A guide to the Mule Creek volcanic vent, the rhyolite of Potholes Country, and obsidian ledges, Gila National Forest, southwestern New Mexico

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Introduction

The Mule Creek eruptive vent of the rhyolite of Potholes Country in the Wilson Mountain 7½-min quadrangle (Ratté and Brooks 1989) is a worthwhile destination for anyone studying rhyolite volcanism in southwestern New Mexico. Directions for accessing the vent are followed by a discussion of the geologic setting, petrography and chemistry of the Potholes Country rhyolite, and economic considerations of this and other rhyolite bodies of similar age in the region.

The Mule Creek vent of the rhyolite of Potholes Country is spectacularly exposed over a vertical distance of approximately 1,100 ft (350 m) in the south-facing wall of the canyon of Mule Creek (cover). The vent is approximately 7 mi (10 km) north of the settlement of Mule Creek, which is approximately 5 mi (3.5 km) east of the Arizona State line on NM–78 (Fig. 1). The cover photo view shows the Mule Creek vent in total outcrop from the south rim of the canyon of Mule Creek. The outcrop probably rates as a world class geologic exposure of a rhyolite eruptive vent in cross section. The overview site from which the cover photo was taken can be reached from NM–78 via Gila National Forest roads and a short jeep track that can be traversed in vehicles lacking four-wheel drive, but having high clearance.

Access to the Mule Creek vent overlook

From the post office at Mule Creek, just east of the ford across Mule Creek on NM–78, the route to the Mule Creek vent overlook proceeds 3 mi (5 km) west to the junction with Gila National Forest road 111 (Fig. 2). Turn right (north) and follow the forest road approximately 0.5 mi (0.8 km) to the Harden Cienega road (a short alternate route back to NM–78); turn left at this intersection and follow the forest road west and north through the private ranch land for 6 mi (10 km) to an intersection where you turn right (east) and continue 2.2 mi (3.5 km) to a side track that leads to

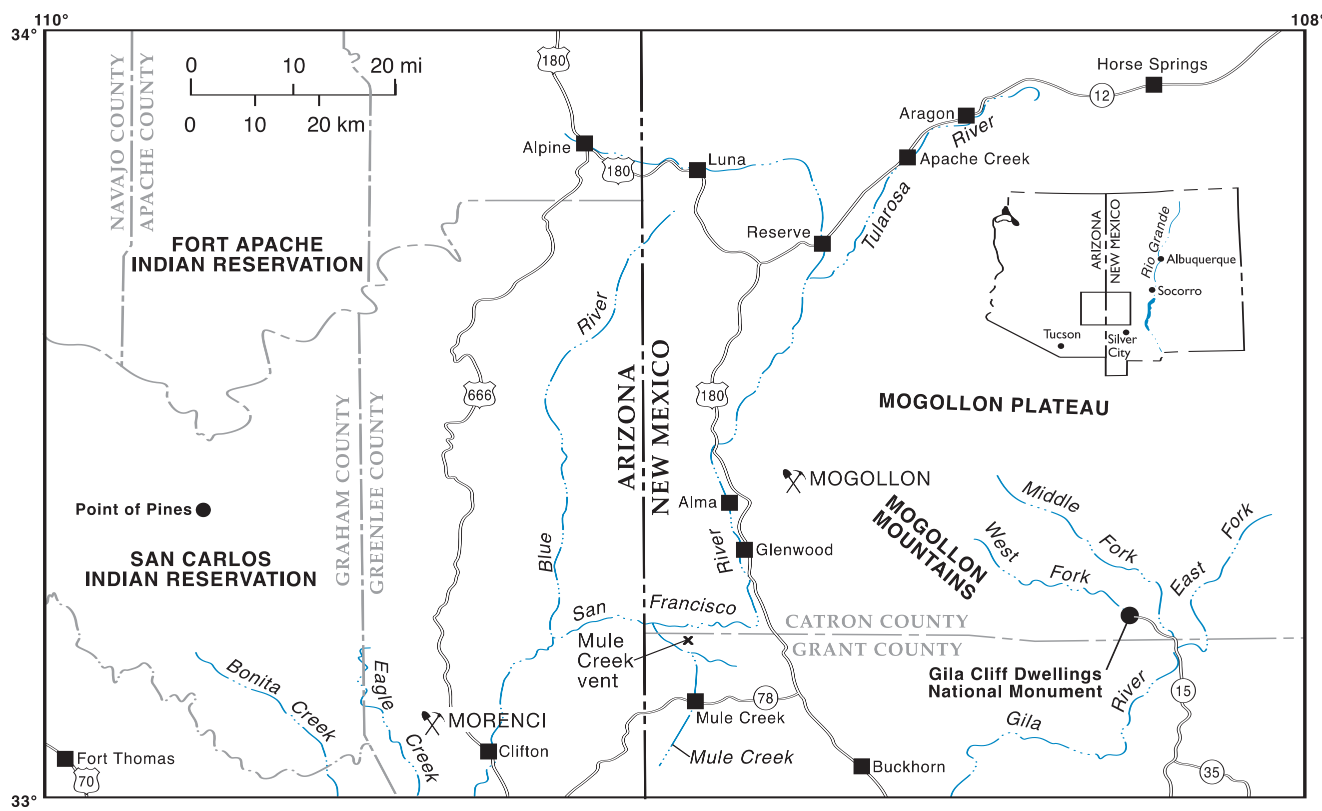


FIGURE 1—Index map showing location of the settlement of Mule Creek and the Mule Creek vent of the Miocene (20–21 Ma) rhyolite of Potholes Country.

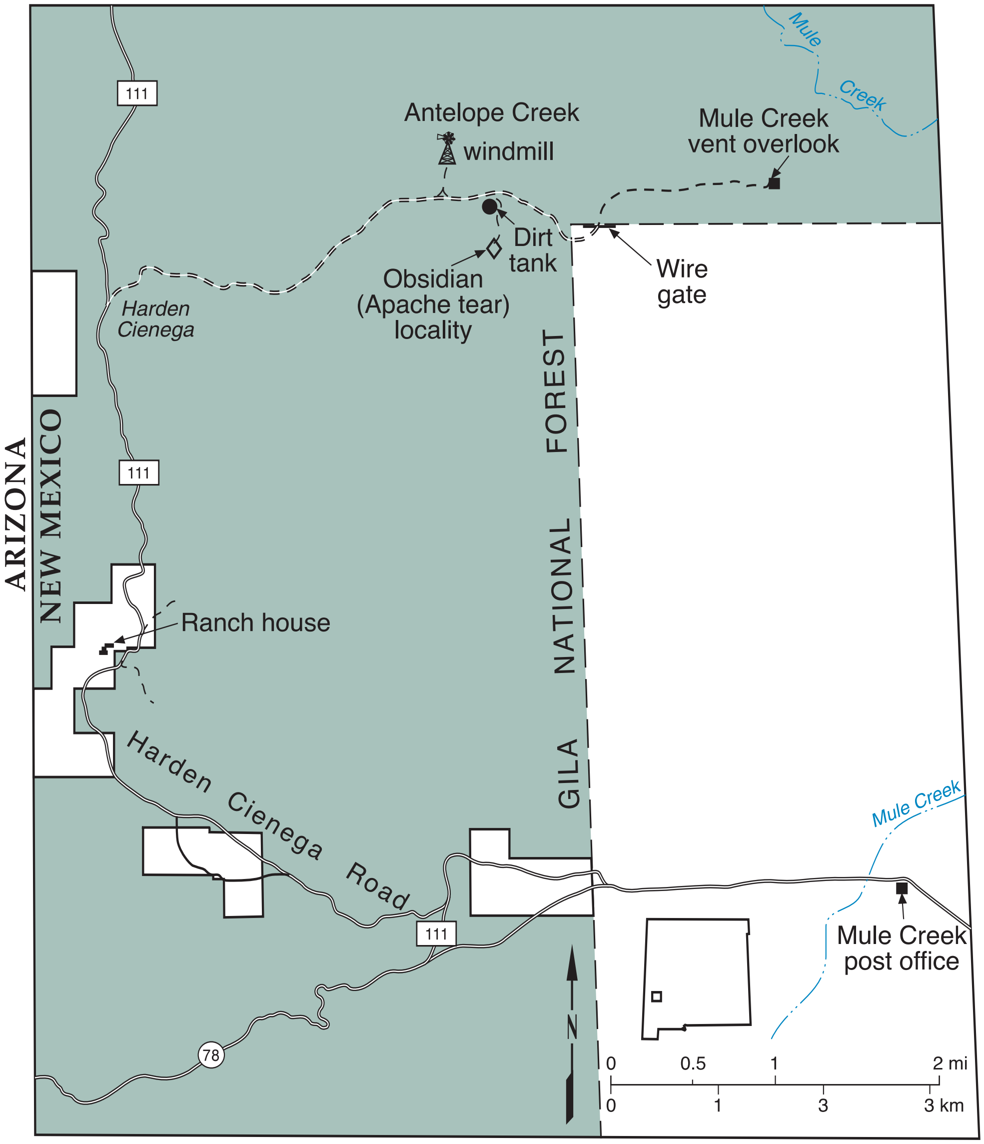


FIGURE 2—Access map to the overlook of the Mule Creek vent of the Miocene (20–21 Ma) rhyolite of Potholes Country on the south rim of the canyon of Mule Creek, and to the obsidian ledges at the base of the Miocene (17–20 Ma) rhyolite of Mule Creek at the head of the gulch south of the dirt tank that is south of the Antelope Creek windmill. Gila National Forest shown in green; private land shown in white.

