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EXCHANGE OF FUNCTION AS A CAUSE OF GEYSER IRREGULARITY[1]

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ABSTRACT. The complex problem of geyser behavior is admittedly far from being solved. All geysers play irregularly, and many with great irregularity. Geysers that play with great irregularity have proved puzzling to former observers. More than fifty months of seasonal observation by the author extending over a period of twelve years have demonstrated that many geysers showing great irregularity are connected subterraneously with other springs and geysers; that from time to time, there is a shift in direction of the flow of the thermal energy from one orifice to another. This shifting of the thermal energy from orifice to orifice and back again is designated as exchange of function. In support of the thesis that exchange of function is one of the causes of vacillation in geyser behavior the behavior patterns of many of the springs and geysers, are described in some detail, especially those in the Daisy and Grand Groups.

INTRODUCTION

THE popular conception of a geyser is that it is a natural mechanism which operates at regular periods. Much of the literature which discusses Old Faithful Geyser gives the reader the impression that this geyser erupts with approximately chronometric precision. A single day of observation in the geyser basins of Yellowstone National Park would reveal that neither Old Faithful, nor any geyser where consecutive intervals can be observed, plays at set periods. Irregularities in the quiet intervals of the geysers are characteristic of all. No geyser offers an exception to this rule. Many, like Old Faithful, may for several eruptions approach regularity, but, when recorded for a longer span, all show considerable fluctuation in the lengths of their quiet intervals.

In discussing irregularities in geysers, Allen and Day (1935, p. 225) state:

"Changes in geysers may be either continuous or fluctuating. Among the various characteristics of these intermittent springs that

[1] Published with permission of Edmund B. Rogers, Superintendent, Yellowstone National Park.

are subject to fluctuations, perceptible in a comparatively short space of time as well as over longer periods, none is perhaps so important from the theoretical standpoint as the time interval between eruptions. *Progressive* changes in the length of this quiet interval are intelligible, but vacillation in behavior is puzzling." These authorities go to some length in considering possible factors which might influence this "vacillation" in geyser behavior, such as weather, gains and losses of heat, and possible variations in water supply, but by way of conclusion they state: "Regarding the whole problem of irregularities in the frequency of geyser eruptions, we are still entirely in the dark."

Since the discovery of Yellowstone's thermal areas the period of observation has been too short to have determined whether or not there is "progressive" change in any geyser's behavior. Old Faithful, the most carefully observed geyser since discovery, does not clearly indicate any progressive or directional change in periodicity; that is, whether the length of its quiet intervals might be, on the average, increasing or diminishing. During the entire period of its observation, Old Faithful, and certain other geysers which will later be indicated, have followed a somewhat definite pattern in their eruptive behavior and have not shown the vacillation, or great irregularity, which is characteristic of so many of the geysers.

It is toward this problem of vacillation in geyser behavior that the present paper is addressed. A number of years ago the realization was forced upon me that, in certain pairs of springs and geysers, changes of behavior take place in a strikingly reciprocal way. The water level in a given spring may undergo a rise, and that in a nearby spring will correspondingly recede. Or a given geyser will cease to erupt, while a neighboring spring or dormant geyser simultaneously enters upon an eruptive cycle. Once this idea was grasped and then observationally confirmed unmistakably for a single example, I recalled numerous other instances that seemed to fit the same general pattern. For these cases, likewise, observation gradually brought confirmation of reciprocal behavior; and added examples were recognized. Inasmuch as a given spring or geyser, though it may be destined to change, may perform in the same general manner for weeks, months or years before it undergoes material modification of behavior, and because my service at the Park since 1937 has rarely included the cold season, the process of confirmation has not been rapid. But it has now become possible to record evidence for a considerable number of examples of what may be termed *exchange of function* between thermal units—hot springs or geysers—occurring in close proximity.

