs have true geyser action." [21] This report lists the site under "Lander County"; actually, the Geysers' area is largely in Eureka County. [22] Of special interest are the two references given: "#143, is A.C. Peale's 1883 report that quotes from Evans' 1869 article on the Geysers' area; and the enigmatic reference, "#174, is published data in the files of the USGS "...including information furnished by the Forest Service, Indian Service and General Land Office." [23] This information has not been located as of 1989; possibly it's a reference to the field notes of Gerald A. Waring, co-author of the report.

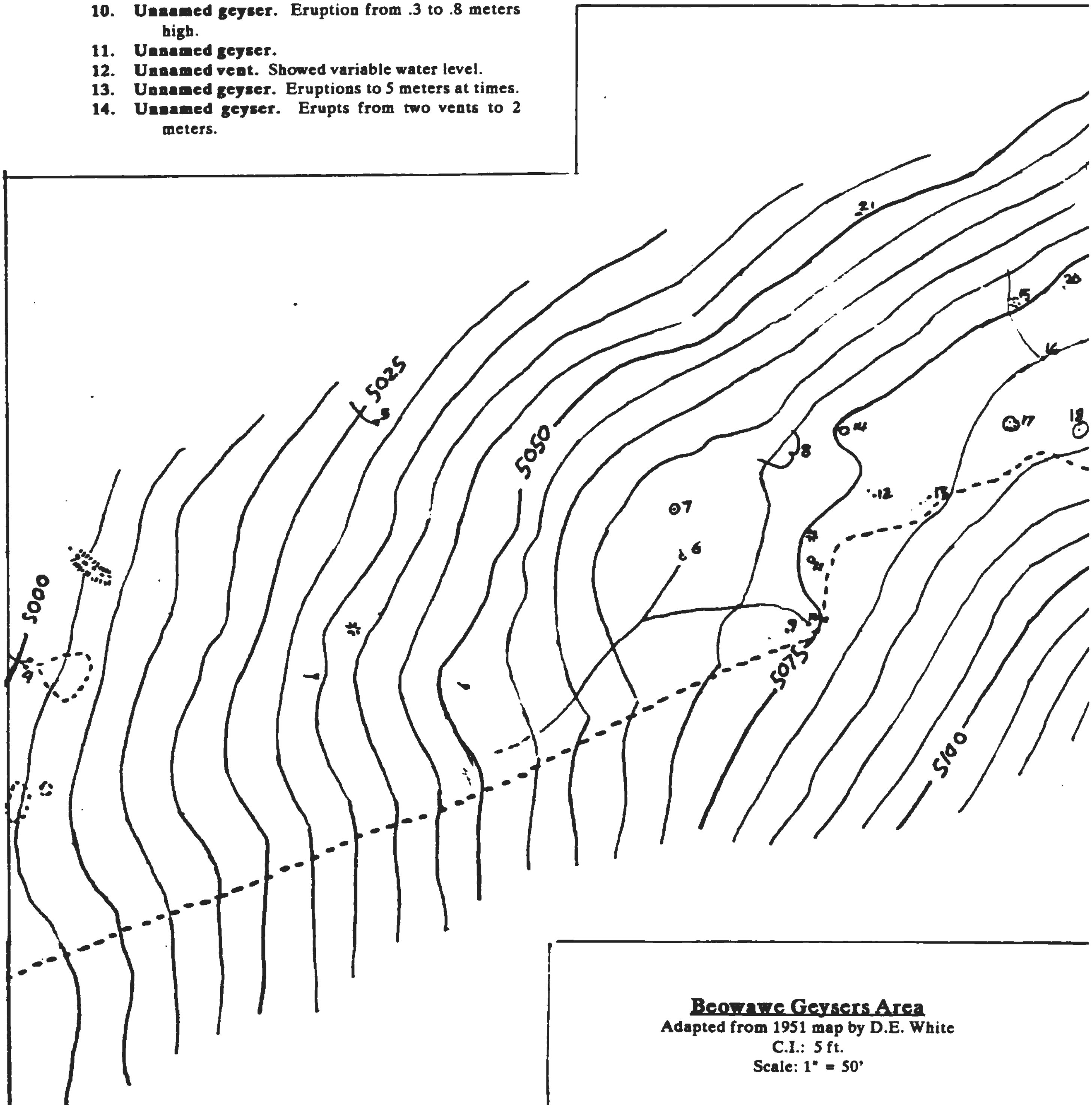
The 1934 report by Nolan and Anderson, prepared in 1935 or 1936 and probably not available in 1937, was not cited in this 1937 USGS report.

The WPA/FWP Nevada state guidebook issued in 1940, describes the Geysers' area. It seems remarkably like a condensed rewrite of Nolan and Anderson's 1934 report, particularly in the closing remarks which read, "In eruption, the waters of most of the geysers rise less than a foot at present (1940) though a few spout with greater force, one

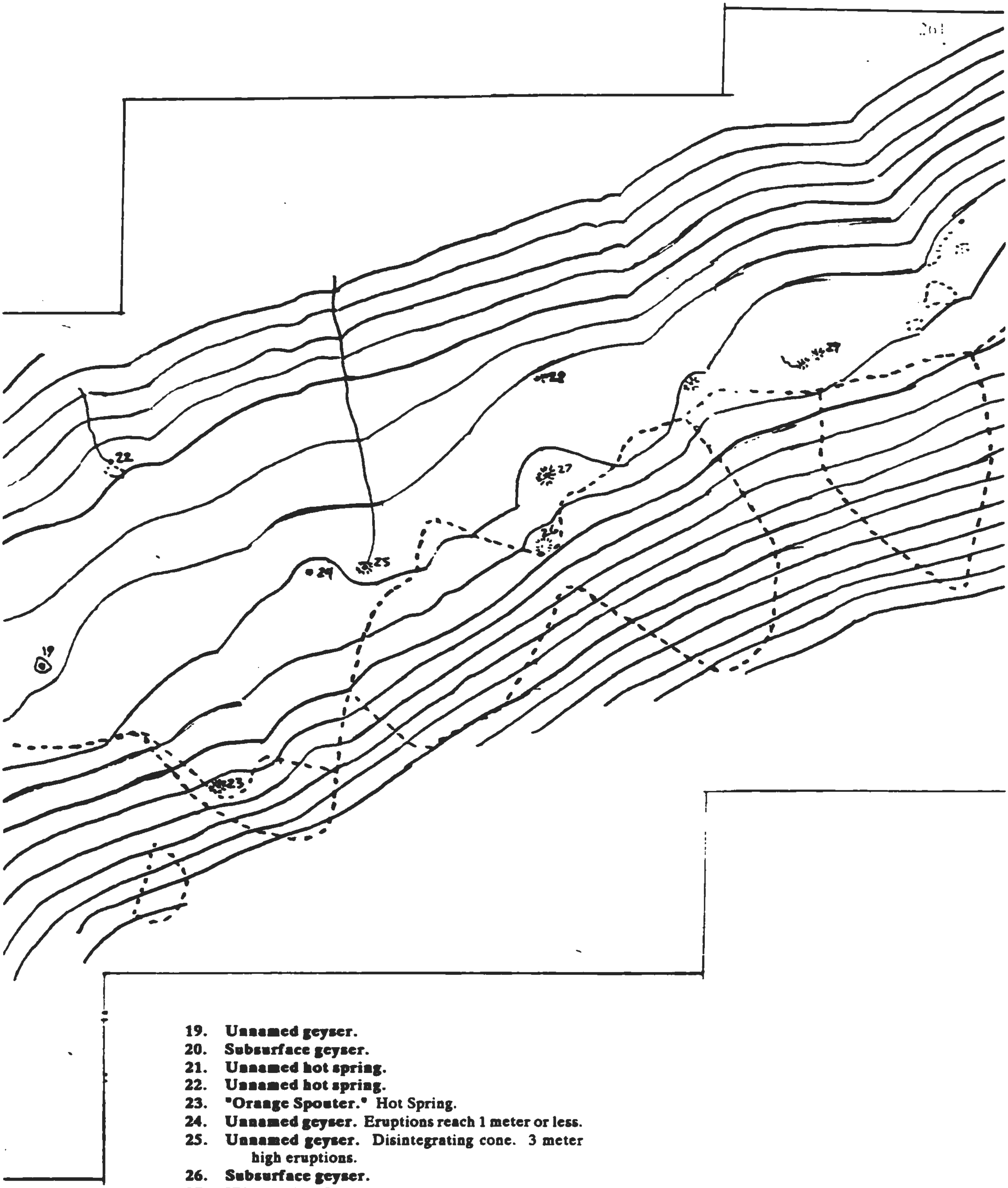
4. **Unnamed hot spring.**
5. **Unnamed geyser.** Hot spring in 1945, 1947, 1948(?), 1949(?), May 1951, October 1951. Small geyser 1950, 1957.
6. **"Tea Kettle" Geyser.** Two vents, eruptions from 2 to 5 meters high.
7. **"Spitefire" Geyser.** Inactive 1945(?), 1947.
8. **Unnamed geyser.** Inactive 1945(?), 1947, 1949, May 1951, October 1951. Active 1948, 1950. Spring(?) 1957.
9. **Unnamed variable spring.**
10. **Unnamed geyser.** Eruption from .3 to .8 meters high.
11. **Unnamed geyser.**
12. **Unnamed vent.** Showed variable water level.
13. **Unnamed geyser.** Eruptions to 5 meters at times.
14. **Unnamed geyser.** Erupts from two vents to 2 meters.

See Plates for photographs 1-6

15. **Subsurface geyser.**
16. **Intermittent spring.**
17. **"White Flame" Geyser.** Eruptions to about 1 meter.
18. **Unnamed geyser.** Eruptions to about 1 meter.



Beowawe Geysers Area
Adapted from 1951 map by D.E. White
C.I.: 5 ft.
Scale: 1" = 50'



19. **Unnamed geyser.**
20. **Subsurface geyser.**
21. **Unnamed hot spring.**
22. **Unnamed hot spring.**
23. **"Orange Spouter."** Hot Spring.
24. **Unnamed geyser.** Eruptions reach 1 meter or less.
25. **Unnamed geyser.** Disintegrating cone. 3 meter high eruptions.
26. **Subsurface geyser.**
27. **"Pincushion Geyser."** Multiple vents, eruptions to 2 meters.
28. **Unnamed geyser.** Eruptions to .3 meters. Variable spring at times, e.g. 1951.
29. **"Beowawe Geyser."** Eruptions from 7 to 9 meters high.

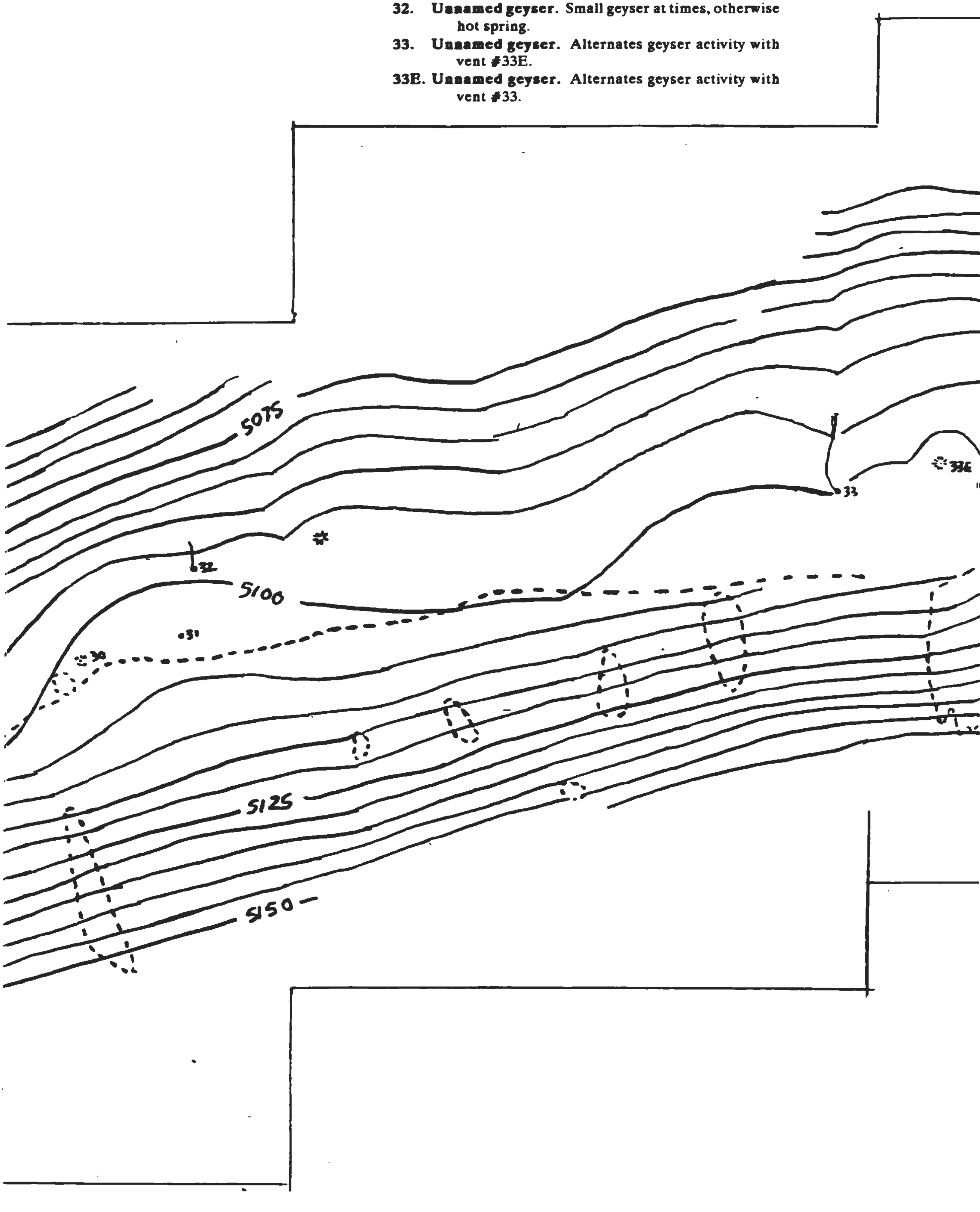
30. Unamed geyser. Active as a geyser in 1947 and 1948, hot spring in 1951.

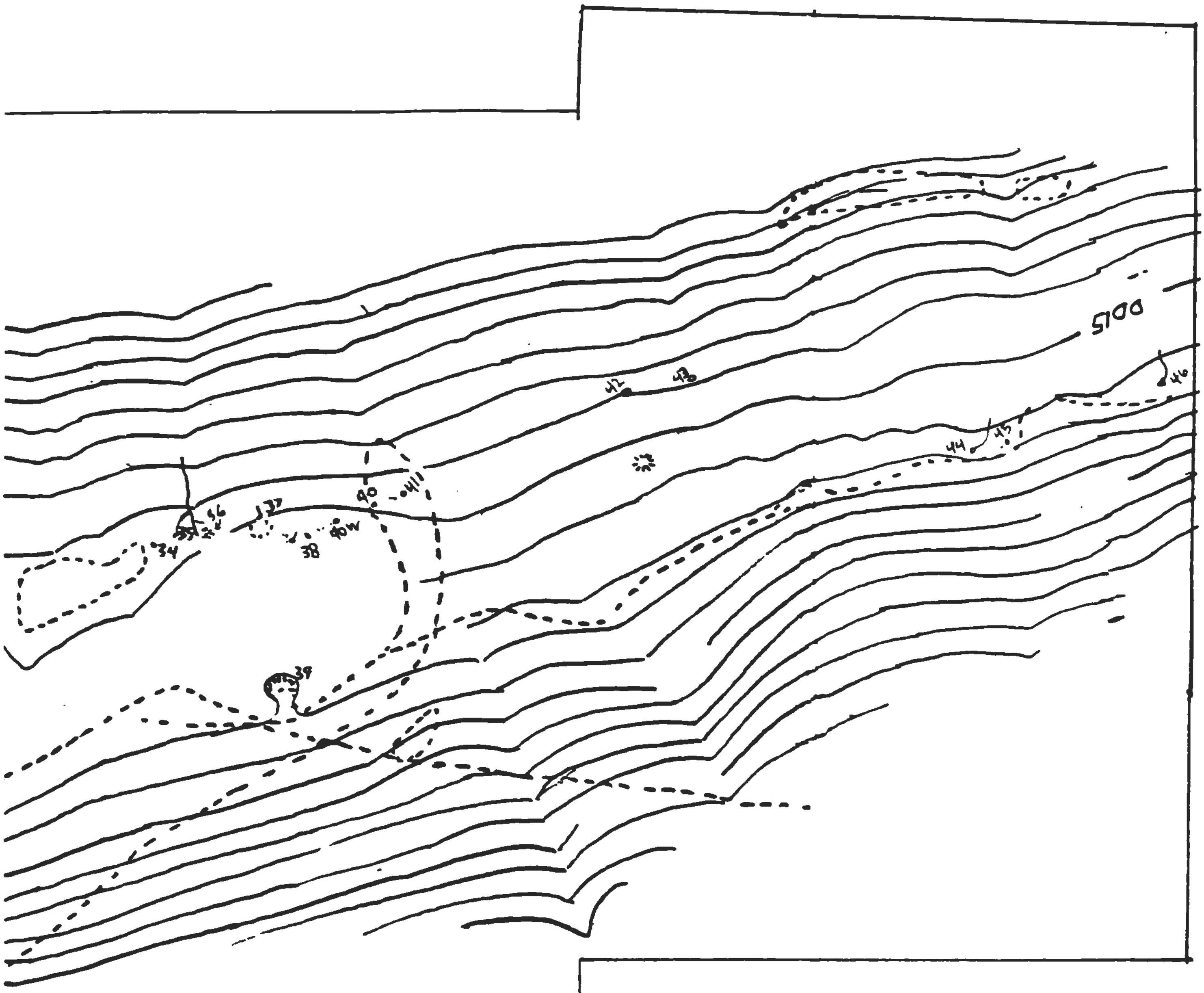
31. Unamed geyser. Small active geyser in 1948, hot spring in 1951.

32. Unamed geyser. Small geyser at times, otherwise hot spring.

33. Unamed geyser. Alternates geyser activity with vent #33E.

33E. Unamed geyser. Alternates geyser activity with vent #33.





34. **Unnamed hot spring.** Slightly acidic.
35. **Unnamed variable spring.**
36. **Unnamed geyser.** Eruptions to 2 meters high.
37. **Unnamed geyser.** Active 1948, 1957. Inactive 1951, hot spring 1947.
38. **Unnamed geyser.** Small geyser erupting from two vents.
39. **Unnamed geyser.** Eruption to 1.3 meters. Inactive in 1951.
40. **Unnamed acid spring.** PH varies from 3.28 to 6.61.
41. **Unnamed acid spring.**
42. **Unnamed spring.**
43. **Unnamed geyser.** Active 1949, 1957. Inactive 1950, 1951. Small.
44. **Unnamed spring.** Small.
45. **Unnamed geyser(?).** Spring in 1945, inactive 1951. Active(?) 1947, 1948, 1949, 1950, 1957.
46. **Unnamed spring.**

throwing water 12 feet. The eruptions last about a minute and the intervals between spoutings vary from 15 minutes to an hour...numerous hot springs and fumaroles, as well as several mud pots, occur along the terrace." [24] The Nevada guidebook also states that geyser activity shows an increase during the winter. During some years, the activity is greater than in other years. [25]

The guidebook gives misleading directions to readers who might want to reach the Geysers' area. One is told to follow State Highway 21 (now 306) south out of the community of Beowawe to reach the Geysers! If you followed those directions you would wind up in Crescent Valley, away from the Geysers' area. This same mistake appears in at least two other publications [26] and a few 1930's Nevada road maps. [27]

The Geysers' area continued to receive some publicity into the 1950's in the form of guidebooks, magazine articles and maps. [28] Perhaps the most interesting modern "popular" description of the Geysers' area was written by Ms. Nell Murbarger, and appeared in the January 1956 issue of *Desert* magazine. [29] Murbarger's article captures the vanished, and vanquished, magic of the Beowawe Geysers through description of the site as it might have appeared when "civilization" was far away in time and space

The article is based in part on Murbarger's two earlier visits to the Geysers area in the 1950's. Though there are some inconsistencies with her 1950 article (see ahead), she told me that she considered her 1956 article to be among some of her best work. [30] Certainly, the article contains some tidbits of information that, when mixed with her personal narrative, enhance the magic of the writing. These include discussions of a cavalry patrol "discovering" the Geysers in 1867 [31]; Native Americans possibly battling over the site [32]; and a Basque sheepherder informing Ms. Murbarger herself of the Geysers' area while she and her companion, Dora Tucker, finished an evening meal camped out somewhere in Nevada. [33] The reference to the cavalry is interesting. The patrol referred to may have discovered the Geysers' area in 1867, or earlier, while chasing Native Americans along the Humboldt River. [34]

Not as well known is another, earlier article by Ms. Murbarger on the Beowawe Geysers. This work appeared in the September 1950 issue of the *Natural History* magazine. The 1950 article has a slightly different storyline and photos than that of her 1956 article. This earlier article states that, rather than a sheepherder, it is an old miner who comes into her camp late in the day and tells her of the Beowawe Geysers! [35] It appears possible that either a miner or a sheepherder could have seen the Geysers' area up close. There were mining prospects located in the area, and sheepherders were active along the Humboldt River...as were cattle ranching outfits. [36]

From 1945 to 1957, Donald E. White, of the USGS (Carson City, Nv.), made several trips to the Beowawe Geysers and, mapped 50 active thermal vents on the sinter terrace, plus two or three more near the foot of the terrace. Included in this was Nolan and Anderson's intermittently boiling spring, which White called "Frying Pan Geyser". [37] White concluded that there were as many as 30 active natural geysers, most of them located on the sinter terrace, erupting to heights ranging from 1 to 30 feet. [38] Brues observed, in 1927, 10 geysers erupting to heights of 15-20 feet. [39] Nolan and Anderson observed, in 1932, 5 geysers erupting from 1 to 12 feet. [40] White, during his 8 visits, observed 12 to 28 different geysers in action. The tally of the active geysers White observed during these visits to the site is: Sept. 22, 1945 - 14 active geysers; Sept. 1 & 2, 1947 - 19 active geysers; May 14, 1948 - 27 active geysers; Sept. 8 & 9, 1949 - 20 active geysers; Sept. 30 & Oct. 1, 1950 - 18 active geysers; May 25, 1951 - 12 active geysers; Oct. 15, 1951 - 14 active geysers; Sept. 1, 1957 - 19 active geysers. This tally includes "Frying Pan Geyser"-vent #51 located near the foot of the sinter terrace. [41] It should be noted, that there is no one location from which one can see the entire terrace. It would be easy, therefore, to miss a few geysers. A comparison appears to render support to Nolan and Anderson's comments that there were seasonal and annual variations in the levels of geyser activity. [42]

As an interesting aside, an amusing event occurred at the Geysers' area during one of these trips. White and a few friends discovered a rather bedraggled beaver near the west end of the sinter terrace. The beaver had evidently crawled up a stream, from the Humboldt River to the Geysers' area. The stream was fed by thermal springs' run-off at the base of the terrace. The beaver crawled up this stream and, as the water got warmer, the animal appeared to become more confused! It is fortunate that the beaver survived the ordeal. Later, White and friends returned the beaver to the river. [43] One wonders if the beaver knew not to take that "wrong turn" again!

After White's trip to the Geysers' area on Sept. 1, 1957, he was called away on other USGS business and did not return until September, 1960, after the initial geothermal drilling had been completed. [44] He reports that only steam vents, no geysers, were active on the terrace during his next visit, except for "Frying Pan" at the base of the terrace. [45]

There are other articles published during this time which merit discussion. One article appeared in a 1956 (vol. 16, #2) issue of the magazine, *Nevada Highways and Parks*. [46] Entitled, "Hot Springs Galore," the author of the article is not credited, although it quite possibly may be Donald L. Bowers, editor of the magazine. I have a letter from Mr. Bowers, dating from the early 1960's, which was accompanied by a copy of the magazine in which "Hot Springs Galore" appeared.

The article contains some interesting information on several Nevada hot spring areas, including the Beowawe Geysers, Steamboat Hot Springs, Diana's Punch Bowl, the Fly Ranch Geyser (called the "Cone of Colors" by some), and Pyramid Lake and Wabuska hot springs. The Beowawe Geysers' area is described as having 50 geysers that erupt 1 to 25 feet high at irregular intervals. [47] Also of interest is the mention, in the opening paragraphs, of White's work on hot springs. The author comments that the Beowawe Geysers and Diana's Punch Bowl "...are the first of the state's hot springs areas scheduled to be added to its growing list of supervised recreational spots." [48] Here is a clear statement that, in 1956, the Beowawe Geysers were being considered as a State Park or State recreation area. [49] I admit, that I missed this "clear statement" completely until the 1980's. Had I been more attentive, I could possibly have obtained in the 1960's information no longer available on this subject. Several key people, and photos, are now gone.

Up through the first half of 1959, the Beowawe Geysers area was relatively undisturbed and untouched. It was, essentially, a natural curiosity. For thousands of years, the geysers, hot springs, steam vents and mud pots actively erupted, bubbled, and steamed for an audience composed of animal and, later, human life. Native Americans and, perhaps, their forerunners, made use of the area for camping and other activities.

The active geysers and hot springs must have been a curiosity to them. Perhaps some of the thermal springs were used for medicinal reasons as well as bathing and cooking. [50] The thermal springs were also the subject of "religious" beliefs for those early humans and their ancestors. [51]

The geyser may have been a mystery that awed and perhaps even frightened some of the early inhabitants of the Beowawe area. Even today, such phenomena can appear to be equally mysterious, awe-inspiring, and frightening to some people. For many who are unaware of the mechanics, a geyser may be likened to nature's idea of a stage magicians' trick: amusing, surprising, mystifying, but no practical use beyond entertainment. The wonderment at how the "trick" is done is often tempered by a desire of not wanting to know how the "trick" is done so not to spoil the mystery and wonder. Many of the descriptions of the Geysers' area reflect a sense of mystery and wonder about the thermal springs.

However, if a utilitarian approach can be realized as regards natural phenomena, it frequently will be realized, thereby creating a situation in which the mysterious is metamorphosed into the banal. In the case of the Beowawe Geysers' area, the mystery, the wonder, the magic, dissipated when geothermal energy discovered the site. The year was 1959.

