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POSSIBLE ORIGINS OF DIKES EXPOSED IN NORTHEASTERN NEW MEXICO AND IMPLICATIONS FOR MID-TERTIARY ALKALIC MAGMATISM IN THE REGION

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ABSTRACT — Numerous, little-studied dikes are exposed in northeastern New Mexico, particularly in the area south of Raton along the eastern margin of the Raton basin. We describe preliminary geochronology, geochemistry, and geographic relationships of a small suite of these dikes and discuss their relationships to two large magmatic centers of northern New Mexico, the distal 28.5-15.5 Ma Questa caldera and the proximal 36.7-20.3 Ma Chico Sill complex. Some of the dikes are radial to both the Questa caldera and Chico Sill complex. In contrast, some of the dikes are only radial to the Questa caldera. Two of the more topographically prominent dikes are the Eagle Rock and Little Eagle Rock dikes, which yield new ⁴⁰Ar/³⁹Ar ages of 23.58±0.06 and 21.36±0.06 Ma, respectively. Despite their close proximity to each other (~1 km) and some similarities in composition, the new ages indicate the dikes were emplaced during two separate episodes of magmatism. Although these two dikes are radial to both of the larger potential magmatic sources, the new ages closely match the youngest pulses of postcaldera magmatism at Questa. ⁸⁷Sr/⁸⁶Sr ratios are similar between some Questa caldera mafic rocks and the Eagle Rock dike, but there are prominent differences in ¹⁴³Nd/¹⁴⁴Nd and ²⁰⁶Pb/²⁰⁴Pb ratios, suggesting that if the dikes are related to the Questa caldera magmatic system, the dikes tapped isotopically distinct reservoirs or acquired different isotopic signatures during magmatic transport. No published isotopic data exists for the Chico Sill complex, hindering the establishment of potential links between the dikes and sill complex. Published ages for a dike west of Raton and along the New Mexico-Colorado border, both of which are only radial to the Questa caldera, are 15.5 and 19.5 Ma, respectively, closely correlating to the timing of Questa magmatism. Thus, preliminary data suggest that some dikes exposed in northeastern New Mexico are possibly distal radial dikes associated with the youngest pulses of magmatism at the Questa caldera. However, additional geochronology and geochemistry, together with field assessment to identify the total number of dikes and anisotropy of magnetic susceptibility to determine flow directions, will be necessary to fully resolve potential connections between the dikes of northeastern New Mexico and their relationships to regional tectonics and large mid-Tertiary magmatic systems of the area.

INTRODUCTION

The Eagle Rock dike, or sometimes referred to as the Tinaja dike, is well exposed along I-25 near the Tinaja exit approximately 26 km (16 mi) south of Raton, New Mexico (Fig. 1). The dike is one of a more expansive swarm of little-studied dikes exposed regionally in northeastern New Mexico. These dikes are alkalic (Scott et al., 1990), generally strike in a west to east direction, and can be traced continuously for locally short distances. Some of the larger dikes extend for over 10 km and can be connected by tracing discontinuous exposures across regional low-lying hills and local drainages (Fig. 2A, B). Individual dikes display different compositions and textures (Fig. 2C). Many of the dikes appear composite in that a single dike has multiple internal contacts suggesting pulsed magma flow during emplacement. The Eagle Rock dike, and the nearby Little Eagle Rock dike exposed ~1 km south along I-25, are thicker and more prominent than most of the dikes that are exposed in this region.

The magmatic, tectonic, and geochemical significance of the Eagle Rock and Little Eagle Rock dikes in relation to similar surrounding alkalic dikes and larger magmatic centers of northern New Mexico is not well constrained. Regionally, these dikes may be related to alkalic magmatism that generated mid-Tertiary alkalic rocks in the mountains to the east that are loosely referred to as the Chico Sill complex. Alternatively,

the Eagle Rock dike and other dikes in the region may result from distal emplacement of magmas associated with the 25.4 Ma Questa caldera (Zimmerer and McIntosh, 2012) located within the Latir volcanic field along the eastern edge of the Rio Grande rift in the southern Rocky Mountains south of the Colorado-New Mexico border. The Eagle Rock and Little Eagle Rock dikes, along with other regional dikes, are radial to both the Chico Sill complex (located ~10 to 30 km away) and the Questa caldera (located ~60 to 90 km away). We briefly discuss preliminary geochronology and geochemistry of the Eagle Rock and Little Eagle Rock dikes in assessing their origins and potential connections, if any, to these two different alkalic magmatic provinces.

BACKGROUND

The Eagle Rock and Little Eagle Rock dikes were emplaced in a swarm of northwest-southeast (285±10°) trending dikes exposed on the east and west sides of I-25, ~26 km (16 mi) south of Raton, New Mexico near Eagle Tail Mesa in northeastern New Mexico. The dike exposed at the Tinaja exit of I-25 (i.e., the Eagle Rock dike) displays multiple internal contacts representing numerous injections of magma (Fig. 2A). These dikes are dark grey to black, basanitic in composition, and have granular textures with coarse-grained plagioclase,

