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EPISYENITES IN THE SEVILLETA NATIONAL WILDLIFE REFUGE, SOCORRO COUNTY, NEW MEXICO—PRELIMINARY RESULTS

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Abstract—Brick-red episyenites are found in an outlier of Proterozoic-age rocks on the Sevilleta National Wildlife Refuge in central New Mexico. The term *episyenite* is used to describe altered rocks that were desilicified and metasomatized by alkali-rich fluids. Similar episyenites are found elsewhere in New Mexico and southern Colorado and are thought to be part of a Cambrian-Ordovician magmatic event that is documented throughout southern Colorado and New Mexico. Unlike episyenites in the Caballo and Burro Mountains, which contains moderate to high concentrations of rare earth elements (REE), uranium, and thorium; the episyenites in the Sevilleta National Wildlife Refuge have no economic potential.

INTRODUCTION

Recent geologic mapping by New Mexico Bureau of Geology and Mineral Resources (NMBGMR) revealed brick-red, K-feldspar-rich rocks, called episyenites, in an outlier of Proterozoic-age rocks on the Sevilleta National Wildlife Refuge in central New Mexico (Fig. 1; Allen et al., 2013). Because some of these complexes are known for potential economic deposits of rare earth elements (REE), uranium (U), thorium (Th), niobium (Nb), zirconium (Zr), hafnium (Hf), gallium (Ga), and other elements (Long et al., 2010; McLemore, 2015), the author mapped and sampled these unusual metasomatic rocks to compare to episyenites elsewhere in New Mexico, with the goals of better understanding their tectonic setting and origin and to evaluate their economic potential. Similar episyenites are found elsewhere in New Mexico and southern Colorado and are thought to be part of a Cambrian-Ordovician magmatic event that is documented throughout southern Colorado and New Mexico (Fig. 1; McMillan and McLemore, 2004; Riggins et al., 2014). This Cambrian-Ordovician magmatic event is characterized by the intrusion of carbonatites, syenites, monzonites, alkaline granites, and mafic dikes, and is associated with K-metasomatism (i.e., fenites and episyenites) and REE-Th-U mineral deposition. This report presents preliminary results and interpretations as mapping, geochemical, and geochronological studies are ongoing by the author.

DEFINITION OF EPISYENITES

The term *episyenite* is used to describe altered rocks that were desilicified and metasomatized by alkali-rich fluids (Leroy, 1978; Recio et al., 1997). The metasomatic rocks in several areas in New Mexico, including the Caballo, Burro, and Zuni Mountains and Lobo Hill were erroneously called syenites and alkali granites (McMillan and McLemore, 2004), but are actually metasomatic in origin and not primary igneous rocks (McLemore, 2013; Riggins, 2014; Riggins et al., 2014). Elsewhere

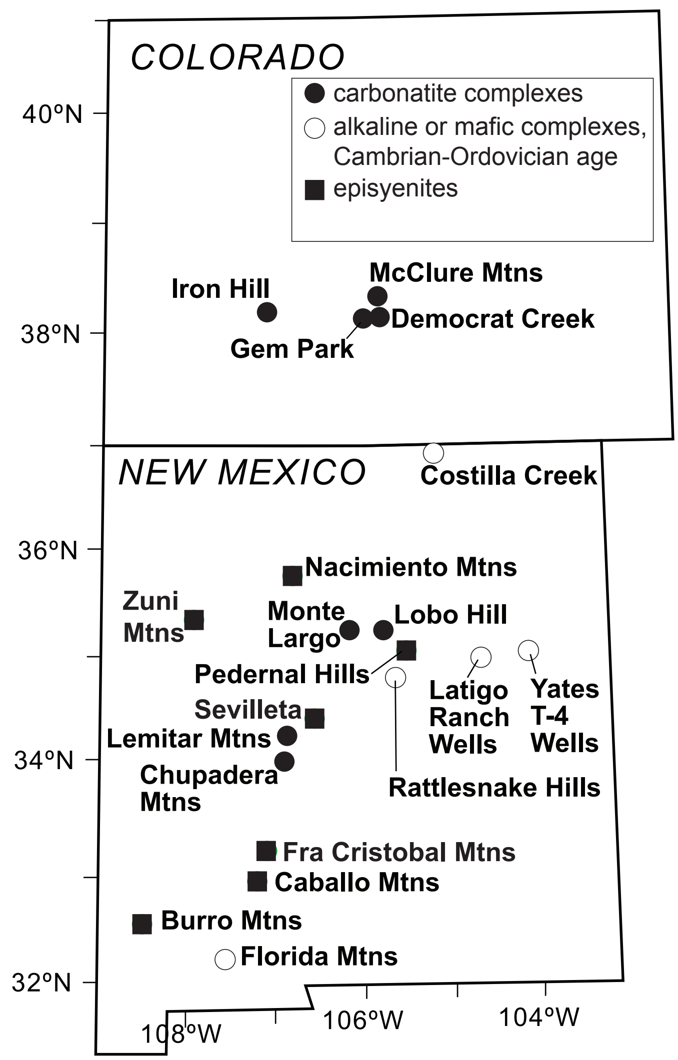

FIGURE 1. Cambrian-Ordovician carbonatite, alkaline and mafic igneous rocks, and episyenites in New Mexico and Colorado.