GEOTHERMAL ENERGY EXPLORATIONS: 1959 to 1966

The initial geothermal exploration of the Beowawe Geysers' area began with the March 30, 1959 incorporation of the Nevada Thermal Power Company, a subsidiary of Magma power Company, of Los Angeles, California. [1] Magma Power Co., the successful geothermal developer of "the Geysers" area of Sonoma County, Ca. (where there are no true geysers, but natural steam vents), leased the western "half" (NW-1/4, Sec. 17, T. 31 N., R. 48 E.) of the Beowawe Geysers area on June 17th, 1959 from the owners, Gordon and Dorothe MacMillan, who also owned Horseshoe Ranch, Beowawe, Nevada. [2] (See Land Ownership section, below.) Although Magma Power had been in existence for only a short period of time, since about 1952, the company was already engaged in an ambitious geothermal exploration program in the western United States, in addition to its geothermal developments at "The Geysers" in California. [3] In 1959 and 1960, Magma Power Co. was exploring for geothermal energy at a number of different sites in Nevada. These included Brady's Hot Springs, Steamboat Hot Springs, and the Beowawe Geysers' area. [4] Hot springs areas in Oregon and California were also drilled during this time (1959/61) for geothermal energy. [5] Drilling was directed by Magma Power Co., and/or its subsidiary and sometimes partner, the Vulcan Thermal Power Co. [6].

By early Oct.,1959, Magma (and/or its subsidiary) was drilling its first geothermal test well near the foot of the sinter terrace at the Beowawe Geysers. [7] This first test well was not a successful test, in that it did not produce a steady flow of steam/hot water. Instead, it "geysered". [8] A second well was drilled, therefore, on the west end of the terrace and was completed by May 10, 1960. [9] This second test well signaled the beginning of the end of the geysers and hot springs that were active on top of the sinter terrace. By June of 1960, the "free blowing" of this well had created new steam vents along the top of the terrace. One report stated that the new steam vents were the result of "...a progressive lowering of the ground water table along the Terrace fault zone...[which]...has allowed the steam to migrate along the fault zone...". [10] Judging from this appraisal, the lowering water table had to adversely impact the thermal springs on top of the sinter terrace. Reportedly, the initial impact of the geothermal well(s) on top of the terrace stimulated geyser activity. This initial impact was, however, followed by a decline in geyser activity. [11] It is known that geysers, and some hot springs, have been induced into action by artificial methods. This activity changes water levels in thermal springs by causing a draining of the water out of the spring. Similar "side effects" have been noted at sites where geothermal wells and well drilling operations are introduced. [12] Several significant examples of artificially induced geyser eruptions are known in Yellowstone National Park. [13]

After June, 1960, Magma's partner, Vulcan Thermal Power Co., had three more geothermal wells drilled on top of the sinter terrace. The last of three wells was completed in June, 1961. [14] The four wells on the terrace must have diverted large amounts of thermal water away from the active geysers and hot springs. [15] In the long run, this caused cessation of geyser eruptions and hot spring flow. [16] However, there was other damage to the thermal springs on the terrace, in addition to that caused by the wells.

A 1962 report on well performance tests on these four "terrace top" wells, noted that "steam leaks" were active near these wells and that the "leaks" likely were causing a drop in well performances. [17] This report states: "There [are] a great many leaks, or fumeroles [sic], in the geyserite capping upon which the well head is located. Some of these are very extensive and active. This leakage area has been extended to the West and Southwest especially. There are numerous activities in this area where there were only a few prior to the drilling of the well. Doubtless some of the drop in pressure and volume in this well can be attributed to the leaks thru [sic] the geyserite cap. A grout of cement and sand would seal off most of this activity." [18] This report goes on to describe the surface conditions around Well #2: "As in the case of #1 well, there are numerous fumeroles [sic] discharging a considerable amount of steam in the immediate vicinity of the well head. It is the writer's [William W. Allen, Engineer, Magma Power Co.] belief that these discharging vents and fumeroles [sic] can be effectively sealed off by using a sand cement grout. Undoubtedly, they have some effect on the well capacity." [19]

It has also been reported that a bulldozer was used to try and seal off the "steam leaks" on top of the terrace during the same time period (1960/61?). [20] One can still see bulldozed debris covering major portions of the western half of the sinter terrace.

While it is feasible that steam was leaking from the well bores, it is more likely that the "steam leaks/fumaroles" were the result of a vaporization of water in the terrace by the latent heat contained in the sinter mass and steam "boiling" off the declining water table. The end result was a situation in which, once the water table had declined below the bottom of the well casings, only steam could reach the surface through channels in the sinter that had once supplied the active geysers and hot springs.

After 1961, additional geothermal wells were drilled at the Geysers' are: two wells were drilled above and near the east end of the terrace (NE-1/4, Sec. 17) under the sponsorship of the Vulcan Thermal Power Company. [21] In 1964/65, four more test wells were drilled by the Sierra Pacific Power Company (of Reno, Nv.), in the NW-1/4 and SW-1/4 of section 17. [22] One well, Sierra #3, is located halfway up the flank of the terrace. The drill road leading up to it left an ugly scar that severely mars the symmetry and beauty of the sinter terrace.

Sierra Pacific subleased the acreage from Magma in 1963 and, failing to find a suitable supply of steam, relinquished the subleases back to Magma in 1966. [23] According to Sierra Pacific officials, the geothermal wells (totaling 11 by the end of 1965) at the Beowawe Geysers, were not producing a sufficient amount of steam/hot water to justify the construction of a geothermal power plant. [24]

More recent (1970's/80's) reports on the damage to the geysers on the sinter terrace have included some strange errors in evaluating the damage and in indicating those responsible. A chart with references is available for those who wish to know more about this topic. It is sufficient to state here that major damage to the geysers, active on the terrace prior to September, 1959, had been established by 1960 or 1961.

In the next chapter, we will take a look at some more recent (1970's and 80"s) publications that describe the thermal spring activity at the Beowawe Geysers' area. Leading off will be a 1960 report that has been cited earlier regarding the initial geothermal energy explorations. This report also provides some interesting data on several geysers at the base of the terrace which may be natural, but were probably an indirect result of the erupting wells. One of these is called the "Horst" Geyser.

THERMAL SPRING ACTIVITY 1959 to 1979

During the month of May, 1960, William A. Oesterling, a geologist for the Southern Pacific Company's Land Department, surveyed the Beowawe Geysers' area, noting the active thermal springs on the terrace and on the valley floor. [1] It is unfortunate that only the modified (and highly condensed) version of this report has been located at this time. The original report was Oesterling's detailed comparison of the thermal springs activity with what Nolan and Anderson reported in 1934. [2] The modified report covers a wide range of topics in addition to the thermal spring activity: oil and gas rights to the Geysers' area; geology; details on the initial geothermal explorations at the site; and details on the impacts of one geothermal well on thermal spring activity. This report contains some choice data, not seen in any other report, on several active geysers and hot springs at the site. Of special interest, is the description of the "Horst" Geyser, located on the margin of the western end of the Geysers' area at valley floor level (see map).

The "Horst" Geyser is reported, by Mr. Oesterling, as being active during his survey of the Geysers' area. He writes, "It is the most vigorous of all geysers at the site. This geyser erupts water to an average height of 15-20 feet with a 30 foot maximum. The climax lasts for 3 or 4 minutes followed by several minutes during which a large volume of steam is discharged. The length of the cycle was not determined, and may be sporadic instead of constant. The geyser cone is small, approximately six feet in diameter and only one or two feet in height." [3]

The report goes on to describe other active geysers and hot springs on the valley floor. Nolan and Anderson's intermittent boiling spring is, in 1960, in perpetual eruption maintaining a height (18 inches max.) and discharge (estimate of 20 gpm) greater than that Nolan and Anderson witnessed in 1932 (6 inches max./5 gpm discharge, estimated). A geyser, located about 75 feet south of this intermittent boiling spring, is seen erupting "...between 6 to 10 feet [high] twice within a period of 1 hour and 46 minutes when observed in May, 1960." [4]

Of the geyser and hot spring activity on the sinter terrace, Oesterling merely quotes Nolan and Anderson's 1934 report for the most part, but he does state that the eastern "half" (900 feet) of the terrace "...contains many fumaroles, small hot springs, and tiny geysers." [5]

In his report, Oesterling concludes that there has been a general decline in the level of thermal spring activity on the sinter terrace and a general increase in the level of thermal spring activity on the valley floor. He attributes this to a self-sealing of the channels in the sinter terrace, resulting in the diversion of thermal fluids to the valley floor thermal springs. [6]

The 1965 USGS publication by Gerald A. Waring and others, on thermal springs in the United States and other countries, gives another interesting view of the Beowawe Geysers' area. [7] This report describes the Geysers' area in a way much like the description Waring, et al, gave of the site in 1937. [8] There are some key revisions present in the 1965 description. Waring states there are, "about 50 springs and mud pools on hillside tufa [travertine] terrace 0.75 mile long, also 3 springs in nearby lowland. Two or three springs show true geyser action, 1 spouting to a height of 30 ft.". [9] Note that the number of springs has changed from 35 in 1937, to 50 in 1965; and the discharge in 1937 (not quoted earlier in this report) has gone from 50 gpm (estimated) to 100 gpm (estimated in 1965). [10] The number of springs, "50", is a puzzle in that none of the references given (Evans, 1869; Murbarger, 1956; Nolan & Anderson, 1934) state the number of thermal springs present. I believe that the number, "50", may have come from White. [11] The figure of "30 feet" for one of the geyser eruptions appears to have come from Nell Murbarger's 1956 description of the Geysers' area [12]; however, it is possible that Waring may have relied on White's field data.

In 1968, John S. Rinehart investigated the Beowawe Geysers' area and concentrated largely on the valley floor thermal springs, evidently because none of the terrace springs were discharging any water. Dr. Rinehart identified 3 principal geysers and a "dead geyser" cone (see map). [13] His studies indicated that: the "South" Geyser erupted to a height of 2 meters, at intervals of 4 minutes or more; the "Middle" Geyser (Nolan and Anderson's intermittent boiling spring/White's Frying Pan Geyser-vent #51) erupted to a height of 30 to 60 cm above the rim of its basin, at about 23 minute intervals; and the "North" Geyser (I have called it "Tea Cup Geyser" for the shape of the cone in the middle of the geyserite plate) erupts to a height of 1 meter every two hours. [14]

Rinehart says very little about the thermal spring activity on the sinter terrace in his 1968 report. He does state "...commercial power interests heave heavily worked the upper sinter terrace, disrupting all natural geyser activity there." [15] Rinehart's 1980 book on the subject of geysers and geothermal energy briefly mentions the Beowawe Geysers' area, stating: "Until being drilled for possible use as a geothermal power supply, thermal activity was largely restricted to the surface of a 60 meter high sinter terrace...about 100 fumaroles, at least an equal number of hot springs, and a few geysers were scattered along the top of the terrace." The description goes on to note that only three geysers erupted to any substantial height; "two erupted to a height of 1 meter and the third to 4 meters." It appears that Rinehart used Nolan and Anderson's 1934 data exclusively. He concludes his description by stating: "A few formerly pulsating pools lying at the foot of the terrace changed into small geysers subsequent to the drilling operations..." [16] There is no explanation as to what data sources he used in order to come to this intriguing conclusion.

Another open-file USGS report, by R.K. Hose and B.E. Taylor, came out in 1974. In this report, the subject of geothermal systems in northern Nevada is covered. The Beowawe Geysers' area is discussed in some detail and some interesting comments are made regarding the reported levels of geyser activity, as well as the effects of geothermal wells (and drilling) on that activity. These comments bear reviewing. [17]

This 1974 report states: "When the Beowawe thermal area was first described by Nolan and Anderson in 1934, the natural system was much more active than it is now. Specifically, it included three geysers, two of which played to heights of 3 feet and one to 12 feet. In 1951, White observed about the same level of hydrothermal activity as Nolan and Anderson." [18] Same level?! White's 1945-1957 data shows that comment to be wide of the mark. At least 12 geysers were active in 1951, versus the 5 geysers actually seen by Nolan and Anderson in 1934, [19] (6 geysers if Frying Pan Geyser, Nolan & Anderson's intermittent boiling spring, were included in the tally). It is possible that there were other geysers active in 1934 than those observed by Nolan and Anderson.

Also of a curious nature, is this report's summary of the effects of geothermal drilling and well tests on the natural thermal system as being "unknown". The copy of the report that I have has margin notes by other USGS staffers, including White, stating that data on this very topic was available from White, and that "...there were gross changes" - a comment seconded by White himself in the margin. [20] This report does correctly conclude that vandalization, in the early 1970's, of several of the geothermal wells on the sinter terrace caused additional damage to the remaining thermal springs on the terrace. These vandalized wells began to vent large volumes of hot water and steam and this "...resulted in the diminution of spring flow and cessation of others." [21]

In 1979, two more reports containing descriptions of the thermal springs activity at the Geysers' area were printed. The first is a report, published by the Nevada Bureau of Mines and Geology, on thermal springs in Nevada. The second deals with the Beowawe Geysers' area exclusively, and is by Mary Lou C. Zoback. First, an examination of the Nevada Bureau of Mines and Geology (NBMG) report.

The NBMG report contains several photos of the Beowawe geysers' area, including an aerial photo of the site, and two photos of the test wells erupting steam/hot water into the air. The description of the active and once active geysers is largely a distillation of several sources: Nolan & Anderson, 1934; Rinehart, 1968; and Hose and Taylor, 1974. The NBMG report contains much interesting data on the episodes of geothermal drilling, well production, geology, and a re-drafted map originally done by William Oesterling. This map, which is misdated "1962" (the correct date is "1960"), shows the major active thermal springs to be located mainly on the valley floor - 2 or 3 are shown on or near the sinter terrace. [22] The map shows the "Horst" geyser, on the valley floor, labeled "geyser (max. 30 ft.)", along with Nolan & Anderson's intermittent boiling pool (aka "Frying Pan Geyser") and "twin vents (6 ft. geyser)".

Also shown are the geothermal wells that existed in 1960 (not 1962). There are five in total, four of them located on top of the sinter terrace. [23] The original edition of Oesterling's map, also dated 1960, shows only two geothermal wells. [24]

The Zoback report contains a considerable amount of detail on the geology of the area, plus data on the history of geothermal explorations and thermal spring activity. In summation, Zoback reports: "The top of the terrace is covered with numerous vents, fumaroles, and bubbling springs as well as small intermittent geysers...". The report also states that there are two uncapped wells venting steam and hot water continuously to heights of more than 30 meters. Ms. Zoback refers the reader to Hose & Taylor, Nolan & Anderson, Rinehart, and Evans for additional details on thermal spring activity at the site. [25]

Although this next report falls outside the time frame of this chapter, it is too valuable a source of information to be excluded here. The report is the 1985 Bureau of Land Management assessment of the Beowawe Geysers' area geothermal development. It was issued by the BLM office in Battle Mountain, Nevada. [26] The extent of coverage of this 80+ page report is amazing: cattle guards/wire fence construction; geology; history of geothermal exploration; thermal spring activity; and the design of Chevron's geothermal power plant.

Of particular interest is the mention of the one geyser, located in a group of hot springs on the valley floor, that was active in 1985. [27] Even more interesting is the observation that the wells on the sinter terrace are pressure responsive to the wells that supply steam/hot water to Chevron's geothermal power plant, located about a mile and a half to the southwest of the terrace. Tests by Chevron revealed a pressure response in less than an hour's time "...irrespective of the distance between wells." [28] This may explain why the valley floor hot springs are now dry craters - the power plant wells may be diverting these springs' water supply.

As a final note of interest, this report states that the sinter deposit at the Geysers' area may have taken about 2.5 million years to accumulate! [29]

BEOWAWE GEYSERS' AREA LAND OWNERSHIP

Prior to the arrival and settlement of the area by white men, the western "half" of the Great Basin was the province of Native Americans, largely Northern Paiute and Western Shoshone. [1] In 1849, this region was proclaimed a part of the State of Deseret by the Mormons who had established Salt Lake City and other settlements within the Great Basin region. [2] On September 9, 1850, the Territory of Utah was proclaimed by the U.S. government as the official replacement for the State of Deseret. Both the State and the Territory embraced the Beowawe Geysers' area. [3] The State of Nevada was created out of the western "half" of the Territory of Utah in 1864. Nevada's Lander County embraced the Geysers' area until 1873, when newly created Eureka County subsumed a part of the eastern Lander County, including the Geysers' area. [4]

The U.S. government had apparently assumed control of the land in the Humboldt River corridor in the creation of the Territory of Utah. This included the Geysers' area. The government granted about half of the acreage in this corridor to the Central Pacific Railway Company in order to help that company's construction of the western "half" of the transcontinental railroad in the 1860's. [5] The land grant was quite generous: 20 miles of territory on both sides of the railroad line in alternating, square mile sections of land. The railway company obtained the odd numbered sections of land, and the U.S. government retained the even numbered sections of land. The railway company also had the option of land trade-offs with the government. [6]

The acreage that embraces the Geysers' area is Section 17 (N-1/2 and SW-1/4 only) and E-1/2 NE-1/4 of Section 18, of Township 31 North, Range 48 East. The land in Sec. 17 was selected by Central Pacific Railway Co. in 1862 and 1864. [7] It is unclear who selected the land in Section 18 and the SE-1/4 of Sec. 17.

It is of interest to consider the "what ifs" in this land grant for Sec. 17: what if...the railway company had been granted the even numbered sections of land; or, what if...the land survey of the lands had begun a mile east or west of the position selected? Either way, it would have resulted in the Beowawe Geysers' area being U.S. government property.

Before going any deeper into the history of land ownership of the Geysers' area (Sec. 17, T 31 N., R. 8 E., etc.), let me share with you a tantalizing bit of information I found on an early land record of Township 31 N, Range 48 E. On the record sheet, there is the mention of a "geyser spring", in the NE-1/4 / SE-1/4 of Sec. 18. [8] Accompanying the mention of "geyser spring" on the land record, appears this note: "Range impr. Proj. N6-R-33". [9] What the note means has not yet been determined.

The identity of this "geyser spring" is uncertain. If the land survey is accurate, then it could be a geyser (or hot spring) that was active, at that time (1860's), on or near the western end of the sinter terrace. If the land survey was inaccurate or the surveyors cheated (some did!), then this "geyser spring" could be any one of the active thermal springs at the site. With this location, perhaps the identity of this "geyser spring" is: Nolan & Anderson's intermittent boiling spring (White's "Frying Pan Geyser"); or Oesterling's "Horst Geyser", which is located nearly on the section line of Secs. 17 & 18.

The land ownership records are confusing regarding who owned what portions of the Beowawe Geysers' area. Here is a review, nonetheless.

The Central Pacific Railway Co. appears to have been in no hurry to claim the lands in Section 17 that it selected in 1862/64. The company did not acquire the acreage until 1902/03...and then sold the NW-1/4 acreage to George W. Grayson by 1911 (?) [10] The railway company retained the NE-1/4 and SW-1/4 of Sec. 17 until the 1950's.

George W. Grayson, a physician from San Francisco, was quite an interesting fellow historically. He was involved in a host of business operations, including cattle ranching and mining, in California, Idaho, and Nevada. He also owned a butcher/meat packing plan in San Francisco. Dr. Grayson was one of the earliest owners of the Horseshoe Ranch, which he co-owned with Andrew Benson, of Beowawe, Nv., in the 1870's. [11]

Benson founded this ranch when he came to the Beowawe area in the late 1860's. He operated the Beowawe Hotel in Beowawe, Nv., during that time. [12] The hotel likely served people who disembarked at the Beowawe railroad station in the 1870's. [13] The Grayson/Benson partnership dissolved in 1885, and Grayson became the owner of the Horseshoe Ranch. [14]

Grayson had powerful and rich friends: Comstock developer William C. Ralston, of the Bank of California; and fellow California pioneer/businessman, Elias J. "Lucky" Baldwin. [15] Ralston is said to have been "...one of the first owners of portions of the Horseshoe Ranch" [16]; and E.J. Baldwin reportedly had a descendant, Baldwin N. "Lucky" Baldwin, who owned the Horseshoe Ranch in the early 1950's. [17]

Regarding the Grayson ownership (1870's to 1912) of the Horseshoe Ranch, an intriguing story has been reported. It is claimed that "...in the last century, passengers on southern Pacific trains stopping at Beowawe would board coaches for side trips to get a close-up view of the geysers...". [18] This story is said to have originated with Grayson Hinckley, Dr. Grayson's grandson. [19] If Dr. Grayson was as well off financially as he appears to have been, he may have paid for a private railroad car, in order to bring himself, family/friends/etc., out to the Horseshoe Ranch. The Geysers' area may have served as a pleasant diversion for visitors who came out to the Horseshoe Ranch. Perhaps the Geysers' area was an attraction that Grayson was finally able to buy in the 1900's after the C.P. Railway Co. decided to take control of the land selected/claimed 40 years earlier.

Grayson died in 1912 and left all his property to his two daughters who, in turn, passed the title to the Horseshoe Ranch (and the NW-1/4 of Sec. 17) to Grayson's grandson, Grayson Hinckley, or Hinkley, in 1933. [20] Hinckley was unable to hold onto the Horseshoe Ranch due to some bad business deals, and the Ranch, including the NW-1/4 of Sec. 17, was sold to a person with a very familiar name - Dean Witter. [21] It appears that, in 1936, Grayson Hinckley bought the E-1/2, NE-1/4 of Sec. 18, T.31 N., R. 48 E., land that embraces the location of the "Horst" geyser. Witter bought this land in 1945 from the State of Nevada! [22]

Witter bought the Horseshoe Ranch (and the NW-1/4 of Sec. 17) in 1936 and held onto the property until the 1950's (1953?). [23] During the years of 1934 to 1940, initial attempts to establish: 1) A National Monument; and 2) a State Park and/or State Monument were made. This subject will be covered in more detail in the next chapter.

In the 1950's, yet another title transfer took place. Witter sold the Horseshoe Ranch, and his portion of the Geysers' area, to a company known as, "Horseshoe Ranch, Inc.", in 1950/51. [24] This company in turn sold the Horseshoe Ranch and lands to Baldwin N. "Lucky" Baldwin, in 1953. [25] Baldwin sold out to R. H. Hadley in 1957. [26] Mr. Hadley's very short ownership marks another period in which a State Park proposal was made for the Geysers' area

Hadley sold out to Gordon and Dorothe MacMillan in 1958. [27] The MacMillans' also expressed interest in having a State Park at the Geysers' area. The couple sold the Horseshoe Ranch in 1968 to W.K. Day, but retained the title to their portion of the Geysers' area. [28] So ended the Horseshoe Ranch/western "half" of the Beowawe Geysers' area joint ownership.

Gordon MacMillan died in 1968, just a few days after selling the Horseshoe Ranch to Mrs. Day. [29] Thus, Mrs. MacMillan received the title to the western "half" (as defined above) of the Geysers' area, in 1970. Mrs. MacMillan died in the early 1970's. Her will granted the NW-1/4 of Sec. 17, and the E-1/2 NE-1/4 of Sec. 18, (T. 31 N., R. 48 E.) to Stanford

University, of Palo Alto, California, effective 1972. [30] It is ironic that what was Central Pacific Railway Co. land, from 1862/64 to the 1900's, wound up in the possession of a University that was established by Leland Stanford, a major founder of the Central Pacific Railway Co.!

The NE-1/4 and the SW-1/4 of Section 17 were still owned by the successor to the Central Pacific Railway Company, the Southern Pacific Co., until 1951, when that acreage was sold to H.J. and Elsie Buchanan. [31] The Buchanans sold said land to Max B. and Grace Arnold in 1952. [32] H.J. Buchanan may have retained part interest in the land ownership to the NE-1/4 and SW-1/4 (and the SE-1/4-?) portions of Sec. 17, until early 1959, when the acreage was sold to Crescent Valley Ranch & Farms. [33] People within this company then bought the following acreage: Sam and Ann Dermengian, the SW-1/4 of Sec. 17, in 1959; and Mr. & Mrs. Robert G. Batz, the NE-1/4 of Sec. 17, (the so called "eastern half" of the Geysers' sinter terrace). [34] (Mr. Batz also offered his portion of the Geysers' area for State Park purposes.) The Dermengian's property embraces the top of the plateau above the sinter terrace. This property is the locale of Sierra Pacific's first two geothermal test wells (Sierra # 1 and #2), drilled in the Geysers' area in 1964. [35]

THE PARK AND MONUMENT PROPOSALS 1934 to 1960 (...including 1973)

Now for the almost completely unknown story of failed attempts to establish a National Monument, and, later, a State Park/Monument at the Beowawe Geysers. It is a story of near misses and blunders that will emphasize the tragedy of the Beowawe Geysers' destruction by geothermal exploration. Consider this story as a geyser gazer's equivalent to the sinking of the ocean liner, Titanic, another story of "near misses" and mistakes. This may sound overly dramatic, but the story concerning the National Monument/State Park/State Monument proposals for the Beowawe Geysers' area is a story of missed opportunities and miscues. No one died in this story (unlike the Titanic tragedy), but an entire geyser area did "die", and now countless numbers of people will never get to see the site in its natural splendor.

Before covering this subject, let me tell of the events that led to the discovery of these Park/Monument proposals for the Beowawe Geysers' area. The key to the research on this subject rested, in part, on three magazine articles and a 1985 letter I came across which sparked my interested on this subject. Important too, was my "shot-in-the-dark" inquiry into the National Park Service Archives in Harpers Ferry, West Virginia, regarding information on record on National Park/Monument proposals. What I received in my mail was truly a surprise!

The 1956 magazine article, by Donald Bowers (presumably), noted earlier, mentioned the Beowawe Geysers' area as a site that was scheduled to be added to the State of Nevada's list of official recreation areas. [1] The May 1972 issue of the *Nevada Highway News* has an article by its editor, Frank Smyth, on an area in Nevada that he knew well, the Beowawe Geysers. Smyth grew up in that region. [2] Smyth was outraged at the damage done to the Geysers by the geothermal explorations (of 1959 to 1965), and by the fact that the site was not protected. His concluding remarks in the article express his anger over the damage and the failure of unnamed people to preserve the Geysers. "Here and there, both on the valley and on the white terrace above, the caged force of the underground pressures are beginning to escape once more, creating miniature geysers and fumaroles in the promise that what has once been destroyed could be preserved...if anyone cared enough." [3] Smyth's article is worth reading, despite some technical errors, because of the personal story he gives of his 1936 Senior Class visit to the Geysers' area, coupled with his 1972 trip to that site. In a 1977 article on the Beowawe Geysers' area, T. Scott Bryan makes comments similar to Frank Smyth's, about the failure to preserve the Geysers' area in its natural state. [4] For example, Bryan's article has a long subtitle that reads, "Except for some vandals and overeager government officials, Nevada would be world famous for its geysers", followed by, "Beowawe was never set aside as a park of any sort. It wasn't even given recognition. And its a shame...". [5]

A shame indeed, but not because no one cared, nor because the site was not recognized. Indeed, there was both caring and recognition. The "shame" is that these Monument/Park proposals went nowhere, in spite of the efforts of some truly determined individuals to see that a State Park was established at the site.