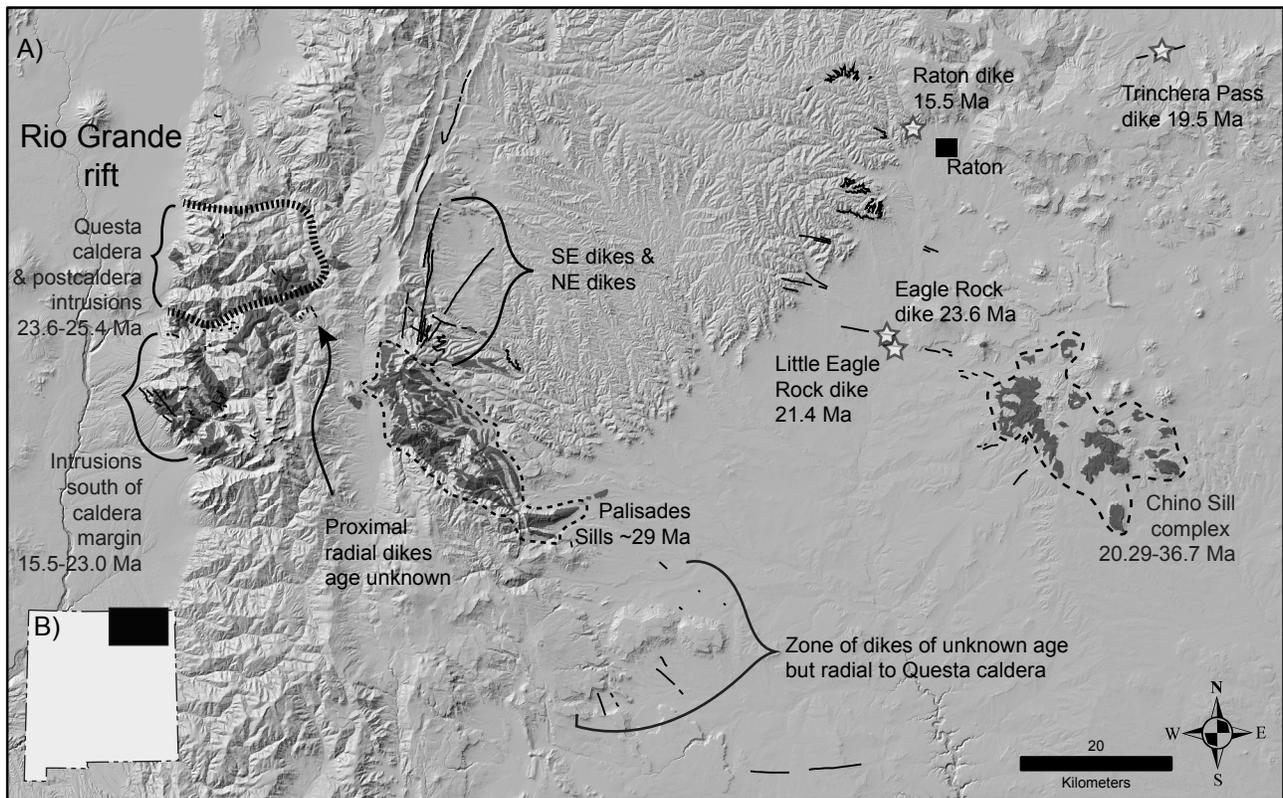


FIGURE 1. **A)** Simplified map showing the location of dikes and larger mid-Tertiary magmatic centers (Questa caldera of the Latir volcanic field, Palisades Sills, and Chino Sill complex) of northern and northeastern New Mexico. Stars denote dated dikes. Eagle Rock and Little Eagle Rock dikes were dated as part of this study. The Raton and Trinchera Pass dikes were dated by Stroud (1997). U/Pb and $^{40}\text{Ar}/^{39}\text{Ar}$ ages of intrusions at the Questa caldera are from Tappa et al. (2011), Zimmerer and McIntosh (2012), and Gaynor et al. (2019). The K/Ar ages of the Palisades Sill and Chino Sill complex are from Scott et al. (1990). **B)** Index map showing the approximate extent of map A in northeastern New Mexico.

potassium feldspar, hornblende, biotite, sodalite, minor clinopyroxene, and oxides (Scott et al., 1990). The dikes have multiple splays that have variable thicknesses and textures. The larger splay has an altered selvage that is green and highly friable. It grades into a dike that contains coarse-grained (up to 2 cm) hornblende (Fig. 2c). Locally, however, the dike has variable textures and mineralogies. Hornblende from the Eagle Rock dike was previously dated using the K/Ar method, which yielded an age of 24.16 ± 1.01 Ma (Scott et al., 1990).

The texture and mineralogy of the Eagle Rock dike shows some similarity to descriptions of the Buena Vista dike, located north of Las Vegas, New Mexico. Both dikes have crystals that are oriented perpendicular to the dike edges (Lindline et al., 2015; Scott et al., 1990). The Buena Vista dike and a second associated smaller dike, together referred to as the Buena Vista dikes, have outer portions that are gabbroic in nature with dike interiors becoming more felsic and plagioclase-rich.

Exposed approximately ~1 km (0.6 mi) south of the Eagle Rock dike is the Little Eagle Rock dike, which also forms a prominent topographic ridge that crosses I–25. The dike is light gray in color with several internal contacts suggesting that it also formed as a result of multiple pulses of magma injection. The Little Eagle Rock dike is phonolitic (Scott et al., 1990) and hosts hornblende and clinopyroxene phenocrysts. Similar to the Eagle Rock dike, the Little Eagle Rock dike contains zones of coarse-

grained hornblende-bearing phases. No published ages existed for the Little Eagle Rock dike prior to this study.

