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GEOLOGY AND MINERAL RESOURCES IN THE OJO CALIENTE NO. 2 MINING DISTRICT, SOCORRO COUNTY, NEW MEXICO

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Abstract—The Ojo Caliente No. 2 mining district is located in the northern Sierra Cuchillo in southwestern Socorro County. Volcanic-epithermal vein deposits (Taylor mine) and the Apache Warm Springs volcanogenic beryllium deposit are found in the district. At least three separate geothermal systems are present in the Ojo Caliente No. 2 mining district in the Montoya Butte quadrangle: 1) the oldest system forming the volcanic-epithermal veins (~28-36 Ma), 2) the system forming the Apache Warm Springs beryllium deposit and associated alteration (~24.4-28 Ma), and 3) the current, modern system related to Ojo Caliente, Willow Springs, and other warm springs feeding Cañada Alamosa. Copper-silver production has been insignificant from the volcanic-epithermal veins and a small quantity of uranium ore reportedly was produced from the beryllium deposit. The resource potential of the volcanic-epithermal veins is low with a moderate to high degree of certainty, because the vein deposits exposed at the surface are low grade and too small for economic development in the current market. The resource potential of the Apache Warm Springs beryllium deposit is low to moderate with a moderate to high degree of certainty, because the known extent of the beryllium deposit at the surface and in the subsurface where drilled is low grade and too small for economic development in the current market. But, additional exploration drilling could locate additional beryllium. Deposits of uranium and rare earth elements could be associated with the beryllium deposit. Any potential exploration or subsequent mining would have to plan for environmental issues, especially the effects of mining on the Ojo Caliente and adjacent warm and cold springs feeding the Cañada Alamosa.

INTRODUCTION

The Ojo Caliente No. 2 mining district (also known as the Taylor district, district identification number DIS230, New Mexico Mines Database, McLemore et al., 2005a, b) is located in the northeastern Mogollon-Datil volcanic field in northern Sierra Cuchillo in southwestern Socorro County, central New Mexico (Fig. 1). Volcanic-epithermal vein deposits (Taylor mine) and the Apache Warm Springs volcanogenic beryllium deposit (also known as the Sullivan Ranch site; Hillard, 1967, 1969; Meeves, 1966; McLemore, 2010a) are found in the district. The Ojo Caliente No. 2 mining district is one of numerous epithermal-vein deposits found in southwestern New Mexico (McLemore, 1996a, 2001) and southeastern Arizona (Keith et al., 1983) and the district also is one of a few districts in New Mexico that contains significant beryllium deposits not hosted by pegmatites (McLemore, 2010b, c). The purposes of this report are 1) summarize the geology, geochemistry, and mineral production of the district, 2) discuss the age and formation of these deposits, and 3) comment on the future economic potential of mineral deposits in the district.

METHODS OF STUDY

This work is part of ongoing studies of mineral deposits in New Mexico and includes updates and revisions of prior work by North and McLemore (1986, 1988) and McLemore (1996a,b, 2001, 2010a, b, c, 2012a). This report is part of a field mapping project of the Montoya Butte 7½ quadrangle (McLemore, 2010a, 2012a) and an evaluation of beryllium resources in New Mexico and adjacent areas (McLemore, 2010b, c). Names of types of mineral deposits (i.e. volcanic-epithermal veins and volcanogenic beryllium deposits) are from Cox and Singer (1986), North and McLemore (1986, 1988), McLemore (1996a,b, 2001) and Foley et al. (2010).

The first stage in any geologic investigation is compilation and interpretation of all available published and unpublished geological, geochemical, hydrological, geophysical, and mineral production data. Mineral databases were examined, including the Mineral Resource Data System (MRDS) of the U.S. Geological

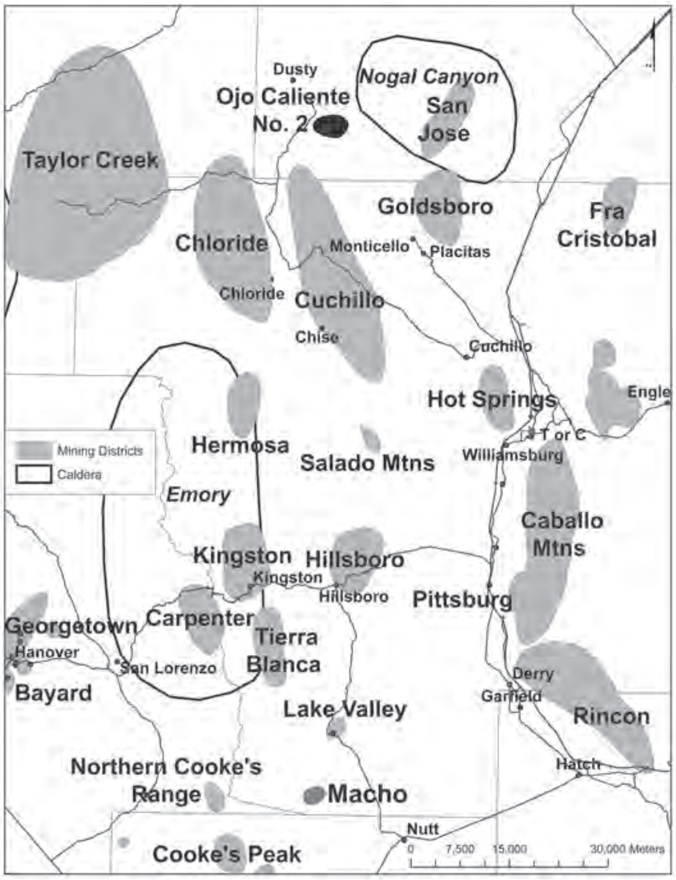

FIGURE 1. Location of Ojo Caliente No. 2 mining district in central New Mexico.

Survey (Mason and Arndt, 1996), the Minerals Industry Location System (MILS) of the U.S. Bureau of Mines (U.S. Bureau of Mines, 1995), U.S. Forest Service Abandoned and Inactive Mines database, AMLIS (U.S. Bureau of Land Management), the New Mexico Mines Database (McLemore et al., 2005a, b), and unpublished files at the NMBGMR. Mineral occurrences, deposits, mines, prospects, and mills were identified using these databases and plotted on base maps, and updated in the New Mexico Mines Database (McLemore, 2010a). Geophysical data (regional magnetic and gravity maps), aerial photographs, and Landsat satellite imagery of the project area were examined. Using these data, areas of anomalous structural complexity, hydrothermal alteration, mineralization, and anomalous coloration were delineated, examined, mapped and sampled. Many of the mines, prospects, and mineral deposits were examined as part of a regional study of mineral resources in Sierra County in 1998-2005 and additional examination of mines, prospects, and mineral deposits was conducted in 2005-2009 during geologic mapping of the Montoya Butte quadrangle (McLemore, 2010a, 2012a). Geologic mapping of the Montoya Butte quadrangle was at a scale of approximately 1:12,000, using the USGS topographic map as a base by the author as part of the NMBGMR state geologic map and mineral resources programs (McLemore, 2012a). Cross sections were constructed (McLemore, 2012a).

GEOLOGIC AND TECTONIC SETTING

The Ojo Caliente No. 2 mining district lies in a tectonically active and structurally complex area of the southwestern U.S. that is known for numerous types of mineral deposits associated with Eocene-Oligocene volcanic rocks. The Mogollon-Datil volcanic field is part of a late Eocene-Oligocene volcanic province that extends from west-central New Mexico southward into Chihuahua, Mexico (McDowell and Claubaugh, 1979; McIntosh et al., 1991, 1992a, b; Chapin et al., 2004). In southwestern North America, Tertiary volcanic activity began ~40-36 Ma with the eruption of andesitic volcanism, followed by episodic bimodal silicic and basaltic andesite volcanism during ~36 to 24 Ma (Cather et al., 1987; Marvin et al., 1988; McIntosh et al., 1992a, b). Approximately 25 high- and low-silica rhyolite ignimbrites (ash-flow tuffs) were erupted and emplaced throughout the Mogollon-Datil volcanic field during the second event. Source calderas have been identified for many of the ignimbrites (McIntosh et al., 1992a, b; Chapin et al., 2004). The western edge of the Nogal Canyon caldera lies east of the Ojo Caliente district and the Red Paint Canyon fault zone could be a ring fracture of the caldera (Fig. 2; McLemore, 2010a). Subsequent faulting, hydrothermal alteration, and volcanism have offset, altered, and covered portions of the ignimbrites, which creates difficulties for regional correlations.

A summary of the geologic units in the Ojo Caliente No. 2 mining district is in Table 1, shown in Figure 2, and described in detail by McLemore (2010a, 2012a) and Maldonado (1974, 1980, 2012). Permian sedimentary rocks are exposed in the southwestern portion of the area and likely underlie much of the area at depth. Volcanic rocks include an older sequence of andesite, lahar, and latite (around >38-36 Ma) followed by a younger sequence of ash flow tuffs and rhyolite lavas (around 22-29 Ma) associated with the formation of the Nogal Canyon (28.4 Ma) and Bear Trap Canyon (24.4 Ma) calderas in the San Mateo Mountains. The Datil Group contains all late Eocene-early Oligocene volcanic strata up to the 31.8 to 29.4 Ma regional hiatus in volcanism, according to the definition of Cather et al. (1994). This includes the andesite of Monticello Box, lahar, and latite of Montoya Butte. Additional calderas have been recently proposed in the area but are not shown on Figure 1 (Ferguson et al., 2012). Local alkaline basalt flows are ~18 Ma ($^{40}Ar/^{39}Ar$; McLemore et al., 2012), overlie the older Tertiary sedimentary rocks and are similar in composition to basalt flows in central New Mexico that are 2-4 Ma (McLemore, 2010a). Local and regional faulting formed the Monticello graben where Cañada Alamosa flows between the San Mateo Mountains and Sierra Cuchillo (Fig. 2). Quaternary sedimentary rocks eroded from the San Mateo Mountains and Sierra Cuchillo filled the Monticello graben and formed a series of alluvial fans, pediments and stream terraces. Cañada Alamosa cut through the Tertiary sedimentary rocks and the ~18 Ma basalt flows.

