MINERALOGY, GEOCHEMISTRY, AND CHRONOLOGY OF THE CABALLO AND BURRO MOUNTAINS REE-BEARING EPISYENITES

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ABSTRACT

Extraordinarily potassium feldspar-rich, brick-red rocks, termed *episyenites*, in the Caballo and Burro Mountains, New Mexico, have anomalously high concentrations of U, Th and TREE (2,329 ppm, 9,721 ppm and 1,378 ppm, respectively). Some episyenites contain high HREE (as much as 133 ppm Yb and 179 ppm Dy). *Episyenite* is a term used to describe altered rocks that were desilicated and metasomatized by alkali-rich fluids solutions and may be similar to fenites. Field and electron microprobe investigations of outcrop distribution and mineralogical textures suggest episyenites formed by interaction of K-rich metasomatic fluids with Proterozoic granitic host rocks, resulting in K-feldspar-rich rocks with bulk compositions containing up to 16 wt.% K_2O. The secondary feldspars are significantly less fractured than primary igneous feldspar, display no perthitic textures, and contain micron-size hematite inclusions. The most reddened episyenites are composed largely of interlocked K-feldspar crystals, which display no relict igneous texture. Electron microprobe investigation of rocks with the highest concentrations of U, Th, and REE indicate complex mineralogy associated with fluid alteration, particularly of primary magmatic mafic silicates, now replaced by a combination of secondary chlorite, hematite, carbonate, apatite, rutile, synchysite, priorite, xenotime, thorite and uranophane. Synchysite is the major host of LREEs, up to 63 wt.%, while HREEs are concentrated dominantly in xenotime, up to 16 wt.%, and priorite, up to 9 wt.%. The geochemical and textural characteristics of these rocks are consistent with alteration of host granite by fluids related to alkaline or carbonatitic magmatism. In the Caballo Mountains, timing of metasomatism is constrained to be older than late Cambrian as episyenite clasts occur in the C-O Bliss Sandstone that unconformably overlies metasomatised basement. One such clast contains xenotime with the same chondrite-normalized REE pattern as episyenite-hosted xenotime found in other areas of the mountain range, constraining mineralization to be older than late Cambrian, as well. Direct dating of the metasomatism using the $^{40}Ar/^{39}Ar$ method on sub-milligram fragments of metasomatic K-feldspar yield complex and intriguing age results that may be related to multiple fluid-alteration events. In the Caballo Mountains age spectra range from nearly flat to highly disturbed with total gas ages (TGA) between ~40 and 460 Ma. Individual fragments with flat spectra from single samples vary in TGA by ~140 Ma (approx. 320 to 460 Ma). However, one sample from the Burro Mountains yields a plateau age at approx. 540 Ma that may record late Cambrian metasomatism caused by an alkaline or carbonatitic intrusion in the subsurface.

INTRODUCTION

Worldwide, alkaline igneous complexes similar to carbonatites and metasomatic rocks found in southern Colorado and New Mexico (Fig. 1; McMillan McLemore, 2004) are well known for potential economic deposits of REE, U, Th, Nb, Zr, Hf, Ga, and other elements (Long et al., 2010; McLemore, 2012). Brick-red, K-feldspar-rich rocks, called episyenites are found in the Caballo Mountains in southern New Mexico that contain anomalous concentrations of REE, U, Th, and other elements. 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. This 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 Th-REE-U mineral deposits. Carbonatites are found in the Lemitar and Chupadera Mountains, Lobo Hill, Monte Largo and southern Colorado (Wet Mountains, Iron Mountain). It is possible that the episyenites are related to alkaline or carbonatite plutons at depth and are possibly related to this widespread Cambrian-Ordovician magmatic event.

PURPOSE

The overall objectives of this research are to address the following questions:

- What are the mineralogy and chemistry of the episyenites? Where are the REE and other elements found?
- What is the origin of the episyenites? Are they magmatic or metasomatic or both?
- What is the mineral resource (U, Th, REE, Nb, Ga, Zr, Hf, Y, other) potential of the episyenites and associated veins in the Caballo and Burro Mountains?

DEFINITION OF EPISYENITES

The term *episyenite* is used to describe altered rocks that were desilicated and metasomatized by alkali-rich fluids solutions (Leroy, 1978; Recio et al., 1997). These metasomatic rocks in the Caballo Mountains were erroneously called syenites and alkali granites, but are actually metasomatic in origin and not primary igneous rocks. Elsewhere 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 rocks formed by fenitization and could 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 in the Caballo and Burro Mountains because a carbonatite or alkaline magma source is not found at the surface in this area.