The published age and geochemistry of the Eagle Rock dike is similar to characteristics of local intrusive rocks of the alkaline Chico Sill complex (Scott et al., 1990) as well as exposed postcaldera intrusions of the more distant Questa caldera. Magmatism associated with these volcanic and magmatic centers generally encompasses latest Eocene to middle Miocene ages (Fig. 3). Magmatism of the Chico Sill complex began as early as latest Eocene as reflected in the Slagle Trachyte (36.7 ± 1.3 Ma). Continued activity generated the Laughlin Peak Trachyte (32.5 ± 1.5 Ma) and the Chico Hills Phonolite (25.80 ± 0.88 Ma). The youngest activity terminated at 20.29 ± 0.90 Ma with emplacement of the Chico Phonolite at Tinaja Mountain located just northeast of the Eagle Rock dike. Additional rocks associated with the Chico Sill complex include nepheline syenite at Point of Rocks Mesa, variable phonolites regionally, phonotephrite at Joe Cabin Arroyo, and syenite, quartz monzonite, and biotite trachyte at Turkey Mountain (Scott et al., 1990).

Magmatism at Questa caldera ranges from Oligocene (28.50 ± 0.19 Ma) to middle Miocene (15.50 ± 0.05 Ma; Fig. 3) with peak volcanism occurring during eruption of the peralkaline 25.39 ± 0.04 Ma Amalia Tuff and collapse of the Questa caldera (Zimmerer and McIntosh, 2012; Gaynor et al., 2019). Volcanic and plutonic rocks associated with Questa caldera are

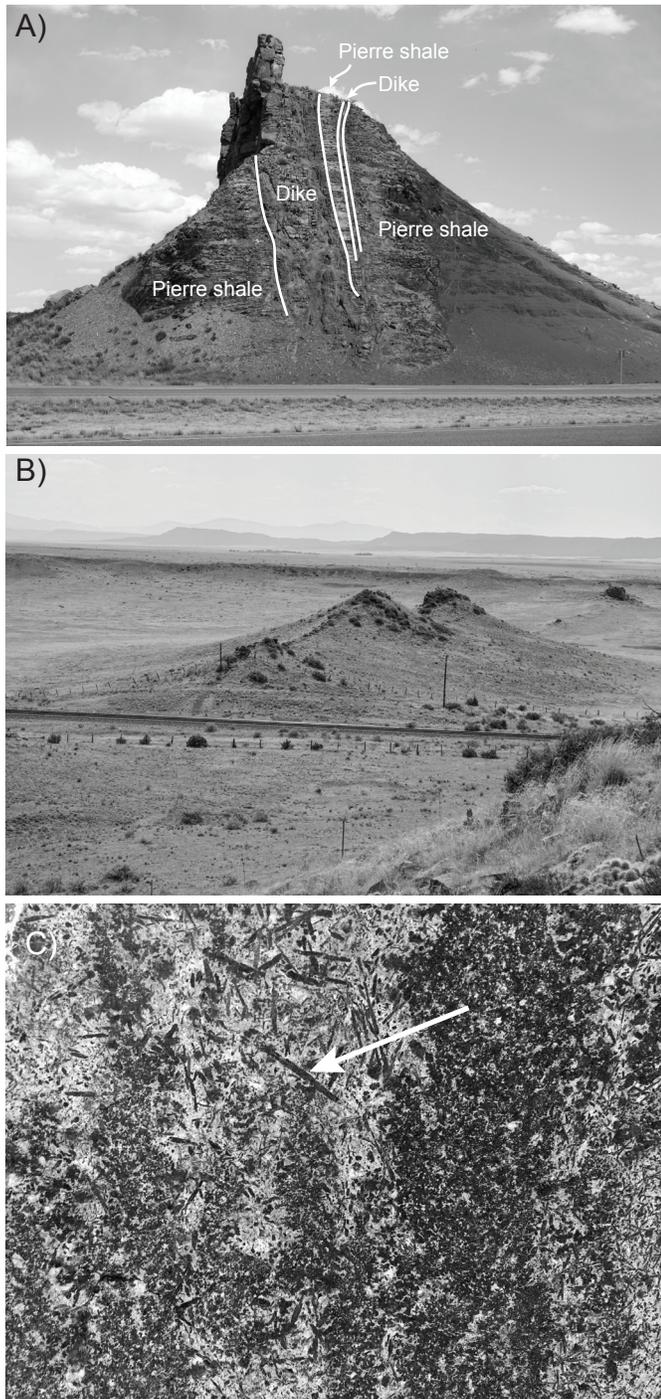


FIGURE 2. Field photos showing different aspects of the Eagle Rock dike. **A)** View looking east across Interstate 25 to the roadcut that exposes the Eagle Rock dike. Here, the dike intrudes the Cretaceous Pierre shale. The main body of the dike is ~6-7 m in width. A parallel, <1m-thick dike is located to the right (in this photo) of the main dike. **B)** Photo from near the top of the Eagle Rock Dike looking west to an unnamed dike located south of the Eagle Rock dike. This dike is ~2m-thick, strikes parallel to the Eagle Rock dike, and is traceable for at least 1 km to the west. **C)** Example of the coarse-grained texture common to the Eagle Rock dike. The hornblende crystal identified by the arrow is approximately 2 cm in length. The dike displays significant textural variability.

compositionally diverse, but in general trend to more evolved compositions. Volcanic rocks include mostly andesites, dacites, and rhyolites. Intrusive rocks include granite, granodiorite, quartz monzonite, and minor leucogranites (Lipman et al., 1986). More mafic compositions associated with Questa caldera include 15–16 Ma basalts and mafic dikes, as well as mafic enclaves within the larger intrusions. A Bouguer gravity anomaly identified beneath Questa is interpreted to represent a large batholith, which based on recent dating of exposed intrusions, was incrementally emplaced and solidified during postcaldera magmatism largely between 25.3 and 19.9 Ma (Tappa et al., 2011; Zimmerer and McIntosh, 2012; Gaynor et al., 2019). Although the Questa caldera is more distant to the Eagle Rock dikes compared to the Chico Sill complex, distal dike emplacement has been observed at other large magmatic centers including on the Columbia Plateau (Taubeneck, 1970), the Socorro-Magdalena caldera cluster (Chamberlin et al., 2009), and the Platoro caldera (Lipman and Zimmerer, 2016).

