



## ***40Ar/39Ar ages of selected basalts in the Sierra Cuchillo and Mud Springs Mountains, Sierra and Socorro counties, New Mexico***

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## <sup>40</sup>AR/<sup>39</sup>AR AGES OF SELECTED BASALTS IN THE SIERRA CUCHILLO AND MUD SPRINGS MOUNTAINS, SIERRA AND SOCORRO COUNTIES, NEW MEXICO

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**ABSTRACT**—Basalt flows have been mapped throughout the Sierra Cuchillo and in the Mud Springs Mountains. These basalts are typically small volume flows that are interbedded with sedimentary rocks. Before this study, many of these basalts were inferred to be Pliocene, based mostly on appearance and mineralogy compared to that of Pliocene basalts dated by K/Ar methods. Ten basalt flows were dated by the <sup>40</sup>Ar/<sup>39</sup>Ar method in an effort to understand the depositional and tectonic evolution of the Monticello and Winston grabens. The basalt flows in the Cañada Alamosa and Spring Canyon areas of the Sierra Cuchillo range in age between ~18.0 and 18.7 Ma, with typical errors of 0.05 to 0.3 Ma. The Priest Tank basalt flow is similar in age at 19.06 ± 0.05 Ma relative to the stratigraphically equivalent basalt flows in Cañada Alamosa and Spring Canyon to the north. These basalts, which are interbedded with Neogene sedimentary deposits, indicate that the Monticello graben was undergoing sedimentation at ~18-19 Ma, probably in conjunction with tectonic subsidence. The andesite of Winston graben also is ~18 Ma (K/Ar). Two separate eruptions formed the basalt cap on Tabletop Mountain near Winston at 4.23 ± 0.36 and 4.91 ± 0.03 Ma. The Tabletop Mountain basalt places a minimum age on the end of deposition of the Santa Fe Group sediments in the Winston graben. These <sup>40</sup>Ar/<sup>39</sup>Ar results indicate two episodes of basalt magmatism in the Sierra Cuchillo, at 19-18 Ma and again at 4.9 - 4.2 Ma, with the first episode occurring during a time of sparse volcanism in the rift. The Mud Springs Mountains basalt flow is 5.55 ± 0.21 Ma. Chemical analyses of selected basalts indicate that they are alkaline basalts.

### INTRODUCTION

Basalt flows have been mapped throughout the Sierra Cuchillo (Fig. 1), specifically in the Cañada Alamosa area (Figs. 2, 3; Maldonado, 1974, 1980, 2012; McLemore, 2010, 2012a, b), Priest Tank area (Fig. 4; Heyl et al. 1983), and Tabletop Mountain near Winston (Fig. 5; Seager et al., 1984; Harrison, 1989, 1992, 1994; Jahns et al., 2006). Basalts also were mapped in the Mud Springs Mountains (Fig. 6; Lozinsky, 1986; Maxwell and Oakman, 1990). These basalts are typically small volume flows that are interbedded with sedimentary rocks. Prior to this study,

many of these basalts were inferred to be Pliocene in age, based mostly on appearance and mineralogy to that of a few Pliocene basalts dated by K/Ar methods (Table 1). Knowing the ages of these basalt flows is important to understand the sedimentologic and structural evolution of the Monticello and Winston grabens. Although, some of these basalt flows have been previously dated by K-Ar methods (Table 1), none in the area have been dated using <sup>40</sup>Ar/<sup>39</sup>Ar methods. The purpose of this report is to describe selected basalt flows in the Sierra Cuchillo and Mud Springs Mountains, present new <sup>40</sup>Ar/<sup>39</sup>Ar ages, and briefly discuss the importance of these ages.

