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**Alkaline Complexes of the Wet Mountains Area, Colorado: A
Geological Summary, Bibliography, and Data Compilation of
Critical Mineral Laboratory Results**

By

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DISCLAIMER

The material presented here is from a limited literature review and is intended for general information purposes only. Those making use of or relying upon the material, previous exploration results, results of this investigation, and any other information provided herein assume all risks and liability arising from such use or reliance. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the Colorado Geological Survey.

INTRODUCTION

Colorado hosts several alkaline igneous intrusions that formed in a variety of geological settings. These intrusions are associated with some mineral deposits of economic interest, including the precious metal deposits at Cripple Creek and other deposits that contain potential titanium, niobium, rare earth elements (REEs), uranium, and thorium resources. The U.S. critical minerals list recently updated by the U.S. Geological Survey (USGS) (Fortier and others, 2018) includes niobium, REE, titanium, strontium, and other elements typically associated with alkaline igneous intrusive rocks and carbonatites. An area along the western flank of the Wet Mountains located in Custer and Fremont counties, Colorado, hosts three alkaline complexes that reportedly contain elevated concentrations of these critical minerals (Figure 1).

The Colorado Geological Survey (CGS) compiled historic sample results of select critical minerals (e.g., REEs, niobium, titanium) from this area as reported by other authors. Although thorium is not listed as a critical mineral, some of the first studies in the area concentrated on thorium exploration, therefore, it was included in the data compilation. Recent data collected by the CGS are also included in the data set. The data compilation is provided in an electronic ArcGIS file, spreadsheet, and a comma-separated values (csv) file available for download that includes sample locations, sample descriptions, concentrations, references, and other locations of associated alkaline rocks, veins, dikes, etc. in this area. A summary of the geology, mineralization, and data set, plus a bibliography, are presented below. The bibliography includes documents referenced in this report as well as other publications that pertain to this area. Appendix A includes documentation and the laboratory results of the samples collected by the CGS. Appendix B contains a data dictionary and explanation of data modifiers and acronyms used in the data compilation. This open-file report may be updated with additional data in the future.

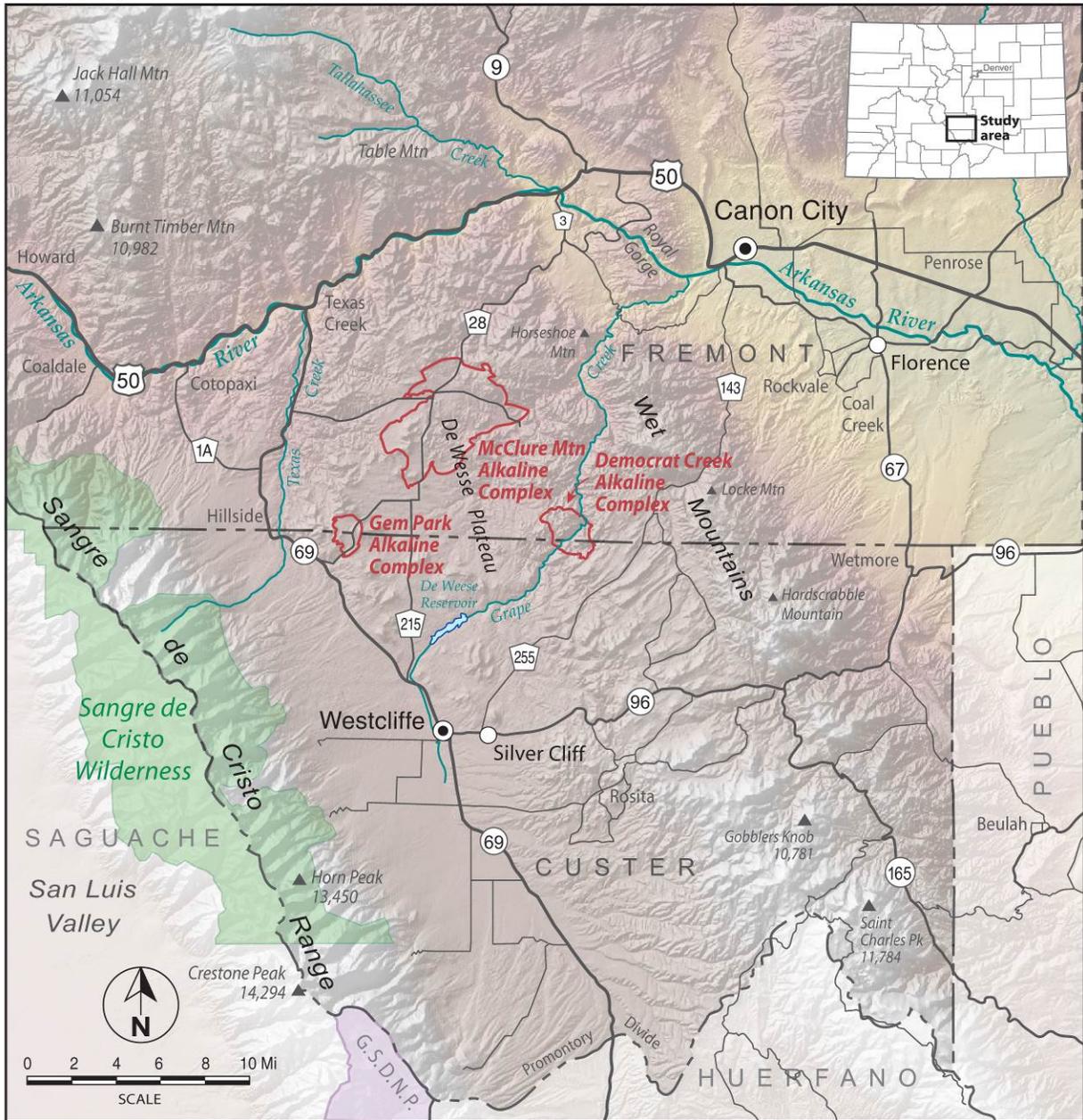


Figure 1 – General location map of the Wet Mountains area and the general location of the three alkaline complexes.

GEOLOGY

Three alkaline complexes are located along the west flank of the Wet Mountains, near the Fremont and Custer County border, ~25 kilometers (km) southwest of Cañon City (Figure 2). The intrusions are located on the DeWeese Plateau, between the Wet Mountains peaks to the east and the Wet Mountain Valley to the west at the base of the Sangre De Cristo range. The McClure Mountain, Gem Park, and Democrat Creek alkaline complexes consist of stocks, dikes, and veins of several rock types. These early Cambrian alkaline complexes, or intrusive centers, contain a series of mafic and ultramafic rocks (e.g., gabbro, pyroxenite, and anorthosite), syenites, lamprophyres, and various vein/dike rock types, including carbonatites, all of which were intruded into Proterozoic gneiss and granite. Most of the dikes and veins strike northwest and, in places, the rocks have been finitized (alkali metasomatism) along dikes and the larger intrusions. Carbonatite dikes, stocks, and potential cone sheets (curved dikes in sets that dip towards a center — especially at the Gem Park alkaline complex) intrude older mafic-ultramafic layered bodies and syenite intrusions. At least one other relatively smaller alkaline intrusion occurs to the west of the Democrat Creek alkaline complex (known as the Dead Mule Gulch “*sheets*” – see Alexander, 1981; Taylor and others, 1975) and smaller syenite bodies exist to the east-southeast near the Democrat Creek complex (Christman and others, 1959; Taylor and others, 1975; Armbrustmacher, 1988). The Wet Mountains area is cut by numerous faults. Several major normal northwest-trending faults, including the Texas Creek and Ilse faults, border the main alkaline complexes to the west and east, respectively. The Dead Mule Gulch Fault trends northwest-southeast through the area (Figure 2) (Armbrustmacher, 1988; Taylor and others, 1975).

McClure Mountain

The McClure Mountain alkaline complex is the largest of the three complexes and contains mafic and ultramafic rocks, including dunite (minor), peridotite, olivine gabbro, gabbro, anorthosite, pyroxenite, and titaniferous (ilmenite) magnetite bodies (with spinel inclusions) exposed in the northeast. The relatively larger southwestern portion of the exposed intrusion contains hornblende-biotite syenite, nepheline syenite, and mafic-nepheline-clinopyroxene

rocks (ijolite) (Parker and Hildebrand, 1963; Shawe and Parker, 1967; Kilbane, 1978; Alexander, 1981; Armbrustmacher, 1984; Cappa, 1998). The mafic and ultramafic rocks in the northeast are reportedly funnel-shaped; intruded by the hornblende-biotite syenite and several syenite/carbonatite dikes; and contain a series of layered rocks formed by magmatic cumulate processes, and some intrusive plugs of pyroxenite and anorthosite (Kilbane, 1978; Armbrustmacher, 1984). The gabbro contains lenses of titaniferous magnetite bodies ~ 1.5 to 8 meters (m) wide, several tens of meters long, and in places, form several alternating layers with the gabbro (Becker and others, 1961). Fenitization occurs near the contact between the intrusion and the host rock (minor) and it also occurs adjacent to some of the numerous dikes within the major intrusive bodies and surrounding Proterozoic gneiss and granite (Kilbane, 1978; Alexander, 1981; Armbrustmacher, 1984).

Dikes associated with the McClure Mountain alkaline complex are abundant to the west, northwest and north of McClure Mountain — sometimes called a dike halo — and extend north of the Arkansas River Valley (Figure 2) (Kilbane, 1978; Heinrich and Dahlem, 1967; Heinrich and Dahlem, 1968; Heinrich and Salotti, 1975; Alexander, 1981). Alexander (1981) mapped more than 200 dikes and numerous veinlets in the dike halo area that have not been included in this data compilation (the CGS was unable to obtain a complete copy of the map associated with this dissertation). Gabbro dikes and irregular masses that cut Proterozoic rocks crop out to the northeast of McClure Mountain and north of the Arkansas River Valley (Taylor and others, 1975). The age of these dikes is uncertain but thought to be Cambrian based on dates of other gabbro outcrops in the area (Taylor and others, 1975). Some dikes associated with the McClure Mountain alkaline complex (~524 millions of years ago [Ma]) may be significantly younger (483 ± 2 Ma, or Early Ordovician) than the main intrusive body (Pivarunas and Meert, 2019). Other dike rock types include lamprophyres, carbonatites, various syenite dikes, and thorium-bearing veins (Armbrustmacher, 1979 and 1984).