METHODS

Whole rocks of three dikes were sampled for isotopic analyses (Table 1). These included the Eagle Rock dike sampled at the I–25 roadcut and the Buena Vista dikes sampled north of Las Vegas, New Mexico (Table 2). The Buena Vista dikes were analyzed for comparative purposes. Whole rock samples were crushed using a jaw crusher and powdered using a shatterbox at New Mexico State University. These whole rock powders were dissolved, purified, and analyzed for Sr, Nd, and Pb isotopes. Purification procedures followed those of Ramos (1992). Strontium isotopes were analyzed using seven Faraday collectors in multi-dynamic mode using a VG Sector thermal ionization mass spectrometer with Sr isotopes normalized to $^{86}\text{Sr}/^{88}\text{Sr}=0.1194$. Nd and Pb isotopes were measured using seven collectors in static mode using a ThermoScientific NeptunePlus multi-collector inductively coupled mass spectrometer with Nd isotopes normalized to $^{146}\text{Nd}/^{144}\text{Nd}=0.7219$ and Pb isotopes normalized to $^{203}\text{Tl}/^{205}\text{Tl}=0.41892$. All isotopes were measured at the Johnson Mass Spectrometry Laboratory at New Mexico State University.

Samples from the Eagle Rock and Little Eagle Rock dikes were also collected for $^{40}\text{Ar}/^{39}\text{Ar}$ dating. Hornblende was concentrated from both samples using crushing, sieving, magnetic, and heavy density liquid separation techniques. Hornblende was then picked under a binocular microscope to remove altered grains or those with inclusions.

Hornblende samples were dated at the New Mexico Geochronology Research Laboratory. Hornblende separates were step-heated using a diode laser. Extracted gas was cleaned in an all metal, fully automated extraction line fitted with a cold trap and getter pumps operated at different temperatures to remove unwanted gas species. Gas was then measured on a high-resolution ThermoScientific Helix MC Plus mass spectrometer fitted with Faraday collectors at masses 40, 39, 38, and 37, and a ion counting multiplier at mass 36. More information regarding the operating procedures, spectra, inverse isochron plots, and data tables are presented in Data Repository 20190004.

