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A preliminary study of older hot spring alteration in Sevenmile Hole, Grand Canyon of the Yellowstone River, Yellowstone Caldera, Wyoming

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ABSTRACT

Erosion in the Grand Canyon of the Yellowstone River, Yellowstone Caldera (640 ka), Wyoming, has exposed a cross section of older hydrothermal alteration in the canyon walls. The altered outcrops of the post-collapse tuff of Sulphur Creek (480 ka) extend from the canyon rim to more than 300 m beneath it. The hydrothermal minerals are zoned, with an advanced argillic alteration consisting of an association of quartz (opal) + kaolinite ± alunite ± dickite, and an argillic or potassic alteration association with quartz + illite ± adularia. Disseminated fine-grained pyrite or marcasite is ubiquitous in both alteration types. These alteration associations are characteristic products of shallow volcanic epithermal environments. The contact between the two alteration types is about 100 m beneath the rim. By analogy to other active geothermal systems including active hydrothermal springs in the Yellowstone Caldera, the transition from kaolinite to illite occurred at temperatures in the range 150 to 170 °C. An $^{40}Ar/^{39}Ar$ age on alunite of 154,000 ± 16,000 years suggests that hydrothermal activity has been ongoing since at least that time. A northwest-trending linear array of extinct and active hot spring centers in the Sevenmile Hole area implies a deeper structural control for the upflowing hydrothermal fluids. We interpret this deeper structure to be the Yellowstone Caldera ring fault that is covered by the younger tuff of Sulphur Creek. The Sevenmile Hole altered area lies at the eastern end of a band of hydrothermal centers that may mark the buried extension of the Yellowstone Caldera ring fault across the northern part of the Caldera.

1. Introduction

More than three hundred vertical meters of pervasively hydrothermally altered post-Yellowstone Caldera collapse rhyolites are exposed in the walls of the Grand Canyon of the Yellowstone River, Yellowstone Caldera, Wyoming. The Grand Canyon has exposed about a thousand vertical feet of older altered rocks and provides an excellent opportunity for extensive cross-sectional studies of hydrothermal alteration. Our preliminary work in the Sevenmile Hole area of the Canyon, reported here, has found various hydrothermal minerals including quartz, opal, kaolinite, dickite, alunite, illite, adularia, and pyrite in the canyon walls. These hydrothermal minerals form two major alteration types, advanced argillic and intermediate argillic, that are characteristic of shallow hydrothermal systems developed in volcanic environments (Cooke and Simmons, 2000; Simmons et al., 2005). Elsewhere, geothermal systems are used as energy resources (e.g., Broadlands–Ohaaki, New Zealand, Henley and Ellis, 1983), and extinct shallow volcanic hydrothermal systems are important hosts for precious and base metal mineral deposits (e.g., Summitville, Colorado, Stoffregen, 1987).

By analogy to the active Yellowstone hydrothermal system, the older hydrothermal alteration in the Grand Canyon of the Yellowstone River was most likely formed in an environment of steep thermal gradients by rising and boiling fluids as observed elsewhere in the Park's thermal basins (White et al., 1975). Many Yellowstone hot springs, including the hot spring basins along the upper Firehole River (Old Faithful area), are discharging boiling, near-neutral to alkaline chloride-rich fluids as first reported by Allen and Day (1935). Allen and Day (1935) and White et al. (1971, 1988) note that these alkaline-chloride fluids are the most common type of fluid discharged from the Yellowstone hot springs. These boiled fluids have pH in the range from 6 to 8 and high Cl and SiO_2 concentrations. Other fluid compositions are found in many areas of the Yellowstone geothermal system (White et al., 1971, 1988; Fournier, 1989). As noted at Norris Geyser Basin by White et al. (1988), these include Cl^- and SO_4^- rich acid waters, and acid-sulfate waters with low Cl concentrations. Boiling and fluid mixing are common near-surface processes at Yellowstone and influence the compositions of all four fluid types, and

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condensation of deep steam may be important in some areas (White et al., 1971, 1988). Studies of a number of epithermal systems have shown that the alkaline-chloride and acid-sulfate-chloride fluids alter intermediate to silicic igneous rocks to distinctively different hydrothermal mineral assemblages (Henley and Ellis, 1983; Cooke and Simmons, 2000). These hydrothermal associations would, therefore, be expected to occur at Yellowstone at shallow levels in the geothermal system.

Epithermal alteration forms in near-surface hydrothermal environments, and numerous descriptive classifications for epithermal systems have been proposed in the past several decades (see Simmons et al., 2005, for a thorough recent summary). Nearly all of them divide epithermal mineral deposits into two broad classes that draw important distinctions based on fluid pH and redox state that are reflected in their associated hydrothermal mineral assemblages. The most important difference in fluid chemistry is pH. Low pH fluids produce an alteration assemblage that usually includes alunite, pyrophyllite, and dickite as characteristic phases, and may contain residual vuggy quartz and kaolinite. This type of alteration has been referred to as acid sulfate (Hayba et al., 1985; Heald et al., 1987) and high sulfidation (White and Hedenquist, 1990). Neutral to slightly alkaline fluids produce an assemblage that may include quartz, adularia, illite, and carbonate minerals as characteristic minerals. This assemblage has been called adularia-sericite (Hayba et al., 1985; Heald et al., 1987) and low sulfidation (White and Hedenquist, 1990). As noted by Simmons et al. (2005), most epithermal alteration is associated with subduction-related magmatism, although occurrences are known in back-arc, continental rift, and postsubduction magmatic environments. Yellowstone volcanism, however, is related to continental hot-spot magmatism (for example, Pierce and Morgan, 1992; Smith and Braile, 1994; Camp, 1995; Shervais and Hanan, 2008), although not all would agree (Christiansen et al., 2002).