A major fault zone, Red Paint Canyon fault zone (McLemore, 2010a), separates the volcanic rocks in the Ojo Caliente No. 2 district from Quaternary sedimentary rocks of the upper Alamosa Creek basin (Fig. 2). The Red Paint Canyon fault zone consists of several parallel and subparallel faults and fractures west of Monticello Box (Fig. 2; McLemore, 2010a, 2012a). The beryllium deposits are along the southern portion of this fault zone and the volcanic-epithermal copper-silver vein deposits are east and south of the Red Paint Canyon fault zone. Ojo Caliente, Willow Springs, and other the warm and cold springs feeding the Cañada Alamosa, Alum Spring, and two water wells also are within the Red Paint Canyon fault zone. This fault zone truncates and offsets older faults (McLemore, 2010a, 2012a).

MINING HISTORY

The name of the Ojo Caliente No. 2 mining district is from Lasky (1932) and File and Northrop (1966), although the district also has been called the Taylor district, after the name of the first known mine. Mineral deposits in the Ojo Caliente No. 2 district include volcanic epithermal vein deposits (Lasky, 1932; McLemore, 1996a) and volcanogenic beryllium (volcanic-hosted replacement, volcanic-epithermal, Spor Mountain Be-F-U deposits; Lindsey and Shawe, 1986; Foley et al., 2010). Only one mine has yielded metals production from this district, the Taylor mine (mine identification number NMSO0073, New Mexico Mines Database), which yielded one car load of copper, silver, and lead ore about 1950. Several veins of calcite, quartz and locally fluorite, possibly with trace base metals, are found throughout the district (McLemore, 2010a). During the uranium boom a small amount of uranium was produced from Red Paint Canyon, according to Hillard (1967, 1969).

Beryllium, found as mostly as bertrandite ($H_2Be_4Si_4O_9$), was first noted in Red Paint Canyon about 1961 by M. Howard Milligan (NMBGMR files). Shawe (1966) included the Apache Warm

TABLE 1. Descriptions of geologic units in the northern Sierra Cuchillo and western San Mateo Mountains, Montoya Butte quadrangle, Socorro County, youngest to oldest (age dates, thickness, and descriptions are modified from Jahns et al., 1978, 2006; Hillard, 1967, 1969; Maldonado, 1974, 1980, 2012; McCraw, 2003; Lynch, 2003; Ferguson et al., 2007; McLemore, 2010a, 2012a; McLemore et al., 2012).

Symbol	Unit (age)	Description	Thickness (m)
af	artificial fill	areas of disturbed, excavated, or filled ground due to human activity, commonly earthen dams or stock tanks	
Qal	modern alluvium	valley bottom clays, sands, and volcanic gravel deposits found in modern and active stream channels and adjacent floodplain deposits	0-2
Qa	valley-floor alluvium	alluvium occupying the floors of modern valleys that is composed of fine-grained sediment with minor coarse channel-fills; Historical erosion has formed low terraces whose upper surface (i.e., tread) lies less than 2-3 m above adjacent major streams	2-6
Qc	colluvium and talus, undivided	colluvium and talus deposits on hill slopes that are composed of sand and volcanic gravels; these deposits conceal bedrock	0-6
QTsf	Santa Fe Group	undivided, poorly to moderately consolidated clay-silt, sand, and gravels comprising the main piedmont alluvial fans and bajadas adjacent to uplands, locally includes some terrace deposits (Qt); thickness 0-390+ m (in part after McGraw, 2003)	0-390+ (QTc, Qt, Qp, Qa, Qal)
Qt	Terrace surfaces, undivided	clays, silts, sands and volcanic gravels forming upper terrace deposits (above active stream channels and floodplains), subdivided by age/inset relationships where possible (Qtm, Qtv, Qts) (in part after McGraw, 2003)	3-8
Qtm	Montoya terrace (youngest)	Fifth or youngest terrace, Qt5-3-15 m above modern grade of Cañada Alamosa; unit consists of silt, sand, gravel, and boulders (mostly rhyolite), generally well-developed, cemented soils; locally unconformable on Tertiary volcanic rocks; 3-8 m thick	3-8
Qtv	Victorio terrace (second youngest terrace)	Fourth terrace, Qt4-10-30 m above modern grade of Cañada Alamosa; unit consists of silt, sand, gravel, and boulders (mostly rhyolite), generally well-developed, cemented soils; 3-8 m thick	3-8
Qts	San Mateo terrace (third youngest terrace)	Third terrace, Qt3-15-45 m above modern grade of Cañada Alamosa; unit consists of silt, sand, gravel, and boulders (mostly rhyolite), generally thin soil and some caliche development; 3-8 m	3-8
Qp	Pediment deposits	poorly to moderately consolidated sand and gravel similar to that found on terraces; larger surfaces are included in QTsf, includes the Burma pediments	0-8
QTc	Santa Fe Group—basal conglomerate	well-cemented, orange to brown to buff, poorly sorted conglomerates and sandstones composed of volcanic material	0-9
Tb	basalt (18 Ma; McLemore et al., 2012)	fine grained, black to dark gray basalt flows and sills, <1% phenocrysts of feldspar, olivine, and late-stage calcite, vesicular to massive with local pillow-like texture	0-10
Tc	volcaniclastic sedimentary rocks	well-cemented, massive to thin-bedded, volcaniclastic conglomerate, sandstone, and siltstone; includes a white ash-fall or ash-flow tuff north of Black Mountain	0-7
Tan	andesite flows	andesite flows interbedded with volcaniclastic sedimentary rocks (Tc)	0-7
Tts	Turkey Springs Tuff (24.4 Ma; Lynch, 2003; 24.5 Ma, McLemore, 2010a)	gray, welded to nonwelded tuff containing 5-30% phenocrysts (quartz, sanidine, biotite) (Ferguson and Osburn, 2007)	0-60
Tas	rhyolite of Alum Spring	interbedded rhyolite ash-flow tuff, lava and volcaniclastic beds with strong argillic (acid-sulfate) alteration, thickness 0-350 m in drill holes	0-350?
Til	granite of Kelly Canyon (28.3 Ma; Lynch, 2003)	pinkish gray to gray holocrystalline to porphyritic granitic stocks, typically with large K-feldspar phenocrysts	intrusion
Tac	rhyolite of Alamosa Canyon (28.4 Ma; Lynch, 2003; McLemore, 2010a)	pinkish gray to gray rhyolite lava, phenocryst poor (1-3% sanidine, 1-3% quartz, locally amethyst or smokey, 1-5% biotite, pseudobrookite), with contorted flow bands, brecciated and vuggy (especially near the top), local sphereulitic texture, interbedded with local ash-flow tuffs and vitrophyre, thickness 0-300+ m	0-300+
Tvp	Vicks Peak Tuff (28.4 Ma; Lynch, 2003)	pinkish-gray, welded rhyolite ash flow tuff, phenocryst poor (1-10% sanidine, biotite), 4-15% pumice, locally columnar jointed	0-690+
Tr	rhyolite dikes	pink gray rhyolite dikes	intrusion
Tbd	andesite to basalt dikes	dark gray to black to olive green andesite to basalt dikes, locally with porphyritic texture	intrusion
Tgr	granite to quartz monzonite	pink to gray, coarse- to fine-grained granite to quartz monzonite, consisting of K-feldspar, plagioclase, quartz, and biotite (Hillard, 1963)	intrusion
Tql	latite to quartz latite dikes	greenish gray to brown gray, porphyritic quartz latite dikes, 5-10% phenocrysts of albite, some Carlsbad twins, xenoliths common (Hillard, 1963)	intrusion
Tpl	latite of Montoya Butte (35.7 Ma, McLemore, 2010a)	platy, gray to brown gray latite, up to 60% phenocrysts of sanidine, plagioclase, and biotite, locally interbedded with green to gray siltstone and sandstone	0-185
Tmbx	lahar (mudflow)	mudflow, matrix supported, contains andesite and rhyolite boulders and cobbles	0-220
Tmb	andesite of Monticello Box	black to gray, porphyritic to aphanitic andesite	0-120
Py	Yeso Formation and San Andres Limestone, undivided	Brown, thin- to medium-bedded sandstone and siltstone, and dark gray, fine-grained limestone	<643 in Sierra Cuchillo