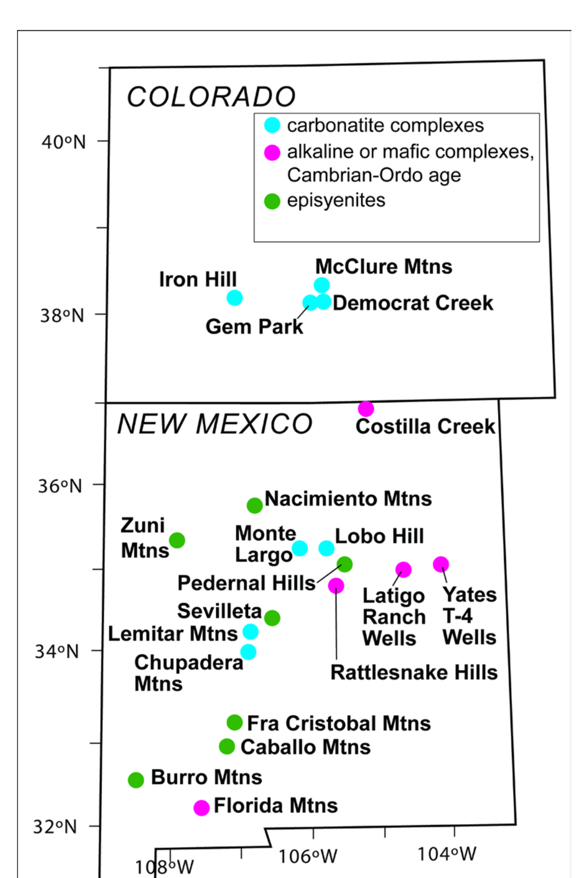
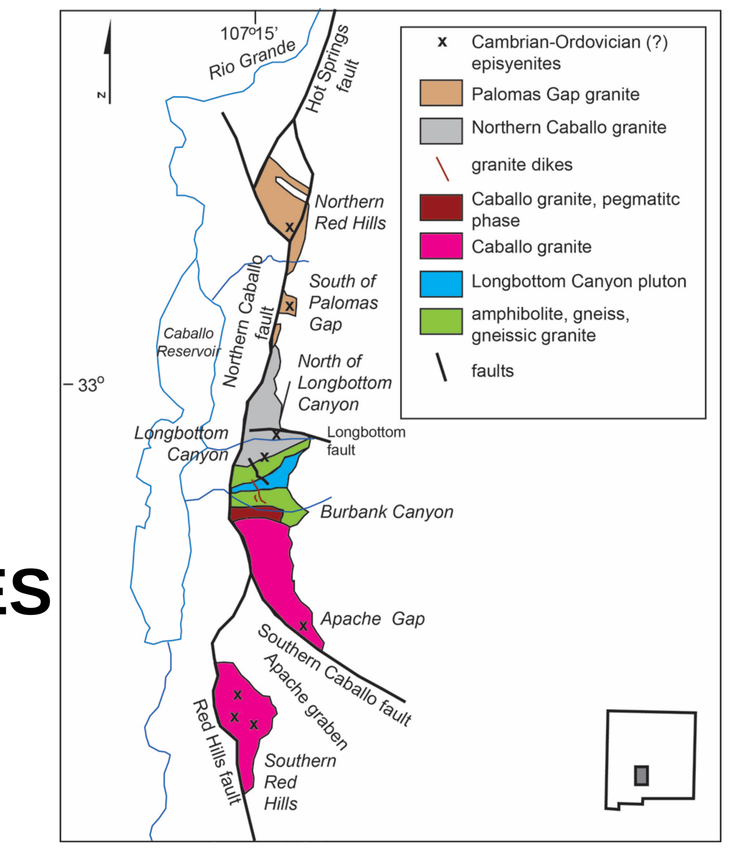


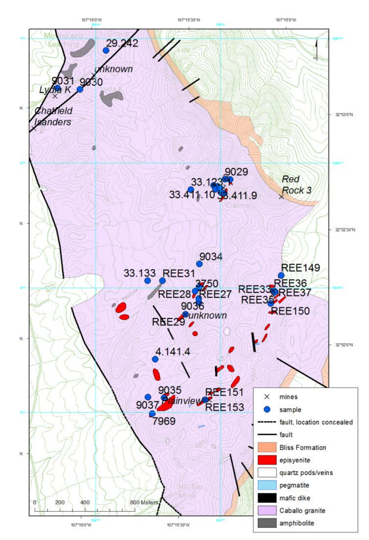
FIGURE 1—Cambrian-Ordovician carbonatite, alkaline, and mafic igneous rocks and episyenites in New Mexico and Colorado.



Simplified geologic map of Proterozoic rocks and Cambrian-Ordovician episyenites in the Caballo Mountains, New Mexico (modified from Condie and Budding, 1979; Seager and Mack, 2003; McLemore et al., 2012).

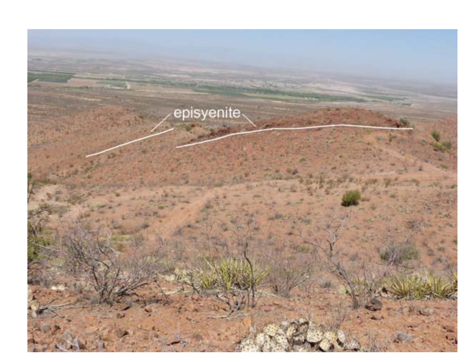
Southern Red Hills, Caballo Mountains

More than 25 lenticular to elongate pods, lenses (<100 m long, <10 m wide), narrow pipe-like and dike-like bodies (<2 m wide, 400 m long) of episyenites are found scattered throughout the Protereozoic Cablallo Granite (1487 Ma, Amato et al., 2012) in the Southern Red Hills



Geologic map of the Southern Red Hills area, Caballo Mountains.

