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Pyroxene thermometry of rhyolite lavas of the Bruneau–Jarbidge eruptive center, Central Snake River Plain

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ABSTRACT

The Bruneau–Jarbidge eruptive center of the central Snake River Plain in southern Idaho, USA produced multiple rhyolite lava flows with volumes of <10 km^3 to 200 km^3 each from ~11.2 to 8.1 Ma, most of which follow its climactic phase of large-volume explosive volcanism, represented by the Cougar Point Tuff, from 12.7 to 10.5 Ma. These lavas represent the waning stages of silicic volcanism at a major eruptive center of the Yellowstone hotspot track. Here we provide pyroxene compositions and thermometry results from several lavas that demonstrate that the demise of the silicic volcanic system was characterized by sustained, high pre-eruptive magma temperatures (mostly ≥950 °C) prior to the onset of exclusively basaltic volcanism at the eruptive center. Pyroxenes display a variety of textures in single samples, including solitary euhedral crystals as well as glomerocrysts, crystal clots and annealed microgranular inclusions of pyroxene ± magnetite ± plagioclase. Pigeonite and augite crystals are unzoned, and there are no detectable differences in major and minor element compositions according to textural variety — mineral compositions in the microgranular inclusions and crystal clots are identical to those of phenocrysts in the host lavas. In contrast to members of the preceding Cougar Point Tuff that host polymodal glass and mineral populations, pyroxene compositions in each of the lavas are characterized by single rather than multiple discrete compositional modes. Collectively, the lavas reproduce and extend the range of Fe–Mg pyroxene compositional modes observed in the Cougar Point Tuff to more Mg-rich varieties. The compositionally homogeneous populations of pyroxene in each of the lavas, as well as the lack of core-to-rim zonation in individual crystals suggest that individual eruptions each were fed by compositionally homogeneous magma reservoirs, and similarities with the Cougar Point Tuff suggest consanguinity of such reservoirs to those that supplied the polymodal Cougar Point Tuff. Pyroxene thermometry results obtained using QUILF equilibria yield pre-eruptive magma temperatures of 905 to 980 °C, and individual modes consistently record higher Ca content and higher temperatures than pyroxenes with equivalent Fe–Mg ratios in the preceding Cougar Point Tuff. As is the case with the Cougar Point Tuff, evidence for up-temperature zonation within single crystals that would be consistent with recycling of sub- or near-solidus material from antecedent magma reservoirs by rapid reheating is extremely rare. Also, the absence of intra-crystal zonation, particularly at crystal rims, is not easily reconciled with cannibalization of caldera fill that subsided into pre-eruptive reservoirs. The textural, compositional and thermometric results rather are consistent with minor re-equilibration to higher temperatures of the unerupted crystalline residue from the explosive phase of volcanism, or perhaps with newly generated magmas from source materials very similar to those for the Cougar Point Tuff. Collectively, the data suggest that most of the pyroxene compositional diversity that is represented by the tuffs and lavas was produced early in the history of the eruptive center and that compositions across this range were preserved or duplicated through much of its lifetime. Mineral compositions and thermometry of the multiple lavas suggest that unerupted magmas residual to the explosive phase of volcanism may have been stored at sustained, high temperatures subsequent to the explosive phase of volcanism. If so, such persistent high temperatures and large eruptive magma volumes likewise require an abundant and persistent supply of basalt magmas to the lower and/or mid-crust, consistent with the tectonic setting of a continental hotspot.

1. Introduction

This study of compositional and textural relations of pyroxene in rhyolite lavas of the Bruneau–Jarbidge eruptive center (BJEC) provides an opportunity to examine the relationship of effusive to explosive volcanism in a continental hotspot. Additionally, the results presented