in the world, these alkali-rich metasomatic rocks are associated with uranium and thorium deposits (Costi et al., 2002; Condomines et al., 2007; Cuney et al., 2012), gold deposits (López-Moro et al., 2013) and tin-tungsten deposits (Charoy and Pollard, 1989; Costi et al., 2002; Borges et al., 2009), but unmineralized episyenites are found as well (Petersson and Eliasson, 1997; Recio et al., 1997; Hecht et al., 1999). Episyenites are similar to altered rocks formed by fenitization and would be called fenites by some geologists. Fenitization is the alkali-metasomatism associated with carbonatites or alkaline igneous activity (Le Bas, 2008). However, we are reluctant to use the term fenite for these rocks studied here because there is no definitive spatial association with carbonatite or alkaline igneous rocks.

METHODOLOGY

A detailed geologic map was compiled in ArcMap using USGS topographic maps as the map base and by detailed field mapping at a scale of approximately 1:6,000 (Fig. 2). A handheld GPS unit was used with the current topography loaded in the unit to more accurately map the episyenites. Selected samples of the Proterozoic host rocks and episyenites were collected and analyzed by X-ray fluorescence (XRF) spectroscopy and inductively coupled plasma spectroscopy (ICP-OES and ICP-MS) by Activation Laboratories in 2012 and 2015, methods for which can be found at www.actlabs.com. Locations of samples and whole-rock geochemical analyses are in Table 1.

DESCRIPTION OF PROTEROZOIC ROCKS AND EPISYENITES IN THE SEVILLETA NATIONAL WILDLIFE REFUGE

An outlier of Proterozoic rocks in the Sevilleta National Wildlife Refuge was mapped by Wilpolt et al. (1946), Myers et al. (1986), and Allen et al. (2013). Structural relationships are complex as rocks have been deformed by Proterozoic, Paleozoic, Laramide, and mid-Tertiary tectonic events.

Proterozoic granite

The predominant rock in the Proterozoic outlier in the Sevilleta National Wildlife Refuge (Fig. 2) is a medium to coarse-grained, reddish gray to pinkish gray, nonfoliated to slightly foliated granite, consisting of euhedral plagioclase (30-40%), quartz (25-35%), and K-feldspar (25-35%), with trace amounts (<2%) of biotite, muscovite, and magnetite. Small (<15 cm) xenoliths of gray muscovite schist and black amphibolite are found locally within the granite. The granite forms rounded knobs to steep cliff faces in the area. Pale pink to pale red aplite dikes and red and white, quartz-feldspar-biotite pegmatites and white quartz veins intruded the granite and are <1 m wide and as much as several hundred meters long. Some of these thin (<0.5 m) quartz veins contain minor barite-fluorite (±malachite) veins. Iron and manganese oxide breccias cut the Proterozoic rocks locally. Many of the small faults cutting the Proterozoic granite are filled, in part, by manganese-oxide cemented breccia.