Uranophane crystals in fractures in episyenite

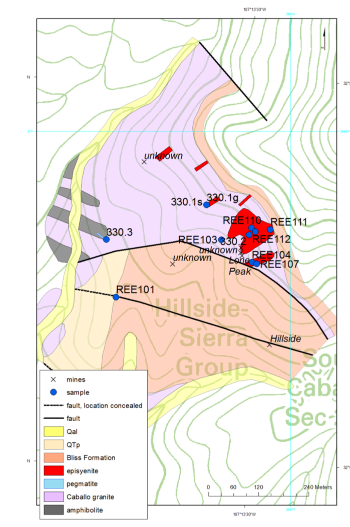


Dike-like episyenite forming ridges in Caballo Granite in Southern Red Hills

Adit in episyenite in Proterozoic Caballo Granite.

Sharp contact between episyenite in Proterozoic schist (~1600 Ma)

LOCATION AND FIELD RELATIONSHIPS



Brick red episyenites are found in a fault block in the Apache Gap area, near the base of the Caballo Mountains

Apache Gap, Caballo Mountains

Episyenites in the Apache Gap area, unconformably overlain by the Bliss Formation (looking north).

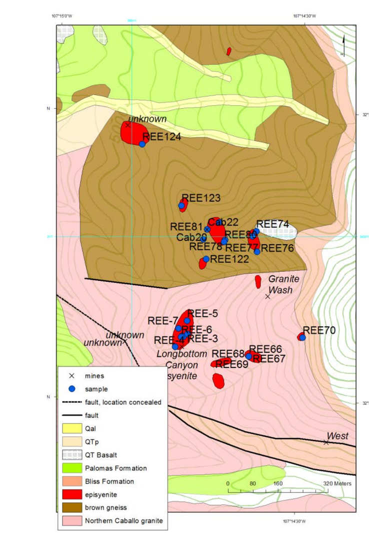
Xenolith of granitic schist surrounded and cut by episyenite.

Vuggy texture along gradational contact between episyenite and Caballo granite

Longbottom Canyon, Caballo Mountains

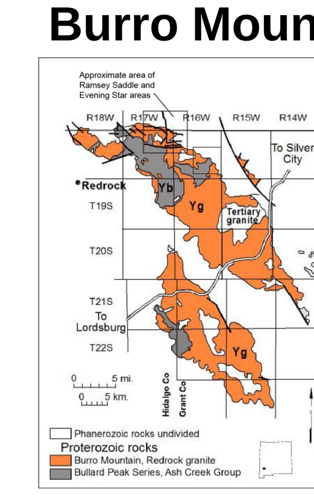
Dike-like episyenite in Longbottom Canyon area

Sharp contact between episyenite and schist in Longbottom Canyon area

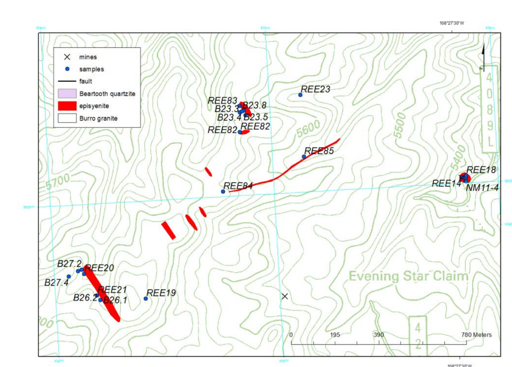


Geologic map of the Longbottom Canyon area, Caballo Mountains

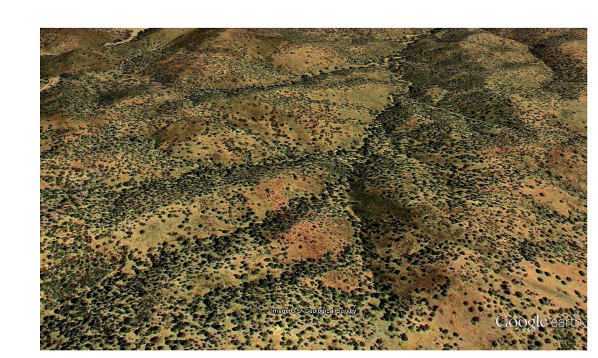
Burro Mountains



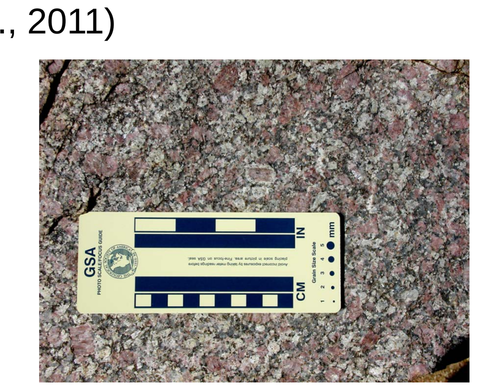
Episyenites are found in Proterozoic Burro Granite (1460 Ma, Amato et al., 2011) and Jack Creek Granite (1461 Ma, Rämö et al., 2002) in the northern Burro Mountains (Hedlund, 1978a, 1978b, 1978c, 1978d; McLemore et al., 2000)



