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GEOLOGY AND MINERAL RESOURCES OF THE NOGAL-BONITO MINING DISTRICT, LINCOLN COUNTY, NEW MEXICO

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ABSTRACT—The alkaline igneous rocks in the Nogal-Bonito mining district were formed as multiple intrusions and dikes emplaced between 33 and 26 Ma. Four types of mineral deposits found in the Nogal-Bonito district include gold placers, Ag-Pb-Zn (±Au, Mo) and Ag-Au fissure veins, gold-bearing breccia pipes, and porphyry molybdenum-copper deposits. Although local high concentrations of gold do occur in some of the vein deposits, most appear to have low gold grades overall. However, companies will continue to re-examine the breccia pipe deposits in the Nogal-Bonito district as the price of gold rises, and the rare earth elements (REE) potential of the area is attractive. Undiscovered breccia pipe deposits that could potentially contain gold may be at depth beneath some of the vein deposits, but require drilling to locate them. Porphyry molybdenum-copper deposits in the Nogal-Bonito district are small and low grade and are not of economic interest at this time. Although REE or tellurium deposits have not been found in the Nogal-Bonito district, the alkaline rocks in the district are similar in composition to alkaline rocks that host known REE and tellurium deposits elsewhere in the world. Any additional exploration activities would be prudent to analyze for these elements as well as gold and other metals.

INTRODUCTION

The Nogal-Bonito mining district (DIS095, New Mexico Mines Database, McLemore et al., 2005a, b) surrounds the town of Nogal (originally called Dry Gulch and then Parsons) in southern Lincoln County and includes several small mining camps or subdistricts (Fig. 1; as defined by Griswold, 1959 and File and Northrop, 1966), including Vera Cruz, Parsons (Rialto), Bonito, Nogal, and Alto (Cedar Creek/Eagle Creek). The district covers portions of the Nogal Peak, Angus, Church Mountain, and Nogal 7.5-minute quadrangles. The Nogal-Bonito district was discovered about 1863 and is estimated to have yielded approximately 15,000 oz lode Au, 200 oz placer Au, and 20,000 oz Ag from 1865–1955 (Table 1) from three types of mineral deposits, including: (1) placer gold, (2) Ag-Pb-Zn (±Au, Mo) and Au-Ag fissure veins, and (3) gold-bearing breccia pipe deposits. A fourth type of mineral deposit is found in the Nogal-Bonito district, porphyry molybdenum-copper deposits, but there has been no mineral production. Hydrothermal alteration is extensive in the district. Several companies examined the Nogal-Bonito district for potential gold deposits during the 1980s-1990s and several investigations were published (Fulp and Woodward, 1991b; Eng, 1991; Ryberg, 1991). Since these investigations, the price of gold and silver has increased, resulting in re-examination of gold and silver mining districts throughout New Mexico for their mineral resource potential. The purposes of this paper are to: (1) summarize the geology, geochemistry, and mineral production of the district, (2) discuss the age and formation of these deposits, (3) evaluate previously collected data, and (4) comment on the future economic potential of mineral deposits in the district.

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), McLemore (1991, 1996, 2001) and Goff et al. (2011). Published and unpublished data on

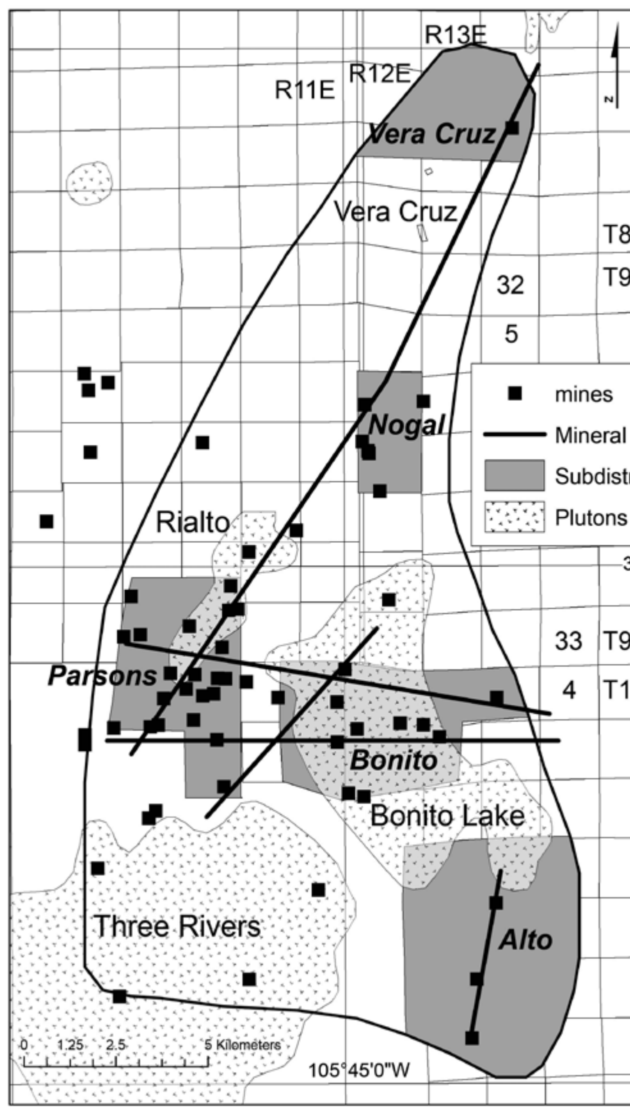

FIGURE 1. Subdistricts, plutons, mines, prospects, and mineral deposits in the Nogal mining district, Lincoln County, New Mexico.

Appendix data for this paper can be accessed at:
http://nmgs.nmt.edu/repository/index.cfm?rid=2014005

existing mines and mills within the Nogal-Bonito district were inventoried and compiled in the New Mexico Mines Database (McLemore et al., 2005a, b). Geologic mapping was conducted as part of the New Mexico Bureau of Geology and Mineral Resources Statemap program (Rawling, 2004, 2012; Cikoski et al., 2011; Goff et al., 2011).

Mineral production is summarized in Table 1. Mining and production records are generally poor, particularly for the earliest times, and many early records are conflicting. These production figures are the best data available and were obtained from published and unpublished sources (NMBGMR file data). However, production figures are subject to change as new data are obtained. Any resource or reserve data presented here are historical and are provided for information purposes only, and do not conform to Canadian National Instrument NI 43–101 requirements.

