



Short communication

Radiocarbon dating of silica sinter deposits in shallow drill cores from the Upper Geyser Basin, Yellowstone National Park

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ABSTRACT

To explore the timing of hydrothermal activity at the Upper Geyser Basin (UGB) in Yellowstone National Park, we obtained seven new accelerator mass spectrometry (AMS) radiocarbon ^{14}C ages of carbonaceous material trapped within siliceous sinter. Five samples came from depths of 15–152 cm within the Y-1 well, and two samples were from well Y-7 (depths of 24 cm and 122 cm). These two wells, at Black Sand and Biscuit Basins, respectively, were drilled in 1967 as part of a scientific drilling program by the U.S. Geological Survey (White et al., 1975). Even with samples as small as 15 g, we obtained sufficient carbonaceous material (a mixture of thermophilic mats, pollen, and charcoal) for the ^{14}C analyses. Apparent time of deposition ranged from 3775 ± 25 and 2910 ± 30 ^{14}C years BP at the top of the cores to about 8000 years BP at the bottom. The dates are consistent with variable rates of sinter formation at individual sites within the UGB over the Holocene. On a basin-wide scale, though, these and other existing ^{14}C dates hint that hydrothermal activity at the UGB may have been continuous throughout the Holocene.

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1. Introduction

Yellowstone's hydrothermal system consists of more than 10,000 diverse thermal features, including geysers and non-erupting springs and pools that deposit siliceous sinter from neutral, Cl-bearing thermal waters (Fournier, 1989; Hurwitz and Lowenstern, 2014). A significant proportion of Yellowstone's silica-saturated waters issue from thermal springs in the Firehole River drainage, including from the iconic geysers of the Upper Geyser Basin (UGB) (Fig. 1). Approximately 33% of Yellowstone's chloride flux comes from the Firehole River (Hurwitz et al., 2007), and about one-third of that derives from the UGB (Allen and Day, 1935; Fournier et al., 1976). Intact sinter deposits of the UGB ($\sim 2.5 \text{ km}^2$) presumably formed after the end of the Pinedale glaciation, which was at its maximum on the Yellowstone Plateau 14.6 ± 0.7 kyr ago (^{10}Be exposure ages of moraines in Licciardi and Pierce, 2008). Older deposits include Pinedale-aged and older hydrothermally cemented glacial till deposits (kame) and outcrops of late Pleistocene rhyolite flows (Muffler et al., 1982).

Thermal waters currently discharging in the UGB have elevated concentrations of chloride, sodium, and silica (Hurwitz et al., 2012). As thermal waters cool following discharge, the solubility of silica (SiO_2) decreases (Fournier, 1985), leading to precipitation of opal-A and

deposition of siliceous sinter that forms cones, domal mounds, and terraces. Repeated wetting and evaporation of surfaces and capillary effects are the main controls on the deposition, morphology, and microstructure of the sinter. Particles of rock, plant matter, charcoal, pollen, and other materials can be trapped in the sinter as it grows. The abundance of microbial filaments within the sinter deposits also suggests that some biotic processes are involved (Lowe and Braunstein, 2003; Guidry and Chafetz, 2003; Jones et al., 2001; Campbell et al., 2015).

The timing of post-glacial hydrothermal activity in Yellowstone's geyser basins is poorly constrained because only a few published radiometric dates of associated deposits are available. Wood embedded in Old Faithful geyser's sinter mound that was radiocarbon dated by Marler (1956) yielded a ^{14}C age of 730 ± 200 years BP (years before present; 0 years BP = 1950 A.D.). Radiocarbon dating of organic matter trapped in sinter has been successfully used at a number of geothermal areas (Foley, 2006; Lynne et al., 2005, 2008; Howald et al., 2014). Using similar techniques, Castle Geyser's shield (Fig. 1) yielded ages of $10,472 \pm 70$ and 8787 ± 60 years BP and three dates from the geyser's cone range between 1038 ± 35 and 926 ± 35 years BP (Foley, 2006). Uranium-series disequilibrium dating of two samples from a siliceous spire in northern Yellowstone Lake yields ages of $\sim 11,000$ years (Morgan et al., 2007). In this study, our primary goal was to determine whether there is evidence that hydrothermal activity (and sinter deposition) in the Upper Geyser Basin continued during the period in between the two sets of dates found at Castle Geyser (cf. Fournier,