Geologic map of the Evening Star Canyon area in the Burro Mountains showing dike-like episyenites along fractures in Burro Granite (1460 Ma, Amato et al., 2011)



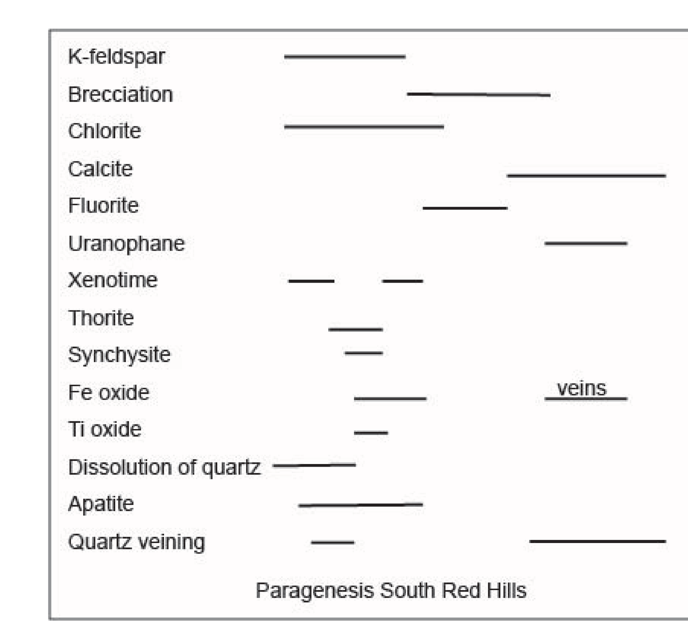
Orthoimage from GoogleEarth looking north at an elongate exposure of episyenite in the Evening Star Canyon area.



1461 Ma Jack Creek Rapakivi Granite (Rämö et al., 2002)

The rapakivi texture is preserved within the episyenite, suggesting a metasomatic origin.

PARAGENESIS



Simplified paragenesis of episyenites in the Southern Red Hills as determined from field relationships, petrographic observations, and electron microprobe studies.

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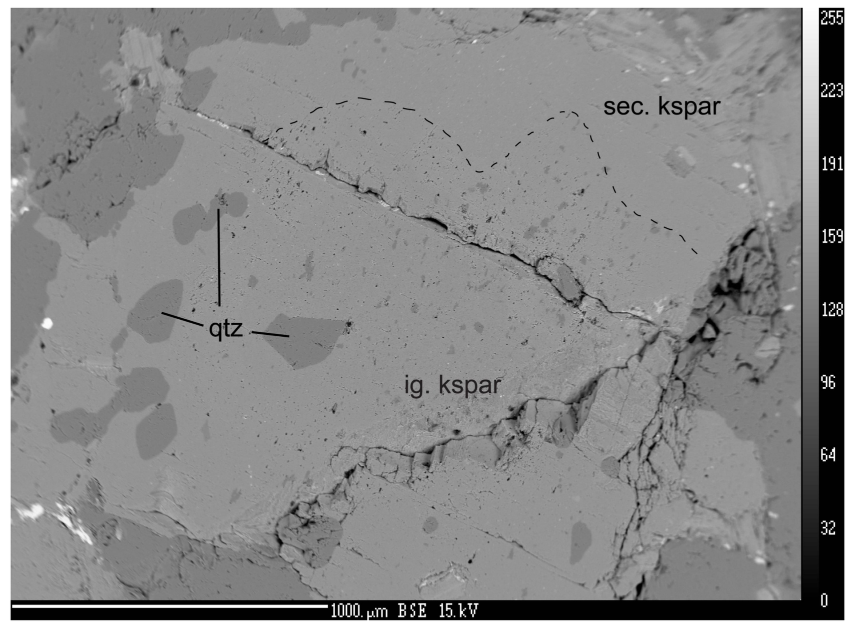
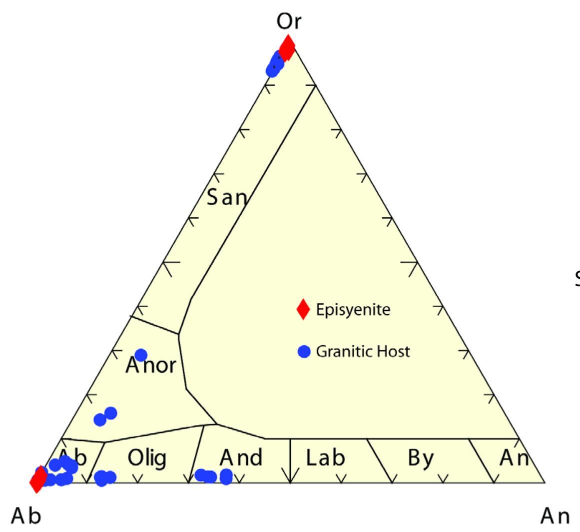
MAJOR MINERALOGY AND CHEMISTRY

