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MOUNT TAYLOR DIKES

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ABSTRACT—We present data on trends, widths, petrography and chemistry of volcanic dikes in the Mount Taylor volcano region, New Mexico. The dikes are subdivided into two distinct groups: 1) Nephelinite to trachybasalt dikes cutting Cretaceous sediments and Pliocene volcanic rocks in canyons and ravines south and west of Mount Taylor, and 2) Trachyandesite to trachydacite dikes cutting volcanic and intrusive rocks in the amphitheater of Mount Taylor. One dike from each group with particularly good exposures (Horace Mesa and South Wall dikes) is highlighted to show the differences in each dike type. Lastly, Mount Taylor mafic and silicic dikes are briefly compared to those at Ship Rock, New Mexico, and Summer Coon, Colorado, respectively. Although there are some similarities, there are many more differences primarily in dike configuration, length, and other varying characteristics.

INTRODUCTION

Volcanic dikes are tabular igneous intrusions that cut across the bedding or foliation of country rocks; thus, some dikes form spectacular geologic features. Dikes can provide constraints on age, evolution and style of magmatic processes. Dikes are a common geologic feature in the Mount Taylor amphitheater and in the canyons and ravines south and west of Mount Taylor (Hunt, 1938; Perry et al., 1990; Goff et al., 2008; Osburn et al., 2009). Because of the terrain and erosion in the Mount Taylor area, wide varieties of volcanic dikes are exposed and can be studied in great detail. In this short paper we present general structural information, petrography and chemistry of dikes in the Mount Taylor area and discuss two dikes in particular that display interesting geologic relations: a trachybasalt dike cutting the east side of Horace Mesa and a trachydacite dike cutting the south amphitheater wall of the volcano.

BACKGROUND

Mount Taylor is an extinct composite stratovolcano ranging in age from about 3.3 to 2.5 Ma located roughly 20 km northeast of Grants and 60 km west of the Rio Grande rift (Fig. 1; all dates cited in this paper are found in Goff et al., 2008, 2010; McCraw et al., 2009; Osburn et al., 2009). Structurally, Mount Taylor is located on the southeast margin of the Colorado Plateau just west of the north-trending Rio Grande rift, and is one of many Miocene to Quaternary volcanic centers comprising the northeast-trending Jemez volcanic lineament (Aldrich and Laughlin, 1984). The volcano forms two prominent peaks, Mt. Taylor summit (3445 m; 11,300 feet) and La Mosca (3365 m; 11,036 ft) (Fig. 2). Mount Taylor is composed primarily of trachyandesite to alkali rhyolite flows and subordinate tuffs surrounded by several mesas capped by alkali basalt, trachybasalt (hawaiite) and minor basanite ranging from 3.7 to 1.25 Ma (Fig. 2). The geochemistry and age of Mount Taylor and Grants Ridge volcanic products were previously described in several reports (Baker and Ridley, 1970; Lipman and Moench, 1972; Crumpler, 1982; Perry et al., 1990; Shackley, 1998; Fellah, 2011). Wilson (1989) noted that Mount Taylor represents a prime example of an intraplate alkalic stratovolcano. Since 2007, much new information has been obtained on the volcanology of Mount Taylor from detailed geologic mapping of six quadrangles funded by the NM STATEMAP Program (e.g., Goff et al., 2008; McCraw et al., 2009; Osburn et al., 2009).

SOUTH AND WEST CANYON DIKES

During our recent mapping efforts, we found more than fifteen basaltic dikes in the canyons and ravines south and west of Mount Taylor (e.g., locations 1 to 4, Fig. 2). Most of them strike to the northeast, following the general structural orientation of the Jemez Lineament (Fig. 1), but there are many exceptions on trend. Most are ≤3 m wide and cut only Cretaceous rocks. Hand specimens reveal that most dikes are olivine and/or olivine-plagioclase phyric, although one contains large megacrysts of augite (location 2), and another contains so many olivine phenocrysts we identified it in the field as picrite (location 1; but see discussion below and Fig. 3. The dikes are very prone to weathering and alteration; thus we have not attempted to date them. Nonetheless, field relations and the mineralogical and chemical similarity of the dikes to Mount Taylor lava flows allows us to

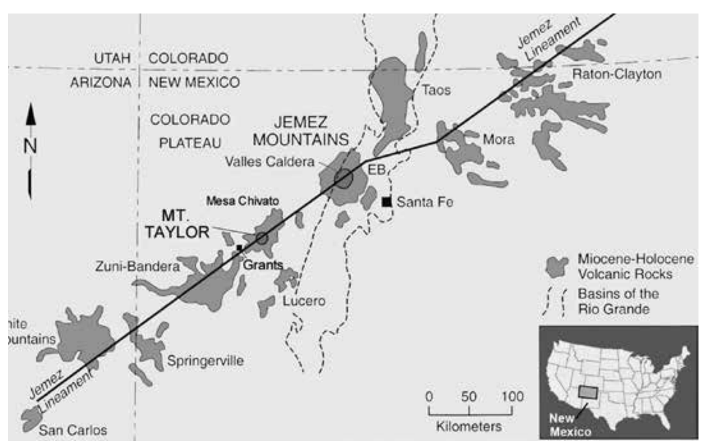

FIGURE 1. Map showing location of Mount Taylor with respect to other volcanic features of the Jemez Lineament and to basins of the Rio Grande rift; EB = Española Basin segment of the rift.

