



Geochemistry of the Tajo Granite, Socorro County, New Mexico

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GEOCHEMISTRY OF THE TAJO GRANITE, SOCORRO COUNTY, NEW MEXICO

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ABSTRACT—The Proterozoic Tajo granite consists of six outcrops along two northwest-striking faults east of Socorro, New Mexico. The area was originally examined for uranium, but fluorite and rare earth elements (REE) are reported as well (Fieldman, 1977). REE consist of the 15 lanthanide elements, including scandium and yttrium, and are fundamental to modern society. Although common in the crust, REEs are not often found in economically viable concentrations. Some Proterozoic granites in New Mexico, including the Tajo granite, were exploration targets for uranium and REE, but their economic resource potential is unknown. We conducted a petrographic and geochemical study of the Tajo granite to determine its mineral-resource potential. The Tajo granite is a medium- to coarse-grained, peraluminous, A-type granite. Geochemical comparisons of the Tajo granite to two other Proterozoic granites found in central New Mexico that are associated with REE deposits, the Gallinas and Sevilleta granites, show that individual granite bodies have variable REE compositions but the three are approximately similar in total REE. The REE and U are below economic concentrations in the Tajo granite and therefore, the mineral-resource potential of the Tajo granite is low.

INTRODUCTION

Rare earth elements (REE) consist of the 15 lanthanide elements, scandium, and yttrium, and are fundamental to a wide variety of technologies, including electric cars, energy efficient lights, and smart devices (Long et al., 2010). REE are common in the crust, but do not often occur in economic concentrations. Because of the heavy reliance of the United States on other countries for REE supplies, identifying, analyzing, and categorizing potential REE deposits in the U.S. would serve an economic and strategic interest to reduce dependence on foreign imports. Proterozoic granites in New Mexico (Zelenka, 1984; McLemore et al., 1988; McLemore, 2014), including the Tajo granite, could serve as potential mineral resources for REE, if their concentrations are sufficiently high.

In the late 1970s, the Rocky Mountain Energy Company drilled for uranium at the Tajo granite east of Socorro, New Mexico (drill core archived at the NMBGMR core library). The deposit was compared to the granite-hosted Rossing deposit in Namibia (Basson and Greenway, 2004) and to the Alaskan Bokan Mountains (Dostal et al., 2014), both of which contain important resources of U, Th, and REE in granitic rocks. The purposes of this study are to (1) characterize the mineralogy and geochemistry of the Tajo granite, (2) compare the Tajo granite to two other Proterozoic granites in central New Mexico that are associated with REE deposits, and (3) to assess the Tajo's economic mineral-resource potential.

GEOLOGIC SETTING

The Tajo granite is located east of Socorro, New Mexico, in the Quebradas region of Socorro County (Figs. 1, 2). Six granite outcrops are exposed by two northwest-striking fault zones (Fig. 2) and are unconformably overlain by Paleozoic and Paleogene-Neogene sedimentary rocks of the Sandia and Santa Fe formations, respectively (Fieldman, 1977; McLemore, 1983; Cather and Colpitts, 2005). The Proterozoic rocks

are exposed due to footwall uplift along faults bounding the eastern margin of the Socorro Basin of the Rio Grande rift.

Multiple Proterozoic granitic bodies are located within New Mexico, including those exposed in the Sandia (1.45 Ga), Burro (1.2–1.46 Ga), and Los Pinos Mountains (1.65 Ga) (Brookins, 1982; Condie and Budding, 1979; Ramo et al., 2003; Holland et al., 2020). These granites are classified by their source as A-type granites, where the A stands for anhydrous or anorogenic granite (Whalen et al., 1987). A-type granites typically have low water content and a lack of tectonic fabric, and are formed within continental rifts or in extensional basins in continental back arcs (Whalen et al., 1987; Du Bray et al., 2018). This group of granites is also characterized by enrichment in high field strength elements and REE (e.g., La, Nb, Ta, Y). A-type granites are found throughout much of the Southwest, North and Central Rocky Mountains, and northern and central Great Plains, and range in ages between 1.50 Ga and 1.32 Ga (Du Bray et al., 2018). Some of the Proterozoic A-type granites in central New Mexico are associated with REE deposits (McLemore, 2020).

