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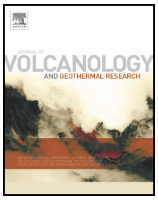

The eruptive and magmatic history of the youngest pulse of volcanism at the Valles caldera: Implications for successfully dating late Quaternary eruptions

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ABSTRACT

New ^{40}Ar/^{39}Ar and U/Th ages provide insight into the youngest eruptions at the Valles caldera and also reveal previously unknown pulses of magmatism. The youngest eruptive units, collectively termed the East Fork Member of the Valles Rhyolite, include the El Cajete pyroclastic beds and co-erupted Battleship Rock ignimbrite, and the disconformably overlying Banco Bonito lava flow. Previous attempts to date these units using a variety of techniques yielded ages ranging from <40 ka to >1 Ma. New ^{40}Ar/^{39}Ar ages were generated using the high-sensitivity, multi-collector ARGUS VI mass spectrometer, which provides more than an order of magnitude increase in precision compared to most single-detector mass spectrometers. ^{40}Ar/^{39}Ar dating of single crystals yields a range of ages, of which the youngest populations are interpreted to represent the eruption age. Sanidine ages indicate that the El Cajete pyroclastic beds and Battleship Rock ignimbrite erupted at 74.4 ± 1.3 ka, whereas the Banco Bonito lava erupted at 68.3 ± 1.5 ka. Populations of older crystals represent variably degassed xenocrysts, explaining why previous ^{40}Ar/^{39}Ar bulk step-heating analyses yielded spuriously old and irreproducible results. U/Th dating of unpolished zircon surfaces also yield multiple age populations, which range from the eruption age to >350 ka, indicating protracted magmatism during the 453-ka-long eruptive hiatus prior to the eruption of the East Fork Member. ^{40}Ar/^{39}Ar and U/Th ages indicate that the East Fork Member represents a short (6.1 ± 2.8 ka) eruptive cycle, from a longer-lived magmatic system beneath the southern caldera. Equally short repose periods, similar to the interval between the El Cajete–Battleship Rock and Banco Bonito eruptions, are possible during future volcanism at the Valles caldera. Results demonstrate that detailed geochronology using single-crystal and in-situ techniques is necessary for understanding the eruptive history and magmatic evolution at some young volcanic systems.

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1. Introduction

The timescales of magmatism and ages of eruptions are vital for understanding the history and hazards of active and dormant volcanic fields. Eruption ages are used to calculate hazard parameters such as recurrence rates and repose periods, as well as to identify vent migration patterns that are crucial to eruption forecasting (Tanaka et al., 1986; Connor and Hill, 1995; Condit and Connor, 1996; Heizler et al., 1999). Timescales of crystallization, typically calculated from U/Th or U/Pb zircon dating, determine the duration of magma assembly, sources of melting, role of assimilation, and transport of magma through the crust (Miller et al., 2007; Claiborne et al., 2010). Both eruption and crystallization ages provide a temporal framework to assess related geothermal systems and to evaluate the implications of low-velocity zones (i.e., crustal melts) and related seismic events beneath volcanic fields.

Despite the geologic and societal importance, the chronologies for many late Quaternary vent loci are poorly understood. Single-crystal ^{40}Ar/^{39}Ar dating of <100 ka samples with previous generation, less-sensitive single-collector mass spectrometers often yields imprecise ages, and thus requires fusing or step-heating multi-grain aliquots in order to obtain large signals for precise measurements. Samples with abundant xenocrysts or that have grains with excess ^{40}Ar will yield anomalously old ages (Deino and Potts, 1990). Likewise, analyses of whole zircons with temporally complex domains, such as those with protracted crystallization histories (i.e., 10 to >100 ka) or inherited cores, will yield an integrated age that neither dates the eruption nor documents the crystallization history (Miller et al., 2007; Lipman and Bachmann, 2015). The high spatial-resolution of in-situ measurements of sectioned zircons using the LA-ICPMS or SIMS techniques can identify unique domains. However, some distinct age domains within zircon are