MINING AND EXPLORATION HISTORY

The oldest mining claim was established in 1863 (Segerstrom et al., 1979). Placer gold was discovered in Dry Gulch (Nogal) about 1865 (Fig. 1). By 1868, veins at the American mine were found. However, the area was then part of the Mescalero Indian Reservation until 1882, when the area was transferred to federal ownership after which exploration and mining intensified (Jones, 1904; Lindgren et al., 1910; Wells and Wootton, 1940). The Parsons mine was claimed in 1884 and by 1918, 75,000 short tons of low-grade ore were produced from that mine (Griswold, 1959, 1964). In 1902–1910, the Parsons Mining Co. consolidated many of the claims near the mine.

The Rialto (Fulmer) claims were first located for gold in 1894, with molybdenum of interest in the 1950s. In 1957, Climax Molybdenum Co. drilled in the Rialto area and found the grade averaged 0.2% Mo (Griswold, 1959; Griswold and Missaghi, 1964; Segerstrom et al., 1979). Other companies have examined the area since, but there has been no production.

Several companies explored and drilled in the area in the late 1970s and 1980s. Pioneer Metals Corp. explored the Great Western and Bonito mines in 1988–1989 and still controls some claims in the area. In 1989, the breccia deposits at Great Western were estimated to contain 190,000 oz of gold (Dayton, 1988). Minor exploration continued until the 1990s. Today, many mining claims are active but no exploration or mining permits have been applied for.

Segerstrom et al. (1975, 1979,1983) and Briggs (1983) conducted extensive mapping and geochemical surveys of the mines in the Nogal-Bonito district as part of their examination of the mineral resource potential of the White Mountain wilderness area. Berry et al. (1981) examined the uranium potential of the area and found no significant uranium resources in the district. Korzeb and Kness (1992) also conducted a limited geochemical survey of the Nogal-Bonito district as part of their study of the Roswell Resource area of the U.S. Bureau of Land Management; geochemical results are in Appendix 2.

A summary of some of the more significant deposits is in Table 2 and additional information on mines, prospects, and deposits in the district is in Appendix 1. Thompson (1966, 1973) estimated that approximately $1 million worth of lead, zinc, silver, and gold were produced from this district, but the published and unpublished U.S. Geological Survey and U.S. Bureau of Mines records

TABLE 1. Metals production from the Nogal-Bonito mining district. Data compiled from U.S. Geological Survey (1902–1927), U.S. Bureau of Mines Mineral Yearbooks (1927–1990), Griswold, (1959), Johnson (1972) and (McLemore, 1991, 2001).

Year	Ore (short tons)	Copper (lbs)	Gold (lode oz)	Gold placer (oz)	Silver (oz)	Lead (lbs)	Total value $
1865–1932	125,000		15,000				250,000
1902–1933				50			
1933	196		240.04	14.27	90		5,289
1934	111		138.4	56.91	146	50	6,922
1935	132		157.06	24.6	81	600	6,440
1936	214		122.12	2.2	214	1,100	4,568
1937	288	100	15.8		340	200	840
1938	41		3.2		195	2,300	344
1939	1				52		35
1940	162		2		623	200	523
1941	51				720	200	523
1946	2				5	1,000	113
1949	9				18	2,000	332
1950	400		9		10		324
1955	3	100			7	100	21
1965	16						
Total 1932–1955	1,626	100	1,710	147.98	2,501	7,750	26,274
Estimated total 1865–1965		W	17,000*	200	20,000	W	300,000

W—withheld. *—includes placer production.

TABLE 2. Deposits in the Nogal-Bonito mining district with reported, historic (non 43–101 compliant) resources. Mine identification number is from the New Mexico Mines Database (McLemore et al., 2005a, b).

Mine identification number	Name of deposit	Short tons of ore	Au grade (ppm)	Ag grade (ppm)	Mo Grade %	Year of estimate	Reference
NMLI0068	Vera Cruz	207,450 (assured)	4.5			1938	Ryberg (1991)
		435,000 (probable)	3.9				
		934,000 (possible)	3.9				
NMLI0207	Great Western	3,600,000	18.7			1992	NMBGMR file data
NMLI0271	Parsons	44,000	16.1			1991	Thompson (1991a, b)
NMLI0121	Rialto	30 million			0.05–0.18%	1978	Hollister (1978)
NMLI0008	Bonito	1.7 million	1.6	16.1		1989	NMBGMR file data

indicates that only an estimated $300,000 worth of lead, zinc, silver, and gold were actually produced (Table 1).

Not much is known about the historic milling in the district. Some ore was shipped to mills outside the district. The ore from the Parsons mine was first processed by an amalgamation mill, approximately 800 m downstream of the mine. In 1914, the mill was replaced by a cyanide concentrator (Griswold, 1959; Drake, 1991). In 1936, a mill and an amalgamation plant were built at the Helen Rae-American mines (Bartsch-Winkler and Donatich, 1995). A cyanide mill also was employed at the Vera Cruz mine. There is probably not enough mercury or cyanide in these operations in the Nogal-Bonito district to impact the local water supplies, because only small amounts of ore were produced and treated. But sampling and chemical analyses are required to determine if there is any residual mercury or cyanide remaining in local areas of the Nogal-Bonito district.

GEOLOGIC SETTING

The Nogal-Bonito district is part of the Rocky Mountain alkaline belt, a north-south belt of alkaline-igneous rocks and crustal thickening, roughly coinciding with the Great Plains physiographic margin with the Basin and Range (Rio Grande rift) and Rocky Mountains physiographic provinces that is associated with relatively large quantities of gold, fluorite, rare earth elements (REE), uranium, and other elements. This belt continues northward into Canada and southward into Mexico (Fig. 2; Mutschler et al., 1985, 1991; Bonham, 1988; Thompson, 1991a; Richards, 1995; McLemore, 1996; Kelley and Luddington, 2002). In Lincoln County, this belt is locally called the Lincoln County porphyry belt (Thompson, 1972, 1991c; Woodward, 1991; Fulp and Woodward, 1991a; Allen and Foord, 1991; McLemore and Zimmerer, 2009). The alkaline-related mineral deposits in New Mexico have been referred to as Great Plains Margin (GPM) deposits by North and McLemore (1986, 1988) and McLemore (1996, 2001). Alternative classifications by other workers include Au-Ag-Te veins (Cox and Bagby, 1986; Bliss et al., 1992; Kelley, 1995; Kelley et al., 1998), alkalic-gold or alkaline-igneous related gold deposits (Fulp and Woodward, 1991a; Thompson, 1991a, b; Bonham, 1988; Mutschler et al., 1985, 1991; Richards, 1995), porphyry gold deposits, and the North American Cordilleran belt of alkaline igneous rocks (Woolley, 1987; Mutschler et al., 1991).