PREVIOUS STUDIES

Fieldman (1977) compiled an unpublished report describing the potential of the Tajo granite and compared it to the Rossing U-bearing deposit. Using X-ray fluorescent spectrograph scans and radiometric readings, Fieldman (1977) identified portions of the granite that contain elevated uranium and REE. In 1983, McLemore (1983) performed fieldwork in the area, producing a geologic map establishing radiometric anomalies and collecting samples for chemical analyses (Fig. 2, Appendix 1; McLemore, 1983). Cather and Colpitts (2005) mapped six polygons of exposed Proterozoic rocks in the Loma de las Cañas quadrangle.

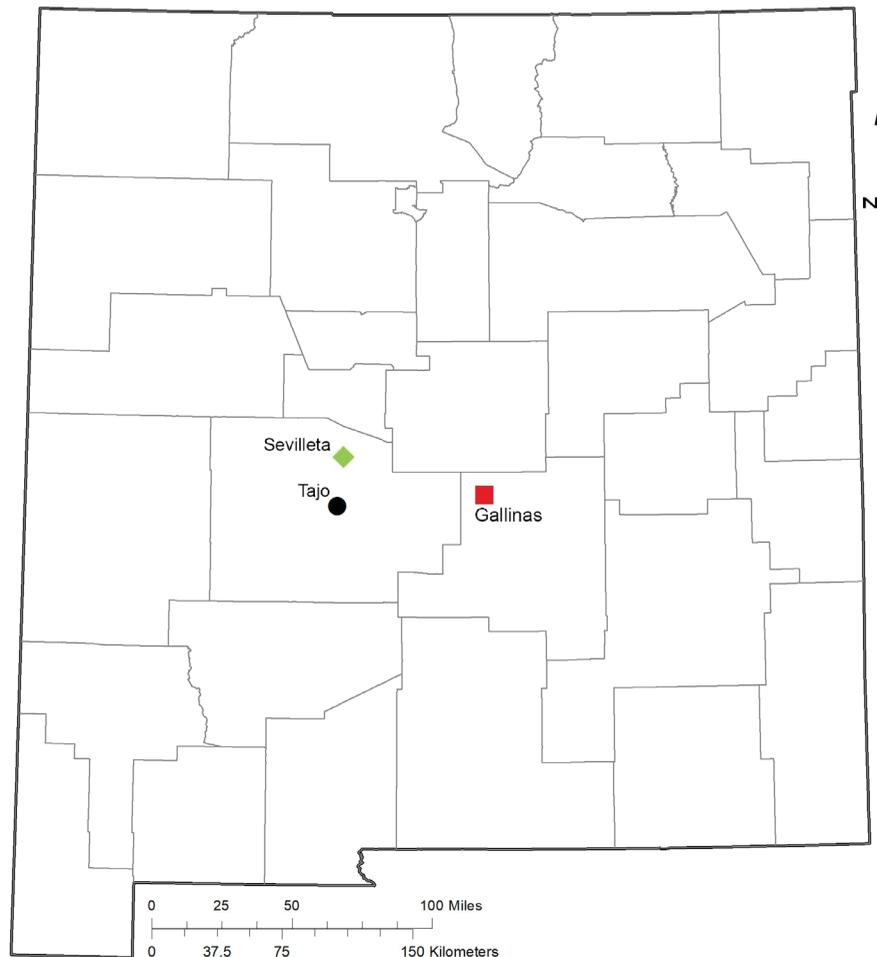


FIGURE 1. Map showing the general sample locations.

METHODS OF STUDY

In this study, drill core was logged and photographed using a form containing descriptions of lithology, color, mineralogy, grain size and shape, alteration, fracture intensity, and hardness; this form can be found at https://geoinfo.nmt.edu/staff/mclemore/projects/mining/REE/documents/Tajo_Drilllog2.pdf. Grain size cards were used to determine grain shape and rounding, and tables were used to determine alteration and fracture intensity. All core was photographed with hole, box, and depth information, and then replaced in the original position.