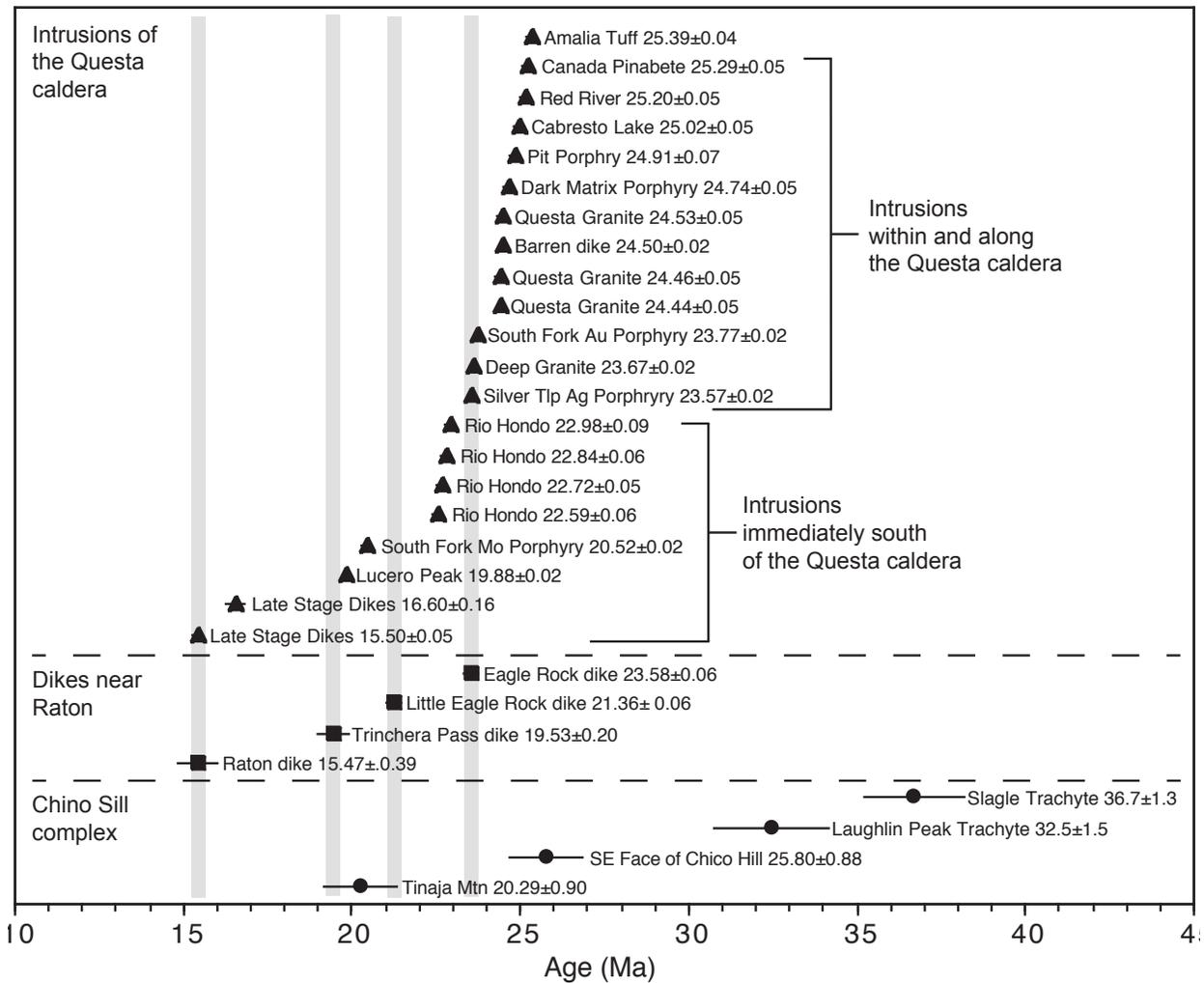


FIGURE 3. Diagram comparing dated dikes of the Raton area to the ages of intrusion at Questa caldera (Tappa et al., 2011; Zimmerer and McIntosh, 2012; Gaynor et al., 2019) and the Chino Sill complex (Scott et al., 1990). All ages reported at 2σ uncertainty. Vertical gray bars show age and uncertainty of the dikes discussed in this paper. A comprehensive chronology exists for the Questa caldera and related intrusions. In contrast, very little data are available for the dikes and Chino Sill complex rocks.

RESULTS

$^{40}\text{Ar}/^{39}\text{Ar}$ Geochronology

Hornblende separates from the Eagle Rock and Little Eagle Rock dikes yield inverse isochron ages of 23.58 ± 0.06 and 21.36 ± 0.06 Ma, respectively. Age spectra of both display initially old ages that decrease during step-heating analyses. When plotted on an inverse isochron, both samples have $^{40}\text{Ar}/^{36}\text{Ar}$ intercepts that are greater than 295.5 indicating the presence of excess ^{40}Ar . The inverse isochron age is the preferred age. Although the Ar closure temperature of hornblende

is $\sim 500^\circ\text{C}$ (Harrison, 1982) and is less than emplacement temperatures, given the observation that the dikes are relatively thin, we suggest that cooling was relatively quick and thus, interpret the hornblende age as the age of dike emplacement.

Geochemistry

Major element compositions of the Eagle Rock dike, Little Eagle Rock dike, and a similar dike, referred to as the Colmor dike, that intersects I-25 to the south in the Colmor Quadrangle (Scott et al., 1990) are presented in Table 2. All dikes have low SiO_2 and K_2O contents but Al_2O_3 and MgO contents vary significantly (Fig. 4). The Eagle Rock dike is generally basanitic in composition. Major element compositional differences between the Eagle Rock dike and Little Eagle Rock dike may result from internal dike compositional variations (Table 2). The mineralogy of the dikes also vary widely and are reflected in substantially different hand sample descriptions

TABLE 1. Table showing sample identifiers, ages, compositions, and locations of the Eagle Rock and Buena Vista dikes.

Sample ID	Age (ka)	Composition	Latitude	Longitude
Eagle Rock dike	23.58 ± 0.06	Basanite	36.6654	-104.4934
Little Eagle Rock dike	21.36 ± 0.06	Phonolite	36.6535	-104.4954
Buena Vista	$14.61 \pm 0.04^*$	Basanite	36.8222	-105.2030

*age from Petronis et al., 2015

TABLE 2. Major element and isotope ratios of Eagle Rock and Buena Vista dike whole rocks.

Sample ID	Eagle Rock dike 80SM25*	Little Eagle Rock dike 81SM28*	Colmor dike 81SM14*	Buena Vista dike	Buena Vista dike #2
<i>XRF major element oxides</i>					
SiO ₂	43	43.3	43.2		
TiO ₂	2.05	1.72	2.48		
Al ₂ O ₃	17.10	11.00	16.80		
Fe ₂ O ₃	5.81	2.70	6.67		
FeO	6.02	8.64	5.88		
MnO	0.16	--	0.15		
MgO	4.95	14.50	5.58		
CaO	10.80	11.80	9.15		
Na ₂ O	4.02	2.59	3.26		
K ₂ O	0.81	1	1.14		
P ₂ O ₅	0.35	0.69	0.52		
Total	100	100	99		
⁸⁷ Sr/ ⁸⁶ Sr	0.705082±0.000010			0.703567±0.000013	0.703720±0.000013
¹⁴³ Nd/ ¹⁴⁴ Nd	0.512662±0.000005			0.512737±0.000013	0.512731±0.000004
²⁰⁶ Pb/ ²⁰⁴ Pb	18.555±0.001			17.808±0.001	17.742±0.001
²⁰⁷ Pb/ ²⁰⁴ Pb	15.551±0.001			15.471±0.001	15.464±0.001
²⁰⁸ Pb/ ²⁰⁴ Pb	38.451±0.002			37.645±0.002	37.596±.002