Samples of the volcanic and intrusive rocks were collected and analyzed for major and trace elements (Goff et al., 2011). The igneous rocks from the Nogal-Bonito area are predominantly metaluminous to slightly peraluminous (Shand, 1943), alkaline (Le Bas et al., 1986), and most intrusive rocks have chemical compositions typical of A-type granites (Whalen et al., 1987) and within plate granites of Pearce et al. (1984), which is characteristic of igneous rocks found in the Rocky Mountain alkaline belt. These samples have light-REE enriched, chondrite-normalized patterns, typical of alkaline igneous rocks (Fig. 3). The rocks from the Nogal-Bonito area are similar in chemical composition to other alkaline igneous rocks in the Lincoln County porphyry belt (Allen and Foord, 1991; Constantopoulos, 2007) and other alkaline igneous rocks in the Rocky Mountain alkaline belt (data compilation by the author).

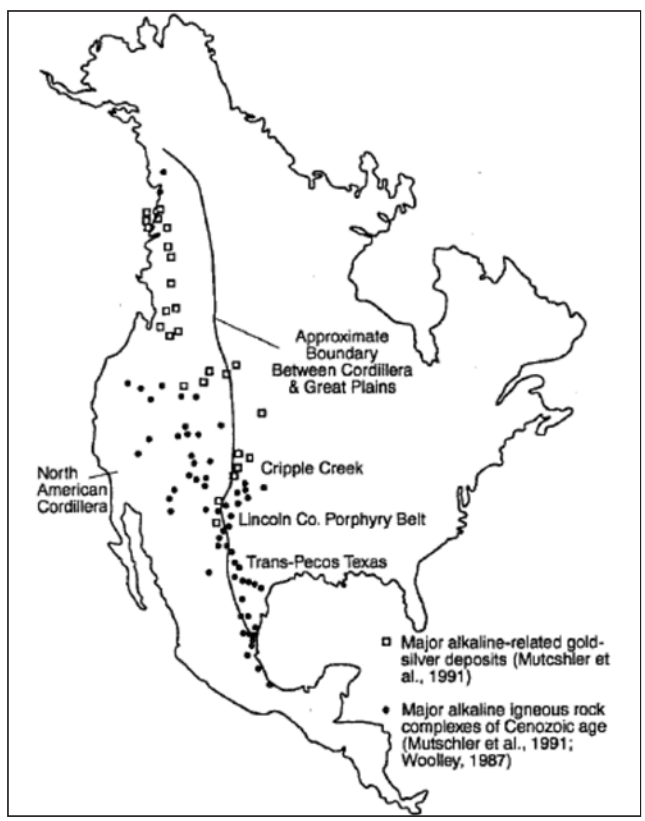

FIGURE 2. Extent of the Rocky Mountain alkaline belt (McLemore, 1996).

DESCRIPTION AND GEOCHEMISTRY OF DEPOSITS

Only summaries of the deposits are presented below and in Table 4. Detailed descriptions of individual deposits are found in several reports (Griswold, 1959; Thompson, 1973; Segerstrom et al., 1975, 1979, 1983; Korzeb and Kness, 1992). Selected geochemical analyses compiled from the literature for the Nogal-Bonito district are presented in Table 3. Selected chemical analyses of mineralized samples from the mines and prospects are in Appendix 2.

Placer gold deposits

Placer gold deposits were first developed in stream gravels along Dry Gulch, northeast of Nogal Peak in 1865 (Johnson, 1972). The placers probably were eroded from the Helen Rae-American and American veins. The gold concentrates by gravity in incised stream valleys and alluvial fans in deeply weathered highlands, such as the Nogal-Bonito area. Native gold and electrum occurs with quartz, magnetite, ilmenite, amphiboles, pyroxenes, pyrite, zircon, garnet, rutile, and a variety of other heavy minerals. The best gold concentrations occur where the gold is trapped by natural processes such as riffles in the river bottom, fractures within the bedrock, along bedding or foliation planes, and/or structures that are transverse to the river flow. Most deposits in the Nogal-Bonito district are thin, low-grade, disseminated deposits consisting of small flakes and blebs of gold.

Fissure vein deposits

Three types of fissure veins are found in the district: Ag-Pb-Zn (±Au, Mo), quartz with local Au-Ag (±pyrite), and carbonate veins. The fissure veins contain accessory iron-manganese oxides and pyrite, with minor barite, galena, sphalerite and copper minerals (Goff et al., 2011). Segerstrom et al. (1979) present gold, silver, and locally some base metals analyses from 1,715 samples collected in and around the White Mountain Wilderness area (Table 3) and a map showing five areas of anomalous molybdenum concentrations. Table 4 summarizes the main characteristics of the fissure veins found in the district.

Fissure veins are narrow (less than 2 m wide), north- to northeast-trending, quartz-carbonate veins with variable gold and copper, lead, and zinc sulfides. The sulfide minerals are in stringers of quartz and dolomite in the monzonite porphyry and quartz-calcite veins in andesite and monzonite porphyry. Some veins exhibit crustiform textures, followed by sulfide deposition and late carbonate (Douglass, 1992), suggesting an epithermal origin. The ore minerals include gold, pyrite, sphalerite, galena, and chalcopyrite. Au-Ag (±pyrite) veins are found predominantly around the Helen Rae-American and Rockford mines. A mass of bleached, kaolinized, and brecciated porphyry, located approximately 1.6 km southeast of Nogal Peak, also has yielded gold and a little silver.

At the Helen Rae-American and American mines, carbonate-quartz veins contained gold, pyrite, galena, and sphalerite (Griswold, 1959; Thompson, 1973; Porter and Hasenohr, 1984).