That 1985 letter mentioned earlier, came from the Nevada State Parks Department and, in part, reads: "Approximately 25 years ago [in 1960], the site [the Beowawe Geysers' area] was proposed as a State Park or State Scientific Monument. The 1960 Legislature even authorized establishment of a monument for public access and enjoyment, but a lack of funding prevented this from occurring." [6] The letter also basically indicated that the Nevada State Parks Department could not "...support the Beowawe Geothermal Power Project as proposed..." partly because of the past State Park proposal, but also because the Geysers' area had been designated a Nevada Natural heritage site. [7] At this point, the contents of this letter were sufficient to spark additional research on the subject of this chapter. First, however, the National Monument proposals for the Beowawe Geysers' area, as described in the files of the National Park Service.

Sometime after 1934, Key Pittman, U.S. Senator from Nevada, sent a reprint of Nolan and Anderson's 1934 Beowawe Geysers' article to Harold Ickes, then Secretary of the Interior. [8] Mr. Pittman requested the drafting of a bill, for his consideration, to establish a National Monument at the Geysers' area. Ickes' response was that he would instruct the National Park Service to investigate the site and report back on the suitability of the Geysers' area as a possible National Monument. [9]

The correspondence between Pittman and Ickes has not been located as yet. However, I did learn that neither man liked the other at all...matter of fact, they despised one another! [10] What that "dislike" may have done to weaken Pittman's National Monument proposal for the Beowawe Geysers' area is uncertain. It could not have helped the proposal in any case.

In 1937, James G. Scrugham, former Governor of Nevada and, at that time, a Representative in the U.S. Congress for Nevada, made an inquiry/proposal similar to Pittman's. Scrugham's proposal, however, went to the Director of the National Park Service in Washington D.C. [11] Fortunately, the paperwork, and the N.P.S. evaluation of the Geysers' area, was found in the national Archives. [12].

Still another inquiry/proposal, similar to Pittman's and Scrugham's, came from U.S. Senator Patrick McCarran of Nevada in 1938, in the form of a letter to the Director of the U.S. Geological Survey. The Director forwarded the letter to the National Park Service. [13] Not all of the paperwork has been located on McCarran's inquiry/proposal at this time. However, enough did turn up to indicate that the Geysers' area was to be suggested as a potential State Park or State Monument in the N.P.S. Park, Parkway and Recreational-Area Study of Nevada.

The 1930's N.P.S. evaluation of the Geysers' area is by Franklin C. Potter, Associate Geologist [14], who merely adapted Nolan and Anderson's 1934 report. A close examination of Potter's evaluation revealed that it is largely a re-working of their report, especially the section on thermal spring activity. The most active and vigorous geysers and hot springs are clearly identifiable [15], in particular, the three largest geysers on top of the terrace (eruption heights of 3 ft. & 12 ft.) and, Nolan and Anderson's intermittent boiling spring (White's "Frying Pan Geyser"). [16] Of the latter, Potter says: "On the valley floor there are a few springs which are embryonic geysers for approximately every 20 minutes they erupt to a height of several inches. The largest has a basin 7 inches [sic - the correct measurement is 7 feet] in diameter and a measurable depth of more than 10 feet. During intervals between eruptions the water [level] is 1 foot below the outlet and the temperature of the water is 90 degrees centigrade. Before an eruption the level of the water rises and gas bubbles 6 inches or more in diameter rise to the surface. The temperature rises to 94 degrees cent. when the pool is overflowing (at a rate of 5 gallons per minute) and the gas bubbles and water erupt to a height of 6 feet [6 inches is probably the correct figure]." [17]

Potter's conclusions at the end of his evaluation report are of interest as well, he says: "Because of the restricted area, the small number and the small size of the geysers and hot springs together with a lack of other natural scientific phenomena of a national monument calibre, Beowawe Geyser area is not of sufficient importance to justify consideration as a national monument. Perhaps the area is of State Park calibre, and if the area is to be investigated, it is recommended that the investigations be undertaken from a State park rather than the national monument viewpoint." [18] What the "conclusions" section of this evaluation failed to do was to point out the active geysers located on the terrace and the reported seasonal and annual levels of geyser activity at the site. The letters sent to Congressmen McCarren and Scrugham by the N.P.S. Directors clearly show that the N.P.S. considered the primary feature at the Beowawe Geysers' area to be the large intermittent boiling spring that Nolan and Anderson describe in their report.

Potter also makes an odd remark in his "conclusions", saying: "...if the area is to be investigated..." leading one to wonder how much on-site inspection he really did.

Since Potter's evaluation is based on the Nolan and Anderson report, it gives reason to believe, despite the fact that the paperwork has not yet been located, that Senator Key Pittman did request a bill to establish a National Monument at the Beowawe Geysers while reportedly sending a reprint of Nolan and Anderson's 1934 report to the Secretary of the Interior. [19]

Of more interest are the replies that James G. Scrugham and Patrick McCarran received from the top officials at N.P.S. headquarters in Washington, D.C. [20] Here is a sample of the reply that Mr. Scrugham received from the N.P.S. The data used is nearly a direct quote from the Potter evaluation of the Geysers' area. "The Service has received your letter...regarding the proposal to establish a national monument in the vicinity of the geysers near Beowawe, Nevada. The geysers...are found within a small area probably less than one quarter of a mile in extent, about six miles southwest of the town. A report by one of our geologists [Potter's evaluation] indicates there is very little geyser action and that the principal interest is a few hot springs which are embryonic geysers which erupt to a height of several inches approximately every twenty minutes. During the intervals between eruptions, the water is about 1 foot below the outlet and the temperature of the water is 90 degrees cent." As one can see, there is not even a hint in this letter that there are other geysers at the site, one erupting to a height of 12 feet. The letter goes on to say the Beowawe Geysers' lack the qualities needed to become a National Monument and finishes with: "The area may be desirable as a State Park, and in this connection it is suggested that the geysers be called to the attention of the proper Nevada authorities." The letter is addressed to James G. Scrugham, Member of Congress, dated Oct. 20, 1937, and signed by A.E. Demaray, Acting Director of the N.P.S., Washington, D.C. [21] One can tell by the N.P.S. response that Demaray did not read Potter's evaluation carefully enough to see that there were geysers that erupted higher than "...several inches...".

Those "proper Nevada authorities" mentioned in the above letter were to be members of the Nevada State Park Commission who made an attempt at establishing a State Park/State Monument at the Beowawe Geysers in the 1930's. The Park Commissioners received some excellent help from then Nevada Governor E.P. Carville. Let's first look, however, at the 1930's N.P.S. program, "Park, Parkway and Recreational-Area Study" for the State of Nevada, which served as a prelude to the Commission's efforts.

The Nevada study, simply called *Nevada Parks*, published in 1938, discusses a number of the potential State Park areas. This study recommends 50+ potential recreation areas. 41 areas are listed as potential state recreational sites, including the Geysers' area, which is called "Beowawe Hot Springs" in this study. [22]

The Geysers' area is listed as site "P-10" and is described in this manner: "25 acres [total]; Private ownership; Present use - None; Class of Recreational Use - geological/picnicking; Accessibility - auto; Recreational and Scientific Possibilities - geysers and hot springs." [23] The study also mentions that certain "potential areas" have "Individual Map and Descriptive Reports of Recommended Potential Areas". [24]

In the process of collecting data on recreational areas in Nevada, the National Park Service (Region #4, i.e. Western Region) office staff in San Francisco contacted various individuals: In the case of the Beowawe Geysers' area, that individual was Robert A. Allen, Nevada State Highway Engineer and member of Nevada's State Planning Board, and the State Park Department Superintendent. Allen, at the request of N.P.S. staffer, Robert E. Floyd [25], provided the N.P.S. office in San Francisco with a copy of his (Allen's) personal file on the Beowawe Geysers...including at least nine photos of the Geysers [26]. Floyd, acknowledged receiving this material from Allen, on Oct. 1, 1937. [27] The nature of this material has not been entirely ascertained at this time. I was able to identify three of the nine photos mentioned above because of the good fortune that these photos were numbered. Negatives, also numbered, for three of the photos turned up in the files of the Nevada State Parks Dept. [28]. The other photos may be in the N.P.S. Region #4 records that are in storage at the National Archives in San Bruno, California. [29]

The rest of the Geysers' data in Robert Allen's file is still a mystery, although Allen did leave over 12 photos of the Geysers' area with the Nevada Historical Society. [30] Some of these photos might be identical to the ones he sent Robert E. Floyd in 1937. [31] Two interesting letters that were located at the Nevada State Archives, in Carson City, Nevada, hit at one item Allen may have had in his "Beowawe" file. The letters concern the brief correspondence on the Beowawe Geysers' area, between Robert A. Allen and Eugene T. Allen. [32] This exchange of letters took place during the months of February and March, 1937. Here are excerpts from E.T. Allen's letter, dated Feb. 24, 1937; "...The pamphlet which Mr. Garnett [this is Ray F. Garnett, Southern Pacific RR station manager at Beowawe Nv.] of Beowawe mentioned to you as coming from me must have been the publication of T.B. Nolan and G.H. Anderson entitled "The Geyser area near Beowawe Eureka Co. Nevada..."; Dr. Allen's written involvement with this report: "My only part in this work of Nolan and Anderson was to convince myself that the Beowawe area contained true geysers and to call the matter to the attention of Dr. Nolan who had been working in Nevada as a member of the U.S. Geological Survey. I would advise you to communicate with Dr. T.B. Nolan U.S. Geological Survey, Washington D.C. who will no doubt be glad to send you a reprint of his article. For pictorial purposes you will need to have special photographs taken as Nolan's are all small and not decorative. While Beowawe is not a highly spectacular locality, it has the distinction of being one of the three geyser occurrences in this country and well deserves the protection by the State of Nevada as a rare natural phenomenon." [33] It is thus possible that Robert Allen obtained a copy of the Nolan and Anderson report, as suggested by Allen, and that this report formed part of his Geysers' file, a copy of which he sent to Robert Floyd in San Francisco.

More important was Eugene T. Allen's recommendation to Robert A. Allen that the State of Nevada should protect the Geysers' area. [34] With E.T. Allen's, and the N.P.S. Region #4 recommendations, the Park Commission did try to follow up on what was the first State Park/State Monument proposal for the Beowawe Geysers' area.

In mid to late April, 1938, C.W. West, M.D., Chairman of the Nevada State Park Commission, made a wide ranging trip through Nevada in order to inspect several existing State Parks and some potential park sites then under consideration by the Park Commission. Of interest to us here, in Dr. West's report, is the brief mention of the Beowawe Geysers' area. "We returned homeward via Ely and Eureka and northward to Beowawe where we made a hasty inspection of the geysers south [actually southwest] of town. A thorough inspection of these [geysers] was not made but they are spectacular, in an area of our State where no State Park or Monument exists, and with their proximity to [U.S.] Highway 40 recommendation is made that consideration be given this area as one suitable for a State Park or Monument." [35] A final note in Dr. West's report states that "...$4,500.00 will be available in a $15,000 appropriation for public camps and improvements for such additional areas as Petrified trees north of Leadville - the Geysers near Beowawe and other scenic or interesting locations which may be later designated as State Monuments or Parks." [36] Thus, the Geysers' area was recognized and highly thought of as a possible new State Park or State Monument as early as May, 1938. The actual negotiations on this subject took place about a year later; specifically starting with the minutes of the April 12, 1939 meeting of the Nevada State Park Commission. [37]

During the April 12, 1939 meeting, the May 2, 1938 report by Dr. C.W. West was read to those attending the meeting; including Robert A. Allen and the Honorable E.P. Carville, Governor of the State of Nevada. On page six of the minutes of the meeting, Allen brings up the subject of the State Park/State Monument proposal for the Beowawe Geysers' area. Although a transcript of the meeting is not available, it is clear that Allen and Governor Carville were interested in the State of Nevada obtaining the Geysers' area for a State Park. Allen mentioned that a road was being constructed to the site, while Gov. Carville said he would personally correspond with Mr. Milton B. Badt, the attorney for the owner of the land, in this case Dean Witter, who owned the NW-1/4 of Sec. 17, or, the western "half" of the Geysers' area, and "...find out if there was a chance of having it donated to the State." [38] A follow-up letter to Gov. Carville, from Allen, dated May 1, 1939, reveals further detail on the land ownership of the Geysers' area. The letter states: "We find that the [legal] description [of the land] is '...S-1/2 of the NW-1/4 of Section 17, T. 31, N., R. 48 E." We would have to procure the S-1/2 of the N.E.-1/4 of Sec. 17 [the so called "eastern half" of the Geysers' area] from the Southern Pacific Land Company." [39] In this same letter, Allen also reminded Gov. Carville of the latter's promise to discuss with the land owner [Dean Witter] a possible donation of the S-1/2 of the NW-1/4 of Sec. 17, to the State of Nevada. [40] Allen's letter identifies the land owner as the Humboldt Land and Cattle Company. However, Attorney Milton B. Badt, representing Humboldt, makes it clear that Dean Witter is the land owner.

Gov. Carville proceeded with his dealings on the matter in a series of letters, during the months of May/June, 1939, to Milton B. Badt, the attorney for Dean Witter, as well as various members of the State Park Commission. [41] Badt replied to the Governor's letters, and consulted with Dean Witter by letter during the same time period. Some oral discussions also took place. The May 8 letter, from Carville to Badt, firmly indicates the State Park Commission's interest in obtaining the Beowawe Geysers' area as a possible State Park, while acknowledging that, "...we have very little funds for this purpose and perhaps your company would be willing to make some concessions and deed this [land-the S-1/2 of the NW-1/4 of Sec. 17] to Nevada for a nominal sum." [42] Before replying to Gov. Carville, Badt sent a copy of the Governor's May 8th letter to Dean Witter along with his own letter (dated May 10th) regarding the Geysers' area. Mr. Badt says: "It is my impression that one of my old files of the Horseshoe Ranch under the Hinckley ownership [i.e., Grayson Hinkley or Hinckley] contains some data concerning the geysers, including a report by Joe Wilson and some photographs taken by him. [43] It would take some time to locate this data. In any event, will you kindly return Gov. Carville's letter with your comments and instructions?" [44] On May 19th, Mr. Badt sent his reply to Gov. Carville, with Dean Witter's thoughts on the Geysers' area, noting in the letter the verbal conversation between Badt and Carville, that occurred when the Governor was in Elko, Nevada, where Badt had his law office. This letter is loaded with interesting information about the State's plans for the Geysers' area and Dean Witter's own ideas, which are similar but more ambitious. Badt indicated it was his understanding that the State of Nevada was contemplating "...the construction of a road to the geysers, the marking of the road by appropriate signs, and some attempt at beautification of the geyser area by the construction of rock walls. This is so indefinite that I am glad to be able to acquaint you with Mr. Witter's views on the subject. He will be happy to cooperate, but would expect some definite commitment on the part of the State as to the improvements to be made. He would expect such improvements to be quite extensive and such as would add to the value of the geysers for scenic and park purposes, and incidentally contribute something of direct or indirect value to his other property in that area. He does not feel that mere deeding of the geyser area would be warranted without specific promise of definite development and improvement. Mr. Witter has always felt that there might be some value inherent in the geysers, and, although remote, there has always been the suggestion of the possibility that a resort or hotel might be established there. This gives the property a potential value which would indicate the propriety of some consideration and a specific promise of development by the State." Badt concluded his letter of May 19, 1939, by expressing the hope of continued negotiations on the matter. [45]

Gov. Carville notified Mr. Badt that his letter of May 19th had been received by the Governor on May 25th, and that the matter would be taken up by the Park Commission. It was, as a number of individuals on that Commission responded to the Badt letter of May 19th, by sending letters to Gov. Carville. At least one Commission member, George S. Greathouse, objected to Dean Witter's "line of reasoning", saying; "It would seem to me, form [sic] the tone of Mr. Badt's letter, that Mr. Witter would consent to give this land to the State, provided he is allowed to dictate to us the extent of the improvements to be made. I do not agree with his line of reasoning. In the first place, we would not want to spend several thousand dollars on this geyser district for the simple reason that the attraction is not such that it would warrant any great expenditure of money." This letter went on to say that the right to decide what improvements should be made rested with the State of Nevada if the Geysers' area were acquired as a State Park. The letter closed with: "If Mr. Witter does not wish to give this land to the State without any restrictions or reservations, then I suggest that the project be indefinitely posponed [sic]." [46] It is of interest to note that Mr. Greathouse, in 1939, lived in Elko, Nevada, which is about 50 miles to the northeast of the Geysers' area. He may, therefore, have been fairly familiar with the site. Obviously, he was not impressed with the area. However, he is on record, at the Park Commission's December 1939 meeting, as supporting continued negotiations with the owners of the Geysers' area, in the hopes of acquiring the site for a State Park. [47]

There appears to be a "time gap" in the Park Commission records regarding the Beowawe Geysers' State Park proposal. From July through October of 1939, there is no further information on the negotiations between the Park Commission and Dean Witter. Furthermore, there is absolutely nothing in the Commission's files indicating what kind of discussion/negotiations might have been going on between the Commission and the Southern Pacific Land Company regarding the "eastern half" of the Geysers' area, (i.e., the NE-1/4 of Sec. 17.) In the closing months of 1939, there were additional developments pertaining to the Geysers' area. The initial development is quite surprising.

Nevada Governor E.P. Carville's files, at the Nevada State Archives, while not complete in terms of Park Commission activities, have consistently yielded interesting information about the Beowawe Geysers' State Park proposals for 1939. A letter, from Carville's files dated Nov. 8, 1939, indicates the Governor's acknowledgment of another letter (now lost) that he received from Lyman Marden, a member of the Water Resources Division, U.S. Geological Survey (Sacramento, Calif. office). Here is a quote from that Nov. 8th letter, sent to Marden: "Dear Mr. Marden: I was extremely pleased to receive your letter of November 2nd, relative to the Beowawe Geysers. Your reaction to the Geyser Area was most satisfactory and I wish to thank you for your thoughtfulness in sending the pictures to me. The matter of proper development and proper publicity of this Geyser area has been before the Nevada State Park Commission for sometime, and we are in hopes of doing something worthwhile...[with the Geysers' area]. Your letter is being referred to a member of the Commission for his consideration." [48] Within a day, Marden's letter was sent to Dr. C. W. West, Chairman of the State Park Commission, with a short letter from Gov. Carville suggesting that West share Marden's letter with the rest of the Park Commissioners. [49] At this point, the trail goes stone cold. Neither the photos Marden sent with his letter of Nov. 2nd, nor his letter, have been located at the Nevada State Archives. Marden himself has not been located or identified.

Some final pieces of information on the State Park Commission's State Park proposal for the Beowawe Geysers' area are of interest as well. One is a letter, dated Nov. 17, 1939, from Dr. C.W. West to Robert A. Allen. West calls the next State Park Commission meeting for Dec. 6, 1939, the main discussion topic to "...be the acquisition of the Beowawe Geyser basin as a State Park or Monument...." West then advises Allen that: "It is quite important that we have at this meeting, the sketches for proposed rock work and so forth for the Beowawe Geyser basin." [50] Allen's reply, dated Nov. 27th states that: "We will also endeavor to have sketches made for the Beowawe Geyser area [by the Dec. 6th meeting of the Park Commission]." [51]

The final piece of information available for this 1930's State Park/State Monument proposal for the Geysers' area comes in the form of the State Park Commission meeting minutes for Dec. 6, 1939. On page 6 we read the following announcement: "In connection with the acquisition of the Beowawe geysers for a State Park site, Mr. Allen presented a drawing of the present area and suggested improvements. It would be necessary to secure forty acres of land from Mr. Dean Witter and forty acres from the Southern Pacific land Company. It was the concensus [sic] of opinion that every effort should be made to secure this land as soon as possible... A motion was made by Mr. [A.C.] Grant that the [Parks Dept.] Superintendent [Robert A. Allen] be requested and authorized to enter into negotiations with the present owners to see what can be done and report back to the Commission at its next meeting. The motion was seconded by Dr. West and passed unanimously, Mr. Grant voting aye for Mr. [U.V.] Perkins and Dr. West voting aye for Mr. [George] Greathouse." [52]

A search of the pertinent records at the Nevada State Archives by myself, and by the Archives staff at my request, turned up nothing in the way of State Park Commission meeting minutes for 1940 onwards, regarding what had transpired by the next Commission meeting. It is as if the Park Commission, the Geysers' area, etc., just disappeared from the face of the Earth. What did not take place is, however, obvious: a Beowawe Geysers State Park or

Monument. A few years later, the Park Commission did literally disappear, largely because the Nevada State Legislature failed to support the State Park system with appropriations. [53] Not until 1953, when newly elected Governor of Nevada, Charles H. Russel, reactivated the State Park Commission, did the Nevada State Parks System begin to revive. Even then the Nevada State Legislature failed to appropriate funds for that operation! [54]

The Geysers' area once more escaped from being added to Nevada's State Park system in the 1950's. In this instance the missed opportunities were and are tragic. Never again will the Beowawe Geysers' have the opportunity to be preserved in a more or less natural state. There will be no State Park or Monument at the Beowawe Geysers.

THE STATE PARK PROPOSAL 1954 to 1960

Charles H. Russell had been the Governor of Nevada for about three years before he "reactivated" the State Park Commission in 1953. However, as mentioned earlier, the 1953 session of the Nevada State Legislature declined to appropriate funds for the parks operation. [1] This may be attributed, in part, to a dispute regarding funding of the Lost City Museum in Overton, Nevada. Other difficulties may have arisen from Governor Russell's own appointment of the colorful and controversial Col. Thomas W. Miller as Chairman of the Park Commission, as well as from Gov. Russell's own conservative budget proposal for 1951. [2] Regarding Russell's budget, it has been stated that,"...Russell warned that strict economic measures should mark the lawmakers' work..." and, Gov. Russell "...warned again that lawmakers should help Nevada to live within its income, first, by not expanding state agencies, and, second by adopting a policy of sound economics." [3] A similar situation occurred when Grant Sawyer became the Governor of Nevada, in December of 1958. The question of budget priorities was once again an issue when Sawyer's Budget Director, Neil Humphrey, pointedly asked the State Park Commission why the Commission was proposing new State Parks when the existing Parks had not yet been brought up to par. [4]

Governor Russell did believe in upgrading the Nevada State Park system, in spite of his 1951 budget message to the State Legislature to be frugal in its expenditures. On Sept. 17, 1954, the Governor requested the National Park Service office in San Francisco, California to advise him on the State Park situation in Nevada and the system's upgrading. [5] The N.P.S. responded on Oct. 19, 1964, with a six page written evaluation and a three page list of potential State Park areas in Nevada. This list mentions 40 areas, including the Beowawe Geysers' area, called "Beowawe Hot Springs." [6]

Of interest in this N.P.S. 1954 evaluation/list is that: 1) The list is based on the 1938 N.P.S. report, *Nevada Parks*; and 2) This list reflects a separate list of areas suggested to the State Park Commission by Nevada citizens. [7] This "citizens' list" has not been located so far. Perhaps the Beowawe Geysers' area is on this list as well.

With the 1954 N.P.S. evaluation/list in hand, the Nevada State Park Commission once again took up consideration of the Beowawe Geysers' area as a potential State Park, although as just one of several potential State Park areas under consideration at the time. [8] The initial actions on the Geysers' area began, according to available records, in 1955.

The agenda for the June 15, 1955 meeting of the Nevada State Park Commission lists, in sections labeled "Exhibit C" and "Exhibit E", the Beowawe Geysers' area as one of several potential State Parks. Both mention that there are 40 acres of B.L.M. (Bureau of Land Management) land at the Geysers' site. [9] What this meant is a mystery at this time. There is nothing in the Commission's June 15th meeting minutes to explain what was discussed regarding these two "Exhibits". [10] Judging from available records of the State Park Commission, there was no further discussion of the Beowawe Geysers' area for the rest of 1955 and the entire year (?) of 1956. If the subject of a "Beowawe Geysers State Park" was simply shelved it may have been a grave mistake. The "western half" of the Geysers' area at that time was owned by Baldwin N. Baldwin. Mr. & Mrs. Martin Milano, of Elko, Nv., knew Baldwin when the Milano's lived in Beowawe. They informed me in October, 1988, that Baldwin would have "given the Geysers' area" to the State of Nevada if asked!" [11] Presumably, the State did not ask!

From 1957 to 1960, the State Park Commission took a more active interest, perhaps due to the input from certain Park Commissioners and Nevada citizens. The letter writing campaign of Josie Alma Woods and other citizens of Eureka County, where the bulk of the Geysers' area is located, was a significant factor in the Geysers' State Park proposals for 1957 to 1959.

Miss Woods' first letter, of many, on the subject of a State Park for the Beowawe Geysers' was sent in July of 1952 to Col. Thomas W. Miller, Chairman of the Nevada State Park Commission, to call his, and the Park Commission's, attention to the Geysers' area, as well as to propose the site for a State Park. [12] Actually, Woods was not telling Col. Miller anything new. Miller was already aware of Geysers' area by 1955 and perhaps had been familiar with it as early as the mid 1930's when he served briefly as Chairman of the State Park Commission. [13] Woods' letter of July 23, 1957, may have spurred Col. Miller to more action by letting him know that: 1) The owners of the Geysers' area (i.e., the NW-1/4 Sec. 17 portion), Mr. and Mrs. R.H. Hadley were in favor of having a State Park at the Geysers; 2) The Beowawe Ladies Sagebrush Club (Miss Woods, Secretary and later, President) were also in favor of the establishment of a State Park at the Beowawe Geysers. [14] Miss Woods kept up a steady stream of letters to nearly every Nevada State Agency or official that she could think of, from Governor Russell on down, in order to get a State Park at the Beowawe Geysers.