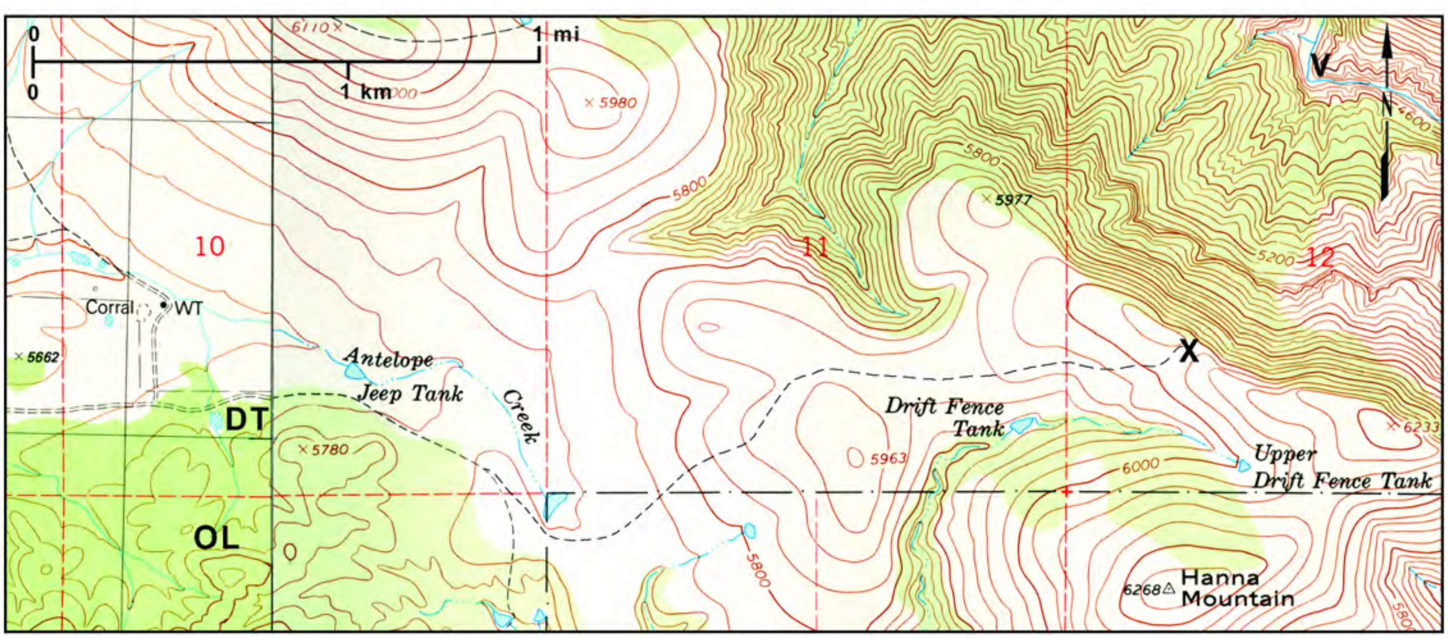


FIGURE 3—Sections 10, 11, and 12 T13S R21W of the Harden Cienega and Wilson Mountain 7½-min quadrangles showing Antelope Creek windmill (**WT**), dirt tank (**DT**), obsidian ledges (**OL**), and jeep track leading northeast to rim (**X**) overlooking Mule Creek and Mule Creek volcanic vent (**V**).

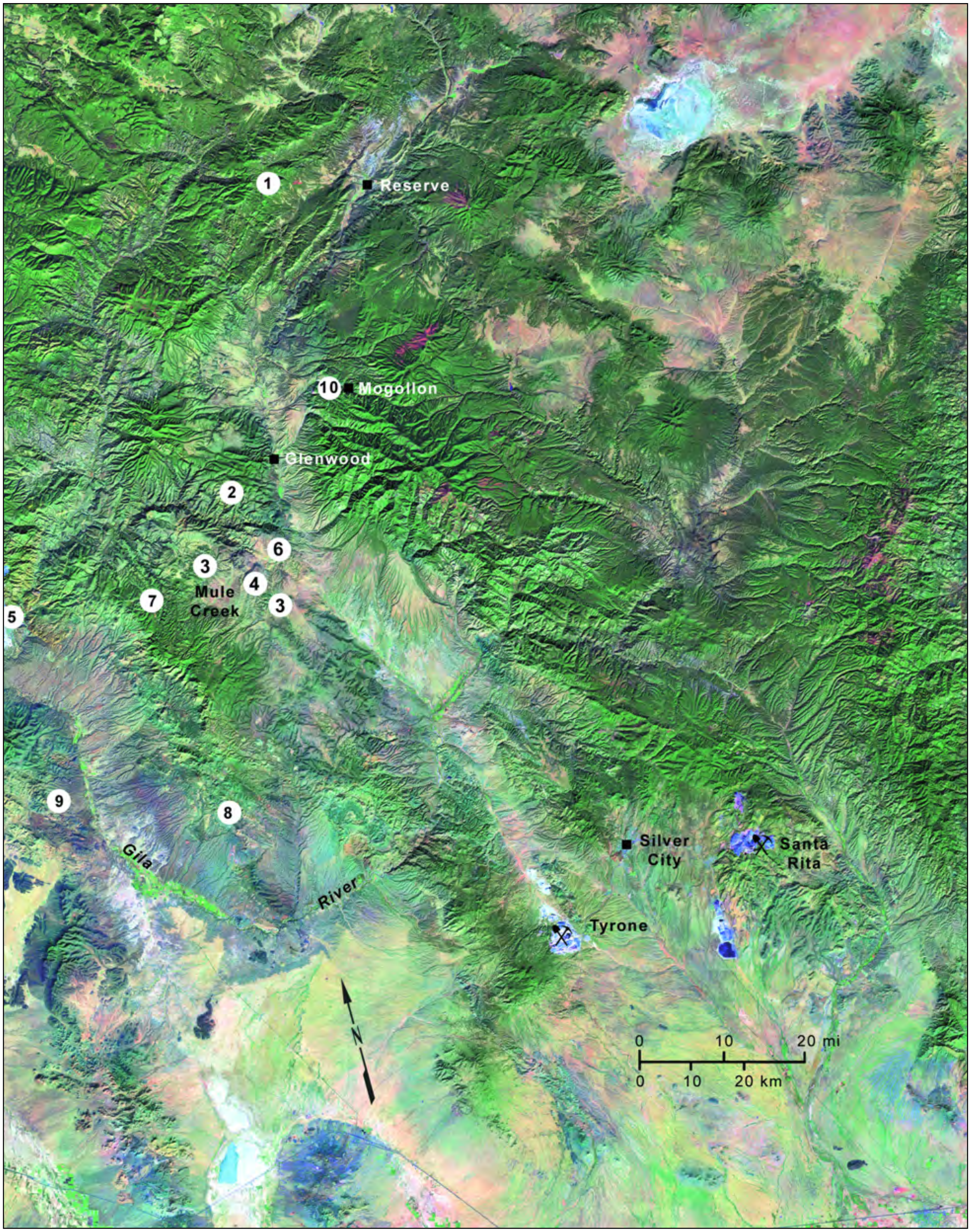


FIGURE 4—Satellite photo of parts of southwestern New Mexico and southeastern Arizona showing the locations of several middle Miocene rhyolitic eruptive centers (Table 1).

corrals and Antelope Creek windmill on the left. Proceed another 0.25 mi (0.4 km) to a dirt tank on the right.*

Continue by car past the dirt tank for 0.6 mi (1 km) to a wire gate through the drift fence on the left. Leave the gate as you found it (open or closed) and follow the track farthest to the right for approximately 1.4 mi (2.5 km) to the east to the rim overlooking Mule Creek (Fig. 3). When parking, be aware of basalt boulders hidden in the grass on either side of the track, as well as within it. Some may prefer to hike from the drift fence rather than submit their vehicle to the rigors of this bulldozed track.