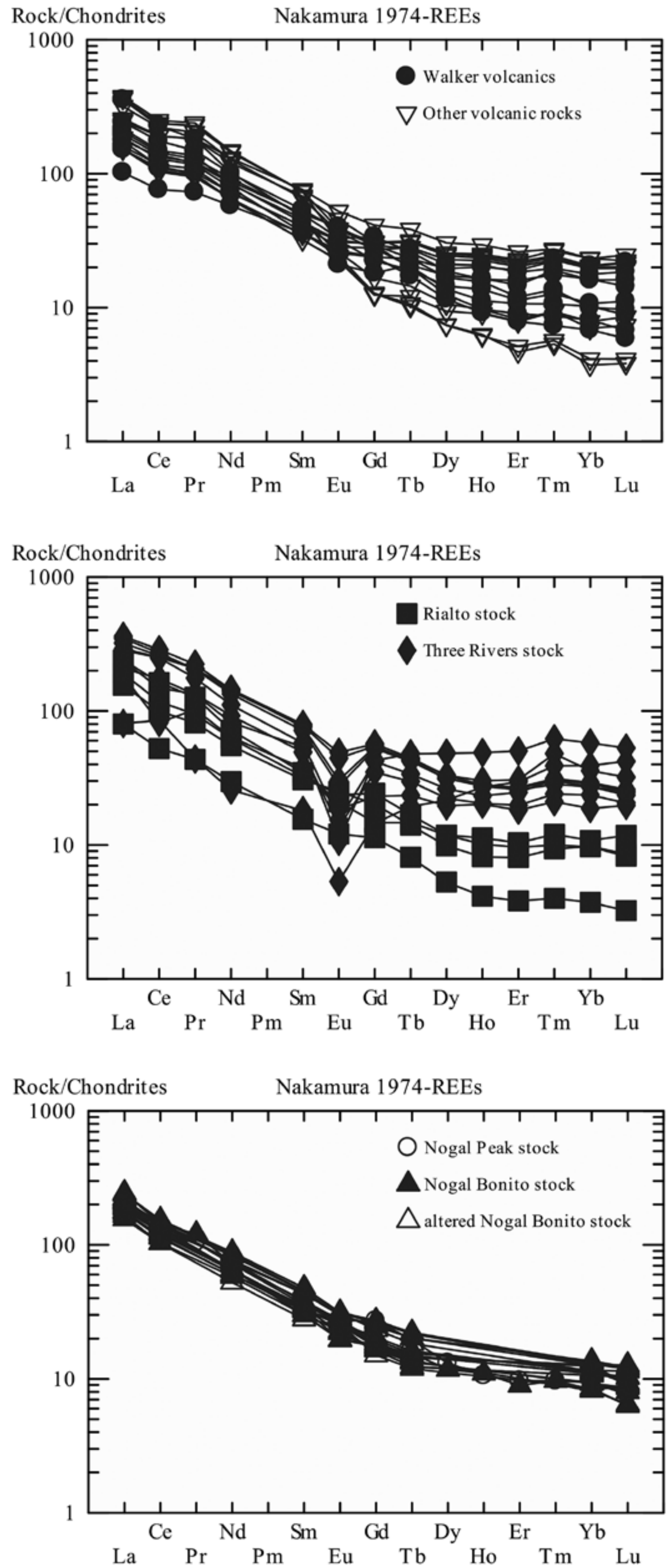

FIGURE 3. Chondrite normalized REE plot for rocks from the Nogal Peak quadrangle. Chondrite values from Nakamura (1974). Most rocks have flat REE patterns except the alkali granites from Three Rivers stock. These have negative Eu anomalies indicating plagioclase fractionation. Chemical analyses from Goff et al. (2011), Constantopoulos (2007), and Kelley et al. (2011) and are in Appendix 3.

TABLE 3. Summary of chemical analyses of rocks in the Nogal-Bonito mining district.

Element (in ppm)	Unmineralized rocks[1]	Stream sediments[2]	Mineralized rocks[2]	Mineralized rocks[3]	Average crustal abundance[4]
As	<0.1–3.5			2–447	4.8
Cd	<0.5–0.6				0.09
Cu	<1–79	50–150	<5–100	32–4,700	28
Hg	<1–2				0.05
Mo	<1–248	50–100	<5–1,500	26–1,770	1.1
Pb	6–49	10–300	10–1,500	12–300,900	17
Sb	<0.05–4.3			0.5–10,000	0.4
Se	<0.2–0.6				0.09
Zn	37–116		<200–10,000	11–108,200	67
U	1–12				2.7
Th	4–48				10.5

1. from Goff et al. (2011). 2. from Segerstrom et al. (1979). 3. Korzeb and Kness (1992) and in Appendix 2. [4] Rudnick and Gao (2005).

TABLE 4. Characteristics of mineral deposits in the Nogal-Bonito district (modified from Douglass, 1992).

Attributes	Gold breccia pipe deposits	Ag-Pb-Zn (±Au, Mo) vein deposits	Porphyry Mo-Cu deposits
Metals	Au>Ag (±Cu, Mo)	Zn>Pb>Ag (±Au,Mo)	Mo, Cu (zoned)
Style of mineralization	Open spaces or breccia cements	Open space veins	Disseminated
Host rock	Volcanics, intrusions, Crevasse Canyon Formation	Volcanics	Intrusions
Alteration	Vein envelope, propyllitic, weak argillic, carbonate	Pervasive, propylitic, weak phyllic	
S abundance	Low (S>2%)	High (S 50–75%)	Low
Temperature ore stage minerals	224–538º C, average 260º C	188–416º C, average 240º C	
Salinity of ore stage minerals	2–50 wt% NaCl	2–18 wt% NaCl	3–5 wt% NaCl
δ^{18}O fluid (per mil)	-5 to 9.5, average 1.9	-5.7 to -3.4, average -2.6	1.1
δ^{34}S (per mil)			-1.1 to -8.3

The highest grade ore was found at the intersection of the main vein with smaller crosscutting veins. The 0.3-m-wide Crow vein, exposed by the Renowned and Crow mines, consists of quartz with galena, sphalerite, pyrite, and chalcopyrite in altered andesite and contained 11.3% Pb (Griswold, 1959). Samples from the Crow vein contained as high as 1,800 ppb Au, 383 ppm Ag, 447 ppm As, 3,650 ppm Cu, 30.09% Pb and 10.82% Zn (Korzeb and Kness, 1992). The Maud mine exposes a vein containing quartz, sphalerite, galena, pyrite, chalcopyrite, and barite. A composite sample assayed 7.1% Pb, 0.39% Mo, 10 ppm Au, and 41.3 ppm Ag (Thompson, 1973). The Great Western and Bonito mines consist of quartz-pyrite veins exposed by several adits. The Main Zone at the Great Western is estimated to contain 1.3 million short tons of 14.5 ppm Au and the Blue Front Zone is estimated to contain 2.305 million short tons of 1.84 ppm (Dayton, 1988; Bartsch-Winkler and Donatich, 1995). Some veins contain high concentrations of molybdenum (>100 ppm; Segerstrom et al., 1979).

Gold-bearing breccia pipes

The gold-bearing breccia pipes are conical bodies, less than 200 m in diameter, and consist of breccia clasts of highly altered and silicified country rock (Table 3). The breccias are cemented by silica and contain pyrite, chalcopyrite, bornite, gold, and local trace molybdenite. The upper portions of many breccia pipes are oxidized consisting of iron oxides, malachite, and other supergene minerals. Best production of gold came from the Parsons mine (Fig. 4), a breccia pipe within the Rialto stock. Samples from the Parsons mine contained as much as 503 ppb Au, 4 ppm Ag, 10 ppm As, 1,733 ppm Cu, 332 ppm Mo, 42 ppm Pb, and 248 ppm Zn (Korzeb and Kness, 1992). The Mudpuppy-Waterdog prospect is a breccia pipe and samples from the deposit assayed as high as 222 ppb Au, 0.60% Cu, 0.9% Mo, and 3.2 ppm Te (Fulp and Woodward, 1991b). The grade at the Great Western mine is 1.29 ppm Au (Eng, 1991).