Her letters reveal an impatience with Col. Miller and the general slowness of the Park Commission to act on an area she believed deserved first rate attention as a State Park. As a former member of the Nevada State Legislature and a successful business woman, Woods was definitely a woman of considerable stature in the State of Nevada in the 1950's. Woods continued her letter writing campaign aimed at establishing a "Beowawe Geysers State Park" until at least June of 1959, before moving to Sun City, Arizona. [15]

Miss Woods made it clear, in more than one letter, that Col. Miller's actions and words were not to her liking. Her letter of August 1, 1957 to Howard W. Squires (Director, Nevada State Parks Dept.) says of Col. Miller: "He seems to think the Geysers are hot springs, and they surely are not...we feel they should be preserved, and should have been a long time before this. Eureka county is putting a graveled road into the geysers now... Mr. Miller [i.e., Col. Miller] mentioned everything he could think about not to do anything about them, but we feel our part of the state is just as important as any other part, and we know for sure no other part has geysers." This is not true, of course, but Woods may be forgiven for this comment since Steamboat Springs appears neither to have been available nor considered for a State Park. [16] Woods' letter of August 1, 1957, finishes with this barbed comment about Col. Miller: "We will have a delegation to meet with you in Austin [Nevada] the 10th [of August 1957, the place and time of the State Park Commission's meeting] and do hope you can help us out, instead of coming down stiff legged in front like Col. Miller." [17] It is a wonder that Miller and Woods were on speaking terms at that August 10th meeting, after a letter like that! They did talk peaceably, though later correspondence between Woods and State Park officials show that things were not completely smoothed over. [18]

Nevertheless, the State Park Commission was proceeding with plans to include the Geysers' area in the Nevada State Park system, both before and after the Commission meeting of August 19, 1957. Miller mentioned to Woods, in a letter to her dated July 29, 1957, that a new road will be needed to provide access to the site by skirting private ranch lands, and a custodian will be necessary to prevent visitors from injuring themselves in some of the hot water pools. [19] The Park Commission continued to investigate the Geysers' area by inquiring upon the land ownership status, concentrating entirely on the NW-1/4 of Sec. 17 portion of the Geysers' area. Apparently the Park Commission was interested solely in that part of the site and not the NE-1/4, Sec. 17 portion. [20]. A reply by the Eureka County Clerk, Ed Delaney, on August 29, 1957, informed State Park Director Howard W. Squires that R. H. Hadley owned the Geysers' area, at least the NW-1/4 of Sec. 17 portion. [21] On Sept. 3, 1957, Squires sent a letter to Hadley, c/o, The Horseshoe Ranch at Beowawe, Nv., to see if he would be interested in leasing, or signing a special use permit, for the Beowawe Geysers' as a State park. [22] Hadley quickly replied that he was definitely interested in having a "Beowawe Geysers State Park" [23]. However, the Park Commission waited until Dec. 20, 1957, before sending Hadley a rough draft for his consideration. [24] Miss Woods could not have been pleased with that delay of three months. As far as can be determined from available records [25], Hadley did not reply to the letter and rough draft proposal sent to him by Squires. [26]

During 1957, a number of interesting newspaper articles appeared regarding the Beowawe Geysers' area as a possible State Park. The general theme of most of the articles was: "No money, no Park". [27] One newspaper article dated July 29, 1957, stated: "BEOWAWE GEYSERS FOR STATE PARK...the geysers are rated by many as being second only to those in Yellowstone Park [on the North American continent. White had for years voiced a similar appraisal of the Beowawe Geysers] but have been allowed to deteriorate through neglect. Some years back they are reputed to have shot streams 50 feet into the air but due to having been partly filled with trash, the highest stream is said to be only 12 feet now. It is feared by the women's organizations sponsoring the state park idea that unless something is done immediately to preserve them, they may be ruined entirely." [28] *The Reno Evening Gazette* covered the Geysers' State park proposal in an article dated August 7, 1957, and said: "STATE PARK AT GEYSERS DEFERRED BY COMMISSION...the State Park Commission is 'alive to the advantages' of having a state park in the Beowawe area, but must postpone any 'active operation' because it can't afford to hire a custodian [for safety reasons] at the geysers." [29] Still another newspaper article, saying the same thing, appeared in the *Reno Journal* (?) on August 8, 1957. This article is entitled, "BEOWAWE GEYSERS CLOSED BY LACK OF CUSTODIAN." [30] The *Journal* also ran an editorial on Aug. 8, 1957 regarding the Nevada State Parks program, noting that the legislative appropriations for the parks program, while more generous than in the past, were not enough. At the same time, this editorial warned Nevada citizens and organizations not to push too many potential park sites on the park Commission for fear of spreading the Commission's funding too thin, thus chancing possible ruin of the park program. [31] However, an earlier newspaper editorial in the *Ely Record*, dated May 18, 1957 discussed the State Parks system as beginning "...to act 'bureaucratic' before it had never gotten its feet on the solid ground of essential work." [32] The editorial goes on to say that the "...basis of the trouble was not in the office [of the Parks Dept.], however, but in the [State Park] Commission itself. The chairman and members were good men [and women], dedicated and anxious to work well, but the chairman was the type of personality who wanted to keep all the reins in his own hands and lacked the ability to work smoothly and effectively with others who shared the authority. This situation worsened rapidly until the available energy and intelligence of commissioners and employees was being dissipated in quarrels, misunderstandings and uncertainties, rather than spent on doing the job of securing, protecting and developing valuable state parks for the benefit of the state and its people...We have no grudge against any of the people involved. There is much to be said for all of them. But we do wonder how long the people of Nevada are going to tolerate confusion, waste, indecision, and lack of effective leadership in a matter of such basic and far reaching importance to each and every member of this state." [33] Here is at least one clear indication of the Park Commission's operating problems (beyond financial) for 1957. In October, 1957, another dispute broke out at a Park Commission meeting over alleged misuse of operating funds at Ichthyosaur State Park, located southwest of Austin, Nevada. [34] Obviously, the "quarrels, misunderstandings and uncertainties" mentioned in the May 18, 1957 editorial of the *Ely Record* newspaper, had not been resolved by October of 1957. The significance of this as to "why" the Beowawe Geysers' area was not made a State Park is not certain, but the disputes and quarrels could not have helped matters.

That same October 29, 1957 Park Commission meeting, Commissioner Margaret "Peggy" Wheat, who had been in the thick of the dispute about Ichthyosaur State Park (now a State Monument,) read from a letter she had received from a geologist who said the Beowawe Geysers were "...the second most active in the United States and possibly this hemisphere." [35] This piece of information, located at the Northeastern Nevada Museum Library, is further explained in the transcript of the Commission's meeting. Opening remarks on the subject by Col. Miller and Mrs. Wheat: "[Miller speaking] We'll pass that up and discuss Beowawe Geysers. I understand some of you [Park Commission members] have visited since our last meeting. What have you got to say, Mrs. Wheat, I understand you were there?" [Wheat] I found it very delightful, I found it exceptionally delightful. Ihave...[inaudible?]...of correspondencewithone of the geologists who worked that area under the scientific reports on it - I haven't looked up the records as yet to...[inaudible?]...what he gave me for other references. It's a very nice letter, it tells some of the things about it. Would you care to have me read it? It gives you an idea of how it [the Beowawe Geysers] compares with other Geyser areas in the country. Would you like to hear that?...[inaudible comments but obviously the Commission's reply was "Yes" for Wheat read the letter].

> "Dear Peggy [Wheat]: This query comes at just the right time to get a quick and vigorous response from me. I have long considered Beowawe Geysers as one of the outstanding geological points of interest, [at this point, Wheat said to the Commission, "By the way, this man is a geologist from the Geological Survey at Menlo Park"] in Nevada known by a few people and generally unappreciated in comparison to the interest that it should have. It is the second most active geyser area in the United States, [Wheat again stops reading to say, "Which I think is of very high interest,"] and, I believe, possibly in the Western Hemisphere. There is one possibility in Mexico and one in South America that might rival with description. But I won't know until I see for myself if they are adequately described in scientific literature. I have made seven or eight trips to Beowawe and have mapped the area in detail, but have never gotten around to publishing the results. It is of interest that of about 50 individual springs, at least 26 have definitely erupted as Geysers during my various visits and possibly far more. During any single visit of a few hours the tourist might see as many as five and possibly 10 different geysers. Most of them are small erupting only...[inaudible] But one rather large one erupts rather consistently to 10 feet in height, but it seems to be active only about half the time and is unpredictable. In case you may not know this, the area has been described by T.B. Nolan and B.[sic, it's "G"] H. Anderson, etc. The Geyser Area near Beowawe, Eureka County, Nevada, American Journal...series, etc. [Mrs. Wheat skipped reading a portion of the letter]--Nolan now, incidentally, is director of the survey [U.S. Geological Survey]. Has your Board considered Steamboat Springs as a State Park? I think it most unfortunate that an area of such natural interest should not belong to the people of Nevada and..." [Wheat may have finished reading this letter at this point; the rest of the transcript shows that there is a lull in discussion at the Park Commission meeting, or, the tape recorder failed to pick up the conversations.] [36]

Although Wheat apparently did not mention the name of the geologist whose letter she was reading, there is little doubt that the geologist is Donald E. White, of the U.S. Geological Survey, in Menlo Park, California. White made 7 to 8 trips to the site, mapped the Geysers' area in detail and noted 50 major thermal springs on the sinter terrace. White's professional opinion of the level of total geyser activity at the Beowawe Geysers, was that Beowawe was in this regard second only to Yellowstone in the United States. [37] Furthermore, it is highly unlikely anyone other than White would have possessed so much knowledge about the Beowawe Geysers' (and Steamboat Springs) in 1957! Unfortunately, White did not recall having made the suggestion to anyone in 1957 to establish a State Park at the Beowawe Geysers' area. [White, personal communication, September, 1988]

The Park Commission transcript for the Oct. 29, 1957 meeting contains additional interesting discussions on the Beowawe Geysers' area. Commissioner Chris Sheerin commented about the land ownership of the Geysers. His comments were followed by remarks from Col. Miller: "[Sheerin] That is privately owned, Tom [Miller]" Miller: "Yes, I have a letter here from the rancher who owns it. Mr. Squires [Howard W., the State Park Department Director] contacted him. This is the letter: 'We would very much like to have the Beowawe Geysers improved and maintained as a State Park. As the location is within our deeded land [only the NW-1/4 of Sec. 17], we would be very happy to lease or let a special use permit for whatever area is desired. We feel that the geysers are of great interest, but through neglect and an accummulation [sic] of debris are in need of preservation of park. Sincerely yours, R.H. Hadley'". Miller then discussed some of the problems he saw in trying to establish a State Park at the Geysers' area. One was access to the area by a road that passed through private ranch lands, and the other problem was safety for visitors to the area. Miller was concerned that children "...could fall down and scald their legs...." [38] Miller had a point here. In 1962, a Boy Scout troop took a side trip to the Beowawe Geysers while on the way to a swimming party at the Crescent Valley Spa. While exploring the Geysers' area, one boy was injured when the ground gave way beneath him. His right foot and leg were plunged into "steam and hot water" causing "serious, painful and permanent and disabling injuries..." according the court records on file at the Elko County Courthouse in Elko, Nevada. [39]

Regarding the access problem, Miller said: "...some of my rancher friends were very hostile. They said please don't encourage people to come in here. They leave our gates open and I found them open, and shut them." [40]

Commission member Louise Marvel, a cattle rancher herself, from Battle Mountain, Nv., then spoke up: "Mr. Chairman, I think there was just one rancher, wasn't there, who complained, and that was ironed out. I understand that the Commissioners of Eureka County are willing to put a road in and they can put a road in and they can get the easement over...."[41]

Miller continued the discussion about fencing some of the Geysers for safety reasons; Mrs. Marvel agreed, saying: "...that would eliminate having a caretaker." Wheat did not agree, saying: "I don't think they should be fenced, don't quote me." (!) [42] A curious remark by Wheat, who, at the Aug. 10, 1957 Park Commission meeting, discussed the danger and liability involved in establishing a State Park at the Geysers' area. Wheat then inquired regarding the possibility of the State Park Commission carrying public liability insurance on all State Parks! [43]

Mrs. Marvel wrapped up the argument for the Geysers' area as a State Park by stating: "I think that something should be done for that part of the country [north-central Nevada]. You've already established these [State Parks], in Lincoln County there are three. There is nothing in...[inaudible comment] or Lander County at all. I'd say it's better to develop these Geysers and forget the Lander County...[inaudible comment]". Miller asked if the Commission as a whole, would authorize the start of negotiations with R.H. Hadley, regarding a "Beowawe Geysers State Park" project. The reply was "yes" with Marvel making the motion and Wheat seconding the motion. State

Park Dept. Director Howard W. Squires then asked if there were plans for installations. Likely he was referring to picnic tables, sun shades, sanitary facilities, etc. This triggered a new conversation on the lease language and the planned new access road. Marvel encouraged Miller and the rest of the Park Commission to move immediately on the Geysers' State park proposal because: "My understanding is that there might be a sale on that particular part of the 'Horseshoe [Ranch]' property. And a lot of them have the same feeling, and I think it's a good idea to get this done before they have that." Miller agreed and called for the vote on opening the negotiations with R.H. Hadley. The Park Commission voted unanimously in favor. [44]

As noted earlier, there was about a three month delay before Mr. Hadley was sent a rough draft of a special-use permit regarding Hadley's "half" of the Beowawe Geysers' area. Through the first quarter of 1958, the State Park Commission apparently waited for Hadley's reply to the special-use permit/draft they sent him. [45] The Park Commission ought to have been aware that such a long wait would be costly, as Mrs. Marvel warned them that the "Beowawe Unit" of the Horseshoe Ranch was reportedly up for sale. And so it was. At the May 5, 1958 meeting of the Park Commission, the State Park Dept. Director (Howard W. Squires) read to the Commission a letter from Mr. Lloyd V. Smith, Attorney for Mr. and Mrs. Gordon MacMillan. This letter announced that R.H. Hadley was planning to sell the "Beowawe Unit" of the Horseshoe Ranch to his clients, the MacMillans. [46] The MacMillans were buying the Horseshoe Ranch, located at Beowawe, Nv. This site included the NW-1/4 of Sec. 17, with Hadley retaining a Ranch called the "Upper Horseshoe", located some distance to the NE near Carlin, Nevada. [47] Although the Park Commission voted, apparently at Mr. Smith's encouragement, to continue negotiations for the Geysers' area with the new owners, the Commission did not come as close to establishing a State Park at the Beowawe Geysers' area as they would have with Mr. Hadley. One real opportunity for a "Beowawe Geysers State Park" had passed the Park Commission by. [48]

During the latter part of May, 1958, both Josie Alma Woods and Mrs. Marianne Smithwick sent Governor Russell a letter inquiring as to the reported progress, or lack of progress, on proclaiming the Beowawe Geysers' area as a State Park. [49] Woods appealed to Russell to take an active hand in this particular park proposal. Woods noted that many people were driving out to the Geysers' area, in spite of the awful road that provided access to the site. [50] She also stated there is "...not even a road sign either on the highway [U.S. 40] where you turn off to Beowawe [the town] or in [the town] Beowawe." [51] One would have thought the Governor might have done more to help, but his reply to Mrs. Smithwick and Ms. Woods was identical: "I have checked with the Park Department and they informed me that there are no funds available to improve this site at the present time, however, they assure me that in the very near future, they will request that this site be proclaimed a State Park." [52] Another letter, dated October 7, 1958, from the MacMillans' attorney, Lloyd V. Smith, to Col. Miller of the Park Commission, stated that the MacMillans' will buy out R.H. Hadley as previously discussed, by Nov. 1, 1958. Smith indicated that the MacMillans were very much interested in the establishment of a "Beowawe Geysers' State Park." [53]

The State of Nevada had one last opportunity to secure the Beowawe Geysers' for a State Park in 1959. The new Nevada Governor, Grant Sawyer, revamped the State Park Commission. Several Commissioners were not asked back, including the Chairman, Col. Thomas W. Miller. [54] However, Gov. Sawyer and his revamped Park Commission were no more successful than their predecessors in establishing a "Beowawe Geysers State Park".

One of the returning Park Commissioners was Margaret M. "Peggy" Wheat, who sent the new Governor, Grant Sawyer, an outline of proposals that were "...to be considered in connection with the future development of the Nevada State Park and Recreation system...." [55] Wheat mentioned several geyser and hot spring areas in Nevada she believed needed to be protected by the State. The sites were: a) Beowawe, b) Lee's Geyser, near Fallon, c) Diana's Punch Bowl, d) Fly Ranch Geyser, a drilled well near Gerlach. [56] Note that Steamboat Springs, south of Reno, are, once again, not mentioned. In June of 1959, Josie Alma Woods wrote yet another letter to Howard W. Squires, State Parks Department Director, inquiring about the status of the State Park proposal for the Geysers' area. Squires sent a copy of Woods' letter to the new chairman of the State Park Commission, Dr. Fritz L. Kramer. [57] Woods, a few days after posting her letter to Squires, sent another letter to Kramer, outlining the details of the past (1957 - 1958) State Park proposals for the Geysers' area. She indicated and that there had been an initial appropriation of $3,000 to $4,000 for this proposed park. [58] Kramer responded quickly, reaffirming the Park Commission's continued high interest in the site as a State Park, and indicating that new negotiations were already under way with the land owners. He added there were difficulties due to an inadequate Parks budget. [59]

Other correspondence on this subject, took place between Leslie M. Gould, M.D., the Vice-chairman of the Park Commission, and Robert G. Bates (or "Batz") of the M. Penn Phillips Co., a California based firm involved with the Crescent Valley Ranch & Farms operation mentioned earlier. [60] Bates (and/or the M. Penn Phillips Co.) owned the NE-1/4 Sec 17 of the Geysers' area in 1959 and was interested in the State Park proposal. In the letter Gould sent to Bates on June 16, 1959, there is discussion regarding a topic that is not stated openly. This topic appears to concern the MacMillans' portion of the Geysers' area. From the tone and wording of the letter, one may infer that the topic is geothermal energy exploration. Dr. Gould's letter opens by thanking Mr. Bates for calling the State Park Commission about the Beowawe Geysers and then mentions an unnamed Realtor "...who deals in ranches and knew about the MacMillans willingness to offer the land for Park purposes. [He] told me at lunch that day of what happened. So, apparently many different people know about it. Lloyd Smith, attorney for the MacMillans, also told me that he had written to them sometime previously and thought it best under the circumstances to wait until he heard from them before pursuing the matter further." [61] Dr. Gould continued: "I fear that this is only one opportunity that has been lost to the people of the state of Nevada through following some sort of half-thought-out policy of not acquiring park sites until money is available for their development." [62] Gould concludes his letter to Bates by saying: "I hope the present [State Park] commission may be able to reverse this policy and do all we can to secure and protect important scenic geologic archaeological and recreational sites for development when funds become available." [63] Dr. Gould closes his letter by welcoming Mr.

Bates to continue the discussion of the properties the latter controls in regards to sites of scenic/recreational purposes. All of these pleasantries were, in the case of the Beowawe Geysers, too late, as will be demonstrated in the closing portion of this chapter.

A letter dated June 17, 1959, from Dr. Gould to Dr. Kramer, spells out the "topic" previously mentioned. The fact is that geothermal energy exploration was almost certain to come to the Beowawe Geysers' area. [64] Dr. Gould's letter starts off with this remark:

> "During the morning of June 15, [1959], Mr. Bates, a geologist with the M. Penn Phillips Company called me telling me that he was almost certain that the McMillans [sic - Dr. Gould's spelling], who owned the geysers had signed a lease and operating agreement with Magma Power Company to permit the company to drill in the Beowawe area and harness any available energy for the production of electricity. This is the same company that is now drilling in the neighborhood of Steamboat Springs. Mr. Bates tells me that they [Magma Power Co.] have been vigorously securing these leases throughout this part of the country. [65] He is skeptical of the long-term success of the project as he fears there simply isn't enough water in the Beowawe area to supply the steam necessary for economical power. At any rate, the Magma [Power] Company has, he understands, three months or so in which to develop the power. They will then pay a handsome royalty for continued power production to the McMillans [sic]." [66]

Regarding the State Park proposal for the Geysers' area, Dr. Gould says in his letter: "Mr Bates stated that the plan in operation [geothermal exploration] is definitely second choice so far as the McMillans [sic] are concerned. They have long envisioned something like a 'McMillan State Park'. Mr. Bates hopes that the Park Commission will secure some kind of over-ride or sub-option which will operate in event of the failure of the power development, or even if successful, if the area isn't too badly blighted." [67] Gould identifies the unnamed realtor he mentioned in his letter of June 16, 1959, who informed him of the possibility that the MacMillans were planning to lease their portion of the Geysers area for geothermal energy exploration. The realtor was Mr. "Ham" McCaughey [68], who, in Gould's words, "...felt that this was a real loss to the park system and believed the McMillans [sic] would also [feel that way.]" Bates requested that he not be identified as the source of this information, so Gould advised Kramer to document McCaughey as the source on Magma's geothermal plans! [69] The letter closes with two interesting comments. First, Gould commented on the past failures to preserve Nevada's scenic and historic features. He pulled no punches when he said: "This is an example of what I fear Nevada will have lost on many fronts during the past several years. We must not be guilty of the same dilatory tactics concealed by pious phrases of good intent." Second, Bates told Gould that the M. Penn Phillips Co. "has some hot springs and perhaps geisers [sic] in the same general Crescent Valley-Whirlwind Valley area and is most desirous of making them available to the state park system. In fact the company owns a quarter section of land adjoining the McMillans [sic] property at the geiser [sic]." [70] In fact, the quarter section of land adjoining the MacMillans' land at the Beowawe Geysers and the "hot springs and...geisers" that M. Penn Phillips Co. owned, were one and the same: namely the NE-1/4 Sec. 17 portion of the Beowawe Geysers. (The MacMillans owned the NW-1/4). It is apparent that neither the State Park Commission nor Park Department adequately researched the land ownership of the Geysers' area. [71]

On June 25, 1959, Kramer sent a letter of inquiry to Mr. Joe (Joseph) Aidlin, Secretary and General Counsel of Magma Power Co., in Los Angeles, Calif., asking about his company's intentions for the Beowawe Geysers' area. Kramer also informed Aidlin of the State of Nevada's interest in the Geysers' area as a possible State Park. [72] Here is what Kramer wrote: "As you may know, there has been some discussion concerning this geyser area as a possible site for a State Park. It appears that our former State Park Commission was only mildly interested in this project. [Not quite true as shown earlier.] There has been mounting pressure, however, from various sources in the State, toward the goal of establishing this park." An intriguing comment, but Kramer did not elaborate in his letter upon "who" these sources were. Kramer concluded his letter by asking that Aidlin's company respond as to the company's position regarding the establishment of a State Park at the Beowawe Geysers' area. [73] Aidlin responded to Kramer with a letter dated July 6, 1959, confirming that Magma Power Co. had leased the MacMillans' portion of the Beowawe Geysers "...for the purpose of drilling to develop steam in sufficient quantity for generation of electric power." Aidlin continued: "We feel that the Beowawe area contains the potential for the development of a large quantity of steam which can be used for the development of electric power, and if our expectations are correct, the benefits to the northern part of Nevada are of course apparent because power from this source is cheap power. [For the benefit of the reader, the geothermal power plant that Chevron Resources Co. operates at the Beowawe site, sells its power to Southern California customers, according to Sierra Pacific Power Co. officials. [74]] We are very serious in our desire to test the area and if the tests establish the validity of our expectations, then to develop the area on a more intensive scale." [75] Aidlin goes on to cite Magma Power Company's program of geothermal development in the "Big Geysers" area of Sonoma County, California, noting that it "...is an area which for years has been a well known resort area." [76] Again, it should be noted that the "Big Geysers" area does not have natural geysers and is not on record as a suggested state park site with the California State Parks Dept. [77] The reader may draw his/her own conclusions regarding what might have happened to the Beowawe Geysers - and Magma Power Co. - if the State of California had established a state park, early on, at the "Big Geysers" of Sonoma county, possibly blocking off Magma's successful geothermal operation there. Aidlin finishes his letter of July 6, 1959, by saying: "Mr. B.C. McCabe, President of Magma Power Company, and all the directors are men with a high level of civic interest and responsibility. The same is true of Mr. Gordon Macmillan, owner of the land. We are of course interested in your plans. It might be wise, however, to first test the area. This we plan to do within the next few months." [78] And test they did, for on October 2, 1959, Aidlin notified Kramer that "...Magma Power Company has commenced drilling a well in the Beowawe area. I will keep you advised of the results of the drilling", says Aidlin. [79] If he did advise Kramer of the drilling of Magma's first test well, that letter has not been found.

There was, meanwhile, other correspondence between Robert G. Bates and Kramer, as well as Park Ranger Al Greenhalgh and Eureka County Assessor Tom Pastorino regarding land ownership of the Geysers' area, Magma's lease, etc., and the following interesting memo, dated "11/23/59." This memo reads in it's entirety: "Al: Governor Sawyer informs me that the McMillans [sic], present Beowawe owners, told him that they are willing to turn title to the State for park purposes. A field contract wouldn't hurt - but we can wait for the Assessor's report. [Signed] Herb" [80] Although the Beowawe Geysers' are not directly mentioned in this memo, they were the topic of discussion. It appears that the MacMillans' were, perhaps, "fence sitting", and still interested in the idea of turning over their portion of the Beowawe Geysers' area to the State of Nevada for Park purposes. Perhaps the MacMillans were not satisfied with the initial results of Magma's first test well. Recall Bates' comments to Gould that the Beowawe area lacked enough water to produce steam in economic amounts. [81] This memo appears to be the first mention of Governor Sawyer's involvement with the State Park proposal for the Beowawe Geysers' area. It is also the only mention, so far as has been determined, of the Governor's involvement with this park proposal.

Although many of the letters, memos, etc. for 1959, indicate that the Park Commission was continuing to try and secure the Beowawe Geysers' area for a State Park (Mr. Bates had offered the NE-1/4 Sec. 17 portion to the State for Park purposes [82]), nothing came out of any of the efforts. The memo of 11/23/59 may have been the Park Commission's "last chance" to secure the MacMillans' portion of the site. If the MacMillans had considered turning over their portion of the Geysers because Magma's first geothermal well was essentially a bust, then "Herb's" advice to "Al" to "...wait for the Assessor's report" was yet one more mistake by State officials. By Dec. 1, 1959, Robert G. Bates, had leased his portion of the Geysers' area (NE-1/4 of Sec. 17) to Magma Power Company [83], even though the State Park Commission/Parks Department continued through September 15, 1960, to express a desire to obtain his section of the area. [84] These events bring us near the close of the story. There are a few more items of interest which will round out the "last gasp" Park efforts of 1960.