Access to the Mule Creek vent, and related geologic features associated with the rhyolite of Potholes Country, is also available to hikers and river runners from the mouth of Mule Creek at the San Francisco River, approximately 1.5 mi (2.5 km) downstream from the vent.

Geologic setting of the rhyolite of Potholes Country and the Mule Creek vent

The 20–21 Ma rhyolite of Potholes Country is one of several small, early to middle Miocene, silicic- to intermediate-composition eruptive centers in the southwest part of the Mogollon–Datil volcanic field of southwestern New Mexico and adjacent parts of southeastern Arizona (Fig. 4; Table 1). Potholes Country rhyolite comprises a number of coalescing tuff rings surrounding a half dozen or more rhyolite plugs and vents, surmounted by low, domal accumulations of rhyolite lava in the Wilson Mountain 7½-min quadrangle (Ratté and Brooks 1989), and the Moon Ranch 7½-min quadrangle (unpublished geologic map of the Moon Ranch quadrangle). Several prominent breccia pipes (Fig. 5A,B) and small rhyolite dikes intrude the Bearwallow Mountain Andesite lava flows. Thickness of the Potholes Country high-silica rhyolite pyroclastic rocks and lava flows varies from 0 to approximately 328 ft (0–100 m), and the total exposed volume of Potholes Country rhyolite is on the order of 1–3 km^3. Potholes Country rhyolite crops out largely within or adjacent to the northwest-trending Potholes Country graben, where the rhyolite underlies an inverted topography over an area approximately 2 mi (3 km) wide and 10 mi (15 km) long (Figs. 6, 7).

Rock underfoot at the Mule Creek vent overlook, in the south wall of the Potholes Country graben, is the ~23–25 Ma Bearwallow Mountain Andesite. Beneath the viewpoint, upper and lower members of the Bearwallow Mountain Andesite are separated locally by a discontinuous layer of rhyolitic pyroclastic rocks known as the rhyolite of Angel Roost, which is derived from another small eruptive center at Angel Roost, approximately 2 mi (3 km) northeast of the Mule Creek vent (Ratté and Brooks 1989).

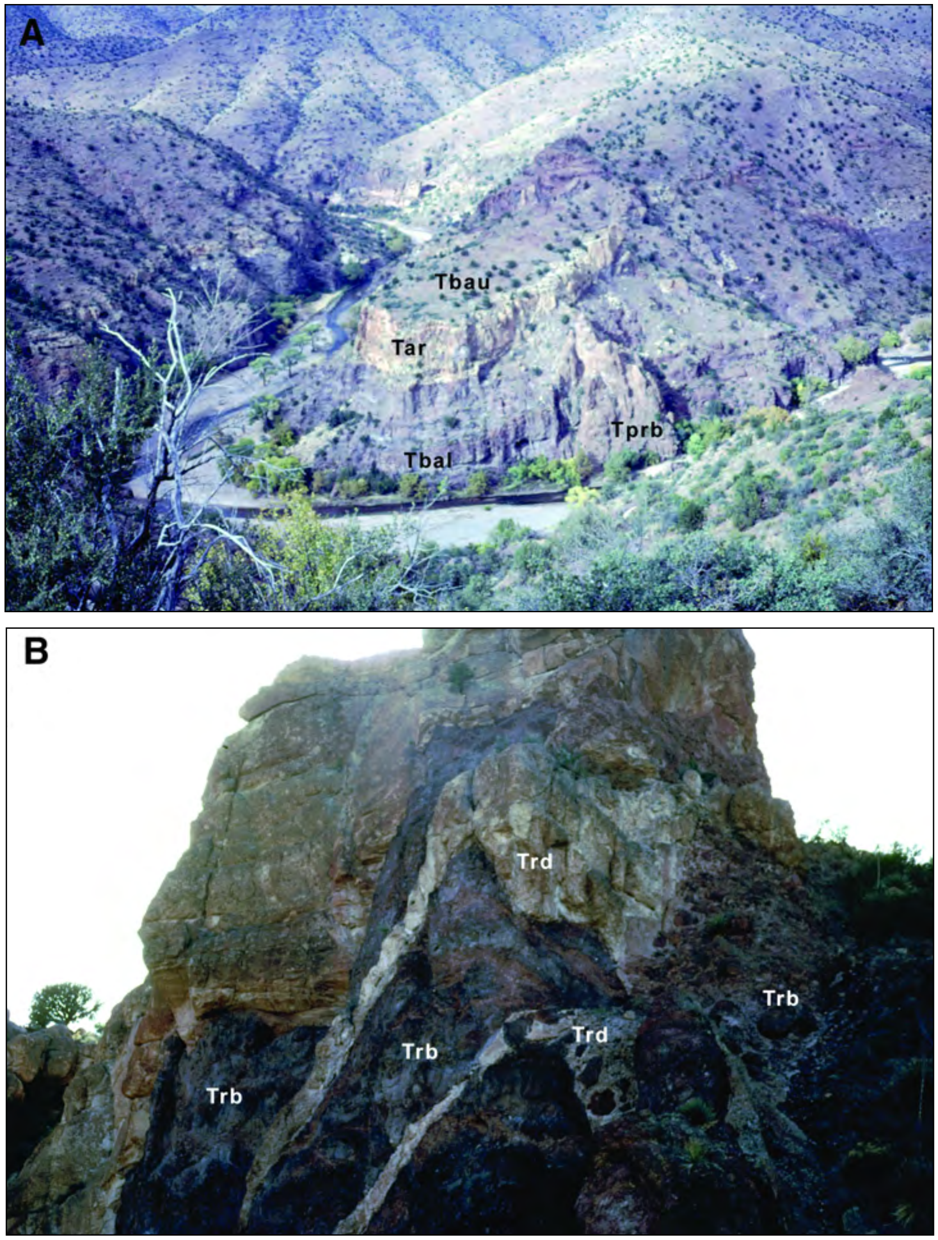


FIGURE 5—Photos of breccia pipes related to the rhyolite of Potholes Country (**Tprb**) on the San Francisco River below the mouth of Mule Creek. **A**–Breccia pipe (**Tprb**) on north side of San Francisco River intrudes lower Bearwallow Mountain Andesite (**Tbal**). Light-colored layer separating upper (**Tbau**) and lower Bearwallow Mountain Andesite is rhyolite of Angel Roost (**Tar**). **B**–Breccia pipe (**Trb**) on south side of San Francisco River showing rhyolite dikes (**Trd**).

Also visible within the Potholes Country graben, from the viewpoint on the south side of Mule Creek, is an elliptical breccia pipe approximately 500 by 300 ft (150 by 100 m) in cross section. The pipe includes Bearwallow Mountain Andesite clasts in a rhyolite matrix presumed to be Potholes Country rhyolite (Fig. 8). Two additional breccia pipes of similar dimensions extend across Mule Creek slightly farther to the east (Fig. 9), and approximately 1 mi (1.6 km) northwest of the overlook, a ridge-capping exposure of tuff breccia represents the initial pyroclastic deposits from the Mule Creek vent (Fig. 10A,B).

Petrography and composition

Potholes Country rhyolite lava flows vary from aphyric felsite to porphyritic rhyolite that contains as much as 15% small (1–2 mm) phenocrysts of sanidine, oligoclase, and quartz and sparse accessory biotite,

*Obsidian ledges, up the gulch behind the dirt tank, are described on pp. 121–122. The obsidian ledges provide an optional locality that can be one's primary destination or can be visited before or after the Mule Creek vent overlook.

