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EMPLACEMENT OF SHALLOW INTRUSIONS AT GOBLIN COLONY AND THEIR IMPACT ON PALEOHYDROLOGY AND ALTERATION, SOUTHERN JEMEZ MOUNTAINS, NEW MEXICO

FRASER GOFF[1], MATTHEW J. ZIMMERER[2], AND CATHY J. GOFF[3]

[1]Department of Earth and Environmental Science, Institute of Mining and Technology, 801 Leroy Place, Socorro, NM 87801; candf@swcp.com
[2]New Mexico Bureau of Geology and Mineral Resources, 801 Leroy Place, Socorro, NM 87801
[3]Private consultant, 5515 Quemazon, Los Alamos, NM 87544

Abstract—Goblin Colony is a recently described area in the southern Jemez Mountains that contains 0.15 km^2 of zeolite-altered Tshirege Member of the Bandelier Tuff. The altered tuff (ignimbrite) fills a southwest-trending paleovalley in which preexisting basal-contained sediments provided water for the alteration of the tuff. The southeast side of the paleovalley is bounded by a prominent trachydacite to trachyandesite dike and plug zone that formed a hydrologic barrier to fluid flow. In this short paper, we describe the intrusions, the results of recent $^{40}Ar/^{39}Ar$ dates on the intrusions, and their impact on paleohydrology and low-temperature alteration of the tuff in the Goblin Colony.

INTRODUCTION

Dikes are defined as tabular magmatic intrusions, subvertical, that cut across preexisting country rocks. There are many subtle variations on this basic definition (e.g., Carrigan, 2000; Marsh, 2015). Dikes commonly deform and bake country rocks along their contacts, but they are highly variable in composition, length, width, and other characteristics (Delany and Pollard, 1981; Goff et al., 2013). Dikes can form hydrologic barriers to groundwater flow perpendicular to their strike direction and can capture and facilitate groundwater flow parallel to their strike direction (e.g., Babiker and Gudmondsson, 2004; Comte et al., 2017; Cavalcante et al., 2020; Carle, 2022). In this report, we discuss the timing of emplacement and the impact of a 1.5-km-long trachydacite to trachyandesite dike and plug zone on the paleohydrology at the Goblin Colony.

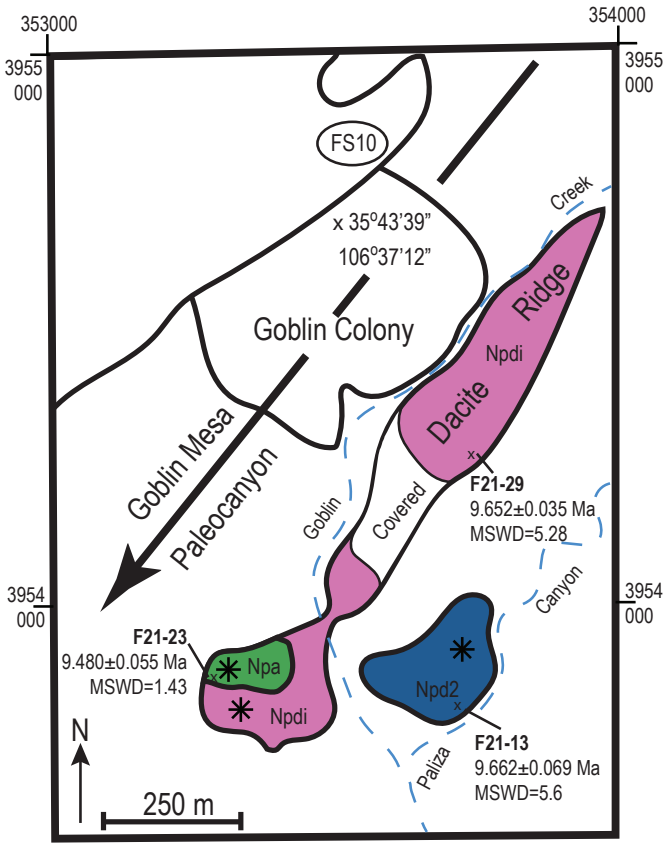
BACKGROUND

Goblin Colony is an area of stunningly beautiful, altered Tshirege Member, Bandelier Tuff (1.231±0.001 Ma; Nasholds and Zimmerer, 2022) located in the southern Jemez Mountains ~11 km south of the southern Valles Caldera rim and ~5 km north of the village of Ponderosa (Fig. 1; Goff et al., 2023). The name of the area is thought to derive from the sound of wind blowing through features that look like goblin faces on moonlit nights. Self et al. (1996) first described an outcrop of "vapor-phase pipes" along Forest Service Road 10 on the northwest side of Goblin Colony. It was later found that Goblin Colony consists of about 0.15 km^2 (37 acres) of pronounced vertical spires, fins, spire and fin clusters, walls, columns, and tabular ledges that occupy a steep, southeast-facing slope on the north side of a tributary of Paliza Canyon watershed (informally called Goblin Creek on Fig. 1). Because of the statuesque nature of the goblins, some of which look eerily like eroded faces (Fig. 2A), this area has become a destination for hikers who want an easy but rewarding adventure (Holsapple, 2019, 2021). However, the hike descriptions on these websites provide no geologic explanation for how Goblin Colony and the surrounding rocks were formed. Thus, we spent several months in the summer of 2021 compiling a detailed geologic map of the area and determining the petrographic and geochemical characteristics of the rocks. We combined these data with an aerial drone survey to determine how Goblin Colony formed (Goff et al., 2023).