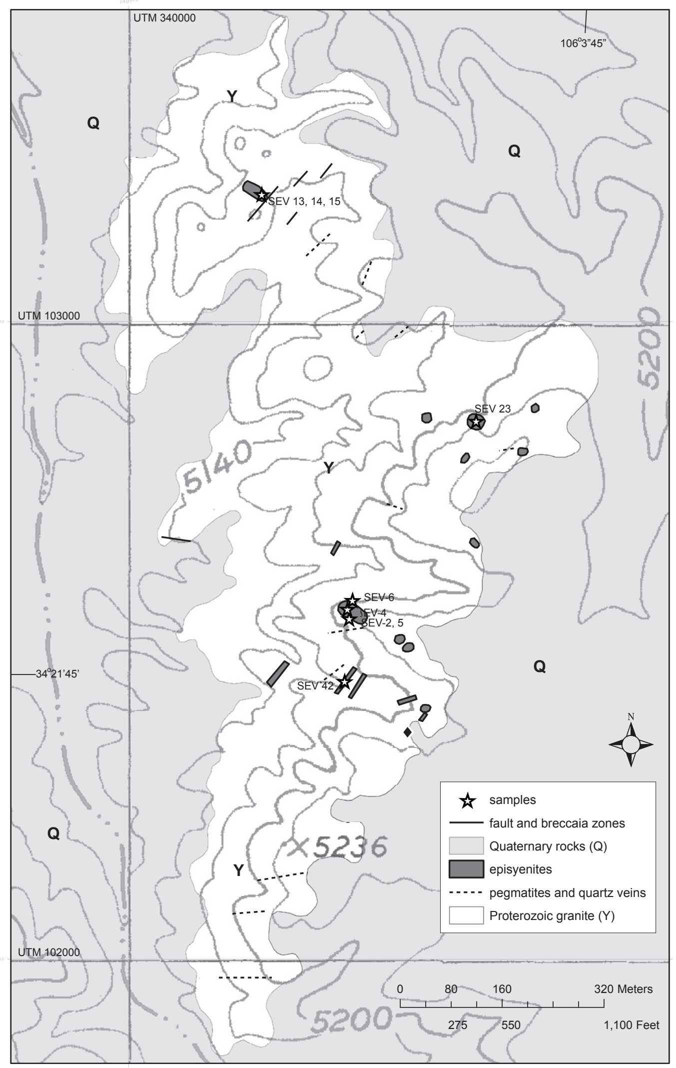

FIGURE 2. Geologic map of the Proterozoic outlier on the Sevilleta National Wildlife Refuge. Detailed mapping of the Proterozoic outlier by V.T. McLemore and D. Love. Modified from Allen et al. (2013), Becker SW topographic quadrangle.

Larger xenoliths and breccias of amphibolite and granitic gneiss (0.5- to 1-m diameter) are found in the granite in the southern-most portion of the Proterozoic outlier. The amphibolite xenoliths are speckled black and white to greenish black and consist of hornblende, epidote, biotite, quartz, and plagioclase with some magnetite. These xenoliths are similar to amphibolites found in Los Pinos Mountains.

Episyenites

Numerous radioactive, pink to red, small stock-like to flat-lying tabular bodies (<300 m long), near-vertical pipes (<30 m in diameter), and dike-like bodies (<2 m wide, 400 m long) of episyenites are mapped in the exposed outlier (Fig. 2). Some areas have numerous small episyenite bodies in a geographically restricted area, suggesting fracture or fault control. The contacts between the episyenite bodies and the host rocks vary from location to location, from very sharp to distinctly gradational, crosscutting the foliation of the host rock (Fig. 3). At

FIGURE 3. Sharp contact between brick red episyenite (upper right) and pink granite (lower left) on the Sevilleta National Wildlife Refuge.

one locality, a quartz-feldspar-muscovite pegmatite dike grades into coarse-grained, K-feldspar-rich episyenite with no quartz. The episyenites contain 20-80% alkali-feldspar, 20-40% plagioclase, 0-10% quartz, 1-5% opaque minerals (predominantly iron oxides), trace-5% biotite (partially to completely altered to chlorite), and trace amounts of apatite, sericite, calcite, and carbonate. Some alkali-feldspar crystals are more than a centimeter long. Plagioclase is commonly altered to carbonate, hematite, and clay. Iron oxides occur as fine-grained red-brown disseminations within the feldspars, and as small red cubes and octahedrons that were probably once magnetite. The rocks are almost devoid of ferromagnesian minerals.

WHOLE-ROCK GEOCHEMISTRY

Selected samples of granite and episyenites in the Sevilleta National Wildlife Refuge were collected and analyzed for major and trace elements (Table 1). In addition, published chemical analyses of the Priest granite, Los Pinos Granite, Sepultura granite and episyenites from the Caballo Mountains (Condie and Budding, 1979; Riggins, 2014) are included for comparison to the Sevilleta samples. The Sepultura granite is south of the Los Pinos Granite and is similar in texture and composition to the Los Pinos Granite (Condie and Budding, 1979). The Priest granite was included because it is found north of the Los Pinos Granite and could be a potential correlation to the Sevilleta granites, although the Priest granite has different texture and composition compared to the Los Pinos Granite.

The Sevilleta, Los Pinos, and Priest granites are metaluminous to peraluminous (according to Shand, 1943; Frost et al., 2001), alkali-calcic (Frost et al., 2001) and syn-collisional to within-plate granites (according to Pearce et al., 1984); they plot in the active continental margins zone, according to Schandl and Gorton (2002). The Sevilleta granites have similar geochemical compositions as the Los Pinos Granite (Table 1; Figs. 4, 5), although the REE patterns of the Sevilleta granites are closer to that of the Priest granite (Fig. 6).