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here bear on the behavior of a large silicic system as it evolves from maturation to its demise. The Bruneau–Jarbidge eruptive center of the Yellowstone hotspot track is noted for the exceptionally large volume of high-temperature silicic magmas that were erupted over its lifetime from 12.7 to ~8.1 Ma. Eruptive activity at the BJEC can be conveniently divided into two major episodes: 1) approximately 2.2 myr of explosive eruption of large-volume ashflow tuffs from 12.7 to 10.5 Ma, and 2) approximately 2.4 myr characterized by effusive eruption of rhyolite lavas from ~10.5 to 8.1 Ma. There is evidence for only limited overlap between the two distinct periods of eruptive activity. Estimates of the cumulative volume of the multiple members of the Cougar Point Tuff (CPT) and subsequent rhyolitic lava flows erupted from the BJEC range from 7×10^3 km^3 to more than 1×10^4 km^3 (e.g. Perkins and Nash, 2002; Bonnichsen et al., 2008); the lavas are estimated to constitute ~15% at minimum of this total (Leeman et al., 2008). The unusually large volume lavas associated with the BJEC are one feature of what has been recently recognized as a distinctive style of large-scale silicic volcanism, including high-grade ignimbrites and voluminous rhyolite lavas, termed Snake River (SR)-type volcanism (Branney et al., 2008). The extended duration of effusive volcanism that defines the terminal stages or "demise" of the BJEC appears to be unmatched by other eruptive centers of the CSRP (e.g. Twin Falls eruptive center) and Yellowstone hotspot track, and also contrasts with other large caldera systems such as Long Valley where the episode of large volume rhyolite lava extrusion is restricted to the 100 ka- year interval following the climactic eruption of the Bishop Tuff (Hildreth, 2004). The ~4.6 Ma interval of volcanism at the BJEC is distinguished in part from younger volcanic centers of the YHS track such as the Heise volcanic field and the Yellowstone Plateau by its consistently high pre-eruptive magma temperatures of ~900–1000 °C that commonly exceed 950 °C in both tuffs and lavas (Honjo, 1990; Honjo et al., 1992; Cathey and Nash, 2004) and by its higher eruptive frequency (Perkins and Nash, 2002). The rhyolitic tuffs and lavas of the Bruneau–Jarbidge eruptive center also constitute the largest low $\delta^{18}O$ silicic volcanic province yet documented, as indicated by O isotopic ratios in feldspar ($\delta^{18}O = -1.3$ to 3.8‰) (Boroughs et al., 2005) and quartz ($\delta^{18}O = 1.3$ to 4.5‰) and zircon ($\delta^{18}O_{rims} = -3.1$ to 3.3‰) (Cathey et al., 2007). The implications of sustained, large-volume, low $\delta^{18}O$, high-temperature silicic magma generation for the nature of its connection to the basaltic magma supply that must drive crustal melting (e.g. basaltic magma emplacement depths, emplacement rates, and total volume and duration of basaltic magmatism) have been addressed recently by Leeman et al. (2008). In this paper, our purpose is to provide new detail on the thermal evolution and the protracted waning phase of the silicic system as it is recorded by pyroxene compositions, textures, and equilibration temperatures.

Other workers have recently suggested that it may be appropriate to consider the BJEC and the Twin Falls eruptive center (TFEC) — inferred to be the immediate successor to the BJEC to the east — as parts of a cogenetic system of magmatism encompassing the Central Snake River Plain (CSRP), based on available petrological and geochronologic evidence (Bonnichsen et al., 2008). Results of this study are consistent with that view. However, for purposes of discussion, the definition of the BJEC used here is the same as the one originally described by Bonnichsen (1982b), and its approximate boundaries are illustrated in Fig. 1. This study compares the ten members of the CPT (12.7–10.5 Ma) with lavas that erupted from ~11.2 to ~8.1 Ma, one of which is intercalated with the CPT, and nine that postdate it. We present data for the Three Creek Rhyolite, a unit originally grouped with rhyolite lavas of the BJEC (Bonnichsen, 1982a) but that shares physical characteristics with both rheomorphic lavas and high-grade ignimbrites (Branney et al., 2004); Bonnichsen et al. (2008) note that this flow has subsequently been re-interpreted as an ignimbrite. Eruption ages for lavas included in this study (see below) span the known duration of effusive rhyolite volcanism at the BJEC, although we note that this study does not fully represent the complement of BJEC rhyolites as described by Bonnichsen (1982a) in that three (Mary's Creek Rhyolite, Long Draw Rhyolite, rhyolite of the Juniper–Clover area) have not been included. Based on whole rock compositions (Bonnichsen, 1982a; Bonnichsen et al., 2008), phase assemblages, petrographic characteristics and unpublished preliminary mineral data, these three units are similar to other lavas of the BJEC