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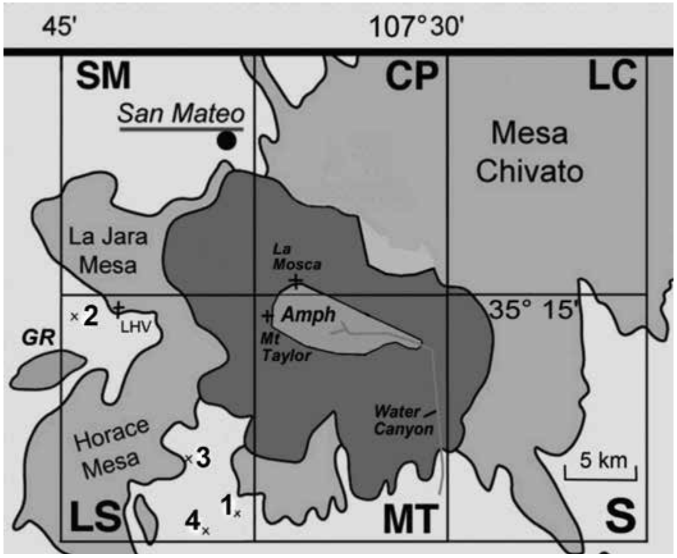

FIGURE 2. Map showing general distribution of volcanic rocks, major physiographic features, geologic quadrangles, and sample locations of basaltic dikes (Table 1) in the Mount Taylor volcano area: Gray = mostly mafic volcanic rocks; dark gray = mostly trachyandesite to trachydacite volcanic rocks; GR = Grants Ridge rhyolite center; Amph = Mount Taylor amphitheater composed mostly of volcanic and intrusive rocks; light gray = mostly Mesozoic sedimentary rocks. Quadrangles: CP = Cerro Pelon, LC = Laguna Cañoneros, LS = Lobo Springs, MT = Mount Taylor, S = Seboyeta, SM = San Mateo. Numbers 1 to 4 with X are the locations of basaltic dikes discussed in text and analyzed in Table 1. Other features: San Mateo = village of San Mateo; LHV = La Jara trachybasalt vent.

estimate their ages (Table 1). For example, most Mount Taylor basaltic lavas are trachybasalt and many contain large augite megacrysts (Perry et al., 1990; Goff et al., 2008). Thus, the augite-phyric trachybasalt dike in western Lobo Canyon (Fig. 3a) is probably similar in age to an augite-phyric vent and flows on adjacent La Jara Mesa (2.78 Ma; LHV, Fig. 2).

Five dikes have been chemically analyzed (Table 1) and the petrography of three dikes is described in Appendix 1. Overall, the basaltic dikes display remarkable diversity in texture, mineralogy and bulk chemistry. We analyzed two dikes in the mouth of Rinconada Canyon (location 4, Fig. 2) that have the same northeast trend, look superficially the same, and occur less than 100 m apart. Surprisingly, they are quite different chemically (Table 1). One is basalt, and the other is trachybasalt (Fig. 3b). On a total alkalis versus silica plot (Fig. 4), the dikes range from trachybasalt (hawaiite) through basalt to basanite. The olivine-rich "basanite" (sample F07-40, Table 1, Fig. 3c) is an exceptionally silica-undersaturated, larnite-normative rock and is best classified as nephelinite, not as picrite. Lavas of similar composition have been described from the mid-Miocene Santa Fe Group in and around the Jemez Mountains to the northeast (Fig. 1; Wolff et al., 2005). Obviously, the basaltic dikes of the south and west canyons do not originate from a common magma chamber or the same source region in the mantle.

Table 1. Locations, dike trends and widths, ages, and major element chemistry (normalized to 100 %) of Mount Taylor dikes. Locations are UTM NAD 27; analyses from Fellah (2011).