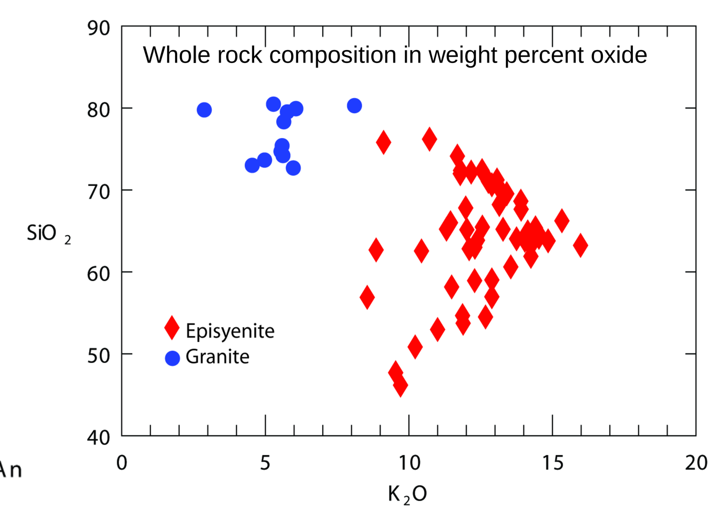
We used the electron microprobe to examine mineralogical characteristics of episyenites, in order to better understand the process by which they form. Of particular interest are samples like the one shown below, which exhibit a gradient in degree of alteration.

1" diameter electron microprobe mount of a variably episyenitized sample.

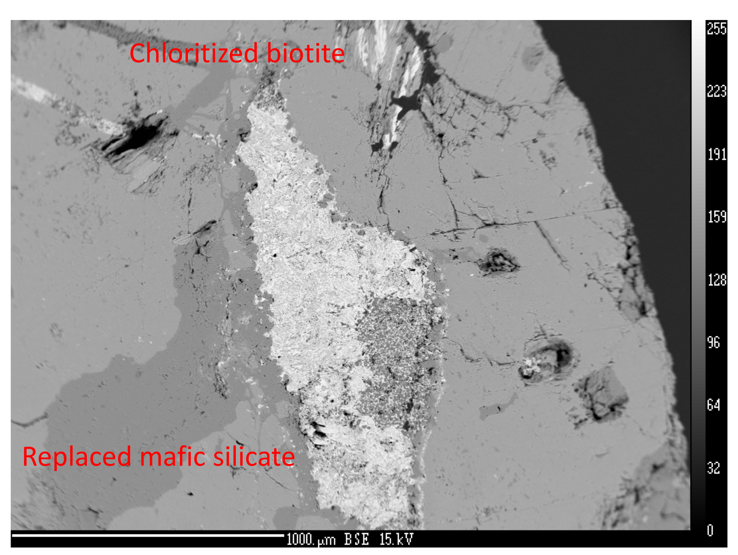


Backscattered electron image of area shown in black box on sample mount. Primary igneous feldspar, as well as a secondary potassium feldspar, are shown, with the dashed line showing the contact between the two. Small bright Fe-oxide inclusions can be seen in the secondary potassium feldspar





Electron microprobe analyses of feldspar (diagram on left) show that secondary feldspar in episyenites is end-member K feldspar. The albitic feldspar with "episyenite" symbols represent relict igneous feldspar in episyenitized samples. Whole rock analyses (right) show that bulk chemical composition of episyenites trends towards a pure potassic feldspar composition.

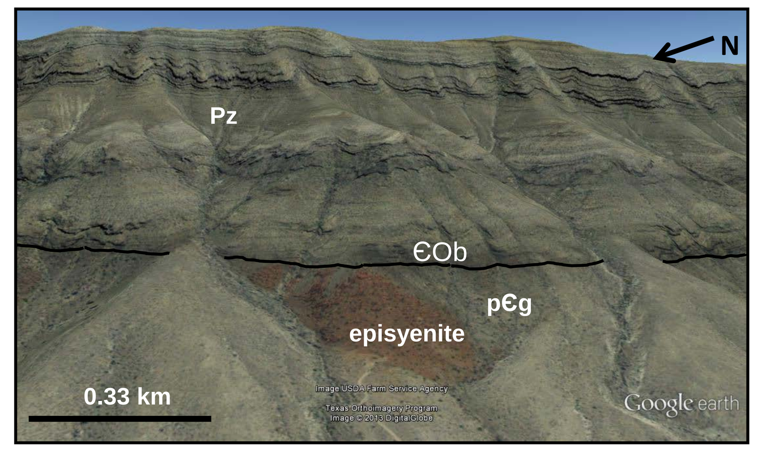


Episyenites are also characterized by relict mafic silicates replaced by Fe and Ti oxides, and chloritized biotite

The presence of primary igneous feldspar cores surrounded by rims of secondary K-feldspar suggest that episyenites are metasomatic in origin. The core and rim morphology suggests fluid-driven alteration of the granitic host, causing dissolution of the primary Na- and Ca-bearing feldspars, and precipitation of K-feldspar. Disseminated iron-oxide inclusions, which are likely to give these rocks their brick-red color, are diagnostic of secondary K-feldspar, and may be derived from the dissolution of primary mafic silicates. The composition of episyenite feldspars also suggest a low temperature, metasomatic origin because low temperature microcline preferentially excludes Na.