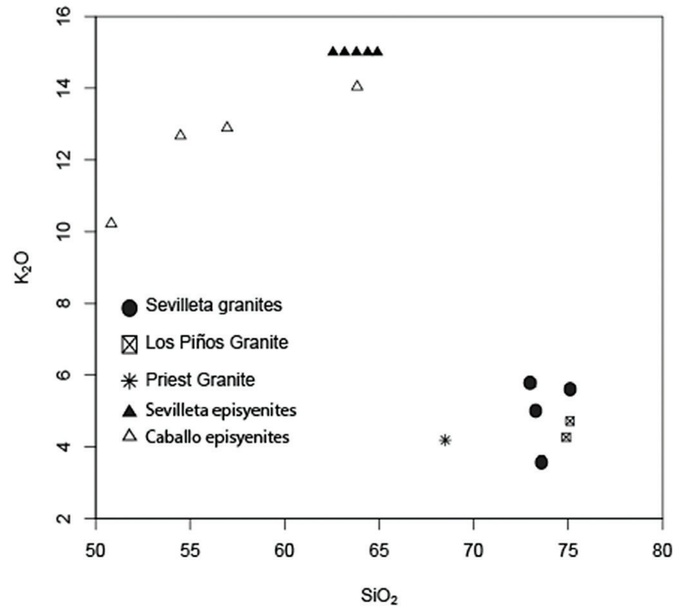

FIGURE 4. SiO_2 verse K_2O plot of the granites and episyenites. Note the high K_2O of the episyenites and the similarity in composition between the Sevilleta and Los Pinos granites. Chemical analyses are in Table 1. Chemical analyses of Caballo episyenites are from Riggins (2014).

The Sevilleta episyenites are high in K_2O and low in SiO_2 (Fig. 4), with slightly enriched light REE patterns (Fig. 7). The Sevilleta episyenites are similar in composition to episyenites found in the Caballo, Burro, and Zuni Mountains and at Lobo Hill (Figs. 4, 7; McLemore, 1986; McLemore and McKee, 1988, 1989; McLemore et al., 1999; McMillan and McLemore, 2004; Riggins, 2014; Riggins et al., 2014).

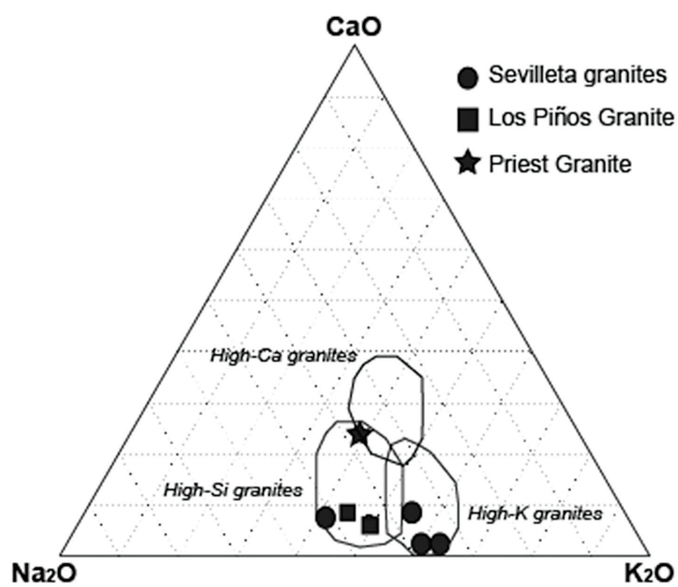

FIGURE 5. Na_2O-CaO-K_2O plot of the granites. Note the the similarity in composition between the Sevilleta and Los Pinos granites. Chemical analyses are in Table 1.

TABLE 1. Chemical analyses of Sevilleta granites and episyenites and Priest, Los Pinos, and Sepultura granites (from Condie and Budding, 1979). Major oxides are in percent (%) and trace elements are in parts per million (ppm). Latitude and longitude are in NAD27. Na=not available. REE=rare earth elements. Fe_2O_3T=Total iron calculated as Fe_2O_3.