Intimately related to this phenomenon of reciprocal or interchanging behavior is another inseparable condition of at least equal significance. Most of the major geysers give no indication of having direct underground connections with each other. That is to say, the eruption of any particular geyser does not have an observed effect upon other major geysers. A similar implication of mutual independence applies to many of the non-erupting springs. But there are numerous exceptions in each category. In every instance thus far recognized of interchange of function between neighboring units *there is* clear evidence of their subterranean interconnection. Indeed, it appears to be only by virtue of their common accessibility to the same local supply of underground hot water that their reciprocal interchange of behavior is possible. Realization and confirmation of this condition of sub-surface intercommunication arose and proceeded simultaneously with that concerning exchange of function.

The existence of subterranean connection is essential not only to reciprocal or competitive behavior of nearby units. It also permits and explains other notable examples of opposite import wherein neighboring units act strikingly in concert. Exemplification of this is found in the simultaneous rise (or fall) of the water level in two or more nearby springs; or in the approximate or exact coincidence of the beginning of play by neighboring geysers; or in some simultaneous manifestation of aggressive action of nearby spring and geyser, such as respective overflow and eruption.

The recorded data on Yellowstone's thermal areas support the conclusion that the geysers having underground connections with other springs or geysers have shown great irregularity in their active periods; some of them have had eruptive cycles, followed by stretches of dormancy, and *vice versa*. Occasionally some have approached regularity, but none has remained essentially unchanged in the consistency of its periods. The opposite, however, cannot be asserted, for some geysers of conspicuous irregularity are not known to have connection with other springs or geysers.

UNCERTAINTY AS TO IDENTITY AND PERFORMANCE

The desirability is obvious of supplementing the span of my own observation on changing behavior of certain springs and geysers by resort to the earlier accounts. Before discussing specific examples of competitive or reciprocal and of cooperative performance by nearby pairs or larger groups of thermal units, reference may be made to the difficulty of securing from the multifarious past record a sure and consistent understanding of certain pertinent facts. The following comments are introduced not only toward some hoped-for clarification of earlier writings but also because they are believed to bear pertinently on the present discussion.

The present sign at the Splendid Geyser states:

"At one time this was the location of one of the most interesting geysers in this basin, but in 1892 activity ceased from this orifice and a near-by, previously unnamed opening became the source of the Daisy Geyser which can rightfully be considered as the successor to the Splendid."[2]

This does not agree with earlier records. The "Guide to Yellowstone Park[3] (1890), in commenting on the Splendid, states:

"Quite unlike other geysers, the Splendid throws its stream at a sharp angle instead of vertically, which fact, when it was first discovered, caused it to be called the Comet; this designation, however, soon gave way to its present more appropriate appelation."

As now known the Splendid does not play at an angle; its eruptions are vertical. The configuration of the Splendid orifice suggests that only an essentially vertical eruption is possible. The Daisy plays at a *sharp angle*, suggesting a comet. The "Guides" prior to 1890 offer further proof that what is now the Daisy was formerly called the Comet, and later called the Splendid. These two earlier names for the Daisy have apparently become attached subsequently to the nearby units now respectively so named.

[2] Allen and Day (1935), state that the "Daisy Geyser sprang into being when its neighbor the Splendid first became dormant (1896)."

[3] Bauer (1937), quotes Phillips as saying that the Splendid "first played in about 1892 when the Daisy which, up to that time had been obscure, began playing more regularly."

Such uncertainty and ambiguity of identification—a situation by no means confined to the units of the Daisy Group—presumably must be ascribed in part to the brevity of observation, and the common lack of explicitness in the earlier records. Each newcomer to a given site, naturally seeking to correlate his observations with the reports of predecessors, did so in the light of his own impressions and interpretations. But it seems highly probable that if the scene confronting each observer at any site had remained unchanging, far greater agreement would exist among the series of reports on any given spring or geyser. However, if a given geyser at a specified locality is reported as active and is assigned a name by observer A, but proves to be dormant though another geyser is active when B visits that same locality, B is likely to assume that the geyser he sees in action is the same geyser seen in action by A, but naturally B describes it differently. If the scene has again changed when observer C comes along, he may agree with A or B or with neither. In any case, the chance for confusion or ambiguity of identity, naming and description is obvious.

In more recent years, when many competent observers have viewed the Park, some of them repeatedly, and when reasonably accurate sketches of the location and names, and reasonably realistic descriptions of individual units have been published in accumulating numbers, fewer additions to the earlier stock of errors and uncertainties have been made. Yet the old contradictions and confusions have not been adequately explained and removed.