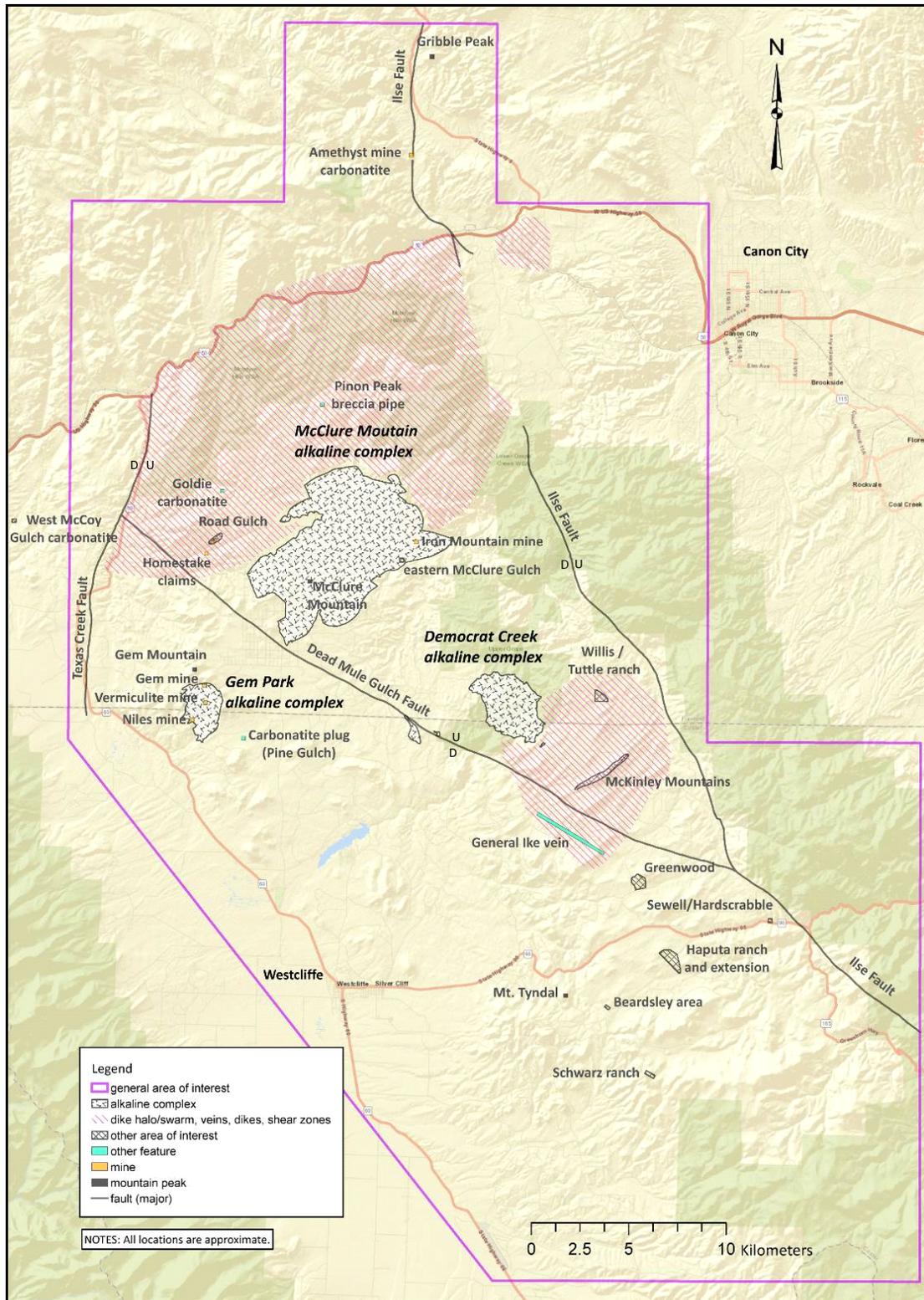


Figure 2 – Location of the Wet Mountain alkaline complexes and other site features.

Alexander (1981) provided a more detailed petrology of the dike rock types that includes: melagabbro, trachytes, mela-nepheline syenite, nepheline syenite, lamprophyres, carbonatites, soda trachytes, and quartz trachytes. Breccia pipes have been observed north of McClure Mountain (Heinrich and Dahlem, 1967) and near the Democrat Creek alkaline complex. Carbonatite dikes thought to be associated with the McClure Mountain alkaline complex are observed as far north as the Amethyst mine (Heinrich and Shappirio, 1966) and also west of the Texas Creek Fault at West McCoy Gulch (Figure 2) (Heinrich and Salotti, 1975). Carbonatite veins in the Road Gulch area (Figure 2) crop out along a ~450 m-long northeast-trending shear zone located west of the McClure Mountain alkaline complex (Staatz and Conklin, 1966).

Gem Park

The Gem Park alkaline complex contains mafic and ultramafic rocks, including layered cumulate rocks with varying percentages of plagioclase, clinopyroxene, olivine, and magnetite. Parker and Sharp (1970) (also Papson, 1981) identified gabbro and pyroxenite rock outcrops at the Gem Park alkaline complex while Armbrustmacher (1984) referred to these rocks as plagioclase-clinopyroxene orthocumulates (rocks containing ~75 to 85% minerals in the groundmass) and clinopyroxene adcumulates (rocks containing ~93 to 100% mineral crystals in a fine-grained groundmass), respectively. Plagioclase and magnetite cumulate rocks are also observed in the area. Papson (1981) reported that the contact between the pyroxene and gabbro is gradational and the pyroxenite appears to be associated with larger carbonatite dikes as observed in drill hole core. Most of the cumulate mafic-ultramafic rocks are similar to the McClure Mountain alkaline complex although lower amounts of olivine were observed in the Gem Park alkaline complex (Armbrustmacher, 1984). Mineral-layering in the cumulate rocks dips toward the center of the complex, suggesting a funnel-shaped intrusion (Armbrustmacher, 1984). Other exposed rock types at the Gem Park alkaline complex include nepheline-syenite-pegmatite and, similar to McClure Mountain, lamprophyre, syenite, and carbonatite dikes (Parker and Sharp, 1970; Papson, 1981; Armbrustmacher, 1984). Like the McClure Mountain alkaline complex, red syenite dikes, typically radioactive, also intrude rocks of the Gem Park alkaline complex and south of the alkaline complexes (Armbrustmacher, 1988). A small

carbonatite plug at Pine Gulch was identified to the east of the main complex (Figure 2) (Parker and Sharp, 1970; Armbrustmacher, 1988). Two general types of fenitization occur at the Gem Park alkaline complex: alteration due to the later intrusions (mostly carbonatites) and alteration in the surrounding country rock from the earlier intrusion of the complex (Armbrustmacher, 1984). The occurrence of vermiculite near the center of the Gem Park alkaline complex may be associated with a carbonatite intrusion in the subsurface (Armbrustmacher, 1984).

Democrat Creek

At the Democrat Creek alkaline complex, a majority of the exposed intrusive body is quartz syenite (compared to the absence of quartz in the McClure Mountain syenite). The quartz syenite is bordered by an early intrusive breccia, with syenite and Proterozoic metamorphic rock fragments, and surrounded by a relatively younger syenite (Taylor and others, 1975; Alexander, 1981; Armbrustmacher, 1984). There are reportedly six breccia bodies along the south border of the main quartz syenite intrusion (Christman and others, 1959; Alexander, 1981). Other rock types in the complex include minor amounts of relatively older gabbro intruded by syenite along the southern margin (Alexander, 1981), and additional lenses of gabbro and ultramafic rocks, reported by some authors as metamorphosed, which crop out south of the complex (Christman and others, 1959; Brock and Singewald, 1968).

Gabbro and pyroxene-rich ultramafic dikes and irregular masses also occur up to 24 km southeast of the Democrat Creek alkaline complex. Taylor (1974) indicates that the age of these rocks is likely Cambrian based on similar rock types near the Gem Park and McClure Mountain alkaline complexes. Several other dike rock types occur south-southeast of the Democrat Creek alkaline complex including gabbro, lamprophyre, syenite, quartz syenite, mafic syenite, carbonatite (mostly replacement — see discussion in the following sub-section), and quartz-barite-thorite veins (Christman and others, 1959; Brock and Singewald, 1968; Armbrustmacher, 1988). Between ~350 and 400 veins were mapped southeast of the Democrat Creek alkaline complex, in an area known as the McKinley Mountain area (Figure 2), with most dikes trending between N 50° W to N 70° W with other documented trends (Christman and others, 1959).

Veins occur along fractures as coatings (no visible vein material), fracture fillings, or wall-rock replacement (Christman and others, 1959; Armbrustmacher, 1988).

Carbonatites, Red Syenite Dikes, and Quartz-Barite-Thorite Veins

Most of the elevated concentrations of thorium, uranium, REEs, and niobium observed in samples collected in the Wet Mountains alkaline complexes are associated with dikes, fracture zones, veins, and irregular masses. Dikes and veins in the Wet Mountains area generally include carbonatites, red syenite, lamprophyre, and quartz-barite-thorite veins. Carbonatites occur as dikes and irregular-shaped intrusions in and around both the Gem Park and McClure Mountain alkaline complexes (Armbrustmacher, 1988).

Previous work attempted to group carbonatites in the area (Heinrich and Dahlem, 1969; Parker and Sharp, 1970; and Armbrustmacher, 1979). For example, at the Gem Park alkaline complex, Parker and Sharp (1970) divided the carbonatite dikes into four mineralogical categories, including dolomite-pyroxhlore, dolomite-apatite, dolomite-blue-amphibole-pyroxhlore, and dolomite-barite-monazite dikes. However, these categories made it difficult to classify other carbonatites observed in the area (Armbrustmacher, 1979; Papsen, 1981). Armbrustmacher (1979) divided the carbonatites associated with the alkaline complexes into replacement and primary magmatic types based on petrography, mineralogy, and geochemistry. Replacement carbonatites show nearly complete replacement textures of original igneous rocks; contain elements associated with carbonatites; contain trace element signatures of the original precursor rocks; and minerals containing thorium, niobium, and REEs as primary constituents are generally rare (Armbrustmacher, 1979). Primary magmatic carbonatites do not show replacement textures; contain greater average amounts of elements associated with carbonatites; and contain thorite, bastnaesite, synchisite, ancylite, and monazite. These minerals are generally responsible for the elevated concentrations of thorium and REEs observed in the carbonatites compared to the other intrusive rocks in the area (Armbrustmacher, 1979). Well-known carbonatites in the area include the Goldie carbonatite (Heinrich, 1965), McClure Gulch carbonatites (Armbrustmacher and others, 1979), Amethyst

carbonatite (Heinrich and Shappirio, 1966), the Gem Park carbonatites (Parker and Sharp, 1970; Roden, 1977; Papson, 1981), Pine Gulch carbonatite plug (Parker and Sharp, 1970; Armbrustmacher, 1988), and the Road Gulch area carbonatites (Staatz and Conklin, 1966) (Figure 2). Armbrustmacher (1988) provides a summary of the geology and mineralization at most of these locations.

Red syenite dikes mainly occur south of the alkaline complexes. Although their thickness is highly variable, these dikes are typically ~1-meter thick, they contain elevated concentrations of thorium, and they intrude Proterozoic rocks and some of the intrusive bodies at the McClure Mountain and Gem Park alkaline complexes (Armbrustmacher, 1988). Red syenite dikes can be traced for several kilometers and contain thorium- and REE-bearing minerals, including brockite, thorite, and possibly bastnaesite (Armbrustmacher, 1988).

Quartz-barite-thorite veins and fracture zones have been identified as far north as the Amethyst carbonatite as far south as the Custer-Huerfano county line (Figure 2). These veins and fracture zones reportedly contain the largest resources of thorium in the area, appear to be more abundant south of the alkaline complexes, and typically are radioactive. Many of these radioactive veins/fracture zones southeast of the Democrat Creek alkaline complex were mapped out in the 1950s (Christman and others, 1959). Material within the vein is reportedly irregular and unpredictable; therefore, collecting a representative sample from these veins may be difficult (Armbrustmacher, 1988). As with the red syenite dikes, these veins include two types of mineral suites: epigenetic minerals deposited by hydrothermal fluids and other minerals deposited in the vein/fracture zone host rocks (Armbrustmacher, 1988). Epigenetic thorium and REE-bearing minerals include brockite, monazite, synchsite, thorite, xenotime, and possibly ancylite. The quartz-barite-thorite veins also typically contain primary iron oxides (hematite) and secondary iron oxides, including goethite, hematite, and possibly jarosite (Armbrustmacher, 1988). Limonite (iron oxide) is also present (Christman and others, 1953b). Other minerals associated with the quartz-barite-thorite veins include galena (common),

altered to cerussite in places, and other sulfide minerals that are less common, like sphalerite, chalcopyrite, and pyrite (Armbrustmacher, 1988).