* Data from Scott et al., 1990. Whole rocks were generated from hand-picked gravels. Isotope ratios are not age corrected. Strontium isotopes were analyzed using TIMS and Nd and Pb were analyzed using MC-ICP-MS at NMSU. NBS987 Sr standard results were 0.710293 (n=37) with 0.000033 SD, JNdi-1 results were 0.512093 (n=44) with 0.000008 SD; and NBS981 results were ²⁰⁶Pb/²⁰⁴Pb=16.929 (n=59) with a 0.003 SD, ²⁰⁷Pb/²⁰⁴Pb=15.482 (n=59) with a 0.003 SD, ²⁰⁸Pb/²⁰⁴Pb=36.668 (n=59) with a 0.010 SD for the six months surrounding the actual period of analyses. NBS987 analyzed with the samples was ⁸⁷Sr/⁸⁶Sr= 0.710281, n=2. Similarly, JNdi-1 Nd standard was ¹⁴³Nd/¹⁴⁴Nd: 0.512093, n=2 and ¹⁴⁵Nd/¹⁴⁴Nd: 0.348406, n=2. NBS981 Pb standard ratios were ²⁰⁶Pb/²⁰⁴Pb: 16.931, n=2, ²⁰⁷Pb/²⁰⁴Pb: 15.485, n=2, and ²⁰⁸Pb/²⁰⁴Pb: 36.677, n=2.

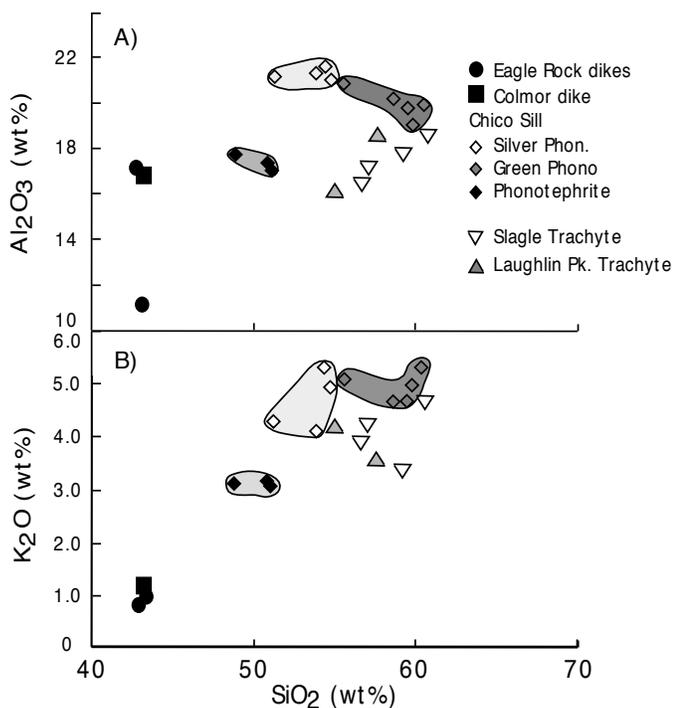


FIGURE 4. Diagrams illustrating major element variations of the Eagle Rock, Little Eagle Rock, and Colmor dikes compared to major element compositions of alkalic rock of the Chico Sill complex. **A)** Al₂O₃ contents vary significantly likely due internal, local compositional variations. **B)** All dikes have lower SiO₂ and K₂O contents and basanitic compositions.

(e.g., Scott et al., 1990) even though parts of the dikes may look similar in outcrop. The Colmor dike, located south of the Eagle Rock dike, has a similar major element composition as that of the Eagle Rock dike (Scott et al., 1990).

In addition to the Eagle Rock dike, samples of the Buena Vista dikes were also analyzed for Sr, Nd, and Pb isotopes. The Buena Vista dikes retain less radiogenic ⁸⁷Sr/⁸⁶Sr ratios but more radiogenic ¹⁴³Nd/¹⁴⁴Nd ratios compared to the Eagle Rock dike (Fig. 5A). The Buena Vista dikes retain less radiogenic ²⁰⁶Pb/²⁰⁴Pb and ²⁰⁷Pb/²⁰⁴Pb ratios (Fig. 5B). These ratios are different than those of the Eagle Rock dike suggesting very different magmatic sources for these dike-related magmas.

DISCUSSION

Temporal Relationships to Other Dikes and Magmatic Centers

Hornblende ages of the Eagle Rock and Little Eagle Rock dikes provide insight into the timing of emplacement and links to other regional dikes and magmatic centers of northern and northeastern New Mexico. The new ⁴⁰Ar/³⁹Ar age of the Eagle Rock dike of 23.58±0.06 Ma is indistinguishable, albeit more precise, than the previously determined K/Ar age of 24.16±1.01 Ma (Scott et al., 1990). The emplacement age of the Little Eagle Rock dike is 21.36±0.06 Ma. No previous age existed for this dike. Despite the close proximity of these dikes and the similar mineralogies and textures of the dated samples—differ-