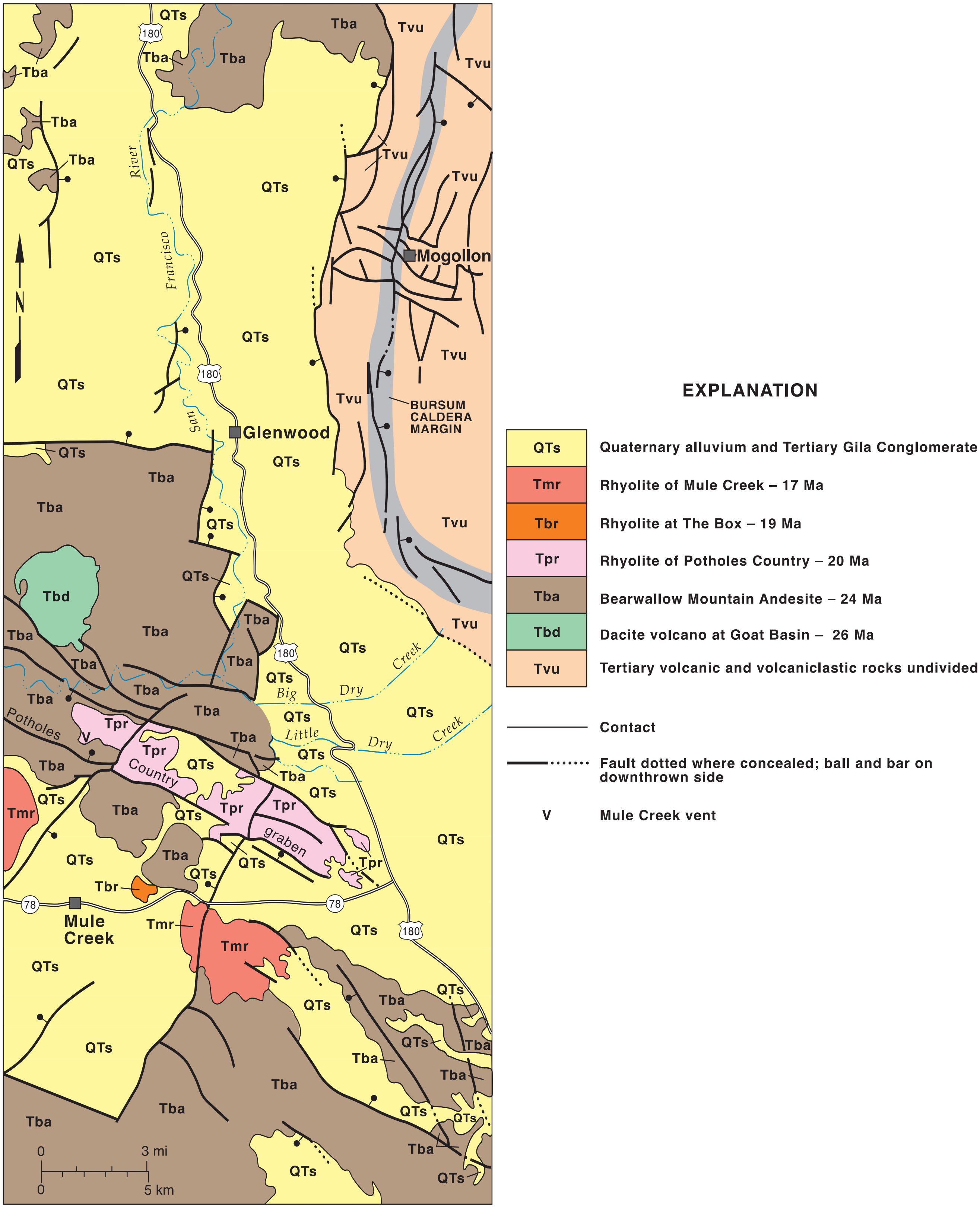


FIGURE 6—Geologic map showing the geologic setting of the rhyolite of Potholes Country and the Potholes Country graben. Geology modified from Ratté and Gaskill (1975) and Ratté and Brooks (1989, 1983).

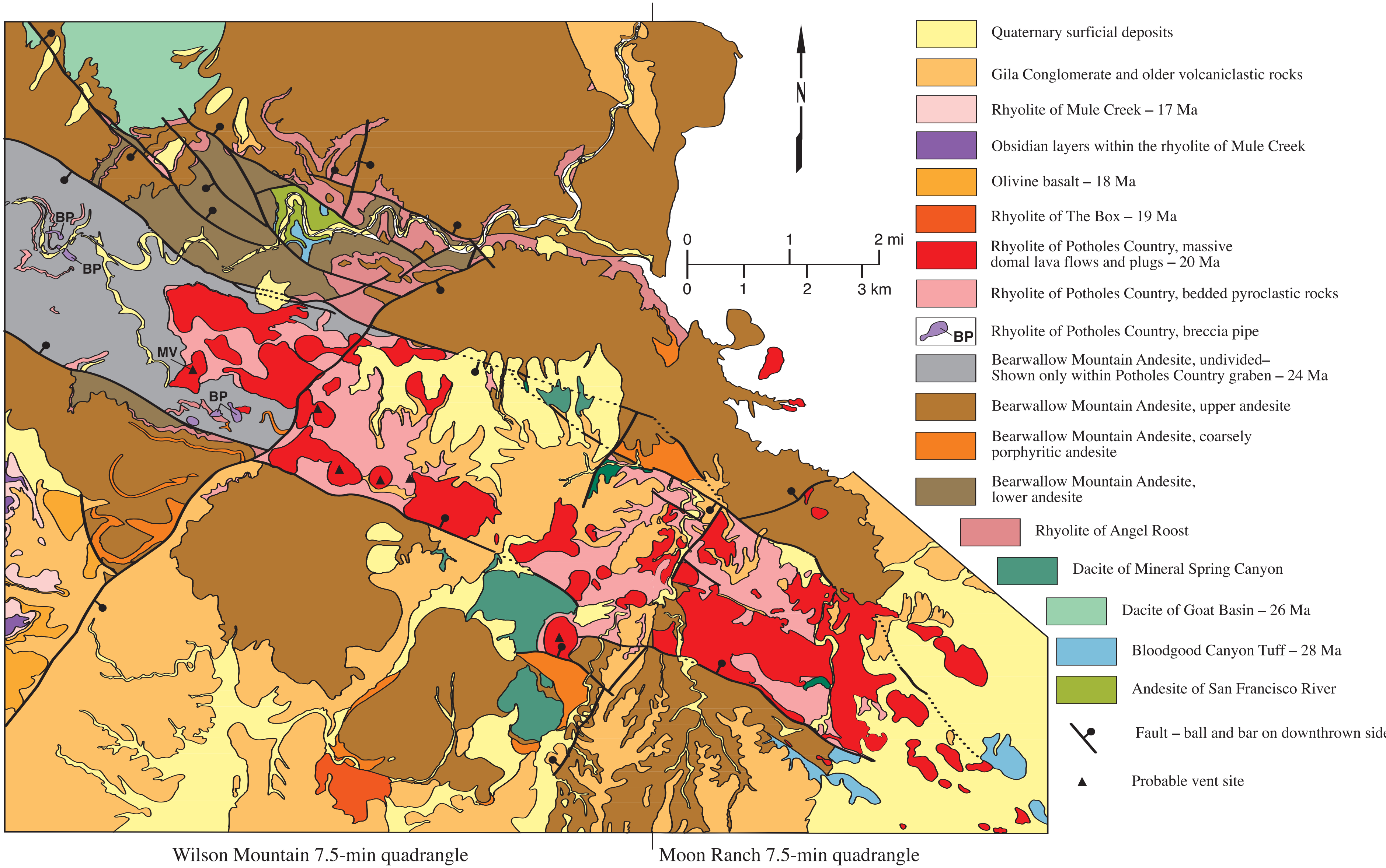


FIGURE 7—Geologic map of the Potholes Country graben showing pyroclastic and flow facies of the rhyolite of Potholes Country, the Mule Creek vent (**MV**), and breccia pipes (**BP**). From Ratté and Brooks (1989) and unpublished mapping.

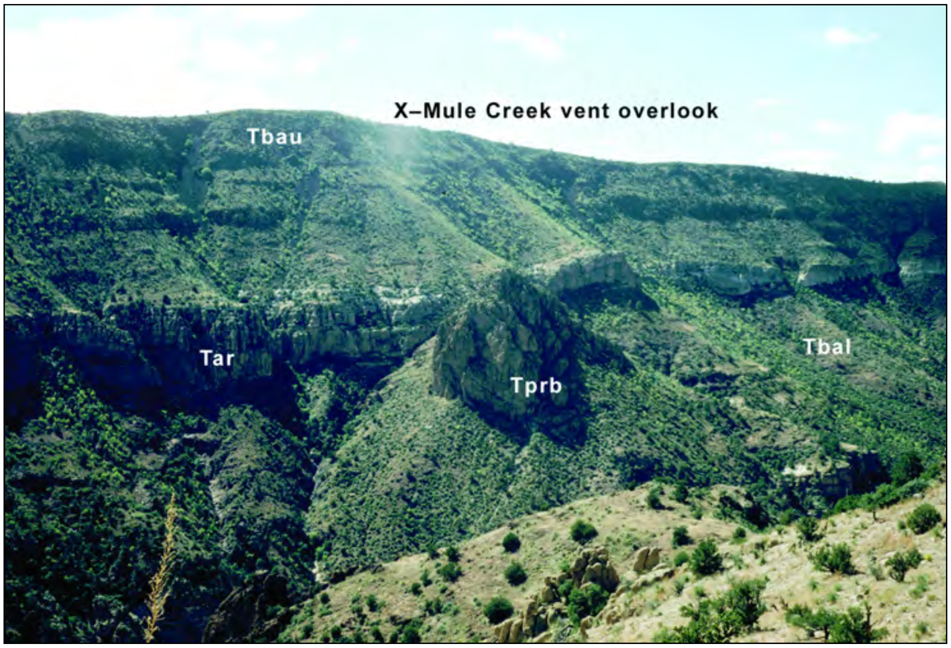


FIGURE 8—View west across Potholes Country graben toward location of Mule Creek vent overlook (**X**); Potholes Country rhyolite breccia pipe (**Tprb**); upper and lower Bearwallow Mountain Andesite lava flows (**Tbau** and **Tbal**); and rhyolite of Angel Roost (**Tar**) interlayered between the andesite lava flows.