Samples of the drill core were split in half using a drill core splitter. One half was returned to the box to preserve the core. The other half was split into sufficient sizes for thin section preparation and chips for chemical analysis. Sampled intervals are indicated by a note denoting who collected the sample, date, purpose, project, hole, box, and depth.

Selected outcrop and drill core samples were sent to ALS Geochemistry Laboratory in Reno, Nevada, for whole-rock and trace element analysis using ICP-AES. Details of analysis and sample preparation can be found at ALS (2022). Additional analytical procedures and accuracy and precision are found in McLemore et al. (2021, appendix 5).

RESULTS

Descriptions of Tajo Granite and Nearby Proterozoic Rocks

Here, we focus on description of the Tajo granite, but also include summaries of two other central New Mexico granites that host REE deposits to which we compare the Tajo granite: the Gallinas and Sevilleta granites.

Tajo granite

In outcrop and drill core, the granite is maroon to orange and varies from medium- (0.25–0.50 mm) to coarse-grained (0.50–1.0 mm). The primary mineralogy consists of quartz, potassium feldspar, and plagioclase, with accessory minerals including muscovite, biotite, chlorite, sericite, pyrite, and hematite. The granitic outcrop located at Arroyo del Tajo consists of quartz (29%), potassium feldspar (35%), plagioclase (35%), and muscovite (1%), with prevalent hematite staining and rare 2–10 mm fine-grained, pink barite and greenish-blue fluorite veins cutting the granite. Similar veins are also present in the drill core. The potassium feldspar ranges in color from light to dark pink, and the plagioclase alters to greenish-white sericite.