Economic Geology

Historic mineral-related activities in this area includes small-scale mining of titaniferous (ilmenite-rich) magnetite in the mafic and ultramafic rocks at the Iron Mountain Mine within the McClure Mountain alkaline complex (Figure 2). Production at this mine started in 1873 (Singewald, 1913; Harrer and Tesch, 1959; Becker and others, 1961; Shawe and Parker, 1967). Before 1955, total production from the mine was likely below a few thousand tons. Magnetite aggregate was produced in 1955 and 1956 for use in underwater pipeline applications (Becker and others, 1961). Analyses of titaniferous magnetite samples from the mine detected between ~47.9-50.7% iron with 13.5-14.1% titanium dioxide (TiO₂) (Becker and others, 1961).

Limited mining activities at the Gem Park alkaline complex consisted of shallow workings at the Gem Mine (Figure 2) that reportedly produced an unknown but small quantity of nickel-silver ore before 1885, and two vermiculite mines: the Niles Mine to the west and an unnamed mine (vermiculite mine) in the center of the district (Figure 2), that together produced 3,000 tons of vermiculite prior to and during World War II (Parker and Sharp, 1970). Parker and Sharp (1970) reported that an unknown minor amount of magnetite ore was removed from the surface in the southern portion of the Gem Park alkaline complex. Armbrustmacher (1984) reported that activities in and around the Gem Park alkaline complex have included exploration for nickel, native silver, vermiculite, niobium, magnetite, and ornamental stone. Eckel (1961) reported the occurrence of niccolite, annabergite, chalcocite, and native silver, with small amounts of bornite, pyrite, and chalcopyrite at the Gem Mine, possibly from a Gem Park alkaline complex carbonatite (Armbrustmacher, 1988). The main ore mineral at the historic Gem Mine was niccolite, partly altered to annabergite, with some ore containing 34% nickel and 3-4% copper (Eckel, 1961). The niccolite occurs in globular masses disseminated through what Eckel (1961) called "*granular limestone*," but was later identified as carbonatite.

As reported by Armbrustmacher (1988) and summarized by Long and others (2010), syenite, mafic, and ultramafic rock units within the main alkaline complexes do not contain elevated concentrations of thorium or REEs when compared with other dikes/veins in the area:

- McClure Mountain alkaline complex syenites, pyroxenite, and gabbro = up to 10 parts per million (ppm) thorium, up to 335 ppm REEs (Long and others, 2010).
- Gem Park alkaline complex gabbro and pyroxenite = up to 13 ppm thorium, average of 190 ppm REEs (Long and others, 2010).
- Democrat Creek alkaline complex quartz syenite = average 62 ppm thorium, 700 ppm REEs (Long and others, 2010).

Christman and others (1953a, 1953b, 1959) conducted their investigations and economic assessments in an area known as the Wet Mountains thorium district. These assessments included detailed radioactive surveys, sampling, geological mapping, and a small drilling program at Haputa Ranch (Figure 2). They reported elevated thorium concentrations along northwest-trending veins, dikes, and fractures over a large area near the alkaline complexes and especially in the McKinley Mountain area east and southeast of the Democrat Creek alkaline complex (Figure 2). In the McKinley Mountain area and southeast, thorium resource assessments were conducted mostly in an area extending ~18 km south-southeast and ~6 km east of the Democrat Creek alkaline complex. Fracture zones and veins containing elevated radioactivity were also identified at locations near the Custer-Huerfano border (20 km southeast of the Democrat Creek alkaline complex) and in areas adjacent to and between the three alkaline complexes (Christman and others 1953; Christman and others, 1959; Staatz and Conklin, 1966; Parker and Sharp, 1970; Armbrustmacher and Brownfield, 1978; Armbrustmacher, 1988). Thorium is generally found in carbonatites, red syenite dikes, and quartz-barite-thorite veins and fracture zones, with most of the historical exploration concentrating on the quartz-barite-thorite veins where higher concentrations of thorium were observed (Armbrustmacher, 1988). Elevated concentrations of light REEs (LREEs) and heavy

REEs (HREEs) associated with the thorium deposits were reported in some areas as discussed below.

Southeast of the Democrat Creek alkaline complex, larger faults are not mineralized; reportedly, some dikes are completely mineralized or they are unaltered and adjacent to mineralized veins within the same fracture (Armbrustmacher, 1988). Most of the veins are < 1.5 m wide and can be traced for over 300 m. A few of these veins are up to ~15 m wide and extend up to ~1,500 m (Christman and others, 1959; Armbrustmacher, 1988). However, the General Ike vein is 3,139 m long, averages only about 0.3 m wide, and is 76 m deep (Armbrustmacher, 1988). Elevated thorium concentrations were detected in veinlets, and vein coatings, disseminated through fracture zones, and found in more well-defined veins with quartz, barite, carbonatite, and various types of iron oxide (Christman and others, 1953b; Christman and others, 1959; Armbrustmacher, 1988). Exploration in this area and farther southeast revealed additional areas (Figure 2) with elevated thorium and, in some cases, elevated REEs, including the Beardsley area, General Ike vein, Greenwood property, Haputa Ranch, Tuttle (Willis or Lepley) Ranch, Sewell Ranch, and Schwarz Ranch. Drilling and sampling activities discovered at least five shear zones, three of which were reportedly of economic interest in the 1950s, containing elevated thorium and REE concentrations in the Haputa Ranch area (Christman and others, 1953b; Christman and others, 1959). The following average (arithmetic mean) concentrations were reported for some of these areas, as summarized by Armbrustmacher (1988):

- Beardsley area, 1 sample: 1,090 ppm LREEs; 810 ppm HREEs; 3,412 ppm thorium.
- General Ike vein, 10 samples: 1,839 LREEs ppm; 331 HREEs ppm; 1,922 ppm thorium.
- Haputa Ranch area, 10 samples: 1,478 ppm LREEs; 8,581 ppm HREEs; 6,855 ppm thorium.
- Tuttle (Lepley) Ranch area, 9 samples: 710 ppm LREEs; 1,014 ppm HREEs; 4,704 ppm thorium.
- Schwarz Ranch, 6 samples: 2,175 ppm LREEs; 7,690 ppm HREEs; 39,625 ppm thorium.

Additionally, based on 46 sample analyses, it appears that the red syenite dikes contain between: 0.011 and 4% thorium with a mean of 0.27%; < 0.06 to 0.5% LREEs with a mean of 0.078%; and <0.05 to 1% HREEs with a mean of 0.077% (Armbrustmacher, 1988). Based on the analyses of 201 samples of veins and fractures in the Wet Mountains area, Armbrustmacher (1988) reported an average grade of 0.46% thorium dioxide (ThO₂) with an average thorium-to-total-REEs ratio of about 2.2:1. Armbrustmacher (1988) reported the following resource estimates associated with these veins and fractures:

- Reserves of 64,200 tons ThO₂ and probable potential resources of 160,500 tons ThO₂ in veins and fracture zones.
- Based on an average grade of 0.21% total LREEs and 0.14% total HREEs, reserves of 29,300 tons total LREEs and probable potential resources of 73,200 tons total LREEs. Reserves of 19,540 tons total HREEs and probable potential resources of 48,850 tons total HREEs.
- Based on samples containing 0.012% niobium pentoxide (Nb₂O₅), reserves of 1,675 tons Nb₂O₅ and probable potential resources of 4,185 tons.

As documented by Armbrustmacher (1988), *“Total resources are divided into reserves— that is, those resources that are directly measured and sampled—and into probable potential resources, which are logical extensions of measured reserves both laterally and vertically.....Reserves were calculated by multiplying the known length of the vein by average thickness by a depth equal to one-third the length but not exceeding 3,000 feet. A tonnage factor of 12 ft³/short ton converts vein volume to vein weight. Vein weight is then multiplied by the average grade of the particular elements. To calculate probable potential resources, the vein was extended along the surface 25 percent of the known length in each direction unless limited by geologic constraints. The same average width is used and vein depth is calculated the same as for reserves.”*

Additional smaller resources reported by Armbrustmacher (1988) include primary carbonatite dikes in the Wet Mountains area. Average grades and resources of the seven largest carbonatite dikes observed at the surface include (Armbrustmacher, 1988):

- 0.17% ThO₂; 131 tons of reserves; 753 tons probable potential resources.
- 2.15% total REEs; 2,500 tons of reserves; 14,300 tons probable potential resources.
- 0.0097% Nb₂O₅; 40 tons of reserves; 228 tons probable potential resources.
- 0.0031% triuranium octoxide (U₃O₈); 17 tons of reserves; 105 tons of probable potential resources.

Several additional reports identified the Wet Mountains area as a potential source of REEs and other critical minerals (Parker and Sharp, 1970; Cappa, 1998; Orris and Grauch, 2002; Long and others, 2010; Van Gosen and others, 2019). For example, Orris and Grauch (2002) estimated REEs resources and ore grades of 13.96 million metric tons with 1.0% rare earth oxides. Armbrustmacher (1979) reported that carbonatite dikes, especially the primary carbonatites, possibly contain a potential resource for REEs, niobium, and thorium, with the greatest potential at the Gem Park alkaline complex. Previous investigations proposed that a larger concealed carbonatite body or bodies and other alkaline rocks may exist at depth in this area, especially at the Gem Park alkaline complex (Parker and Sharp, 1970; Papson, 1981; Armbrustmacher, 1988). According to Armbrustmacher (1988), drilling in the Gem Park alkaline complex area uncovered “*economically interesting*” amounts of niobium in a stockwork carbonatite that intruded other rocks of this complex. Also, coarse-grained clinopyroxene accumulates observed in a drill core collected from the northern portion of the Gem Park alkaline complex contained epigenetic sulfide minerals, including pyrite, pyrrhotite, and chalcopyrite (Armbrustmacher, 1984).

Investigations at the Gem Park alkaline complex (Parker and Sharp, 1970; Papson, 1981) reported some of the highest REEs concentrations in the Wet Mountains area, especially in the dolomite-barite-monazite carbonatite dikes associated with monazite, ancylite, and apatite —

total REEs concentrations average ~4% and go up to ~10% (Parker and Sharp, 1970). Parker and Sharp (1970) also reported other types of carbonatite dikes in this area (e.g., dolomite-apatite carbonatite, dolomite-pyrochlore carbonatite, and dolomite-blue-amphibole-pyrochlore carbonatite) average ~0.2% REEs. The carbonatites and fenitized rocks, or fenite, contain mostly LREEs (La, Ce, Nd); most of the REEs detected in the fenite are associated with monazite, they noted. Parker and Sharp (1970) also indicated that elevated concentrations of phosphorus (up to ~10%) occur in most of the carbonatites in the Gem Park alkaline complex but especially in the dolomite-barite monazite carbonatites mostly associated with apatite and monazite.