	Basaltic Dikes South and West of Mount Taylor					Trachyandesite and Trachydacite Dikes in Mount Taylor Amphitheater								
Sample	F07-40	F07-43	F07-55	09KF45	09KF46	F08-13	F08-26	09KF06	09KF13	09KF14	09KF19	09KF21	09KF52	09KF61
Site	San Fidel Dome	W Lobo Can	E Horace Mesa	Rinconada Can	Rinconada Can	East floor	South wall	North wall	West wall	NW wall	NW wall	NW wall	S flank	S flank
Location	1, Fig. 2	2, Fig. 2	3, Fig. 2	4, Fig 2	4, Fig. 2	1, Fig. 6	2, Fig. 6	3, Fig. 6	4, Fig. 6	5, Fig. 6	6, Fig. 6	7, Fig. 6	8, Fig. 6	9, Fig. 6
Field name	Picrite	Cpx Tbasalt	Tbasalt	Oliv Tbasalt	Oliv Basalt	Hbd Tdacite	Bio Tdacite	Bio Tdacite	Bio Tdacite	Bio Tdacite	Tandesite	Tandesite	Tandesite	Hbd Tdacite
Northing	3891323	392089	389628	3890975	3890961	390161	3900191	3902682	3902943	3903096	3902780	3902836	3989519	3899575
Easting	259223	24993	25699	257539	275558	26760	266296	264228	263175	263444	262845	262948	264057	263865
Trend	N80E	N75W	Curves[1]	N30E	N30E	Curves[2]	N20W	N45W	N80W	N30W	N75W	N60W	N05W	N10E
Width	1.5-2 m	1.5 m	2-3 m	3 m	3 m	50 m	30 m	30 m	8 m	40 m	1 m	3 m	7 m	20 m
Age, Ma	2.6?	2.9 - 2.7	2.5 - 2.2	3.0?	3.0?	2.64 ± 0.06	2.69 ± 0.03	<2.7	<2.7	<2.7	<2.68	<2.68	<2.8	<2.7
SiO_2	41.82	50.13	48.38	48.43	47.33	62.78	64.69	63.68	63.31	67.98	61.88	61.88	61.89	61.58
TiO_2	3.349	3.414	2.257	3.475	2.876	0.893	0.675	0.767	0.865	0.365	0.822	0.949	1.103	0.863
Al_2O_3	8.72	18.54	15.39	18.77	15.52	17.69	17.06	17.23	17.45	16.49	18.03	17.24	16.85	17.37
FeO*	12.15	7.54	10.54	13.68	12.56	5.12	4.83	4.77	5.04	2.93	5.44	6.41	6.26	6.17
MnO	0.191	0.190	0.156	0.117	0.162	0.123	0.103	0.114	0.053	0.067	0.119	0.163	0.136	0.183
MgO	14.72	2.72	8.28	1.74	5.80	0.41	0.26	0.79	0.42	0.26	0.94	0.86	1.22	0.89
CaO	15.02	11.51	8.16	7.74	10.41	2.67	1.84	2.84	2.62	0.97	3.24	2.59	3.40	2.69
Na_2O	1.91	3.99	4.22	2.88	3.14	5.64	5.41	5.47	5.59	5.54	5.28	5.80	5.11	5.96
K2O	1.33	1.34	1.87	2.30	1.50	4.21	4.86	3.94	4.22	5.29	3.90	3.75	3.54	3.92
P_2O_5	0.782	0.618	0.741	0.861	0.717	0.480	0.268	0.404	0.431	0.103	0.337	0.347	0.482	0.372
Total	99.99	99.99	99.99	99.99	100.02	100.02	100.00	100.01	100.00	100.00	99.99	99.99	99.99	100.00
Tot alkalis	3.24	5.33	6.09	5.18	4.64	9.85	10.27	9.41	9.81	10.83	9.18	9.55	8.65	9.88

1 Dike trend changes from N25E in canyon bottom to about N80E on mesa top.
2 Dike trend is arcuate, changing from nearly due north at north end to about N60E at south end.

FIGURE 3A. Photo looking east of augite megacrystal trachybasalt dike (sample F07-43, Table1) intruded along a small fault (left side down) cutting Cretaceous Mancos Shale and Main Member, Gallup Sandstone in western Lobo Canyon. Width of dike is about 1.5 m. (See also Color Plate 7A)

FIGURE 3B. Photo looking southwest of olivine trachybasalt dike cutting Cretaceous Mancos Shale at mouth of Rinconada Canyon (sample 09KF45, Table 1); hammer handle is 46 cm long. (See also Color Plate 7B)

FIGURE 3C. Photo looking west of nephelinite dike cutting Cretaceous Mulatto Member, Mancos Shale (sample F07-40, Table 1); hammer handle is 46 cm long. (See also Color Plate 7C)

Horace Mesa Dike

The trachybasalt dike on the east edge of Horace Mesa (location 3, Fig. 2; Fig. 5) is particularly interesting because it can be traced from the bottom of the mesa where it cuts Cretaceous mudstone and shale of the Gibson Coal Member (Crevasse Canyon Formation), to the top of the mesa where it enters the base of an eroded scoria cone and associated flow (Goff et al., 2008). On the way up, the dike cuts Grants Ridge Tuff (3.26 Ma) and an overlying sequence of volcaniclastic gravels containing pumiceous beds dated elsewhere at about 2.7 to 2.8 Ma. The lava flow associated with the dike is overlain to the north by more volcaniclastic gravels and by a different lava flow dated at 2.0 Ma. Thus, we estimate the age of the dike, scoria cone and associated flow at roughly 2.5 to 2.2 Ma.

