Dating Castle Geyser: Preliminary Results and Broad Speculations on the Geologic Development of Geysers and Hydrothermal Systems in Yellowstone National Park, Wyoming, USA

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ABSTRACT

How old are Yellowstone's geysers? How do geysers grow? What do the growth of geysers and the geologic development of hydrothermal systems tell us about deeper geologic and magmatic processes in the Yellowstone supervolcano? Seven carbon 14 (14C) dates have been successfully obtained from geyser and hot spring deposits at Castle Geyser, in the Upper Geyser Basin in Yellowstone. Castle Geyser has an imposing cone that sits upon a broad terrace or shield of sinter. The shield upon which the geyser is built dates from 8,800 to 10,400 years ago, while all dates from the cone of Castle are younger than 1,040 years.

3-D laser mapping is a new technique that holds great promise in small-scale geologic investigations. A preliminary 3-D laser map of Castle Geyser allows clear identification of at least three distinct stages in the growth of the geyser.

The gap of dates between approximately 10,000 years from the shield and 1,000 years from the cone, combined with distinct morphologies illustrated by 3-D laser mapping, suggests that Castle Geyser has had pulses of activity followed by times with much less activity. Many geologic systems, from volcanoes to geysers, operate in a similar pulse (eruptions) and pause (between eruptions) style. Perhaps we are living in a millennial (or longer?) pulse of activity and we are fortunate to be able to see so many geysers in Yellowstone.

Introduction

Previous research about hydrothermal systems in Yellowstone (Figure 1) has tended to either be descriptive of individual features (Marler, 1973; Foley, 2006) and/or emphasize, especially for geysers, their eruptive patterns (Bryan, 2001). Recent years have seen the application of approaches from sedimentary geology to hydrothermal deposits, including development of conceptual models that describe different zones of silica deposition from thermal waters and the use of scanning electron microscopy to distinguish samples (e. g., Braunstein and Lowe, 2001; Guidry and Chafetz, 2002, 2003). Changes in hot spring and geyser deposits through time have also been documented (Hinman, 1995). There also have been

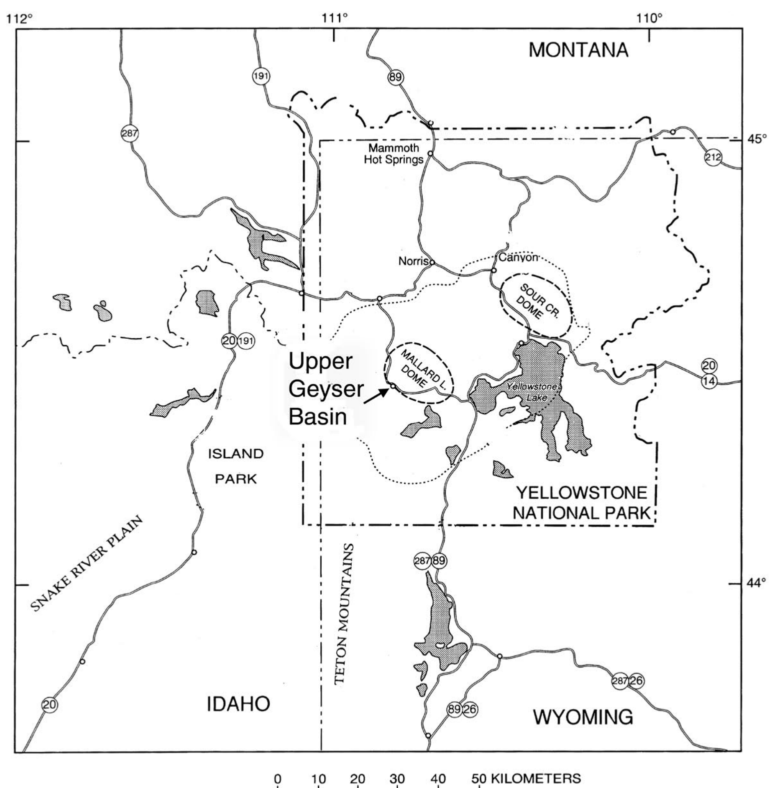

Figure 1. Location map of Yellowstone National Park showing the Upper Geyser Basin. The dotted line inside park boundaries indicated the approximate boundary of the 640,000 year old caldera. Modified from Fournier and others, 1994.

extensive studies of microbial communities in thermal waters (e. g., Ward and Cohan, in press; Reysenbach, Voytek and Mancinelli, 2001). Remote sensing studies have emphasized changes in minerals brought about by hot waters (Hellman and Ramsey, 2003).