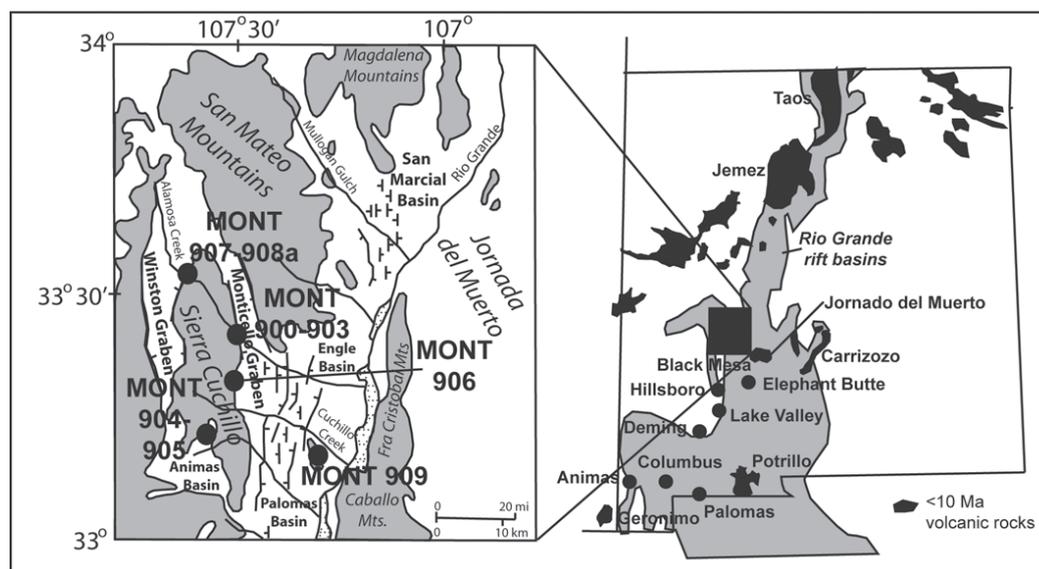


FIGURE 1. Location of Eocene to Oligocene volcanic rocks and Rio Grande rift basins (simplified from Anthony et al., 1992; Chapin et al., 2004b; Baldrige, 2004) and locations sampled for <sup>40</sup>Ar/<sup>39</sup>Ar dating. Sample descriptions are in Table 2.

**Supplemental data for this paper can be accessed at:**

<http://nmgs.nmt.edu/repository/index.cfm?rid=2012003>

TABLE 1. K-Ar ages of Miocene-Pliocene basalts in the Sierra Cuchillo, Mud Springs, and Animas Mountains, central New Mexico. Locations are in Figure 1.

LOCATION	AGE (Ma)	COMMENTS	REFERENCE
Jornado del Muerto	0.76±0.1		Bachman and Mehnert (1978)
Engle cinder cone	2.1±0.4		Bachman and Mehnert (1978)
Mitchell Point	2.9±0.3		Bachman and Mehnert (1978)
North of Granite Wash, Caballo Mountains	3.1±0.1	In Camp Rice Formation	Seager et al. (1984)
Hillsboro	4.2±0.1	Overlies gravels	Seager et al. (1984)
Hillsboro	4.5±0.1	Underlies Palomas surface	Seager et al. (1984)
Tabletop Mountain	4.8±0.1	Flow overlies Santa Fe beds and is along a fault	Seager et al. (1984)
Mimbres basalt	6.29±0.41	K/Ar	Elston et al. (1968, 1973)
andesite of Winston graben	18.3± 0.4		Seager et al. (1984)
Hachita basalt	11.8±0.3		Seager et al. (1984)

## METHODS AND RESULTS

Ten basalt samples from the Sierra Cuchillo and Mud Springs Mountains were dated by the  $^{40}\text{Ar}/^{39}\text{Ar}$  method and sample locations are shown in Figure 1. Laboratory methods are described at <http://geoinfo.nmt.edu/labs/argon/home.html>. The results are summarized in Table 2 and complete details of the argon analyses are presented in Appendix 1. Overall the  $^{40}\text{Ar}/^{39}\text{Ar}$  age spectra are moderately well behaved and reveal plateau and/or isochron segments that are interpreted to record eruption ages between about 19 and 4.2 Ma (Fig. 7). Complexity of age spectra can be attributed to excess  $^{40}\text{Ar}$  in some cases and thus for several samples an isochron age is preferred over a plateau age (Fig. 7; Appendix 1). The basalt flows in the Cañada Alamosa and Priest Tank areas of the Sierra Cuchillo range in age from  $17.97 \pm 0.21$  to  $19.06 \pm 0.05$  Ma. The basalts at Tabletop Mountain near Winston (Sierra Cuchillo) are  $4.23 \pm 0.36$  and  $4.91 \pm 0.03$  Ma, whereas the basalt from the Mud Springs Mountains is  $5.55 \pm 0.21$  Ma.