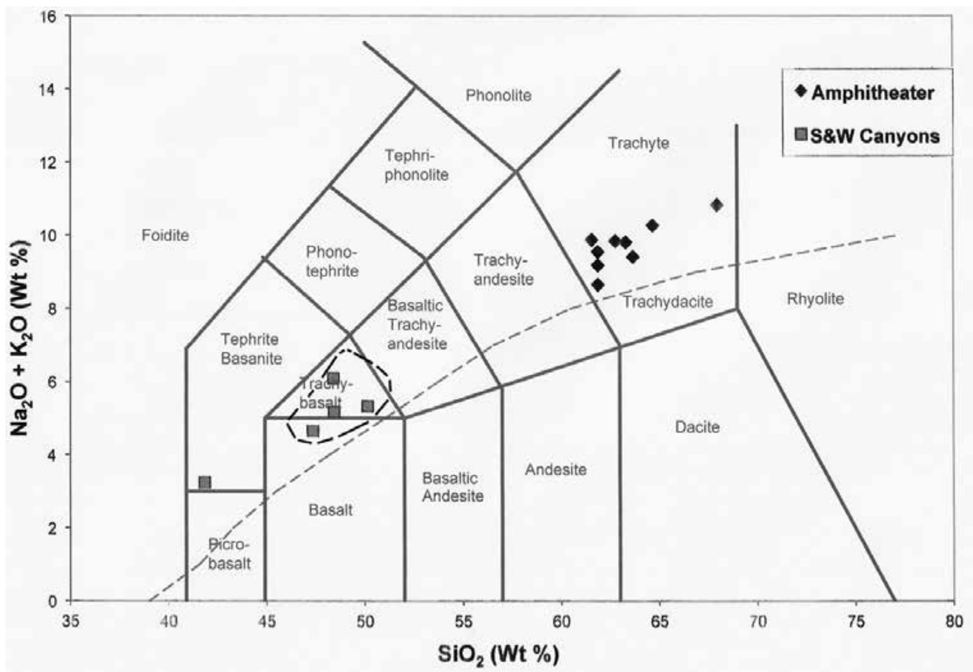

FIGURE 4. Plot of total alkalis versus silica content for Mount Taylor dikes, Table 1 (after Le Bas et al., 1986). Black dashed line shows range of compositions for Mount Taylor basaltic rocks (from Fellah, 2011). Red dashed line separates alkalic and sub-alkalic magma compositions (Miyashiro, 1978).

The dike is relatively thin (2-3 m wide) but stands several meters above the rocks it cuts, particularly the tuff and gravels, due to its greater resistance to erosion. Total dike length is about 0.5 km and total change in elevation (mesa bottom to scoria cone) is about 155 m (Fig. 5a). Remarkably, the strike of the dike is N25E in the underlying Cretaceous mudstones but curves as it rises to a strike of N80E at the base of the cone. The dike consists of at least three en echelon segments exposed in the mesa wall. Where the dike penetrates the tuff, the tuff has been fused to dark gray glass but the thickness of the fused tuff rarely exceeds 10 cm. The dike margins are chilled, very fine-grained, aphyric and glassy (Fig. 5b), but the interior of the dike is slightly olivine porphyritic. In contrast, the dike entering the base of the scoria cone is aphyric (Fig. 5c). At this stage of our studies, it is not clear if the greater abundance of small olivine crystals in the lower interior of the dike is caused by slower cooling, some gravity settling of olivine, a small change in dike chemistry, or some combination of all processes.

