GEOCHRONOLOGY OF OLIGOCENE MAFIC DIKES WITHIN THE SOUTHEASTERN COLORADO PLATEAU: IMPLICATIONS TO REGIONAL STRESS FIELDS OF THE EARLY RIO GRANDE RIFT

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ABSTRACT:

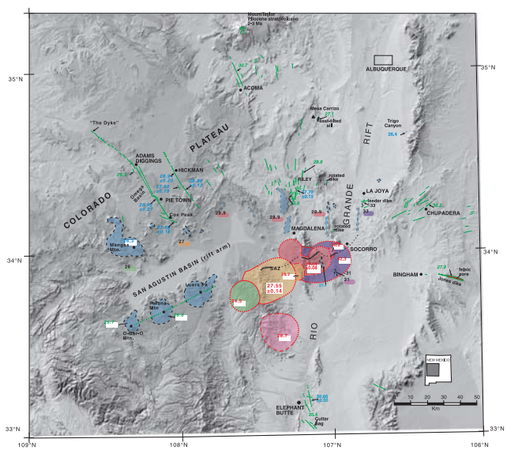
Oligocene mafic dikes exposed on the southeastern Colorado Plateau are part of a large radial array known as the Magdalena radial dike swarm (MRDS). The MRDS spans 260º of arc and is broadly focused on the westward younging Socorro-Magdalena caldera cluster (SMCC) of Oligocene age (32-24 Ma) within the central Rio Grande rift. Ignimbrite sheets from the SMCC repeatedly buried high-angle normal fault scarps in the early rift.

Six new $^{40}Ar/^{39}Ar$ ages of mafic dikes and field observations imply lateral intrusion into the Colorado Plateau margin from mafic roots of the SMCC during short-lived periods of high magma pressure, possibly coeval with pre-caldera tumescence. Closely spaced NNW- to NNE-trending dikes at Riley are attributed a local coaxial relationship between magmatic stress fields and westward tectonic extension across the rift.

Three coeval dikes that span 70 degrees of arc from Cox Peak eastward to Riley are focused on the Mt. Withington caldera, source of the South Canyon Tuff, precisely dated at 27.55 ± 0.07 Ma (n=3). From west to east, the arcuate array yielded clockwise younging $^{40}Ar/^{39}Ar$ plateau ages of 27.88± 0.18, 27.80± 0.19 and 27.70 ± 0.15 Ma. The two older dikes are high-K olivine basalts and the youngest dike is a pyroxene-plagioclase basaltic andesite. Considering analytical error (0.7%), the three radiating dikes are coeval, but the WNW-striking dike is at least 0.08 Ma older than the Mt. Withington caldera.

Two long, NNW-striking, aphyric, xenocrystic basaltic andesite dikes near Pie Town and Hickman locally show gently southeast plunging flow lineations along their margins. Sparse xenocrysts of strongly resorbed sanidine and quartz, plus the presence of small resinous to black siliceous spherules, suggest the basaltic andesite magmas were mixed with rhyolitic magma just prior to their intrusion. The Pie Town dike produced a slightly disturbed plateau age of 28.92±0.27 Ma and two widely-separated samples of the Hickman dike yielded plateau ages of 28.90± 0.13 and 28.94± 0.20 Ma. All three dates are analytically equivalent to the age of the La Jencia Tuff, which was erupted from the Sawmill Canyon caldera at 29.04± 0.04 Ma (n=4). The Pie Town and Hickman dikes are orthogonal to the WSW-trending axis of the SMCC; they do not necessarily indicate the orientation of early rifting, as previously published.

FIGURE 1—OLIGOCENE CALDERAS, MAFIC LAVAS AND RADIATING MAFIC DIKES OF THE SOCORRO-MAGDALENA MAGMATIC SYSTEM



Calderas (Ma)
- Bear Trap Canyon (24.5)
- Mount Withington (27.6)
- Hardy Ridge (28.2)
- Nogal Canyon (28.7)
- Sawmill Canyon (29.0)
- Black Canyon (30.2)
- Socorro (32.3)

Structures
- Caldera margin (dotted where concealed)
- Mafic dike (dotted where concealed or inferred)
- Vent area of shield volcano
- Basaltic andesite lavas (remnant of shield or plateau)
- Transverse accomodation zone (SAZ)