GEOCHONOLOGY

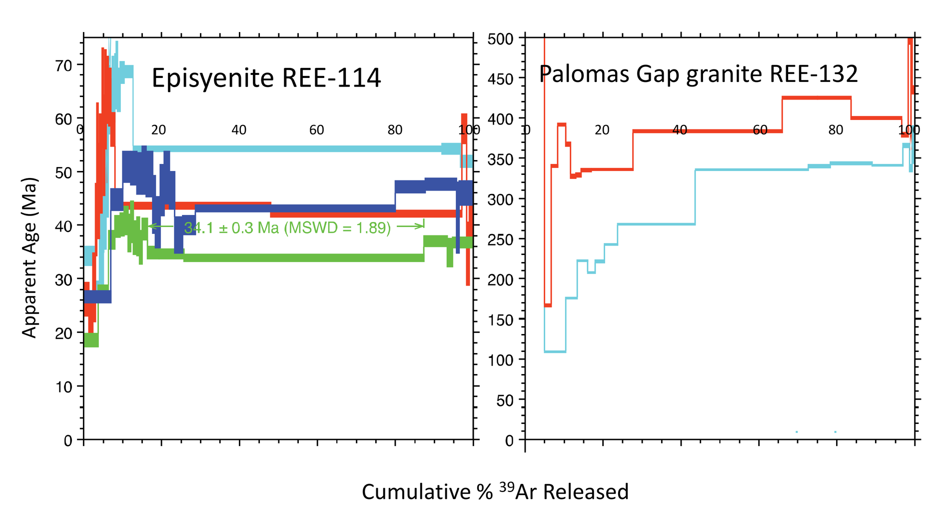
Field relationships, such as the apparent truncation of episyenite by Cambrian-Ordovician Bliss Sandstone (COb) (top image) and presence of red, altered feldspar in the basal Bliss Sandstone (bottom image) suggest that episyenites are no younger than Cambrian-Ordovician.



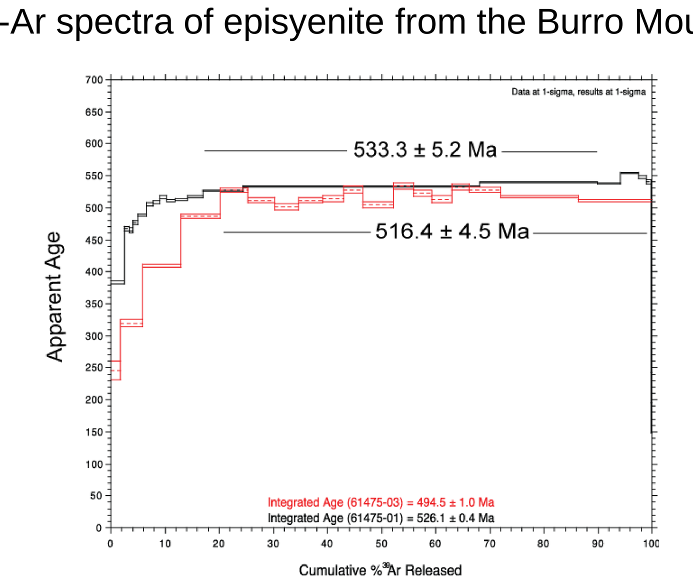
Ar-Ar geochonology of episyenite samples, as well as samples of host granites from the Caballo Mountains yield complex results, probably as a results of multiple episodes of reheating and/or feldspar recrystallization. The true formation age of episyenite formation is difficult to deconvolve. An episyenite sample from the Burro Mountains, however, yield ages consistent with episyenite formation in the Cambrian.

The complexity of the Ar-Ar results highlight the importance of field observation in interpretation of geochronology.