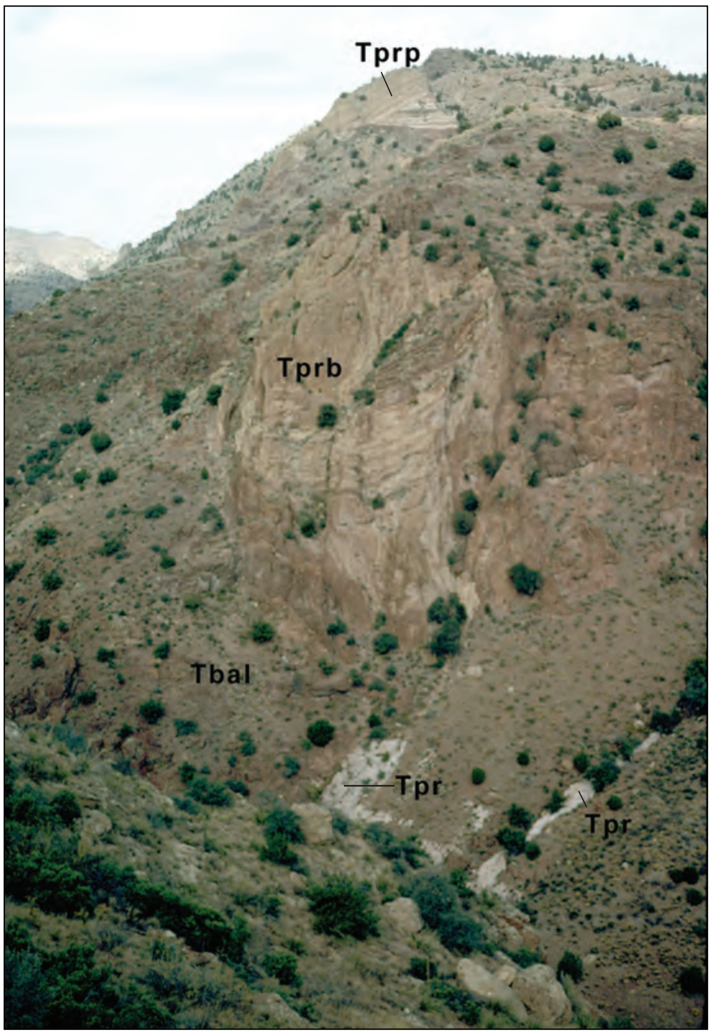


FIGURE 9—Photo of one of two Potholes Country breccia pipes (**Tprb**) that intrude lower Bearwallow Mountain Andesite on north side of Mule Creek east of the Mule Creek vent. Crossbedded pyroclastic rocks of Potholes Country rhyolite (**Tprp**) on northeast rim of Mule Creek vent are visible in background at top of photo. Light-colored outcrops at creek level in lower right of photo are intrusive Potholes Country rhyolite (**Tpr**) viewed through erosional windows in lower Bearwallow Mountain Andesite (**Tbal**).

opaque oxides, and sphene. Accidental fragments of older volcanic rocks that are unrelated to the Potholes Country rhyolite are rare in the lava flow rocks within the vent and in the dome-forming flows, but common to abundant in the pyroclastic facies of the rhyolite. Within the Mule Creek vent, flows are largely aphyric but may contain as much as about 5% 1–2-mm phenocrysts of quartz and feldspar. The flows are all high-silica (>75%) alkali rhyolite (Ratté and Brooks 1989, table 1). Additional analyses of rhyolite from within the vent are included in Stasiuk et al. (1996, tables 1 and 2).

Description of the Mule Creek vent

The Mule Creek vent is the most completely exposed, if not the largest, of the several eruptive centers of Potholes Country rhyolite (Fig. 7). Most of the other centers are exposed only in two dimensions and are commonly expressed by localized masses of moderately to steeply dipping flow rhyolite cutting older pyroclastic layers of Potholes Country rhyolite. The salient physical features of the Mule Creek vent are identified in Figure 11, which is modified from the sketch by Art Isom that is reproduced in GQ-1611 (Ratté and Brooks 1989), and keyed to the cover photo. A tapering, dike like body of Potholes Country rhyolite, approximately 30 ft (10 m) at its widest, is exposed down to the level of Mule Creek, where it is the deepest manifestation of the rhyolite associated with the vent. A talus-covered gap of approximately 300 ft (100 m) separates the dikelike body from an upper, bulbous outcrop of rhyolite that is bordered by a black vitrophyre chill zone a few meters thick (Fig. 12). The bulbous projection of rhyolite flares upward into a broad mass of rhyolite approximately 1,500 ft (500 m) wide, which cuts up through the andesite lava flows and breccias of the older Bearwallow Mountain Formation to the pre-eruptive land surface. Above the paleosurface, which is preserved midway in the present canyon wall, rhyolite within the vent cuts through the thick sequence of initial pyroclastic deposits erupted from the vent. These layers, which consist of both juvenile rhyolite tuff and accidental andesite blocks from the vent walls, vary in color depending on the ratio of dark-brown andesite blocks to light-colored rhyolite matrix. The lower, dark-brown layers, which may contain as much as 50% or more andesite, are well exposed approxi-