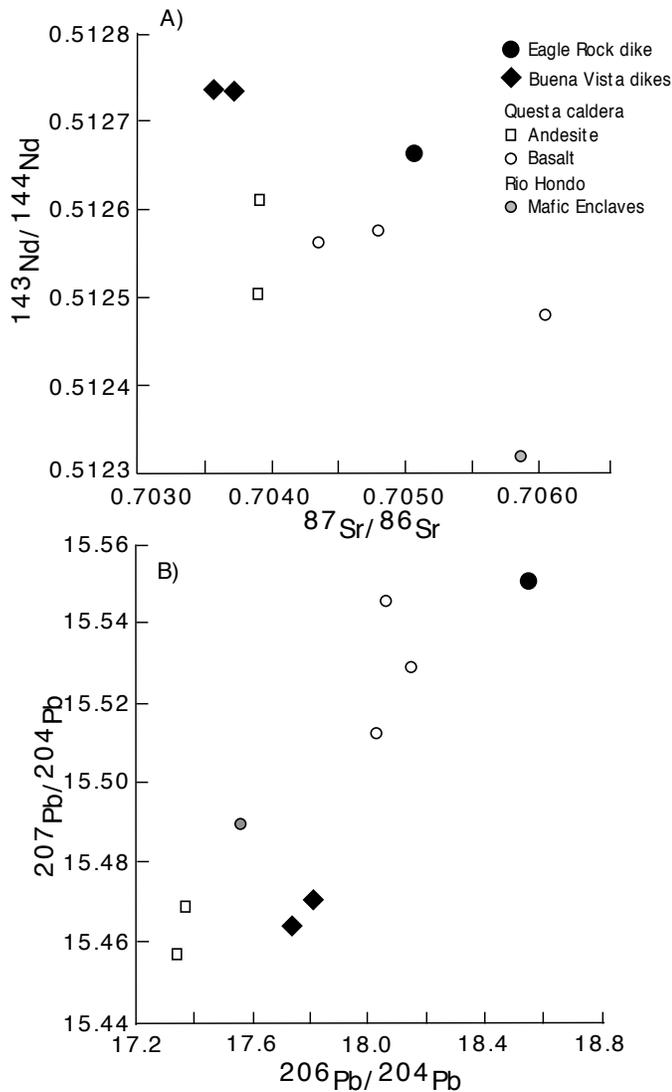


FIGURE 5. Diagram showing isotope variations of the Eagle Rock and Buena Vista dikes in relation to mafic rocks associated with Questa caldera. **A)** The Eagle Rock dike has more radiogenic $^{87}\text{Sr}/^{86}\text{Sr}$ and less radiogenic $^{143}\text{Nd}/^{144}\text{Nd}$ compared to the Buena Vista dikes. Both dikes have more radiogenic $^{143}\text{Nd}/^{144}\text{Nd}$ than mafic rocks associated with Questa caldera. **B)** The Eagle Rock and Buena Vista dikes have more radiogenic $^{206}\text{Pb}/^{204}\text{Pb}$ ratios at a given $^{207}\text{Pb}/^{204}\text{Pb}$ ratio. The Eagle Rock dike however lies at the more radiogenic end of the trend defined by mafic rocks at Questa caldera.

ences between composition and textures are apparent between the two dikes for undated samples—, the new ages indicate that these two dikes were emplaced during two different emplacement episodes spanning ~ 2.2 My, rather than a single emplacement event. Dating of other local dikes might indicate an even more extensive duration of magma emplacement.

Only a few published ages for dikes in northeastern New Mexico exist, although several dozen appear on various maps of differing scales (e.g., Scholle, 2003). A prominent dike is exposed along the Colorado-New Mexico border near Trinchera Pass for which Stroud (1997) reports an age of 19.53 ± 0.20 Ma (Figs. 1, 3). This dike is oriented SW to NE ($\sim 255^\circ$) in contrast to those (i.e., the Eagle Rock dike) south of Raton oriented E-W or NW-SE. The Trinchera Pass dike is thus only radial to the

Questa caldera (Fig. 1). A NW-SE oriented dike exposed just west of Raton (here referred to the Raton dike) yields a $^{40}\text{Ar}/^{39}\text{Ar}$ age of 15.47 ± 0.39 Ma (Stroud, 1997). Two subparallel dikes are mapped just west of Raton (Wood et al., 1953); it is not clear which of the two dikes was dated by Stroud (1997). A dike located south of the Eagle Rock dike in the Colmor Quadrangle yields an imprecise K/Ar age as young as 15.6 ± 0.7 Ma (Scott et al., 1990). The orientation of this dike is \sim E-W and is neither radial to either the Questa caldera nor the Chico Sill complex.

With respect to timing of emplacement, the Eagle Rock, Little Eagle Rock, Trinchera Pass, and Raton dikes most closely match the timing of postcaldera pluton emplacement at the Questa caldera (Fig. 3). The Eagle Rock dike was emplaced at 23.58 ± 0.06 Ma, which is indistinguishable to pluton emplacement and mineralization along the southern margin of the Questa caldera (South Fork Au Porphyry, Deep Granite, and Silver Tlp Ag Porphyry of Gaynor et al., 2019). The 19.53 ± 0.20 Ma Trinchera Pass dike (Stroud, 1997) is only marginally younger than the Lucero Peak pluton, emplaced at 19.88 ± 0.02 Ma (Gaynor et al., 2019). The Raton dike was emplaced at 15.47 ± 0.39 Ma (Stroud, 1997), which is indistinguishable to Late Stage dikes at the Questa caldera (Gaynor et al., 2019). No exposed plutons at Questa match the age of the Little Eagle Rock dike (i.e., 21.36 ± 0.06 Ma). However, given the abundant postcaldera magmatism at Questa, we suspect that the absence of 21–22 Ma intrusions at Questa is most likely related to incomplete exposure of the subvolcanic batholith rather than a true cessation of magmatism at this time.

Although the age of the Little Eagle Rock dike is indistinguishable to the K/Ar age of the sills at Tinaja Mountain (20.29 ± 0.90 Ma), this is somewhat an artifact of the low-precision capabilities of the K/Ar method. Furthermore, Scott et al. (1990) indicated that some dikes proximal to the Chino Sill complex cross cut the sills, indicating the dikes are post-sill-emplacement and thus were not a source of the dikes.