The first item is the Nevada State Assembly's Bill #156, passed in early 1960. This bill contains language authorizing the State Park Commission to purchase title to the Beowawe Geyser Basin area, ("Lander County [sic?] 200 acres, more or less..."), only if land described in a previous section of the bill, is obtained "without cost to the state...." [85] Item number two is a letter, dated August 10, 1960, from (new) State Parks Dept. Director William J. Hart, to Leslie M. Gould, M.D., Chairman, Parks Commission. Hart mentioned to Gould the seven proposed new State Park areas, (Beowawe was one of the seven,) followed by the apt suggestion "...to have each of these proposed units sponsored by particular Legislators with special bills carrying sufficient funds to acquire, develop and administer the site...." [86] This very good idea came a little too late, in August of 1960, to help the Beowawe Geysers. The third item is an undated memo from the State Park Director to the Park files that describes the Director's visit to the Beowawe Geysers' area on Wednesday, August 31st, and Monday, September 5th, 1960. [87] The Director's memo relays the story of his meeting with three individuals at a particular well, including one man who is said to have drilled the well. It is further noted in the memo that the men knew who the Director was and that, "There was little friendship evidenced [by the three men the Park Director met] and some down right misleading information given." [88] Unfortunately, what was expressly said was not recorded. The memo concludes that the Beowawe Geyser basin still had interesting possibilities "...as a natural phenomena and stopping place along U.S. 40. The M. Penn Phillips Company continues to express great interest and desire to help in establishment of state status for the gyser [sic]. What the price tag will be with the ultimate development of Magma Power [Company] will be undoubtedly the final determintent [sic] in the status. At this point, there is little question that the drilling operation of Magma Power [Company] has reduced the natural attractiveness and value of the [geyser] basin." [89] The Parks Director would find that the Geysers' area would be even more damaged within a year's time when Magma Power Company's partner, Vulcan Thermal Power Co., arranged for the drilling of three more geothermal wells on top of the sinter terrace. The November 14th - 15th meeting minutes of the Park Commission mention that, "Plans are now afoot for several more wells in the gyser [sic] basin to produce sufficient total flow to support a geothermal power plant. The basin would be tough to develop without disfacement [sic] and disruption of the field. I [Park Director William J. Hart] have found the corners and a fresh water source - the BLM [Bureau of Land Management] property authorized would be used for access purposes if the Commission ever desires to proceed further." [90] Some of the preceding dialogue isn't clear in meaning, particularly the part that reads: "The basin would be tough to develop without disfacement [sic] and disruption of the field." Did Director Hart mean that by establishment of a State Park the geysers would be damaged, or does he mean that geothermal drilling would damage the geysers thus making the site less desirable as a park? At this time, there is no way of knowing which, if either, of the two "meanings" he wished to express. However, if Hart was thinking that the geothermal drilling would make the Geysers' area less attractive as a State Park, then he was entirely correct. The damage caused from 1959 to 1961 by geothermal drilling did make the site far less appealing. There may be no way to tell at this late date what the State Park Commission's considerations were, because the State Park Commission records for 1961 onwards have not been examined. A fire in a storage warehouse in Carson City, Nv. in roughly 1965 destroyed a large collection of State records which might have revealed the answers to what the Park Commission was considering concerning the Geysers' area. [91]

One final attempt at incorporating the Geysers' area into Nevada's State Park system was made in September of 1972, when Mrs. Martin Milano, of Beowawe, Nv., pushed for a State Park at the Geysers' area. Milano sent her letter of request to Eric Cronkhite, Nevada State Parks Dept. Administrator, on Sept. 27, 1972, imploring the Parks Dept. to do something to preserve the beauty of the site. She says: "Magma Inc. is in the process of welding casing to cap the Geysers. [This is, actually, a reference to the streams of hot water/steam coming out of the vandalized geothermal wells]. I am hoping that you can do something to prevent this from happening. We haven't anything like the Geysers any place in Nevada. ...a great many people from all over the United States come out to see them. They [are] very impressed. The last time the Geyseres [sic] were drilled, they were left in a deplorable state. In fact, Mr. Frank Smyth [qv] wrote a very good story about it in the Nevada Magazine." [92] This magazine article may be the one Smyth wrote for the *Nevada Highway News* in May 1972. Cronkhite's reply, dated Oct. 2, 1972, indicated that the State Park Advisory Commission was planning to hold their next meeting in Elko, Nv. Milano was asked to attend and perhaps show Commission members the site. Also, Cronkhite requested Milano to furnish additional information on the site, such as land ownership, to him. [93] Cronkhite, on Dec. 7, 1972, contacted Stanford University President W.T. Fuller III, regarding the possibility of the Nevada State Parks System acquiring the Beowawe Geysers' area for a State Park. Mr. Cronkhite's letter reads: "Our records indicate that Stanford University recently acquired this property by gift from a Mrs. McMillan [sic, this is Mrs. Gordon MacMillan, first name, "Dorothe"]. Beowawe [Geysers] is a natural phenomena worthy of preservation and is quite accessible to major highways. This site also is an important link to interpreting the natural heritage of Nevada. We would like to know of the University's plan for Beowawe and if you would consider making the site available for State Park purposes...". [94] Robert R. Augsburger responded for President Fuller of Stanford University. In a letter dated Dec. 19, 1972, he expressed thanks for Cronkhite's suggestion that the Beowawe Geysers' area, included in the 320 acres given to the University by Mrs. MacMillan, be considered for use as a State Park. Augsburger points out the continued interest in the site as a potential source of geothermal power, and that Mrs. MacMillan had given the 320 acres to the University to benefit medical research. [95] The closing portion of the Augsburger letter reads: "I should mention that Mrs. MacMillan's bequest to Stanford was for the express purpose of medical research. The University is therefore required to devote the bequest to that purpose and would not have the right to dedicate the land to a public use other than medical research." [96] Cronkhite sent a follow-up letter to Augsburger, on January 4, 1973 saying: "You [Augsburger] have asked our opinion regarding future [geothermal] exploration of the Beowawe Geysers as it may be consistant [sic] with preservation of the areas as a state park. One only needs to observe the present environmental degradation which has occrued [sic] on the site from past [geothermal] exploration to know that exploration in the future would also be inconsistant [sic] with State Park purposes. You noted that Mrs. MacMillan's bequest to Stanford was for the expressed purpose of medical research. I would assume the only relationship between medical research and Beowawe geysers would be the revenues produced to conduct medical research." [97] This is an assumption Augsburger later acknowledged to be correct. Cronkhite mentioned in his letter that the State of Nevada would be interested in outright purchase of the Geysers' area. If, however, the University were to retain the property, the area could be dedicated toward State Park purposes while a program of exploration was conducted under strict environmental control. [98] Neither option proved to be workable in the minds of Stanford University officials, even though Augsburger's follow-up letter to Cronkhite indicated a willingness to continue discussions. [99] Like previous attempts made to establish a State Park at the Beowawe Geysers, this 1970's attempt also failed in its objective. After a few more exchanges of letters between Park officials, up to mid-May of 1973, this Park proposal seems to have died a quiet death. [100] On the 27th of September, 1978, the Board of Trustees for Stanford University leased the NW-1/4 Sec. 17, the "western half" of the Geysers' area, to Chevron USA, the parent company of Chevron Resources Co. [101] The latter company had already been engaged in geothermal exploration work in the Beowawe area. By 1986, Chevron Resources Co. had succeeded at producing geothermal power from the Beowawe area, something that Magma, Vulcan Thermal, and Sierra Pacific Power Companies had failed to do in the 1960's. [102]

In retrospect, the State Park proposal for the Beowawe Geysers may have, arguably, suffered from indecision, lack of commitment, and mistakes made by those on the State Park Commission, the Commission's support staff and, perhaps, even the Governors of Nevada, for not sufficiently exercising their influence and authority. The real problem was that the Nevada State Legislature literally hand-cuffed the State Park Commission/Parks Department by not appropriating sufficient funds to either maintain existing state parks and recreational areas, or to acquire new park and recreation sites. There is more detail, than is included in this report, on the recorded difficulties of funding the operation and maintenance of existing parks in Nevada. It is of interest to note that of the 30+ potential State park sites in Nevada which the National Park Service's 1938 *Nevada Parks* study, and its 1954 summary recorded and recommended, only 2 areas have been incorporated into the State's Park system. [103] Obviously, all 30+ sites would have been difficult to absorb into any State's Park system, but adopting only 2 in 30 years or so is a travesty.

THE NATIONAL NATURAL LANDMARKS PROGRAM

The Beowawe Geysers' area still receives major attention from time to time. The most recent example occurred just ten years ago.

In 1979, the National Park Service's National Natural Landmarks program "surveyed" the area, via inquiries to Stanford University, Chevron Resources Company, several individual consultants, and the Elko, Nv. office of the Bureau of Land Management.[1] Of relevance is the BLM letter of May, 1979, to John Cherry, Regional Director, of the NPS subagency which administered the Landmarks program, concerning the Geysers' area. [2] The BLM letter is from Rodney Harris, the District Manager. It reads:

> "In response to Ms. Lynne Nakata's [Mr. Cherry's assistant] letter of April 5, 1979 I have had my Outdoor Recreation Planner [who is not named] do some research on the Beowawe Geyers [sic] in reference to the National Natural Landmarks program that your service administers. I will respond to your information request in the same order that Ms. Nakata listed them. #1 - Current description of the site's natural values and significance, or available resource data: The geysers in their natural condition were 14 small, irregular unspectacular geyers [sic] that spouted less than 3 feet. When the Sierra Pacific Power Company drilled into that area all but 2 of the geyers [sic] ceased spouting. However, the two remaining now spout steam to the height of about 50 feet. The geysers as they exist today cannot be considered natural but they are a spectacular phenomena enjoyed by many persons becasue [sic] of its easy access from I-80 [freeway]."[3]

The BLM letter goes on to mention that the Geysers' area is within the BLM's Elko, NV. District; an Environmental Impact Statement is to be issued in Sept. 1986 [4]; the fact that the land use includes livestock grazing, oil and gas and geothermal exploration, mining and "dispersed recreational activities"; and the names and addresses of major land owners in the immediate Geysers' area (data useful in research of this article). The following interesting statements are made: "According to the U.S. Geological Survey the geysers are spouting steam at about 204.8 degrees F.It well may have the potential for development as a future electric steam plant [an interesting way of describing it!]. The area was also used as a former Shoshone Native American winter village." [5]

When I checked with the BLM office in Elko, Nv., on this point and others, the BLM staff had somewhat retreated from their statement that a winter Native American village was located in the Geysers' area, saying only that the possibility of said village could not be excluded. [6]

Regarding the data listed under "#1 - Current description of the site's natural values and significance...[etc.]" in the May 1, 1979 BLM letter to Cherry and Nakata, the data is nearly all in error. Much of this same data has been covered earlier in this report. However, it is useful to touch on these errors again. First, the "...14 small, irregular unspectacular geyers [sic] that spouted less than 3 feet..." constitutes an error, as demonstrated in data quoted elsewhere in this report. Second, attributing the destruction of the geyser activity to Sierra Pacific Power Company's geothermal drilling operations has been shown to be in error. Third, the statement about the "...14 small irregular unspectacular 'geyers'" condensed down into "...the 2 remaining [geysers] which now spout steam to a height of about 50 feet..." is the most misleading, error-filled statement I have yet to discover on this subject. [7] The "...2 remaining 'geysers'..." are, in reality, the geothermal wells that were vandalized sometime between 1970 and 1972. [8]

The basic data source the BLM's Outdoor Recreation Planner apparently used to prepare the May 1, 1979 reply to Cherry and Nakata, came from a National Park Service report, *Inventory of Natural Landmarks of The Great Basin* (1975), by Vernon Bostick, et al. The source of the number of geysers as "14" is a mystery. Bostick's report does not give a specific number of geysers, saying, "There were numerous small, irregular, unspectacular geysers - the highest about three feet - until Sierra Pacific Power Company drilled into the sinter terrace...Now water and steam spouts spectacularly - 50 feet - and continuously from three well casings". [9] Baring the mention of a specific number of geysers, the reader can see the striking similarities in the data Bostick uses and the May 1, 1979 BLM letter.

Available correspondence from NPS files in San Francisco, California, on the National Natural Landmarks proposed designation for the Beowawe Geysers' area revealed that neither Chevron Resources Co. nor Stanford University officials were keen on such a designation for the Geysers' area. They feared that such a designation might interfere with Chevron's geothermal operations program. [10] Infact, the NPS staff in San Francisco said that: "Designation of a site as a [National Natural] landmark does not affect ownership status. One of the main purposes of the landmark program is to encourage and assist private individuals and organizations in protecting and preserving important elements of our Nation's natural heritage." [11] One might therefore surmise, that site designation would carry no "legal teeth" for enforcement of retaining any chosen site in its natural condition. In the case of the Beowawe Geysers' area, this proved to be a moot point because the NPS utilized five individual evaluations to decide that the Geysers' site was unsuitable as a "National Natural Landmark." The primary reason for turning down the site was the severe damage done to the sinter terrace by the earlier geothermal energy explorations and operation. [12] The evaluation form itself is titled, "Site Not Recommended for Designation." [13]

SOME FINAL THOUGHTS

Denied the possibility of National Monument status due to inadequate evaluation, denied development on more than one occasion, as a possible State Park or State Monument due to a variety of factors, the Beowawe Geysers were also denied the designation of National Natural Landmark. Overlooked and/or forgotten was the fact that the site was, from 1869 to the early 1900's, a recognized landmark on the Union/Central Pacific transcontinental railroad route.

The Beowawe Geysers' area has "taken it on the chin" several times because its unique natural features were not fully recognized or appreciated by those who had the power and opportunity to preserve them. It is unlikely that the geysers and hot springs at this site will ever return to natural levels that existed prior to geothermal energy explorations which began in late 1959. If the thermal springs do come back to a level similar to the pre-geothermal explorations levels, it will be because Mankind no longer wishes to extract geothermal power from such areas. Even so, it might take hundreds or thousands of years of spring flow and deposits to hide the scars of geothermal development.

The Beowawe Geysers are truly an example of a first class failure to preserve a unique area. Perhaps author/naturalist T. Scott Bryan came closer to the gist of the matter than he realized when he entitled his 1977 article on the Geysers' area: "BEOWAWE - Except for some vandals and overeager government officials, Nevada would be world famous for its geysers." [1] In light of the information presented here, one might change one word in the preceding title - namely "overeager" to "under-eager". Let us hope that vandals and eager government officials will not be allowed to turn Yellowstone's geysers into a similar, much larger version of what the Beowawe Geysers have become, by failing to realize that thermal springs are fragile phenomena. Mankind can destroy such phenomena - and has.

THERMAL SPRING ACTIVITY 1969/70 and 1988

I first became familiar with the Beowawe Geysers' area in the early portion of the 1960's, largely through introduction to the geysers of Yellowstone National Park. [1] By 1964, at least, I had started my now large collection of data on thermal springs. The Beowawe area may have been the first non-Yellowstone geyser area I became interested in, an interest which included building scale model geysers for a Junior High School Science Fair.

My first visit to the Beowawe Geysers' area occurred in the early part of the Summer of 1969, followed by a second visit in 1970 at about the same time of the season. A third visit, almost by chance, came in early September of 1970. All three of these visits lasted just a few hours and, regrettably, not enough photos were made of the various thermal springs that were still active. My most recent visit to the Geysers' area was during the first week of October, 1988, when I had the opportunity to look over the site for a time period of three days, with many, many photos taken. The following account is a summary of my 1969, 1970, and 1988 visits.

During my first trip (June or July, 1969), time permitted my inspection of the valley floor thermal springs and the "western half" of the sinter terrace. At that time, the valley floor thermal springs consisted of about 8 different springs, one of which was Nolan and Anderson's intermittent boiling spring or, as White dubbed it, "Frying Pan Geyser." This spring "boiled up" every 20+ minutes [2], much in the same manner in which Nolan and Anderson's 1934 report portrayed it. There were several other thermal springs nearby, which Nolan and Anderson's 1934 report, beyond some map references, said little about. One of these springs was the geyser which I refer to as "Tea Cup" due to the shape of its crater, centered roughly in the middle of a sinter "plate". [3] I do not recall witnessing any eruptions from this geyser while at the site in 1969.

The sinter terrace, in 1969, was nearly devoid of active thermal springs. Activity was limited to a few soupy mud pots and several steam vents: a dismal representation of the activity that others witnessed prior to the initial geothermal drilling. Of some interest were the two geothermal wells which someone had opened. [4] One was truly awesome to behold as it alternated between a water phase and a steam phase several times in an hour. The steam phase of this well generated a sound that so loud and shrill that it forced one to retreat a considerable distance! Alas, the spectacle was entirely artificial.

The second trip during the early summer of 1970 was made at an opportune time. A rare heavy rain, which lasted over three days time, had produced some previously unencountered surface thermal activity. In the vicinity of one of the valley floor thermal springs, an area of red soupy mud was the site of several small pseudo-spouters which coughed soupy red mud several inches up into the air.

While inspecting an interesting series of parallel fissures, full of boiling water near the western foot of the sinter terrace, another member of my party brought my attention to the sudden eruption of the geyser I have called "Tea Cup"...which ceased erupting before I could examine it close up. By comparison with clumps of sagebrush around the geyser, we estimated an eruptive height of 8 to 10 feet for "Tea Cup Geyser." This was the only geyser I observed which ejected water to an appreciable height. "Frying Pan Geyser" merely boiled over at periodical intervals, while a third "geyser" would "plop" water out of the center of its pool to a height of perhaps one foot.

Examination of the top of the terrace on this same trip revealed the same active "mud pots" and geothermal wells, as well as some new steam vents apparently caused by the "hot ground" vaporizing the water from the three days' rain mentioned earlier. One tiny vent produced a noticeable steam plume, accompanied by an audible hissing noise. I remember this vent all too well, for I had, in 1969, noted its location and temperature first by hand, and then by thermometer. The thermometer reading had been 204 degrees F.! From then on, I used a thermometer to check all vents, active or not. On this 1970 trip, I was able to inspect the full length of the top of the terrace, particularly the so called "eastern half," which proved to be more benign yet then the "western half". I do not recall witnessing any active thermal vents on that portion of the sinter terrace.

While in the Beowawe area in 1970, I stopped at what I believed to be the Horseshoe Ranch in order to find out if the thermal spring area underwent any "winter time" increase in activity, as reported in Nolan and Anderson's 1934 report. The only thing I learned was that the area was simply colder, nothing more!

My second 1970 visit to the Geysers' area occurred in early September by chance. I was on a trip to Lehman Caves, as well as other non-commercialized caves in eastern Nevada, and managed to convince my traveling companions to stop at the Geysers' area. "Tea Cup Geyser" produced some interesting noises, but did not erupt. I examined other remaining thermal springs on the valley floor. At one particular thermal spring, I noticed that there was a slight rise and fall of the water level. Was this caused by the introduction of hot dogs on sticks which we were cooking, or a natural phenomena which I had just not noticed before? There is no way of knowing because this particular thermal spring, as well as the rest of the valley floor spring, are now dry craters. They have certainly been dry since 1988 and, according to some reports, since as early as 1986.

This brings me to my October 1988 visit to Beowawe. Originally, the plan was to go to Nevada and California in early July of 1988, and meet with one of the land owners of the area, Sam Dermengian. Dermengian and I had been communicating regularly by letter and phone. Dermengian, as publisher of a magazine on geothermal energy, supplied a considerable amount of data on various locations, including the Beowawe area.

I was able to make arrangements with Chevron Resources Co. for permission to visit the Beowawe Geysers' area. Chevron controls the access to the site. After securing permission from Mr. Gene Cole, of Chevron Resources, the final stop of the trip was arranged for Elko. The other stop, however, was the Reno/Carson City area, where I engaged in major research for this report at the Nevada Historical Society, the State Archives, and Nevada State Park Department. I then met Chevron's Beowawe Geothermal Power Plant Manager, Jim DeGraffenreid, at the AMTRACK station in Elko. Mr. DeGraffenreid and his boss, Gene Cole, in San Ramon, Ca., were most gracious and helpful by allowing me to inspect the Geysers' area freely. The result was a three days' inspection of the Geysers' area and a tour of Chevron's power plant. I was able to closely examine the sinter terrace from one end to another. I located the "Horst Geyser" cone. I also spent time in Elko interviewing Park Commissioner Chris Sheerin, Mr. and Mrs. Martin Milano, Attorney Orville Wilson, and several others, as well as visiting the Northeastern Nevada Museum and Library, the Elko County Courthouse, and the First American Title Insurance Co. of Nevada.

A quick review of my survey revealed that at least 8 major valley floor thermal springs were entirely dry, although wisps of steam were visible at times, emanating from the craters. It was also evident that several of the craters were enlarged from the collapse of the original spring "bowls." The "Tea Cup Geyser" cone had suffered deterioration of its distinctive cup-like rim, although it was recognizable.

The sinter terrace had several vapor and steam vents, plus a few hot springs and soupy mud pots. Most of the former were located on the so-called "eastern half" of the terrace, while the active springs and mud pots were concentrated on the "western half" of the terrace. At no time during the three day survey did I observe any active geysers, although active geysers had been reported on the terrace within the past 2 years. I watched a couple of videos on geothermal power projects in the State of Nevada which featured scenes at Beowawe. A couple of "geysers" were shown on these videos - eruptions were not impressive. The videos were at Chevron's Beowawe power plant in Whirlwind Valley, courtesy of Plant Manager, Jim DeGraffenreid.

The vapor and steam vents, particularly those located on the "eastern half" of the sinter terrace were interesting for the varied, albeit dead, insect life which I found in them. I have no idea what kinds of insects they were.

The "western half" of the terrace had all of the thermal spring activity, as witnessed by this writer in October, 1988, whereas the "eastern half" apparently had no active thermal springs. On either "half", former hot spring vents are clearly visible. There are "new" thermal vents on the terrace which I was not able to identify through comparison with my earlier visits and the maps of the terrace provided by White.

While at the site, I attempted to pinpoint various thermal vent locations on the top of the sinter terrace which were documented on White's 1950 map of the terrace. Some vents were tentatively identifiable, but the overall survey results were disappointing to say the least. Perhaps G.O.S.A. should conduct a formal survey of the sinter terrace in an effort to identify precisely the "surviving" thermal vent locations, as well as the areas on the terrace top that are covered with debris which undoubtedly covers many vents. One might then correlate the new survey with White's maps of the terrace. In a generation or two, old maps and a few photographs may be all that remains of the Beowawe Geysers' area.

CHAPTER NOTES

Abbreviations:

B.L.M.	Bureau of Land Management.
D.R.I.	Desert Research Institute, Reno, NV.
D.E.W.	Donald E. White.
N.A./W	National Archives, Washington D.C.
N.A./S	National Archives, San Bruno, CA.
N.S.A.	Nevada State Archives.
N.S.P.C.	Nevada State Park Commission, Carson City.
N.S.P.D.	Nevada State Parks Department, Carson City.
N.H.S.	Nevada Historical Society, Reno, NV.
N.E.N.M.	Northeastern Nevada Museum & Library, Elko.
N.P.S.	National Park Service.
U.N.L.V.	University of Nevada/Las Vegas.
U.N.R./S.C.	University of Nevada/Reno Library - Special Collections.
U.S.G.S.	United States Geological Survey.

EARLY HUMANS: 600(?) BC TO 900(?) BC

#1 *D.R.I. Technical Report #13*, June 1980. Elizabeth Budy, "Archaeological Surveys at Beowawe, Nevada", Part A.

#2 *Ibid.*, Budy, pg. 2, Map 1.

#3 *Ibid.*, Budy, pg. 6.

#4 *Ibid.*, Budy, pg. 12.

#5 *Ibid.*, Davis/Fowler/Rusco (1976:50), in Budy, pg. 12.

NEVADA INDIANS: 900(?) AD TO 1869(?) AD

#1 *D.R.I. Technical Report #13*, June 1980: "Archaeological Surveys at Beowawe, Nevada"; Part A, by Elizabeth Budy. Part B: "A BLM Class III Cultural Resources Inventory of 14 Proposed Geothermal Drill Sites and Access Roads," by Alvin R. McLane. For a different opinion on this topic, see Davis/Fowler/Rusco, *D.R.I. Technical Report #2*, "Archaeological Investigations Near Treaty Hill, Humboldt county, NV." (Dec. 1976) pg. 6.

#2 There are several works on this topic, including: *Handbook of North American Indians*, vol 10 - Southwest (1983), pp 113 to 119, and, Vol 11 - Great Basin (1986).

#3 *Handbook of North American Indians*, vol 11 - Great Basin indicates that the Beowawe/Whirlwind Valley area falls into the territory of the Western Shoshone Indians. The following publications indicate the area was used by Paiute/Northern Paiute Indians: A) Federal Writers' Program, *Nevada, a Guide to the Silver State*, (1940) pg 126. B) H. Cyril Johnson, *Scenic Guide to Nevada*, (1945), pg. 53, under topic of "Old Indian Battleground." C) Weldon F. Herald, *Scenic Guide to Nevada*, (1952) (rev. ed. of the H.C. Johnson guide of 1945) pg. 5, under topic, "Beowawe". D) *SUNSET Travel Guide to "Nevada"* (1971) pg. 36. E) Helen S. Carlson, *Nevada Place Names*, (1974), pp. 49-50 under "Beowawe".

#4 *Handbook of North American Indians*, Vol 11.

#5 Doug McMillan, "Geothermal: Full Steam Ahead for state's growing energy resource", *Reno (Nevada) Gazette-Journal*. (Date uncertain but thought to be 1985 or 1986, judging by contents of article.)

#6 *Op cit.*, Reference #3 A - E, *ante*.

#7 George R. Stewart, *American Place Names*, (1970); pg. 43, "Beowawe".

#8 Helen S. Carlson, "Nevada Place Names" (1974, U.N.R. Press), pp. 49-50.

#9 *Ibid.*, pp. 49-50.

#10 J.H. Beadle, *The Undeveloped West* (1873); pg. 576. Beadle states that the Spanish spell it "Beowawe", but the Mosquis Indians spell the same word as "Baowahway." See also Beadle's book, *Western Wilds*, 1878, pg. 277, where the spelling is "Beowawa" and "Baowahwa".

#11 Albert S. Evans, "In Whirlwind Valley," *Overland Monthly*, (Feb. 1869), pg. 112.

#12 One road map dates from 1936 and shows both the Geysers' area and this "Battleground" to be alongside Nevada State Highway #21 (now #306) which places both in nearby Crescent Valley! This Shell Oil Co. map of Nevada is in the N.H.S. map collection; the company that prepared this map (and others with the same data) is the H.M. Gousha Company.

#13 H. Cyril Johnson, *Scenic guide to Nevada*, (1945); pg. 53, "Old Indian Battleground" along side Nevada State Highway #21.

#14 Weldon F. Heald, *Scenic Guide to Nevada*, (1952). Revision of Johnson (1945), *op. cit.* Pg. 6, under topic "Beowawe." This guidebook's state map, p. 40, shows the geyser's area and "Indian Battleground" alongside Nevada State Highway #21.

#15 Nell Murbarger, "Geysers of Whirlwind Valley," *Desert Magazine*, (1956), pg. 20.

#16 *Op cit.*, Budy, 1980, Map 1, pg. 2.

#17 Personal communication, B.L.M./Elko, Nv. office, 1980's. Also personal communication Evelyn Seelinger, Nevada State Museum (Carson City, NV), 1987. The latter serves as a center for archaeological surveys and discoveries in the State of Nevada.

#18 *Op cit.*, Murbarger, (1956), pg. 20.

#19 Donald E. White, *The Beowawe Geysers Geothermal System of Nevada*. U.S.G.S. Professional Paper (in press.) Fig. 13, 14, 15 and captions. Also, pg. 15.