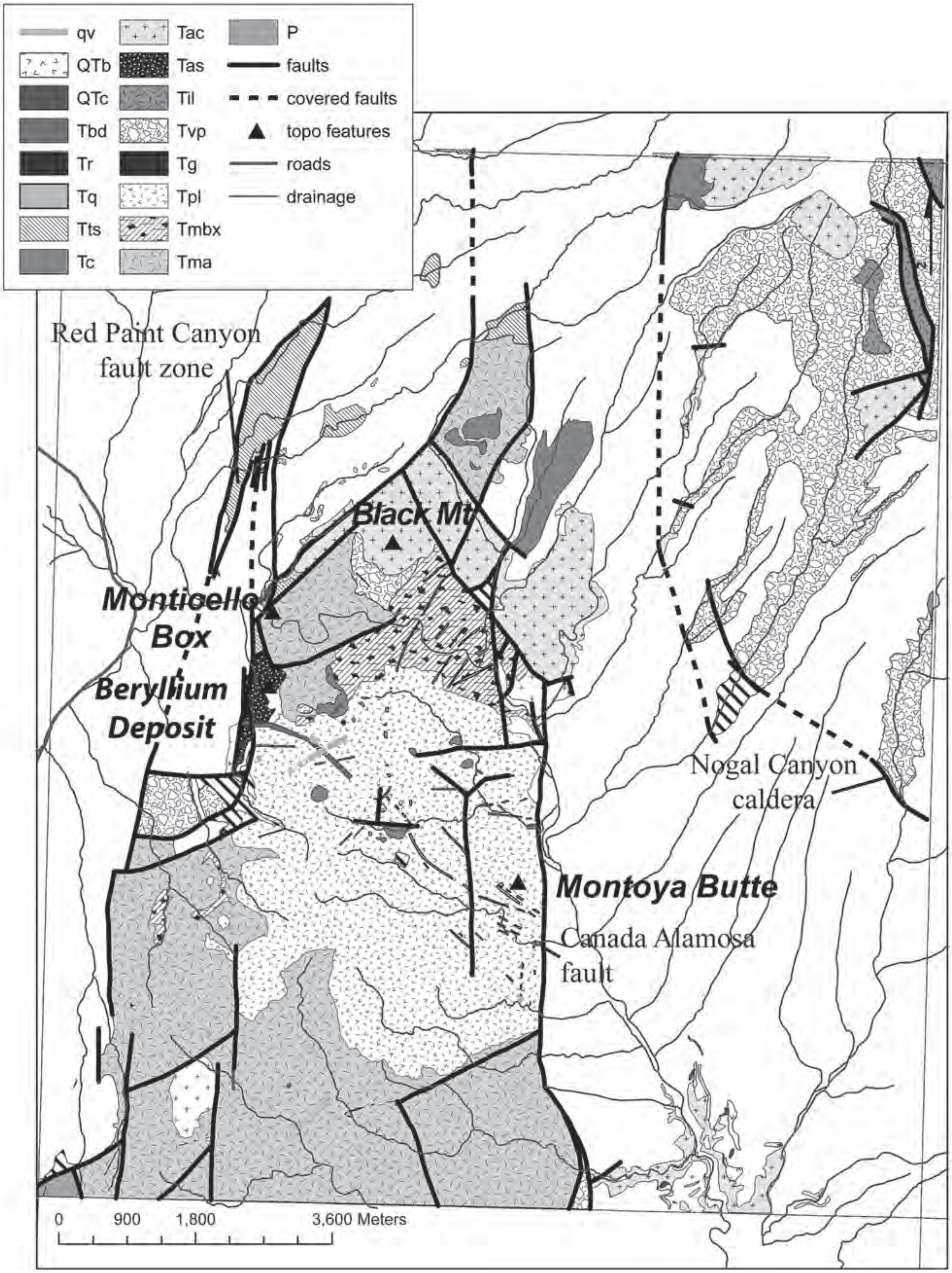

FIGURE 2. Simplified geologic map of the Ojo Caliente No. 2 mining district in the northern Sierra Cuchillo and western San Mateo Mountains, Montoya Butte quadrangle (simplified from McLemore, 2010a, 2012a). See Table 1 for definition of legend symbols. Color version of this map can be found on Plate 2, p. 174.

Springs beryllium deposit as part of the New Mexico-Arizona beryllium belt, which also includes Iron Mountain to the south (Fig. 1). Meeves (1966) described the results of field reconnaissance mapping, trenching, and drilling for beryllium by a commercial company under contract to the U.S. Bureau of Mines. Eighteen holes were drilled as part of these early exploration efforts (summarized in McLemore, 2010a).

The Beryllium Group, LLC controlled the Apache Warm Springs beryllium deposit in 2001-2002, and drilled 14 holes (Mining Engineering, 2002). Great Western Exploration, LLC controlled the property from 2004-2007 (P and E Mining Consultants Inc., 2009). In October 2007, BE Resources Inc. acquired the property and was issued exploration permits for additional drilling. Drilling began in September 2010 (summarized in McLemore, 2010a) and the company dropped the project in August 2011 due to economic considerations. There has been no beryllium production from the property.

Beryllium, tungsten, and iron have been produced from the Iron Mountain deposit (Cuchillo Negro mining district), which is south of the Apache Warm Springs deposit in the Sierra Cuchillo (Fig. 1; Lovering and Heyl, 1989). Griffitts and Alminas (1968) conducted a stream-sediment reconnaissance of the Monticello Box area for base metals and found the area to have numerous minor geochemical anomalies, but did not analyze for beryllium.

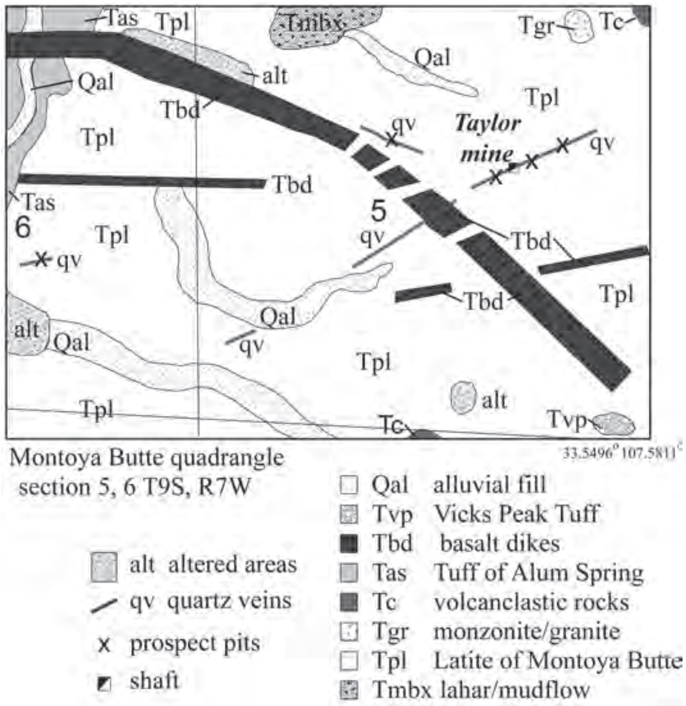

FIGURE 3. Geologic map of the Taylor mine area, Ojo Caliente No. 2 mining district, Socorro County, New Mexico (McLemore, 2010a, 2012a).

DESCRIPTION OF MINERAL RESOURCES

Volcanic-epithermal vein deposits

The volcanic-epithermal veins in the Ojo Caliente No. 2 mining district are small and occur exclusively along faults and fractures within fault zones (Fig. 3). Three types of veins are found in the district, copper-silver veins (<4.5 m wide), calcite veins (<2 m wide), and quartz veins (<2 m wide). The Taylor mine is the only vein developed by a shaft (Fig. 4); only a few small prospect pits are found along some of the other veins in the district (McLemore, 2010a, 2012a). Detailed descriptions of individual prospects and mineral deposits are in McLemore (2010a).

The copper-silver veins are found at the Taylor mine, east of the Red Paint Canyon fault zone (Fig. 3). The shaft is estimated to be 38 m deep with 29 m of drifts at the bottom (Lasky, 1932), and is above the water table. Quartz veins with copper minerals strike N65-75°E and dip 80°NW to vertical and cut altered andesite. The andesite is altered to epidote and chlorite and silicified. The main vein at the Taylor mine is approximately 4.5 m wide, 300 m long and contains various amounts of malachite, azurite, chrysocolla, and cerussite with iron and manganese oxides. A reported assay contained 61.7% Pb, 1.2% Cu, 433 ppm Ag, and 0.65 ppm Au (Lasky, 1932). A sample collected from the mine waste rock pile for this study contained 1.29% Pb, 0.99% Cu, and 1.65% Zn (McLemore, 2010a; silver and gold were not analyzed).

A second type of vein deposit is simple fissure-filling or fracture-coating of white calcite with minor colorless to green fluorite and colorless to white quartz (Fig. 5; McLemore, 2010a). The calcite is typically coarse-grained, with white calcite crystals as large as several centimeters. Complex vein textures, such as banding, multiple brecciation and rhythmic layering typical of most volcanic-epithermal districts (McLemore, 1996a), are generally absent. These calcite veins are variable in size, rarely exceeding 1 m wide and usually less than 30 m long. Chloritization, epidotization, and locally silicification are found adjacent to the calcite veins. Coarse-grained calcite also is locally found filling fractures, amygdules, and cavities within the andesite flows. No visible pyrite or any other sulfides are found. Fluorite rarely exceeds a few percent.

A third type of vein consists mainly of quartz that is brecciated, bifurcating, sinuous, and pinches and swells along strike. It locally contains calcite, epidote, chlorite and clay minerals. These veins exhibit one or two stages of brecciation cemented by quartz. Complex vein textures, such as multiple brecciation and rhythmic layering, are typically absent. These veins are variable in size, rarely exceeding 2 m wide and usually less than 50 m long. A few of these veins are banded with calcite cores surrounded by quartz-epidote, but there is no visible pyrite or other sulfides. Typically silicification, chloritization, epidotization, and clay alteration are found along and between the veins.

The most extensive alteration adjacent to and along faults in the district is silicification. Silicified zones vary in width along strike and some zones reach widths of several tens of meters. Locally parallel or bifurcating faults or veins occur that are separated by silicified and locally brecciated host rock. Quartz and calcite occur as amygdules, fracture coatings, thin quartz veins, breccia cements, and as replacements of primary minerals near the faults. Locally, chloritization, argillization, and sericitiza-

FIGURE 4. Taylor shaft, looking east.

tion occur in a halo surrounding mineralized faults. Epidote can occur within this halo and indicates temperatures of formation >200°C (McLemore, 1993). The volcanic-epithermal veins in the Ojo Caliente No. 2 district are simple quartz-calcite veins and one copper-silver vein that indicates warm to hot hydrothermal waters circulated through the area along faults and fractures.