Results of the drilling at the Gem Park alkaline complex were summarized by Armbrustmacher (1988) and presented in Papson (1981). Lithology logs from three borings, two angle holes (completed to ~120 and 180 m below the surface), and one vertical hole (completed to 448 m below the surface) were included in Papson (1981) and documented small carbonatite dikes — about 10 between ~15 centimeters [cm] and 0.6 m thick; one is ~1.5 m thick — to a depth of ~448 m below the surface at the Gem Park alkaline complex (Papson, 1981). The following concentrations were reported by Papson (1981) based on the analyses of 29 samples from drill core collected from the Gem Park alkaline complex:

- Total REEs range between 121 and 57,165 ppm with an average of 13,974 ppm.
- LREEs range between 100 and 56,700 ppm with an average of 13,588 ppm.
- HREEs range between 11 and 3,650 ppm with an average of 386 ppm.
- Niobium ranges between 10 and 7,000 ppm with an average of 745 ppm.
- Strontium ranges between 1,500 and more than 100,000 ppm with an average of 23,086 ppm.
- Thorium ranges between 2 and 590 ppm with an average of 104 ppm.
- Uranium ranges between 0.2 and 131 ppm with an average of 18 ppm.

As summarized by Armbrustmacher (1988), Papson (1981) identified at least three types of carbonatites at the Gem Park alkaline complex (from oldest to youngest):

- Oldest carbonatite: dolomite, fluorapatite, magnetite, and phlogopite with accessory pyrochlore and zircon with low-grade niobium (mean = 584 ppm) and REEs (mean = 3,713 ppm) occurring mostly in pyrochlore. Also, uranium and copper were detected at concentrations up to 131 ppm and at a mean of 49 ppm, respectively.
- Intermediate carbonatite: calcite, monazite, hematite, pyrite, and bastnaesite with higher-grade niobium (mean = 1,754 ppm) and REEs (mean = >3.35% or 33,500 ppm) with less uranium (up to 3 ppm) and about the same for copper. Only small dikes of this material were observed; however, larger deposits of this carbonatite could exist.
- Youngest carbonatite: calcite, barite, and strontianite with accessory celestite, ancylite, and rhabdophane with the lowest grade of niobium (mean = 190 ppm) and the highest grades of REEs (mean > 5.23% or 52,300 ppm) with trace uranium and about the same for copper.

DATA COMPILATION

Published reports document the geology, mineral occurrences, and geochemistry of the Wet Mountains alkaline complexes. The CGS compiled historical sample locations and laboratory results for REEs, niobium, thorium, uranium, and strontium from these reports into an ArcGIS file to provide a summary of the available data in electronic format and to guide future mineral exploration and mapping in this area. Examples of the data compilation are provided as Figure 3 for REEs, Figure 4 for LREEs, Figure 5 for HREEs, Figure 6 for niobium, and Figure 7 for thorium. Results from samples collected by the CGS were also included and are discussed in Appendix A. Analytical data were compiled from the following reports into the ArcGIS file:

- Christman and others (1953a and 1953b).
- Christman and others (1959).
- Staatz and Conklin (1966).
- Shawe and Parker (1967).
- Parker and Sharp (1970).
- Kilbane (1978).
- Roden (1977).
- Armbrustmacher and Brownfield (1978).
- Papsen (1981).
- Armbrustmacher (1988).

Some of the data limitations are discussed here and provided in the data compilation. For a full discussion of analytical data limitations, please see the referenced reports. Much of the data presented in the above reports were provided in percent or weight percent (both assumed to be weight percent) and are converted here to ppm by multiplying by 10,000. Although much of the data reported in Christman and others (1953a) was the same as Christman and others (1953b), there were slight variations in the reported results; therefore, both sets of data are included in the compilation.

REEs, thorium, and uranium concentrations reported in many of the older publications were calculated or estimated using concentrations of other elements or compounds. For example, thorium oxide was calculated from the equivalent uranium by subtracting the analyzed chemical uranium and multiplying the difference by a conversion factor. In some cases, REEs concentrations were calculated in a similar way and then reported as rare earth oxide concentrations. Analytical results from many of the studies included in this compilation were reported as semiquantitative. For example, Parker and Sharp (1970) noted that all of their results were reported as semiquantitative. They indicate that their results were: *“reported in percent to the nearest number in the series 1, 0.7, 0.5, 0.3, 0.2, 0.15, 0.1, and so forth; these numbers represent approximate midpoints of group data on a geometric scale. The assigned group for semiquantitative results will include the quantitative value about 30 percent of the time.”*

The CGS georeferenced figures from these historic publications and the points were digitized from these maps in ArcGIS. Several of the maps did not contain enough detail to accurately determine their exact location during georeferencing. This is especially true for several of the maps/figures provided in Christman and others (1953a, b). For example, the location of the detailed maps provided in this publication for both the Greenwood property and Haputa Ranch area did not provide a survey grid; georeferencing these maps was completed by using roads and other features. Therefore, the location of sample locations provided on several maps are estimated and may vary up to +/- 150 m. The sample locations in Armbrustmacher and Brownfield (1978) are provided on a generalized map within the report and appear to correlate with unnumbered points on the plate provided in Armbrustmacher (1988). This CGS report uses both the figure and plate to more accurately display these locations. Locations of carbonatites, faults, veins, and dikes were digitized from Armbrustmacher (1988, see Plate 1). The estimated location of the West McCoy Gulch carbonatite is from Heinrich and Salotti (1975).

This publication includes the following files for download on the CGS website:

- CGS_OFR20_11_WetMtns.shp – An ArcGIS shapefile with locations (NAD 83 meters), select analytical data (REEs, niobium, strontium, thorium, uranium, and titanium), sample descriptions, and references. A data dictionary is included in the metadata for this file.
- OFR-20-11D Wet Mountains Critical Mineral Data Compilation.xlsx – A Microsoft Excel file containing the same information as the ArcGIS shapefile and a data dictionary.
- OFR-20-11D Wet Mountains Critical Mineral Data Compilation.csv – A comma-separated file containing the same information as the ArcGIS shapefile.

A data dictionary is also provided in Appendix B of this report.

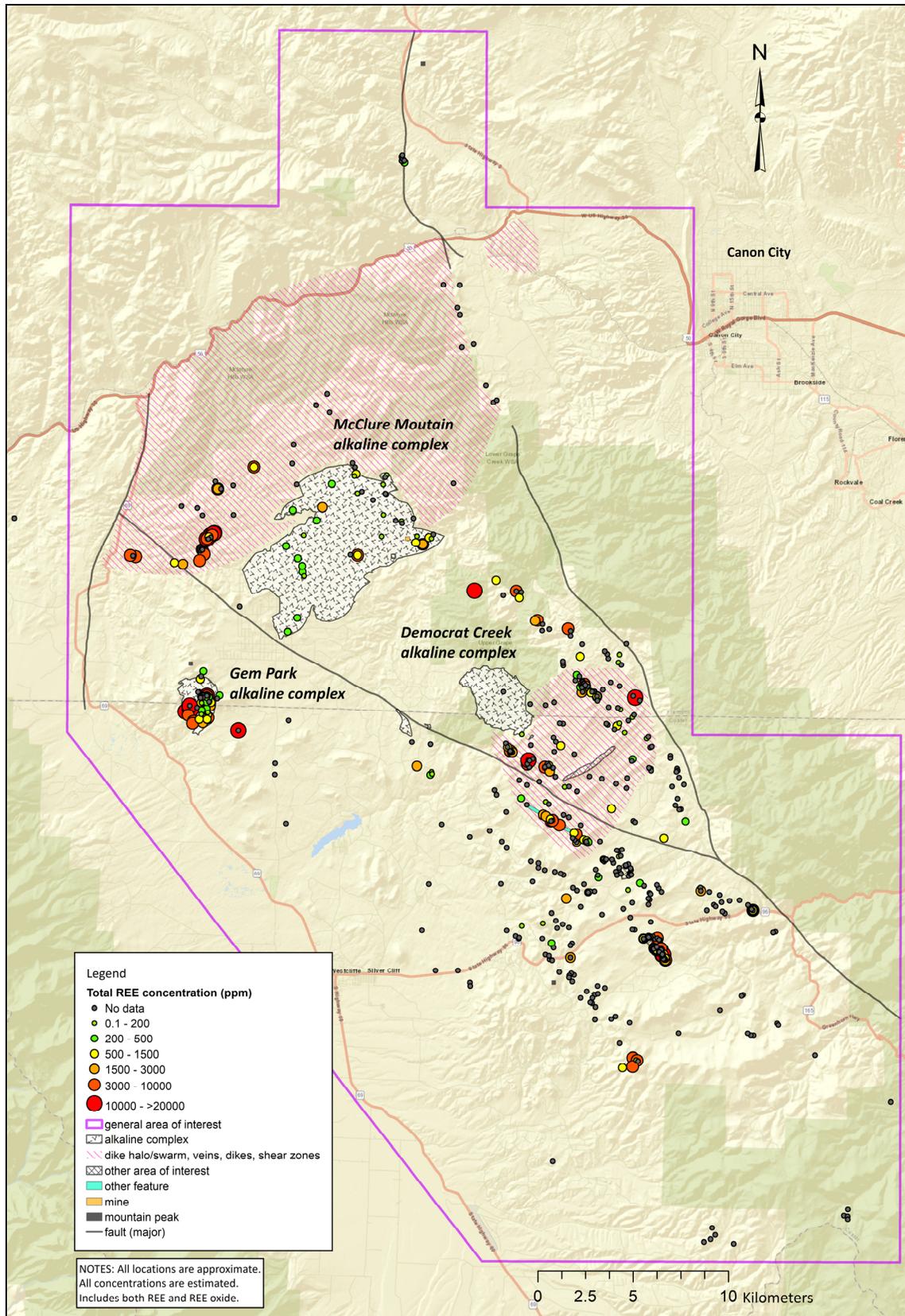


Figure 3 – Distribution of total REEs concentrations.