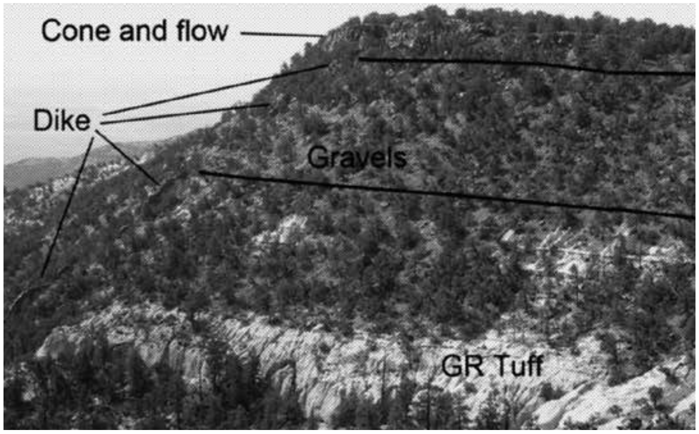

FIGURE 5A. Photo looking south of Horace Mesa dike cutting Grants Ridge Tuff (3.26 Ma) and volcaniclastic gravels (2.7 to 2.8 Ma). Dike feeds eroded scoria cone and flow (2.5 to 2.2 Ma) at mesa top. The scoria in this photo underlies the flow but thickens west away from the edge of the mesa. This cone and flow are overlain to the north (right) of photo by more gravels and another flow dated at 2.0 Ma (Goff et al., 2008).

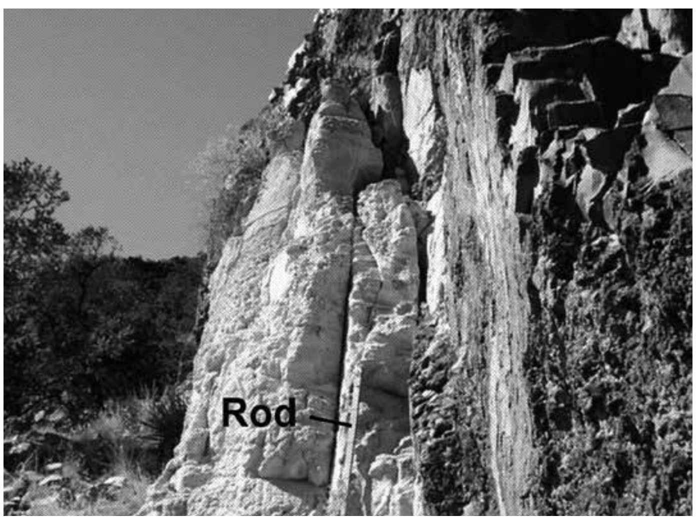

FIGURE 5B. Photo of Horace Mesa dike intruding Grants Ridge Tuff; stadia rod has 0.1 m graduations.

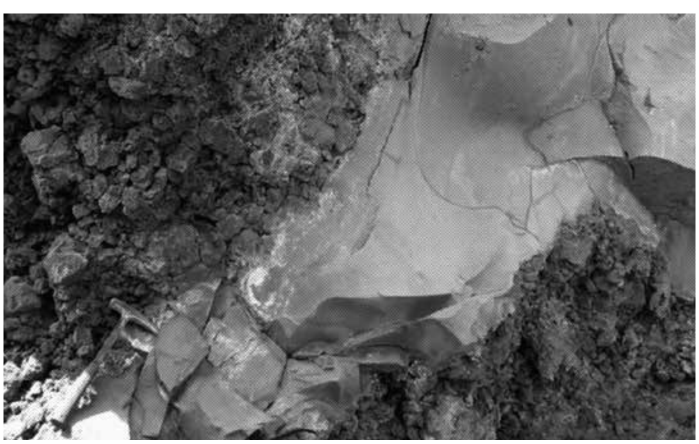

FIGURE 5C. Photo of Horace Mesa trachybasalt dike (sample F07-55, Table 1) feeding into scoria cone and flow (hammer handle is 46 cm long).

Comparison with Ship Rock Dikes

Most of the above-described features (en echelon segments, thin chill zones, coarse-grained interior, possible changes in dike composition) are common in mafic dikes such as those at Ship Rock, New Mexico (Delaney and Pollard, 1981, 1982; Delaney et al., 1986). Dikes in the canyons south and west of Mount Taylor and those at Ship Rock are hosted by similar Cretaceous rocks: Mancos Shale, Gallup Sandstone and Gibson Coal at Mount Taylor; Mancos Shale and Gallup Sandstone at Ship Rock. However, there are many differences. Ship Rock is much larger and older (26 Ma), the intrusive rock is minette (potassium-rich mafic magma containing phlogopite, sanidine, olivine, and augite), the core of the intrusion is diatreme breccia, and dike lengths are ≤9 km, although dike widths are similar. Another major difference is depth of erosion: the Horace Mesa dike is vertically exposed for 155 m at a high level, from host mudstone at bottom to eroded scoria cone at top. In contrast, Ship Rock and associated dikes are deeply eroded to a depth of roughly 1 km (Delaney and Pollard, 1981). Finally, Ship Rock is a large monogenetic volcano whose dikes display crude radial symmetry. Ship Rock no doubt had a protracted eruptive history encompassing both explosive phreatomagmatic and effusive phases. There must have been minette flows, and there could have been small cones, flanking the main Ship Rock maar following the diatreme eruption(s). No large basaltic volcano with radial dikes has been found in the Mount Taylor region and we have not identified a mafic center with such protracted history.