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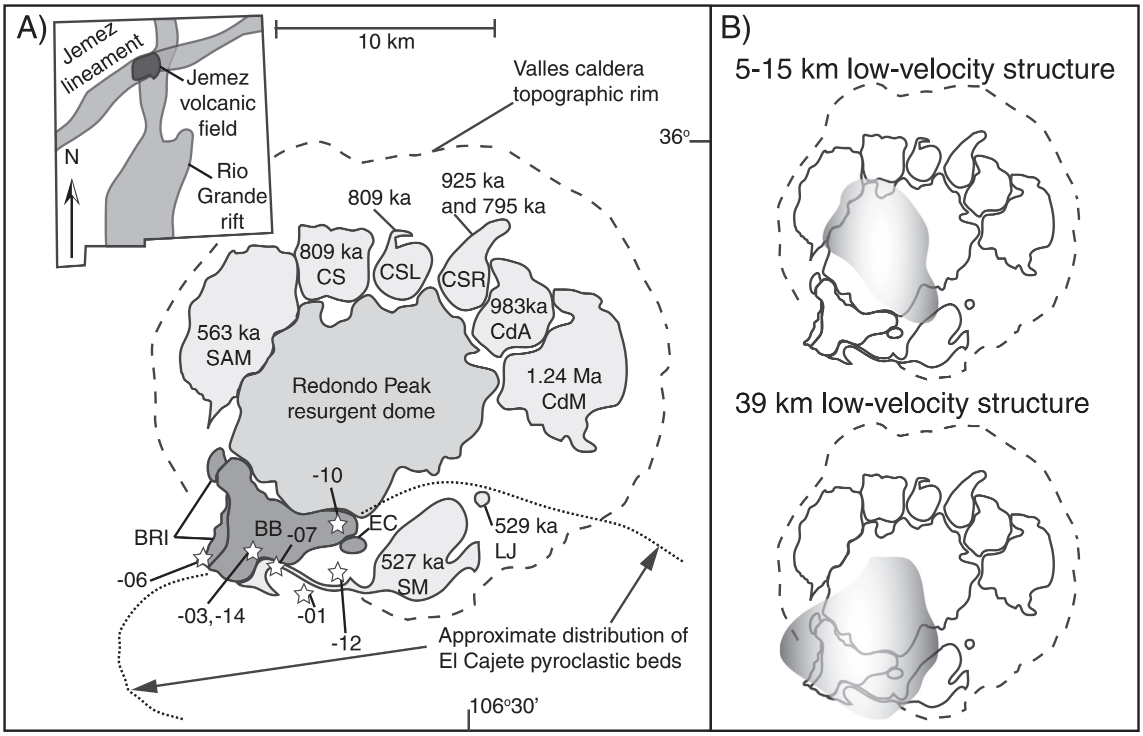

Fig. 1. A. Simplified geologic map of Valles caldera. White stars indicate sample locations. Ages of rhyolite domes from Spell and Harrison (1993) and Phillips et al. (2007) are also shown. Abbreviations are: CdM — Cerro del Medio, CdA — Cerro del Abrigo, CSR — Cerro Santa Rosa, CSL — Cerro San Luis, CS — Cerro Seco, SAM — San Antonio Mountain, LJ — La Jara, SM — South Mountain, BRI — Battleship Rock ignimbrite, EC — El Cajete crater (vent for El Cajete and Battleship Rock ignimbrite), and BB — Banco Bonito lava flow. Not shown on this map are the postcaldera lavas on the flanks of the resurgent dome. The inset map of New Mexico shows location of the Jemez volcanic field in relation to the Rio Grande rift and Jemez lineament. B. Approximate location of seismically imaged low velocity zones beneath the Valles caldera, from plate 1 of Steck et al. (1998).

too fine to measure individually (Corfu et al., 2003), including the outermost rims that document the youngest phase of zircon growth prior to the eruption.