## DESCRIPTION AND AGES OF BASALTS

### Southern Cañada Alamosa

Basalt and associated scoria flows are found interbedded with sediments along the southern Cañada Alamosa (lower box) near San Mateo Canyon (Fig. 2). These basalt flows are up to 24 m thick, black to dark gray, fine grained, locally porphyritic, dense to vesicular, and exhibit local pillow-like structures (Fig. 8). The basalt consists of phenocrysts of plagioclase, pyroxene, and trace olivine (altered to iddingsite), magnetite, calcite, and iron oxides in a fine-grained groundmass. Locally, the basalt flows overlie either a well-cemented, poorly sorted, orange-gray to brown conglomeratic sandstone (Tc) or the rhyolite of Alamosa Canyon (Tac, 28.4 Ma; McLemore, 2010), and the basalt flows are overlain by up to 400 m of unconsolidated sediments of the Santa Fe Group (QTsf) in the Monticello graben. These basalt flows were thought to be similar in age to the Winston and Hillsboro basalt flows, based upon appearance and composition (Maldonado, 1974, 1980, 2012; McLemore, 2010). However  $^{40}\text{Ar}/^{39}\text{Ar}$  dates indicate that these basalts are much older than previously thought. One flow on the east side of southern Cañada Alamosa near San Mateo Canyon (Fig. 2) is  $18.72 \pm 0.11$  Ma (MONT 901) and a second flow is  $18.69 \pm 0.27$  Ma (MONT 900). A basalt flow or dike near the Burma Road, north of San Mateo Canyon, is  $17.97 \pm 0.21$  Ma (MONT 902). A basalt flow on the west side of Cañada Alamosa (Fig. 2) is  $18.38 \pm 0.12$  Ma (MONT 903). The  $^{40}\text{Ar}/^{39}\text{Ar}$  ages do not all overlap at 2 sigma error. Field relationships indicate two or more distinct flows.

### Spring Canyon, north of Cañada Alamosa

Similar basalt flows are found in Spring Canyon near the Spring Canyon well, north of Ojo Caliente warm springs and Monticello Box of Cañada Alamosa, upstream of the southern Cañada Alamosa flows (Fig. 3). The lower basalt flow at Spring Canyon (Fig. 3) is  $18.72 \pm 0.04$  Ma (MONT 907) and the upper flow is  $18.67 \pm 0.06$  Ma (MONT 908a). Field relationships sug-

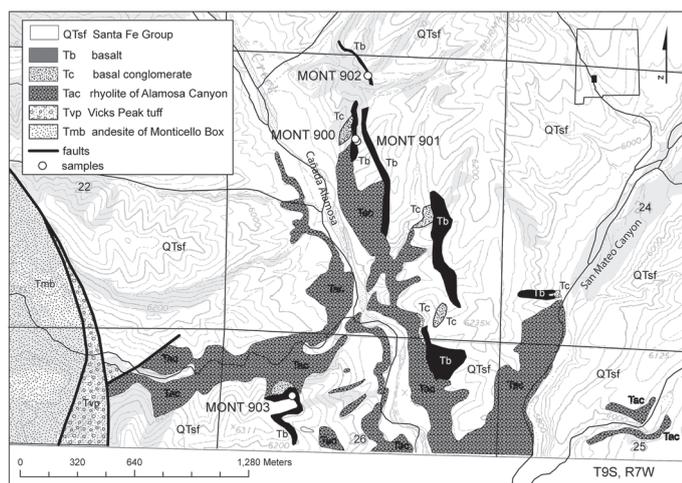


FIGURE 2. Simplified geologic map of the southern Cañada Alamosa (lower box) near San Mateo Canyon, Socorro County, New Mexico (from McLemore, 2010, 2012a). The latite of Montoya Butte is 35.7 Ma (McLemore, 2010) and overlies the andesite of Monticello Box, which older than 35.7 Ma.

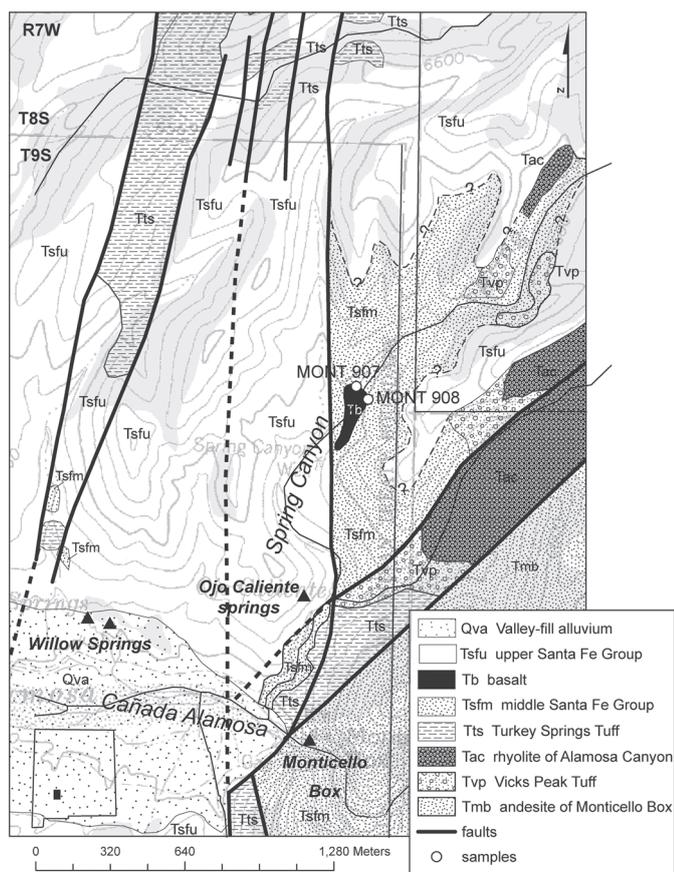


FIGURE 3. Simplified geologic map of the Spring Canyon area near the Spring Canyon well, north of Ojo Caliente warm springs and Cañada Alamosa, Socorro County, New Mexico (from McLemore, 2010, 2012a using the terminology of Koning, 2012, this guidebook and Cikoski, and Harrison, 2012, this guidebook).

gest that these are two distinct flows, although <sup>40</sup>Ar/<sup>39</sup>Ar dates indicate they erupted nearly simultaneously, and synchronously to the basalt flows in the southern Cañada Alamosa.