Columns, walls, and other eroded alteration structures at Goblin Colony are formed primarily by low-temperature zeolite replacement (mordenite and clinoptilolite) of the glass in Unit 1 of the host tuff (Self et al., 2022; Goff et al., 2023). The alteration is observable at all scales from examination of thin sections, X-ray diffraction analyses, scanning electron microscope images, and whole rock chemistry (Goff et al., 2023). Zeolite replacement is ≤18 wt%. Most of the glass and mineral phases (sanidine, quartz, clinopyroxene, Fe-Ti oxides, etc.) are surprisingly unaltered. Significantly, Goblin Colony samples contain relatively minor amounts of cristobalite and tridymite indicating virtually no high-temperature vapor-phase alteration (i.e., ≥400°C; Ross and Smith, 1960; Cas and Wright, 1987). The zeolitic alteration occurred at ≤200°C and probably at ≤150°C (Barger and Keith, 1995; Stimac et al., 2015; Goff et al., 2023).

Goblin Colony is located within a broader region of canyons, arroyos, and cliffs that expose older, eroded volcanic rocks and sediments of the Jemez Mountains volcanic field. The Tshirege Member at Goblin Colony fills a 100 m-deep, northeast-southwest-trending paleocanyon that was cut into earlier deposits of the Otowi Member of the Bandelier Tuff (1.61±0.01 Ma; Izett and Obradovich, 1994). Geologic mapping shows that the paleocanyon occupied by altered Goblin Colony tuffs is buttressed by a prominent northeast-southwest-trending "dike zone" of trachydacite to trachyandesite rocks of the earlier Jemez Mountains volcanic field (Goff et al.,

2023). These intermediate-composition volcanic rocks were not previously dated, although Gardner (1985) indicated that they were probably emplaced between 7 and 9 Ma.



QUATERNARY TO NEOGENE ROCKS
UNDIVIDED

Includes alluvium, colluvium, landslides, El Cajete Pumice, Bandelier Tuff, gravels, sediments, trachydacite flows and basalt flows.

NEOGENE
PALIZA CANYON FORMATION

Npa — Andesite Plug—Dark gray eroded plug (and flow?) of fine-grained, two-pyroxene andesite, Paliza Canyon Formation.

Npdi — Dacite Intrusions—Tan to gray biotite dacite intrusions forming two circular plugs and an elongate dike; much of the dike is partially hidden by El Cajete Pyroclastic Beds.

Npd2 — Dacite Plug—Dark gray to black, aphyric, biotite-hornblende dacite plug; extreme near-vertical sheeting on southeast side.

FIGURE 1. Simplified location map shows the area of Goblin Colony and three intrusive bodies with their sample locations and dates. The dark line with arrow shows the approximate position of the southwest-trending paleo drainage discussed in text. The waypoint noted within the Goblin Colony is the trailhead along Forest Service Road 10. All dates are isochron ages determined on groundmass separates because of their aphyric fine-grained texture. MSWD = mean square weighted deviation (e.g., Nasholds and Zimmerer, 2022). These dates and many others will be tabulated in a forthcoming report on recent $^{40}Ar/^{39}Ar$ results in the Jemez Mountains region.

INTRUSIVE ROCKS

We sampled the three intrusive bodies that constitute the "dike zone" within the Goblin Colony area to obtain new $^{40}Ar/^{39}Ar$ ages (results are shown on Fig. 1; data and figures can be found in Appendix 1). All ages are isochron results based on analyses of aphyric fine-grained groundmass separates; full details are provided in Appendix 1.

Chemical analyses and thin section summaries are presented in Goff et al., 2023, table 1. The oldest intrusion (Npd2; 9.662±0.069 Ma) is a northeast-trending lenticular plug of black glassy aphyric trachydacite containing sparse phenocrysts of biotite, hornblende and plagioclase (Gardner, 1985). This unit may have been one of many sources of archaeological dacite scattered around the southern Jemez Mountains (e.g., Shackley, 2011).