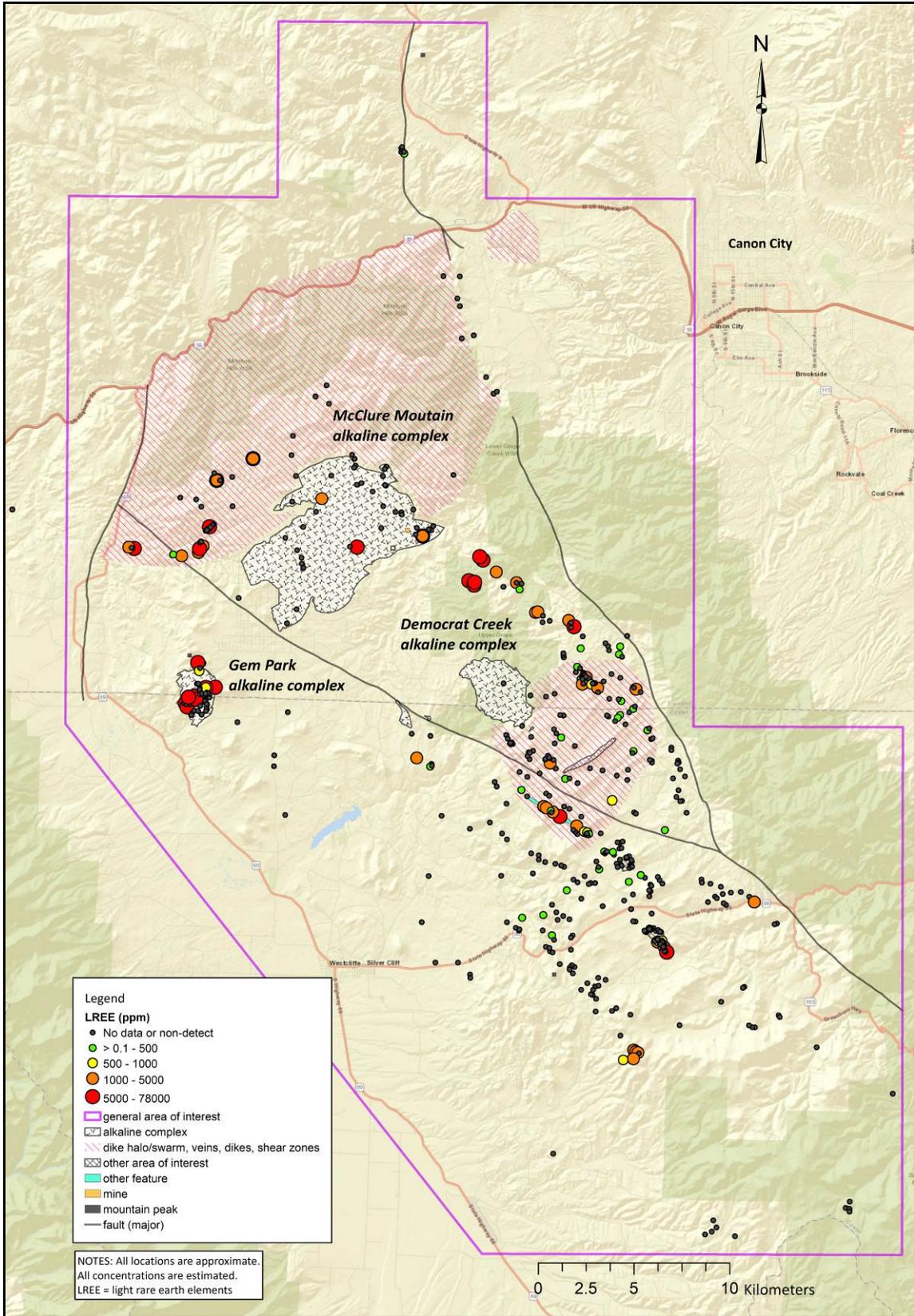


Figure 4 – Distribution of LREEs concentrations.

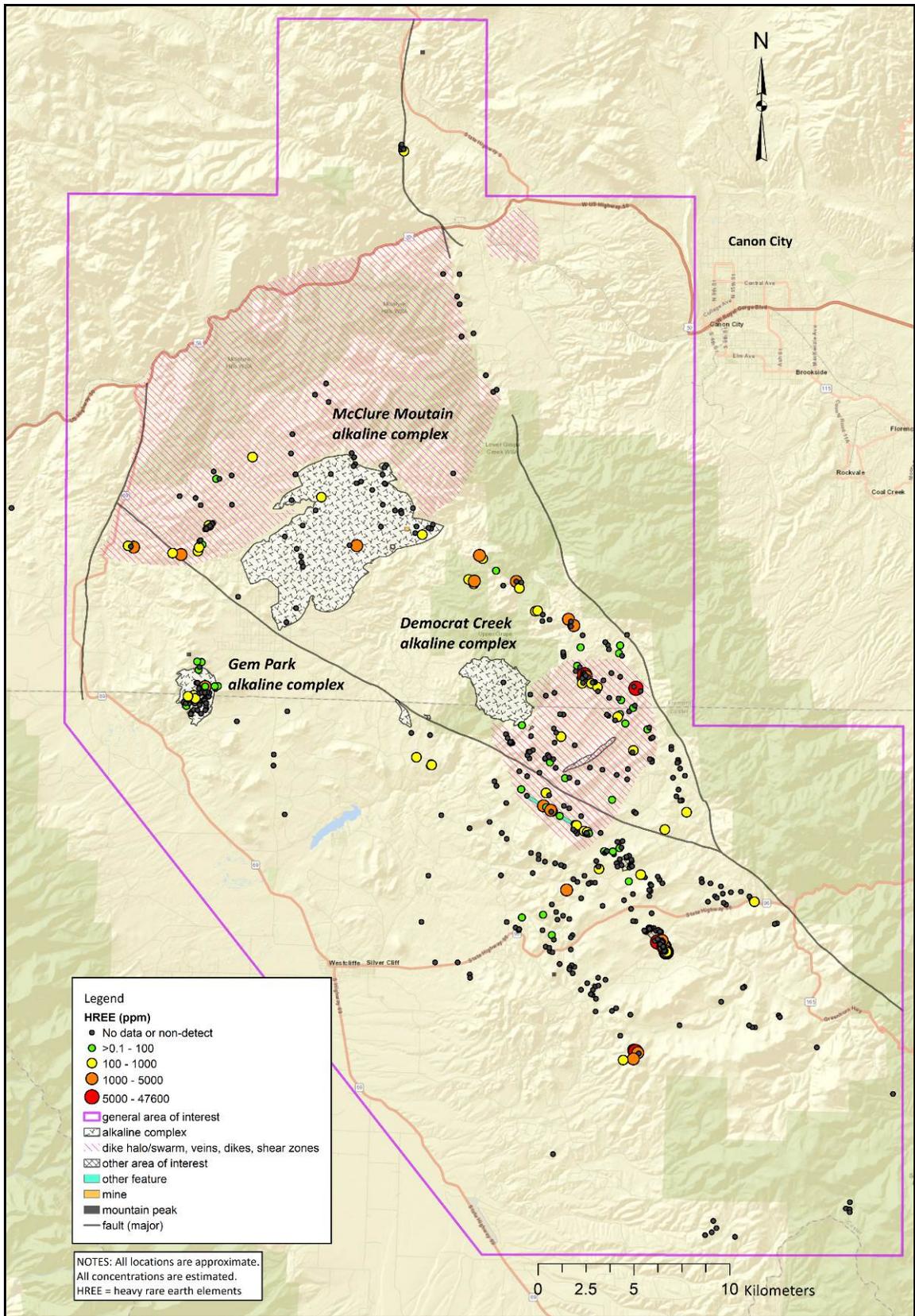


Figure 5 – Distribution of HREEs concentrations.

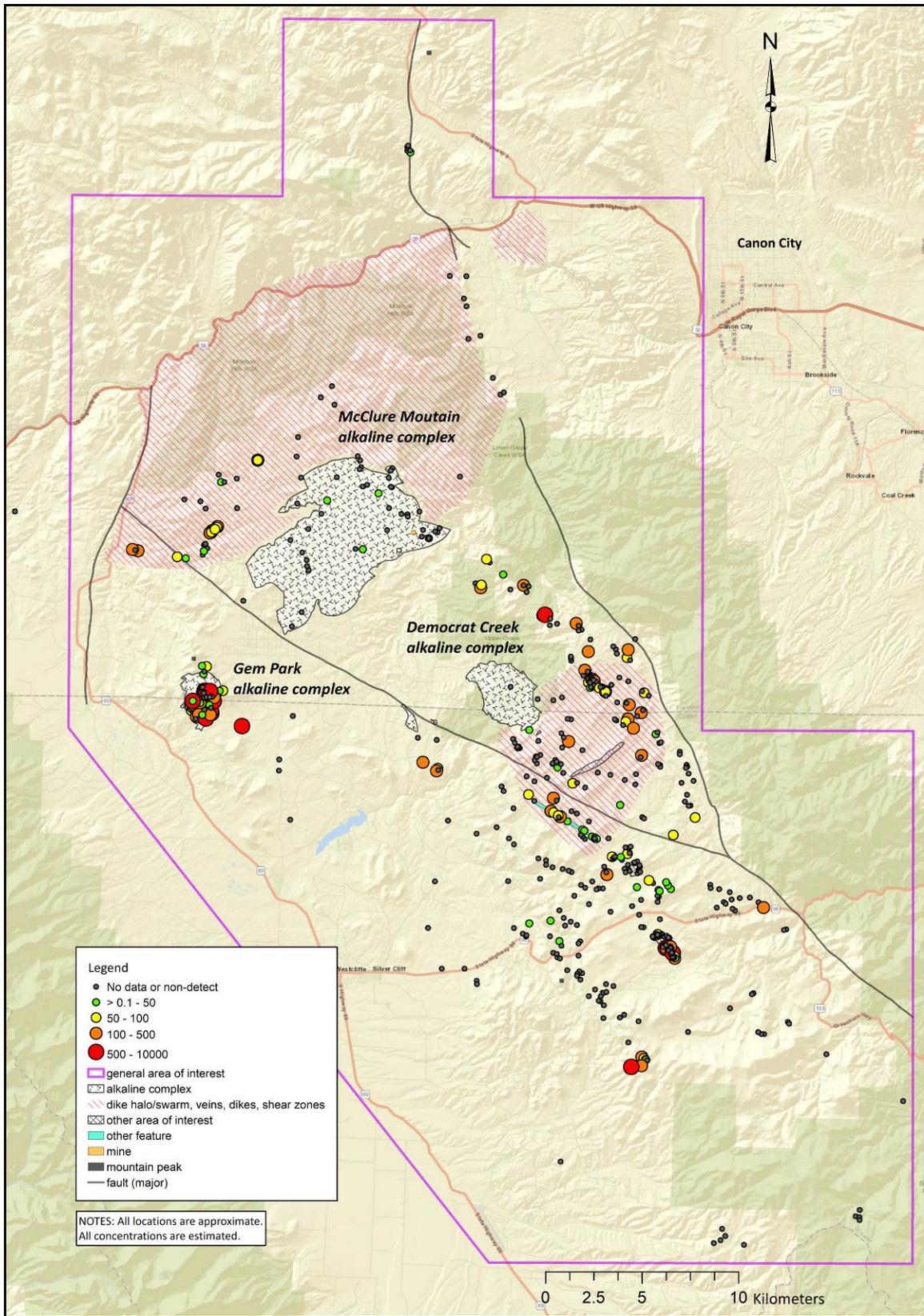


Figure 6 – Distribution of niobium (ppm) concentrations.