Age Data
- 32.3 $^{40}Ar/^{39}Ar$ age of caldera-forming ignimbrite
- 28.90 $^{40}Ar/^{39}Ar$ age of basaltic andesite lava or dike
- 27.7 K/Ar age of mafic dike, sill or shield volcano
- ~33 Approximate age of lava or dike from stratigraphic relationships
- 28.9 Approximate age of stratigraphically oldest basaltic lava

FIGURE 2—ARGON SPECTRA OF MAFIC DIKES COEVAL WITH THE LA JENCIA TUFF (SAWMILL CANYON CALDERA)

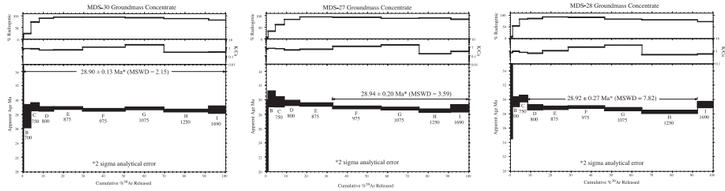
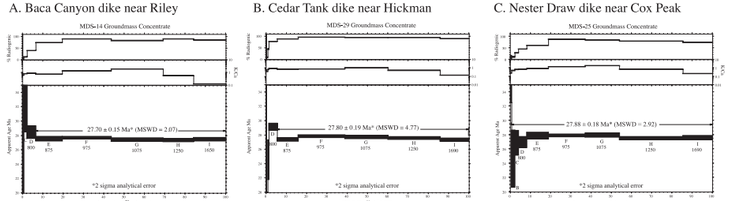


FIGURE 3—ARGON SPECTRA OF MAFIC DIKES COEVAL WITH THE SOUTH CANYON TUFF (MT. WITHINGTON CALDERA)



NOTE: All $^{40}Ar/^{39}Ar$ age data presented here are based on a FCT monitor age of 28.02 Ma. For comparison previously published $^{40}Ar/^{39}Ar$ ages (FCT=27.84Ma) should be mulitplied by 1.00647.

FIGURE 4—GEOCHRONOLOGY OF MAFIC DIKES AND CALDERA-FORMING IGNIMBRITES

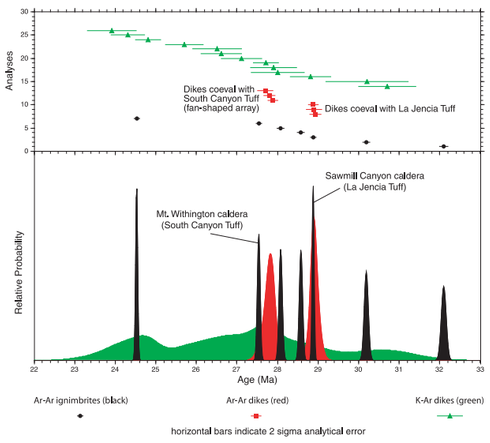
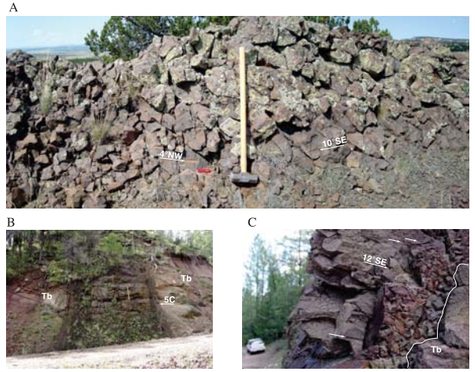


FIGURE 5—PRIMARY FLOW LINEATIONS IN THE PIE TOWN AND HICKMAN DIKES



A. Near horizontal ellipsoidal vesicles (light brown) on northeast margin of the Pie Town dike near Techado. Sledge handle is vertical.
B. Hickman dike cuts Eocene Baca Formation beds (Tb) at Monument Saddle in Datil Mountains. View is to southeast; sledge is 98cm long. Arrow shows location of Figure 5C.
C. Southeast plunging tubular vesicles (arrows) along southwest margin of the Hickman dike at Monument Saddle. Note reddish brown to gray chilled margin of dike at contact with Baca sandstone bed (Tb).