Most of the active hot springs at Yellowstone (Fig. 1) are confined within the area of the Yellowstone Caldera that formed at 0.640 Ma (Christiansen, 2001), and most lie near the Caldera margins (Fournier, 1989). A north-trending linear array of hot springs extends from Norris Junction to Mammoth Hot Springs (Fig. 1), and their distribution is most likely controlled by normal faults that serve as fluid conduits (Pierce et al., 1991; Kharaka et al., 2000). The architecture of the shallow portion of the Yellowstone hydrothermal system (White et al., 1988) is similar to the Caldera hydrothermal flow model for the 23-Ma Lake City Caldera, Colorado (Larson and Taylor, 1986a,b, 1987), and to the active system associated with the Valles Caldera, New Mexico (Goff and Gardner, 1994). At both Lake City and Valles Calderas, faults along caldera ring zones are important channelways for upflowing hydrothermal fluids. By analogy to these other caldera hydrothermal systems, a linear array of active and extinct hot spring centers in the Sevenmile Hole area could be the surficial expression of a deeper structural control over fluid flow (White et al., 1971, 1988; Christiansen, 2001). This inferred structure lies semi-parallel but inward from the Yellowstone Caldera topographic wall. This positioning suggests that this structure would most likely be a fault related to the Yellowstone Caldera margin that is concealed by the post-collapse tuff of Sulphur Creek (a ring fault?). However, direct evidence for a buried deeper structural control is lacking.

The initial results from our investigations of the older hydrothermal alteration in the Sevenmile Hole altered area of the Grand Canyon of the

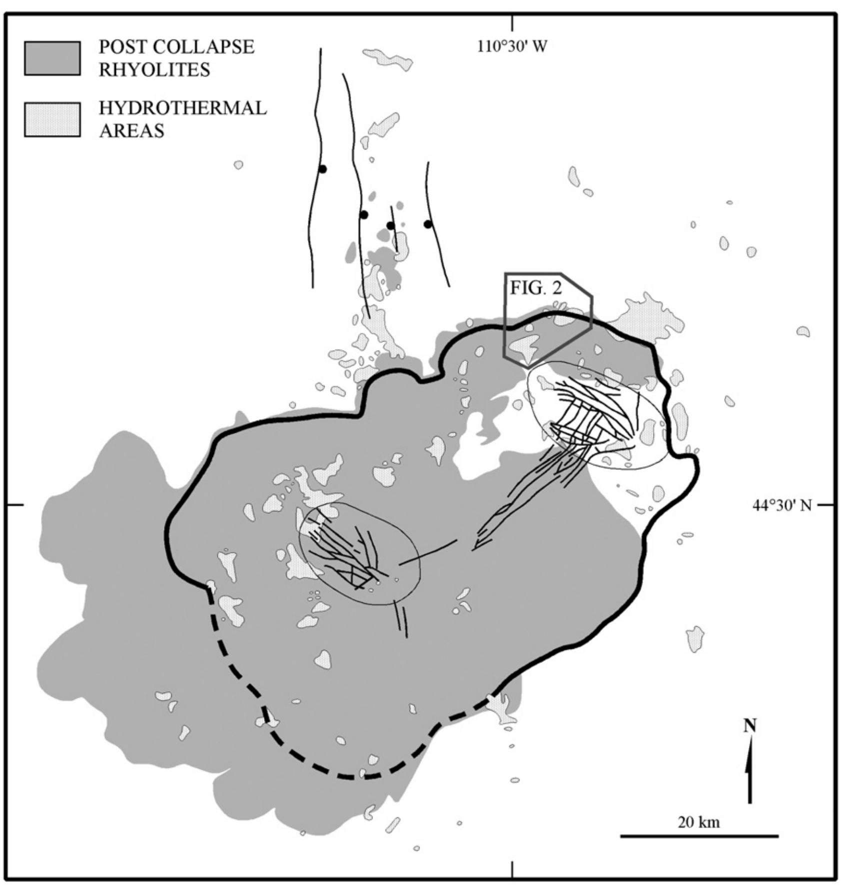

Fig. 1. A geologic map of the Yellowstone Caldera modified from Christiansen (2001) and Morgan et al. (2007), that shows the distribution of post-collapse rhyolites and hydrothermal areas. The heavy black line is the topographic rim of the Caldera, and it is dashed where covered by younger rhyolite flows. The two resurgent domes are outlined by light lines and are dissected by grabens. The Sour Creek dome lies to the northeast and the Mallard Lake dome to the southwest. The Elephant Back fault system extends southwest from the Sour Creek dome. The sense of fault movement is not shown on the domes' graben faults (heavy lines). The Norris–Mammoth corridor of post collapse rhyolites and active hot springs lies outside the Caldera and is shown extending northward from its central area. The corridor lies along a broad structural basin that is most likely related to basin-range tectonics. Several of the basin bounding faults are shown with balls on their downthrown sides. The area of Fig. 2 is outlined.