EARLY EXPLORATION OF THE BEOWAWE AREA BY NON-INDIANS

#1 Glyndwr Williams, *Ogden's Snake Country Journals*, (1971). pp. lvi-lviii and 110-114 give detail on Ogden's expedition regarding the Beowawe area.

#2 *Ibid.*

#3 *Ibid.*

#4 *Ibid.*

#5 *Ibid.*, pp. lxv-lxviii.

#6 Victor O. Goodwin, *The Humboldt - Nevada's Desert River*, (1966). Pine Valley Sub Basin, pg. 2; Battle Mtn. Sub Basin, pg. 1.

#7 There are several publications regarding early exploration and travel along the Humboldt River. For example: A) Federal Writer's Project, *Nevada, A guide to the Silver State*, (1940). Pg. 289, "Chronology". B) William H. Goetzmann, *Army Exploration in the American West*, (1959, 1965). Pg. 114, Map #5 shows Fremont's 1845 Expedition using the Humboldt River Trail when in fact only part of Fremont's part used that trail (Kern/Talbot/Walker and others) - Fremont and ten men used a much different route. See pg. 120. C) Effie M. Mack & Byrd W. Sawyer, *Our State: Nevada*, (1940). Pg. 24 of this book says, "Sometimes the loose sand of the desert is caught up by a strong wind ... then suddenly rises to form giant whirlwinds. So many of them were seen by Fremont near Beowawe that he named it 'Whirlwind Valley'." Indeed, whirlwinds are frequently seen in this so-named valley, but this writer has not been able to locate Mack & Sawyer's data source for this intriguing place name explanation.

#8 Zenas Leonard, *Adventures of Zenas Leonard, Fur Trader*, (1959). Edited by John C. Ewers.

#9 Capt. James H. Simpson, *Report of Explorations Across the Great Basin ... in 1859*, (1876). Kern's travel journal is reproduced in this report under Appendix Q.

CALIFORNIA/HUMBOLDT RIVER TRAIL: 1841 TO 1869

#1 Merrill J. Mattes, *Platte River Road Narratives*, (1989).

#2 George R. Stewart, *The California Trail: An Epic With Many Heroes*, (1962) is an excellent work on this particular route. Also see Thomas H. Hunt, *Ghost Trails of California* (1987); Julia C. Altrocchi, *The Old California Trail*", (1945); Irene Paden, *The Wake of the Prairie Schooner* , (1943 - reprinted recently); Helfrich & Hunt, *Emigrant Trails West*, (1984).

#3 Those interested in a list of diaries/journals consulted thus far are advised to contact the author through G.O.S.A.

#4 John McGlashan's 1850 Diary. Copy in this writer's files and at the Chicago Historical Society. The June 22nd entry reads in part, "... I noticed a large plain to our left which seemed incrusted [sic] all over with salts. A boiling spring sent out smoke from the center." Some California Trail scholars (Helfrich and Hunt, in, *Emigrant Tales West*) place this entry/observation in the Beowawe area. If so, then McGlashan's "boiling spring" might have been one of the thermal springs, at the Beowawe Geysers', that is located on the valley floor.

#5 The writer suggests that readers may contact him for more detail on this subject of early maps of the Humboldt River Trail. Some maps in this category include government surveys of the Pacific Railroad, Pacific Wagon Roads, Clarence King's 40th Parallel Survey, T.H. Jefferson's 1840's map of the California/Humboldt River Trail.

#6 T. Scott Bryan, *The Geyser's of Yellowstone*, (1979), pg. 196. See also Bryan's 1986 revised edition, pg. 258; and; "Beowawe...", *Nevada Magazine*, #3, 1977, pg. 54.

#7 This writer is still in the process of indexing the half dozen or so emigrant diary/journal references to have reported "whirlwinds" seen along the California/Humboldt River Trail.

#8 *Op cit.*, Stewart (1962); Hunt (1987); Paden (1943); Helfrich/Hunt (1984). Dale L. Morgan, *The Humboldt, Highroad of the West*, (1943) does not mention the Beowawe Geysers' area at all, either as a "landmark" on this trail, or in passing.

#9 Frederick B. Rogers, *Soldiers of the Overland*", (1938) gives a good account of the units of General Patrick E. Connor's troops who spent some time searching for Indians in the Beowawe/Gravelly Ford area of the Humboldt River; the actual reconnaissance reports have not been located. The map that accompanies Mr. Roger's book does not show the Beowawe Geysers' area. Also see the following: Victor O. Goodwin *The Humboldt*, (1966), Pine Valley Sub Basin, Pg. 7; Edna B. Patterson, et al, *Nevada's Northeast Frontier*, (1969), pg. 103. Both of these publications give some detail on the extent of Connor's 2nd California Cavalry troop activities in the Beowawe/ Gravelly Ford area.

\#10 Beckwith's report is entitled, "Report of Exploration of a Route for the Pacific Railroad..." in Vol. #2 of the 12vol. *Pacific Railroad Surveys*, (1856-1857), U.S. Senate Ex. Doc. 78, 33rd Congress, 2nd Sess.

\#11 See W.T. Jackson, *Wagon Roads West, a Study of Federal Road Surveys, 1846-1869*, for information on the Humboldt River road. This writer recently examined a first edition of the 1850's road survey that covers the Beowawe area, alas, the report and map contain no mention of the Geysers' area.

\#12 The map of the Humboldt River road referred to previously shows the hot springs at or near Elko, Nv., Thousand Springs Valley, etc., but not the Beowawe Geyser's area, indicating that the surveyors did not do any exploring away from the main trail.

\#13 *Op Cit.*, Goodwin (1966), Pine Valley Sub Basin, pp. 3-6, and, Battle Mtn. Sub Basin, pp. 11-12. Goodwin says that one of Chropening's stage stations of the 1850's is still standing (1966) at the Horseshoe Ranch, 1 mile north of Beowawe, Nevada, which leads one to wonder if any of the station hands, in the 1850's, might have noticed the Geysers' area from the station and investigated that area! Regarding the volume and kinds of traffic on the California/Humboldt River Trail, the reader is directed to Mattes (1989) on emigrant trail diaries; and John M. Townley, *The Trail West*, (1988).

THE COMING OF THE RAILROADS
1868 and onwads

\#1 See previous section reference on the Pacific Railroad Surveys of the 1850's.

\#2 A number of sources, usually cataloged under "Railroads (U.S.)-History."

\#3 *Op cit.*, Goodwin (1966), Pine Valley Sub Basin, pg. 3, and, Battle Mtn. sub Basin, pg. 2, places the railroad construction crews at Gravelly Ford, up stream from the Beowawe area, by Oct. 26, 1868.

\#4 Col. Evans article on the Beowawe Geysers', aka "Volcano Springs," first appeared in the Feb. 1869 issue of the *Overland Monthly magazine*. This article, and a brief biography of Evans, have been recently reprinted in Robert A. Bennett, *The Bohemians*, (1987), pp. 64 to 70.

\#5 *Ibid.*, Bennett, pg. 65.

\#6 *Ibid.* see pp. 3-11 for details on this magazine's history. Evans' article in the original magazine appeared on pp. 111-115 of the *Overland Monthly*, Feb. 1869, (v. 2, #2). Evans' spells "Beowawe" as Beaowawe".

\#7 Many have called the site the "Beowawe Geysers", however, the first person to do so and when is not clear. E.T. Allan and A.L. Day, *Hot Springs Of The Yellowstone National Park*, (1935), calls the site the "Beowawe Geysers" on pg. 171. The U.S.G.S. map of the area, DUNPHY 15 minute topographic quadrangle (1956), calls the site, "The Geysers".

\#8 *Op cit.*, Bennett, (1987), pg. 66.

\#9 This writer has compiled a short list of these 19th Century railroad guide books that mention the Beowawe Geysers' area. Some of these guides are listed elsehere in these notes.

\#10 For more information on the life and times of George A. Crofutt, see J. Valerie Fifer, *American Progress*. This book does not, however, mention the Beowawe Geysers' area.

\#11 A number of Crofutt's 1869 to 1873 railroad guide books place the Geysers' area east of Beowawe, Nv., which is in error. A sample is the 1971 reprint of the 1869 Crofutt/Dadd book, *Great Trans-Continental Railroad Guide*, pp. 162-163.

\#12 *Crofutt's New Overland Tourist and Pacific Coast Guide*,"(1880), pp.150-151.

\#13 Henry M. Robert's 1868 map of north-central Nevada, shows the "Beowawe Gate" and Whirlwind Valley clearly, but not the Geysers' area, probably because the map covers too much territory to show fine details. This map has been reproduced in Carl Wheat, *Mapping The TransMississippi West, 1540-1861*, (1957-1963), Vol. #5, Part 2, pp. 226-227.

\#14 *Op cit.*, Crofutt (1880), pp. 150-151.

\#15 Personal communication, D. E White, specifically White's maps of the thermal spring activity on the Geysers' sinter terrace.

\#16 Several editions of this book: Specifically see Henry T. Williams' edition for 1881, pg. 185; and, Frederick E. Shearer's edition of 1884 (reprinted in 1970), pg. 202.

\#17 T. Nelson, et al., *The Central Pacific Railroad: A Trip Across The North American Continent From Ogden To San Francisco*, (1870), pg. 83, under "Cluro". The Beowawe Geysers' area is briefly mentioned as "...about four miles below Cluro the celebrated Hot Springs (sulphureous) rise from a hundred orifices." This brief description is apparently a very condensed version of the Crofutt/Dadd 1869 description of the Geysers' area.

\#18 This series began in 1889 and continued through 1908. On pg. 150 of the 1908 edition, there is a description of the Geysers' area, under the entry for "Beowawe" as follows: "To the south [of Beowawe, Nv.] eight or ten miles lies Hot Springs Valley, taking its title from the hot springs which are found there in great number. These springs are intermittent in their flow, resembling in this characteristic, though in a lesser degree, the geysers of the Yellowstone." This writer examined several different editions of this guide book at the California State Railroad Museum Library (Sacramento, Ca.) and found similar worded descriptions of the Geysers' area in each edition.

\#19 The primary guide is, *Wayside Notes Along Ogden Route*, (1917), published by the Southern Pacific Company. On pg. 5, under "Beowawe". The entire entry reads, "Beowawe, meaning 'Gate', is named from the peculiar formation of the hills at this point on either side of the Humboldt Valley. Five miles to the south are Volcano Springs, geyser-like in character. At Beowawe is located a power plant from which runs a wire conveying power to the mill of the Buckhorn mines, thirty-seven miles south. These mines have over seven million dollars' worth of gold ore in sight." Note that the Southern Pacific Co. called the Geysers' area, "Volcano Springs" in 1917. Company guide books for 1940 to 1963 do not mention the Geysers' area, and only one, in 1950, mentioned the community of Beowawe, Nv.

#20 A. C. Peale, "The Thermal Springs Of Yellowstone National Park" (1883), in F.V. Hayden, *U.S. Geol. & Geog. Survey Terr. 12th Annual Report for 1878.* Beowawe Geysers as "Volcano Springs" on pp. 322 to 323.

#21 W. T. Lee, et al, *The Overland Route*, U.S.G.S. Bulletin #612, Part B (1915), pp. 169-170, described the geysers as follows: "Leaving behind Beowawe, the railroad swings to the north [and then to the west]. Across Whirlwind Valley to the south may be seen a white line, or terrace, against the distant mountain side. This is a hot-spring deposit and, like so many others in Nevada, is situated just below the steeper part of a mountain front. Here, as elsewhere, the spring has probably risen along the line of the fault or displacement which blocked out the mountains from the valley."

#22 This book was published in 1870 by Julius Bien, of New York.

#23 *Ibid.*, Hayden (1870), pg. 134.

#24 Clarence King, Geologist-in-charge, *Geological Survey Of The Fortieth Parallel*" (1870-1880), U.S.G.S., 7 volumes and one atlas. King's own volume in this series, "Systematic Geology" (Vol. #2, 1878), mentions the geology of the Beowawe/Whirlwind Valley area on pp. 660 to 662. Vol. #3, "Descriptive Geology", by Arnold Hague and S. F. Emmons, also mentions the geology of the same area on pg. 618. Neither volume mentions the Geysers' area.

MODERN KNOWLEDGE: 1917-1950's

#1 This writer is still researching the numerous potential sources of information for this time period; this chapter reflects the preliminary research done, as of the end of 1988.

#2 On file at the N.H.S., in Reno, Nv.

#3 Copy in this writer's file, from the U.S. Department of Transportation Library, Washington D. C.

#4 Charles T. Brues, "Studies On The Fauna Of Hot Springs In The Western United States", (Vol. 63, #4, - July, 1928), Spring #24, pp. 153-154.

#5 *Ibid.*, Brues (1928).

#6 *Ibid.*, Brues (1928); pg. 153.

#7 Diary of Beirne B. Brues (1927), pg. 59, c/o, Alice M. Brues, Daughter, transmitted to this writer Feb. 12, 1987.

#8 T.B. Nolan & George H. Anderson, "The Geyser Area Near Beowawe, Eureka County, Nevada" (5th series, Vol. #27, #159, 1934), *American Journal Of Science* pp. 215-229.

#8 *Ibid.*, Nolan & Anderson (1934); pg. 219, map of area, 9 photos of thermal springs area scattered through out the report.

#9 White and this writer spent some time looking at White's large Beowawe Geysers photo collection, including an unpublished photo identified as originating from T. B. Nolan's Beowawe Geysers "collection". White and this writer are positive that this unpublished photo of Nolan's is a view of White's "Beowawe Geyser".

#10 Allen and Day, *Hot Springs of the Yellowstone National Park*, Carnegie Institution, Washington D.C., Publication #466 (1935). Beowawe Geysers' area, pp. 171, 173-174.

#11 *Ibid.*, pg. 173.

#12 *Ibid.* This inquiry took place in early 1932.

#13 *Ibid.*

#14 *Op. cit.*, Nolan and Anderson (1934), pg. 215, indicates that Allen notified Nolan of the existence of the Beowawe Geysers. Also, personal communication with family and friends of Mr. Anderson (in the 1980's) revealed much about Anderson and his friendship with Nolan. Incidentally, Anderson was never a member of the U.S.G.S., as some writers have stated.

#15 *Op cit*, Nolan & Anderson (1934), pg. 215.

#16 Published by the Nevada Department of Highways, beginning in 1936 and continuing into the 1960's until undergoing a reformation into the *Nevada Magazine*. As *Nevada Highways And Parks*, the magazine occasionally contained information (photos, etc.) on the Beowawe Geysers' area, scattered through various issues.

#17 N. D. Stearns, H. T. Stearns, G.A. Waring, *Thermal Springs Of The United States*, (1937), U.S.G.S. Water-Supply Paper #679-B, pp. 59 to 206. Beowawe Geysers-Spring location #77a, pg. 161.

#18 Federal Writers Program/American Guide Series, *Nevada: A Guide To The Silver State* , (1940). Beowawe Geysers' area on pg. 126. The guide book says the discovery of the site is credited to A. S. Evans in 1867, but "...the springs must have been known long before that time for on cool mornings their steam is visible for miles." (Note: From this point on, "Federal Writers Program" will be abbreviated as "F.W.P.")

#19 Nevada road maps dating back to 1936, that are in the map collection of the N.H.S., in Reno, Nv.

#20 *Op cit., Nevada Highways and Parks.*

#21 *Op cit.*, Sterns, Stearns, and Waring (1937). White has voiced the opinion that Gerald Waring supplied the Beowawe Geysers' data for this publication, based on Waring's own visits to that site (pers. comm.). See also White's Beowawe report (pg. 24), in press.

#22 *Op. cit.*, Stearns, Sterns, Waring (1937). Spring location #77a, pg. 161.

#23 *Ibid.*, pg. 114.

#24 *Op. cit.*, F.W.P./Nevada guide (1940); pg. 126.

#25 *Ibid.*, pg. 126.

#26 *Op cit.*, Johnson (1945) pg. 69; *Op cit.*, Herald (1952) pg. 6 and 40 (state road map for Nevada).

#27 *Op. cit.*, 1930's Nevada road maps in N.H.S. map collection.

#28 *Op cit.*, Herald (1952) pg. 25. Also some state road maps may show the Geysers' area in much the same way as the 1930's and 1940's maps.

#29 Nell Murbarger, "Geysers of the Whirliwind Valley", *Desert*, (1956), pp. 17-20.

#30 Personal communication, Ms. Murbarger in the 1980's.

#31 *Op cit.*, Murbarger (1956); pg. 17.

#32 *Ibid.*, pg. 20.

#33 *Ibid.*, pg. 17.

#34 *Op cit.*, Rogers (1938), pg. 32-35; *Op cit.*, Goodwin (1966), Pine Valley Sub Basin, pg. 7; *Op cit.*, Patterson, et al (1969), pg. 103.

#35 Nell Murbarger, "Nevada's Valley Of Geysers", *Desert*, (1950), pp. 320-325, specifically, pg. 320.

#36 D.E. White, personal communication.

#37 *Op. cit.*, White (in press); pp. 17-19 and Table #2, Spring #51.

#38 *Op cit.*, White (in press), Table #2. Also, personal communication.

#39 *Op cit.*, Brues (1928).

#40 *Op cit.*, Nolan & Anderson (1934).

#41 *Op cit.*, White (in press), Table #2.

#42 *Op cit.*, Nolan & Anderson (1934), pg. 222. *Op cit.*, F.W.P., *Nevada guide* (1940). pg. 126.

#43 D.E. White, personal communication, in Sept. 1988.

#44 *Op cit.*, White (in press), pg. 13. Also, White, personal communication.

#45 White, personal communication.

#46 A magazine that as previously noted has mentioned the Beowawe Geysers' area from time to time, in a variety of ways. This 1956 issue is special for its rather full coverage of several of Nevada's more interesting thermal spring areas, coverage of these areas on pp. 16 to 21.

#47 *Op cit.*, Bowers (?), (1956), pg. 19. White has expressed the opinion that Bowers prepared a unpublished article on the Beowawe Geysers' area that utilized a lot of data from White. The data used on pg. 19 of the "Hot Springs Galore" article concerning the Beowawe Geysers may be an indirect quote of White's Beowawe data excepting for the "50 geysers" statement which is numerically correct for the number of thermal spring vents that White mapped on the sinter terrace. D.E. White, personal communication.

#48 *Ibid.*, pg. 19.

#49 The subject of the Beowawe Geysers' area as a State Park, etc. will be fully covered in an upcoming chapter.

GEOTHERMAL ENERGY EXPLORATIONS: 1959 to 1966

#1 Information came from records of the Secretary of State of Nevada, Carson City, Nv.; May 1987 correspondence.

#2 N.S.P.D Beowawe file #319.0 Letter, dated July 6, 1959, Joseph W. Aidlin, General Counsel, Magma Power Co. to Fritz L. Kramer, Chairman, N.S.P.C.

#3 Information on Magma Power Company pieced together from a variety of data sources in this writer's file.

#4 Larry J. Garside, *Geothermal Exploration And Development In Nevada Through 1973* (with 1978 update, *Exploratory Geothermal Drilling In Nevada*). Report #21 (1974), pub. by Nevada Bureau of Mines and Geology, Reno, Nv. The areas that Magma Power Co. drilled also included Monte Nevada Hot Springs, Hot Springs point (Crescent Valley), the Fernley area, Darrough Hot Springs, Wabuska Hot Springs, Hot Springs (Tipton) Ranch, with the drilling dates beginning in 1959 and going into the 1970's. During 1959, Magma Power Co. and Associates, drilled at the Beowawe Geysers, Brady's Hot Springs, Steamboat Springs, and Wabuska Hot Springs.

#5 *Op cit.*, Sec. of State/Nevada records revealed that the Vulcan Thermal Power Co. was incorporated under the laws of the State of Nevada on January 17, 1961. This company's history is imperfectly known.

#6 Norman V. Peterson, "Lake County's New Continuous Geyser, (Sept. 1959), *The Ore Bin*, publication of the Oregon Dept of Geology & Mineral Industries. First page of article states that the "Crump Geyser" resulted from a geothermal well drilled by the Nevada Thermal Power Co., "...the exploratory division of the Magma Power Company of 631 S. Wilmer St., Los Angeles 17, California..." This well, according to the article, was abandoned by the company on June 29, 1959.

#7 N.S.P.D. Beowawe file (#319.0); letter, dated Oct. 5, 1959, Joseph W. Aidlin, Secretary, Magma Power Co. to Fritz L. Kramer, N.S.P.C. Chairman. Also see William A. Oesterling's report to the Southern Pacific Co., *Geological Appraisal Of Geothermal Steam Resources At The Geysers Near Beowawe, Nevada* (May 1960-modified by Kiersch and McCulloch, June 27, 1960), pg. 11.

#8 Wm A. Oesterling, Personal communication, letter dated December 14, 1986.

#9 William A. Oesterling, *Geological Appraisal Of Geothermal Steam Resources At The Geysers Near Beowawe, Nevada* (May 1960), modified by George A. Kiersch & W. A. McCulloch (June 27, 1960), pg. 12. This report identifies these first two geothermal wells drilled at the Geysers as Beowawe #1 and Beowawe #2. #2 well is on top of the west end of the sinter terrace.

#10 *Ibid.*, (1960), pg. 15.

#11 Wm A. Oesterling, personal communication, letter dated December 29, 1965.

#12 Several publications and authorities have discussed this subject: T. Scott Bryan, *The Geysers Of Yellowstone*; *Final E.I. Statement of the Island Park Geothermal Area*, by the staffs of the U.S. Forest Service and B.L.M., (1980), pp. 111-112; D. E. White, personal communication.

#13 *Op cit.*, Allen & Day (1935), pg. 173.

#14 *Op cit.*, Oesterling to this writer, letter dated December 14, 1986. Also, William M. Middleton, *Report On Beowawe Nevada Geothermal Steam Wells For Vulcan Thermal Power Company*" (1961), pg. A1.

#15 *Op cit.*, White (in press), pp. 10-11.

#16 *Ibid.*, note #12.

#17 William W. Allen, *Field Data From Geothermal Steam Well Tests On Beowawe, Nevada, Geothermal Steam Wells For Magma-Vulcan Thermal Power Project*, (1962). Magma Power Co. unpub. report, at Nevada Bureau of Mines & Geology, Reno, Nv., various pages.

#18 *Ibid.*

#19 *Ibid.*

#20 *Op cit.*, White (in press), pg. 10.

#21 *Op cit.*, Garside (1974), Table #1 (and 1978 update of same) identifies these two wells as "Vulcan Well #5" and "Vulcan Well #6", both less than 500 ft. deep and perhaps abandoned as 'unproductive'.

#22 *Ibid.*, Garside (1974, with 1978 update), Table #1 indicates that the four Sierra geothermal exploratory wells were drilled during the years of 1964 to 1965.

#23 Personal communication, Sierra Pacific Power Co. officials, mid 1960's and 1980's.

#24 *Ibid.*, mid 1960's.

THERMAL SPRING ACTIVITY: 1959-1979

#1 *Op cit.*, Oesterling et al., (May 1960), (modified June 27, 1960, by Kiersch and McColluch).

#2 *Ibid.*

#3 *Ibid.*, pg. 6.

#4 *Ibid.*, pg. 6.

#5 *Ibid.*, pg. 3.

#6 *Ibid.*, pp. 8-9.

#7 Gerald A. Waring, *Thermal Springs Of The United States And Other Countries Of The World, A Summary*" (1965), U.S.G.S. Prof. Paper # 492. Beowawe Geysers-Nevada spring location #77A, pg. 35.

#8 *Op cit.*, Sterns/Sterns/Waring (1937).

#9 *Op cit.*, Waring (1965).

#10 *Op cit.*, Stearns/Stearns/Waring (1937). *Op cit.*, Waring (1965).

#11 *Op. cit.*, White (in press).

#12 *Op cit.*, Murbarger (1956).

#13 Dr. John S. Rinehart, "Geyser Activity Near Beowawe, Eureka County, Nevada" (1968), *Journal Of Geophysical Research*, (Vol #74, #24), pp. 7703-7706.

#14 *Ibid.*

#15 John S. Rinehart, *Geysers and Geothermal Energy*, (1980), pp. 11 and 12.

#16 *Ibid.*, pg. 12.

#17 Richard K. Hose & Bruce E. Taylor, *Geothermal Systems Of Northern Nevada*, (1974) U.S.G.S. open-file report #74-271, pp. 5, 8-9.

#18 *Ibid.*, pg. 9.

#19 *Op cit.*, White (in press).

#20 *Op cit.*, Hose & Taylor (1974), pg. 9. One of the margin notes is signed "D.E.W."

#21 *Ibid.*, pg. 9.

#22 Larry J. Garside & John H. Schilling, *Thermal Waters Of Nevada* (1979), N.B.G.M. Bulletin #91. Beowawe Geysers, pp. 28-33, map on pg. 31.

#23 *Ibid.*, map, pg. 31.

#24 *Op cit.*, Oesterling, et al., (1960), Fig. #1 (map), entitled "Areal Geology of The Geysers and Vicinity-Eureka and Lander Counties, Nevada" (Southern Pacific Co. Mineral Resources Survey, Geology by W. A. Oesterling, May 1960). This same map was revised (revision undated) after May 1960 in order to show the three new geothermal wells (Vulcan Well #1, #2 & #3) on the sinter terrace that are credited to the Vulcan Thermal Power Co., a copy of this revised map is at the Nevada Bur. of Mines and Geology.

#25 Mary Lou C. Zoback, *A Geologic And Geophysical Investigation Of The Beowawe Geothermal Area*, (1979), School of Earth Sciences, Stanford University, Calif., pg. 22.

#26 B.L.M. staff report, *Beowawe Geothermal Environmental Assessment*, (March 1985) B.L.M., Battle Mountain District Office.

#27 *Ibid.*, pg. 22 and 28.

#28 *Ibid.*, pg. 22 and 41.

#29 *Ibid.*, pg. 22.

BEOWAWE GEYSERS' AREA: LAND OWNERSHIP

#1 *Op. cit.*, *Handbook Of North American Indians*, (1986), Vol. #11-Great Basin.

#2 *Op cit.*, F.W.P/Nevada guide (1940). pg. 290, "Chronology".

#3 *Ibid.*, pg. 290.

#4 *Op cit.*, Mack & Sawyer (1940), pp. 160-161. Also, pg. 172 presents a map of Nevada showing general land ownerships. The railroad grant lands and the private lands within the grant are a conspicuous swath across the State.

#5 The subject of government land grants is too vast to adequately quote here; Mack & Sawyer's (1940) history of the State of Nevada provided some data on this subject, with the rest drawn from a myriad of sources, printed and oral.

#6 *Ibid.* Also Railroad lands' map of Beowawe area, dated 1909, from map collection of N.H.S., Reno, Nevada.