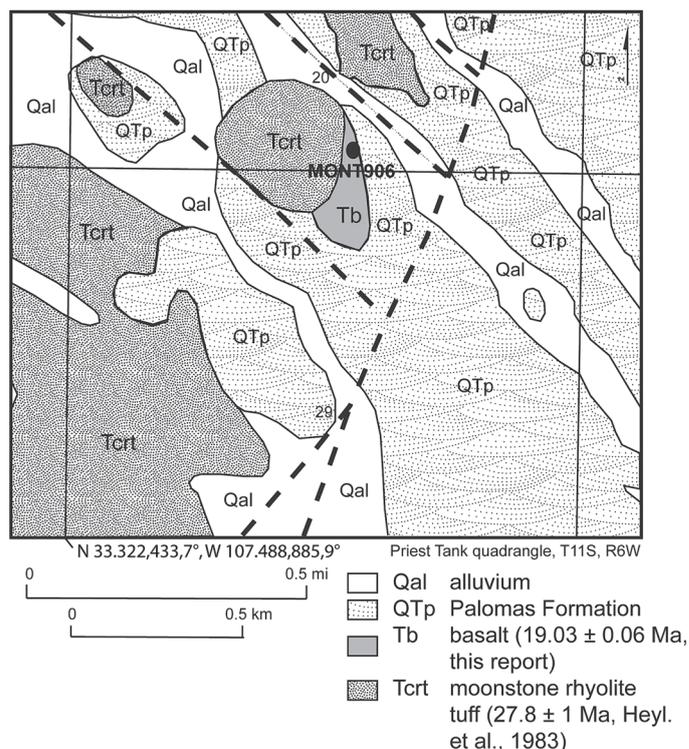


FIGURE 4. Simplified geologic map of the Priest Tank area (from Heyl et al. 1983).

**Priest Tank**

A poorly exposed vesicular basalt flow is exposed in the Priest Tank area on the eastern slopes of Sierra Cuchillo (Fig. 4; Heyl et al. 1983). The flow is 19.06 ± 0.05 Ma (Table 2; Fig. 8) and may be slightly older than the basalt flows in Cañada Alamosa and Spring Canyon to the north. The Priest Tank basalt is in a paleo-valley cut into Oligocene rocks and is similar in position to the Cañada Alamosa basalt flows overlying the rhyolite of Alamosa Canyon within the Monticello graben. The Priest Tank basalt is on the western footwall of Monticello graben.

TABLE 2. Brief description and location of samples of Miocene-Pliocene basalt collected for this study from the Sierra Cuchillo and Mud Springs Mountains, Socorro and Sierra Counties (UTM zone 13, NAD27). Locations are in Figure 1.

SAMPLE NUMBER	UTM E	UTM N	DESCRIPTION	<sup>40</sup> Ar/ <sup>39</sup> Ar age ±1σ
MONT900	264848	3711140	alkaline basalt, east Alamosa Canyon	18.69 ± 0.27
MONT901	264839	3711154	alkaline basalt, east Alamosa Canyon	18.72 ± 0.11
MONT902	264851	3711504	alkaline basalt, Burma Road	17.97 ± 0.21
MONT903	264485	3709710	alkaline basalt, west Alamosa Canyon	18.38 ± 0.12
MONT907	259369	3718307	Spring Canyon, lower basalt flow	18.72 ± 0.04
MONT908a	259366	3718310	Spring Canyon, upper basalt flow	18.67 ± 0.06
MONT906	269274	3690805	Priest Tank basalt flow	19.06 ± 0.05
MONT904	257036	3694467	Tabletop Mountain basalt flow, upper	4.23 ± 0.36
MONT905	256675	3694455	Tabletop Mountain basalt flow, lower	4.91 ± 0.03
MONT909	286743	3670124	Mud Springs basalt flow	5.55 ± 0.21