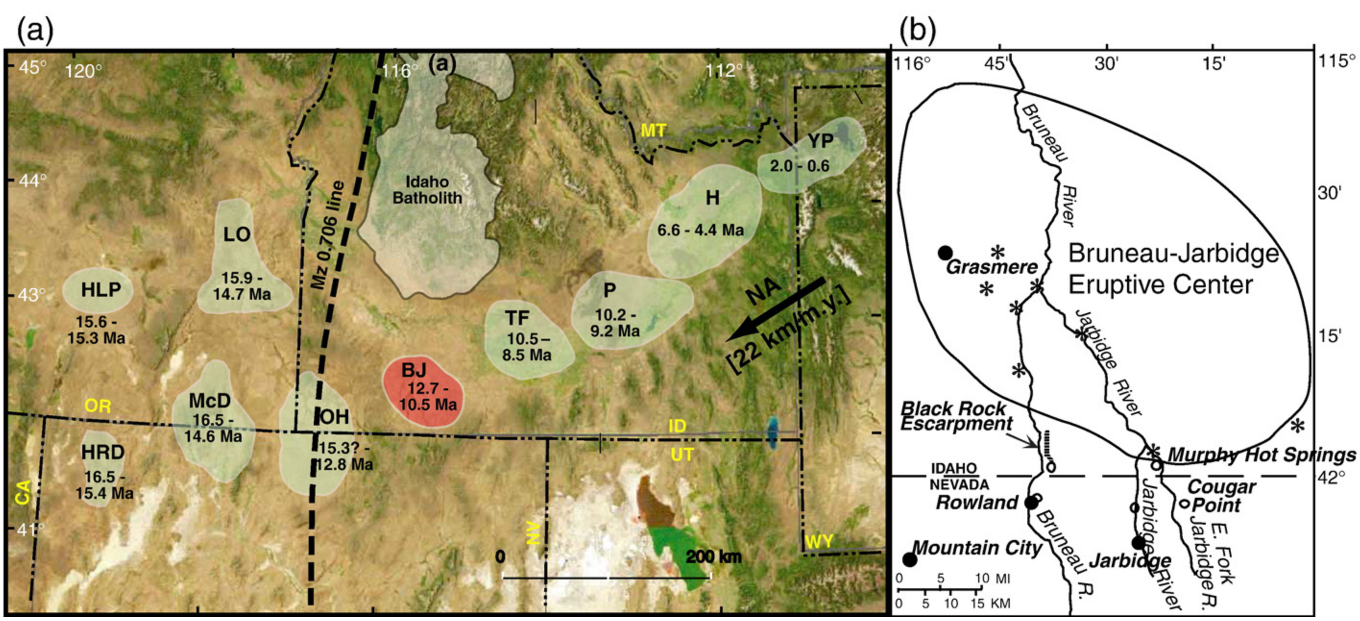

Fig. 1. (a) Major silicic volcanic centers associated with the Yellowstone hotspot showing location of the Bruneau–Jarbidge (BJ) eruptive center east of the $^{87}Sr/^{86}Sr$ (i) = 0.706 isopleth. All eruptive center margins are approximate only, except for the Yellowstone plateau, and show the relative positions of inferred loci of silicic volcanism. HLP = High Lava Plains; LO = Lake Owyhee; HR = High Rock Desert; McD = McDermitt; O–H = Owyhee–Humboldt; TF = Twin Falls; P = Picabo; H = Heise; YP = Yellowstone plateau. (Adapted from Pierce and Morgan, 1990, 1992; Nash et al., 2006). (b) Generalized reference map of the Bruneau–Jarbidge eruptive center. Asterisks indicate collection locations of rhyolite lava samples from nine flows described by Bonnichsen (1982a), as well as one lava intercalated with the CPT at Black Rock Escarpment. Vitric samples were collected from bases of lava flows. No glassy material was found for the Lower Rhyolite at Poison Creek. In this case, devitrified samples were collected. Collection areas for the Cougar Point Tuff are indicated by open circles. Map adapted from Bonnichsen, 1982b.