#7 N.A.S. Land records for Township 31 North, Range 48 East.

#8 *Ibid.*, Land Records for T. 31 N., R. 48 E. (with a date of July 11, 1918 stamped on these records).

#9 *Ibid.*

#10 Eureka County land ownership records for T. 31 N., R. 48 E., copies of records provided by the First American Title Insurance Co. of Nevada, Elko, Nv., in October, 1988.

#11 *Op cit.*, Goodwin (1966), Battle Mtn. Sub Basin, pp. 12-13; "Historical Information," pg. 2. Pages 3 to 4 of this chapter discuss some of the history of sheep herding along certain portions of the Humboldt River. Also, *Op cit.*, Patterson, et al (1966), History of the Horseshoe Ranch on pp. 332-334. Also, *Battle Mountain Scout,* (Nevada) newspaper article, "Famed Old Horseshoe Ranch Is Taken Over By Hadleys", dated January, 1957.

#12 *Op cit.*, Patterson, et al., (1969), pg. 332.

#13 *Op cit.*, Williams, *The Pacific Tourist,* (1881), pg. 185.

#14 *Op cit.*, Goodwin (1966), Battle Mtn. Sub Basin, pg. 12. Also, *Op cit.*, Patterson, et al., (1969), pg. 332.

#15 *Op cit.*, Goodwin (1966): Battle Mtn. Sub Basin, pg. 13. Also, *Op cit.*, Patterson, et al., (1969), pg. 334.

#16 *Op cit.*, *Battle Mtn. Scout,* newspaper article, (1957), mentions that Ralston "...was one of the first owners of portions of the Horseshoe Ranch. Later, Dr. Grayson....acquired the outfit...".

#17 *Op cit.*, Goodwin (1966). Also, *Op cit.*, Patterson et al., (1969).

#18 K. J. Evans, "Nevada's First Working Geothermal Power Plant" (1986), *Elko Free Press,* Elko, Nv. Besides the story about train passengers disembarking at the Beowawe train station in order to visit the Geysers close up, Evans' article also says, "Local old-timers remember being able to see the steam from the geysers when driving by on old U. S. Highway 40. Virginia Colyer, who grew up on a ranch near the geysers, recalls that people who lived in the vicinity...used the geyser area as a picnic site because eggs were easily boiled in the pools of hot water..."

#19 Antoine Primaeux, personal communication, (1980's). Concerning the story Primeaux 'collected' regarding the train passengers who visited the Geysers close up, Primeaux expressed the opinion that either George Grayson's grandson, Grayson Hinkley, or Eureka County Commissioner Fen Fulderson, supplied this story.

#20 *Op cit.*, Patterson, et al., (1969), pp.333. Also, *Op cit.*, Goodwin (1966), Battle Mtn. Sub Basin, pg. 12.

#21 *Op cit.*, Patterson, et al (1969), pp. 333-334.

#22 *Op cit.*, Eureka County land records.

#23 *Op cit.*, Patterson, et al., (1969), pg. 334. Also, *Op cit.*, Eureka County land records. Also, *Op cit.*, Goodwin (1966), Battle Mtn. Sub Basin, pg. 13.

#24 *Op cit.*, Patterson (1969), pg. 334. Also, *Op cit.*, Eureka County land records.

#25 *Ibid.*

#26 *Op cit.*, Goodwin (1966), Battle Mtn. Sub Basin, pg. 13. Also, *Op cit.*, Patterson (1969), Pg. 334. Also, *Op cit.*, *Battle Mtn. Scout* article (1957). Also, *Op cit.*, Eureka County land records.

#27 *Op cit.*, Goodwin (1966), Battle Mtn. Sub Basin, pg. 13. Also, *Op cit.*, Patterson (1969), Pg. 334. Also, *Op cit.*, Eureka County land records.

#28 *Ibid.*

#29 *Op cit.*, Patterson (1969), pg. 334. Also, *Op cit.*, Eureka County land records.

#30 *Op cit.*, Eureka County land records. Also, personal communication,(1980's),Stanford University officials.

#31 *Op cit.*, Eureka County land records.

#32 *Ibid.*

#33 *Ibid.*

#34 *Ibid.* Also N.S.P.C. records regarding the 1950's State Park proposals identify the buyers of this particular portion of the Geysers' area.

#35 *Op cit.*, Eureka County land records. Also, a 1964 Sierra Pacific Power Co. map of Geysers' area shows these two test wells, plus the others that had been drilled up to 1964/65.

THE PARK AND MONUMENT PROPOSALS: 1934-1960.

#1 *Op cit.*, Bowers (?), (1956), pg. 19.

#2 Frank Smyth, "The Sad Story Of Beowawe's Geysers", *Nevada Highway News,* (May, 1972), pp. 2-5. Smyth, on page 2 of his article, mentions that railroad conductors on the Southern Pacific and Western Pacific passenger trains used to point out the Geysers' area to passengers. Mr. Martin Milano, formerly a long-time resident of Beowawe, Nv. (now living in Elko, Nv.) told this writer in Oct. 1988, a similar story that "news butchers" (those who sold newspapers, etc., while on the trains) also pointed out the geysers.

#3 *Ibid.*, Smyth (1972), pg. 3.

#4 *Op cit.*, Bryan (1977), pg. 53-55.

#5 *Ibid.*, pg. 53.

#6 Letter, dated April 23, 1985, from Steve Weaver, Assistant administrator, Nevada State Parks Dept.

(N.S.P.D.), Carson City, Nv., to John Walker, Office of Community Services, 1100 E. William, Suite 117, Carson City, Nv. (Letter on file with B.L.M., Battle Mtn. office, Nv.)

#7 *Ibid.*

#8 Lawrence C. Hadley (compiler), N.P.S., *Suggested Areas Resumes* , (January 1957), N.P.S. Region #4-Nevada, pg. 1. Compiled in the Branch of N.P.S. Planning, Washington, D. C. Also, (unknown compiler), N.P.S. (1947), N.P.S. Region #4-Nevada, pp. IV-13.

#9 *Ibid.*

#10 Fred L. Israel, *Nevada's Key Pittman*, (1963). This book contains much information on Senator Pittman and his often stormy relationship with Harold Ickes. Unfortunately, there is nothing in this book about Pittman's request for the establishment of a "Beowawe Geysers National Monument".

#11 Letter, dated Sept. 28, 1937, from Mr. Scrugham to the Director of the N.P.S., Washington, D.C. Letter in N.P.S. records at N.A./W.

#12 N.A./W. N.P.S. Records group #79, *Proposed National Monuments* File #0-35, under the classification of "Central Classified Files," copy of the Scrugham letter, the N.P.S. evaluation/ report on the Beowawe Geysers' area, and misc. N.P.S. letters on this subject.

#13 *Op cit.*, Hadley/N.P.S. (1957), Nevada, pg. 1. Also, Letter, dated June 8, 1938, Arno B Cammerer, N.P.S. Director to Senator Pat McCarran. In N.A./S., N.P.S. Region Four records, (1935 to 1953), "Nevada-Misc. Proposed Areas" (File # 0-32).

#14 Franklin C. Potter, (1935), *Beowawe Geyser Area, Eureka County, Nevada*, adapted by Potter from Nolan & Anderson's 1934 *American Journal Of Science* report on the Beowawe Geysers' area, so stated on pg. 1 of Potter's evaluation/report. The last page of this evaluation/report is signed, "Franklin C. Potter, Associate Geologist".

#15 *Ibid.*, pp. 3-5, with pg. 4 consisting of two sketch drawings of the sinter terrace and a geyser in eruption, by M. E. Prescott. The text description is largely a rewording of Nolan and Anderson's 1934 report.

#16 *Ibid.*, pg. 3 & 5.

#17 *Ibid.*, pg. 5.

#18 *Ibid.*, pg. 7.

#19 This writer has searched Key Pittman's papers held at the N.H.S., in Reno, Nv., as well as having others search Pittman's papers at the Library Of Congress, in Washington, D. C. The Civil Archives Div. of the National Archives, Washington, D. C., searched the N.P.S. records for Pittman and McCarran without turning up their correspondence on this subject.

#20 Scrugham received the "bad" news about his "Beowawe Geysers National Monument" proposal from A. H. Demaray, Acting Director of the N.P.S., in a letter dated Oct. 20, 1937. McCarran received an almost identically worded reply from N.P.S. Director Arno B. Cammerer, in a letter dated June 8, 1938. N.A./W.

#21 Letter, dated Oct. 20, 1937, from Demerey to Scrugham; N.A/S, N.P.S. records' File #0-32, "Nevada-Misc. Proposed Areas".

#22 The full title of this report is: *Park, Parkway, and Recreational Area Study* (1938), by the combined efforts of the N.P.S., N.S.P.C. and the N.S.P.B. (Nevada State Planning Board). Specific references to the Beowawe Geysers in this report are: "Map of the State of Nevada; Potential Park & Recreational Areas", and, "Park, Parkway and Recreational Area Study-Summary Report Of Potential Areas".

#23 *Ibid.*, "Summary Report".

#24 *Ibid.*

#25 Allen to Floyd, Letter, dated Oct. 1, 1937. N.S.A./N.S.P.C. files.

#26 *Ibid.*

#27 *Ibid.*, Letter, dated Oct. 1, 1937, from Acting Director, N.P.S. Region #4, Perry R. Gage, to Robert A. Allen.

#28 Duplicates of these four photos are in this writer's Beowawe file.

#29 Apparently the records of Region #4 of the N.P.S. went to the San Francisco Branch of the National Archives, which is at San Bruno, Calif. according to Kathleen O'Connor, Archivist, at that branch of the National Archives. Personal comminication.

#30 Copies of these photos area also in this writer's Beowawe file.

#31 *Op cit.*, Allen to Floyd. Oct. 1, 1937.

#32 *Op cit.*, E.T. Allen to R.A. Allen, N.S.A./N.S.P.C. Letter, dated Feb. 24, 1937. In care of Nevada Dept. of Highways.

#33 *Ibid.*

#34 *Ibid.*

#35 C.W. West to R.A. Allen, N.S.A./N.S.P.C. files. Letter (12 pages long), dated May 2, 1938.

#36 *Ibid.*, pg. 11, under "Recommendations".

#37 N.S.A., Governor E.P. Carville's files (1939), N.S.P.C. meeting minutes for April 12, 1939.

#38 *Ibid.*, N.S.P.C. meeting minutes for April 12, 1939; pg. 6.

#39 *Ibid.*, Allen to Carville, May 1, 1939.

#40 *Ibid.*

#41 About ten letters, if one includes the copy of a letter that Milton B. Badt sent to Dean Witter, with a carbon copy to Carville. All of these letters are from Carville's files at the N.S.A., in Carson City, Nv.

#42 N.S.A./Gov. Carville's files.

#43 *Ibid.* This is the carbon copy mentioned above.

#44 *Ibid.*

#45 *Op cit.*, Carville's files.

#46 *Ibid.* Carville files. Letter, dated June 9, 1939; Greathouse to Carville. N.P.S.C. member Archie Grant suggested to Carville, in a letter dated May 29, 1939, that C.C.C. workers be used to "improve" the Geysers' area.

#47 N.S.A./Carville'sfiles,N.S.P.C meetingminutes, Dec. 6, 1939, pg. 6.

#48 N.S.A./Carville's files: Gov. Carville was acknowledging Marden's letter of Nov. 2, 1938, a letter that has not been located.

#49 *Ibid.* Letter dated Nov. 8, 1939; Carville to West.

#50 *Ibid.*

#51 *Ibid.* The only item that resembles a sketch of the Geysers' area is a map of same that shows 12 thermal spring vents on the sinter terrace, coupled with the names of the two principle landowners of the area (Sec. 17, T. 31 N., R. 48. E.); the land owners are the Humboldt Land and Cattle Co. (a Dean Witter-owned enterprise) and the S.P. Land Co., which can only be Southern Pacific Land Co.

#52 *Op cit.*, N.S.A./Carville's files, N.S.P.C meeting minutes, (Dec. 6, 1939), pg. 6.

#53 N.S.P.D. Assistant Administrator Steve Weaver's 30+ page report on the history of Nevada's State Parks program, completed in 1988.

#54 *Ibid.* Also see Mary E. Glass, *Nevada's Turbulent 50's*, (1981), pg. 22.

THE STATE PARK PROPOSAL: 1954 TO 1960

#1 *Op cit.*, Glass (1981), pg. 22.

#2 *Ibid.*

#3 *Ibid.*, pp. 11-12.

#4 N.S.A./State Parks files, Memo, Dec. 17, 1958, pg. 1.

#5 *Op cit.*, Glass (1981), pg.23. Also, N.S.A., Gov. Russell's files: Letter, dated Sept. 17, 1954, Russell to Lawrence C. Merriam, Director, N.P.S. Region #4, San Francisco. Also see Merriam's letter of September 9, 1954, on this same subject.

#6 U.N.R./S.C., Col. Thomas W. Miller's papers, Letter, dated Oct. 19, 1954, Herbert Maier, Acting Dir., N.P.S. Region #4, to Gov. Russell and N.P.S. evaluation of Nevada's State Park system with list of potential State Park sites. Raymond E. Hoyt, who prepared this evaluation/list also prepared the 1938 "Nevada Parks" report.

#7 *Ibid.*, N.P.S. 1954 evaluation/list, pg.2.

#8 N.S.P.D./N.S.P.C., June 15, 1955, N.S.P.C. meeting minutes Agenda list; Exhibit "C" lists 41 sites, including existing and potential State Parks, including the Beowawe Geysers. Of interest is the fact that Steamboat Springs, south of Reno. Nv., is not on this list, nor is that site on the 1938 and 1954 N.P.S. lists of recommended potential State Park sites.

#9 *Ibid.*

#10 There is the possibility of locating these minutes in other files of State officials for 1955, e.g. Gov. Russell's papers, Col. T.W. Miller's papers, etc.

#11 Mr. & Mrs. Martin Milano, personal communication, Elko, Nv., 1988.

#12 N.S.P.D. Beowawe file, #319.0. This file containst over 60 items regarding the 1957-1960 and 1970's State Park proposals for the Beowawe Geysers.

#13 *Op. Cit.*, Steve Weaver, N.S.P.D. histoy of Nevada's State Park system.

#14 *Op. Cit.*, Woods to Miller, letter dated July 23, 1957.

#15 The N.S.P.D. Beowawe file shows that Wood's last known letter on this subject is dated June 11, 1959.

#16 *Ibid.*, N.S.P.D. Beowawe file.

#17 *Ibid.*

#18 Woods sent letters to several state officials, including Gov. Russell, in an attempt to spur the State Park Commission into moving on the state park proposal for the Beowawe Geysers.

#19 *Ibid.*, N.S.P.D. Beowawe file.

#20 Part of the problem may reside in the incomplete information that Eureka County officials supplied the State Park Commission regarding the exact acreage involved.

#21 *Op. Cit.*, N.S.P.D. Beowawe file. Ed Delaney, Eureka County Clerk, replied on September 3, 1957 to Squires' letter of August 29, 1957, that R.H. Hadley owned the Geysers. In fact, he did not own all of that site. How this error might have affected the Park Commission's plan for the Geysers area has not been determined.

#22 *Ibid.*

#23 *Ibid.*

#24 *Ibid.* Letter and draft of "use permit" from N.S.P.D. Director Howard W. Squires to R.H. Hadley.

#25 The records consulted regarding the state park proposal, including N.S.P.C. and N.S.P.D. files, failed to turn up a reply.

#26 U.N.R./S.C., Col. Thomas W. Miller papers, N.S.P.C. "Outline Of Special Activities, From 7/1/57 to 12/31/57", dated January 20, 1958. This "Outline...", (page 4, Item #11) states: "Beowawe Geysers proposed State Park. On 12/20/57, a proposed 'Use Permit' together with land descriptions, proposed recreational installations and maintenance was sent to Mr. R. H. Hadley, the owner of this area. No reply as yet."

#27 At least two different Nevada newspapers noted the lack of money needed to hire a custodian. (See notes #29 & #30, below.)

#28 N.S.A., Gov. Russell's files, *Reno(?) Gazette* newspaper article, dated 7/29/57. There is no reporter credit other than the story originated in Eureka, Nv.

#29 *Ibid.*

#30 *Ibid.*

#31 *Ibid.* The correct date of the Journal's editorial is August 28, 1957.

#32 *Ibid.*

#33 *Ibid.*

#34 *Elko Free Press*, Elko, Nv. Article entitled, "State Park Squabble Boils Over At Meet." Date of article is Wednesday, Oct. 30 1957, and this article describes the dispute as "The simmering feud between State Park Director Howard P. Squires and California paleontologist Dr. Charles Camp..."; the "squabble" lasted for an hour and a half at one point, says this article! The importance of this N.S.P.C. meeting, held Oct. 29, 1957, and the "squabble" is that at this same meeting, the Beowawe Geysers State Park proposal was thoroughly discussed. See note #35, below.

#35 Newspaper article, "Steps Are Taken To Bring Geysers Into State Parks," Friday, Nov. 1, 1957 issue of the *Elko Daily Free Press*.

#36 N.S.A., N.S.P.C. files. Transcribed recording of the Oct. 29,1957 meeting of the N.S.P.C., pp. 113-117 deal with the proposed State Park for the Beowawe Geysers' area.

#37 D.E. White, personal communication. Also see White's Beowawe Geysers report (U.S.G.S. Prof. Paper, in press).

#38 *Op cit.*, N.S.A., N.S.P.C. files. Transcribed recording of the Oct. 29,1957 meeting of the N.S.P.C., pp. 113-117.

#39 Elko County Courthouse, Elko, Nv. Defendant case #10426, *Flora M. Thuraton v. The Boy Scouts of America*. Case filed Aug. 29, 1963.

#40 *Op cit.*, N.S.P.C. meeting transcription, Oct. 29, 1957.

#41 *Ibid.*

#42 *Ibid.*

#43 N.S.P.D., N.S.P.C. meeting minutes for May 5, 1958: pp. 12-13, Beowawe Geysers' area.

#46 *Ibid.*

#47 *Op cit.*, Goodwin (1966). *Op cit.*, Patterson (1969), sections pertaining to the history of the Horseshoe Ranch.

#48 Examination of available State Park Commission/Park Department records on the proposed Beowawe Geysers' State Park reveal that some discussion between the MacMillans and State Park officials took place, but apparently a "Use Permit" similar to the one sent to R. H. Hadley, was not sent to the MacMillans. That is a missed opportunity, the MacMillans were interested in the establishment of a State Park at the Geysers. See note #53.

#49 N.S.A., Gov. Russell's files. Mrs. Smithwick sent Russell a letter on May 20, 1958; Miss woods letter was sent to Russell on May 15, 1958.

#50 *Ibid.*, letter, dated May 15, 1958, Woods to Russell.

#51 *Ibid.*

#52 *Ibid.*, letter, dated May 22, 1958, Russell to Woods. Also, letter, dated May 27, 1958, Russell to Smithwick, Chairman of Park Committee, Beowawe Ladies Sagebrush Club, Beowawe, Nv.

#53 N.S.P.D. Beowawe file (#319.0). Letter, dated Oct. 7, 1958, Smith to Col. Miller. Smith informed Miller that he was sure that his clients, the MacMillans, could "...go along with the arrangements which were previously being made with Mr. Hadley concerning these geysers." The letter has an additional note on it, dated May 25, 1959, stating: "Talked with Mr. Smith, stated, 'Mr. MacMillan & wife have been away a great deal of the time.' Mr. Smith feels reasonably sure that if the [State Park] Commission will submit a final draft to be signed by Gordon MacMillan and Dorothe Macmillan, wife [the present owners of 160 acres of Beowawe Geysers], contingent upon an appropriation next year, that they will sign it. This will give the Park Commission a basis to work with for an appropriation. Note: Any agreemnt [sic] binding the State must be approved by the Office of the Attorney General. [signed] HWS" (Howard W. Squires, the State Park Dept. Director) As shown below, the "appropriation" for the Geysers' area failed to be approved in time by the Nevada State Legislature.

#54 *Op cit.*, Glass (1981), pg. 24.

#55 N.S.A. Letter and 11 page list of recommendations and suggestions by Mrs. Wheat, on ways to improve Nevada's State Park system.

#56 *Ibid.*, pg. 5, Part B, of Mrs. Wheat's list.

#57 N.S.P.D. Beowawe file, letter, dated June 8, 1959.

#58 N.S.P.D. Beowawe file, letter, dated June11, 1959.

#59 N.S.P.D. Beowawe file, letter, dated June 13. 1959.

#60 N.S.P.D. Beowawe file: letter, dated June 16, 1959.

#61 *Ibid.*

#62 *Ibid.*

#63 *Ibid.*

#64 N.S.P.D., Beowawe file, letter dated June 17, 1959.

#65 *Ibid.*

#66 *Ibid.*

#67 *Ibid.*

#68 *Ibid.*

#69 *Ibid.*

#70 *Ibid.*

#71 Again, part of the problem with identifying the Geysers' acreage appears to reside with the Eureka County officials who kept stating that the various owners of the Horseshoe Ranch also owned the Geyser area...which was of course only "half" true!

#72 N.S.P.D. Beowawe file.

#73 *Ibid.*

#74 Dick Richards, Sierra Pacific Power Co., Reno, Nv., personal communication, 1980's.

#75 *Op cit.*, letter, Aidlin to Kramer.

#76 *Ibid.*

#77 Information collected by this writer, including, personal correspondence with officials of the California State Parks Dept. during the 1980's.

#78 *Op cit.*, letter, Aidlin to Kramer.

#79 N.S.P.D. Beowawe file: letter, dated Oct. 5, 1959.

#80 N.S.P.D., memo, dated 11/23/59.

#81 N.S.P.D., letter, dated June 17, 1959, Gould to Kramer.

#82 *Ibid.*

#83 Eureka County land records.

#84 N.S.P.D. Beowawe file: letter, dated Sept. 15, 1960, State Park Dept Director William J. Hart to Robert Batz.

#85 N.S.P.D./N.S.P.C. file, 1955-1960.

#86 *Ibid.*, meeting minutes, dated Aug. 10, 1960, for the State Park Commission. Item #3, Beowawe Geysers area mentioned along with six other named sites.

#87 N.S.P.C. Beowawe file: memo, undated but thought to be 1960.

#88 *Ibid.*

#89 *Ibid.*

#90 N.S.P.D./N.S.P.C. file for 1955-1960. Meeting minutes for Nov. 14-15 1960, pp. 10-11.

#91 Jeffrey Kintop, Archivist, N.S.A, Carson City, Nv. Personal communication in the 1980's.

#92 *Op. Cit.*, N.S.P.D. Beowawe file (#319.0). Letter, Milano to Cronkhite. Smythe's article on the Beowawe Geysers' area has been covered earlier in this report.

#93 *Ibid.*

#94 *Ibid.*

#95 *Ibid.*

#96 *Ibid.*

#97 *Ibid.*

#98 *Ibid.*

#99 *Ibid.*, N.S.P.D. Beowawe file (#319.0). Letter, dated January 12, 1973, George L. Burtness, for Augsburger, Acting Manager, Land Resources, Stanford University, to Eric Cronkhite, Administrator, N.S.P.D.

#100 *Ibid.*, N.S.P.D. Beowawe file (#319.0). Last (?) piece of correspondence in the N.S.P.D. Beowawe file is a letter dated May 15, 1973, from Eric Cronkhite to Mr. Thomas Conger & Co., regarding Conger's inquiry as to the plans the State of Nevada has for the Beowawe Geysers' area: Conger & Co. were preparing a "General Plan" for Eureka County in 1973.

#101 Eureka County land records.

#102 Information obtained by the writer while visiting Chevron's Beowawe geothermal power plant, in Oct. 1988.

#103 The one area suggested in 1938 that was adopted into Nevada's State Park system by 1958, is "Fort Genoa," in Douglas County.

THE NATIONAL NATURAL LANDMARKS PROGRAM

#1 N.P.S./Western Region, San Francisco, Calif. Personal Communication, July, 1987. N.P.S. file on the Beowawe Geysers' area as a suggested "National Natural Landmark."

#2 *Ibid.*, letter, dated May 1, 1979, Rodney Harris, B.L.M., Elko, Nv. to John Cherry, Regional Dir., Heritage Conservation & Recreation Service, Pacific SW Region, San Francisco, Ca.

#3 *Ibid.*, letter, May 1, 1979, Harris to Cherry (and Ms. Lynne Nakata).

#4 This may be a reference to the B.L.M. Environmental Assessment that the Battle Mountain (Nevada) office of the B.L.M. issued in March of 1985, on the Beowawe Geysers: There is a chance that the Elko office of the B.L.M. issued a separate Impact Statement on the Geysers.

#5 *Op cit.*, letter, May 1, 1979, Harris to Cherry, et al.

#6 Rodney Harris, B.L.M. Elko, Nv., Personal communication, April 2, 1987.

#7 There are a number of so-called "geysers" in the United States that are drilled wells: The "Calistoga" geyser in California, the "Lakeview" geyser in Oregon, and the "Crump" geyser in Oregon, are all drilled hot water wells that exhibit geyser-like characteristics. There are also the two carbon dioxide powered "geyser wells" in Utah, that too, "erupt" water periodically. None of these "geysers" are natural geysers, but they are often thought of as geysers. D.E. White has expressed the opinion that any hot spring that exhibits geyser activity because of the effects of geothermal exploration should not be considered a "natural" geyser. The B.L.M. letter of May 1, 1979 really confused the definition between a natural geyser and a drilled well that behaves like a geyser (both erupt hot water and steam, comingled) by indicating that "...14 small...geysers..." became just two "geysers" spouting "steam" 50 ft. into the air.

#8 A variety of sources were used in an attempt to pin down an exact date of the vandalization of these geothermal wells. So far, the best that can be said is the vandalization took place before May of 1972, but after September 1970, when I was at the site and these wellheads were intact.

#9 This report was prepared under a contract between the N.P.S. and U.N.L.V., but Bostick recently indicated that he did most of the work on it, including a year of unpaid work because the funds allotted were exhausted! Personal communication, April, 1989. The data on the Beowawe Geysers' area appears on pages 64-65 of the Bostick/N.P.S. report.

#10 *Op cit.*, N.P.S./Western Region, San Francisco, Calif. N.P.S. file on the Beowawe Geysers' area as a suggested "National Natural Landmark."

#11 *Ibid.*, N.P.S./Western Region, San Francisco, Calif. Personal Communication, July, 1987. N.P.S. file on the Beowawe Geysers' area as a suggested "National Natural Landmark." Letter, dated 4/12/79, Eugene Wehunt, National Natural Landmark Project Coordinator, N.P.S., San Francisco, to Barbara Kelly, Real Estate Dept., Stanford University.

#12 N.P.S./Western Region, San Francisco, Calif. Personal Communication, July, 1987. N.P.S. file on the Beowawe Geysers' area as a suggested "National Natural Landmark."