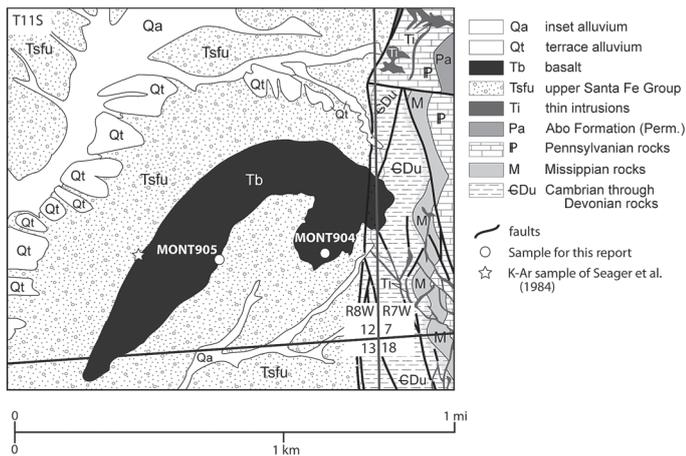


FIGURE 5. Simplified geologic map of the Tabletop Mountain area, east of Winston, Sierra County, New Mexico (from Jahns et al., 2006).

### Winston

A basalt flow erupted onto sediments of the Santa Fe Group on Tabletop Mountain east of Winston (Fig. 5; Seager et al., 1984; Harrison, 1989, 1992, 1994; Jahns et al., 2006; Cikoski and Harrison, 2012). The basalt flow is fine-grained, aphanitic, black to gray, dense to vesicular, and consists of plagioclase and olivine phenocrysts in a groundmass of plagioclase, olivine, pyroxene, and glass. The basalt flowed over the boundary fault between the Winston graben and Sierra Cuchillo (Harrison, 1992), where we infer a low fault scarp ~5 m tall. The basalt flow was originally dated by K-Ar as  $4.8 \pm 0.1$  Ma (Table 1; Seager et al., 1984). Two separate flows were sampled for this study (Table 2). The upper flow is  $4.23 \pm 0.36$  Ma (Mont904) and the lower flow is  $4.91 \pm 0.03$  Ma (Mont905). Despite the large error of Mont904 we sug-

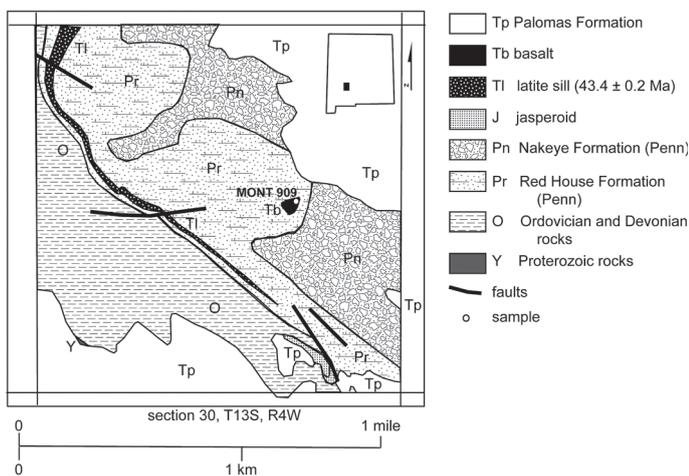


FIGURE 6. Geologic map of the Mud Springs Mountains, Sierra County, New Mexico (simplified from Maxwell and Oakman, 1990).

gest that these that these are two separate flows that were erupted within ~0.1 to 0.7 Ma of each other.

### Mud Springs Mountains

A vesicular olivine basalt flow erupted from a local vent onto shale of the Pennsylvanian Red House Formation in the Mud Springs Mountains (Fig. 6; Lozinsky, 1986; Maxwell and Oakman, 1990). The basalt is 10.7-12.1 m thick and contains numerous xenoliths of limestone, shale, jasperoid, and Proterozoic granite. The basalt flow is  $5.55 \pm 0.21$  Ma (MONT909, Table 2). Clasts of this basalt flow are found in the adjacent piedmont facies, placing a maximum age of these deposits.

### GEOCHEMISTRY

Chemically, the Cañada Alamosa and Winston basalt flows are alkaline, have low  $\text{SiO}_2$ , and have high  $\text{TiO}_2$ , Zr, Nb and Sr similar to the chemical composition of younger basalts in the Elephant Butte and Animas Mountains at Hillsboro (Fig. 9; Fodor, 1975, 1978; Haag, 1991; Anthony et al., 1992; McMillan et al., 2000). These basalts exhibit a typical trace element signature of within plate basalts (Fig. 9). The composition of these basalts is likely controlled by partial melting in the upper mantle as a result of crustal thinning and upwelling asthenosphere in the Rio Grande rift (Anthony et al., 1992; McMillan et al., 2000; Baldrige, 2004; Chapin et al., 2004a, b). There are no chemical analyses of the basalts from Spring Canyon, Priest Tank, or Mud Springs Mountains.