The published ages for the youngest series of eruptions at the Valles caldera (Fig. 1A) are not sufficiently precise or reproducible to develop a conclusive eruption chronology useful for hazard assessment. The youngest eruptions at the Valles caldera are collectively known as the East Fork Member of the Valles Rhyolite, which includes the El Cajete pyroclastic beds and co-erupted Battleship Rock ignimbrite, and the overlying Banco Bonito lava flow (Gardner et al., 2010). Previous attempts to date these units using numerous dating techniques (Fig. 2) have yielded widely varying ages, from <40 ka to >1 Ma (Miyachi et al., 1985; Self et al., 1988; Ogoh et al., 1993; Spell and Harrison, 1993; Toyoda et al, 1995; Reneau et al., 1996; Phillips et al., 1997; Lepper and Goff, 2007), although the most commonly cited ages for the two eruptions are 55 and 40 ka (Goff and Gardner, 2004) based on electron spin resonance (Ogoh et al., 1993; Toyoda et al., 1995), ^{14}C (Reneau et al., 1996), and ^{21}Ne dating (Phillips et al., 1997). In particular, the range of ^{40}Ar/^{39}Ar ages for K-bearing minerals is likely due to the abundance of xenocrystic material and the presence of excess ^{40}Ar (Spell and Harrison, 1993). In addition to constraining the last pulse of volcanic activity, the ages of these units are particularly important because the vents are located above low-velocity structures (Fig. 1B) interpreted to be zones of partial melt at ~5–15 km and ~39 km depth (Lutter et al., 1995; Steck et al., 1998; Aprea et al., 2002).

In order to better assess the timing of the youngest eruptions at the Valles caldera, new ^{40}Ar/^{39}Ar and U/Th ages were determined for the East Fork Member. ^{40}Ar/^{39}Ar ages were generated using the newest generation ARGUS VI mass spectrometer, which permits precise dating of late Quaternary samples at the single-crystal level. Unpolished zircon crystal faces, rather than sectioned grains, were dated using the U/Th method to investigate the youngest pulse of zircon growth, further constraining the eruption ages and crystallization history. The combination of ^{40}Ar/^{39}Ar and U/Th ages provides insight into the timescales of eruptions and magmatic pulses during postcaldera volcanism at the Valles caldera.

2. Geology of the East Fork Member of the Valles Rhyolite

Numerous studies have investigated the temporal and spatial trends of volcanism at the Valles caldera. (e.g., Spell and Harrison, 1993; Phillips et al., 2007; Kelley et al., 2013). The Valles caldera, located in the Jemez Mountain volcanic field of north-central New Mexico (Fig. 1A), is a classic example of a resurgent caldera (Smith and Bailey, 1968). The Jemez field is located at the intersection of the Rio Grande rift, a major east–west extensional feature extending from central Colorado to northern Mexico, and the Jemez lineament, a northeast trending zone of crustal weakness that has concentrated tectonic, magmatic, and volcanic activity (Chapin et al., 2004). Compositionally diverse magmas were erupted from widely scattered centers beginning as early as ca. 16 Ma and continuing to ca. 2 Ma (Gardner and Goff, 1996; Kelley et al., 2013), when magmas evolved to more rhyolitic compositions during the Quaternary (Self et al., 1988; Gardner et al., 2010). The Toledo caldera formed during the 1.651 ± 0.011 Ma[1] eruption of the Otowi Member of the Bandelier Tuff (Izett and Obradovich, 1994). Located in nearly the same location as the Toledo caldera is the morphologically well-preserved Valles caldera. The Valles caldera formed at 1.264 ± 0.010 Ma during the eruption of Tshirege Member of the Bandelier Tuff (Phillips et al., 2007). Within 57 ka after the eruption of the Tshirege Member the caldera floor was resurgently uplifted more than 1000 m to form Redondo Peak (Phillips

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[1] All published ages are recalculated relative to 28.201 Ma Fish Canyon sanidine.