FIGURE 5. Brecciated quartz veins, eastern Montoya Butte quadrangle.

Apache Warm Springs volcanogenic beryllium deposit

The most significant mineral deposit in the Ojo Caliente No. 2 district is the Apache Warm Springs volcanogenic beryllium deposit (Fig. 6, 7; mine identification number NMSO0152). Volcanogenic beryllium deposits have been previously called volcanic-hosted replacement, volcanic-epithermal, and Spor Mountain Be-F-U deposits (Lindsey and Shawe, 1986; Foley et al., 2010; McLemore, 2010b, c). A detailed geologic map and cross section as interpreted by the author is in Figure 6. Bertrandite ($Be_4Si_2O_7(OH)_2$) is found in small quartz veins and stringers, along fractures with clay minerals, and disseminated with the rhyolite and rhyolite ash-flow tuff. Drilling is summarized

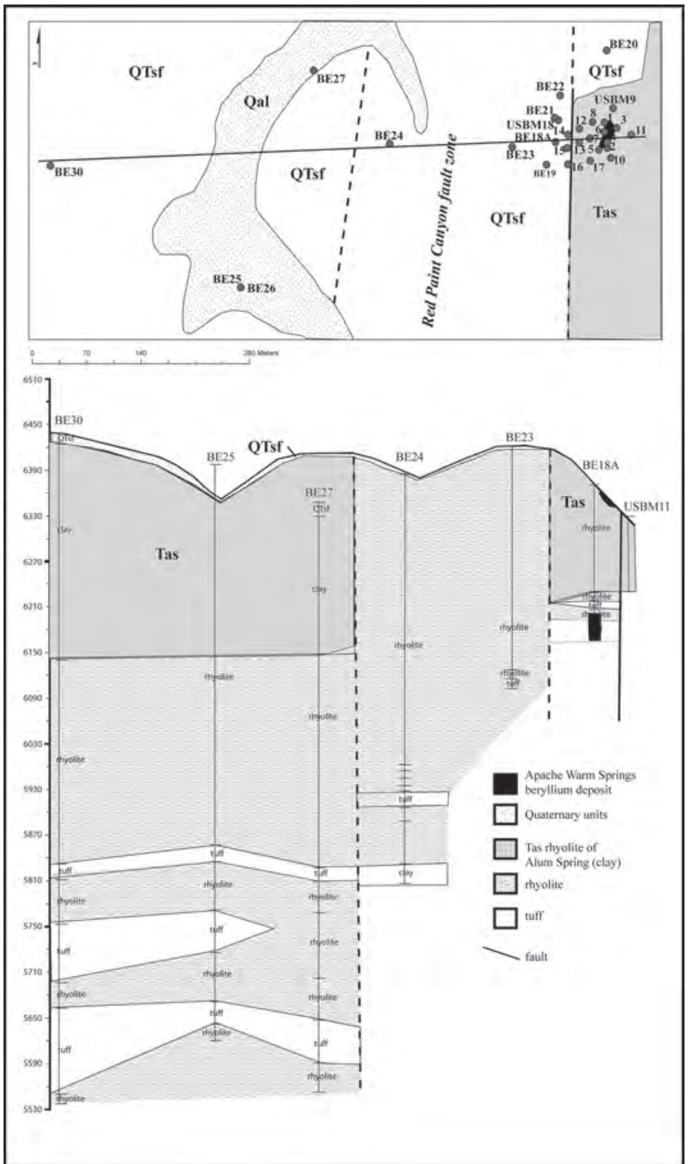

FIGURE 6. Geologic map and cross section of the Apache Warm Springs beryllium deposit and adjacent area (N section 6, T9S, R7W; McLemore, 2010a). Interpretations are by the author from examination of drill cuttings, using available drill data (McLemore, 2010a), and surface mapping. A color version of this figure is presented on Plate 3, p. 175.

FIGURE 7. Apache Warm Springs beryllium deposit (black line), as delineated by P and E Mining Consultants, Inc. (2009) as determined from trenching and drilling, looking northeast (N section 6, T9S, R7W).

in McLemore (2010a, b). Meeves (1966) reports assays as high as 2.05% BeO in drilling during the U.S. Bureau of Mines drilling program, additional chemical analyses for beryllium are in McLemore (2010a). Only one hole in the recent drilling, BE18A, contained beryllium analyses higher than 50 ppm, with the highest analysis of 2600 ppm Be (Fig. 6; P and E Mining Consultants, Inc., 2009; McLemore, 2010a). Low values of rare earth elements also are found (<2000 ppm). It is possible that the beryllium deposit could continue south of the known extent in Red Paint Canyon (Figs. 2, 6), as indicated by the magnetic anomalies (McLemore, 2010a).

The depth to water at the Apache Warm Springs deposit varies from 16 to 152 m, as determined by drilling (McLemore, 2010a). Drilling indicates that several perched water tables and/or water-bearing zones in the rhyolite are present and the perched water zones and the rhyolite lavas are offset by faulting (Fig. 6; Meeves, 1966; McLemore, 2010a). At least one of the recent drill holes was converted to a stock well for the rancher who owns the area.

Alteration

The Apache Warm Springs volcanogenic beryllium deposit is characterized by intense acid-sulfate alteration (also known as advanced argillic alteration), which produces the multiple shades of white, red, yellow, orange, purple, green, brown, and black that gives Red Paint Canyon its name. This type of alteration typically forms a zoned halo surrounding the mineral deposit and is an attractive target for prospecting, especially for volcanic-epithermal gold-silver veins, porphyry copper, molybdenum, and volcanogenic beryllium deposits, to name a few types of associated mineral deposits. A modern analog for the formation of this alteration and beryllium mineralization would be a geothermal system, such as the Norris Geyser Basin in Yellowstone National Park (Muffler et al., 1971; Henley and Ellis, 1983; Kharaka et al., 2000; Rodgers et al., 2002).

The alteration at the Apache Warm Springs beryllium deposit can be differentiated into two zones on the basis of mineralogy, texture, and inferred temperatures as (1) clay zone and (2) silicified zone (Fig. 8). Boundaries between the zones are typically gradational and are distinguished by quartz content and texture. The altered areas are characterized by the leaching and replacement of the matrix and primary minerals in the original host rock by kaolinite, illite, quartz, hematite, and locally illite/smectite, pyrite, anatase, alunite, bertrandite, and possibly pyrophyllite. The texture of the original lithologies (Tas) is typically destroyed and replaced by clay minerals. The largest of these altered areas are mapped in Figure 8. Stratigraphic position and relict textures suggest that original lithologies were volcaniclastic rocks and rhyolite ash-flow tuffs (rhyolite of Alum Spring, Tas), and possibly were part of a rhyolite dome structure. The intensity of alteration varies and some primary minerals such as quartz, titanite, zircon, and apatite are locally preserved. The alteration is older than the Quaternary-Tertiary sedimentary rocks, which are unaltered and contain boulders and clasts of the altered tuff (Tas).

The outermost altered zone in Apache Warm Springs beryllium deposit is designated the clay zone, which is characterized by the alteration and replacement of the matrix and primary minerals in the host rock by kaolinite, illite, quartz, hematite, and locally illite/smectite, pyrite, anatase, tridymite, diaspore, alunite, despujolsite(?), and rare pyrophyllite. This mineral assemblage results in bleached and iron-stained rocks that occur in multiple shades of white, red, yellow, orange, purple, green, brown, and black. The intensity of alteration varies and locally some primary minerals such as quartz, titanite, zircon, and apatite are locally preserved. Some areas within the clay zone are soft and friable and consist only of clay minerals. This alteration represents the outermost altered zone typical of many acid-sulfate altered areas in many districts, where this alteration forms a halo surrounding

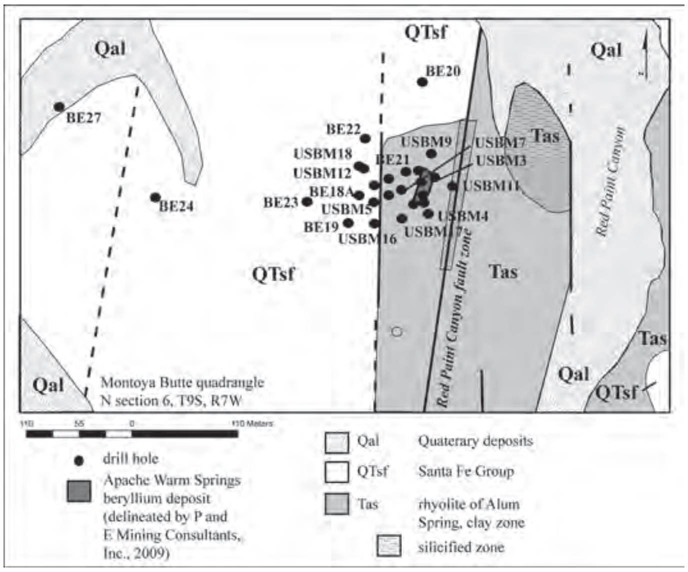

FIGURE 8. Alteration map of the Apache Warm Springs beryllium deposit. The western fault (between BE27 and BE24) is identified from drilling data (McLemore, 2010a).

precious- and base-metal vein deposits (McLemore, 1993, 1996a, 2010a).