Sample	SEV-2	SEV-4	SEV 13	SEV 23	SEV 42	SEV-5	SEV-6	SEV 14	SEV 15	Priest	Los Pinos	Sepultura
Lithology	episyenite	episyenite	episyenite	episyenite	episyenite	granite	granite	granite	granite	granite	granite	granite
latitude	34.353718	34.3536	34.35956	34.356443	34.352715	34.3536	34.35382	34.35956	34.35956	na	na	na
longitude	106.7359	106.7359	106.738	106.7338	106.736	106.7359	106.7358	106.7375	106.7375	na	na	na
SiO_2	63.8	64.4	62.56	64.91	63.17	75.2	73.7	73.35	73.2	68.5	74.9	75.1
Al_2O_3	18	18.15	18.3	17.55	18.22	13.05	14.65	14.17	13.96	15.4	12	13.4
TiO_2	0.03	0.17	0.25	0.23	0.36	0.15	0.04	0.2	0.2	0.39	0.24	0.22
Fe_2O_3T	0.28	0.27	1.6	0.6	1.05	1.32	0.91	1.7	1.52	2.92	2.75	1.2
CaO	0.16	0.15	0.22	0.21	0.35	0.25	0.68	0.74	0.25	2.58	0.84	0.64
MgO	<0.01	<0.01	0.63	0.05	0.12	0.45	0.1	0.45	0.61	1.6	0.08	0.07
MnO	<0.01	<0.01	0.03	0.02	0.01	0.02	0.02	0.05	0.02	na	na	na
Na_2O	0.28	0.24	0.3	0.28	0.34	2.93	4.48	3.2	3.63	4	4.37	4.19
K_2O	>15.0	>15.0	>15.0	>15.0	>15.0	5.58	3.62	5.04	5.77	4.19	4.27	4.72
P_2O_5	0.1	0.09	0.12	0.11	0.1	0.09	0.06	0.11	0.1	na	na	na
LOI	0.22	0.1	0.52	0.18	0.47	0.76	0.58	0.77	0.66	na	na	na
Total	98.57	99.34	100.15	99.78	100.4	99.86	98.85	99.86	99.92	99.58	99.45	99.54
Ba	380	709	885	669	539	310	13.6	475	557	597	1035	631
Cr	<10	10	10	10	10	10	<10	10	20	22	2	4
Cs	19.8	6.86	6.33	9.36	14.3	7.71	15.55	13.8	7.01	8.8	2.6	3
Ga	17.8	16.3	19.7	19	18.8	16.1	26.1	20.6	15.9	na	na	na
Hf	1.1	4.5	6.4	5.3	9	3.7	1.4	4.6	4.4	na	na	na
Nb	10.2	23.6	25.2	24.2	23.2	20.9	45.3	29.5	26.8	na	na	na
Rb	697	622	612	666	681	283	306	356	307	191	135	223
Sn	1	2	2	1	3	2	4	3	2	na	na	na
Sr	24.5	51.3	56.3	53.1	55.1	41.4	12.6	79.6	53.7	342	63	24
Ta	6.3	3.3	3.4	3.5	3.1	3.8	8	3	3.3	na	na	na
Th	6.51	22.2	23.5	20.9	17.55	23.9	8.73	18.45	19.65	na	na	na
U	3.19	4.07	3.46	4.43	2.34	2.26	4.22	3.1	1.95	na	na	na
V	<5	6	14	16	14	14	<5	19	16	na	na	na
W	56	71	2	1	2	84	94	2	2	na	na	na
Y	38.4	25.9	27.9	28.2	29.6	25.6	20.1	22.9	16.2	na	na	na
Zr	12	141	228	183	363	109	15	159	139	131	na	na
Co	11	16	2	1	1	15	15	3	2	na	na	na
Cu	6	7	8	38	8	16	5	33	4	na	na	na
Li	<10	<10	10	<10	<10	10	50	20	10	na	na	na
Mo	<1	<1	<1	<1	<1	<1	<1	<1	<1	na	na	na
Ni	<1	1	7	<1	<1	4	<1	4	6	na	na	na
Pb	26	27	22	65	21	19	20	28	20	na	na	na
Sc	1	4	3	4	5	5	9	9	6	na	na	na
Zn	<2	<2	12	10	6	18	12	34	15	na	na	na
As	0.4	0.5	2.7	1.4	0.7	1.1	0.3	0.6	0.7	na	na	na
Bi	0.08	0.21	0.15	10.05	0.26	0.25	0.52	4.85	0.17	na	na	na
Sb	0.14	0.16	0.23	0.51	0.13	0.15	0.1	0.08	0.11	na	na	na
Sc			0.8	1.7	0.6			1	0.9	na	na	na
Se	0.4	0.3	0.5	0.5	0.4	0.4	0.4	0.6	0.4	na	na	na
Te	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.1	0.01	na	na	na
Tl	0.1	0.11	0.04	0.07	0.07	0.06	0.09	0.07	0.03	na	na	na
La	5	10.6	11.9	45.6	32.5	17.6	5.7	32.5	23.9	44	70	52
Ce	9.6	19	24.7	86.6	63.5	46.1	12.5	65.9	56.8	98	170	141
Pr	1.35	2.45	3.03	10.2	7.31	4.52	1.59	7.5	6.02	na	na	na
Nd	5.7	9.2	11.8	35.8	25.5	16.7	6.2	27.3	21.3	na	na	na
Sm	2.41	2.27	3.1	7.59	5.19	4.24	2.48	5.62	4.97	6.7	21	18
Eu	0.3	0.37	0.48	0.74	0.45	0.45	0.2	0.67	0.57	0.78	3.1	2.4
Gd	3.22	2.2	3.32	5.85	4.59	3.59	2.34	4.53	3.58	na	na	na
Tb	0.78	0.52	0.65	0.86	0.82	0.63	0.57	0.73	0.57	0.68	4	2.8
Dy	5.28	3.59	4.23	4.39	4.94	4.07	3.43	3.97	2.91	na	na	na
Ho	1.16	0.83	0.95	0.94	1.01	0.92	0.67	0.81	0.6	na	na	na
Er	3.64	2.68	2.96	2.91	2.9	2.79	2.3	2.27	1.7	na	na	na
Tm	0.48	0.48	0.47	0.48	0.39	0.39	0.37	0.33	0.26	na	na	na
Yb	3.38	3.21	3.64	3.59	2.94	3.09	3.59	2.4	2.12	1.6	12	11
Lu	0.41	0.49	0.56	0.58	0.41	0.45	0.48	0.38	0.33	0.29	1.9	1.8
TREE	42.71	57.89	71.79	206.13	152.45	105.54	42.42	154.91	125.63	152.05	282	229