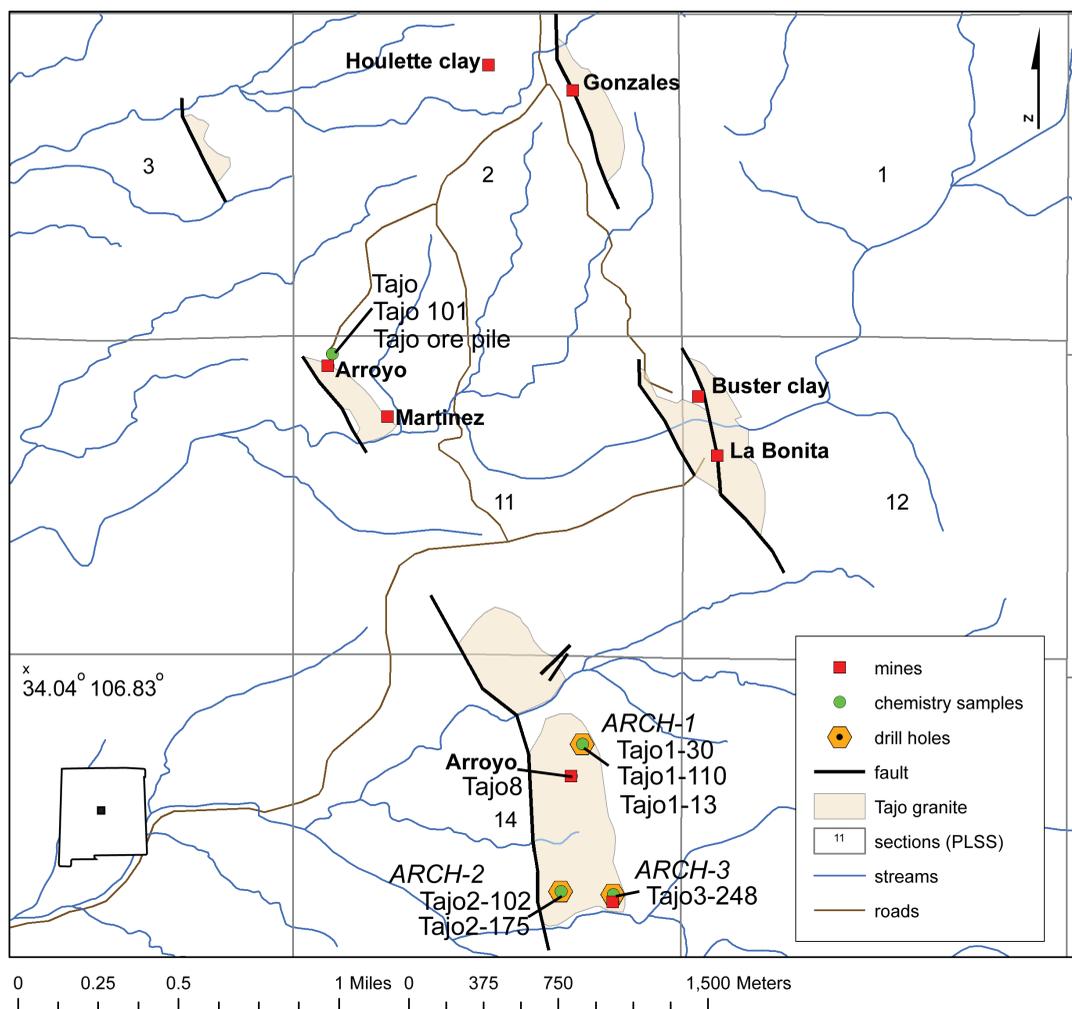


FIGURE 2. Geologic map of the Tajo granite showing sample locations, modified from McLemore (1983) and Cather and Colpitts (2005).

Tajo granite has a granular, non-foliated texture. The granite is lightly to intensely fractured with striations indicative of faulting on some (<5%) of the drill core faces.

In thin section, minerals include euhedral quartz, microcline, plagioclase, and a clear mica. Accessory minerals are sericite, chlorite, hematite, apatite, and fluorite. Quartz displays undulatory extinction and is also found in hematite-quartz veins. Microcline shows pericline and albite twinning, and the plagioclase exhibits Carlsbad twinning. Sericite was identified as dusty masses within the plagioclase, with second to third order interference colors that disrupt the expression of Carlsbad twinning. The mica is identified by birds-eye extinction and cleavage, which remains clear in plane-polarized light, displaying a lack of pleochroism consistent with muscovite or other white mica. Biotite is identified in hand sample based on softness, cleavage, and color, but was not observed in the thin sections examined. Chlorite alteration around the boundaries of mica is characterized by faint blue pleochroism and first order interference colors. Hematite is opaque to deep red in thin section and is present in all samples. Fluorite is colorless and isotropic in thin section with high relief. Paragenesis relationships specified below establish that quartz veining came first and fluorite second, with hematite alteration (hematization)

occurring last.

Alteration of the Tajo granite includes hematization, sericitization, and chloritization. The degree of hematization is variable throughout the granite, causing color changes from light pink to dark maroon-brown and can alter between 5% and 20% of the host rock. The hematization is concentrated along fractures in the core or is pervasive throughout the rock, changing the color of the microcline and often obscuring the underlying mineralogy. Sericitization (alteration by white, fine-grained phyllosilicates) alters the plagioclase from white, euhedral grains to soft, greenish-white, anhedral grains; sericitization affects between 5% and 10% of the host rock. Chloritization alters the biotite in trace amounts, indicated by a dark-green color change.

Thin veins composed of quartz, fluorite, and barite occur within the granite (Fig. 3). The quartz veins are 2 mm to 5 cm thick and display both massive and comb textures. The core locally breaks along the quartz veins and reveals 2–5 mm terminated, clear to gray quartz crystals. The fluorite ranges in color from light blue-green to violet in veins 5 mm to 3 cm thick. The fluorite tends to be massive and associated with the quartz veining. Barite veins are rare with short, truncated veins ranging between 2 mm and 1 cm (Fig. 3). White and yellow



FIGURE 3. Orange barite vein cross-cut and offset by purple quartz + fluorite vein. Sample size is 4 cm x 9 cm.

calcite forms thin veinlets along fractures in the granite.