Some of the modern accounts correctly record certain modifications in behavior of certain geysers, such as cessation, revival or noteworthy change in period of eruption. But, on the whole, these changes of behavior are presented as if, and seem to be accepted as if, they were chance, unrelated happenings—mere challenging puzzles. The challenge and the puzzlement would, by such view, greatly increase if the complete number of instances of change in function were on record—record not only as to number of individual springs and geysers involved but also as to number of changes of function back and forth for given individuals.

The early magnified impressions of great regularity in geyser behavior—still retained by many people—and the more recent and realistic awareness of striking though unexplained irregularity still add up to confusion, as Day and Allen have so truly emphasized. It is to be hoped that clear recognition of frequent instances of subterranean interconnection and of both competitive and cooperative action by units so interconnected may help dispel some of the prior darkness as to geyser irregularity.

EXAMPLES IN EVIDENCE

One of the first instances to draw my attention to underground interconnections and periodic exchange of function was in the behavior of Beauty and Chromatic Pools, located about 150 feet apart in the Upper Basin north of the Grand Geyser. For a period of from 6 weeks to 4 months (these are the extremes noted to date), water will flow from one pool; then, with cessation and but an inch of ebbing in the first pool and a consequent inch of rise in the other pool, flow will be maintained in the latter pool for a similar period. During its periods of overflow, the temperature of water in the deeper part of the pool then flowing is increased about 15 degrees, resulting in the destruction of the algae, which re-establishes itself during each ebb stage. Two springs in the Round Spring Group show the same characteristic exchange of ebb and flow as do Beauty and Chromatic. Their periods, if at all rhythmic, have not as yet been determined.

This interchange of function among non-erupting springs of an interconnecting group throws light upon the capricious behavior manifested by some of the geysers. An excellent example, not only of geyser vacillation but also of considerable periods of dormancy, is at times strikingly afforded by the Daisy Group. This Group consists of Comet, Daisy and Splendid Geysers, Bonita and Brilliant Pools, a small unnamed geyser 40 feet south of the Splendid and two small pools also near Splendid. These units are closely spaced within an area of about 40 by 150 feet.[4]

During most of the Park's history the Daisy has been one of the more regular and popular geysers, playing at intervals of about every 1½ to 2 hours. Daisy's connections with the

[4] Two hundred feet east of Daisy and commonly regarded as belonging to the Daisy Group, are several small springs but none show underground connections with the rest of the Daisy Group.

above-named springs and geysers is made very evident by the lowering of the water level in these other vents at the time Daisy plays. They all refill simultaneously with the Daisy; the high water level being at the top of the rims of all the craters, with the exception of the unnamed geyser near Splendid. Though the water stands at the rims of the craters prior to Daisy's activity there is ordinarily no overflow from any vent except that of the Daisy. Occasionally, though infrequently, water will rise high enough in some one of the connecting vents to cause overflow there. Such overflow is small in volume, but without exception it has been sufficient to produce dormancy in the Daisy. As long as this overflow lasts the Daisy does not erupt.

During the 1938 season, hitherto inactive Bonita Pool, an algae-coated pool, not only began overflowing but erupted as well. The eruptions were of a minor character, but frequent. This condition lasted for 3 days when eruptive activity ceased, though with a steady overflow continuing. During both the eruptive and overflow stages of Bonita, Daisy was dormant. It was while Bonita was overflowing following its eruptions, that I surmised that this overflow, though small, was robbing from Daisy the energy necessary to bring about Daisy's activity. By way of experimentation I checked Bonita's overflow by depositing three shovelfuls of fragmental sinter at the point of outlet. The water level thereupon rose slightly in Bonita, perhaps half an inch, and then remained fixed without overflow. Within a matter of minutes the water was seen to be rising in the Daisy with an increasing vigor of boiling. This condition continued until the Daisy erupted, 30 minutes after the damming of Bonita. This was the first eruption of the Daisy in 4 days. Only once since then (1939) has Bonita, during the summer season, overflowed. That overflow likewise produced the above-described condition in the Daisy, and damming of Bonita again resulted in Daisy's immediate resumption of normal behavior.