### DISCUSSION AND CONCLUSIONS

These  $^{40}\text{Ar}/^{39}\text{Ar}$  results indicate that basalt magmatism in the Sierra Cuchillo first erupted at 19-18 Ma, during the magma "gap" of Chapin et al. (2004a, b), and correlate with the Hayner Ranch Formation in southern New Mexico (Mack et al., 1998). The basalt flows in the Cañada Alamosa and Spring Canyon areas of the Sierra Cuchillo range in age from ~18.0 Ma to 18.7 Ma. The Priest Tank basalt flow is  $19.06 \pm 0.05$  Ma and is perhaps slightly older than the basalt flows in Cañada Alamosa and Spring Canyon to the north. The andesite of Winston graben (upper andesite sequence of Jahns et al., 1978, 2006) also is ~18 Ma (K/Ar; Seager et al., 1984). Thus, 19-18 Ma basaltic volcanism was relatively widespread in the Sierra Cuchillo and adjacent Winston and Monticello grabens. The presence of these 19-18 Ma basalt flows interbedded with Tertiary sedimentary deposits in the Cañada Alamosa and Priest Tank areas indicates that sedimentation was occurring in the Winston and Monticello grabens during this time.

The Cañada Alamosa basalts overlie either the 28.4 Ma rhyolite of Alamosa Canyon or a few meters of conglomeratic basin fill. This implies that in Cañada Alamosa, the base of the Monticello graben is now exposed and the attitude of the conglomerates, basalt flows, and the rhyolite of Alamosa Canyon are all indicating that the graben floor is tilted slightly to the northeast, toward the graben-controlling fault on the northeast side of the graben.