Paragenetic relationships established through studying drill core indicate that barite was first, followed by quartz and fluorite. As can be seen in Figure 3, an orange barite vein contains clasts of granite and is offset by a vein containing quartz and fluorite, indicating the quartz and fluorite vein occurred after the barite vein (Fig. 3). In thin section and hand sample, comb-textured quartz is observed with fluorite in the middle, supporting the interpretation that fluorite came after quartz. Because of the lack of relevant paragenetic relationships, it is unknown when the calcite veining occurred.

Quartz vugs are also common along fractures within the core and in outcrops. Quartz crystals are 2–5 mm, terminated, and clear to gray. Some of the vugs contain hematite-bearing quartz crystals, identified by the maroon to dark red color and pervasive alteration of the surrounding core. Fluorite and barite crystals within the vugs are found locally.

Gallinas granite

In the Gallinas Mountains in central New Mexico, REE deposits are found as REE-fluorite veins hosted in Proterozoic granite, Permian sedimentary rocks, and Oligocene syenite and trachyte intrusions. In this mining area, a small amount of bastnäsite (671 short tons), a REE fluorocarbonate mineral, was recovered during historic processing for fluorite (McLemore et al., 2021). The fluorite-REE deposits in the Gallinas Mountains are related to the alkaline igneous rock flare-up at 29 to 27 Ma (McLemore et al., 2021). The Gallinas granite consists of quartz, microcline, oligoclase, and biotite, and contains local, secondary alteration to hematite, mica, and clay, similar to the Tajo granite.

Sevilleta granite

The Sevilleta granite is located in central New Mexico ~30 km northeast of Socorro on the Sevilleta National Wildlife Refuge. The granite consists of plagioclase, quartz, potassium feldspar, muscovite, and biotite (McLemore, 2016). Elevated REE concentrations (uneconomic) are found in episyenites associated with the Sevilleta granite (McLemore, 2016). The REE-bearing episyenites are believed to be Cambrian-Ordovician in age (McLemore, 2016; McLemore et al., 2020).

GEOCHEMISTRY

Total REE concentrations in the Tajo granite range from 69.55 ppm (sample #Tajo2-102) to as much as 285.51 ppm (#Tajo; Table 1). Individual REE constituents include as much as 144.5 ppm Y (#Tajo1-110), 25.3 ppm Yb (#Tajo101), and 28.7 ppm Er (#Tajo 101; Appendix 1). Uranium concentrations of the Tajo granite range from 5.43 ppm (#Tajo3-248) to as much as 262 ppm (#Tajo101). The Tajo granite locally contains elevated concentrations of some elements, with as much as 6880 ppm Ba (#Tajo3-248), 20,000 ppm F (#Tajo1-13 and Tajo3-248), and as much as 46 ppm Th (#Tajo ore pile; Table 1, Appendix 1). On average, the Tajo granite contains elevated concentrations of U and Rb (Table 1; Appendix 1).

The Tajo granite is a ferroan, metaluminous to peraluminous granite (Fig. 4). It is an A-type granite, plotting in the A-type granite field in Nb vs. Ga/Al and $(\text{Na}_2\text{O}+\text{K}_2\text{O})/\text{CaO}$ vs. Ga/Al plots (Fig. 5; Whalen et al., 1987; Eby, 1992). The Tajo samples have Y+Nb values >50 ppm, which is characteristic of A-type granites (Appendix 1; Pearce et al., 1984). The variation of Y+Nb values among the samples could be explained by alteration and unequal distribution of minerals in the samples.