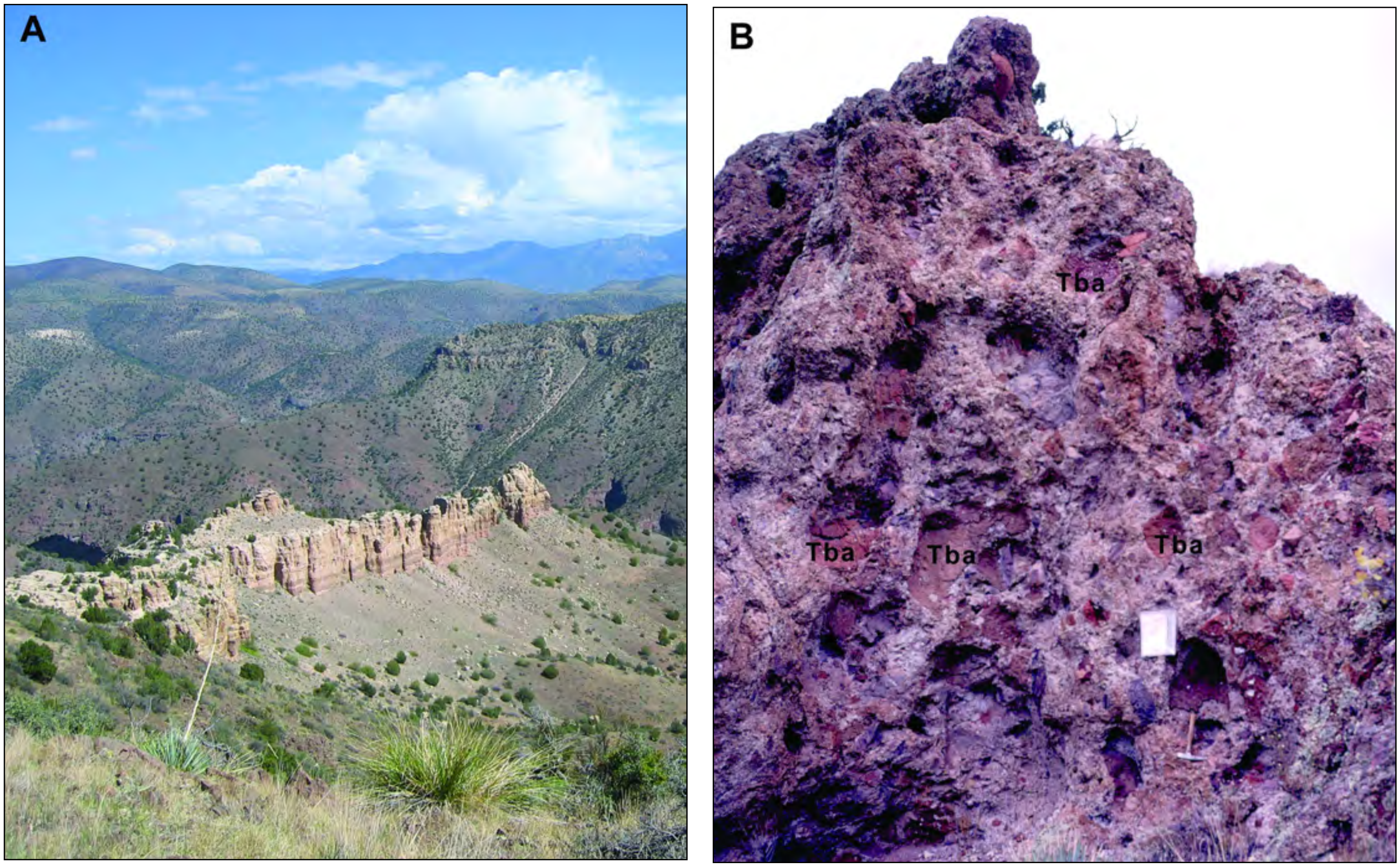


FIGURE 10—Two views of pyroclastic breccia produced by initial eruptions from Mule Creek vent. **A**–View northwest from Mule Creek vent overlook showing increasing ratio of light-colored, pyroclastic rhyolite to dark-brown accidental andesite from bottom to top layers as eruption progressed. **B**–Close-up view of pyroclastic breccia showing more than 50% blocks of Bearwallow Mountain Andesite (**Tba**) in matrix of Potholes Country rhyolite. Scale shown by geologic pick and map case. Photo on the left by Scott Lynch.

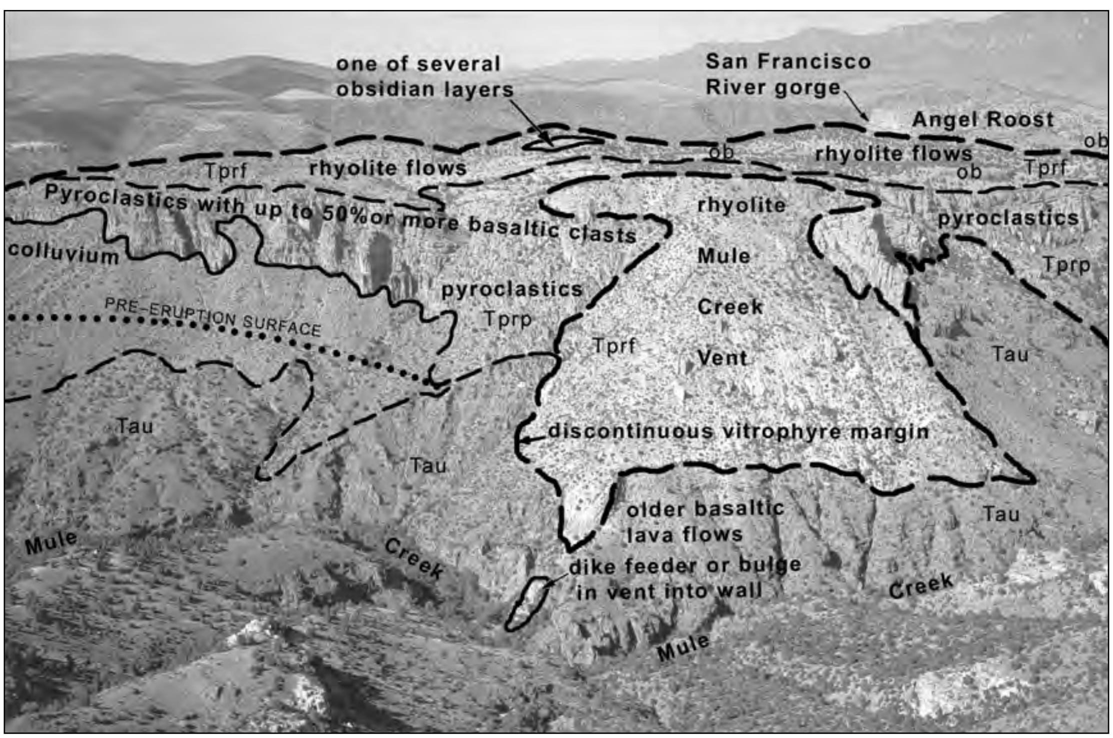


FIGURE 11—Overlay on cover photo showing main features of the Mule Creek vent and eruptive center of the rhyolite of Potholes Country. **Tau**–Bearwallow Mountain Andesite; **Tprp**–pyroclastic breccia deposits formed by initial eruptions from the Mule Creek vent; **Tprf**–rhyolite lava flows that fill the vent and overflow on the surface; **ob**–obsidian (vitrophyre layers in surface flows and at vent margins).

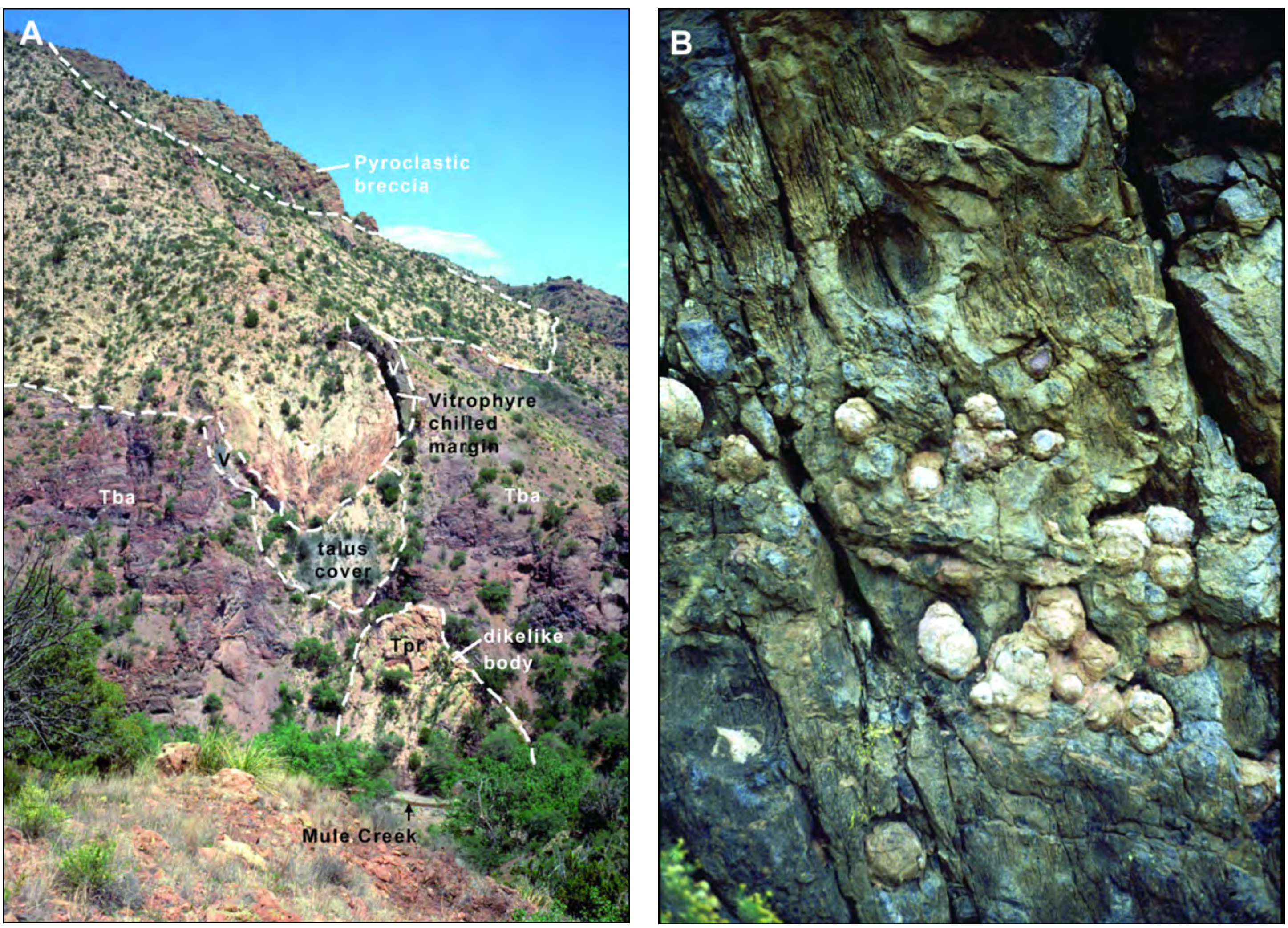
TABLE 1—Selected early to middle Miocene rhyolitic to dacitic eruptive centers in the southwestern Mogollon–Datil volcanic field, southwestern New Mexico and southeastern Arizona.