The Vera Cruz breccia pipe is associated with the Vera Cruz laccolith, which is fine-grained, slightly peraluminous, subalkalic trachyandesite (Ryberg, 1991). The best gold assays in the Vera Cruz deposit appear to be in silicified portions (4.71 ppm Au) of the breccia pipe compared to argillized altered portions (0.6 ppm Au). Assays of samples are as much as 175 ppm Au in the silicified zones that contain iron oxides and oxidized pyrite (Ryberg, 1991). Production from the Vera Cruz breccia pipe is estimated at 50,000 short tons and the breccia pipe contains 934,000 short tons of possible ore at a grade of 3.9 ppm Au (Table 2; Ryberg, 1991).

Three additional areas of hydrothermal breccia (two shown previously by Thompson, 1973) were mapped by Goff et al. (2011).

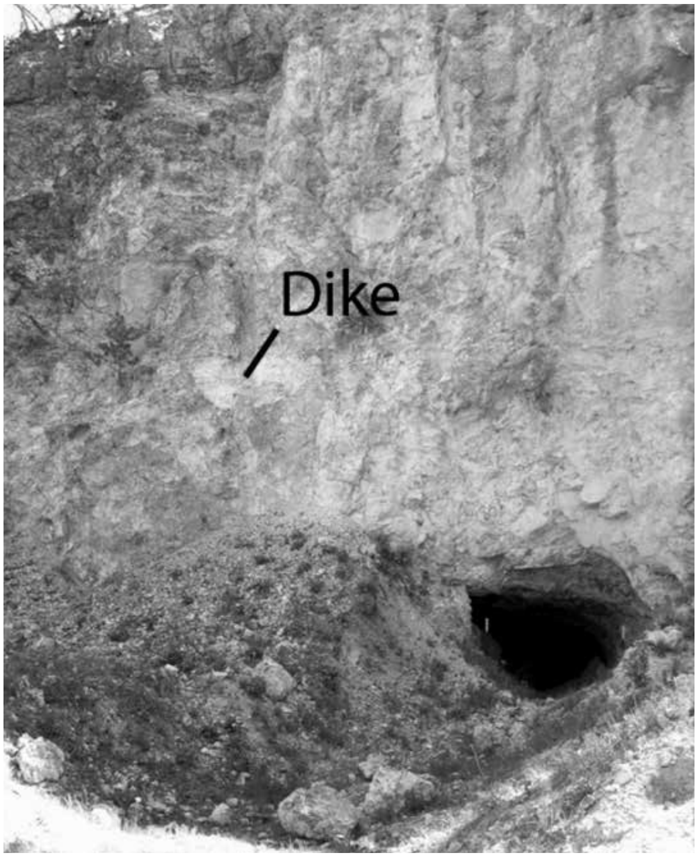

FIGURE 4. Photo of east wall of Parsons gold mine showing breccia pipe texture; phyllic alteration has retrograded to argillic alteration. Vertical dike of altered trachydacite (?) cuts large block left of "D." The rocks surrounding the mine contain anomalous copper (partly as turquoise) and molybdenum.

FIGURE 5. Banded breccia of fine-grained sapphire, lazulite (Mg, Al phosphate), alunite and quartz occurs in a faulted pipe within Walker lava on the north side of the mouth of Bluefront Canyon.

The first, at the Great Western mine, consists of an east-west striking mass of broken, extremely silicified rock approximately 1 km long and 300 m wide occurring just north of the Three Rivers stock. Three small breccia pipes occur within this mass and tower roughly 40 to 60 m above the main breccia body. The original host rock is Walker Group volcanic lavas; a small trachyandesite vent or flow is still recognizable within the west end of the breccia body. Accessory alteration consists of hematite, other iron oxides, pyrite, and manganese minerals, but most of the body is fine-grained, massive, brecciated quartz. The Great Western body has been intensively explored for gold and molybdenum (Segerstrom et al., 1979; Eng, 1991; Fulp and Woodward, 1991b). Old adits, glory holes and prospect pits are found in and next to the breccia. At least seven abandoned exploration holes were drilled into the main breccia body.

The second large mass of hydrothermal breccia occurs north and east of Elk Point (Area B, Appendix 1) on the north edge of the Three Rivers stock approximately 2 to 3 km southwest of the Great Western breccia body. This body is roughly 1.5 km long and 200 m wide. The Elk Point mass is developed within the Elk Point porphyritic rhyolite plug, and within Walker Group lavas and flow breccias directly east of the plug. The breccia body looks very similar to the Great Western body. The silicified volcanic rocks contain many quartz veins that contain minor gold and molybdenum (Segerstrom et al., 1979).

The third hydrothermal breccia occurs on the north side of the mouth of Bluefront Canyon in Walker lavas on the southwest edge of the Bonito Lake stock (Segerstrom et al., 1979). This mass is faulted off along both the south and east sides. What remains looks cylindrical in shape, approximately 400 m in diameter and extending over 200 m up the canyon wall. The mineralogy of this breccia body has been described by Goodell et al. (1998) and consists mostly of banded, fine-grained, blue corundum (sapphire) and lazulite, with eggshell-colored alunite and quartz (Fig. 5). Examination of brecciated rocks in the cliff above the canyon floor suggests that the banded alteration partly replaces relict flow banding or flow foliations in Walker lavas. Some of the banded material displays high angle dips indicating that large blocks of lava were disrupted before alteration. Presence of alunite and corundum suggests that the hydrothermal fluids forming the deposit were acidic (Meyer and Hemley, 1967; White and Hedenquist, 1990; Barton et al., 1991).

The banded sapphire has no economic value; it was once sold for decorative facing stone in nearby villages, but freezing conditions caused the stone to disintegrate along foliations. The U.S. Geological Survey evaluated the deposit for alumina, because of the large amount of alunite (Segerstrom et al., 1979). A large pile of sapphire "ore" lies along the trail in the mouth of Bluefront Canyon. Pine trees nearly 24 m tall have grown on the ore pile indicating that this rock was mined about 100 years ago. Nonetheless, the Bluefront breccia pipe deserves considerably more research.

Porphyry molybdenum-copper deposits

The porphyry molybdenum-copper deposits are found in the northern portion of the Rialto stock (Nogal Peak) and along the northern and eastern portions of the Three Rivers stock.