The small unnamed geyser near the Splendid will erupt one or more times during some seasons, while during others no activity is observed. Its eruptions start at about the time Daisy is due to play. Its activity produces the same lowering of water level in the other pools and geysers of the Daisy Group, the Daisy included, as does an eruption of Daisy itself. This geyser is small, playing about 15 feet high for about 20 minutes; its height of eruption is much less than Daisy's, but the duration is five to seven times as long. It is believed that the explanation of these differences lies in the fact that because of its small vent, this unnamed geyser requires much longer to drain the water system than does the Daisy. The occasional activity of this unnamed geyser has been taking place for a long period of time, as indelibly recorded in the geyserite surrounding its orifice.

Three times during my observation the Brilliant Pool has risen high enough to overflow; the Splendid has overflowed once. On each of these occasions dormancy resulted in the Daisy; also, without exception, the checking of the overflow by a few shovelfuls of sinter resulted in Daisy's immediate response and consequent eruption.

The Daisy's extreme sensitiveness to any loss of water is demonstrated on every windy day. Former observers have noted that the intervals of the Daisy were measurably lengthened whenever a stiff breeze blew across the Daisy and the large, shallow basin that is filled during the period of overflow. These lengthened intervals were explained as being due to the "more rapid cooling of the water as a result of the increased evaporation produced by the wind." Whatever importance should properly be assigned to this interpretation, another influence unquestionably enters. Any wind across the Daisy pool sufficient to produce waves will, when the Daisy is overflowing and approaching an eruption, increase the rate of discharge. This loss of water and consequent drain of energy tends to retard the eruption. Winds have a similar effect upon the Morning Geyser.

Since 1892 (information on present sign at Splendid) the geyser now definitely named as Splendid has played infrequently. During those occasional periods of activity which have been carefully noted, there have resulted lengthened periods between eruptions for the Daisy, the interval of the Daisy lengthening to over 4 hours following Splendid instead of the usual 2 hours between Daisy's eruptions.

If the past performances of the Splendid and Daisy Geysers, as evidenced by recorded data as well as by their structural details, are useful criteria for predicting future functioning, it would seem reasonable to expect that the Splendid may sometime assume a new role of activity with an infrequent or quiescent Daisy.

It is questionable if the unit now known as the Comet ever played any differently from its present type of activity. It has an almost constant splashing type of eruption, the water rising a few feet above the crater's rim, most of it falling back into the crater. The drainage from the Comet does not offer the slightest suggestion that there ever was a heavy discharge of water at all comparable to the discharge from the Splendid, Daisy, or "unnamed geyser." The sinter surrounding the crater of the Comet has no erosion channels. Such channels are always a part of the surface structure where there is discharge of water at all comparable in volume to that of the other eruptive units of the Daisy Group.

In addition to the Daisy Group, other related groups which definitely show functional exchange as a cause of vacillation are the Kaleidoscope Group in the Lower Basin, the Rainbow Pool and Green Spring in the Black Sand Basin, and the Grand Group in the Upper Basin.

The Grand Group will be considered in detail because the Grand is a frequent and spectacular performer, excelling Old Faithful in height and power of display. The history of the Grand indicates that its intervals have varied from a minimum of about 8 hours to a maximum of weeks. During the eight seasons I had observed the Grand prior to the 1947 season, 18 hours and 120 hours were the extremes checked for lengths of interval. The average interval for this period was 38 hours. During the 1946 season the Grand showed an increased frequency of function over any previous seasonal observations I had made. The average interval for the season was 27 hours, as against a 44-hour average for the 1942 season—the last season prior to 1946 when any observations were made. The increased activity of the Grand during the 1946 season was but a prelude to what occurred the next year. During the 1947 season the average interval for 244 consecutive eruptions was 12 hours and 5 minutes; 7 hours being the shortest interval and 16½ hours the longest. This greatly shortened interval for the Grand was also evident the next season and until the 5th of July 1948. From that date until the close of the season Grand lapsed back to about its 1946 average. During the period of frequent activity of the Grand no difference in the duration or character of its eruption was observed as compared with those of other years.

