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Hydrothermal alteration and melting of the crust during the Columbia River Basalt–Snake River Plain transition and the origin of low-$\delta^{18}O$ rhyolites of the central Snake River Plain

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ABSTRACT

We present compelling isotopic evidence from ~15 Ma rhyolites that erupted coeval with the Columbia River Basalts in southwest Idaho's J-P Desert and the Jarbidge Mountains of northern Nevada at that suggests that the Yellowstone mantle plume caused hydrothermal alteration and remelting of diverse compositions of shallow crust in the area where they erupted. These rhyolites also constitute the earliest known Miocene volcanism in the vicinity of the Bruneau–Jarbidge and Twin Falls (BJTF) volcanic complexes, a major center of voluminous (10^3–10^4 km^3) low-$\delta^{18}O$ rhyolitic volcanism that was previously defined as being active from 13 to 6 Ma. The Jarbidge Rhyolite has above-mantle $\delta^{18}O$ ($\delta^{18}O$ of +7.9‰ SMOW) and extremely unradiogenic ε_{Hf} (−34.7) and ε_{Nd} (−24.0). By contrast, the J-P Desert units are lower in $\delta^{18}O$ (+4.5 to 5.8‰), and have more moderately unradiogenic whole-rock ε_{Hf} (−20.3 to −8.9) and ε_{Nd} (−13.4 to −7.7). The J-P Desert rhyolites are geochemically and petrologically similar to the younger rhyolites of the BJTF center (the one exception being their high $\delta^{18}O$ values), suggesting a common origin for J-P Desert and BJTF rhyolites. The presence of low-$\delta^{18}O$ values and unradiogenic Nd and Hf isotopic compositions, both of which differ greatly from the composition of a mantle differentiate, indicate that some of these melts may be 50% or more melted crust by volume. Individual J-P Desert units have isotopically diverse zircons, with one lava containing zircons ranging from −0.6‰ to +6.5‰ in $\delta^{18}O$ and from −29.5 to −2.8 in ε_{Hf}. Despite this diversity, zircons all have Miocene U/Pb ages. The range of zircon compositions fingerprints the diversity of their source melts, which in turn allow us to determine the compositions of two crustal end-members which melted to form these rhyolites. These end-members are: 1) Archean basement with normal to high-$\delta^{18}O$ and unradiogenic ε_{Hf} and 2) hydrothermally altered, shallow, young crust with low-$\delta^{18}O$ (0–1‰) and more radiogenic ε_{Hf}. We suggest that the shallow crust's low-$\delta^{18}O$ composition is the result of hydrothermal alteration which was driven by a combination of normal faulting and high heat fluxes from intruding Yellowstone plume-derived basalts shortly prior to the onset of silicic magmatism. Furthermore, zircon diversity in the J-P Desert units suggests rapid assembly of zircon-bearing melts of varying isotopic composition prior to eruption, creating well-mixed magmas with heterogeneous zircons. We suggest that this hydrothermal priming of the crust followed by remelting upon further heating may be a common feature of intraplate mantle plume volcanism worldwide.

1. Introduction

The time transgressive series of eruptive centers along the Yellowstone hotspot track connects the modern eruptive center at the Yellowstone Plateau with the ~16 Ma Columbia River flood basalts (CRBs) (e.g., Pierce and Morgan, 1992). The flood basalts and their associated silicic magmatism, together with the younger hotspot track, are most commonly interpreted as the expression of a deep-sourced mantle plume (Camp and Ross, 2004; Schmandt et al., 2012), though other interpretations are also discussed (Carlson, 1984; Christiansen et al., 2002; Liu and Stegman, 2012). Unlike the focused silicic centers that characterize past and present activity along the hotspot track of the Snake River Plain (SRP) and Yellowstone, the syn-CRB silicic volcanism occurred nearly simultaneously over a roughly circular region at least 400 km across which is presumed to have been underlain by the head of the Yellowstone plume (Fig. 1) (Camp and Ross, 2004; Coble and Mahood, 2012; Ferns and McClaughry, 2013).