Numerous studies have centered on iconic Old Faithful Geyser, leaving other geysers less investigated. The regularity of its eruptions was noted by early explorers (Hayden, 1872). Throughout park history, eruption patterns of Old Faithful (how faithful is it?) have been studied by many (e. g., Fix, 1949; Marler, 1969; Azzalini and Bowman, 1990; Stephens, 2002). Seismicity of the geyser has been studied by Kieffer (1984) and Kedar, Kanamori and Sturtevant (1998). Hutchinson, Westphal and Kieffer (1997) studied downhole characteristics of the geyser using a video camera. Marler (1956; 1969) described the geologic development of the geyser.

Questions related to the age of hydrothermal systems have either been approached indirectly by relating hydrothermal deposits to glacial ages (White, Hutchinson and Keith, 1988) or quantitatively by measuring rates of silica precipitation from hydrothermal waters (Hinman and Lindstrom, 1996). Measured or estimated short-term deposition rates have been extrapolated over long time spans to account for the thickness of deposits that are formed by hot springs and geysers (Marler, 1956; Watson, 1961). While quantitative dates exist for the Mammoth Hot Springs system (Averill, 1989; Pierce, Adams and Sturchio, 1991; Foley, unpub. data), only one quantitative date (Marler, 1956) has been obtained by carbon-14 methods from geyser deposits in the Upper Geyser Basin.

Existing maps of the geysers have generally been made to depict regional or local geology (e. g. Muffler, White, Beeson and Truesdell, 1982), mineralogy (Hellman and Ramsey, 2004) or to depict geographic distribution of the geysers (Bryan, 2001). There currently are no maps that are sufficiently detailed for use as baseline data for future deposition or erosion analysis of individual geysers.

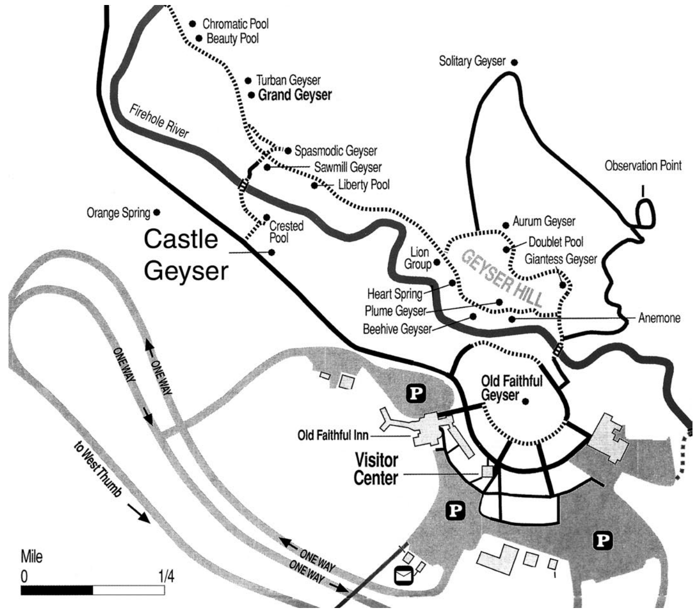

Figure 2. Location map of Castle Geyser in Upper Geyser Basin (modified from Yellowstone Association, 2003).

that his measured rate was applicable, without change, through the geologic history of Castle Geyser. He did not state where the measurement was made (vent, splash zone, pool, runout channel, or elsewhere.), or even if it was made at Castle Geyser or one of the adjacent hot springs or geysers. Bryan (2001) reports an age of Castle of 5,000 to 15,000 years, which he states (personal communication, March 2006) was "... based on the long-standing 'rule of thumb' sort of estimate."

Carbon 14 Dating

Many questions can be asked about the chronology of geysers. When did the hot spring and geyser systems turn on?

Castle Geyser

Castle Geyser (Figure 2) was chosen as the focus for this research due to its large cone, which rises over the surrounding sinter shield (Figure 3). This cone provides vertical relief for sampling, and also provides a challenge to 3-D laser mapping. Although the cone of Castle is larger than cones at other geysers, its overall form is common as there are many other geysers that display a cone constructed over a sinter shield (e.g., Beehive, Lion, Giant).

Castle has long been noted as a major geyser (Doane, 1870, cited in Bonney and Bonney, 1970) that well deserves its name because it resembles "the ruin of an ancient stronghold" (Winser, 1883). The size of its cone has led to speculation that it is old. Watson (1961) estimated that the geyser is over 8,000 years old, based on his calculation that "the measured annual increment of silica sinter in this vicinity is 1/40 inch per year." He assumed

Figure 3. Photograph of Castle Geyser, showing large cone of the geyser rising above small terraces, which overlie a broad sinter shield (foreground).