TABLE 1. Continued.

Sample	REE113	REE114	REE115	REE116
Lithology	episyenite	episyenite	episyenite	episyenite
latitude	33.0742213	33.0741465	33.07345	33.07345
longitude	-107.228879	-107.228523	-107.22697	-107.22697
SiO_2	56.96	63.84	54.49	50.83
Al_2O_3	17.92	15.94	15.25	14.59
TiO_2	0.19	0.06	0.28	0.41
Fe_2O_3T	6.73	3.73	5.65	7.5
CaO	0.24	1.08	5.65	6.57
MgO	3.16	0.05	0.7	2.3
MnO	0.035	0.045	0.049	0.107
Na_2O	< 0.01	0.07	0.1	< 0.01
K_2O	12.89	14.04	12.67	10.22
P_2O_5	0.007	0.03	0.13	0.013
LOI	2.27	1.11	5.07	6.91
Total	100.5	99.995	100.039	99.63
Ba	600	397	375	491
Cr	< 20	< 20	< 20	< 20
Cs	0.6	0.7	0.7	< 0.5
Ga	26	9	14	22
Hf	5.6	3.5	5.8	15.6
Nb	3	2	10	27
Rb	370	362	323	317
Sn	1	< 1	4	3
Sr	11	11	31	39
Ta	0.8	1	1.4	1.8
Th	33.6	39.9	43.9	26
U	4.4	3.5	3.9	205
V	39	18	59	68
W				
Y	24	45	24	642
Zr	211	89	193	4730
Co				
Cu	< 10	< 10	< 10	< 10
Li				
Mo				
Ni				
Pb	< 5	< 5	< 5	16
Sc				
Zn	< 30	< 30	< 30	< 30
As	< 5	< 5	< 5	5
Bi	< 0.4	< 0.4	< 0.4	2.6
Sb	< 0.5	< 0.5	< 0.5	< 0.5
Sc				
Se				
Te				
Tl				
La	68.4	2.8	22.5	23.8
Ce	170	8.7	49.6	93.9
Pr	14.3	1.19	5.35	10.6
Nd	50.8	5.6	18.2	49.5
Sm	8.1	3.1	3.8	18.9
Eu	1.13	0.72	0.6	4.11
Gd	6.5	4.2	3.5	29.5
Tb	0.8	1.1	0.6	7.7
Dy	4	7.6	3.6	69.9
Ho	0.7	1.6	0.7	19.8
Er	2.2	4.7	2.6	77.5
Tm	0.34	0.71	0.47	15.2
Yb	2.4	4.7	3.5	133
Lu	0.43	0.76	0.65	26.9
TREE	330.1	47.48	115.67	580.31