A chondrite-normalized REE spidergram of the Tajo samples is shown in Figure 6; data for the Gallinas and Sevilleta granites are also shown for comparison. Note the high degree of variability of REE compositions within each of the three granites, particularly the Tajo and Gallinas granites. For the Tajo samples, this spidergram shows a flat, depleted pattern (i.e., relatively low concentrations of REE elements to left of Eu on the plots) and slight enrichment of heavy REE (REE elements to right of Eu) compared to the other granites, particularly

Granite tectonic discrimination - Frost et al. (2001)

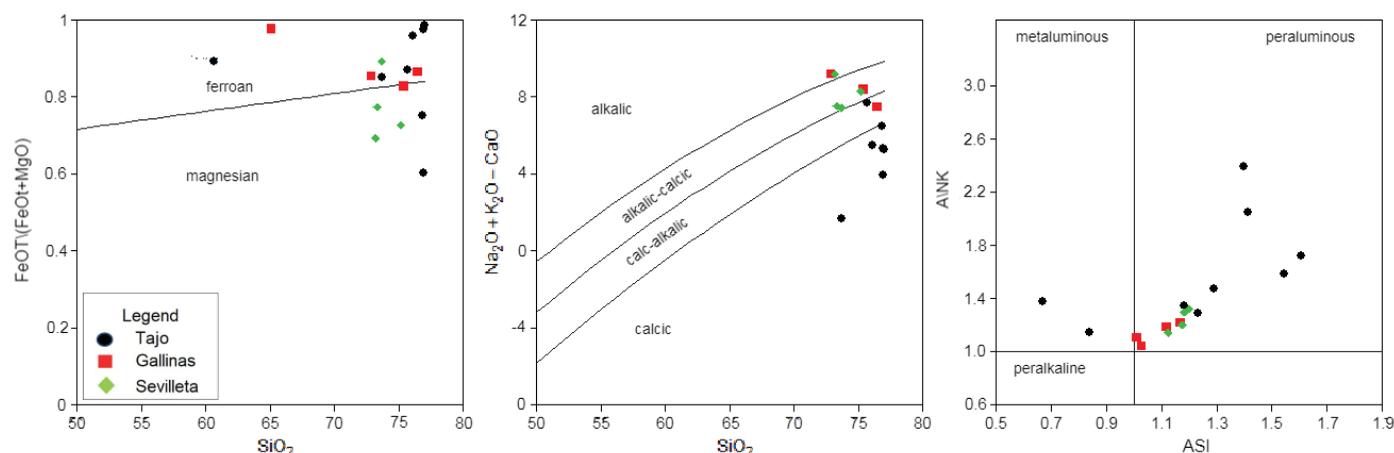


FIGURE 4. Granitic tectonic discrimination plot (Frost et al., 2001) of Tajo, Sevilleta, and Gallinas samples.

TABLE 1. Table depicting Rb, Th, U, and total REE (ppm) values from the Tajo, Gallinas, and Sevilleta granites. NA stands for not available. Additional geochemical analyses are in Appendix 1.

	Rb (ppm)	Th (ppm)	U (ppm)	Total REE
Tajo	391	35.3	182	285.51
Tajo 101	181	16.95	262	281.68
Tajo1-30	455	21.6	20.1	181.91
Tajo1-13	353	18.65	24.5	163.48
Tajo1-110	391	23.1	21.3	176.85
Tajo2-102	181	9.2	8.024	69.55
Tajo2-175	455	21.4	9.45	138.51
Tajo3-248	353	11.25	5.43	102.07
Tajo12 (McLemore, 1983)	433	21	42	NA
Tajo8 (McLemore, 1983)	390	29	17	NA
Tajo ore pile (McLemore, 1983)	340	46	161	NA
Average	356.6	23	68.4	174.9
Gal97 (McLemore et al., 2021)	254	20.9	4.53	370.21
Gal56 (McLemore et al., 2021)	167	4.4	0.89	31.39
Gal245avg (McLemore et al., 2021)	122.5	39.85	8.635	264.535
Gal246 (McLemore et al., 2021)	236	29.9	2.41	98.63
Average	194.9	23.8	4.1	191.2
SEV-5 (McLemore, 2016)	283	23.9	2.26	105.54
SEV-6 (McLemore, 2016)	306	8.73	4.22	42.42
SEV-14 (McLemore, 2016)	356	18.45	3.1	154.91
SEV-15 (McLemore, 2016)	307	19.65	1.95	125.63
Average	313	17.7	2.9	107.1