When do they turn off? What stages do they go through? How long do the stages last? Do the geysers all turn on and off together? Do the geyser basin systems operate in a manner similar to the chronology of hydrothermal systems in the Mammoth Hot Springs area, which apparently pulsed and paused for the last 400,000 years (Pierce, Adams and Sturchio, 1991)?

Drilling by the U.S. Geological Survey (White and others, 1975) demonstrated that hot spring and geyser deposits in the Upper Geyser Basin overlie obsidian-rich gravels and sands that are likely related to streams that flowed next to melting glaciers (Marler and White, 1975). Sinter thicknesses from holes drilled in and near the Upper Geyser Basin are reported as ranging from approximately 5 feet to 11.5 feet (White and others, 1975).

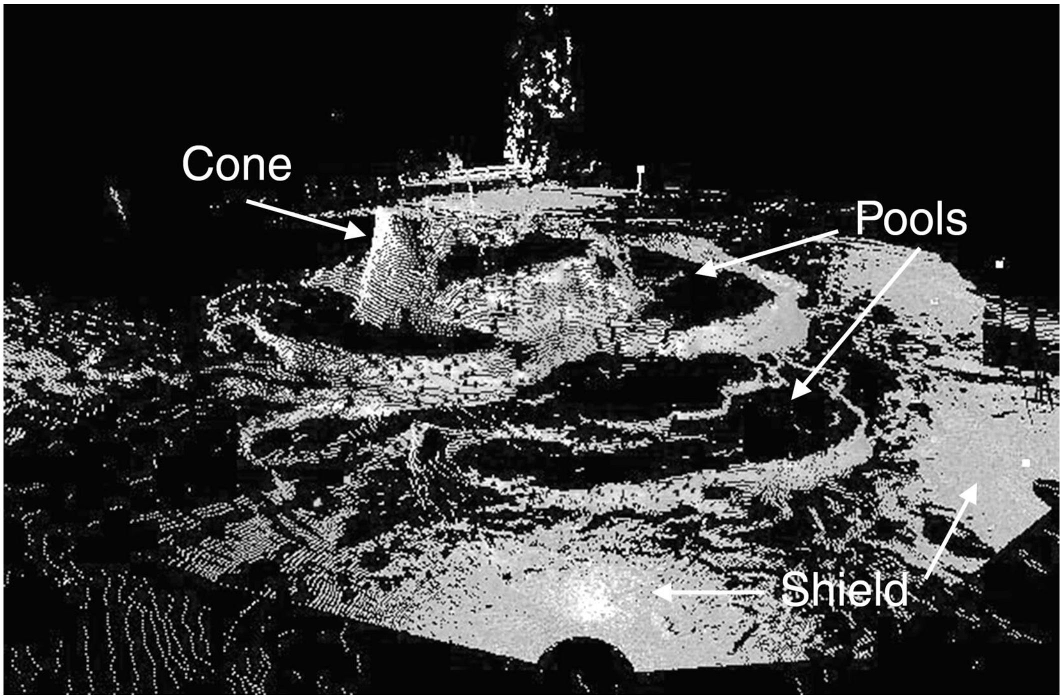

Figure 4. 3-D laser map of Castle Geyser, with surrounding sinter shield, pools and modern cone identified.

New 14C sample preparation techniques, in conjunction with Accelerator Mass Spectrometry carbon-14 dating, now allow successful dating of silica-rich hydrothermal deposits. Carbon sources likely include both pollen and microbial activity. The techniques have been pioneered by researchers at Rafter Radiocarbon in New Zealand, and applied in the United States at a few hydrothermal systems in Nevada and Utah (Lynne and others, 2003; Lynne and others, 2005; Lutz and others, 2002).

Table 1. Results of carbon-14 dating from Castle Geyser.

Location	Date (BP)
Shield	8787 +/- 60
Shield	10472 +/- 70
Cone	1038 +/- 35
Cone	926 +/- 35
Cone	928 +/- 40
Pool at top	214 +/- 35
Pool at top	-244 +/- 30

Preliminary results from seven 14C dates at Castle Geyser are shown in Table 1. These dates were determined from sinter deposits that form the shield around the geyser, from the geyser cone, and from a pool near the top of the geyser (Foley, 2004, 2005). The 14C dates fall into three groupings. Two dates from the shield of old deposits, upon which the geyser is built, are about 8800 and 10,500 years before present (BP; 1950 in 14C dating). Three dates from the geyser cone cluster about 930 and 1040 BP. Dates from the pool near the top of Castle Geyser were too contaminated by modern carbon to provide meaningful results (they were 214 and –244 years, respectively). It is worth noting, however, that these uppermost samples were youngest, and the results are useful in clarifying that future sampling protocols must avoid current pools, in which there may be modern microbial activity that could influence dating results.