Both the Rialto and Three Rivers stocks are alkaline and have high concentrations of fluorine and niobium (Giles and Thompson, 1972; Segerstrom et al., 1979; Westra and Keith, 1981; Goff et al., 2011).

The deposit in the Rialto stock consists of disseminated sulfides and thin veinlets in a brecciated zone in monzonite and consists of quartz, pyrite, molybdenite, and copper sulfide minerals. Four zones are recognized: (1) inner molybdenite zone, (2) magnetite zone, (3) copper-rich zone that truncates the molybdenite and magnetite zones along the southern portion of the deposit, and (4) extensive lead-zinc zone on the eastern and southern portions of the stock (Thompson, 1968; Segerstrom et al., 1979). Molybdenum decreases outwards from the central molybdenite breccia zone (Thompson, 1973; Gander, 1982). The host rocks are extensively altered by silicification, sericitization, kaolinization, and pyritization (Griswold and Missaghi, 1964; Giles and Thompson, 1972; Thompson, 1973; Westra and Keith, 1981). The Rialto porphyry molybdenum deposit is estimated to contain 27 million metric tons (30 million short tons) of 0.05–0.18% Mo (Hollister, 1978).

The deposits in the Three Rivers stock are in silicic altered zones. Three styles of mineralization are found: (1) thin fracture coatings of molybdenite and fine-grained disseminations in quartz veinlets, (2) molybdenite in breccia zones, and (3) fine-grained disseminations of molybdenite in high silica rocks (Giles and Thompson, 1972; Segerstrom et al., 1979). Fluorite is found in miarolitic cavities and open fractures throughout the Three Rivers stock. Low concentrations of molybdenum (10–1000 ppm) also are found in and near the Cone Peak rhyolite plug and dikes west and northwest of the Three Rivers stock (Black, 1977a, b; Goff et al., 2011).

HYDROTHERMAL ALTERATION

Hydrothermal alteration has affected virtually all igneous rocks within the district. White, brown and orange alteration zones are no doubt what excited prospectors in the late 1800s. The geologic map by Goff et al. (2011) contains information on visible alteration that could easily be identified while mapping and includes a table of x-ray diffraction results from a few altered rock samples. Except for the sapphire deposit from Bluefront Canyon (described above), the alteration minerals in these samples are quite predictable and typical of gold deposits associated with volcanic rocks.

Names of alteration assemblages used herein follow the definitions and examples used in Meyer and Hemley (1967). In general the rank and intensity of alteration (Browne, 1978) increase to the south and east, in particular near the margins of and within the stocks. As might be expected, alteration within a given area also increases downwards from ridge tops into canyon bottoms. In the northwest part of the Nogal Peak quadrangle, alteration is best characterized as argillic, consisting of smectite clay, mixed layer illite-smectite, some chlorite, opal or chalcedony, calcite and iron oxides. Veins are few and thin and most are carbonate veins. To the southeast alteration becomes progressively propylitic. Most rocks become “greenish” and contain substantial amounts of illite-smectite, illite, chlorite, chalcedony or quartz, calcite, pyrite, and epidote. Near stock margins or within some parts of the stocks, actinolite-tremolite and specular hematite were found. Veins become more abundant and broader, and a few are large quartz veins.

Presence of epidote indicates that temperatures once exceeded 220°C and presence of actinolite-tremolite suggests that temperatures exceeded 350°C (Browne, 1978; Reyes, 1990; Simmons et al., 1992). These temperatures match those determined independently by Douglass and Campbell (1994). Because epidote is a key indicator for higher-temperature epithermal conditions, a dashed line is drawn on the geologic map (Goff et al., 2011) that indicates where epidote becomes visually obvious in most rock exposures. Southeast of this line, exploration for base and precious metals is possible. Northwest of the line, we believe that exploitable deposits of precious and base metals do not exist unless they are very deeply buried.

A few areas of intense phyllic (sericite) alteration (quartz-illite-pyrite) also are shown on the geologic map by Goff et al. (2011), most of which is now undergoing secondary argillic alteration (pyrite altering to various Fe-oxides; rock matrix altering to opal and kaolinite). These phyllic zones occur within the Rialto stock, especially near the Parsons mine (Thompson, 1973), along the southeast margin of the Rialto stock just west of Washington Canyon, and within an area surrounding the Great Western mine. Black (1977b) also has outlined an area of phyllic alteration in the Bonito Lake stock just east of Kraut Canyon and the boundary of Nogal Peak quadrangle.

AGE, DISTRICT ZONATION, AND ORIGIN OF THE DEPOSTS

Recent $^{40}Ar/^{39}Ar$ dates indicate that the coarse-grained phase (phase 1) of the Rialto stock (primarily monzonite to syenite) consists of multiple intrusions and dikes emplaced between 33.9 ±0.2 and 30.87 ±0.04 Ma (see Goff et al., 2011 for map and phase relations). A later phase (phase 2) of fine-grained, biotite-hornblende quartz diorite dikes and broad tabular bodies intrudes phase 1 rocks and is dated at 25.92 ±0.08 Ma. A single new $^{40}Ar/^{39}Ar$ date on the Bonito Lake syenite is 26.79 ±0.08 Ma, which compares favorably to the previous K/Ar date of 26.6 ±1.4 Ma reported by Thompson (1972). The Three Rivers stock consists of large bodies of syenite and quartz syenite emplaced at 28.95 to 28.24 Ma (Goff et al., 2011) that are intruded by a series of later alkali granite dikes, plugs and larger bodies dated at about 28.2 to 27.2 Ma. We are continuing to refine the dates of the various intrusive rocks in the Nogal-Bonito district.

The porphyry molybdenum-copper deposits were probably formed during or shortly after intrusion of the more voluminous Rialto phase 1 monzonite-syenite and the Three River syenite and quartz syenite. Mineralogy, alteration styles, geochemistry, and isotopic data indicate that two additional, but separate mineralizing events occurred in the district: sulfide Ag-Pb-Zn (±Au, Mo) veins followed by Au-Ag veins and gold-bearing breccia pipes with little or no base metals deposition (Griswold, 1959; Campbell et al., 1991; Douglass and Campbell, 1994; 1995).

Fluids forming the gold-bearing breccia pipe deposits are chemically different from the Ag-Pb-Zn (±Au, Mo) veins and porphyry molybdenum-copper deposits (Table 3; Douglass, 1992). The Parsons breccia pipe was probably emplaced during or slightly after the Rialto phase 2 quartz diorite event.