DISCUSSION:

A dike is a magma-filled crack that propagates along a vertical plane in the direction perpendicular to the least principal horizontal stress at the time of emplacement (Rubin, 1995). Mafic dikes on the SE Colorado Plateau appear to faithfully record the geometry of the crustal stress fields during their emplacement, but they do not tell us the origin of the stresses (e.g. tectonic, magmatic, gravitational loading) or the effects of preexisting anisotropy. Ongoing geologic mapping and $^{40}Ar/^{39}Ar$ dating of the Magdalena radial dike swarm (MRDS) has now established a strong temporal and spatial link between WNW- to NNE-striking basaltic dikes on the SE Colorado Plateau and a coeval caldera cluster (32-24 Ma) of the early Rio Grande rift (Figs. 1-4; Chapin et al., 2004).

Observed flow lineations and rhyolitic xenocrysts in the 28.9-Ma basaltic-andesite dikes at Pie Town and Hickman (Figs. 5-7) are consistent with lateral intrusion upwards and outwards from the mafic roots of the SMCC, most likely just prior to eruption of the La Jencia Tuff from the Sawmill Canyon caldera. Three single-crystal $^{40}Ar/^{39}Ar$ age determinations (n = 67 sanidine crystals) from rhyolite lava domes on the SE flank of the Sawmill Canyon caldera yield a mean age of 28.89 ± 0.06 Ma for pre-ignimbrite tumescence (Chamberlin et. al., 2004). This precisely dated tumescent event is analytically equivalent to the mean age of the well-dated Hickman dike at 28.92 ± 0.10 Ma (n=2). Bulk sanidine ages of ignimbrites shown on Figure 1 (McIntosh et. al., 1991) tend to be slightly old, due to the presence of unrecognized xenocrysts (McIntosh and Chamberlin, 1994).

Angular unconformities between Oligocene ignimbrites define the tops of early rift high-angle domino blocks in the San Mateo, Magdalena and Lemitar mountains, plus the Joyita Hills. Average slip vectors on low-angle early rift faults in the latter two areas (Chamberlin, 2004; Beck and Chapin, 1994) indicate tectonic extension was primarily westward (265 to 270; Fig.7). WNW-oriented slip lines (290) in the Joyita Hills may also reflect the orientation of pre-existing weak lithosphere under the Albuquerque Basin.

Three age-equivalent basaltic dikes that are slightly older or analytically coeval in age to the 27.6-Ma South Canyon Tuff define a radial extensional stress trajectory focused toward the Mt Withington caldera (Fig.7). These dikes apparently propagated as much as 100 km outward from the roots of the Mt. Withington caldera. Radial dike swarms represent brief periods of time when magmatic pressures have overwhelmed regional stress of plate tectonic origin. Loading of the southeastern Colorado Plateau lithosphere by the growing Oligocene volcanic pile may have also influenced the "regional" stress field (100km length scale).

The distal section of the 72-km-long Pie Town dike, north of Adams Diggings, shows a distinct left-stepping en echelon pattern. Field observations show the north end of dike segments bend down dip into a sill-like geometry, where the dikes step to the left. The distal dike geometry is consistent with westward dextral transtension of tectonic origin. The southern proximal section of the Pie Town die and the Hickman dike are interpreted to represent a domain of west-southwestward directed magmatic dilation, which has been previously interpreted as the direction of tectonic extension (Laughlin et al, 1983; Aldrich et. al, 1986).

Our cross sectional model of lateral dike propagation during pre-caldera tumescence (Fig.8) suggests two key geologic processes. We infer the formation of a CO_2-rich gas cap above the pre-caldera magma body at depths of up to 8 km (cf. Wallace et. al, 1995). Extreme gas pressure can then force rhyolitic magma downward and force mafic magma outwards from the deep roots of the hydraulically connected magma system. The latter is not unrecognized in the geologic record (Bolle, et.al, 2002).

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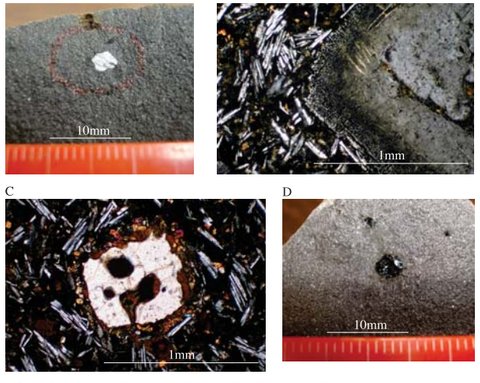
FIGURE 6—XENOCRYSTS AND SILICEOUS SPHERULES IN THE PIE TOWN DIKE