Perhaps the most noteworthy feature of the Horace Mesa dike is its extreme curvature from bottom to top, a change in strike direction of 55°. At this time, we have no explanation for this dramatic change in strike. In contrast, the 2.9 km long northeast dike at Ship Rock changes strike about 15°.

AMPHITHEATER DIKES

Hunt (1938, Fig. 10) was the first to mention the radial nature of Mount Taylor amphitheater dikes, but they have since been described by Perry et al., (1990), Osburn et al. (2009), and Goff et al. (2010). The present center of the volcanic edifice contains a large erosional amphitheater (6.5 x 3.5 km) that drains to the east through Water Canyon (Figs. 2, 6). The amphitheater provides stunning exposure of >50 dikes of all sizes. Many are >20 m wide and form impressive near-vertical ribs that stretch for nearly a kilometer, but most are thinner, shorter and less prominent. Many form en echelon segments of varying length. Some radiate from small stocks and intrusions, particularly from the west half of the amphitheater, while others are isolated and display north to northeast, or arcuate trends. Stop 5, day 3 of this volume examines a large biotite trachydacite dike in the northwest wall of the amphitheater (sample 09KF14, Table 1 and site 5, Fig. 6).

In the field, we identified amphitheater dikes as either trachyandesite or trachydacite. The former dikes contain phenocrysts of plagioclase, augite, and opaque oxides with microphenocrysts of plagioclase, augite, apatite and opaque oxides

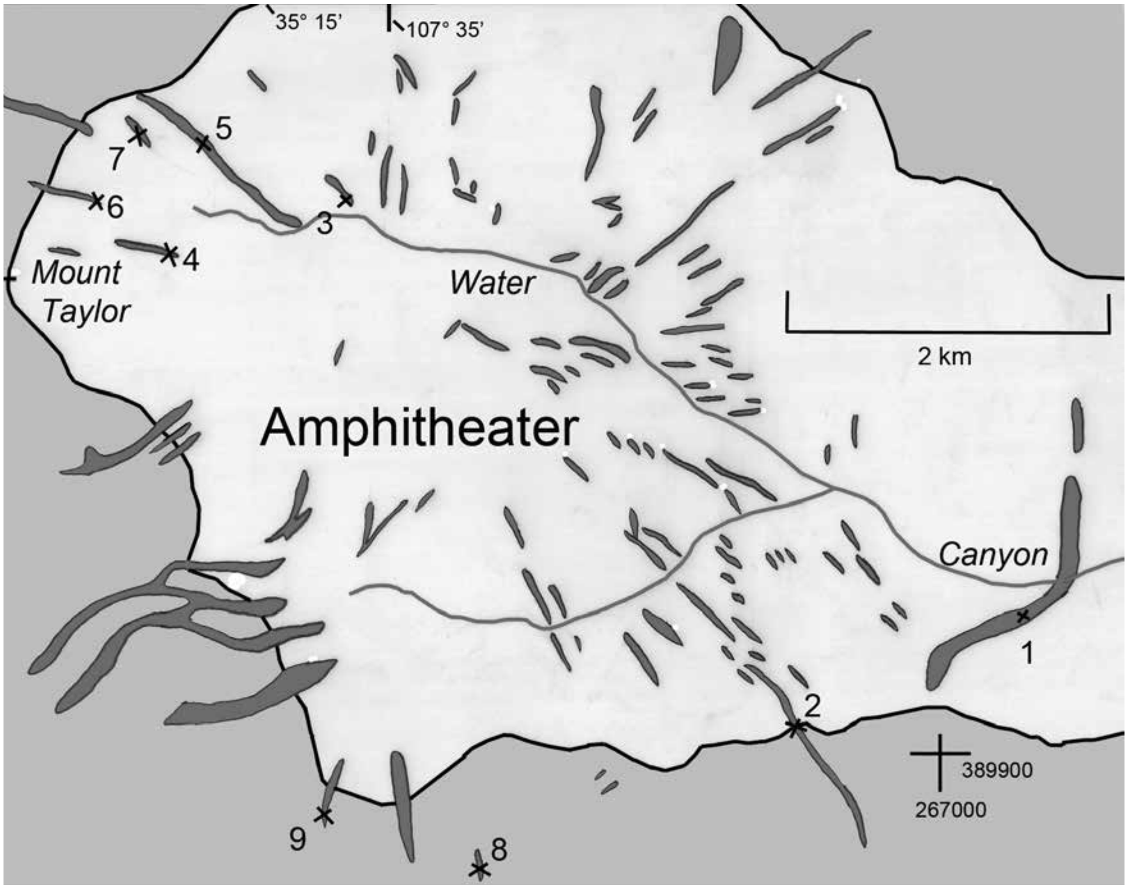

FIGURE 6. Diagram showing the Mount Taylor amphitheater; black = trachyandesite and trachydacite dikes, dark gray = Mount Taylor volcanic pile outside the amphitheater and light gray = undivided volcanic and sedimentary rocks inside the amphitheater (adapted from Osburn et al., 2009). Numbers show sample sites in Table 1.