The Grand is definitely connected with a number of other geysers—the Turban, the Vent, the Triplets and the Rift.[5] All lie within a radius of 100 feet of the Grand. The literature on the Grand, Turban and Vent Geysers discourages belief that they are connected underground. However, more complete and extended observations on the part of Peale, Comstock, Allen and Day and of others who would quote these authorities, would have been convincing to all that the sympathetic relationship between these geysers can be adequately explained by one assumption only—underground connections. During eleven seasons of observation I have witnessed the complete performances of over three hundred separate eruptions of the Grand Geyser and checked several hundred others. The unfailing synchronism and sympathetic response of the Turban and Vent during and after each eruption of the Grand seems to leave no room for doubt as to there being definite and specific subterranean connections. It is believed that all the objections raised by earlier observers can be disposed of, and in any case they must be weighed as suppositions against this record of observed performance.

None of the literature on the Grand makes any allusions to possible underground connections between it and the Triplets. I suspected possible connections from the fact that an eruption of the Triplets would seem to delay the Grand. That is, if it were average, or over average time for the Grand and the Triplets played, it would always be from 2 to 3 hours following one of these eruptions before the Grand would play. The suspicion of subterranean connections was amply verified during the period when the Grand was unusually active.

That the Triplets and the Rift Geysers largely account for the greatly increased activity of the Grand during all of 1947 and until mid-season 1948 is indicated by the following observations: During the prewar years the average interval for the Triplets was about three hours. The Rift did not play oftener than once a day. Sometime during the winter of 1946-7 the Triplets and Rift ceased playing. During all of 1947 and until July 5, 1948 no eruptions occurred. Surface conditions

[5] This geyser has received no official name. I have termed it the Rift in allusion to the opening from which it plays.

were equally indicative that none took place. It was during this period of eruptive inactivity of the Triplets and the Rift that the Grand displayed itself, not only with much greater frequency, but with a regularity which made its eruptions predictable. Sometime during the night of July 4, 1948 the Triplets and the Rift became rejuvenated. From this rejuvenation, and to the close of the 1949 season, the Grand lapsed back to about the same frequency and degree of irregularity that characterized it during the 1946 season.

The Triplets and Rift are modest spouting springs during their active phases, whereas the Grand plays to a height in excess of 150 feet. In discussion with the writer some have expressed doubt as to the ability of a minor geyser to affect the functioning of a major one, it being too much like "the tail wagging the dog." Too little is yet known regarding any geyser's mechanism to give presumptive weight to such an argument. Many phenomena come into conspicuous performance by some "trigger effect" which, by itself, seems quite inconsequential. Definite examples of this are seen at Yellowstone; *e.g.*, the return of Daisy Geyser from a dormant phase to eruptivity by an extremely slight change in water level of Bonita Pool.

Further evidence of the subterranean connection between the Grand, the Triplets and the Rift is found in that during the months when the Triplets and the Rift were non-eruptive and the Grand unusually active, the Triplets would, as unfailingly as the tides, flow before the Grand played, and their craters would empty after each of Grand's eruptions. As a matter of fact, the level of the water in the craters of the Triplets served as a very good index as to the probable time of an eruption of the Grand.

That the 1947-8 period of increased activity of the Grand was largely induced by the failure of the Triplets and the Rift to erupt seems wholly reasonable; probably the water and energy finding expression through the Grand during its show of more frequent activity were dissipated at other times by the Triplets and the Rift. When the thermal energy from the Triplets and the Rift was made available for the Grand, greater frequency for it would result.

In description of the foregoing examples, emphasis has been placed on the disparity of behavior at different orifices that are plainly interconnected underground, and thus on the ability of a given type of behavior to shift from one to another of these orifices. Nevertheless, in some of the groups already described two or more of the orifices may continually or at certain times behave alike: Note, for example, the usually synchronous rise and fall of water level in other vents of the Daisy Group than that of Daisy itself; and also the essentially identical behavior and timing of several members of the Grand Group.