The most extensive unit is Npdi, a sparsely porphyritic biotite trachydacite dike (Fig. 2B) with small plagioclase phenocrysts. This 10–15-m-wide dike is roughly 1.5 km long and

FIGURE 2A. A line of goblins stands sentinel in the approximate center of the Goblin Colony, view looking northeast. Many of the goblins are reminiscent of the famous moai, or monolithic statues, at Rapa Nui (Easter Island) in the southern Pacific Ocean. Although they appear as a line in this view, the goblins are commonly clustered (Goff et al., 2023).

FIGURE 2B. Photo looking northwest shows the dacite dike (Npdi) where it is crossed by Goblin Creek and an abandoned Forest Service road. The southwest (left) part of the dike rises abruptly to form a plug a few hundred meters above the valley floor.

is the source of two plugs and a canyon-filling lava flow. It is partially obscured by pumice deposits erupted from El Cajete crater (74.7±1.3 ka, Nasholds and Zimmerer, 2022) in the Valles Caldera, and consequently the extent and significance of unit Npdi was not previously recognized. A sample of the dike a few hundred meters southeast of Goblin Colony yielded an age of 9.652±0.035 Ma.

The youngest intrusive unit is a relatively small 60-m-wide aphyric trachyandesite to trachydacite plug (Npa, 9.480±0.055 Ma) that intrudes the northwest side of one of the Npdi vents (Fig. 1). We have not chemically analyzed this unit but thin sections reveal that the unit contains very sparse tiny phenocrysts of plagioclase in a groundmass of plagioclase microlites, small ortho- and clinopyroxene crystals and black opaque-oxide-rich glass; thus, we have called it a trachyandesite.

The dike and plugs at Goblin Colony were emplaced in a relatively short span of time (ca. 180 kyr) and may connect at depth to form a larger elongate intrusive body based on their similar petrologic and chemical characteristics. This could possibly be verified by a future ground-based paleomagnetic survey, if warranted. Although much of the largest unit (Npdi) is partially covered, it forms an impressive wall that is cut by "Goblin Creek" and extends along a high "dacite ridge" northeast of the crossing point. Where well exposed, the dike rock contains many small joints and cracks, some horizontal, primarily striking N60W. Many of the joints may be cooling features; some may be tectonic in origin. No cracks are longer than the width of the dike, and all are closed or sealed; there are no extensive open cracks. Thus, the dike likely formed an impermeable barrier to horizontal flow of liquid water.

GEOLOGIC STRUCTURES

The dikes and plugs were emplaced along a north-northeaast-trending fault and/or fracture(s) that is part of the Cañada de Cochiti fault zone (Gardner, 1985; Kelley et al., 2013). Although fault offset in the field cannot be ascertained, the general disposition of older rock units suggests the "dike fault" has down-to-the-southeast displacement.

Detailed geologic mapping has revealed that two NE-trending paleovalleys, basins or drainages have been filled and obliterated in the Goblin Colony area. The older drainage was cut into sedimentary deposits of the Paliza Canyon Formation (PCF, ≤10 Ma) and filled with the Otowi Member of the Bandelier Tuff. This paleo drainage occurred southwest of the map shown in Figure 1, but it is documented in Goff et al. (2023).

The second eradicated drainage is younger and was excavated on the northwestern side of the northeast-trending dike and plug complex described above. The intrusive bodies form an impermeable or restrictive barrier to erosion and surface-water flow toward the south. The paleodrainage developed after the eruption of the Otowi Member when a stream cut deeply into a preexisting layered sequence of Otowi ignimbrite and PCF lava flows and volcaniclastic rocks, of which only remnants presently exist. This drainage had a southwesterly flow direction, semiparallel to the dacite plug and dike complex, but it was later filled with ignimbrites of the Tshirege Member. Goblin Colony rock formations that grew in the Tshirege Member presumably formed above sedimentary deposits that accumulated in this younger paleodrainage, which may have included water-saturated pond or marsh deposits. This ponded water was heated by instantaneous emplacement of hot Tshirege ignimbrite. Rising steam and vapor reacted with glass in the ignimbrite to form mordenite and clinoptilolite replacement minerals at temperatures of ≤200°C (Goff et al., 2023). The zeolite-cemented ignimbrites forming spires, walls and other features at Goblin Colony are more resistant to erosion than surrounding ignimbrites of the Tshirege Member.

CONCLUSIONS

The prominent dike and plug zone at Goblin Colony consists of three petrochemically related trachydacite to trachyandesite intrusions that were emplaced between around 9.7 and 9.5 Ma into a relatively porous substrate of layered lavas and volcaniclastic sediments. The largest exposed feature is a broad northeast-trending trachydacite dike (Npdi, 9.652±0.035 Ma) that is roughly 1.5 km long. This dike formed an impermeable barrier to the southeasterly flow of groundwater, but it became the southeast boundary of a paleocanyon that later played host to the 100 m thick sequence of zeolite-altered Tshirege ignimbrite forming the Goblin Colony.

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Appendices can be found at
https://nmgs.nmt.edu/repository/index.cfml?rid=2024006