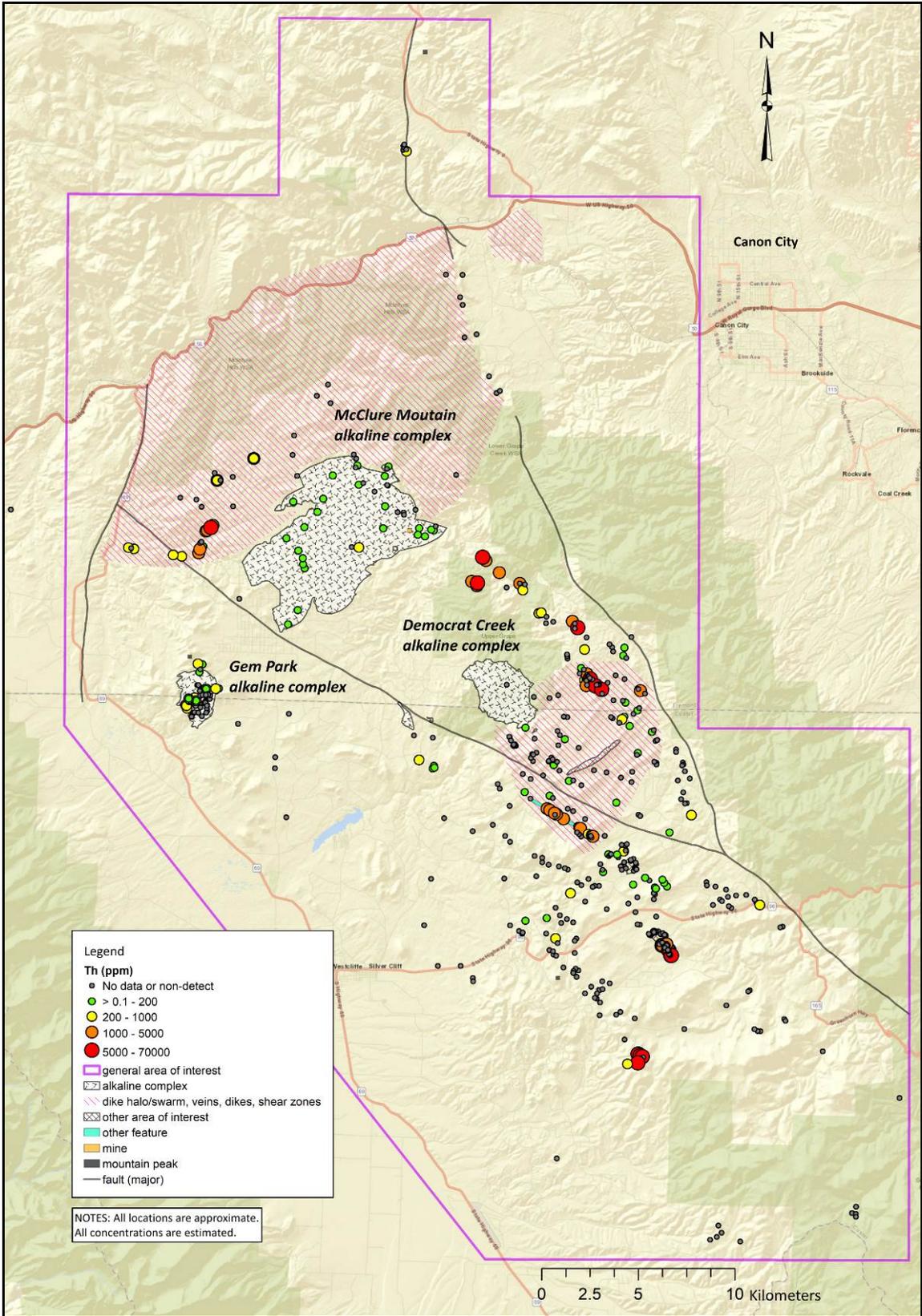


Figure 7 – Distribution of thorium concentrations.

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APPENDIX A – CGS 2018 SAMPLING RESULTS

The CGS performed a limited investigation of the Sewell Ranch vein (see Figure 2 of the report) and two other locations in the Wet Mountains. These locations are included in the ArcGIS compilation presented in this report. This appendix includes a description of these sample locations and presents the laboratory results for locations WM-1 through WM-8. Most of these samples — WM-1 through WM-6 — were collected across a ~3.6-m-thick quartz-barite-thorite vein located at the Sewell Ranch area on the north side of Highway 96 about 2 km west of the Highway 96/165 junction. More information about this vein is provided in Christman and others (1953a, b — Note: see bibliography in report for references) and was also later sampled by the USGS (Long and others, 2010). Sample descriptions are included in Table A1. Discrete samples of different rock types observed in the field were collected across the vein, as shown in Figures A1 and A2, to determine the magnitude and general distribution of REEs, thorium, uranium, and other elements. Close-up pictures of the quartz-barite-thorite vein rocks are included as Figure A3. Sample WM-7 was collected from a waste pile near an adit located about 0.5 km northwest of the Greenwood property (Figure A4). Sample WM-8 was collected from a pile of material adjacent to a prospect pit about 0.5 km southeast of the Greenwood property (Figure A5). Abundant white barite was observed in the samples from both WM-7 and WM-8.

Field screening measurements of radioactivity in counts per minute were collected in the field and at the CGS office using a portable handheld gamma ray spectrometer (scintillometer) (Radiation Solutions Inc. Model RS-125). Potassium, thorium, and uranium concentrations were also measured using the assay mode of this device. Measurements were taken on the outcrop, before the samples were collected, and on the samples themselves at the office. Results of the field screening measurements are summarized in Table A1. Samples were analyzed by the Peter Hooper GeoAnalytical Laboratory at Washington State University by inductively coupled plasma mass spectrometry (ICP-MS) and X-ray fluorescence spectrometry (XRF). The results of the ICP-MS and XRF analyses are provided in Tables A2 and A3, respectively.

Sample Location	Sample Name	Sample Type	Sample Description ¹	Outcrop Field Screening Results ²				Sample Field Screening Results ²			
				Thorium (ppm)	Uranium (ppm)	Potassium (%)	Counts per minute	Thorium (ppm)	Uranium (ppm)	Potassium (%)	Counts per minute
WM-1	WM-1	grab	Gneiss adjacent to vein, abundant quartz veins/veinlets, reddish-brown iron oxide.	204.3	6.5	3.6	12,600	28.3	4.3	1.8	2,824
WM-2	WM-2	grab	Fractured gneiss, 1- to 3-inch quartz veins, iron oxides along quartz veins, altered (finitized?) in places.	186.0	11.9	2.6	12,349	20.6	5.5	2.1	2,596
WM-3	WM-3	grab	Abundant iron oxide (yellowish-brown with some reddish hues), vein rock is unknown and altered (finitized?), large (2- to 7-inch) quartz veins, barite, limonite.	908.4	39.3	3.9	54,475	49.9	4.5	1.7	3,943
WM-4	WM-4A/4B	grab	Highly altered (finitized?) vein material, rock type unknown, yellowish-brown.	484.4	20.0	3.8	28,874	26.4	4.0	1.9	2,544
WM-5	WM-5	grab	Large quartz/barite vein (about 3-feet wide), altered vein host rock, abundant iron oxide.	858.6	40.4	2.6	51,741	33.0	4.9	1.7	3,029
WM-6	WM-6A/6B	grab	Edge of the vein, no or little quartz, altered vein material (rock type unknown), abundant iron oxides.	620.0	19.7	4.3	36,368	154.5	0	2.4	9,467
WM-7	WM-7	grab	Waste pile sample, mined-out vein, estimated at ~12 feet wide, highest reading of 2,200 counts per second in mined out area, background was ~200 counts per second, when sampled rocks do not show elevated radiation, abundant yellowish-brown iron oxides, vein strikes ~north 48-degrees west.	na	na	na	na	25.1	3.8	1.9	2,598
WM-8	WM-8	grab	Waste pile sample, no outcrop, prospect/exploration pit, 400 counts per second in piles, 800 counts per second on the ground about 15 feet east of the waste piles.	na	na	na	na	31.0	9.2	1.9	3,309

NOTES:

Samples collected June 2018.

1 - Samples WM-1 thru WM-6 collected west to east, respectively, along a ~12-foot-long vein outcrop. Vein in gneiss trending ~north 50 degrees west, quartz, barite, brown and yellow with less amounts of red iron oxide, multidirectional veinlets <1 to 6 inches in areas, quartz near middle of vein up to 7 to 8 inches wide, gneiss altered in areas with numerous veinlets, up to 3,500 counts per second in altered vein rock with quartz and iron oxides, vein rock type is unknown and altered.

2 - The outcrop readings were taken prior to sampling but adjacent to where the sample was collected. The sample screening was performed back at the CGS office on the bagged samples. Sample screening performed with a handheld gamma ray spectrometer (Radiation Solutions Inc. RS-125).

Survey mode used for total counts and assay mode used for K, U, and Th concentrations. Background gamma ray spectrometer reading near the vein is very high (up to more than 1000 counts per second) and between about 200 and 250 counts per second away from the vein.

na = not available

ppm = parts per million

Table A1 – Summary of Wet Mountains sample information and field screening results.

As shown in Table A1, the radioactivity, thorium, and uranium field screening results collected at the outcrop and from the samples (as measured in the sample collection bag in the office) vary by an order of magnitude. In some cases, the outcrop field screening results are similar in magnitude for thorium but off by an order of magnitude for uranium when compared to the ICP-MS results. For example, the WM-5 outcrop field screening thorium value of 859 ppm is generally close to the ICP-MS result of 748 ppm; however, the uranium concentration at the outcrop is 33 ppm and the ICP-MS result is 3 ppm (Tables A1 and A2). Although the handheld gamma ray spectrometer may be a good tool for surveying veins in the field and generally guiding sampling, it cannot be relied on for accurate assay values.

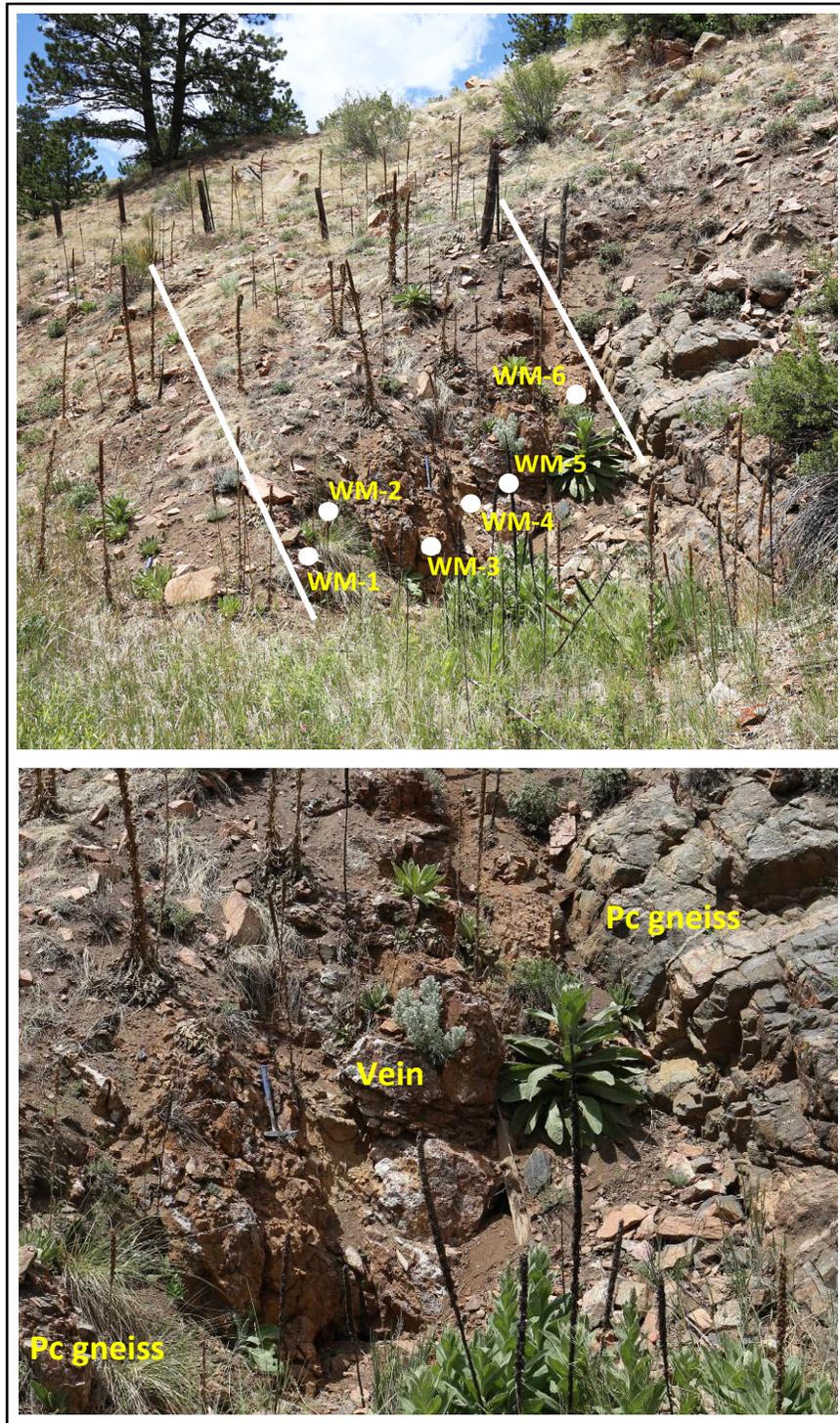


Figure A1 – Sample locations WM-1 thru WM-6. Top: white lines delineate the approximate edge of quartz-barite-thorite vein alteration (~3.7 m wide). Bottom: Close-up of top picture. Hammer is ~41 cm long. Pc = Precambrian.