in fine-grained devitrified glass (Appendix 1). The latter dikes have phenocrysts of plagioclase, augite, sanidine, opaque oxides ± hornblende, and/or biotite with similar fine-grained groundmass. In thin section, the optical properties of the mica resemble common biotite, not phlogopite. Amphitheater dikes cut wall and floor rocks varying from Cretaceous lower Gallup Sandstone and Mancos Shale to early-erupted Mount Taylor trachybasalt through trachyte and rhyolite (Hunt, 1938; Lipman et al., 1979; Perry et al., 1990; Osburn et al., 2009). Two dikes, one cutting Cretaceous rocks in the eastern floor and one cutting the south amphitheater wall (locations 1 and 2, Fig. 6) have been dated by Ar/Ar at 2.64 and 2.69 Ma (Table 1). Ages of other dikes can be estimated by geologic relations among other dated units. For example, several dikes (locations 4, 6, and 7) cut a large body of coarse porphyritic trachydacite dated at 2.68 Ma exposed in the west amphitheater wall (Goff et al., 2008; Osburn et al., 2009). On the other hand, the western portion of the amphitheater is occupied by a small stock of alkali rhyolite-trachydacite dated at about 2.50 to 2.54 Ma (Goff et al., 2010), which has very few dikes. Thus, most amphitheater dikes were emplaced between about 2.7 and 2.55 Ma.

We have analyzed nine dikes within or just outside the amphitheater (Table 1); all are trachydacites (Fig. 4). Those dikes without hornblende or biotite tend to be slightly more mafic. A complete study of the chemistry of every dike shown on Figure 6 is beyond the scope of our investigations. However, it appears that most amphitheater dikes originated from an evolving shallow stock or small pluton of trachydacite in the 2.7 to 2.6 Ma age range that was later intruded by the smaller body of alkali rhyolite-trachydacite.

South Wall Dike

Perhaps the most impressive amphitheater dike is the one shown at site 2 in Fig. 6 that crosses the southern amphitheater wall. This dike has a strike length of roughly 1 km and is typically 30 m or more wide (Fig. 7a). Portions of the dike stand taller than 40 m above adjacent eroded lava flows but much of it is composed of several en echelon segments giving the dike a dinosaur-like appearance. At the location where the dike crosses the wall, the dike forms a knob over 50 m tall with complex cooling joints that could be an eroded plug (Fig. 7b). The dike at the knob is dated at 2.69 ± 0.03 Ma and is composed of biotite trachydacite (Table 1, Appendix 1). At this time we have not studied any variations in chemistry or mineralogy along the full strike length, or from margin to center of the dike, but it would

FIGURE 7A. Photo looking north of "South Wall Dike" just outside the Mount Taylor amphitheater. At this location (east of site 2, Figure 6), the dike displays en echelon segments that stand more than 30 m tall. (See also Color Plate 7D)

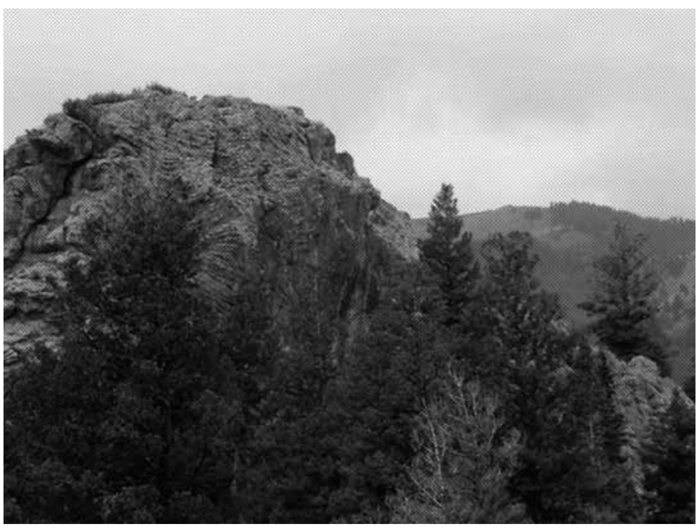

FIGURE 7B. Photo looking north of complex cooling joints in knob at apex of "South Wall Dike" (sample F08-26, Table 1).

not surprise us if there are minor but measurable variations in composition.