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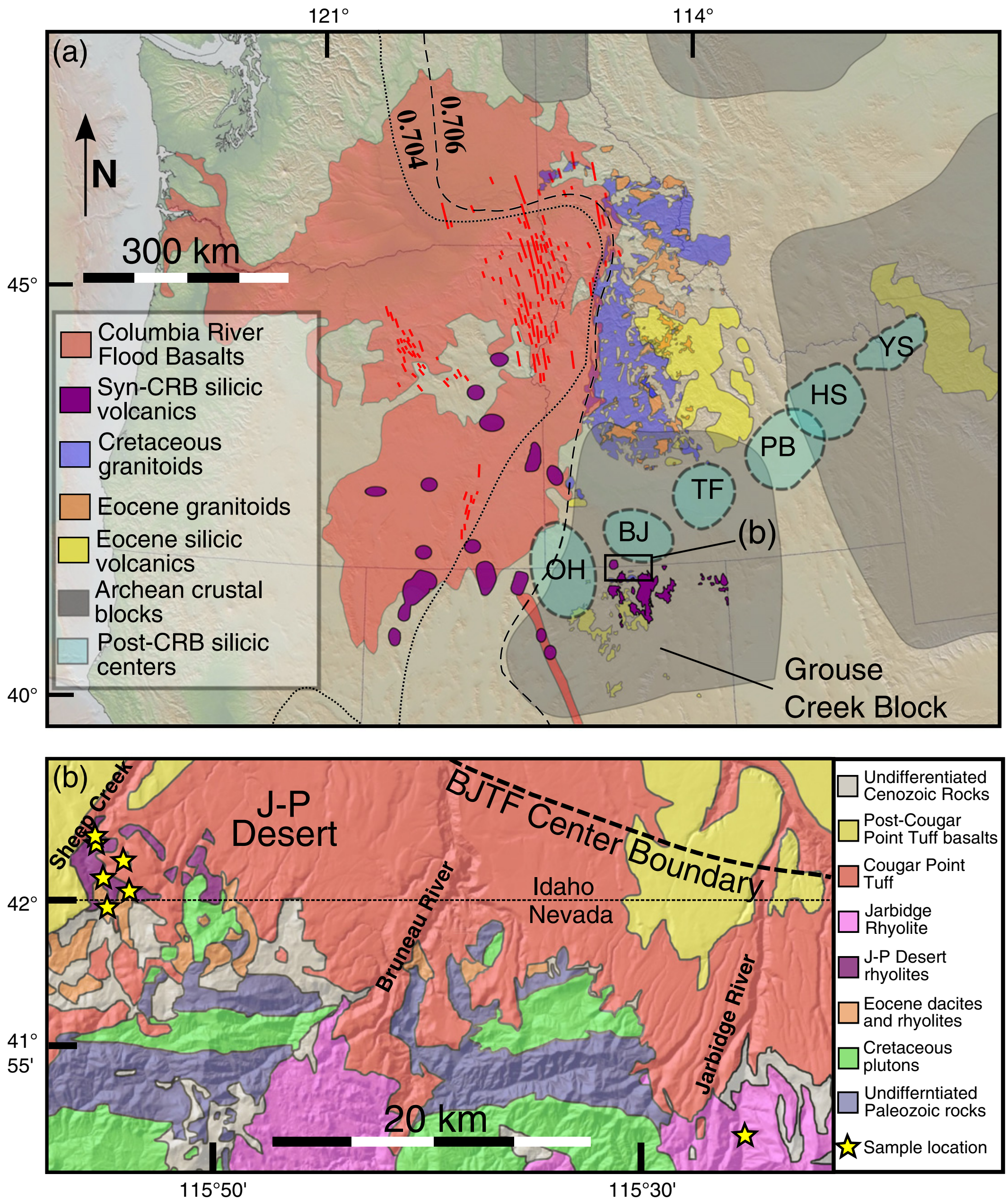

Fig. 1. Regional and local maps of the study area. (a) Extent of volcanism due to the Yellowstone Plume at 14.5–17 Ma. Red areas show the region covered by the CRBs (including the Northern Nevada Rift), which erupted from 17 to 15.5 Ma (Camp and Ross, 2004; Reidel et al., 2013; Wolff et al., 2008). Dike swarms that fed the flood basalt eruptions are shown in dark red (Camp and Ross, 2004). Syn-CRB rhyolites of age 14.5 Ma and older are shown in pink (Coats, 1987; Coble and Mahood, 2012; Ferns and McClaughry, 2013; Steiner and Streck, 2013; Streck et al., 2011). Mapped centers of rhyolitic volcanism are not exhaustive, but show all centers estimated as having at least 20 km^3 of rhyolite by Coble and Mahood (2012, Supplementary material). Large inferred or observed volcanic centers that occurred along the Yellowstone hotspot track from 14.5 Ma to the present are indicated by dotted lines. These include the Owyhee–Humboldt–Juniper Mountain (OH), Bruneau–Jarbidge (BJ), Twin Falls (TF), Picabo (PB), Heise (HS), and Yellowstone (YS) centers (Bonnichsen et al., 2008; Drew et al., 2013). All of these large post 14.5 Ma caldera centers have been host to low-δ^{18}O volcanism. Additional mapped features include the Archean crustal blocks of Foster et al. (gray) (2006), locations of Eocene volcanism of the Challis and Absaroka volcanics (yellow) (Norman and Mertzman, 1991), Cretaceous and Eocene intrusives of the Idaho batholith, Challis intrusives, and adjacent areas (Boroughs et al., 2012; Coats, 1987; Gaschnig et al., 2011). (b) Detail of the study area, simplified from Bernt and Bonnichsen (1982), Coats (1987), and Link (2002). Dashed edge of the ~13–11 Ma Bruneau–Jarbidge volcanic complex is taken from Bonnichsen et al. (2008). Stars show sample locations (Table 1). Bases for both maps obtained from the Global Multi-Resolution Topography (GMRT) synthesis (GeoMapApp.org). Small outcrops of Seventy Six basalt are located south of the map area.

In this study we investigate a group of rhyolites in the J-P Desert of Idaho, which is defined as the area between Sheep Creek and the Bruneau River in Owyhee County, southwest Idaho, and compare them to one sample of the Jarbidge Rhyolite 45 km southwest of the J-P Desert locality in northern Nevada (Fig. 1b). This places them on the geographic boundary between the broad unfocused silicic volcanism that accompanied the CRBs and the more focused silicic volcanism that characterizes the volcanic centers of the SRP. Additionally, these units are overlain by ashflow tuffs identified as belonging to the Bruneau–Jarbidge volcanic center, the oldest of the major eruptive centers of the Snake River Plain (Bernt and Bonnichsen, 1982; Bonnichsen et al., 2008), making them also temporally intermediate between the