It is thus necessary to recognize, among these interconnected groups, not only the reciprocal or antithetical behavior which has here been especially stressed, but also the cooperative or concerted behavior of certain members of the group. Moreover, a given pair of orifices may for a time act in concert and later perform in opposite fashions. This is seen, for example, in the like behavior, for long periods, of Bonita and Brilliant Pools, then occasional eruption of Bonita while Brilliant remains essentially quiescent.

Another type of activity among interconnected units might well be termed a chain action. This chain action finds impressive demonstration following an eruption of Morning Geyser, a member of the Fountain Group in the Lower Basin. The Morning, Fountain, and Clepsydra Geysers (the Morning and Fountain being major geysers) erupt in series, the chain action always being initiated by the Morning. A brief description follows: Morning plays powerfully for a period varying from 45 minutes to an hour. During its activity water slowly ebbs in both Fountain and Clepsydra. Approximately 3 hours following Morning's activity the Clepsydra begins playing from four vents, one of them being in a steam phase, which in its power, is comparable to that of the Black Growler. The Clepsydra plays steadily for a period varying from 3 to 6 hours. From about 6 to 8 hours following Clepsydra the Fountain erupts, its activity lasting for the same duration as the Morning's. As closely as I can determine, this eruption of the Fountain is followed about 6 to 8 hours later by another. Both the Fountain and the Clepsydra occasionally erupt independently of the Morning, but since the 1946 season when the Morning became rejuvenated after a half-century of dormancy, I have checked fifty-two eruptions of this geyser, and without exception this chain action has taken place as described above.

Two examples of interesting behavior are added to the list here discussed, at the suggestion of Dr. L. C. Graton. The massive, undulating sinter of the Turban holds the normal water level a few inches above the surrounding, gently sloping geyserite. At the base of the Turban the veneer of sinter is punctured by the slot-like orifice of the Vent, which erupts at an oblique angle pointing away from the Turban.

The Vent and Turban play in concert with the Grand, the concerted play of Turban and Vent continuing intermittently for several hours after cessation of the Grand. During this synchronized stage of the Turban's and the Vent's functioning, the Vent is ejecting a beautiful, inclined plume some 20 feet in height, while the Turban is characterized by a series of "boiling mounds." Following this joint action the Turban continues playing, with the Vent swallowing such of Turban's overflow as is within its reach. The subterranean interconnections of Turban and Vent cannot be doubted; yet at an appropriate stage in their joint eruption, Vent reverses the direction of flow in its tube.

An entirely analogous example on a smaller scale is afforded at times in the behavior of Minute Geyser and a tiny subsidiary vent at a slightly lower elevation a few feet distant. These units, close to the road just south of Norris parking area, begin eruption almost synchronously, but the smaller one subsides first and then drinks in such of Minute's later overflow as reaches it.

CONCLUSION

Since the discovery of Yellowstone's thermal wonders the geysers which have played with the least irregularity, and which during this period have followed behavior patterns essentially unchanged, are:

1. Artemisia
2. Castle
3. Great Fountain
4. Lion
5. Lone Star
6. Oblong
7. Old Faithful
8. Pink Cone
9. Sawmill
10. Riverside
11. White Dome

All of the above-named geysers, as well as smaller ones that might be appended to the list, seem to be separate and complete units. To date no certain evidence has been discovered that they have underground connections with any other spring or geyser. On the other hand most of the geysers which have shown great irregularity give clear evidence of having subterranean connections with other springs and geysers. Some of the more prominent of the geysers in this category are:

1. Clepsydra
2. Daisy
3. Fan
4. Fountain
5. Giant
6. Giantess
7. Grand
8. Kaleidoscope
9. Morning
10. Mortar
11. Splendid

The evidence that connecting springs and geysers produce vacillation in geysers such as Giant, Giantess, and Fountain is not as clear as with the Daisy and Grand Geysers. The fact that they and the other named geysers all show vacillation, and that all have underground connections with other springs and geysers is highly suggestive, when the data on the Daisy and the Grand are taken into consideration, that exchange of function is one of the causes of their great irregularity.

More detailed and extended observation holds promise of further determinations of the effects of underground relationships on the functioning of geysers. One of the matters especially deserving further consideration is the cause of diversion of thermal energy from one branch of a channelway to another.

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