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Invited research article

The timing and origin of pre- and post-caldera volcanism associated with the Mesa Falls Tuff, Yellowstone Plateau volcanic field

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ABSTRACT

We present new sanidine $^{40}Ar/^{39}Ar$ ages and paleomagnetic data for pre- and post-caldera rhyolites from the second volcanic cycle of the Yellowstone Plateau volcanic field, which culminated in the caldera-forming eruption of the Mesa Falls Tuff at ca. 1.3 Ma. These data allow for a detailed reconstruction of the eruptive history of the second volcanic cycle and provide new insights into the petrogenesis of rhyolite domes and flows erupted during this time period. $^{40}Ar/^{39}Ar$ age data for the biotite-bearing Bishop Mountain flow demonstrate that it erupted approximately 150 kyr prior to the Mesa Falls Tuff. Integrating $^{40}Ar/^{39}Ar$ ages and paleomagnetic data for the post-caldera Island Park rhyolite domes suggests that these five crystal-rich rhyolites erupted over a centuries-long time interval at 1.2905 ± 0.0020 Ma (2σ). The biotite-bearing Moonshine Mountain rhyolite dome was originally thought to be the downfaulted vent dome for the pre-caldera Bishop Mountain flow due to their similar petrographic and oxygen isotope characteristics, but new $^{40}Ar/^{39}Ar$ dating suggest that it erupted near contemporaneously with the Island Park rhyolite domes at 1.2931 ± 0.0018 Ma (2σ) and is a post-caldera eruption. Despite their similar eruption ages, the Island Park rhyolite domes and the Moonshine Mountain dome are chemically and petrographically distinct and are not derived from the same source. Integrating these new data with field relations and existing geochemical data, we present a petrogenetic model for the formation of the post-Mesa Falls Tuff rhyolites. Renewed influx of basaltic and/or silicic recharge magma into the crust at 1.2905 ± 0.0020 Ma led to [1] the formation of the Island Park rhyolite domes from the source region that earlier produced the Mesa Falls Tuff and [2] the formation of Moonshine Mountain dome from the source region that earlier produced the biotite-bearing Bishop Mountain flow. These magmas were stored in the crust for less than a few thousand years before being erupted contemporaneously along a 30 km long, structurally controlled vent zone related to extracaldera Basin and Range faults. These data highlight the rapidity with which magma can be generated and erupted over large distances at Yellowstone.

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1. Introduction

The Yellowstone Plateau volcanic field has produced three of the largest caldera-forming eruptions in the Quaternary and marks the youngest focus of magmatism associated with the Yellowstone hotspot (Christiansen, 2001). Approximately 6500 km^3 of magma has been erupted from the Yellowstone Plateau volcanic field over three caldera cycles during which the Huckleberry Ridge, Mesa Falls, and Lava Creek Tuffs were erupted at 2.077 ± 0.003 Ma (2σ), 1.300 ± 0.001 Ma (2σ), and 0.6313 ± 0.0043 Ma (2σ), respectively (Fig. 1; Christiansen, 1982, 1984, 2001; Ellis et al., 2017; Matthews et al., 2015; Rivera et al., 2016; Singer et al., 2014). Although caldera-forming eruptions at Yellowstone represent the most hazardous events produced by the magmatic system and account for more than half of the material erupted from the Yellowstone Plateau volcanic field (>3700 km^3; Christiansen, 2001), these catastrophic events are short-lived and represent only a small time-fraction of Yellowstone's ~2.1 Myr history. The majority of Yellowstone's eruptive history consists of intermittent effusive (and minor explosive) rhyolitic volcanism that both precedes and postdates the caldera-forming eruptions (Christiansen, 1984, 2001; Christiansen et al., 2007). Recent studies on post-caldera volcanism following eruption of the third-cycle Lava Creek Tuff have provided important constraints on the petrogenesis of Yellowstone rhyolites (e.g., Bindeman et al., 2008; Girard and Stix, 2009, 2010; Loewen and Bindeman, 2015; Stelten et al., 2015; Watts et al., 2012), with implications for both effusive and explosive eruptions throughout Yellowstone's history. These studies highlight the important insights that can be gained by studying the volcanism preceding and postdating caldera-forming eruptions. In order to have a complete understanding