Comparison with Summer Coon Dikes

Summer Coon is a highly eroded stratovolcano in the southeast San Juan volcanic field, which is famous for radiating dikes (Lipman, 1968; Mertzman, 1971; Valentine et al., 2000). Initial construction of the volcano began with eruptions of basaltic andesite flows and breccias that were systematically followed by eruptions of dacite and rhyolite lavas. The core of the volcano is a complex circular stock of dacite, rhyolite and granodiorite porphyry (Mertzman, 1971). Hundreds of small basaltic andesite dikes and 20 large silicic dikes radiate from the core (Fig. 8). Nine dikes dated by Ar/Ar methods range in age from 32.6 to 33.9 Ma; seven dikes are between 33.0 and 33.5 Ma (Perry et al., 1999). Basaltic andesite dikes average 200 m in outcrop length and 1 m in width. They are easily eroded and poorly exposed. In contrast, the silicic dikes (Fig. 8) are long (2-7 km), thick (about 50 m) and tough, often standing 20 m above softer country rocks. Poland et al. (2008) have found that silicic dikes tend to become wider at greater distances from the central vent and have postulated that these wide dikes were feeders to distal eruptions on the flank of the volcano.

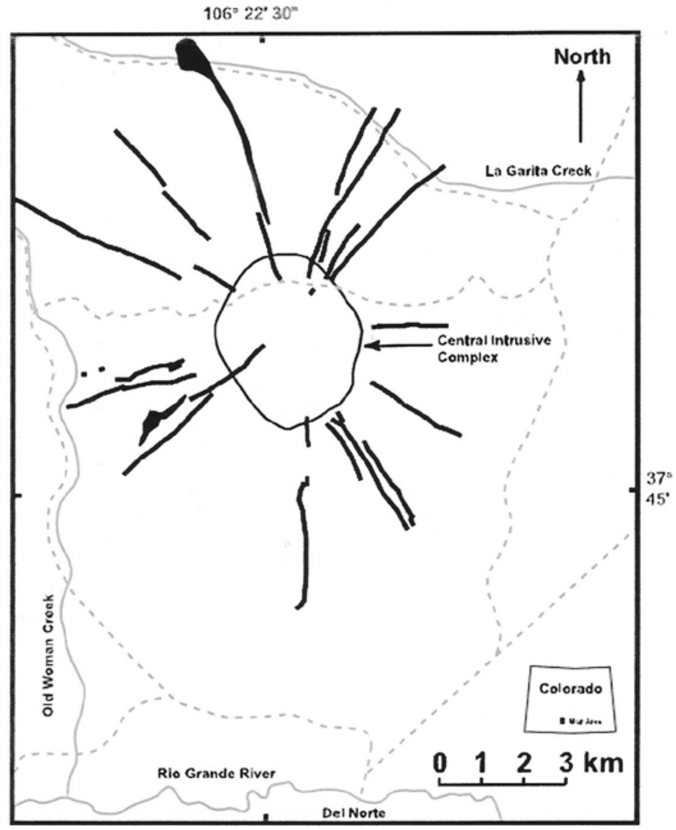

FIGURE 8. Simplified map of Summer Coon volcano (from Poland et al., 2008) showing silicic dikes (heavy black solid lines) radiating from the central intrusive complex; gray dashed lines are roads.

At first glance, Mount Taylor and Summer Coon dikes seem to have many similarities, most obviously their radial distributions. Both volcanoes begin with predominately mafic eruptions and end with more silicic eruptions. Both have centralized stocks and intrusive bodies. Silicic dike widths are similar, heights are roughly similar and en echelon structures are common to both. However, there are many differences between the two volcanoes. Mount Taylor amphitheater is larger and more elongate than Summer Coon stock, and intrusive activity has migrated from the southeast toward the northwest (Osburn et al., 2009). Mount Taylor does not display any, certainly not "hundreds" of, radiating mafic dikes. Mount Taylor contains at least 50 trachydacite dikes but none exceed 1 km in length. Summer Coon has about 20 rhyolite-dacite dikes but the longest is nearly 7 km. Possibly, longer dikes might be exposed at Mount Taylor if the summit area was more deeply eroded.

CONCLUSIONS

Mount Taylor dikes are impressive in their varied geology, petrology, and chemistry, but they need further study. Now that detailed mapping is complete for the entire Mount Taylor volcano area, future research on the basaltic dikes in the canyons south and west of the volcano could potentially divulge information on the stress regime of the shallow crust and magma source variations during the period 2.5 to 3.0 Ma. Research on trachydacite dikes in the amphitheater could help determine the evolution of late stage Mount Taylor intrusive bodies and their connections, if any, to satellite vents of similar composition on the flanks of the volcano.

ACKNOWLEDGMENTS

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