Eruptive center	Age (Ma)	Physical form	Mineralization indicators	Reference
1–Maverick Peak	14	plug and flows	minor iron staining	Ratté 1989
2–Heiffers Delight Canyon	16	two rhyolitic plugs	minor iron staining	Ratté, unpublished geologic map of the Maple Peak quadrangle
3–Mule Creek	17–19	rhyolite dome complexes	minor iron staining	Ratté and Brooks 1983
4–The Box	19	rhyolitic plug dome	none	Ratté and Brooks 1989
5–Enebro Mountain	20	rhyolite dome complexes	minor iron staining	Marvin et al. 1987
6–Potholes Country	20–21	rhyolite dome complex	anomalous gold and silver in quartz-calcite veins	Ratté and Brooks 1989
7–Grassy Mountain	?	rhyolitic plug dome	minor iron staining	Ratté and Brooks 1995
8–Steeple Rock	21	rhyolitic dikes, plugs, and domes	gold, silver, copper, lead, zinc district	Richter et al. 1983
9–Ash Peak	21–23	rhyolite flows and domes	silver, gold, copper, lead in quartz-calcite veins	Richter et al. 1983
10–Mogollon	17	adularia in veins	silver, gold, copper, lead in quartz fissure veins	Kamilli and Ratté 1995

mately 1 mi (1.6 km) northwest of the viewpoint on the south side of the canyon of Mule Creek (Fig. 10A), as well as along both sides of the vent in the north canyon wall. Also noteworthy are the crossbedded pyroclastic layers adjacent to the vent on both sides. Crossbedded pyroclastic layers preserve initial dips of layers away from the vent on its flanks, and inward-dipping layers on the inner crater walls that may represent either initial dips into the crater or slumping and rotation of flank deposits into the crater, or both. Crossbedded pyroclastic deposits in other parts of the Potholes Country graben identify other Potholes Country eruptive centers (Fig. 7).

Following explosive eruption of the pyroclastic deposits surrounding the Mule Creek vent and dissipation of the bulk of the volatile components of the underlying

FIGURE 12—Photos showing chilled, vitrophyre margin of Potholes Country rhyolite. **A**–Chilled vitrophyre (**V**) at edges of bulbous projection of rhyolite (**Tpr**) into Bearwallow Mountain Andesite (**Tba**) near level of Mule Creek. **B**–Devitrification spherulites as much as several inches, 15–20 cm or larger, in vitrophyre at chilled margin of rhyolite.



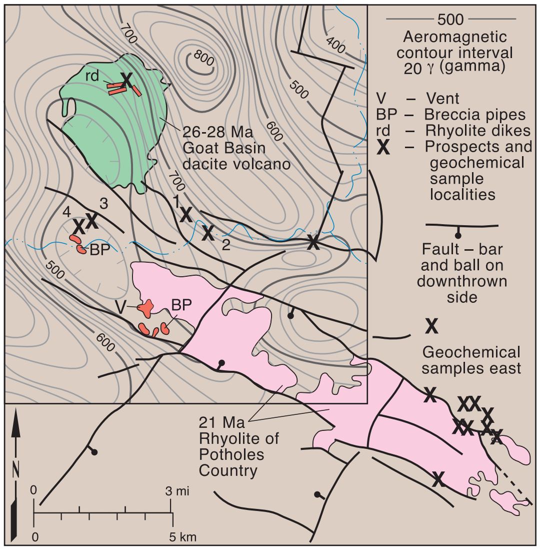


FIGURE 13–Map showing location of mineral prospects and geochemical samples within and adjacent to the Potholes Country graben and the nearby Goat Basin dacite volcano and associated aeromagnetic anomalies within the Lower San Francisco Wilderness Study Area (Ratté et al. 1982).

magma, the vent filled to overflowing with the passive upwelling of rhyolite lava. Where rhyolite cuts across older andesite lava flows and breccias and earlier erupted rhyolite pyroclastic layers to reach the surface, it chilled against these cooler rocks and formed a black, glassy vitrophyre a few meters thick. This vitrophyre is exposed more or less continuously around the vent margins. Finally, stiff, viscous flow-laminated rhyolite lava and interlayered vitrophyre flowed out onto the surface. This same eruptive progression was undoubtedly repeated around many other eruptive centers that constitute the Potholes Country rhyolite.

Rhyolite eruption processes as interpreted from the Mule Creek vent

The vesicularity and other properties of Potholes Country rhyolite within the Mule Creek vent have been studied in detail with respect to degassing mechanisms associated with the transition from explosive to effusive activity during rhyolite magma eruptions (Stasiuk et al. 1996). Stasiuk et al. (1996) concluded that the Mule Creek vent preserves evidence of continuous gas escape from erupting silicic magma during its approach to the surface. In addition, these rocks indicate that open-system conditions probably prevailed below the deepest levels of exposure, approximately 1,100 ft (350 m) below the present surface and approximately half that distance below the pre-eruptive surface. Breccia pipes, rhyolite dikes, and veins of fine-grained, fluidized rhyolite (tuffsite of Stasiuk et al. 1996, pp. 122–124), or micro breccia, associated with Potholes Country rhyolite and the Mule Creek vent are believed to identify gas escape routes and to demonstrate porous flow through the magma in the vent and through shear-related permeability along contacts between the rhyolite and enclosing country rock. The paper by Stasiuk et al. also includes multiple electron microprobe analyses of Potholes Country rhyolite and melt inclusions in quartz phenocrysts, and infrared spectrographic analyses of H_2O, OH, and total H_2O in support of their conclusions.

Economic considerations

The Potholes Country graben (Ratté et al. 1982) has been referred to as a “rhyolite rift zone” (Ratté and Brooks 1991) because of the localization of the Potholes Country rhyolite within or adjacent to the graben, and the graben has been the site of minor prospecting for precious metal deposits (Fig. 13). An eastern group of prospects is located along fault-controlled, banded quartz and calcite fissure veins that are mostly on private land, but land on which the mineral rights are largely owned by the federal government. Geochemical samples from these prospects contained as much as 4.05 parts per million (ppm) gold and 110 ppm silver. Another group of prospects at the northwestern end of the Potholes Country graben is located on altered rocks and fault-controlled quartz and calcite veins within the Lower San Francisco Roadless Area (Ratté et al. 1982). Geochemical samples from the prospects in this area contained traces of gold (0.05–0.35 ppm) and silver (0.5–1.0 ppm).

A magnetic low centered over the western end of the Potholes Country graben, near some of the western prospects (Fig 13; Martin, 1982) could be related to an extensive body of Potholes Country rhyolite at depth beneath this area. A 26–28 m.y.-old dacite volcano at Goat Basin, the eroded out, propylitically altered core of a stratified volcanic cone, is also present in this area (shown in green in Fig. 13). A comparable magnetic anomaly centered over the Goat Basin volcano, the presence of altered (pyritized) dacite, and several small, iron-stained rhyolite dikes of unknown age (but younger than the dacite) exposed in the center of the volcano indicate a possible subvolcanic silcic intrusion (possibly mineralized) at a shallow to moderate depth beneath the volcano.

The significance of these minor shows of mineralization near the Potholes Country rhyolite and associated structures must be considered in the context of other high-silica rhyolites and silicic eruptive centers of similar age in this region (Table 1; Fig. 4). Most noteworthy in this regard is the 17-Ma age indicated for the silver-gold-copper deposits in the Mogollon district on the basis of dated adularia from the Queen vein (W. C. McIntosh pers. comm. 1993). Although there are no known bodies of rhyolite of this age in the Mogollon district, several small, undated rhyolite dikes or intrusion breccias may be of this age (Kamilli and Ratté 1995, p. 458).

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References

Kamilli R. J., and Ratté, J. C., 1995, Geologic studies of the Mogollon mining district, New Mexico—does a porphyry system lie below?; *in* Pierce, F. W., and Bohl, J. G. (eds.), Porphyry copper deposits of the American cordillera: Arizona Geological Society, Digest, v. 20, pp. 455–463.

Martin, R. A., 1982, Geophysical surveys of the Lower San Francisco Wilderness Study Area and contiguous Roadless Area, Greenlee County, Arizona, and Catron and Grant Counties, New Mexico: U.S. Geological Survey, Miscellaneous Field Studies Map MF-1463-A, scale 1:62,500.