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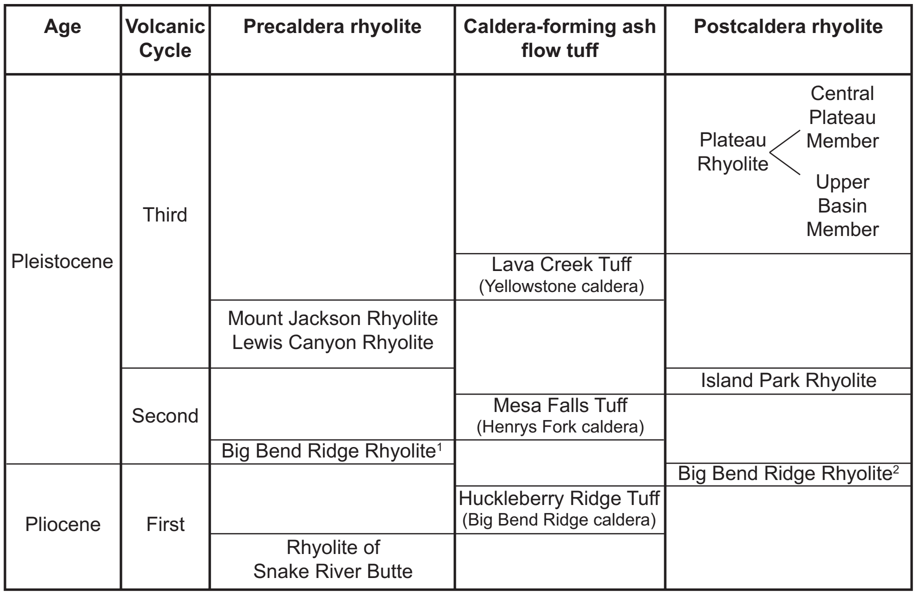

Fig. 1. Generalized stratigraphy for the Yellowstone Plateau volcanic field modified from Christiansen (2001). [1]The pre-caldera Big Bend Ridge Rhyolite of the second volcanic cycle is composed of the ca. 1.3 Ma Green Canyon flow, Bishop Mountain flow, Tuff of Lyle Spring, and potentially Moonshine Mountain. [2]The post-caldera Big Bend Ridge Rhyolite of the first volcanic cycle is composed of the ca. 1.8 ka Blue Creek and Headquarters flows.

of the petrologic evolution of the magmatic system at Yellowstone Plateau, it is essential to have a thorough understanding of the nature and timing of both the caldera-forming eruptions and intervening effusive eruptions.

The age, stratigraphic relations, and geochemical characteristics of volcanic products from the Yellowstone Plateau volcanic field have been the focus of numerous studies over several decades. Early studies at Yellowstone focused on the origin and evolution of volcanic products over the lifetime of the Yellowstone Plateau volcanic field (e.g., Christiansen, 1982, 1984, 2001; Hildreth et al., 1984, 1991), whereas more recent studies have been focused on the age and origin of specific eruptive deposits. In particular, recent work has focused on [1] the three caldera-forming eruptions that produced the Huckleberry Ridge (e.g., Ellis et al., 2012; Myers et al., 2016; Rivera et al., 2014; Singer et al., 2014), the Mesa Falls (Ellis et al., 2017; Rivera et al., 2016), and the Lava Creek Tuffs (Jicha et al., 2016; Matthews et al., 2015), and [2] post-Lava Creek Tuff intracaldera rhyolites that compose the Plateau Rhyolite (e.g., Befus and Gardner, 2016; Bindeman et al., 2008; Girard and Stix, 2009, 2010, 2012; Loewen and Bindeman, 2015; Pritchard and Larson, 2012; Stelten et al., 2013, 2015, 2017; Watts et al., 2012). Comparatively little effort has been given to constraining the nature and timing of pre- and post-caldera rhyolite eruptions of the second volcanic cycle, with only two recent studies examining the age and geochemical characteristics of these rhyolites (Bindeman and Valley, 2001; Troch et al., 2017).