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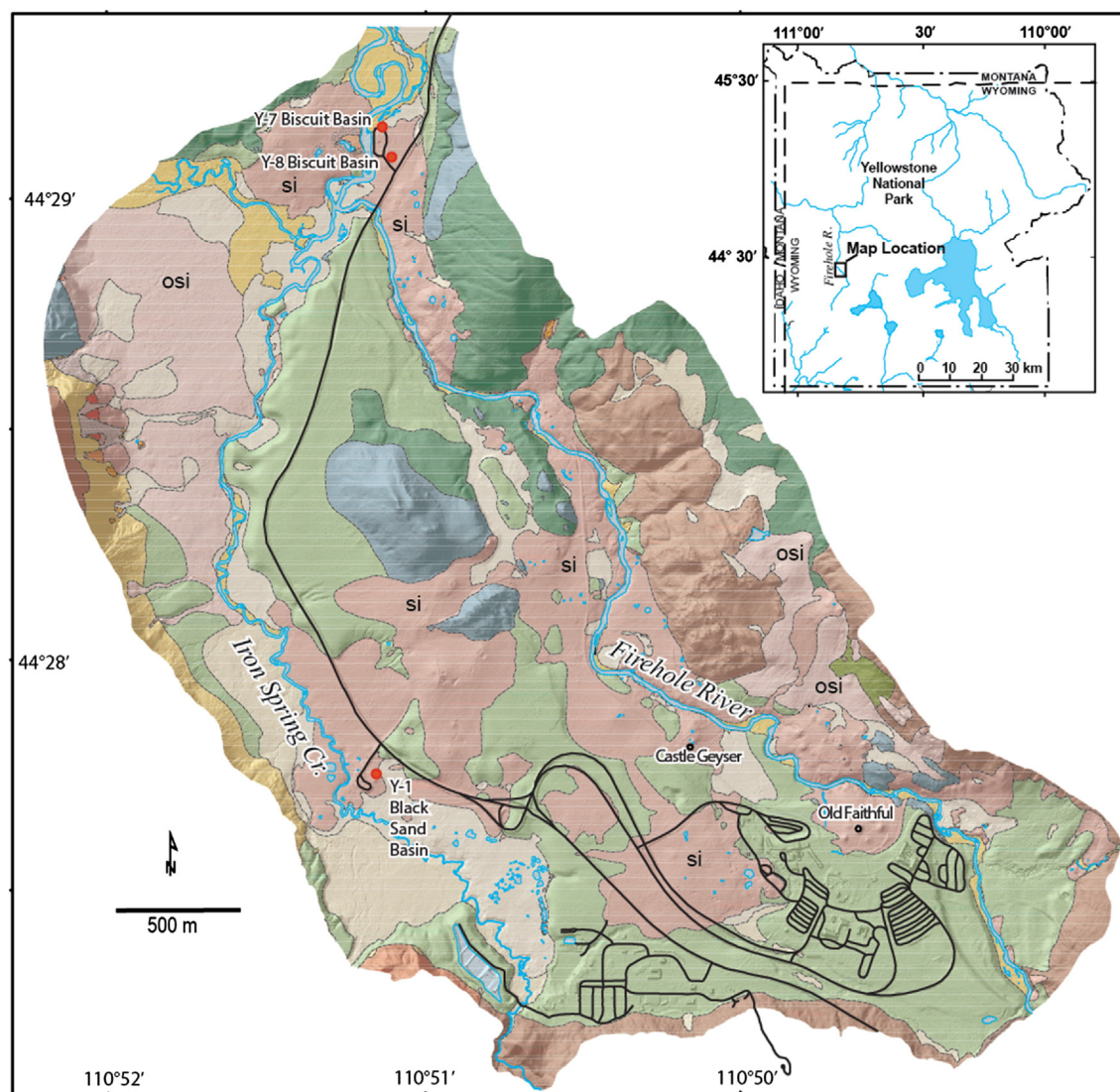


Fig. 1. Map of the Upper Geyser Basin (UGB) showing the locations of research wells Y-1 in Black Sand Basin and Y-7 and Y-8 in Biscuit Basin. Also shown are the locations of Old Faithful and Castle geysers. Black lines are roads. Geology based on Muffler et al. (1982); digital data available in Abedini et al. (2015). Labeled units are si: sinter and osi: old sinter. Green units are glacial deposits. Brown and blue are pre-70 ka rhyolite lava flows. Beige is diatomaceous silt. Light orange is sand and gravel. Geology is overlain on LiDAR topography (available at www.opentopography.org). The inset map shows the location of the Upper Geyser Basin within Yellowstone National Park.

2015). Such information is important to understand the dynamics and timing of hydrothermal flow, both on local and regional scales. If hydrothermal activity can stop for long periods of time, what might this imply about climate, tectonics, and basin-wide flow paths of thermal water?

2. Materials, methods, and results

To obtain a better record of post-glacial hydrothermal activity in the UGB, we extracted sinter samples from cores stored at the U.S. Geological Survey Core Research Center (CRC) in Denver, Colorado. The cores originate from research wells Y-1 in Black Sand Basin and Y-7 in Biscuit Basin (Fig. 1) that were drilled by the U.S. Geological Survey in 1967 to determine the physical conditions and hydrothermal mineralogy in active geothermal systems (White et al., 1975). The Y-1 well penetrated a 64-m-thick sequence of glacial and fluvial sediments before completion in the underlying rhyolite lava at 65 m. The maximum temperature at the bottom of the hole was 163.7 °C (Honda and Muffler, 1970). The first 3.7 m of core are opaline sinter or opal-A (Honda and Muffler, 1970). As in Y-1, the Y-7 core starts with opaline sinter (1.8 m thick), before passing through a series of glacial and fluvial sediments, and finishing

in the Biscuit Basin (rhyolite) flow. Temperatures of ~143 °C were found at the bottom of this 74-m-deep borehole (Keith et al., 1978).

We focused our work on the very top-most opaline sinter at the tops of the two cores. We carefully inspected the cores (Fig. 2a) and regions high in visible dark organic matter were separated for later study (Fig. 2b). Studies by Honda and Muffler (1970) and Keith et al. (1978) conclude that all of the shallow sinters are entirely opal-A and have not been converted to more mature forms of silica. The core boxes are labeled for core depth, but the absolute accuracy of any individual depth may vary. Nevertheless, the relative depths of samples should be reliable. Eight samples ranging from 7 to 25 g were identified for further study. Five sinter samples came from Y-1 and three samples from Y-7, of which one did not have enough carbon for dating and is therefore not reported.

Partly crushed sinter samples were initially bathed in 1 N hydrochloric acid (HCl) for 24 h and then triply rinsed with Nanopure water. The samples were subsequently immersed in concentrated (48%) hydrofluoric acid (HF) solution for up to 48 h. Additional HF was added, as needed, to insure that all soluble material was fully dissolved. The remaining carbonaceous (non-soluble) material was triply rinsed in

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