#13 *Ibid.*

SOME FINAL THOUGHTS

#1 *Op cit.*, Bryan (1977).

THERMAL SPRING ACTIVITY: 1969/70 and 1988

#1 T. Scott Bryan's 1986 edition of his book, *The Geysers Of Yellowstone*, has two photos of this geyser in eruption, pp. 259-260.

#2 This writer recalls that someone at the Sierra Pacific Power Co. offices, in Reno, Nv. told him that Sierra Pacific staff opened two of the geothermal wells. Personal communication, 1969(?).

THE GEYSERS OF MEXICO - A SUMMARY

T. Scott Bryan

The following is a general description of five known or reported geyser occurrences in Mexico. All five have received historical descriptions. Two of these definitely do include true geysers at this time, another is an active thermal area and probably does involve geysers, a fourth certainly has but only after major scale earthquakes, and the last has likely never had an actual geyser. This paper will include historical descriptions of all five areas. For the first three there is also a description of my findings on visits during January and February 1981.

Ixtlan de los Hervores, Michoacan

Per the literature, the most important of the Mexican geyser fields is that lying immediately east of the village of Ixtlan de los Hervores and partially encompassing the smaller community of Salitre. The hot springs are adjacent to the main highway between Laguna Chapala and Zamora in central Michoacan.

Geothermal drilling was conducted at Ixtlan during the early 1960s, and as a typical result most of the geysers of the central, most intense portion of the basin have been severely altered or destroyed. The government has established something of a recreational park at the site. There are some picnic tables under some scrubby trees but no displays. We were charged five pesos each for entry.

The earliest description of these geysers was written by Paul Waitz in 1906, published in French for the Transactions of the International Geological Congress, which met in Mexico City that year. Waitz described 14 geysers. Most were quite small, ranging from about 1 to 6 feet high, but were frequently active. The intervals were generally less than two hours.

The largest geyser was Pozo Verde ("Green Spring"). In 1906 it was said to erupt just once per year, but then with "much force and splendor." Waitz does not list a height. In 1952, this geyser and the nearby Pozo Tritubulario ("Three Vent Spring") were both frequently active to about ten feet high.

Upon our 1981 visit we were disappointed at first. The geysers within the park area showed no signs of recent activity. Most either appeared dry or had only a bit of tepid water standing at a low level. All were choked with garbage. A geothermal bore nearby erupted constantly to about 30 feet.

The disappointment continued, at first, when the area near Salitre was visited. I found Verde and Tritubulario with no problem. Their water levels were higher and temperatures were higher than in the springs to the west, but there was no evidence of high-temperature eruptive action. The runoff channel from Tritubulario was damp and recently used, yet a prickly pear cactus about two feet tall grew in the same channel. Both springs were filled with thick green-brown algae and both waters were less than 130°F.

As I began to return to the car I saw and eruption. Just behind the building of Salitre, it was surely Waitz's Geyser Salitre, described by him as the most vigorous spring in the area. In 1906 it was in continuous ebullition, punctuated by frequent eruptions. Unfortunately, he says nothing about interval, duration, or height. This eruption I saw reached about three feet and lasted fully five minutes after I first saw it. When the eruption ended the pool drained quickly with a very fine whirlpool. The crater contained numerous leafy branches and, as soon as the eruption was done, a number of children approached from the village.

I don't know what the plant was, but the children had clearly been cooking it. While most busied themselves with removing the plant and returning to the village, I asked (in my poor Spanish) for some information. Things were not very clear, but I gathered that eruptions were common. I waited awhile, but although the pool alternately filled and dropped every few minutes I saw no further eruption. Based on this one short visit, Geyser Salitre was apparently the only active geyser left at Ixtlan. Others might have been active, but only infrequently at best.

Comanjilla, Guanajuato

After the experience at Ixtlan de los Hervores, we expected to find little at the Baleaneros de Comanjilla. The location is at the end of a paved road leading about two miles from the highway between Guanajuato and Leon.

The springs at Comanjilla were first described by Dr. Ernesto Wittich in 1910. At that time the springs were entirely undeveloped. Now it is the site of a large and posh resort catering primarily to Americans and wealthy Mexicans. Rooms started at about $60 per day in 1981. The facility has one huge swimming pool and several spas and steam rooms, all using thermal water. At the time of our visit there were just two cars in the parking lot. There seemed to be no disappointment, though, when we turned out to not be customers. The manager, who spoke excellent English, seemed pleased that somebody wanted to look at his hot springs. He led me behind the main building and instructed the gardener that I was free at wander at will for as long as I wanted. So, I spent about four hours among the geysers, and geysers there were.

Back in 1910, Wittich makes clear descriptions of five geysers and several perpetual spouters. It is now somewhat difficult to correlate most of his springs and names with existing features., and it is certain that several significant changes have occurred during the intervening years.

The largest geyser in 1910 was Geyser Humboldt. It showed three kinds of eruption. Minor play was nearly constant, both intervals and durations being about 6 seconds and the height reaching one foot. These were punctuated by major eruptions every 20 seconds to several minutes, again lasting only a few seconds but reaching up to three feet high. Last were rare "great" eruptions; they were of unstated duration but reached up to six feet high.

In 1981 Geyser Humboldt was dormant. I decline to say dead, as the runoff channel was clear and unvegetated. The spring, though, was at a low level and thoroughly choked with algae of an odd pinkish color. The temperature in the vent was 142°F. Wittich described eight intermittently boiling springs up the hillside behind Humboldt. None of the showed the slightest signs of existence in 1981.

Geyser Humboldt was the only old spring in a natural state; all the others with the sole exception of a small geyser of recent origin (see below) have been covered, cemented, and/or fenced. Several, however, were active geysers. El Horno is a concrete structure covering several geysers and spouters. How many is impossible to state as there was certainly no entry. By peering through some openings I could see at least three erupting features, and one of them was intermittent. Its interval was around 20 seconds, duration five seconds, and height fully six feet, enough to strike the roof of the chamber.

Nearby was a geyser within a concrete basin. It played vigorously and every few minutes, reaching perhaps three feet high. Another similar spring did not erupt for me, but beaded geyserite on the concrete far above the water level plus washing in the surroundings both indicated strong, relatively common action.

The best geyser I saw was the nearest to the building. Once lines with brick, the activity has broken the wall apart and carved a cavernous vent into a low bank. It had a single eruption for me. The action sent water outward at a low angle as far as about ten feet. The duration was fully three minutes. This is the only feature that I was told an interval for: "exactly three hours."

The new geyser had recently developed in an area where there were no deposits or other signs of previous activity. Its small vent was mud and the runoff channel contained dead grass. I saw two eruptions about an hour apart, each lasting one minute and playing about two feet high.

There seems to have been essentially uncontrolled development of the springs. Throughout the area are large concrete structures, either old reservoirs or swimming pools. There cement is old and broken and every one contains numerous springs and spouters rising through the floors. I have little doubt that some of these are geysers. There was even one small true geyser erupting a few inches high from beneath the foundation of the laundry room!

In total I observed true geyser eruptions from seven features; two other clearly were geysers although I did not see them play. Add other suspicions and several perpetual spouters and Comanjilla turns out to be a very significant geyser field. All the springs are confined to a small valley not more than 300 feet long and 100 feet wide immediately behind the hotel building.

Araro, Michoacan

Araro is a small village at the eastern end of Laguna Cuitzeo, near the highway between Morelia and Salamanca, in far northern Michoacan. We didn't have much success here. Araro turned out to be a community of a decidedly unfriendly aspect. Many of the cars had California license plates, which might be telling.

The hot springs are located at and near Banos de Huingo, just west of the town. As described by Coyle Singletary of the University of Texas in 1952, they included several small geysers. The largest (of which none are named) erupted 1 1/2 feet high with a total period of 65 to 70 seconds.

One report says that there springs were one of the most sacred places to the early Tarascan Indians, and that they made human sacrifices to the Gods there. Given the unfriendly nature of the place, we made no concerted attempt to visit the springs. Our questions about access received silent stares. We could see them and their steam at a distance, but that was all. Since there has apparently been no form of commercial geothermal development made at Araro, I have every reason to believe that the geysers still exist.

Cerro Prieto, Baja California

The geothermal field at Cerro Prieto is located a few miles south of Mexicali. It has been the site of powerplant developments from more than 20 years, and the natural hot spring regime has therefore been severely altered. It apparently does still include a few small mud pots and fumaroles.

This location has been described as being along "the southern San Andreas Fault System," but to say that is really a misnomer. This is at the north end of the Gulf of California (Sea of Cortez), which as been formed by the East Pacific Rise of the mid-ocean ridge impinging on the North American Continent. These pull-apart zones extend further to the north, with the northernmost positioned at the south end of the Salton sea. This is the only region on Earth excepting East Africa where "sea floor spreading" is occurring within a continental area. Thus the geology of this thermal area is probably more akin to that of Iceland.

The only reference to geyser action at Cerro Prieto that I am aware of was produced by the U.S. Bureau of Reclamation in 1976. I have no yet been able to locate a copy, but information from it was published by Richard H. Sibson in the August 1987 issue of Geology. In this, the implication is that the Cerro Prieto thermal field is essentially sealed. Little geothermal fluid is able to reach the surface unless some event occurs to reopen the overall plumbing system. Such events, of course, are earthquakes.

Large scale earthquakes have occurred repeatedly in this area. Those of 1852, 1915, 1927, 1934, and 1980 resulted in increased hot spring activity; those of 1906, 1940, and 1979 did not. Although the article does not give any magnitude, earthquakes in this region typically reach Richer 6.5 to 7.2. "Hydrothermal eruptions after 1915 and 1852 shock were particularly violent; columns of mud and hot water reached estimated heights of 200-300 meters. In 1852 geysering continued for several months after the main earthquake, reintensifying after major aftershocks" (emphasis mine).

Whether any of this action included what can be called true geysers is not made clear, but the author does make a distinction between surface effusions and geysering. I am still attempting to locate references to these events and hope to have more to report in the future.

El Marmol, Baja California

El Marmol is within the central mountainous portion of the Baja Peninsula, about 350 miles south of the border. There are low-temperature thermal springs in the area. The travertine formed by them is extensive, and has been mined as a decorative building material. One geyser has been described in the El Marmol area, but the water temperatures and general geology are not right for true geyser activity.

The "geyser" is called Pozo Volcan ("Volcano Spring"). Even whether it has ever erupted in any fashion is controversial. Dr. Gordon Gastil, of San Diego State University, is an expert on Baja geology, and in his experience Volcan has never even flowed. He says that the deposits everywhere on the terrace appear old and badly decayed. All deposits are travertine; there is no trace of geyserite. What spring water is present in the area is cold.

However, an article in the December 1947 issue of Desert Magazine describes this "geyser" in some detail. It is important that the stated descriptions are based on the reports of the natives and the author did not see any eruptions himself. Pozo Volcan was reported to erupt once a month. A steady and massive column of water was shot to about 60 feet high for several minutes, with enough force to shake the ground at the village five miles away.

Taking all on balance, I feel that Volcan probably has erupted but that it is not a true geyser. The waters throughout the area are highly charged with carbon dioxide. With a proper structure, such springs can erupt. Pozo Volcan, when it is active, is a cold-water "soda pop" geyser, curious but not the real thing.

References

Sibson, R.H., 1987. "Earthquake rupturing as a mineralizing agent in hydrothermal systems." *Geology*, v. 15, no. 8, pp. 701-704.

Singletary, C.E., 1952. "The Hot Springs, geysers, and solfataras of the northern part of Michoacan, Mexico." *Texas Journal of Science*, v. 4, no. 4, pp. 413-420.

Waitz,P., 1906. "Los Geysers d'Ixtlan." *10th International Geological Congress, Mexico City, 1906, Guide 12, Excursions de l'Quest*, 22p. (In French, translation by M. Short and C. MacIntosh, 1977.)

Walker, L.W., 1947. "Nature's onyx factory." *Desert Magazine*, December 1947, pp. 13-15.

Wittich, E., 1910. "Geysers y maintiales thermales de Comanjilla." *Mexican Geological Society, Bulletin 2*, pp. 71-85. (In Spanish, translation by T.S. Bryan, 1978.)

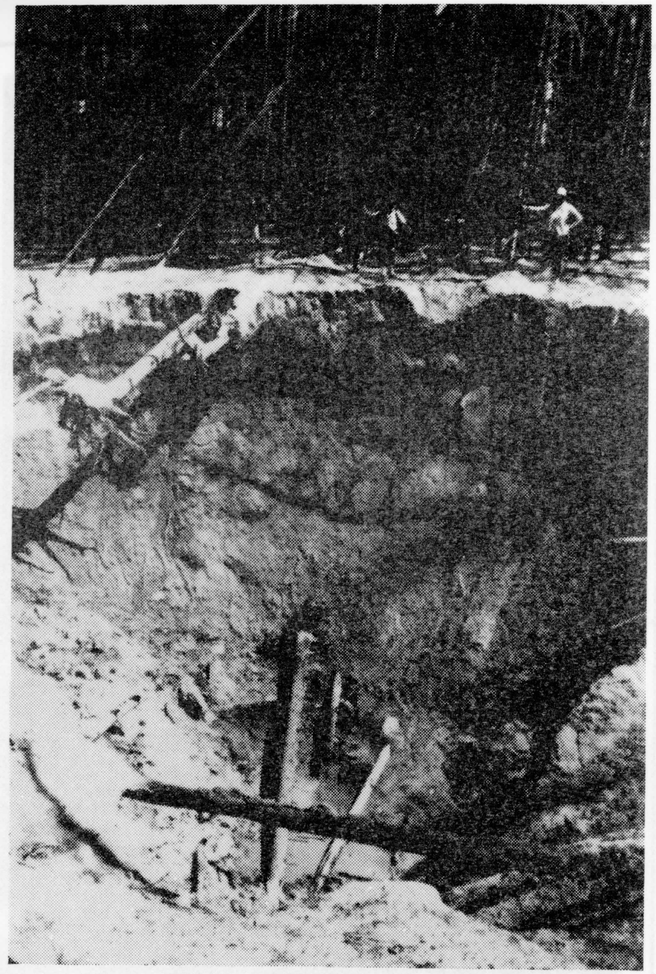
INDEX

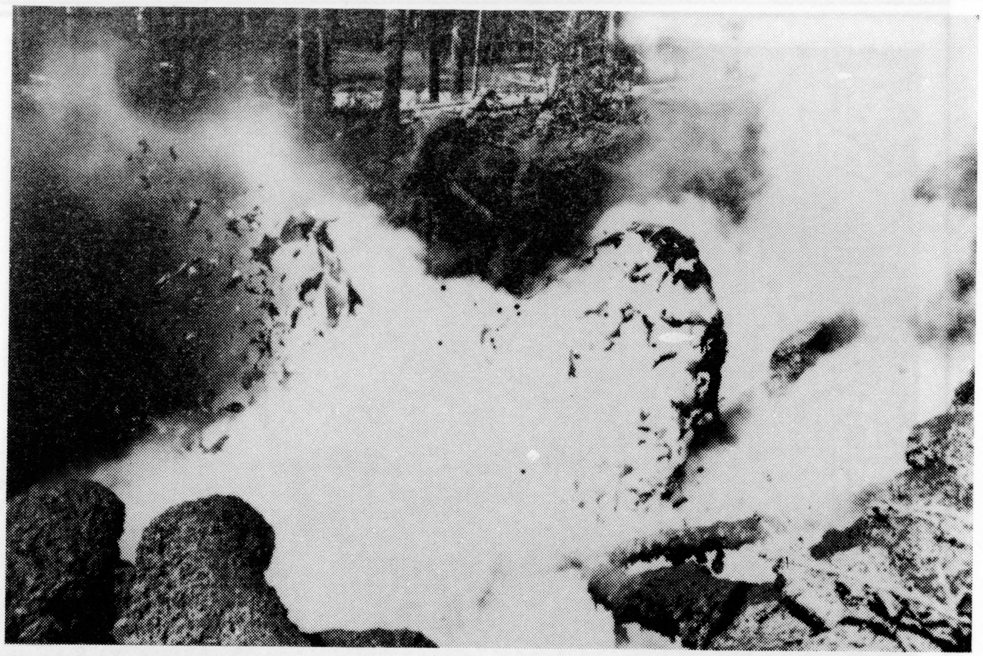
KOENIG, STEAMBOAT SPRINGS.

Photo 1. Geyser 42w.
Photo: P. Strasser.

HOBART, FANTAIL GEYSER.

Figure 1. Fantail Geyser and GOSA representatives.
Photo: J. Hobart.

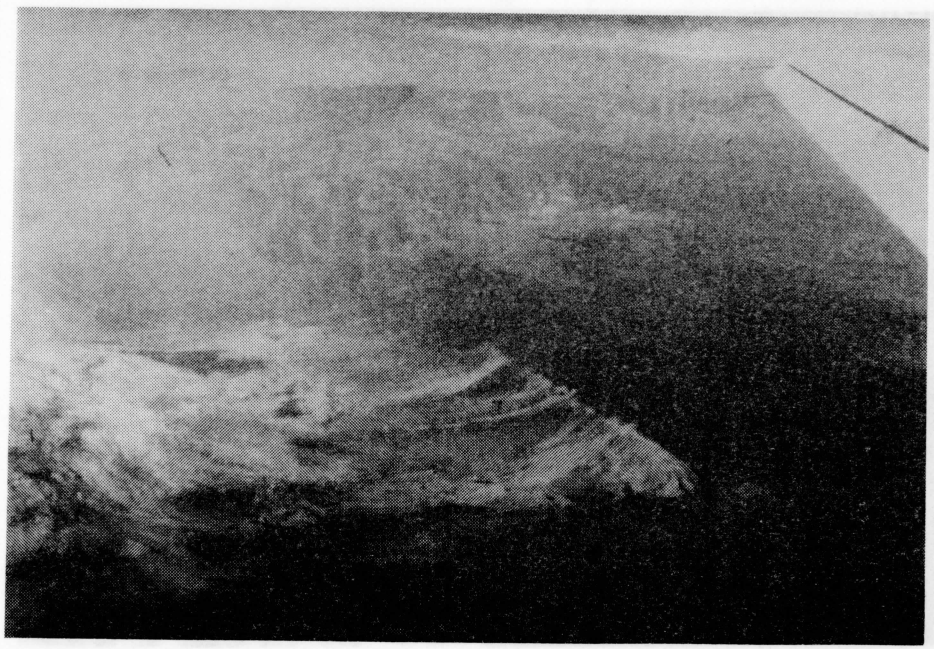




TOP LEFT: Figure 1.
A typical eruption from the second explosion crater. Photo: J. Hobart.

BOTTOM LEFT: Figure 2.
Multiple eruptions from second explosion crater.
Photo: J. Hobart.

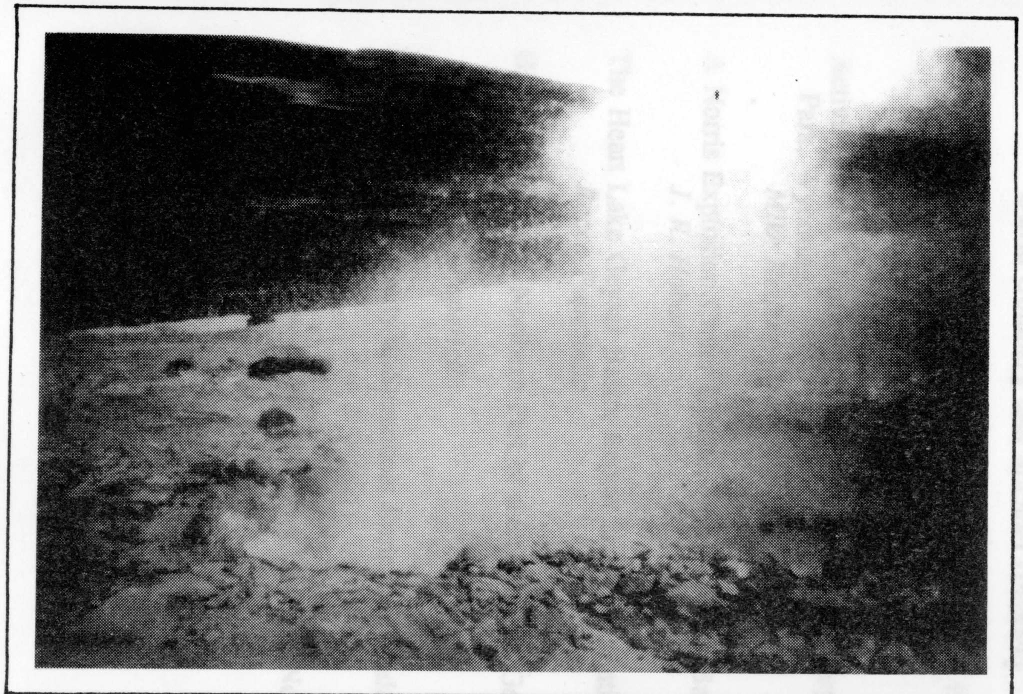
TOP RIGHT: Figure 3.
Status of the first explosion crater as of July, 1987.
Photo: J. Hobart.

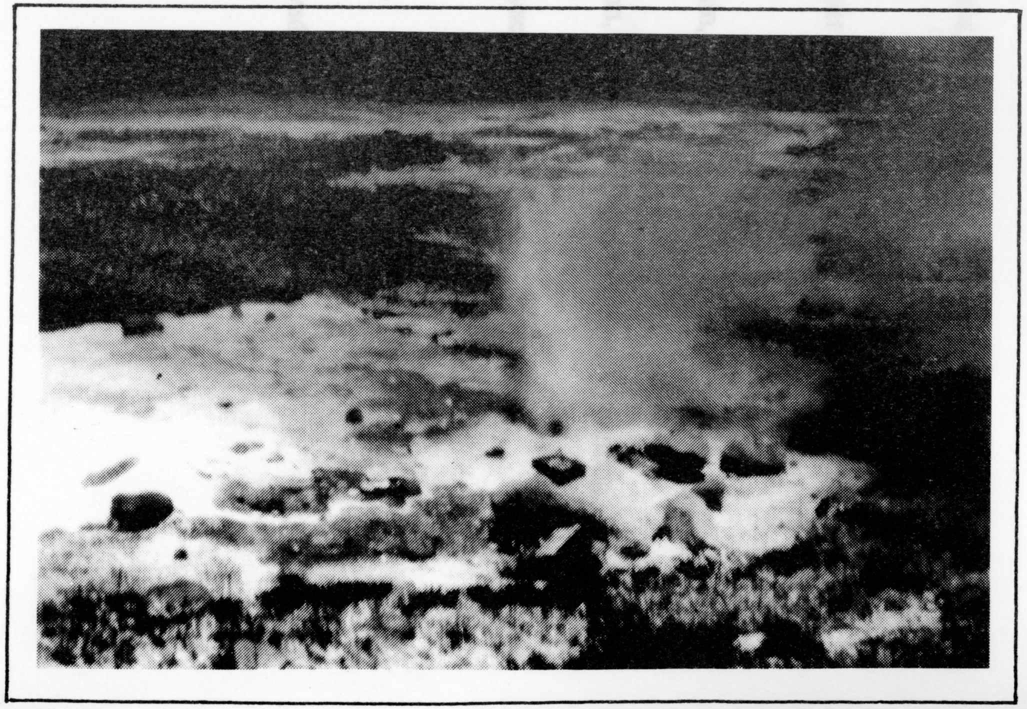


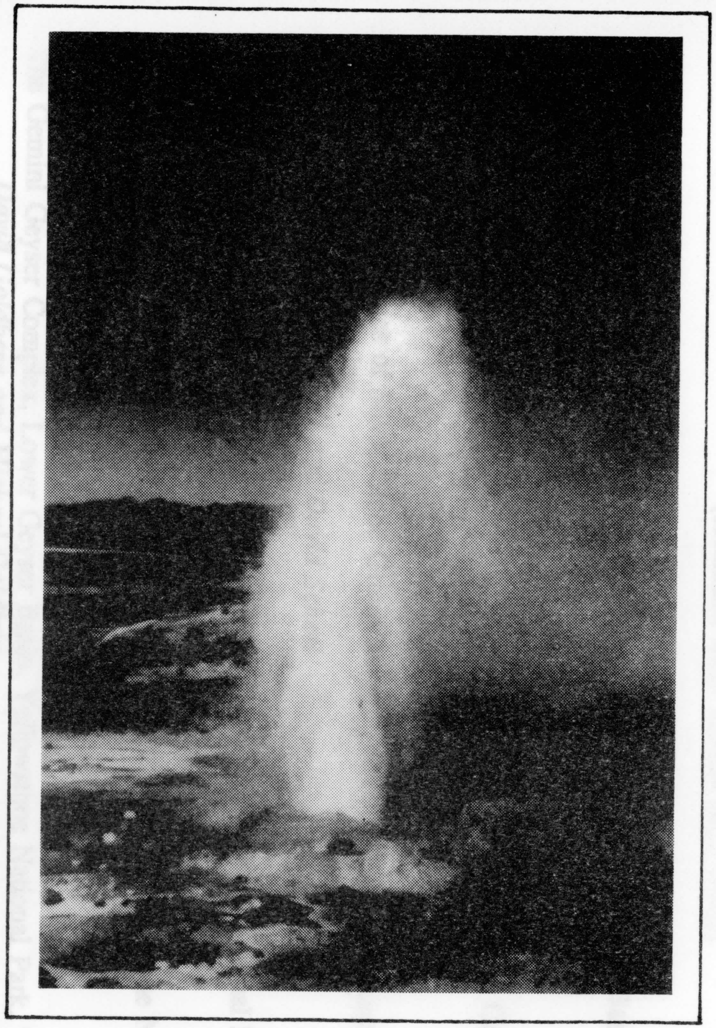
TOP LEFT: View of middle section of Beowawe Geysers sinter terrace, 1930s. View direction - south. Photo: c/o Nevada State Parks Dept., probably Robert Allen.

BOTTOM LEFT: Beowawe Geysers sinter terrace from the air, view towards the east, 10/18/51. Photo: c/o George Thompson, Stanford University.

TOP RIGHT: View of Beowawe Geysers sinter terrace, 1930s. Photo: c/o Nevada State Parks Dept., probably Robert Allen.







TOP LEFT: Unnamed geyser on top of sinter terrace, vent #25. Eruption height 3 meters, maximum. Photo taken 8/45(?), c/o D.E. White.

BOTTOM LEFT: "Beowawe Geyser" vent #29, near end of eruption on 5/25/51. N.E. Whirlwind Valley floor in background. Photo: D.E. White.

TOP RIGHT: "Beowawe Geyser" vent #29, near peak of eruption, 8-10 meters high, on 5/25/51. Photo: D.E. White.