The gold-bearing breccia deposits form two northeast trends (Fig. 1; Douglass, 1992). The Parsons-Vera Cruz trend aligns the veins and breccia pipes of the Argentine, Parsons, Rockford, Helen Rae-American and Vera Cruz deposits. The Great Western trend aligns the Great Western and Waterdog breccia pipe deposits (Fig. 1). The Ag-Pb-Zn (±Au, Mo) veins strike east-west, cutting across the two northeastern trends. Another set of north-northeast-striking veins, the Alto trend, is found in the southeastern portion of the district and warrants further exploration. Thompson (1995) suggests that these trends are related to the intrusion of the Rialto and Bonito Lake stocks. Aeromagnetic and gravity data (Segerstrom et al., 1979; Bowsher, 1991; Roberts et al., 1991) suggest a strong regional northwest trend in the Proterozoic basement and a local northeasterly trend in the Nogal-Bonito district, also noted by Griswold (1959) and Moore et al. (1991). Subsequent erosion formed the placer gold deposits.

The mineral deposits associated with the Lincoln County porphyry belt are likely genetically related to the plutonic rocks. Supporting evidence for a magmatic origin includes: (1) fluid inclusion and stable isotope data from the Nogal-Bonito deposits (summarized in Table 3; Douglass, 1992; Douglass and Campbell, 1994, 1995), (2) fluid inclusion, stable isotope, and age data from the Capitan quartz-REE-Th veins (Phillips et al., 1991; Campbell et al., 1995; Dunbar et al., 1996), (3) the nature of stockwork molybdenum deposits at Sierra Blanca (Thompson, 1968, 1973), (4) the close spatial association of mineral deposits with plutonic rocks (Allen and Foord, 1991), (5) presence of skarn deposits along the contacts of intrusive rocks in other areas of the Lincoln County porphyry belt, and (6) similarity to other deposits at Cripple Creek, Colorado and elsewhere where a magmatic origin is favored (Thompson et al., 1985; Porter and Ripley, 1985; Thompson, 1992; Maynard et al., 1989, 1990; Kelley et al., 1998; Kelley and Luddington, 2002). Initial strontium isotope ratios from the Sierra Blanca igneous rocks range from 0.7038 to 0.7045 and suggest a deep crustal or upper mantle source (Allen and Foord, 1991; Thompson, 1995). Sulfur isotopes from the Nogal-Bonito mineral deposits range from -3.1 to -0.3 per mil and also suggest a mantle-magmatic source (Thompson, 1995).

The co-occurrence of gold, copper, iron, molybdenum, fluorine, tungsten, and other elements is probably the result of several complex magmatic fractionation and differentiation events and tectonic subenvironments, which overlap near the Great Plains Margin. The association of lineaments and other major structures with igneous rocks and mineral deposits in New Mexico suggests that near-vertical deep-seated fracture systems probably channeled the magmas and resulting fluids (McLemore and Zimmerer, 2009). Once the magmas and fluids reached shallow levels, local structures and wall rock compositions determined the final character and distribution of intrusions and mineralization. Figure 6 summarizes the general formation of GPM deposits in New Mexico.

Evidence suggests that multiple intrusions are emplaced in the same area and are needed to generate the fluids necessary to produce GPM mineral deposits. The more productive districts, such as Nogal-Bonito and White Oaks districts occur in areas of complex magmatism that lasted for more than 5 Ma. In areas such as the Capitan Mountains, where intrusive activity occurred in less than 5 Ma, only localized minor Au, Ag, and REE occurrences are found (McLemore and Phillips, 1991).

OUTLOOK FOR MINERAL RESOURCE POTENTIAL IN THE FUTURE

Gold, silver, base metals

Many companies have explored the Nogal-Bonito district looking for gold, silver and base metals. Although resources were identified in several deposits (Table 2), no significant production has occurred since 1965 (Table 1), other than very minor placer gold production. However, as the price of gold increases, companies will continue to re-examine the Nogal-Bonito district because:

- Some gold and silver has been produced in the past.
- Gold deposits have been found that are not yet mined and could be mined in the future (Table 2).
- The mineralized trends offer favorable exploration areas.
- The alkaline igneous rocks and the mineralized veins and breccia pipes indicate a potential for undiscovered deposits in the subsurface.

However, some of the more favorable areas for gold in the Nogal-Bonito district are in or near the White Mountain Wilderness Area or in the National Forest and likely will require more strict reclamation standards, if they are developed. Detailed geochemical and geophysical surveys are recommended to delineate potential drilling sites for undiscovered deposits in favorable areas outside the wilderness boundary. It is unlikely that any exploration will occur for base metals in this district because these deposits are too small and low grade to be economic.

Rare earth elements (REE)

Rare earth elements (REE) are becoming increasingly important in our technological society (McLemore, 2010) and are used in many of our electronic devices. REE include the 15 lanthanide elements (atomic number 57–71), yttrium (Y, atomic number 39), and scandium (Sc, atomic number 21), and are lithophile elements (or elements enriched in the crust) that have similar physical and chemical properties, and, therefore, occur together in nature. However, REE are not always concentrated in easily mined economic deposits and only a few deposits in the world account for current production (Committee on Critical Mineral Impacts of the U.S. Economy, 2008; Hedrick, 2009). The U.S. once produced enough REE for U.S. consumption, but since 1999 more than 90% of the REE required by U.S. industry have been imported from China (Haxel et al., 2002). However, the projected increase in demand for REE in China, India, U.S., and other countries has resulted in increased exploration and ultimately production from future deposits in the U.S. and elsewhere. REE deposits (associated with Th and Zr) have been reported from New Mexico (McLemore et al., 1988a, b; McLemore, 2010), but were not considered important exploration targets in the past because the demand in past years has been met by other deposits around the world. However, with the projected increase in demand and potential lack of available production from the Chinese deposits, these areas in New Mexico are being re-examined for their REE potential. The Lincoln County porphyry belt has known REE deposits (i.e., Capitan Mountains, McLemore and Phillips, 1991; Gallinas Mountains, McLemore, 2010) and the alkaline rocks in the Nogal-Bonito district are similar in composition to alkaline rocks found with known REE deposits elsewhere in the world, suggesting a potential for REE in the Nogal-Bonito district.