relative to the Sevilleta samples in the heavy REE. The CaO-Na₂O-K₂O diagram of various Proterozoic granite plutons in New Mexico shows the alteration (less Na₂O relative K₂O) of the Tajo granite compared to unaltered Proterozoic granites in New Mexico (Fig. 7). The Tajo samples do not plot within any of the groups recognized by Condie (1978), probably because the granite is intensely altered and K₂O has been introduced during the alteration. The Tajo granite contains elevated levels, on average, of U and Rb compared to A-type Proterozoic granites in central New Mexico (Table 1).

MINERAL-RESOURCE POTENTIAL

The *mineral-resource potential* of an area is the probability or likelihood that a mineral will occur in sufficient quantities so that it can be extracted economically under current or future conditions, including the occurrence of undiscovered concentrations of metals, nonmetals, industrial materials, and energy resources (Taylor and Steven, 1983; Goudarzi, 1984; McLemore, 1985). The mineral-resource potential is not a measure of the quantities of the mineral resources, but is a measure of the *potential* of occurrence. Classification of mineral-resource potential differs from the classification of mineral resources and

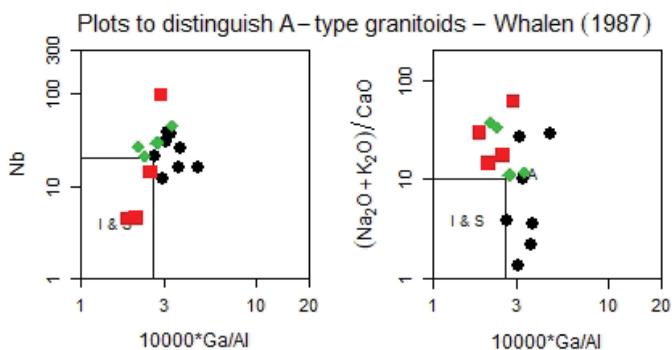


FIGURE 5. Select Nb and (Na₂O+K₂O)/CaO vs Ga/Al plots from Whalen et al. (1987) used to distinguish A-type granites from I- and S-type granites (field labeled "I & S"). Plotted data are from the Proterozoic Tajo, Gallinas, and Sevilleta granite samples. Legend is in Figure 4.

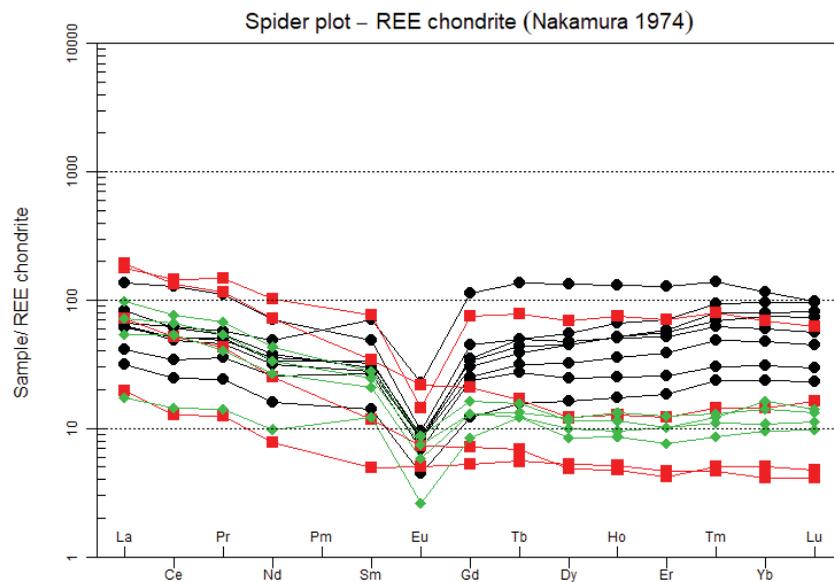


FIGURE 6. Chondrite-normalized REE plot (Nakamura, 1974) comparing Proterozoic Tajo, Gallinas, and Sevilleta granites. Note that the elements on the X-axis are arranged according to atomic weight, increasing to the right. Legend is in Figure 4.