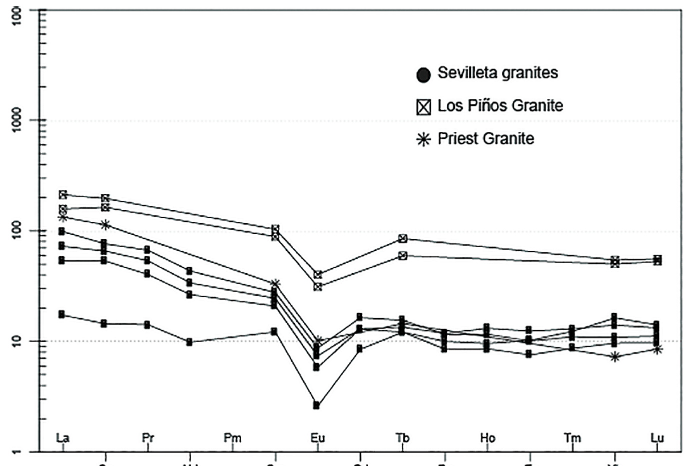

FIGURE 6. Similar sample/chondrite normalized REE patterns for the Sevilleta, Los Pinos, and Priest granites. Chondrite values from Nakamura (1974). Chemical analyses are in Table 1.

DISCUSSION AND CONCLUSIONS

Correlation of the Proterozoic Sevilleta granite

The granite in the Sevilleta National Wildlife Refuge is similar in appearance, texture, and composition to the Los Pinos Granite (Figs. 4, 5; Allen et al., 2013), which is found in the foothills of Los Pinos Mountains (Beers, 1976; Bolton, 1976; Condie and Budding, 1979; Shastri, 1993). The Los Pinos Granite is 1655-1666 Ma and was affected by a younger tectonic event at about 1420 Ma (Shastri, 1993; Karlstrom et al., 2004). More work is needed to properly correlate the granite outlier.

Origin of episyenites

Textures, high K-feldspar contents, and high K_2O concen-

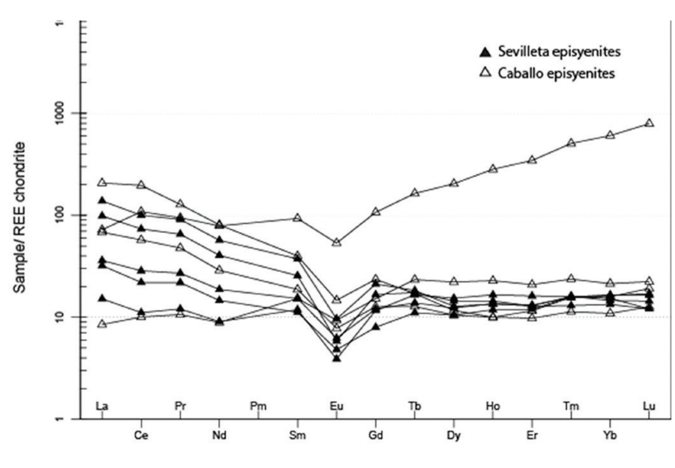

FIGURE 7. Similar sample/chondrite normalized REE patterns for the Sevilleta and Caballo episyenites. The Caballo episyenite with the heavy REE enriched pattern is indicative of potential economic heavy REE concentrations (Riggins et al., 2014), not found in the Sevilleta episyenites. Chondrite values from Nakamura (1974). Chemical analyses are in Table 1. Chemical analyses of Caballo episyenites are from Riggins (2014).

trations support a metasomatic origin of the Sevilleta episyenites. The field and mineralogical observations suggest that the Sevilleta episyenites were formed by interaction of a K-rich fluid with the granitic host rock, possibly along fault, fracture, and shear zones. The most altered rocks contain more than 15 wt.% K_2O, which is close to the composition of endmember orthoclase (15.60 wt. % K_2O; Deer et al., 1992; Riggins, 2014; Riggins et al., 2014), suggesting the most altered rocks are composed almost completely of K-feldspar. The K-rich fluid that caused metasomatism was likely silica undersaturated, resulting in dissolution and/or alteration of primary quartz, biotite and other accessory silicate phases (Cathelineau, 1986), and precipitation of secondary K-feldspar with iron-oxide inclusions. Similar observations are found in the episyenites found in the Caballo and Burro Mountains (Riggins, 2014; Riggins et al., 2014).

Carbonatites and alkaline igneous rocks are commonly enriched in sodium, potassium and REE, due to magmatic processes such as crystal fractionation and late magmatic hydrothermal activity (Sheard et al., 2012; Gysi and Williams-Jones, 2013; Walters et al., 2013). Primitive carbonatitic melts contain significant amounts of sodium and potassium that are incompatible in the crystallizing assemblage, so are fractionated into the residual melt and can then be lost to late-stage hydrothermal fluids, which causes metasomatism (LeBas, 2008). Episyenite textures, mineralogy and mineral chemistry from the Caballo and Burro Mountains suggest that these episyenites have been formed and mineralized by K- metasomatism, with the original fluids possibly derived from carbonatites or alkaline melts (Riggins, 2014; Riggins et al., 2014). Carbonatites are found in the Lemitar and Chupadera Mountains near Socorro (Fig. 1) that could have provided K-rich fluids resulting in the metasomatism in the Sevilleta National Wildlife Refuge.