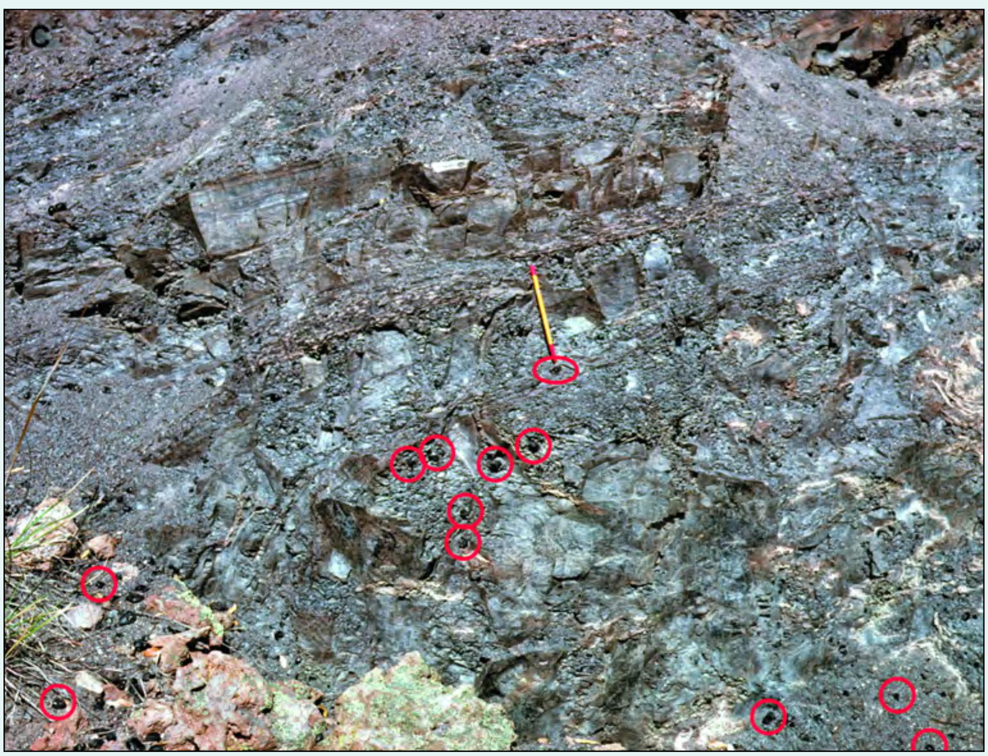
Marvin, R. F., Naeser, C. W., Bikerman, M., Mehnert, H. H., and Ratté, J. C., 1987, Isotopic ages of post-Paleocene igneous rocks within and bordering the Clifton 1° x 2° quadrangle, Arizona–New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 118, 63 pp.

Ratté, J. C., 1989, Geologic map of the Bull Basin

Obsidian ledges

One quarter mile east of Antelope Creek windmill and behind the dirt tank on the right, a short, unnamed gulch leads south approximately 0.25 mi (0.4 km) to obsidian ledges at the head of the gulch. The short hike up this gulch to the obsidian ledges can make an interesting side trip on the way to the Mule Creek vent overlook or on the return trip. The obsidian, which here covers about an acre, is at the base of the rhyolite of Mule Creek (Ratté and Brooks 1989), also described as the rhyolite of the Mule Mountains (Rhodes and Smith 1972). The rhyolite of Mule Creek is slightly younger at 17.7–19.0 Ma (Marvin et al. 1987, sample numbers 34, 35, 36, and 44, pp. 34–35) than the rhyolite of Potholes Country from the Mule Creek vent at 20–21 Ma (Marvin et al. 1987, sample numbers 49 and 50, p. 36). The rhyolite of Mule Creek forms domes, tuff rings, and flows in the Mule Mountains in the Mule Creek 7½-min quadrangle (Ratté and Brooks 1983) and also in the Wilson Mountain quadrangle. The obsidian layers are partially devitrified to felsite and hydrated to pearly, gray perlite. Less hydrated, black obsidian cores or nodules (also known as marekanites) weather out of the light-gray, perlitic glass to form the "Apache tears" that mantle the surface and form a trail down the gulch to the dirt tank. Elsewhere, as along NM–78 east and west of Mule Creek village, the obsidian nodules can be found weathering out of the Gila Conglomerate into which they were reworked during an earlier period of erosion.

The obsidian ledges are of additional interest with respect to the recently recognized importance of this and other Mule Creek



Photos of the obsidian ledges of the Miocene (17–20 Ma) rhyolite of Mule Creek, a major source of "Apache tears." **A**–Overall view of the obsidian ledges at the head of the gulch south of the dirt tank, which is south of Antelope Creek windmill. **B**–Outcrop of obsidian ledge showing layers of variously hydrated and devitrified glassy rhyolite. **C**–Close-up of obsidian ledges showing small (a few millimeters to several centimeters in diameter) black, glassy cores of relatively nonhydrated obsidian, (as at lower end of pencil in center of photo) scattered throughout the light-gray, partially hydrated, perlitic glass.

area obsidian localities as major sources of archaeological obsidian. According to Professor M. Steven Shackley of the Anthropology Department at the University of California, Berkeley, the "Mule Creek regional source" is "probably the geographically largest obsidian source in the Southwest." Shackley (1995) recognized "at least four distinct chemical groups distinguished by their Rb, Y, Nb, and Ba, and to a lesser extent by their Sr and Zr" contents. The four groups are identified as:

1. Antelope Creek (the Apache tear locality of this guide)
2. Mule Mountains (south of NM–78, east of Mule Creek, west of US–180)
3. Mule Creek/North Sawmill Creek (south of Mule Creek Post Office)
4. San Francisco River alluvium

The ability to determine the geographic source of various obsidians found as artifacts at widely dispersed archaeological sites is critical to learning about migration routes, trading contacts, and interrelationships between early Americans.

quadrangle, Catron County, New Mexico: U.S. Geological Survey, Geologic Quadrangle Map GQ-1651, scale 1:24,000.

Ratté, J. C., and Brooks, W. E., 1983, Geologic map of the Mule Creek quadrangle, Grant County, New Mexico: U.S. Geological Survey, Miscellaneous Field Studies Map MF-1666, scale 1:24,000.

Ratté, J. C., and Brooks, W. E., 1989, Geologic map of the Wilson Mountain quadrangle, Catron and Grant Counties, New Mexico: U.S. Geological Survey, Geologic Quadrangle Map GQ-1611, scale 1:24,000.

Ratté, J. C., and Brooks, W. E., 1991, Rhyolite rift zone in southwestern New Mexico—a possible target for precious metals exploration (abs.): Geological Society of America, Abstracts with Programs, v. 23, no. 4, p. 58.

Ratté, J. C., and Brooks, W. E., 1995, Preliminary geologic map of the Big Lue Mountains 15-min quadrangle, Greenlee County, Arizona, and Catron and Grant Counties, New Mexico: U.S. Geological Survey, Open-file Report 95-263, scale 1:48,000.

Ratté, J. C., and Gaskill, D. L., 1975, Reconnaissance geologic map of the Gila Wilderness Study Area, southwestern New Mexico: U.S. Geological Survey, Miscellaneous Investigations Series, Map I-886, scale 1:62,500.

Ratté, J. C., Hassemer, J. R., Martin, R. A., and Lane, M. E., 1982, Mineral resource potential map of the Lower San Francisco Wilderness Study Area and contiguous Roadless Area, Greenlee County, Arizona, and Catron and Grant Counties, New Mexico: U.S. Geological Survey, Miscellaneous Field Studies Map MF-1463-C, scale 1:62,500.

Rhodes, R. C., and Smith, E. I., 1972, Geology and tectonic setting of the Mule Creek caldera, New Mexico, U.S.A.: Bulletin Volcanologique, v. 36, no. 3, pp. 401–411.

Richter, D. H., Sharp, W. N., Watts, K. C., Raines, G. L., Houser, B. B., and Klein, D. P., 1983, Mineral resource assessment of the Silver City 1° x 2° quadrangle, New Mexico–Arizona: U.S. Geological Survey, Open-file Report 83-924, 81 pp.

Shackley, M. S., 1995, Sources of archaeological obsidian in the greater American Southwest—an update and quantitative analysis: American Antiquities, v. 60, pp. 531–551.

Stasiuk, M. V., Barclay, J., Carroll, M. R., Jaupart, C., Ratté, J. C., Sparks, R. S. J., and Tait, S. R., 1996, Degassing during magma ascent in the Mule Creek vent (USA): Bulletin of Volcanology, v. 58, pp. 117–130.