Based on the geochronology presented here, the Buena Vista dikes exposed north of Las Vegas, New Mexico are unlikely related to the Eagle Rock, Little Eagle Rock, Chino Sill complex, or Questa caldera. These dikes were emplaced between 14.2 and 14.7 Ma (Petronis et al., 2015) and are younger than those of this study, as well as the published ages for the Questa caldera (Zimmerer and McIntosh, 2012; Gaynor et al., 2019) and the rocks of the Chino Sill complex (Scott et al., 1990). Likewise, the dikes are oriented NNE-SSW, nearly perpendicular to WNW-ESE Eagle Rock dikes, and not radial to either the Questa caldera or Chino Sill complex.

Chemical Relationships to Other Dikes and Magmatic Centers

Major element compositions of the Buena Vista and nearby dikes are unavailable, but are likely to vary along with gabbroic to anorthositic compositional changes (Lindline et al., 2015) of the dikes themselves. In contrast, major element compositions of the Eagle Rock, Little Eagle Rock, and Colmor dikes are available (Scott et al., 1990) and mostly lie at lower SiO_2 and K_2O contents than Chico Sill complex alkalic rocks (Fig. 4). As

such, Eagle Rock dike major element compositions are not seen in alkalic rocks from the Chico Sill complex but may reflect potential parental magma compositions to rocks of the Chico Sill complex as they do lie along trends such as K_2O and SiO_2 .

In contrast to physical similarities with dikes emplaced to the south (Fig. 2), the Eagle Rock dike is isotopically different than the Buena Vista dikes. The Buena Vista dikes have unradiogenic $^{87}Sr/^{86}Sr$ and radiogenic $^{143}Nd/^{144}Nd$ ratios (Fig. 5A) while the Eagle Rock dike retains more radiogenic $^{87}Sr/^{86}Sr$ and less radiogenic $^{143}Nd/^{144}Nd$ ratios. The Eagle Rock dike also has more radiogenic Pb isotope ratios compared to the Buena Vista dikes (Fig. 5B). Similar to the geochronology, the geochemical differences indicate that dikes emplaced in the Las Vegas, New Mexico area are not generated from sources with the same isotopic signatures as those involved with the Eagle Rock dikes.

The isotopic signatures of the Eagle Rock dike are also different than mafic rocks at Questa caldera (Fig. 5A, B). Although Questa mafic rocks share similar $^{87}Sr/^{86}Sr$ ratios, the Eagle Rock dike has more radiogenic $^{143}Nd/^{144}Nd$ and $^{206}Pb/^{204}Pb$. These isotopic variations suggest that the sources that generated the Eagle Rock dike are either 1) different than those that generated the exposed intrusion at Questa caldera, or 2) that the isotopic signatures of these dikes were modified during transport. Chemically linking the Eagle Rock dike, and other dikes exposed in the region, to the Chico Sill alkalic rocks is not possible because isotope studies of Chico Sill complex rocks have not been undertaken, thus preventing direct comparisons.

CONCLUSIONS WITH EMPHASIS ON DIRECTIONS FOR FUTURE WORK

Preliminary geochronology and geochemistry of a small suite of dikes exposed in northeastern New Mexico, when combined with the limited published data for related intrusions, is beginning to shed light on mid-Tertiary magmatism in the region. Temporally, dikes in the region share similarities to the youngest pulses of magmatism associated with the Questa caldera but some differences in isotope characteristics exist. If indeed connected to the Questa caldera, these isotopic differences may be related to changes in the source during evolution of system where the dikes tapped a different part (e.g., deeper, more mafic) of the magmatic system not represented in the upper crustal intrusions now exposed, or changes in isotopic composition associated with distal magma transport. In contrast, some of the dikes in this region of New Mexico may be related to the typically older, local alkalic rocks of the Chico Sill complex but are much less evolved than the alkalic compositions exposed in the region. Dikes emplaced to the south in the Las Vegas area are younger, have different isotopic characteristics, and thus, are not related to exposed dikes in this part of northeastern New Mexico.

To fully assess the relationship between the dikes of northeastern New Mexico to that of other mid-Tertiary magmatic systems and the tectonic history of the region, we propose additional geochronology and geochemistry studies, combined

with field and anisotropy of magnetic susceptibility methods to determine flow directions. Geochronology should focus on developing a more comprehensive suite of ages for both the dikes and the little studied Chico Sill complex. Scott et al. (1990) indicated as many as 20 dikes throughout the region south of Raton. Likewise, the state geologic map indicates numerous E-W and SE-NW oriented dikes located west of the dikes exposed south of Raton and immediately east of the Questa caldera margin, within the Sangre de Cristo Mountains. Only imprecise K/Ar ages exist for the Chico Sill complex. Similar to the insufficient geochronology for mid-Tertiary intrusions of the region, very limited geochemistry exists for the same suite of rocks. Additional field-oriented studies should focus on establishing the total number of dikes in northeastern New Mexico and their orientation to assess whether they are radial to other larger magmatic centers. Some landforms suggestive of exposed dikes (i.e., topographically resistant linear ridges) are visible on Google Earth, but do not appear as dikes on regional maps. Likewise, flow directions could be determined by exploring the lineation of minerals and grooves/flow features along dike walls and detailed anisotropy of magnetic susceptibility to determine flow directions. Overall, dikes in northeastern New Mexico are poorly studied but have affinities to Questa caldera and local alkalic rocks. The lack of sufficient geochronological and geochemical data limit connecting their origins to other local or regional magmatic sources.

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Supplemental data can be found at <http://nmgs.nmt.edu/repository/index.cfm?rid=2019004>