The silicified zone is typically the most extensive zone in most acid-sulfate altered areas, but in the Apache Warm Springs beryllium deposit it is found only along faults near the beryllium deposit. The silicified zone is characterized by alteration and replacement of primary minerals by quartz, kaolinite, illite, and locally pyrite, diaspore, pyrophyllite, alunite, jarosite, anatase and other iron and titanium oxides. The intensity of alteration varies, but is typically higher than in the clay zone. Quartz content is typically high (>60%) and decreases toward the clay zone. These rocks are usually bleached, iron stained, and found as multiple shades of white, red, yellow, orange, purple, green, brown, and black. Textures vary from fine to medium grained, massive to brecciated and vuggy to sugary. Silica deposition and replacement are common. In some thin sections, thin quartz veins cut the altered rock. Quartz also locally replaces primary minerals such as feldspar, pyroxenes, and amphiboles.

Faults could occur in the altered areas, but they are masked by alteration that is typically too intense to accurately map them. Only a few exposed faults in the altered zone are therefore mapped in Figure 8, based upon visible silicification and brecciation. Additional altered areas are in the vicinity of faults and on ridges east of the known deposit (Fig. 8; McLemore, 2010a, 2012a).

The Apache Warm Springs beryllium deposit is similar in geology and grade to the Spor Mountain beryllium deposit in Utah (Fig. 9), which is the world's most important source of beryllium (Barton and Young, 2002; Cunningham, 2003; Jaskala, 2009).

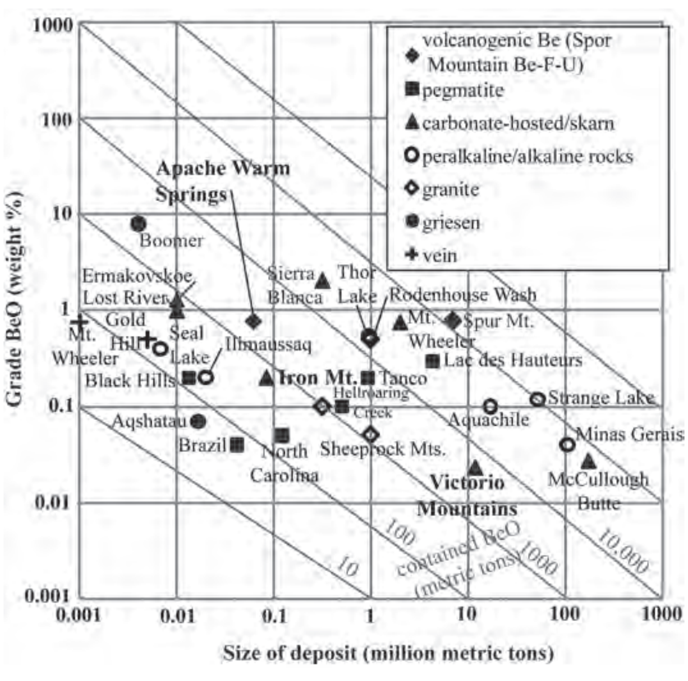

FIGURE 9. Grade and tonnage of selected beryllium deposits, including the Apache Warm Springs deposit (modified from Barton and Young, 2002 using references in McLemore, 2010a). Deposits in bold are located in New Mexico. Note that size of deposits includes production and reserves/resources and are not always NI 43-101 compliant and subject to change.

The Spor Mountain deposit currently produces approximately 40,000-60,000 metric tons Be/year (Brush Engineered Materials, Inc., 2009) and has reserves at the end of 2009 amounting to 6.425 million metric tons with a grade of 0.266% Be, or 15,800 metric tons of contained beryllium, which is sufficient for 100 years at the current production rate (McLemore, 2010b, c). The Apache Warm Springs deposit contains an estimated 39,063 metric tones (43,060 short tons, not NI 43-101 compliant) of 0.05-2.5% Be (Fig. 9; Mining Engineering, 2002).

DISCUSSION AND CONCLUSIONS

Formation and age of mineralization and alteration

The Apache Warm Springs deposit is hosted by rhyolite that could be part of a rhyolite dome similar to the dome found at the junction of Cañada Alamosa and San Mateo Canyon (McLemore, 2010a, 2012a) and elsewhere in the Sierra Cuchillo and San Mateo Mountains (McLemore, 2012b). Red Paint Canyon fault zone likely controlled the emplacement of the rhyolite dome, alteration, and beryllium mineralization. Deposits at Iron Mountain and Reilly Peak in the northern Cuchillo Negro district (Fig. 1; south of the Ojo Caliente No. 2 district), contain Fe-Be-W-Sn skarn deposits that are related to chemically-similar rhyolites (McLemore, 2010a). The rhyolites in the Sierra Cuchillo are ~29-22 Ma (McLemore, 2010a) and adularia from a scheelite skarn at Reilly Peak was dated as 27.3±0.6 Ma (Davis, 1986). The Iron Mountain deposit formed from boiling saline fluids rich in Na-K-Ca-Cl salts at temperatures between 300-385°C (as determined by fluid inclusion studies by Nkambule, 1988). The Apache Warms Springs deposits likely formed at the same time by similar fluids and temperatures.

Although the age of the mineral deposits in the Ojo Caliente No. 2 district cannot be directly determined because suitable dateable minerals are lacking, the age of the mineral deposits can be estimated by stratigraphic position, age of faults, analogy to other deposits, and other geologic evidence. The difference in mineralogy, trace-element chemistry (McLemore, 2010a), associated alteration, and host rocks between the two types of mineral deposits (volcanic-epithermal veins and volcanogenic beryllium deposits) as described above, suggests that they are not related and formed at different times by two separate hydrothermal (or geothermal) systems.

The volcanic-epithermal veins cut the latite of Montoya Butte, but are not found in the Vicks Peak Tuff, rhyolite of Alamosa Canyon, or Turkey Springs Tuff. Furthermore, these younger rhyolites are not significantly altered by hydrothermal fluids. The veins trend north and northeast, similar to the orientations of some of the faults (McLemore, 2010a), suggesting that the veins and faults are of similar age. These northeast-trending faults appear to be some of the oldest faults, probably older than the caldera, because they have a different orientation than the caldera ring fractures and these faults do not cut the Vicks Peak Tuff. Therefore, the volcanic-epithermal veins likely are at least 36 Ma, but possibly younger than the formation of the Nogal Canyon caldera (28.4 Ma).

The Apache Warm Springs beryllium deposit and associated alteration is hosted by the rhyolite of Alum Spring, which overlies the latite of Montoya Butte (36 Ma) and likely overlies the Vicks Peak Tuff, and is overlain by the Turkey Springs Tuff (24.4 Ma). Small areas of acid-sulfate alteration, similar to that at the beryllium deposit, are found in rhyolite tuffs and volcaniclastic rocks within the latite of Montoya Butte, especially along faults (McLemore, 2012a). The Quaternary sedimentary rocks exposed along Cañada Alamosa west of Monticello Box contain rock fragments and cobbles of altered rhyolite of Alum Spring, indicating that the alteration occurred before deposition of these Quaternary units. Therefore, the beryllium deposit and associated alteration is older than the Turkey Springs Tuff (24.4 Ma), but is younger than the latite of Montoya Butte (36 Ma), and likely younger than the Vicks Peak Tuff (28.4 Ma). Similar relationships are found further south in the Cuchillo Negro district in the Sierra Cuchillo, where the Ag-Cu-Pb-Zn veins and skarns are associated with the older ~36-38 Ma granitic-rhyolitic rocks and the Fe-Be-W-Sn skarns are associated with the younger ~29-27 Ma rhyolites (Jahns, 1944a, b; Davis, 1986; McLemore, 2010a,b).

The geothermal system represented by the modern warm springs formed recently and is not related to either of these older mineralized systems. Most modern geothermal systems have durations of episodic activity of less than 3 million years, and most have durations of less than a few hundred thousand years (P.L.R. Browne, unpublished report, Spring 1992; McLemore, 1993, 2010a; Silberman, 1985). Therefore, at least three separate geothermal systems were/are present in the Ojo Caliente No. 2 mining district: 1) the oldest system forming the volcanic-epithermal veins (~28-36 Ma), 2) the system forming the Apache Warm Springs beryllium deposit and associated alteration (~24.4-28 Ma), and 3) the current, modern system related to Ojo Caliente, Willow Springs, and other warm springs feeding Cañada Alamosa.

Relationship to other altered/mineralized areas in central New Mexico

The rhyolite of Alamosa Canyon, rhyolite of Alum Spring, and rhyolite of Spring Canyon are similar in composition to the tin-bearing Taylor Creek Rhyolite; these rhyolites are metaluminous to weakly peraluminous, high-silica, topaz rhyolites (McLemore, 2010a). At Taylor Creek, 20 vents were active with pyroclastic flows, falls, and surges. The first stage of eruption was followed by extrusion of rhyolite flows forming domes (Duffield et al., 1990). The tin was in the rhyolite magma and as the lava cooled and devitrified, the tin differentiated or was transported by residual fluids into the outer rind of the lava. Subsequent low-temperature convection mobilizes them along faults and within permeable tuffs and rhyolites (Burt and Sheridan, 1981; Duffield et al., 1990). A similar origin is proposed for the beryllium deposits at Spor Mountain, except that the rhyolites were erupted through carbonate sedimentary rocks, which appears to have aided concentration of the beryllium.