A. Cleavage face of embayed sanidine xenocryst is distinctly visible within dark gray basaltic matrix.
B. Photomicrograph shows strongly resorbed margin of sanidine xenocryst within basaltic matrix of plagioclase microlites, clinopyroxene and opaque Fe-Ti oxides; nicol prisms are crossed.
C. Photomicrograph shows strongly resorbed and embayed quartz xenocryst (white) surrounded by basaltic matrix; nicols are crossed. Note high-temperature reaction rim of clinopyroxene (yellow-blue birefringence) around quartz crystal.
D. Resinous to black glassy siliceous spherule within aphyric basaltic matrix. Preliminary microprobe analyses indicate the resinous glass contains about 69% SiO_2, 14% FeO, 3.5% MgO, 2.5% Al_2O_3 and 0.75% alkali oxides.

FIGURE 7—TECTONIC AND MAGMATIC STRESS FIELDS OF THE EARLY RIO GRANDE RIFT

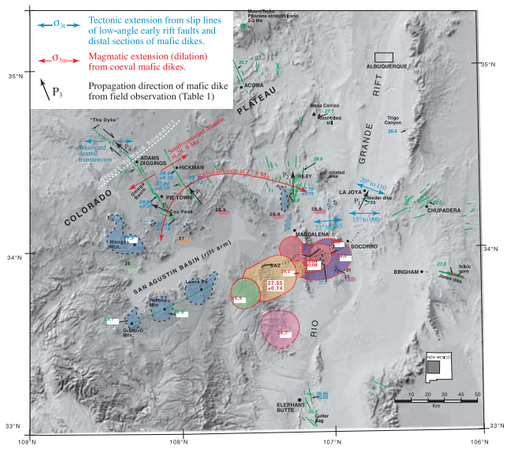


TABLE 1. PROPAGATION DIRECTIONS OF MAFIC DIKES FROM FIELD OBSERVATIONS (FIGURE 7)

P_1— East-tilted and eroded, 10m-wide, NE-striking basaltic feeder dike pinches out rapidly to NE of exhumed vent, which lies stratigraphically below the 32.3-Ma Hells Mesa Tuff. Pressure drop at vent apparently arrested northeastward dike propagation.

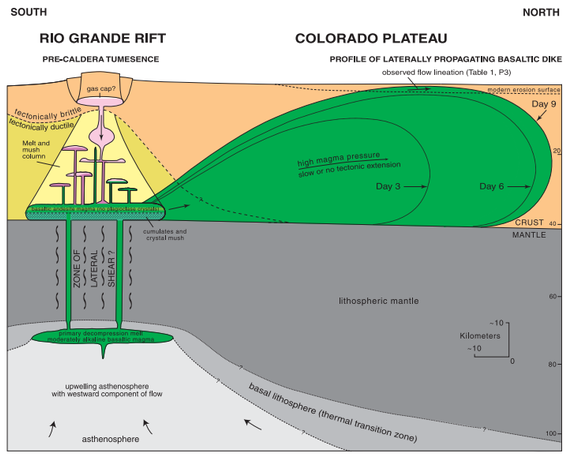
P_2— Northward branching basaltic dike thins progressively at two successive branches. NNW-striking trunk (339) is 10m thick. Medial branches (345 and 005) are 4 and 3 m thick respectively and upper branches (340 and 012) --off western medial branch-- are 3 and 1m wide respectively. Thickness patterns imply northward decreasing magma pressure at each branch (Dimeo and Chamberlin, 2006).

P_3— Tubular vesicles along SW margin of the Hickman dike plunge 12º to 145 (Fig. 5C). Adjacent mudstone beds of the Eocene Baca Formation dip 4º to 174. Removal of late Cenozoic regional tilt indicates this primary flow lineation was rising to the NW at about 8º.

P_4— Distinctly elongated ellipsoidal vesicles along NE margin of the Pie Town dike plunge between 10º to 143 and 4º to 323 (Fig. 5A). NNE-striking late Cenozoic normal faults have tilted this block about 5º to the NW. The original flow lineation was apparently rising to the NW at about 1-15º above horizontal.

P_5— WNW-striking andesitic dike about 8m wide pinches out rapidly to WNW and also steps sharply 3m to right, then continuing on to WNW at thickness of 7m. Highly brecciated dike rock exposed in narrow crotch of the step over implies two pulses of WNW-dike propagation, separated by a brief cooling event near the initial dike tip

FIGURE 8—CROSS SECTIONAL MODEL OF LATERAL DIKE PROPAGATION DURING PRE-CALDERA TUMESCENCE



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