Ar-Ar spectra of episyenite and granite from the Caballo Mountains

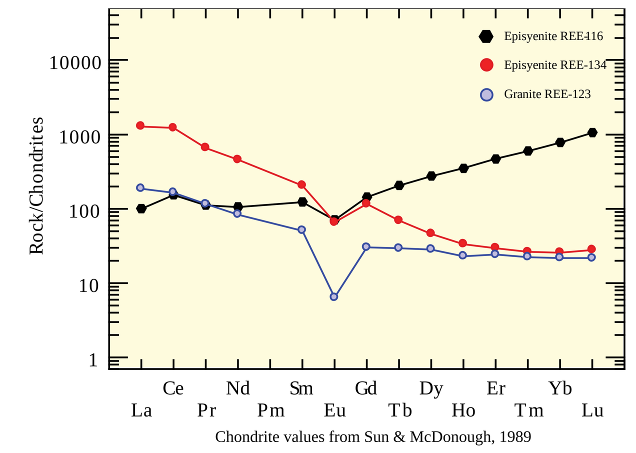


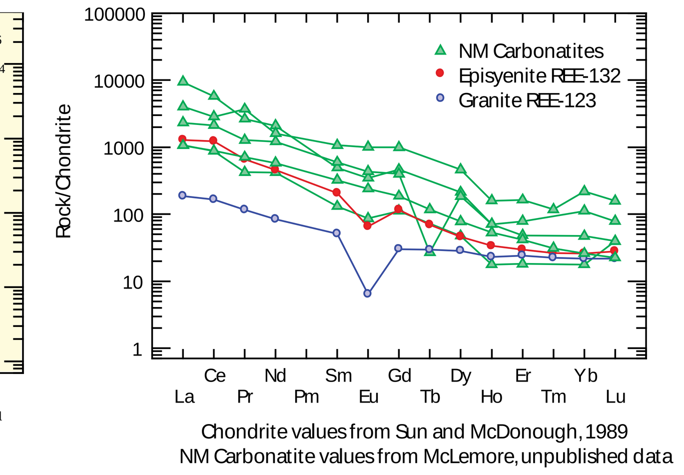
Ar-Ar spectra of episyenite from the Burro Mountains



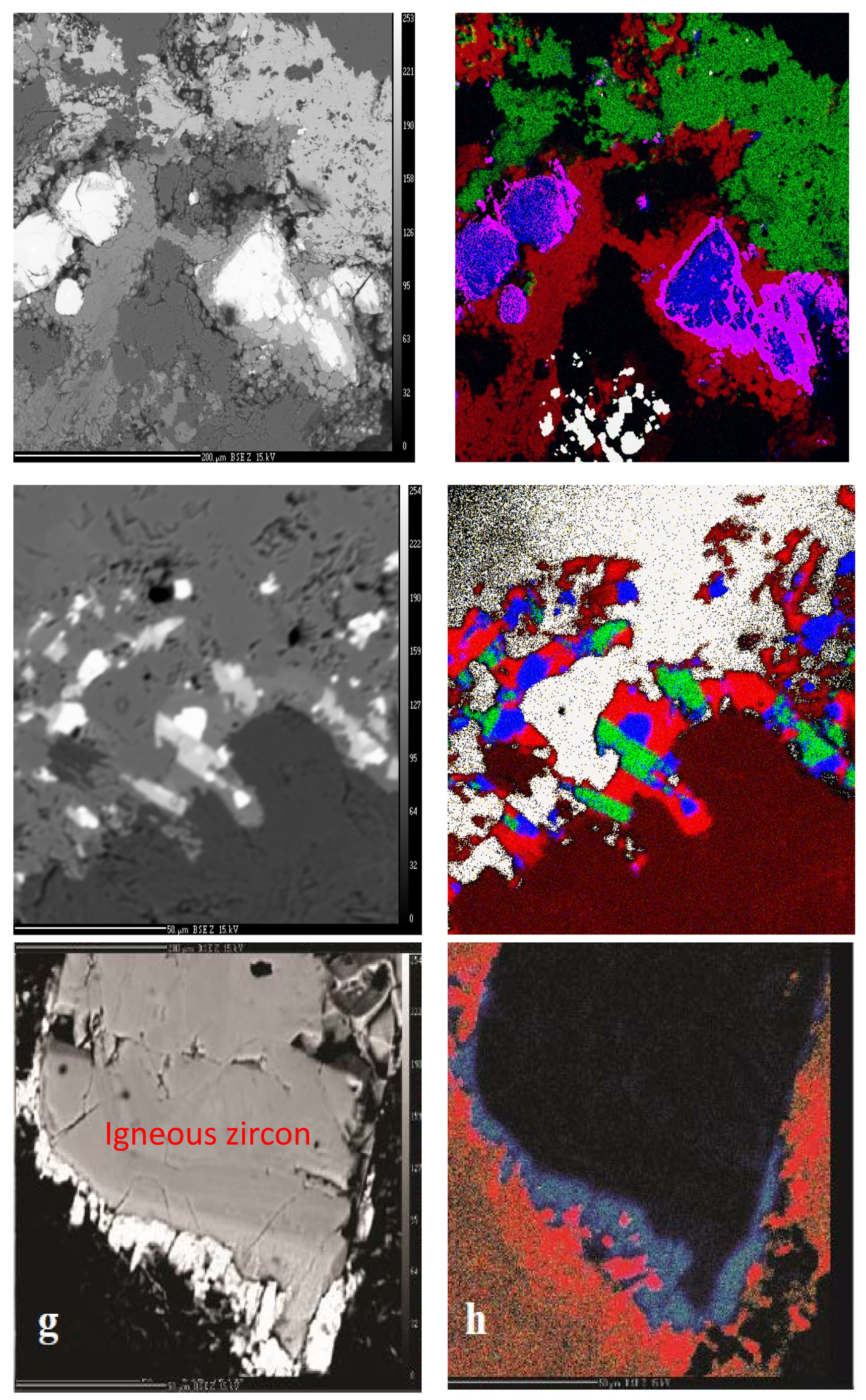
REE CHEMISTRY AND MINERALOGY

Whole rock geochemistry indicates that episyenites are overall enriched in total REE as compared to host granite, and that some episyenites are HREE enriched, and others are LREE enriched (left). Most fall between the LREE and HREE enriched end members. The overall pattern of LREE enrichment is very similar to New Mexico Cambrian-Ordovician carbonatites (right, V.T. McLemore, unpublished data).