In this contribution, we present new $^{40}Ar/^{39}Ar$ ages and paleomagnetic data for rhyolites of the second volcanic cycle at the Yellowstone Plateau volcanic field that preceded and postdated eruption of the Mesa Falls Tuff. The application of both high-precision $^{40}Ar/^{39}Ar$ dating and paleomagnetic analysis improves upon previous work by allowing for a more detailed reconstruction of the eruptive history of Yellowstone during its second caldera cycle than would be possible by using these techniques separately. In addition, these data provide new insights into the petrogenesis of rhyolites erupted during this time period.

2. Geologic background

2.1. The second volcanic cycle at the Yellowstone plateau volcanic field

Yellowstone Plateau volcanic field has experienced three caldera cycles over its ~2.1 Myr lifetime (Christiansen, 1982, 1984, 2001). Each volcanic cycle is characterized by a large volume caldera-forming event (280 km^3–2450 km^3; Christiansen, 2001) that was preceded and postdated by smaller-volume effusive (plus minor explosive) volcanism (Fig. 1). The second volcanic cycle is the smallest in terms of volume of erupted material and culminated in the eruption of the 280 km^3 Mesa Falls Tuff. $^{40}Ar/^{39}Ar$ dating of the Mesa Falls Tuff by Rivera et al. (2016) and Ellis et al. (2017) yielded concordant eruption ages of 1.300 ± 0.001 Ma (2σ) and 1.3011 ± 0.0016 Ma (2σ), respectively. Eruption of the Mesa Falls Tuff resulted in the formation of the ~20 km diameter Henrys Fork caldera, which is located within the western part of the first-cycle caldera that formed as a result of the eruption of the Huckleberry Ridge Tuff (Figs. 2, 3).

Prior to eruption of the Mesa Falls Tuff, the Bishop Mountain flow, Green Canyon flow, and Tuff of Lyle Spring (a local ash-flow tuff) erupted near the western part of the Henrys Fork caldera (Fig. 3). These rhyolites are considered to be part of the Big Bend Ridge rhyolite as defined in Christiansen (2001). The Bishop Mountain and Green Canyon flows overlie the Huckleberry Ridge Tuff and underlie the Mesa Falls Tuff (Christiansen, 2001). The Bishop Mountain flow, Green Canyon flow, and Tuff of Lyle Spring are petrographically distinct relative to all other Yellowstone rhyolites in that they contain millimeter-sized phenocrysts of biotite (Christiansen, 2001). Based on their petrographic similarities and close spatial association, Obradovich (1992) and Christiansen (2001) interpreted the Bishop Mountain flow, Green Canyon flow, and Tuff of Lyle Spring to be similar in age and represent a partially isolated, highly evolved local magma chamber.

Vent locations for the Big Bend Ridge rhyolites are unknown, but are presumed to be downdropped within the second-cycle Henrys Fork caldera. Several authors have suggested that Moonshine Mountain rhyolite dome, which is located just inboard of the western margin of Henrys Fork caldera and adjacent to the Bishop Mountain flow (Fig. 3), represents the downfaulted vent dome for the Bishop Mountain flow based on the fact that the Moonshine Mountain dome also contains millimeter sized biotite phenocrysts (Christiansen, 2001; Hildreth et al., 1984; Obradovich, 1992). K-Ar dating of the pre-caldera Big Bend Ridge rhyolites by Obradovich (1992) yielded ages that are slightly younger than the Mesa Falls Tuff (1.10 ± 0.02 Ma to 1.26 ± 0.02 Ma 1σ) for all units except the Tuff of Lyle Spring, which yielded an age of 1.32 ± 0.02 Ma (1σ). Given that field relations require the Bishop Mountain and Green Canyon flows to have erupted before the Mesa Falls Tuff,

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