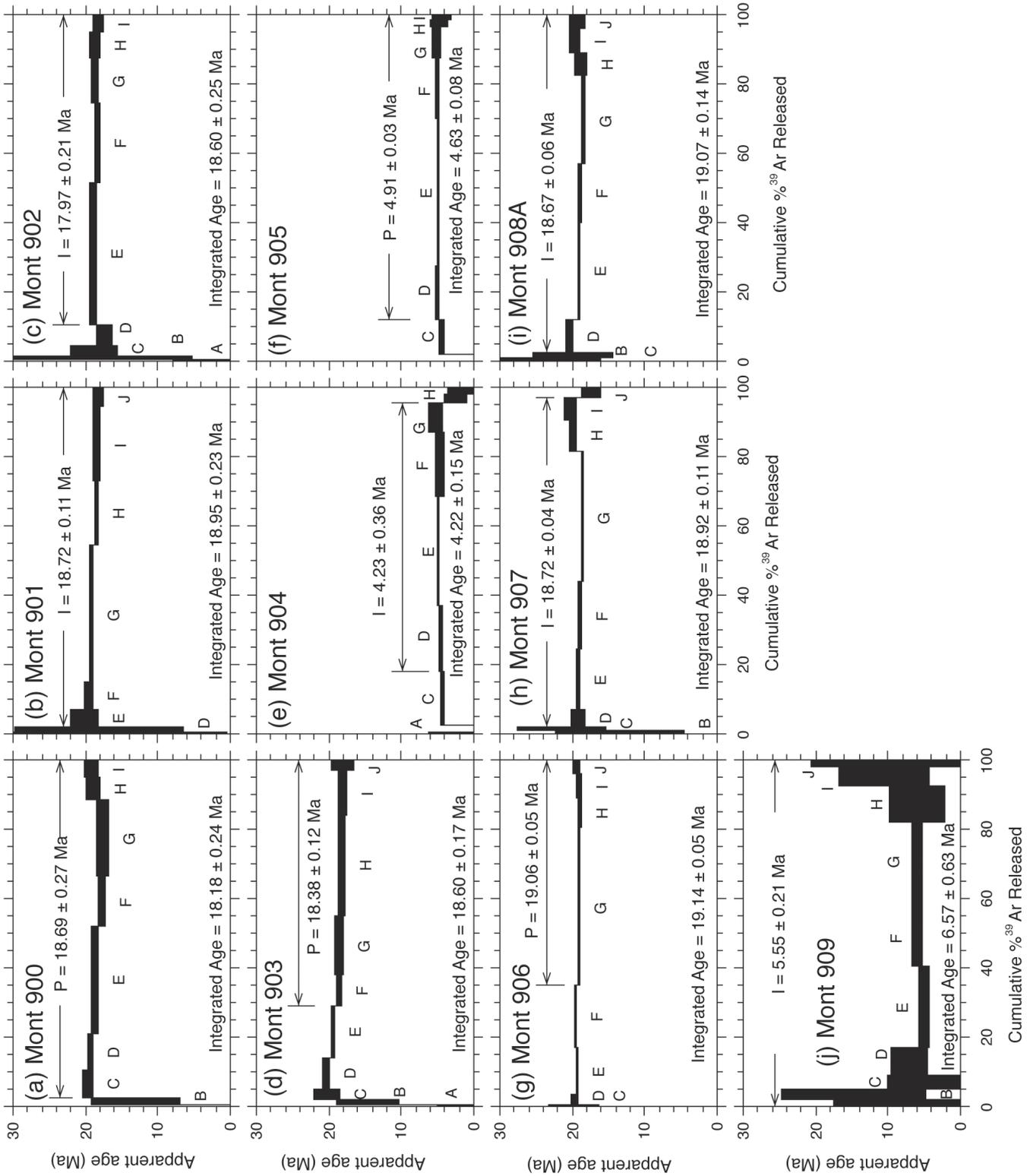


FIGURE 7.  $^{40}\text{Ar}/^{39}\text{Ar}$  age spectra of 10 basalt samples from the Sierra Cuchillo and Mud Springs Mountains, Socorro and Sierra Counties. Description of samples is in Table 2. Sample locations are shown on Figure 1. All data are shown with 1 sigma errors. P designates plateau age and I designates isochron age. Complete data details are given in Appendix I.

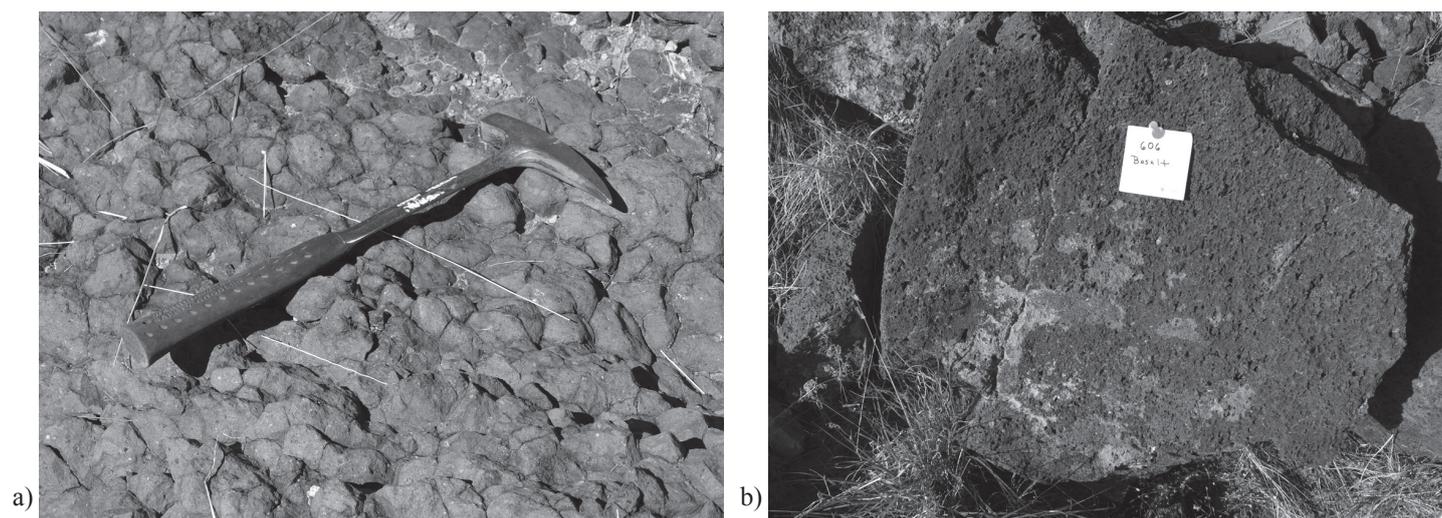


FIGURE 8. a) Pillow-like structures in the basalt flow near the Burma Road (likely related to weathering rather than eruption into water). b) Vesicular basalt in the southern Cañada Alamosa, overlying Tertiary sedimentary rocks and rhyolite of Alamosa Canyon.

Because the basalts are stratigraphically low in the graben fill, the basalts serve as a time-marker for initiation of the graben. The few meters of conglomerate below the basalts represent 10 million years of static base level and erosion in the area. The basalt may have flowed northeast downslope to the Burma Road, where similar age basalts are found, implying some topography during basalt eruption.

In the Winston area of the Sierra Cuchillo and Mud Springs Mountains, basaltic flows erupted at 5.5–4.2 Ma. Two separate eruptions formed the Tabletop Mountain near Winston and give somewhat discordant ages of  $4.24 \pm 0.36$  and  $4.91 \pm 0.03$  Ma. The Tabletop Mountain basalt places a minimum age constraint for deposition of Santa Fe Group sediments in the Winston graben (Cikoski and Harrison, 2012). The Mud Springs Mountains basalt flow is  $5.55 \pm 0.21$  Ma.