The Taylor Creek rhyolite, west of the Ojo Caliente No. 2 district (Fig. 1), also is a topaz-bearing rhyolite. Topaz-bearing rhyolites are compositionally distinct, rare high-silica rhyolites that are enriched in F, Li, Rb, Cs, U, Th, and Be, and are associated with volcanogenic and epithermal deposits of Be, Sn, U, and F (Burt and Sheridan, 1981; Christiansen et al., 1983). The rhyolites at Spor Mountain also are topaz-bearing, high-fluorine rhyolite lava flows forming domes that are interbedded with tuffs, tuffaceous breccias, and associated fault breccias (Bikum, 1980; Lindsey, 1981; Lindsey and Shawe, 1986). The rhyolite of Alamosa Canyon, rhyolite of Alum Springs, and porphyritic rhyolite and rhyolite aplite at Iron Mountain and Reilly Peak are similar in chemistry to topaz rhyolites. Topaz was found in the Iron Mountain rhyolite aplite (Robertson, 1986), but topaz has not been found in the other rhyolites in the Sierra Cuchillo or San Mateo Mountains. Topaz rhyolites appear to be evolved from partial melts of Proterozoic lower crust in an extensional tectonic setting, which is consistent with the formation of the younger ~27-29 Ma rhyolites in the Sierra Cuchillo and San Mateo Mountains. The older Reilly Peak rhyolite, Sierra Cuchillo laccolith, and monzonite plugs in the Montoya Butte quadrangle are more similar to other calc-alkaline rhyolites, not topaz rhyolites, and could represent a transition between older arc-related Laramide volcanism and younger extensional Rio Grande volcanism (McMillan et al., 2000).

Several beryllium deposits are found within the North American Cordilleran alkaline igneous belt (Fig. 10), a diffuse region of Cenozoic igneous rocks that extends along the eastern margin of the North American Cordillera from Alaska and British Columbia southward into Trans-Pecos Texas and eastern Mexico (Shawe, 1966; Barker, 1977, 1979, 1987; Mutschler et al., 1985, 1991; Woolley, 1987, McLemore et al., 1996a, b; McLemore, 1996b, 2010c). Rhyolites from Iron Mountain, Apache Warm Springs, Spor Mountain, and granites from Victorio Mountains associated with known beryllium mineralization are predominantly peraluminous (i.e. $Al_3O_5/(CaO+K_2O+Na_2O) > 1.0$) to metaluminous (i.e. $Al_3O_5/(CaO+K_2O+Na_2O) < 1.0$), and high-Si (silica-saturated). The rhyolites/syenites from Aquachille and Round Top Mountain are peralkaline. They are A-type granites (Whalen et al., 1987; McLemore, 2010b, c) found within-plate to syn-collusion granite fields of Pearce et al. (1984) and are similar in chemistry to topaz-bearing rhyolites. The similarity in chemical composition of rocks in these areas to the composition of rocks formed in within-plate tectonic settings infers that the rocks were formed in complex tectonic settings related to the subduction of lithospheric crust (i.e. volcanic arc) and formation of the Rio Grande rift and Great Basin (i.e. extensional tectonic setting). The formation of the rhyolites is consistent with predominantly fractional crystallization (Bobrow, 1984; Rye et al., 1990). The differences in incompatible trace elements, including beryllium, between the different granitic to rhyolitic rocks are likely related to either differences in the crustal rocks that were assimilated during magmatic differentiation (McMillan et al., 2000; Chapin et al., 2004) or by minor potential contamination from crustal sources and/or magma mixing (Bobrow, 1984). Beryllium and fluorine could be derived from the crustal source and incorporated into the magma.

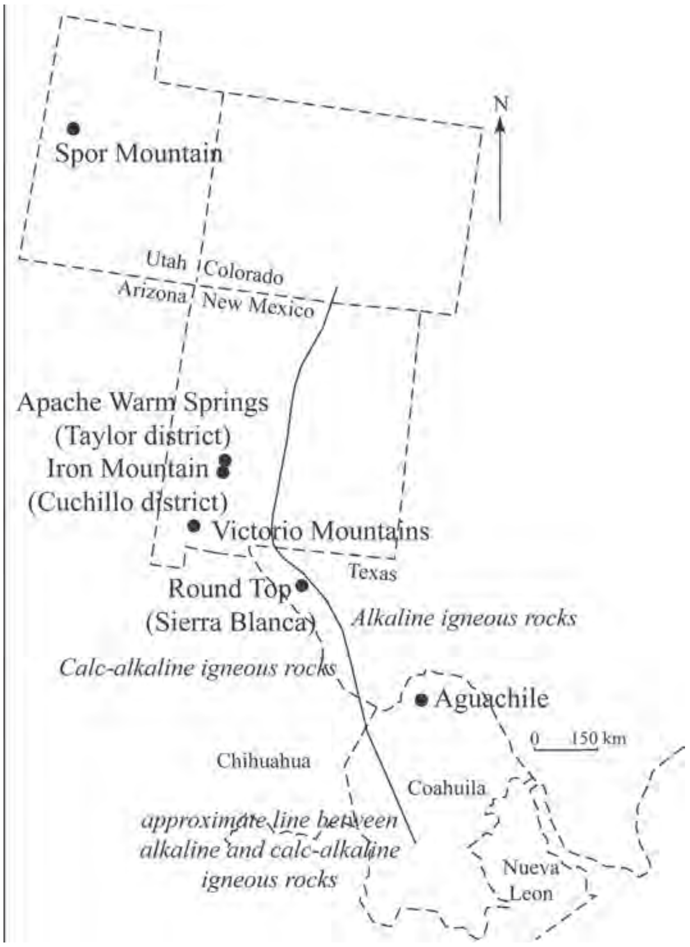

FIGURE 10. Location of selected beryllium deposits with calculated resources found in southwestern U.S. and Mexico. See McLemore (2010b, c) for additional information on these and other beryllium deposits. Approximate line separating the Tertiary alkaline and calc-alkaline igneous rocks is from Price et al. (1987) and McLemore (1996b).

Mineral resource potential

The lack of any significant sulfides or other base-metal minerals or any mineral or alteration zoning (such as a pyrite halo) suggests that a major volcanic-epithermal system containing precious or base metals either never formed in this area or, if one did occur, is at depth. The low chemical analyses and lack of significant geochemical anomalies in the NURE data (McLemore, 2010a) and the survey by Griffitts and Alminas (1968) also indicate that these deposits are not economically significant. Therefore, the mineral-resource potential for volcanic-epithermal precious and base metals vein deposits in the Ojo Caliente No. 2 district is low with a moderate to high degree of certainty.

The mineral-resource potential of the Apache Warm Springs beryllium deposit is low to moderate with a moderate to high degree of certainty, because the known extent of the beryllium deposit at the surface and in the subsurface where drilled is low grade and too small for economic development in the current market. The NURE data also indicate that the stream sediment samples in the area are low in beryllium concentrations (McLemore, 2010a). However, additional exploration drilling could locate additional beryllium in the subsurface. Deposits of uranium and rare earth elements could be associated with the beryllium deposit. Spor Mountain, Utah, produces most of the beryllium used in the U.S. today and the known reserves at Spor Mountain are sufficient to meet projected beryllium demand in the U.S. in the near future (McLemore, 2010b, c).

Environmental issues

The lack of any significant sulfides or other base-metal minerals suggests that acid drainage will not be an issue. Uranium could be present in the deposit. However, any potential exploration or subsequent mining would have to plan for the effect of mining, especially pumping water, on Ojo Caliente, Willow, and cold springs in Cañada Alamosa (McLemore, 2010a). Ojo Caliente, Willow, cold springs in Cañada Alamosa, and Alum Spring lie along Red Paint Canyon fault zone where the Apache Warm Springs beryllium deposit also is located. Future hydrologic studies are underway that will characterize the ground water conditions in this area.

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REFERENCES

Barker, D.S., 1977, Northern Trans-Pecos Magmatic province: Introduction and comparison with the Kenya rift: Geological Society of America Bulletin, v. 88, p. 1421-1427.

Barker, D.S., 1979, Cenozoic magmatism in the Trans-Pecos province: Relation to Rio Grande rift; *in* Riecker, R. E., editor, Rio Grande Rift: Tectonics and magmatism: American Geophysical Union, p. 382-392.

Barker, D.S., 1987, Tertiary alkaline magmatism in Trans-Pecos Texas; in Fitton, J. G. and Upton, B. G. J., eds., Alkaline igneous rocks: Geological Society, Special Publication 30, p. 415-431.

Barton, M.D. and Young, S., 2002, Non-pegmatitic deposits of beryllium: mineralogy, geology, phase equilibria and origin; *in* E.S. Grew, ed., Beryllium—mineralogy, petrology, and geochemistry: Reviews in Mineralogy and Geochemistry, v. 50, p. 591-691.

Bikum, J.V., 1980, Fluorine and lithophile element mineralization at Spor Mountain, Utah; *in* Burt, D.M. and Sheridan, M.F., Uranium mineralization in fluorine-enriched volcanic rocks: U.S. Department of Energy, Report GJBX-225(80), p. 167-414.

Bobrow, D.J., 1984, Geochemistry and petrology of Miocene silicic lavas in the Socorro-Magdalena area of New Mexico: M.S. thesis, New Mexico Institute of Mining and Technology, Socorro, 458 p., http://ees.nmt.edu/alumni/papers/1984t_bobrow_dj.pdf (accessed September 5, 2010).

Brush Engineered Materials, Inc., 2009, Transforming our world and yours: Annual report, 122 p., http://files.shareholder.com/downloads/BW/925738805x0x368575/A9F177AF-D3E5-4546-8707-73F26F14E146/bw2009ar.pdf (accessed September 5, 2010).

Burt, D.M. and Sheridan, M.F., 1981, Model for the formation of uranium/lithophile element deposits in fluorine-rich volcanic rocks; *in* Goodell, P.C. and Waters, A.C., eds., Uranium in volcanic and volcaniclastic rocks: American Association of Petroleum Geologists, Studies in Geology No. 13, p. 99-109.