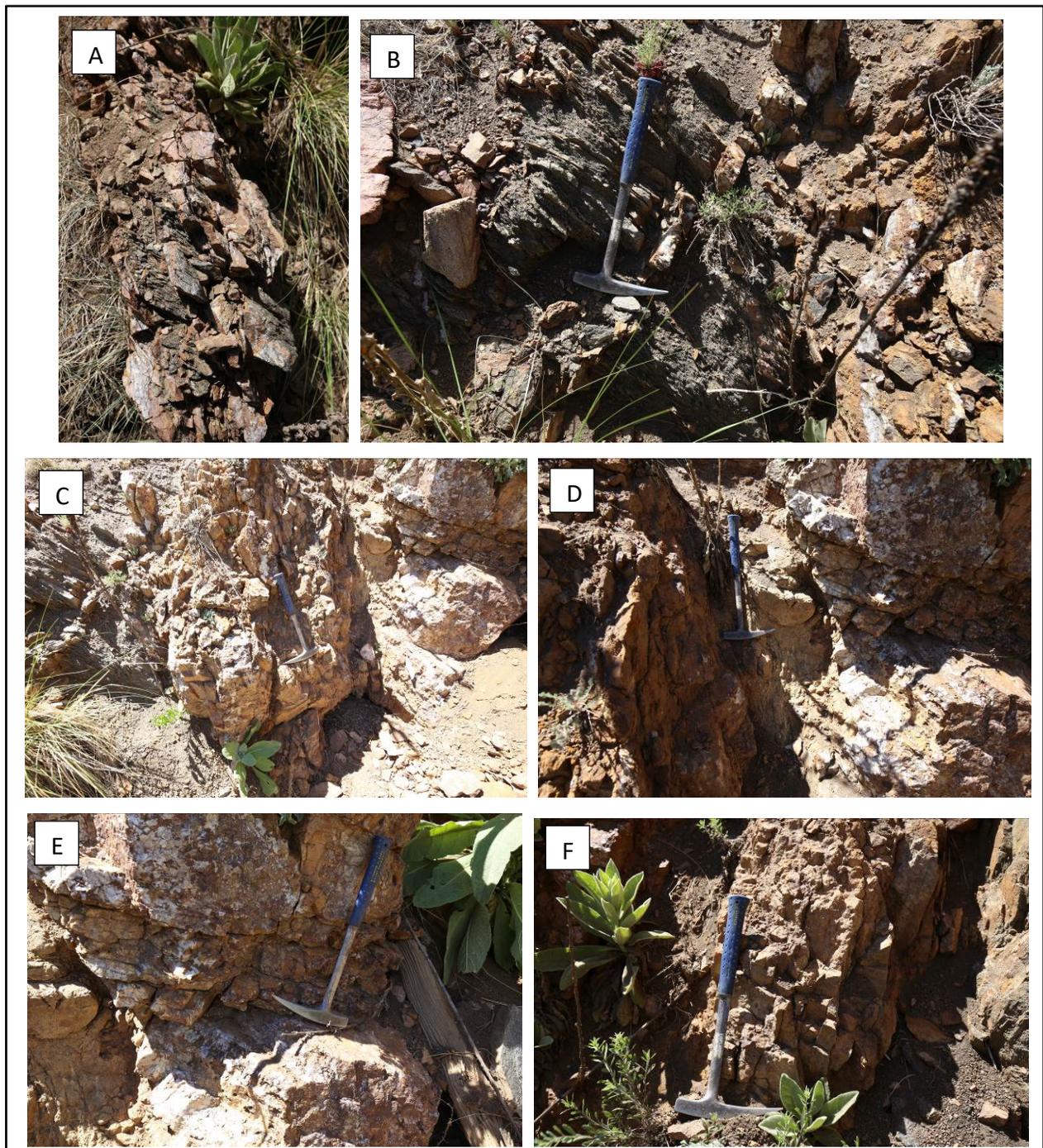


Figure A2 – Close-ups of sample locations WM-1 thru WM-6. Hammer is ~41 cm long. See Figure A1 for general location and Table A1 for general descriptions. (A) WM-1, gneiss; (B) WM-2, gneiss, highly fractured; (C) WM-3, quartz-barite-thorite vein; (D) WM-4, fenite?/altered rock; (E) WM-5, quartz-barite-thorite vein; (F) WM-6, fenite?/altered rock.



Figure A3 – Close-ups of the outcrop (top) and sample (bottom) from the quartz-barite-thorite vein at WM-5. Hammer head is ~18.5 cm and lens cover is ~8 cm wide.

Armbrustmacher (1988) reported that, for the quartz-barite-thorite veins, *“the distribution of vein minerals along strike is irregular and unpredictable, and thus it is difficult to determine how well a sample represents a particular vein.”* This is apparent at the Sewell Ranch vein where the concentrations of total REEs in the main portion of the defined vein — samples WM-3 through WM-6 — range between 190 in WM-4B to 3,565 ppm in WM-5 (Table A2). Concentrations vary significantly of REEs, thorium, and other elements in areas observed in the vein that contain obvious mineralization. For example, concentrations of total REEs in samples WM-3 and WM-5, both collected from areas within the vein containing abundant quartz-barite-iron oxides, are 1,089 and 3,565 ppm, respectively. It was difficult to determine the rock types within these veins as they are significantly altered. This was also the case of the rocks observed at WM-4 and WM-6. Although only sparse quartz and no barite was observed in the hand sample from WM-6, it had more thorium and total REEs than WM-3.

The distribution of LREEs and HREEs minerals also varied within the Sewell Ranch vein. In all of the samples except for WM-2, the total REEs contained 84 to 91% LREEs and 9 to 16% HREEs (Table A2). The sample collected from WM-2 is a fractured gneiss with quartz veins, iron oxides, and weak alteration at the edge of the vein. Analysis of WM-2 detected the lowest concentrations of total REEs (~175 ppm) but the highest percent of HREEs at 36%. Higher concentrations of thorium correlated with higher concentrations of total REEs in all the samples. Analyses of samples WM-7 and WM-8, collected near the Greenwood property, detected lower concentrations of total REEs than observed at the Sewell Ranch vein; however, the sample collected from WM-8 has the highest relative percentage of HREEs (55%) of all the samples and has higher concentrations of HREEs than all the samples collected at the Sewell Ranch vein except for WM-5 and 6 (Table A2).



Figure A4 – Sample location WM-7 (left) and nearby exposed vein in shaft (right). Hammer is ~41 cm long.

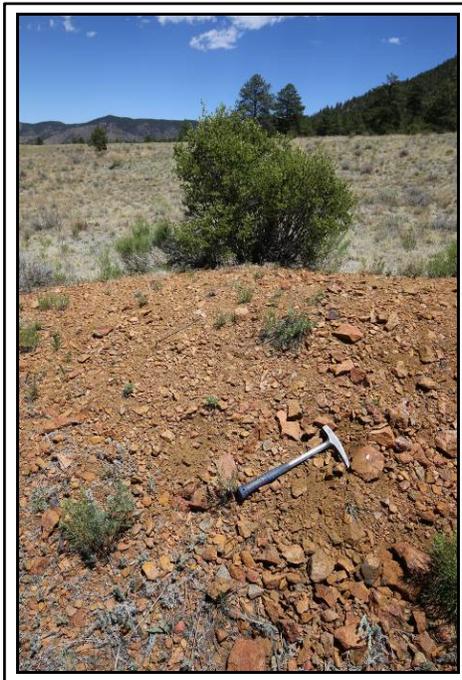


Figure A5 – Sample location WM-8. Hammer is ~41 cm long.

Element	Sample										
	WM-1	WM-2	WW-2*	WM-3	WM-4A	WM-4B	WM-5	WM-6A	WM-6B	WM-7	WM-8
Ba	871.14	412.67	403.48	61304.69	697.72	567.58	50852.69	9082.74	3652.22	235905.62	286557.10
Cs	0.04	0.35	0.33	0.03	0.54	0.71	0.03	0.05	0.05	0.001	0.05
Hf	0.76	3.11	3.08	0.20	4.42	4.12	0.40	1.37	1.74	0.11	13.44
Nb	56.42	11.69	11.26	25.65	45.68	41.23	3.80	473.50	397.78	0.87	76.00
Pb	2352.60	8.33	7.66	178.69	14.83	19.37	391.03	85.52	89.80	155.96	418.19
Rb	21.30	29.34	28.74	3.78	50.44	53.70	0.85	63.37	57.81	0.15	36.91
Sc	11.10	32.41	31.99	5.42	30.84	30.96	10.36	46.26	50.00	0.31	5.77
Sr	131.28	284.00	281.96	141.75	1059.61	732.87	235.99	1108.54	1112.85	79.06	637.28
Ta	0.33	0.62	0.60	0.31	2.48	2.54	0.05	7.48	6.72	0.03	0.39
Th	174.12	3.55	3.41	219.83	40.39	26.13	748.23	479.09	434.64	26.80	48.64
U	0.79	0.74	0.73	1.69	1.32	1.92	3.59	2.30	3.25	0.10	21.07
Y	58.87	41.75	41.05	87.88	20.53	17.23	384.43	174.06	108.12	1.34	102.45
Zr	30.15	107.58	106.03	11.74	236.12	252.50	26.58	75.68	99.21	5.41	817.13
La	129.19	20.10	19.72	164.31	38.75	38.38	486.24	305.75	276.15	1.37	21.88
Ce	282.24	45.78	44.72	362.78	72.48	71.85	1134.76	716.80	651.62	2.22	44.36
Pr	36.92	6.04	5.93	48.23	8.22	8.11	145.21	91.00	81.83	0.32	5.90
Nd	165.21	25.55	24.89	219.23	31.08	30.36	678.76	424.91	381.07	1.91	25.34
Sm	63.26	6.51	6.10	86.07	6.96	6.41	281.81	172.46	153.95	1.44	9.47
Eu	17.88	1.73	1.68	23.29	2.53	2.15	80.40	46.28	41.60	0.64	1.70
Gd	40.08	6.70	6.72	52.52	7.62	6.18	181.63	98.97	85.90	1.17	10.87
Tb	3.63	1.20	1.17	4.76	1.11	0.84	18.22	8.95	7.20	0.11	2.18
Dy	14.47	7.62	7.48	19.70	5.41	4.07	82.04	38.26	27.74	0.36	15.95
Ho	2.33	1.63	1.59	3.29	0.84	0.69	14.35	6.59	4.31	0.04	3.40
Er	5.60	4.57	4.45	8.15	1.93	1.60	36.62	16.65	10.55	0.11	9.75
Tm	0.78	0.66	0.67	1.13	0.25	0.20	5.14	2.39	1.52	0.01	1.48
Yb	4.73	4.32	4.21	6.59	1.54	1.26	30.57	15.18	10.19	0.07	9.16
Lu	0.68	0.67	0.68	0.93	0.25	0.17	4.47	2.35	1.62	0.01	1.33
Σ LREE	734.78	112.41	109.75	956.44	167.65	163.45	2988.82	1856.17	1672.13	9.07	119.52
Σ HREE	91.09	62.43	61.29	132.42	31.86	26.05	575.83	264.43	171.25	2.05	145.69
Σ REE	825.88	174.84	171.04	1088.86	199.51	189.51	3564.66	2120.59	1843.37	11.12	265.22
LREE/ Σ REE (%)	89	64	64	88	84	86	84	88	91	82	45
HREE/ Σ REE (%)	11	36	36	12	16	14	16	12	9	18	55