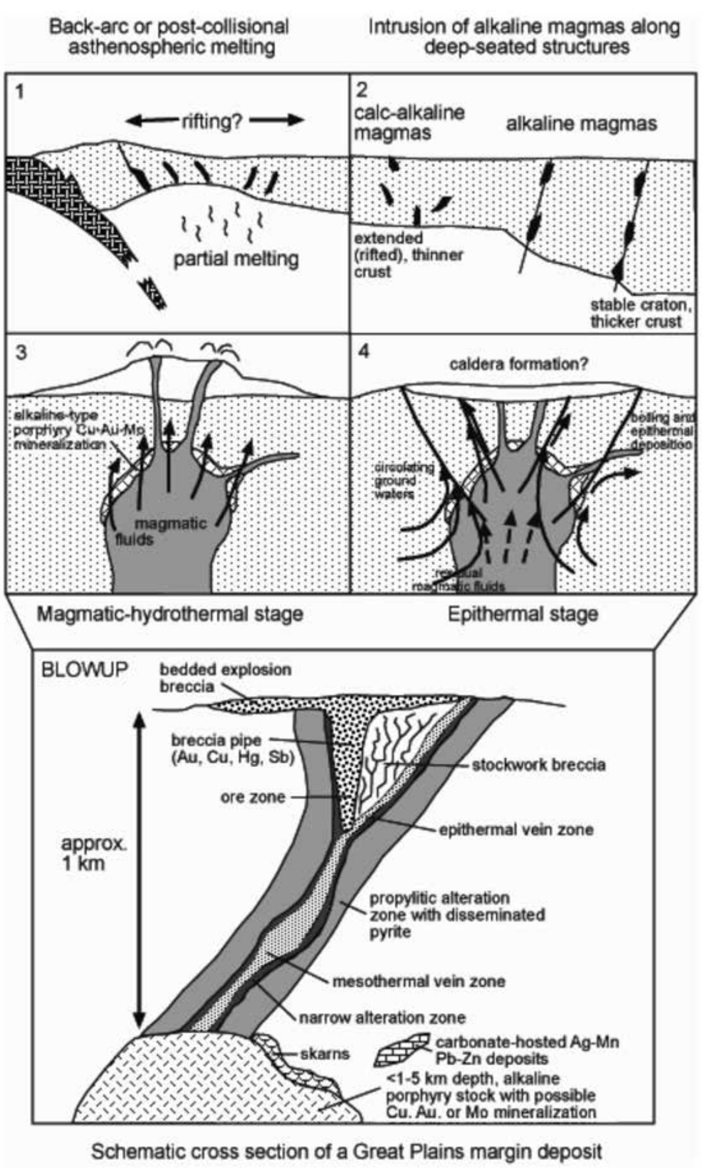

FIGURE 6. Schematic model for formation of Great Plains margin deposits (modified from Richards, 1995).

Available geochemical studies and known mineralogy throughout the Nogal-Bonito district indicate elevated concentrations of REE in the alkaline igneous rocks (Fig. 3; Segerstrom et al., 1979; Constantopoulos, 2007; NURE (National Uranium Resource Evaluation) data; this study), but the REE concentrations are not high enough to warrant additional exploration in this district at this time. Fluorite is associated with most REE deposits and fluorite is found throughout the Three Rivers stock (Giles and Thompson, 1972; Segerstrom et al., 1979), suggesting a higher potential for REE in the Three Rivers stock.

Segerstrom et al. (1979) report a single sample from the head of Indian Creek in the SW part of the Wilderness area that contained elevated REE attributed to the presence of xenotime in syenetite. One of our samples (F09-35, Goff et al., 2011) is an alkali granite at the head of the eastern Ski Apache chair lift containing 2,850 ppm Zr. Zirconium at this level is 5 to 10 times the values in average granite and rhyolite. Any future exploration for REE, Zr, and Th in Nogal-Bonito district should focus on the breccia pipes, alkali granite bodies, rhyolites, related dikes, and quartz veins of the Rialto and Three Rivers stock.

Tellurium

Tellurium (Te) is increasingly used in the manufacture of cadmium-tellurium (Cd-Te) solar cells. In solar cells, the thin films are typically 3–300 microns in thickness and approximately 8 grams of Te is used per solar panel, or approximately 696.8 kg of Te for 10 MW PV production (Green Econometrics, 2014). Tellurium is commonly associated with gold deposits in the Rocky Mountain alkaline belt, but only recently has tellurium become of economic interest. Tellurium can be found as a native metal, but it is more commonly found in more than 40 minerals, many of which are telluride minerals. Calaverite ($AuTe_2$) is the common gold-telluride mineral and sylvanite ($(Au,Ag)Te_2$) is the common Au-Ag telluride mineral. However, tellurium minerals have not been recognized in the Nogal district. Only one deposit has been examined for their tellurium content, the Mudpuppy-Waterdog deposit, where as much as 7.1 ppm Te has been reported from the veins (Fulp and Woodward, 1991b). Limited data from this study indicates tellurium is very low in samples analyzed. However, additional geochemical studies of the deposits including tellurium are recommended as other investigations are conducted.

ENVIRONMENTAL IMPLICATIONS

The Little Bear wildfire started on June 4, 2012 northwest of Ruidoso, New Mexico by a lightning strike and more than 17,800 hectares was burned, including much of the Nogal-Bonito district. Future rain storms have the potential to produce large floods that can mobilize rock, soil, and sediment into the watershed, especially streams, rivers, and lakes in the Nogal-Bonito area, which are sources of regional and local municipal water supplies. Large storms since the fire have already created debris flow deposits along the drainages of Bonito Creek and Three Rivers. Much of the Nogal-Bonito district lies within the area affected by the Little Bear wildfire and there are concerns that contamination from past mining activities as well as the altered rocks surrounding the mineral deposits could adversely impact the rivers, stream, and lakes in the area during these storm events. Geochemically, the mineral deposits in the Nogal-Bonito district contain high concentrations of arsenic, lead, copper, antimony, molybdenum, and zinc (Table 3) and the U.S. Geological Survey Geoenvironmental Models (Plumlee, 1999; Seal et al., 2002) predict that high concentrations of bismuth and selenium (Table 3) also could occur in the district. Acid drainage could be produced in areas of weathered pyrite, including mine waste rock piles (i.e., dumps), tailings, and mineralized or altered outcrops. There is probably not enough mercury or cyanide in the mining operations in the Nogal-Bonito district to impact the local water supplies, but repeat sampling and chemical analyses are required to determine if residual mercury or cyanide remains in local areas of the district. Some of these effects may not be immediate and may not appear for several years. Additional study is needed.

CONCLUSIONS

Four types of mineral deposits are found in the Nogal-Bonito district as gold placers, Ag-Pb-Zn (±Au) and Ag-Au fissure veins, gold-bearing breccia pipes, and porphyry molybdenum-copper deposits. Companies will continue to re-examine the breccia pipe deposits in the Nogal-Bonito district as the price of gold continues to rise. Undiscovered breccia pipe deposits that could contain gold may be at depth beneath some of the vein deposits, which requires drilling to locate them. Porphyry molybdenum-copper deposits in the Nogal-Bonito district are small and low grade and are not of economic interest at this time. Analyses for REE and tellurium as well as gold and other metals would be prudent in future exploration activities.

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