3-D Laser Mapping

With new mapping techniques come new observations and interpretations. In conjunction with sampling for dating at Castle Geyser, a preliminary 3-D laser map was made of the geyser cone (Figure 4). 3-D laser mapping works by sending a laser beam from the instrument to the desired object, and then measuring its time of return, which gives distance from the instrument to the object. Unlike older generation laser distance measuring, with 3-D mapping the instrument records hundreds of thousands of data points from each station. These points have x, y, and z coordinates (3-D) and form a cloud of data. Clouds can be stitched together to make a 3-D virtual model of the geyser. This powerful mapping technique has not yet been used at many other hydrothermal systems.

Implications

How do geysers grow? The preliminary results from Castle Geyser suggest that Marler and White (1975) were generally correct when they proposed that a shield-building phase of hot spring activity (at Castle the 8800 and 10,500 dates) was followed by geyser development (at Castle the 930 +/- and 1040 dates). The lack of dates between 8800 and 1040 BP at Castle

Geyser suggests that development of hydrothermal systems may not be uniform through time, but instead may proceed in pulses of growth, followed by pauses in which little deposition takes place.

An implication of the interpretation of the results Castle Geyser is that measuring the rate of silica deposition over a few months or even years, and calculating the age of a geyser by extrapolating the rate of deposition to account for the estimated thickness of geyser deposits, may be incorrect. Although seven dates are not adequate to rigorously define details of the pulses and pauses at Castle, they do suggest that existing age estimates for geysers in Yellowstone may be incorrect.

The 3-D morphology of Castle Geyser suggests that it has had at least three (shield followed by pools which were followed by the modern cone) or maybe four (shield, followed by perhaps distinct lower and upper stages of pool development and finally the modern cone) stages of activity. The proposed stages are labeled on the 3-D map of Castle Geyser (Figure 4). This figure also shows that pools on different sides of the geyser are likely correlative. These pools probably represent an earlier phase of either hot spring or pool type (e.g., Great Fountain like, not the current cone type) geyser activity. Marler and White (1975) suggested that cone-type geysers had a stage of pool-type activity during their development.

Marler (1956; 1969) studied the development of the mound and cone of Old Faithful. He proposed that deposition from an early hot spring built the mound. This was followed by a period of inactivity during which a forest grew. These trees were killed by reactivation of hydrothermal activity. The younger activity was "very different" from the modern Old Faithful. He suggests that there may have been a pause before current geyser activity began.

Marler (1956) determined an age of 730 +/- 200 years from "silicified wood found embedded in the geyserite." This wood is presumed to have grown before the younger, pre-Old Faithful hydrothermal activity resumed. Marler (1956) goes on to state that, based on the date and on the rate of silica deposition, "The logical inference is that Old Faithful Geyser began to erupt only about two centuries ago."

Marler's (1956) description of the chronology interpreted from the morphology of Old Faithful is remarkably similar to the suggested pulse and pause chronology for Castle Geyser. Early reports at Castle Geyser describe (Stanley, 1873, quoted in Marler, n.d.) and a photograph from 1878 shows a tree covered by silica on an upper terrace of the geyser. This tree, if early souvenir seekers have not removed it, is currently completely covered by silica. The tree, if it grew in place, will date from a time of pause in the activity of Castle Geyser.

The pulse and pause model described from Old Faithful and suggested by preliminary dating at Castle may be typical of Yellowstone hydrothermal systems. For instance, current activity at Grand Geyser has killed mature trees on the hillside near the geyser. Either Grand had a pause in activity during which the trees grew, or it had much less vigorous activity for an extended period of time.

As a broad speculation, the pulse and pause model may also prove, as more systems are investigated and further dating is done, to be typical for many other hydrothermal and geological systems. Pulses and pauses could be important considerations in long-term evaluations of energy potential and geological hazards in active hydrothermal systems.

Conclusions

Preliminary 14C dating and 3-D laser mapping results from Castle Geyser demonstrate the applicability to these techniques to the study of hydrothermal systems. Although unusually large for Yellowstone, Castle Gesyer may be representative of the growth of many other geysers. The pulse and pause pattern suggested by preliminary data from Castle and by earlier researchers at Old Faithful, may be applicable to many other geysers and hydrothermal systems. Detailed geochronology may help identify where a specific system is in its pulses or pauses. Park-wide comparison of hydrothermal system chronology may help identify trends in magmatic evolution. 3-D laser mapping, which can record clouds of points at sub-centimeter accuracy, dramatically demonstrates that improved visualization of geologic features leads to improved interpretations of the stages of geologic development of hydrothermal systems. In Yellowstone, these techniques may allow a new answer to be developed to the old question, "How old are the geysers?"

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