NOTES: Analyses using ICP-MS at Washington State University. All results in parts per million unless otherwise noted.

* - laboratory duplicate analysis.

LREE = light rare earth elements (La, Ce, Pr, Nd, Sm, Eu, Gd)

HREE = heavy rare earth elements (Tb, Dy, Ho, Er, Tm, Yb, Lu + Y)

Table A2 – Summary of ICP-MS sample results.

	Sample										
	WM-1	WM-2	WM-2*	WM-3	WM-4A	WM-4B	WM-5	WM-6A	WM-6B	WM-7	WM-8
Normalized Major Elements (Weight %)											
SiO ₂	79.93	54.08	54.13	88.24	39.15	39.84	69.63	30.56	27.59	-	58.36
TiO ₂	0.15	0.85	0.86	0.10	1.41	1.58	0.02	2.77	2.39	9.90	1.06
Al ₂ O ₃	2.00	15.96	16.04	0.39	5.09	5.50	0.11	7.03	6.48	52.36	21.00
FeO	10.44	9.20	9.16	10.03	12.02	11.87	26.65	16.22	19.45	22.64	5.90
MnO	0.23	0.15	0.15	0.23	0.20	0.22	0.60	0.44	0.57	3.31	0.16
MgO	1.24	6.47	6.51	0.11	12.73	10.00	0.56	10.16	8.95	-	0.01
CaO	4.26	8.54	8.57	0.52	24.78	26.04	2.22	26.34	28.51	5.73	0.51
Na ₂ O	0.10	3.40	3.26	0.00	2.31	2.60	-	-	-	-	5.86
K ₂ O	1.58	1.15	1.14	0.29	1.87	1.91	0.02	6.05	5.52	3.86	6.81
P ₂ O ₅	0.07	0.20	0.18	0.13	0.43	0.43	0.24	0.45	0.55	2.19	0.33
Select Trace Elements (ppm)											
Ni	93	109	111	121	708	639	244	285	356	44	62
Cr	80	194	195	50	2248	2292	115	317	308	-	-
V	27	184	184	16	139	135	24	131	136	54	101
Ga	6	17	18	2	7	8	3	13	11	4	10
Cu	19	95	100	22	44	48	65	48	46	48	57
Zn	873	77	76	1207	253	341	3259	461	559	24	77

NOTES: Analyses at Washington State University by XRF.

- = not detected

* denotes a duplicate bead made from the same rock powder.

ppm = parts per million

Major elements are normalized on a volatile-free basis, with total Fe expressed as FeO.

All trace element concentrations are estimated due high concentrations of barium that lead to the extrapolation of calibration curves and dissolution issues.

Table A3 – Summary of XRF sample results.

APPENDIX B – DATA DICTIONARY AND DEFINITIONS

Table B1 presented below includes descriptions of the fields in the ArcGIS, spreadsheet, and csv files associated with this data compilation. Definitions of the data modifiers and explanation of some of the descriptions are also included at the end of the table.

Field	Description
ID	Record identification number.
location	Sample or location Id from the referenced report.
descript	Sample and location description.
shortref	Short version of the reference field.
notes1	Notes and/or comments.
notes2	Notes and/or comments.
La_ppm	Concentration of La in parts per million.
La_mod	Modifier for La_ppm, see list of modifiers.
Ce_ppm	Concentration of Ce in parts per million.
Ce_mod	Modifier for Ce_ppm, see list of modifiers.
Pr_ppm	Concentration of Pr in parts per million.
Pr_mod	Modifier for Pr_ppm, see list of modifiers.
Nd_ppm	Concentration of Nd in parts per million.
Nd_mod	Modifier for Nd_ppm, see list of modifiers.
Sm_ppm	Concentration of Sm in parts per million.
Sm_mod	Modifier for Sm_ppm, see list of modifiers.
Eu_ppm	Concentration of Eu in parts per million.
Eu_mod	Modifier for Eu_ppm, see list of modifiers.
Gd_ppm	Concentration of Gd in parts per million.
Gd_mod	Modifier for Gd_ppm, see list of modifiers.
Tb_ppm	Concentration of Tb in parts per million.
Tb_mod	Modifier for Tb_ppm, see list of modifiers.
Dy_ppm	Concentration of Dy in parts per million.
Dy_mod	Modifier for Dy_ppm, see list of modifiers.
Ho_ppm	Concentration of Ho in parts per million.
Ho_mod	Modifier for Ho_ppm, see list of modifiers.
Er_ppm	Concentration of Er in parts per million.
Er_mod	Modifier for Er_ppm, see list of modifiers.
Tm_ppm	Concentration of Tm in parts per million.
Tm_mod	Modifier for Tm_ppm, see list of modifiers.
Yb_ppm	Concentration of Yb in parts per million.
Yb_mod	Modifier for Yb_ppm, see list of modifiers.
Lu_ppm	Concentration of Lu in parts per million.
Lu_mod	Modifier for Lu_ppm, see list of modifiers.
Y_ppm	Concentration of Y in parts per million.
Y_mod	Modifier for Y_ppm, see list of modifiers.
REE_Tppm	Total rare earth element concentration in ppm (converted from reported in weight percent and multiplied by 10,000). Note that many analyses do not include all the REEs; therefore, all totals are estimated. See referenced report for more information.
REE_Tmod	REE_Tppm modifier. See list of modifiers.
LREEppm	Light rare earth elements concentration in ppm (assumed to include La/Ce/Pr/Nd/Sm/Eu/Gd - not including Pm because it only exists in small concentrations naturally). See referenced report for more information.
HREEppm	Heavy rare earth element concentration in ppm (assumed to include Tb/Dy/Ho/Er/Tm/Yb/Lu + Y). See notes for variations and referenced report (some totals might not include Y, etc.).
Ga_ppm	Concentration of Ga in parts per million.
Ga_mod	Modifier for Ga_ppm, see list of modifiers.
Nb_ppm	Concentration of Nb in parts per million.
Nb_mod	Modifier for Nb_ppm, see list of modifiers.
Sr_ppm	Concentration of Sr in parts per million.

Table B1 – Description of data compilation fields, modifiers, and notes.

Field	Description
Sr_mod	Modifier for Sr_ppm, see list of modifiers.
Ti_ppm	Ti concentration in parts per million (NOTE: TiO ₂ concentrations reported by many authors not included).
Ti_mod	Modifier for Ti_ppm, see list of modifiers.
Thppm	Concentration of Th in parts per million.
Thppm_m	Modifier for Th_ppm, see list of modifiers.
ThO2eq	Thorium dioxide calculated from the equivalent uranium by subtracting the chemical uranium and multiplying the difference by the conversion factor of 5.6. In parts per million. See referenced report for more information.
ThO2chem	Chemical analysis of thorium dioxide in parts per million reported by some authors. See referenced report for more information.
ThO2chmo	Thorium dioxide modifier for ThO2chem. See list of modifiers.
U_ppm	Concentration of U in parts per million.
Uppm_m	Modifier for U_ppm, see list of modifiers.
Ueq	Chemical equivalent of uranium (calculated, see original publication in reference field for more information).
Ueq_m	Ueq modifier, see list of modifiers.
Uchem	Chemical analysis of uranium concentration in ppm reported by some authors. See original publication for more information.
Uchem_m	Uchem modifier, see list of modifiers.
REEox	Rare earth element oxide concentration in ppm.
REEox_m	REEox modifier, see list of modifiers.
ThREEox	Thorium and rare earth element oxide concentration in ppm (see referenced report for more information).
ThREEoxm	ThREEox modifier, see list of modifiers.
samlength	Sample length in feet, if zero then no length reported or grab sample.
year	Year of referenced publication.
refer	Full reference.
x_meters	x coordinate in NAD 83 meters.
y_meters	y coordinate in NAD 83 meters.
coordsys	Coordinate system.
Modifier	Description
>	Greater than reported value.
a	A total of La/Ce/Nd/Y/Yb only, value converted from weight percent.
e	Estimated.
na	Not analyzed. In some cases (data from Christman and others, 1959), these analytes were analyzed; however, the results were qualitative and only reported by orders of magnitude (e.g., La = 0.X, Ce = 0.0X weight percent). In some cases, the individual REEs were not reported so they are listed as na. Total LREE and/or HREE do include these results (e.g., Armbrustmacher, 1988). Although an element concentration may be reported as 0.0, this modifier indicates that they did not analyze for the element.
nau	Not analyzed unknown - unclear if analyte was not detected or not analyzed.
nc	Not complete - no results were reported for over 3 or 4 of the REEs.
nd	Not detected, same as modifier u.
nr	Not reported here, see referenced report for details.
ppm	Parts per million.
u	Not detected, value is the detection/reporting limit (in many cases, it is unknown if the reported number is the detection or reporting limit, also includes detections that were lower than the detection limit (the detection limit wasn't always reported so, these are essentially non-detects). If element concentration is 0.0 with a "u" modifier, analysis for the element was conducted but not detected.
Notes:	Estimated location not shown on map = the exact location is not shown on the map from the original reference. Only the general location is provided for the claim/property. The location was placed on this location.
	The Tuttle property map was georeferenced however, there were not map points that could be used to georeference this map. Therefore, it's location and sample point locations are estimated.
	The Haputa ranch property map was georeferenced however, its location is estimated and therefore, all the points in this file as well as the Haputa Ranch Extension are estimated.
	Estimated location - only shown in report figure: the report figure doesn't give enough detail to show the location, therefore, the location is estimated.

Table B1 (cont) – Description of data compilation fields, modifiers, and notes.