Age of episyenites

None of the episyenites found in the Sevilleta National Wildlife Refuge have been dated, but are here tentatively correlated to similar episyenites found at Lobo Hill and in the Caballo, Burro and Zuni Mountains, New Mexico (McLemore, 1986, 2013; McLemore and McKee, 1988, 1989; McLemore et al., 1999; 2012; McMillan and McLemore, 2004; Riggins, 2014; Riggins et al., 2014). Field relationships, i.e., the presence of episyenite pebbles in the Cambrian-Ordovician Bliss sandstone lying unconformably on the episyenites and Proterozoic rocks in the Caballo Mountains, indicate that episyenites are older than the Bliss Formation (McLemore, 1986; Riggins, 2014). Episyenite clasts in the Bliss sandstone contain xenotime of similar chemistry to that of xenotime from episyenites in the Caballo Mountains, which suggests that REE mineralization also occurred prior to the Cambrian-Ordovician (Riggins, 2014).

One sample of the episyenite in the Burro Mountains yielded $^{40}Ar/^{39}Ar$ plateau ages of 516.4±4.5 to 533.3±5.2 Ma, which is consistent with formation during the Cambrian-Ordovician (Riggins, 2014). However, other samples from the Caballo and Burro Mountains yields complex and intriguing age results that are likely related to multiple alteration events, and therefore cannot constrain the maximum age of episyenite formation (Riggins, 2014). A monzonite associated with the episyenites at Lobo Hill has been dated as 518±5.7 Ma, suggesting that the Lobo Hill episyenite could be of a similar age (McLemore et al., 1999). Additional age dating is underway.

During Cambrian-Ordovician time, a period of alkaline and carbonatite magmatism and extension occurred in southern Colorado and New Mexico at about 500 Ma (Fig. 1; McLemore and McKee, 1988; Evans and Clemons, 1988; McLemore et al., 1999; McMillan and McLemore, 2004; Riggins et al., 2014) followed by a Paleozoic period of basin formation and uplift as part of the Ancestral Rocky Mountains (Florida uplift, Pedregosa Basin; Ross and Ross, 1986). The Cambrian-Ordovician magmatic event is characterized by the intrusion of carbonatites, syenites, monzonites, and alkaline granites and associated with episyenites, K-metasomatism (i.e., fenitization) and Th-REE-U mineral deposits. This type of magmatic and metasomatic activity is consistent with continental rift and aborted rift systems, although geologic evidence such as rift-basin sediments and geophysical signatures are lacking to support a rift during this time period in New Mexico. Recognition of widespread Cambrian-Ordovician magmatic activity in New Mexico, evidence of relatively rapid uplift and erosion in the Florida Mountains (Evans and Clemons, 1988; Clemons, 1998; Ervin, 1998), and the presence of carbonatites (Olson et al., 1967; Fenton and Faure, 1970; Armbrustmacher, 1984; McLemore, 1983, 1987; McLemore and Modreski, 1990; White-Pinilla, 1996) suggest that New Mexico and southern Colorado was not a simple passive margin during Cambrian-Ordovician time; but rather experienced sufficient extension to perturb the mantle and initiate magmatism (McMillan and McLemore, 2004). Thus, an aulacogen was proposed by McMillan and McLemore (2004) to exist in New Mexico during Cambrian and Early Ordovician time, similar to the Southern Oklahoma aulacogen of the same age (Loring and Armstrong, 1980; Larson et al., 1985; Loring et al., 1987; McConnell and Gilbert, 1990). The Sevilleta episyenites could be another example of alkaline metasomatism associated with this Cambrian-Ordovician event.

Outlook for mineral resource potential in the future

Unlike episyenites in the Caballo and Burro Mountains, the episyenites in the Sevilleta National Wildlife Refuge have no economic potential, except perhaps for red decorative stone. A few episyenites are slightly radioactive, but all samples are low in uranium, thorium, yttrium, niobium and REE (Table 1; Fig. 6). Episyenites at Lobo Hill, near Moriarty have been mined for decorative stone and are at least 10 m deep. It is possible that the Sevilleta episyenites could be enriched in uranium, thorium, yttrium, niobium and REE at depth, but drilling is required to investigate the potential. However, the Sevilleta National Wildlife Refuge is withdrawn from mineral entry.

Future research

Future research includes mineral chemistry (identification of REE, uranium, and thorium minerals) and dating of these rocks.

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