Cather, S.M., McIntosh, W.C., and Chapin, C.E., 1987, Stratigraphy, age, and rates of deposition of the Datil Group (Upper Eocene-Lower Oligocene), west-central New Mexico: New Mexico Geology, v. 9, p. 50-54, http://geoinfo.nmt.edu/publications/periodicals/nmg/downloads/9/n3/nmg_v9_n3_p50.pdf (accessed March 29, 2012).

Cather, S.M., Chamberlin, R.M., and Ratté, J.C., 1994, Tertiary stratigraphy and nomenclature for western New Mexico and eastern Arizona: N.M. Geological Society, 45th Field Conference Guidebook, p. 259-266.

Chapin, C.E., Wilks, M., and McIntosh, W.C., 2004, Space-time patterns of Late Cretaceous to present magmatism in New Mexico; comparison with Andean volcanism and potential for future volcanism; in Tectonics, geochronology and volcanism in the southern Rocky Mountains and Rio Grande rift: New Mexico Bureau of Geology and Minerals Resources, Bulletin 160, p. 13-40, http://geoinfo.nmt.edu/publications/bulletins/160/downloads/02chapin.pdf (accessed March 29, 2012).

Christiansen, E.H., Burt, D.M., Sheridan, M.F., and Wilson, R.T., 1983, The petrogenesis of topaz rhyolites from the western United States: Contributions Mineralogy and Petrology, v. 83, p. 16-30.

Cox, D.P., and Singer, D.A., 1986, Mineral deposit models: U.S. Geological Survey, Bulletin 1693, 379 p.

Cunningham, L.D., 2003, Beryllium: U.S. Geological Survey, Minerals Yearbook, 7 p., http://minerals.usgs.gov/minerals/pubs/commodity/beryllium/berylmyb03.pdf (accessed September 5, 2010).

Davis, L.L., 1986, The petrology and geochemistry of the intrusive rocks and associated iron-rich polymetallic skarn at Reilly Peak, New Mexico: M.S. thesis, University of Georgia, Athens, 108 p.

Duffield, W.A., Reed, B.L., and Richter, D.H., 1990, Origin of rhyolite-hosted tin mineralization: evidence from the Taylor Creek Rhyolite, New Mexico: Economic Geology, v. 85, p. 392-398.

Ferguson, C.A., Osburn, G.R., and McCraw, D.J., 2007, Preliminary geologic map of the Welty Hill quadrangle, Socorro County, New Mexico: New Mexico Bureau of Geology and Mineral Resources, Map 148, scale 1:24,000, http://geoinfo.nmt.edu/publications/maps/geologic/ofgm/downloads/148/Welty_Hill_v1p-01.pdf (accessed March 29, 2012).

Ferguson, C.A., Osburn, G.R., and McIntosh, W.C., 2012, Oligocene calderas in the San Mateo Mountains, Mogollon-Datil volcanic field, New Mexico: this guidebook

File, L., and Northrop, S.A., 1966, County, township, and range locations of New Mexico's Mining Districts: New Mexico Bureau of Mines and Mineral Resources Circular 84, 66 p.

Foley, N.K., Seal, R.R., II, Piatak, N.M., and Hetland, B.R., 2010, An occurrence model for the national assessment of volcanogenic beryllium deposits: U.S. Geological Survey Open-File Report 2010-1195, 4 p., http://pubs.usgs.gov/of/2010/1195/ (accessed September 5, 2010).

Griffitts, W.R. and Alminas, H.V., 1968, Geochemical evidence for possible concealed mineral deposits near the Monticello Box, northern Sierra Cuchillo, Socorro County, New Mexico: U.S. Geological Survey, Circular 600, 13 p., http://pubs.er.usgs.gov/usgspubs/cir/cir600 (accessed September 5, 2010).

Henley, R.W., and Ellis, A.J., 1983, Geothermal systems, ancient and modern: a geochemical review: Earth Science Reviews, v. 19, p. 1-50.

Hillard, P.D., 1967, General geology and beryllium mineralization near Apache Warm Springs, Socorro County, New Mexico: M.S. thesis, New Mexico Institute of Mining and Technology, Socorro, 58 p., http://ees.nmt.edu/alumni/papers/1967t_hillard_pd.pdf (accessed March 29, 2012).

Hillard, P.D., 1969, Geology and beryllium mineralization near Apache Warm Springs, Socorro County, New Mexico: Socorro, New Mexico Bureau of Mines and Mineral Resources Circular 103, 16 p.

Jahns, R.H., 1944a, Beryllium and tungsten deposits of the Iron Mountain district, Sierra and Socorro Counties, New Mexico: U.S. Geological Survey, Bulletin 945-C, p. 45-79.

Jahns, R.H., 1944b, "Ribbon rock," an unusual beryllium-bearing tactite: Economic Geology, v. 39, p. 175-205.

Jahns, R.H., McMillan, D.K., and O'Brient, J.D., 2006, Preliminary geologic map of the Chise quadrangle, Sierra County, New Mexico: New Mexico Bureau of Geology and Mineral Resources, Open-file Map Series OFGM-115, scale 1:24,000, http://geoinfo.nmt.edu/publications/maps/geologic/ofgm/details.cfml?Volume=115.

Jahns, R.H., McMillan, D.K., O'Brient, J.D., and Fisher, D.L., 1978, Geologic section in the Sierra Cuchillo and flanking areas, Sierra and Socorro Counties, New Mexico, *in* Chapin, C.E., and Elston, W.E., eds., Field guide to selected cauldrons and mining districts of the Datil-Mogollon volcanic field, New Mexico: New Mexico Geological Society Special Publication 7, p. 131-138.

Jaskula, B.W., 2009, Beryllium: U.S. Geological Survey, Mineral Commodity Reports, 7 p., http://minerals.usgs.gov/minerals/pubs/commodity/beryllium/myb1-2007-beryl.pdf (accessed March 29, 2012).

Keith, S.B., Gest, D.E., DeWitt, E., Tull, N.W., and Everson, B.A., 1983, Metallic mineral districts and production in Arizona: Arizona Bureau of Geology and Mineral Technology, Bulletin 194, 58 p.

Kharaka, Y.K., Sorey, M.L., and Thordsen, J.J., 2000, Large-scale hydrothermal fluid discharges in the Norris-Mammoth corridor, Yellowstone National Park, USA: Journal of Geochemical Exploration, v. 69-70, p. 201-205.

Lasky, S.G., 1932, The ore deposits of Socorro County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin, 8, 139 p.

Lindsey, D.A., 1981, Volcanism and uranium mineralization at Spor Mountain, Utah; *in* Goodell, P.C. and Waters, A.C., eds., Uranium in volcanic and volcaniclastic rocks: American Association of Petroleum Geologists, Studies in Geology No. 13, p. 89-98.

Lindsey, D.A. and Shawe, D.R., 1986, Spur Mountain Be-F-U deposits; *in* R.L. Erickson, Characteristics of mineral deposit occurrences: U.S. Geological Survey, Open-file Report 82-795, p. 67-69.

Lovering, T.G. and Heyl, A.V., 1989, Mineral belts in western Sierra County, New Mexico, suggested by mining districts, geology, and geochemical anomalies: U.S. Geological Survey, Bulletin 1876, 58 p., http://pubs.er.usgs.gov/usgspubs/b/b1876 (accessed September 5, 2010).

Lynch, S.D., 2003, Geologic mapping and $^{40}Ar/^{39}Ar$ geochronology in the northern Nogal Canyon caldera, within and adjacent to the southwest corner of the Blue Mountain quadrangle, San Mateo Mountains, New Mexico: M.S. thesis, New Mexico Institute of Mining and Technology, 102 p., http://ees.nmt.edu/alumni/papers/2003t_lynch_sd.pdf (accessed March 29, 2012).

Maldonado, F., 1974, Geologic map of the northern part of the Sierra Cuchillo, Socorro and Sierra Counties, New Mexico: M.S. thesis, University of New Mexico, Albuquerque, 59 p.

Maldonado, F., 1980, Geologic map of the northern part of the Sierra Cuchillo, Socorro and Sierra Counties, New Mexico: U.S. Geological Survey, Open-File Report 80-230, map scale 1:24,000, http://pubs.er.usgs.gov/usgspubs/ofr/ofr80230 (accessed March 29, 2012).

Maldonado, F., 2012, Summary of the geology of the northern part of the Sierra Cuchillo, Socorro and Sierra Counties, Southwestern New Mexico: New Mexico Geological Society, this guidebook.

Marvin, R.F., Mehnert, H.H., and Naeser, C.W., 1988, U.S. Geological Survey radiometric ages-compilation C: part 2: Arizona and New Mexico: Isochron/West, v. 51, p. 5-13.

Mason, G.T., Jr., and Arndt, R.E., 1996, Mineral resources data system (MRDS): U.S. Geological Survey, Digital Data Series DDS-20, CD-ROM.

McDowell, T.W., and Claubaugh, S.E., 1979, Ignimbrites of the Sierra Madre Occidental and their relation to the tectonic history of western Mexico: Geological Society of America, Special Paper 180, p. 113-124.

McCraw, D.J., 2003, Quaternary geology of the Montoya Butte 7.5 minute quadrangle, Socorro County, New Mexico: New Mexico Bureau of

Geology and Mineral Resources, Open-file Report OF-GM 69-Q, scale 1:24,000, http://geoinfo.nmt.edu/publications/maps/geologic/ofgm/details.cfml?Volume=69 (accessed February 10, 2010).