#### ACKNOWLEDGEMENTS

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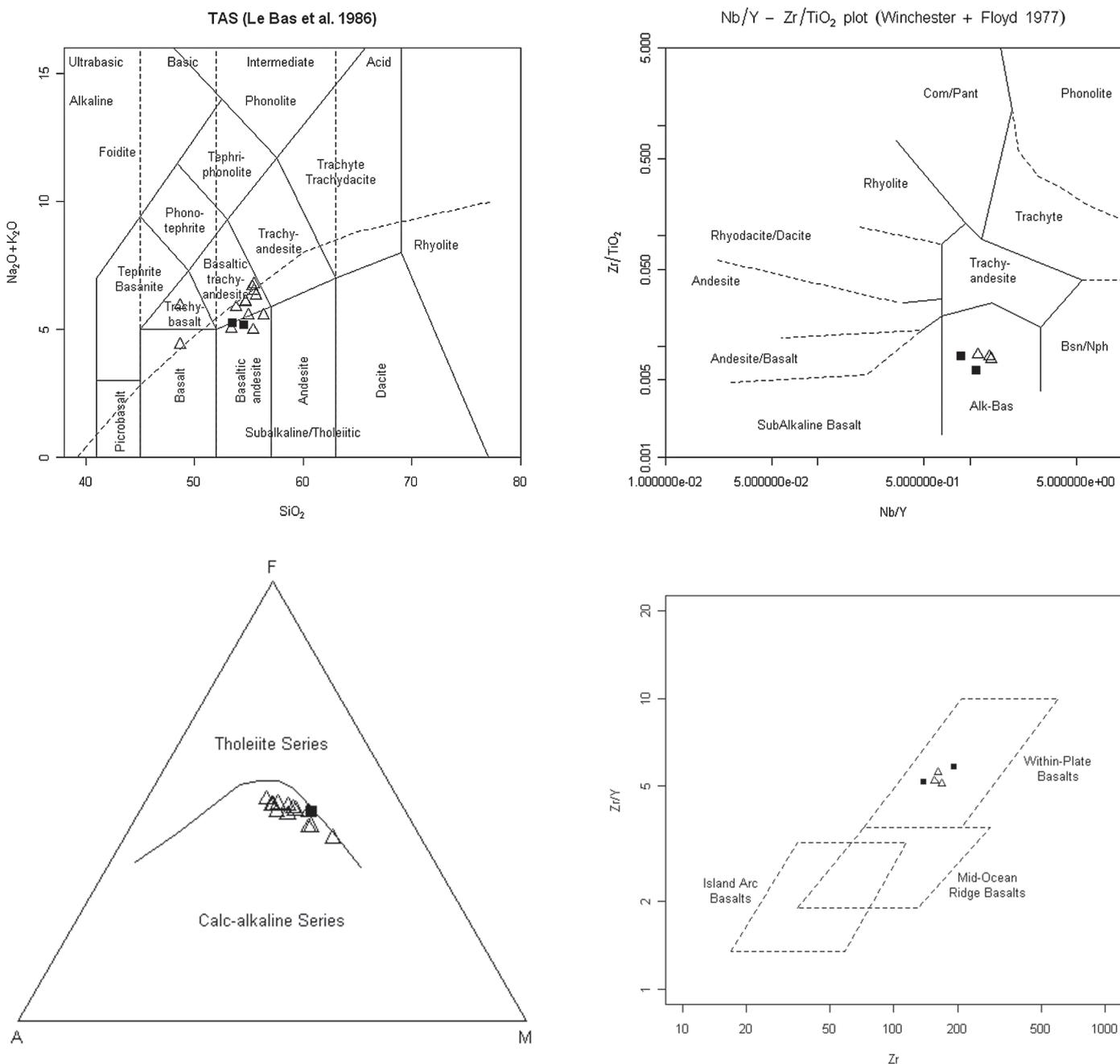


FIGURE 9. Various plots of whole-rock chemical analyses of Miocene-Pliocene alkaline basalts in central New Mexico, showing the similar chemical composition of the basalts. Triangles are 4-6 Ma basalt samples from Lake Valley (O'Neill et al., 2002), Hillsboro (Fodor, 1978; McMillan et al., 2000), and Mimbres (Fodor, 1978). The 18-19 Ma Cañada Alamosa and 4 Ma Tabletop Mountain samples are black squares (McMillan et al., 2000; McLemore, 2010). Chemical analyses are in Table 3. Chemical plots are from Irvine and Baragar (1971), Pearce and Cann (1973), Winchester and Floyd (1977), and Le Bas et al. (1986). TAS is Total alkali (NaO<sub>2</sub>+K<sub>2</sub>O) versus SiO<sub>2</sub>.

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