reserves. Quantities of mineral resources are classified according to the availability of geologic data (assurance), economic feasibility (identified or undiscovered), and as economic or uneconomic. Mineral-resource potential is a qualitative judgment of the probability of the existence of a commodity and is classified as high, moderate, low, or no potential according to the availability of geologic data and relative probability of occurrence (Goudarzi, 1984).

Although preliminary work by Fieldman (1977) suggested that the Tajo granite was a potential economic deposit for uranium and possibly REE, the concentrations of uranium and REE are too low to be economic. The Tajo samples contain as much

as 262 ppm U and 285 ppm total REE (Table 1, Appendix 1). Therefore, the mineral-resource potential of the Tajo granite is low. For comparison, REE ore grades at the currently operating Mountain Pass carbonatite mine exceed 15% (>150,000 ppm).

CONCLUSIONS

The Tajo granite is a metaluminous to peraluminous and ferroan, A-type granite with elevated levels of U and Rb compared to A-type Proterozoic granites in New Mexico (Table 1). Total REE values from individual samples show a high degree of heterogeneity (overlapping values) within a granite, especially in the light REE. Compared to the Sevilleta and Gallinas granites, the total REE concentrations overlap and are approximately similar, with averages ranging from 107.1 (Sevilleta) to 174.9 (Tajo) to 264.535 ppm (Gallinas). The Tajo samples contain as much as 262 ppm U and 285 ppm total REE, which are uneconomic. The Tajo granite has low economic mineral-resource potential because of low concentrations of REE and U.

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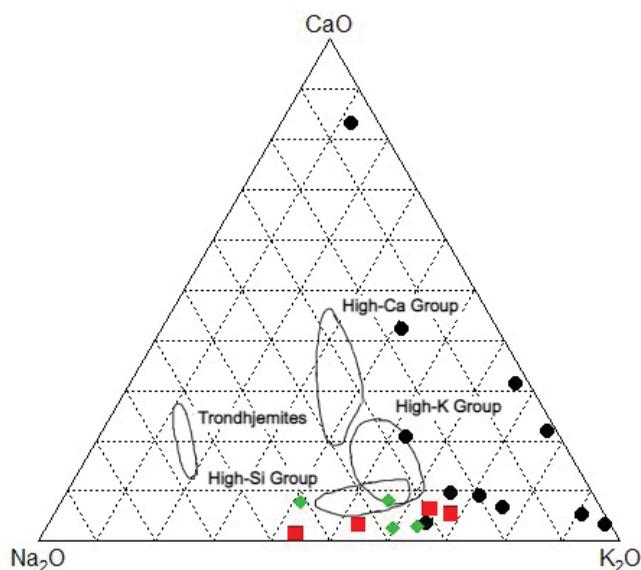


FIGURE 7. CaO-Na₂O-K₂O ternary diagram comparing Proterozoic Tajo, Gallinas, and Sevilleta granite samples to the geochemical groups established by Condie (1978) for Proterozoic New Mexico granites. Legend for samples is in Figure 4. Note the relatively lower Na₂O and higher K₂O of the altered Tajo samples compared to the fresh granite samples elsewhere in New Mexico.

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Appendices can be found at

<https://nmgs.nmt.edu/repository/index.cfm?rid=2022005>



Few things excite dogs as much as a chance to romp around the outdoors, and they sure are nice companions to accompany a field geologist during a long day's work. This photo shows two field dogs in the Quebradas, with Socorro Peak and the Magdalena Mountains in the background. Socorro Peak is on a west-tilted horst block, bounded on the east by the Socorro Canyon fault. On this horst block, 5 miles north of Socorro Peak, lie intriguing carbonatite dikes. Photo courtesy of Lewis Gillard.