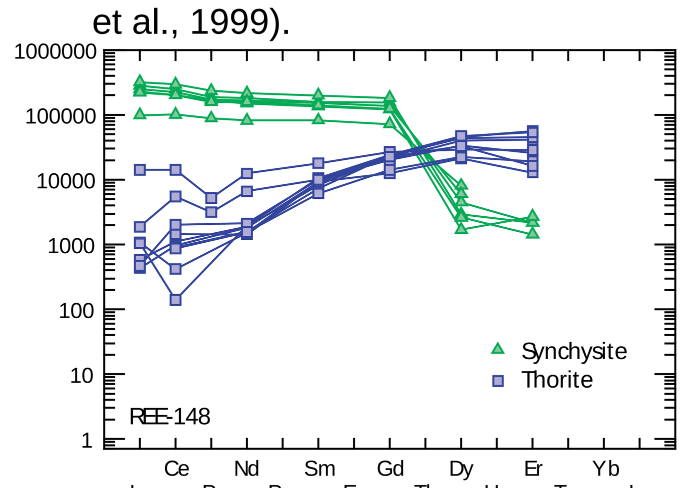


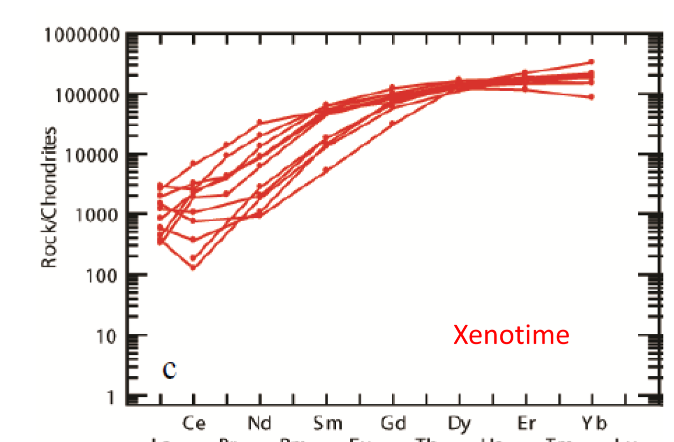
Backscattered electron images (left) and composite geochemical maps (right) suggest co- or sequential precipitation of multiple REE-bearing mineral phases.



Synchysite Ca(LREE)$(CO_3)_2$F
Thorite (Th,U)SiO_4
Xenotime YPO_4
Fe oxide
White on chemical maps is rutile

Quantitative geochemical analysis of the REE-bearing mineral phases by electron microprobe (below) show either HREE or LREE enriched patterns. The whole rock trends shown above may be controlled by variable concentrations of different REE-bearing phases, possibly precipitated by evolving fluids generated by carbonatite or alkaline intrusions at depth, although no such intrusions have been reported in either the Caballo or Burro Mountains. Episyenites in the Lobo Hills area are associated with carbonatites and lamprophyres (McLemore et al., 1999).





MINERAL RESOURCE POTENTIAL

In general the exposed episyenites in the Caballo and Burro Mountains are too small and low grade to be economic in today's market. However, drilling and subsurface sampling are required to fully evaluate the mineral resource potential. The relatively high HREE in some episyenites in the Caballo and Burro Mountains could be of economic interest, but additional mineralogical and geochemical analyses are required to fully assess the mineral resource potential.

CONCLUSIONS

- Brick-red episyenites are metasomatic in origin, possibly related to alkaline or carbonatite intrusions at depth.
- However, there could be multiple fluids of different ages or an evolution of metasomatic fluids over time.
  - Field relationships
  - Apparent $^{40}Ar/^{39}Ar$ ages of the episyenites suggest minimum formation ages of ~460 Ma in the Caballo Mountains
  - Sampling of these metasomatic rocks is critical
- REE minerals are associated with altered amphiboles, magnetite, secondary chlorite, hematite, zircon, and fluorite.
- Surface samples have low-moderate TREE, Th, and U; but some samples have relatively high HREE.
  - Moderate concentrations of TREE (as much as 3167 ppm total REE), Th (as much as 9721 ppm) and U (as much as 2329 ppm).
  - Heavy REE (as much as 133 ppm Yb and 179 ppm Dy).
- Drilling and subsurface sampling are required to fully evaluate the mineral resource potential.

ACKNOWLEDGMENTS

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