McIntosh, W.C., Kedzie, L.L., and Sutter, J.F., 1991, Paleomagnetic and $^{40}Ar/^{39}Ar$ dating database for Mogollon-Datil ignimbrites, southwestern New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 135, 79 p.

McIntosh, W.C., Chapin, C.E., Ratté, J.C., and Sutter, J.F., 1992a, Time-stratigraphic framework for the Eocene-Oligocene Mogollon-Datil volcanic field southwestern New Mexico: Geological Society of America Bulletin, v. 104, p. 851-871.

McIntosh, W.C., Geissman, J.W., Chapin, C.E., Kunk, M.J., and Henry, C.D., 1992b, Calibration of the latest Eocene-Oligocene geomagnetic polarity time sale using $^{40}Ar/^{39}Ar$ dated ignimbrites: Geology, v. 20, p. 459-463.

McLemore, V.T., 1993, Geology and geochemistry of the mineralization and alteration in the Steeple Rock district, Grant County, New Mexico and Greenlee County, Arizona: Ph.D. dissertation, University of Texas at El Paso; also New Mexico Bureau of Mines and Mineral Resources, Open-File Report 397, 526 p., http://geoinfo.nmt.edu/publications/openfile/downloads/OFR300-399/376-399/397/ofr_397.pdf (accessed March 29, 2012).

McLemore, V.T., 1996a, Volcanic-epithermal precious-metal deposits in New Mexico; *in* Cyner, A.R. and Fahey, P.L., eds., Geology and ore deposits of the American Cordillera: Geological Society of Nevada Symposium Proceedings, Reno/Sparks, Nevada, April 1995, p. 951-969.

McLemore, V.T., 1996b, Great Plains Margin (alkalic-related) gold deposits in New Mexico; *in* Cyner, A.R. and Fahey, P.L., eds., Geology and ore deposits of the American Cordillera: Geological Society of Nevada Symposium Proceedings, Reno/Sparks, Nevada, April 1995, p. 935-950.

McLemore, V.T., 2001, Silver and gold resources in New Mexico: New Mexico Bureau of Mines and Mineral Resources, Resource Map 21, 60 p.

McLemore, V.T., 2010a, Geology, mineral resources, and geoarchaeology of the Montoya Butte quadrangle, including the Ojo Caliente No. 2 Mining District, Socorro County, New Mexico: New Mexico Bureau of Geology and Mineral Resources, Open file Report OF-535, 200 p., http://geoinfo.nmt.edu/publications/openfile/details.cfml?Volume=535 (accessed March 29, 2012).

McLemore, V.T., 2010b, Beryllium deposits in New Mexico, including evaluation of the NURE stream sediment data: New Mexico Bureau of Geology and Mineral Resources, Open file Report, 105 p., http://geoinfo.nmt.edu/publications/openfile/details.cfml?Volume=533 (accessed March 29, 2012).

McLemore, V.T., 2010c, Beryllium deposits in New Mexico and adjacent areas: abstract and poster presentation, Society of Economic Geologists, October, 2010, http://geoinfo.nmt.edu/staff/mclemore/documents/BE_seg_mclemore_rev.pdf (accessed March 29, 2012).

McLemore, V.T., 2012a, Geologic map of the Montoya Butte quadrangle, Socorro County, New Mexico: New Mexico Bureau of Geology and Mineral Resources, Open-file Geologic Map, scale 1:12,000.

McLemore, V.T., 2012b, Geology and mineral resources in the San Jose mining district, Socorro County, New Mexico: this guidebook.

McLemore, V. T., Hoffman, G., Smith, M, Mansell, M., and Wilks, M., 2005a, Mining districts of New Mexico: New Mexico Bureau of Geology and Mineral Resources, Open-file Report 494, CD-ROM.

McLemore, V.T., Krueger, C.B., Johnson, P., Raugust, J.S., Jones, G.E., Hoffman, G.K. and Wilks, M., 2005b, New Mexico Mines Database: Society of Mining, Exploration, and Metallurgy, Mining Engineering, February, p. 42-47.

McLemore, V.T., Love, D.W., Heizler, M., and Koning, D.J., 2012, $^{40}Ar/^{39}Ar$ ages of selected basalts in the Sierra Cuchillo and mud springs mountains, Sierra and Socorro Counties, New Mexico: this guidebook.

McLemore, V.T., Lueth, V.W., Guilinger, J.R., and Pease, T.C., 1996a, Geology, mineral resources, and marketing of the Wind Mountain nepheline-syenite porphyry, Cornudas Mountains, New Mexico and Texas; *in* Austin, G.S., Barker, J.M., Hoffman, G., Gilson, N., and Zidec, J., eds., Proceedings of the 31st Forum on the Geology of Industrial Minerals, Borderland Forum: New Mexico Bureau of Mines and Mineral Resources, Bulletin 154, p. 127-136.

McLemore, V.T., Lueth, V.W., Pease, T.C., and Guilinger, J.R., 1996b, Petrology and mineral resources of the Wind Mountain laccolith, Cornudas Mountains, New Mexico and Texas: Canadian Mineralogist, v. 34, pt. 2, p. 335-347.

McMillan, N.J., Dickins, A.P., and Haag, D., 2000, Evolution of magma source regions in the Rio Grande rift, southern New Mexico: Geological Society of America, Bulletin, v. 112, p. 1582-1593.

Meeves, H.C., 1966, Nonpegmatitic beryllium occurrences in Arizona, Colorado, New Mexico, Utah and four adjacent states: U.S. Bureau of Mines, Report of Investigations 6828, 68 p.

Mining Engineering, 2002, News briefs, The Beryllium Group: Mining Engineering, February, p. 14.

Muffler, L.J.P., White, D.E., and Truesdell, A.H., 1971, Hydrothermal explosion craters in Yellowstone National Park: Geological Society of America, Bulletin, v. 82, p. 723-740.

Mutschler, F.E., Griffin, M.E., Stevens, D.S., and Shannon, S.S., Jr., 1985, Precious metal deposits related to alkaline rocks in the North American Cordillera-an interpretive review: Transactions Geological Society of South Africa, v. 88, p. 355-377.

Mutschler, F.E., Mooney, T.C., and Johnson, D.C., 1991, Precious metal deposits related to alkaline igneous rocks-a space-time trip through the Cordillera: Mining Engineering, v. 43, p. 304-309.

Nkambule, M.V., 1988, Skarn mineralization at Iron Mountain, New Mexico, in light of fluid inclusion studies: M.S. thesis, New Mexico Institute of Mining and Technology, Socorro, 60 p.

North, R.M., and McLemore, V.T., 1986, Silver and gold occurrences in New Mexico: New Mexico Bureau of Mines and Mineral Resources, Resource Map 15, 32 p., scale 1:1,000,000.

North, R.M., and McLemore, V.T., 1988, A classification of the precious metal deposits of New Mexico; *in* Bulk mineable precious metal deposits of the western United States Symposium Volume: Geological Society of Nevada, Reno, Symposium held April 6-8, 1987, p. 625-660.

P and E Mining Consultants Inc., 2009, Technical report on the Warm Springs beryllium property, Socorro, County, New Mexico USA: unpublished report for BE Resources Inc., 52 p.

Pearce, J.A., Harris, N.B.W. and Tindle, A.G., 1984, Trace element discrimination diagrams for the tectonic interpretation of granitic rocks: Journal of Petrology, v. 24, p. 956-983.

Price, J.G., Rubin, J.N,, Henry, C.D., Pinkston, T.L., Tweedy, S.W. and Koppenaal, D.W., 1990, Rare-metal enriched peraluminous rhyolites in a continental arc, Sierra Blanca area, Trans-Pecos Texas; chemical modification by vapor-phase crystallization; *in* H.J. Stein and Hannah, J.L., Ore-bearing granite systems; Petrogenesis and mineralizing processes: Geological Society of America, Special Paper 246, p. 103-120.

Robertson, D.E., 1986, Skarn mineralization at Iron Mountain, New Mexico: M.S. thesis, Arizona State University, Tucson, 76 p.

Rodgers, K.A., Cook, K.L., Browne, P.R.L., and Campbell, K.A., 2002, The mineralogy, texture and significance of silica derived from alteration by steam condensate in three New Zealand geothermal fields: Clay Minerals, v. 37, p. 299-322.

Rye, R.O., Lufkin, J.L., and Wasserman, M.D., 1990, Genesis of the rhyolite-hosted tin occurrences in the Black Range, New Mexico, as indicated by stable isotope studies; *in* H.J. Stein and Hannah, J.L., Ore-bearing granite systems; Petrogenesis and mineralizing processes: Geological Society of America, Special Paper 246, p. 233-250.

Shawe, D.R., 1966, Arizona-New Mexico and Nevada-Utah beryllium belts: U.S. Geological Survey, Professional Paper 550-C, p. C206-C213.

Silberman, M.L., 1985, Geochronology of hydrothermal alteration and mineralization: Tertiary epithermal precious-metal deposits in the Great Basin; in E.W. Tooker, ed., Geologic characteristics of sediment-hosted disseminated gold deposits—Search for an occurrence model: U.S. Geological Survey, Bulletin 1646, p. 55-70.

U.S. Bureau of Mines, 1995, MAS/MILS CD-ROM: U.S. Bureau of Mines, Special Publication 12-95, CD-ROM.

Whalen, J.B., Currie, K.L., and Chappell, B.W., 1987, A-type granites: geochemical characteristics, discrimination and petrogenesis: Contributions to Mineralogy and Petrology, v. 95, p. 40-418.

Woolley, A.R., 1987, Alkaline rocks and carbonatites of the world, part 1: North and South America: University of Texas Press, Austin, and British Museum of Natural History, Cambridge, England, 216 p.