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GEOLOGY AND MINERAL DEPOSITS OF THE OROGRANDE MINING DISTRICT, JARILLA MOUNTAINS, OTERO COUNTY, NEW MEXICO

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ABSTRACT—The Orogrande mining district, in the Jarilla Mountains in Otero County, lies within two important mineralized tectonic provinces of the Southwest USA: (1) the Arizona-Sonora-New Mexico porphyry copper province and (2) the Rocky Mountain alkaline belt. The igneous rocks in the Jarilla Mountains are subalkaline to alkaline, metaluminous to peraluminous, and plot as monzonite to quartz monzonite to granodiorite to syenodiorite on geochemical discrimination diagrams. $^{40}Ar/^{39}Ar$ hornblende and alkali-feldspar dating show that the intrusions range between 45.6 and 41.4 Ma. The igneous rocks in the Jarilla Mountains and associated mineral deposits represent the transition between arc-magmatism, which formed the porphyry copper deposits, and extension-related alkaline magmatism and related mineral deposits, such as those found in the Rocky Mountain alkaline belt. Types of mineral deposits found in the Orogrande district include (1) placer gold, (2) skarns and replacement deposits, (3) veins, (4) porphyry copper deposits, and (5) turquoise deposits. Gold, silver, copper, lead, tungsten, iron ore, and turquoise have been produced from the Orogrande district and additional mineral resources are likely present. In addition, the district has potential for the production of garnet for the abrasives industry. Additional geochemical analyses of the deposits including tellurium are recommended as future investigations are conducted.

INTRODUCTION

The Orogrande mining district, also known as Jarilla, Brice, and Silver Hill, is in the Jarilla Mountains, south of Alamogordo and west of the small community of Orogrande (Fig. 1). *Orogrande* is Spanish for *big gold*. The White Sands Missile Range lies west of the district and the McGregor Range is east of the district; both of these areas are withdrawn from future mineral development. Types of deposits found in the Orogrande district include (1) placer gold, (2) skarn and replacement deposits, (3) veins, (4) porphyry copper deposits, and (5) turquoise deposits.

The Orogrande district is at the junction of two important mineralizing tectonic provinces in the Southwest USA: (1) the Arizona-Sonora-New Mexico porphyry copper province, of which the Orogrande district forms the easternmost part of the district (Fig. 2; Beane et al., 1975; Long, 1995; Barton, 1996; Keith and Swan, 1996; McLemore, 2008) and (2) the southern part of the Rocky Mountain alkaline belt (Fig. 3; Mutschler et al., 1985, 1991; North and McLemore, 1986, 1988; McLemore, 1996, 2001; McLemore et al., this volume). The Arizona-Sonora-New Mexico porphyry copper province is one of the largest copper-producing areas in the world (Long, 1995; Barton, 1996; McLemore, 2008). In New Mexico, the Rocky Mountain alkaline belt extends from the Sangre de Cristo Mountains near Raton, southward to the Hueco and Cornudas Mountains, east of El Paso, Texas. Ages of magmatism range from about 48 to 20 Ma (Fig. 3; Mutschler et al., 1985, 1991; North and McLemore, 1986, 1988; McLemore, 1996, 2001; Kelley and Ludington, 2002). Significant mineral production, especially gold, has come from deposits spatially associated with Tertiary alkaline-igneous rocks in the Rocky Mountain alkaline belt (Mutschler et al., 1991; McLemore, 1996; 2001; Kelley and Ludington, 2002). Economic mineral deposits found within this belt have produced nearly 13% of the total lode gold production in the U.S. and Canada and the belt has potential for copper-molybdenum, rare earth elements (REE), tellurium, and other deposits (Mutschler et al., 1991). These 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, 1991; Thompson, 1991a, b; Bonham, 1988; Mutschler et al., 1985, 1991; Richards, 1995), porphyry gold deposits (Cox and Singer, 1986), and the North American Cordilleran belt of alkaline igneous rocks (Woolley, 1987; Mutschler et al., 1991).

This work is part of ongoing studies of mineral deposits in New Mexico and includes updates and revisions of prior work by North (1982), North and McLemore (1986, 1988), New Mexico Bureau of Mines and Mineral Resources et al. (1998), and McLemore (2001). The purpose of this paper is to (1) summarize the mining history, (2) describe the geology, geochemistry, and mineral resources within the Orogrande district, (3) discuss the geochronology and present new radiometric dates of the igneous rocks, (4) discuss the relationship of the Orogrande district with magmatic activity and mineralization in south-central New Mexico and (5) evaluate the mineral resource potential. The mines and prospects in this report are described in Appendix 1 and are identified by a unique mine identification number (Mine id), beginning with NMOt (for example NMOt0054).

Appendix data for this paper can be accessed at:
http://nmgs.nmt.edu/repository/index.cfm?rid=2014006

MINING HISTORY

Turquoise was probably first mined from the district by Native Americans before the 1880s (Weber, 1979; North, 1982). Gold was discovered in the district about 1865. The first mining by Americans occurred around 1879 when J.M. Perkins began prospecting in the district (North, 1982). Amos J. De Meules, a dealer in gemstones and turquoise, rediscovered turquoise in the district in the early 1880s. The first patented mining claim for precious and base metals was at the Grizzly Bear mine in 1890;

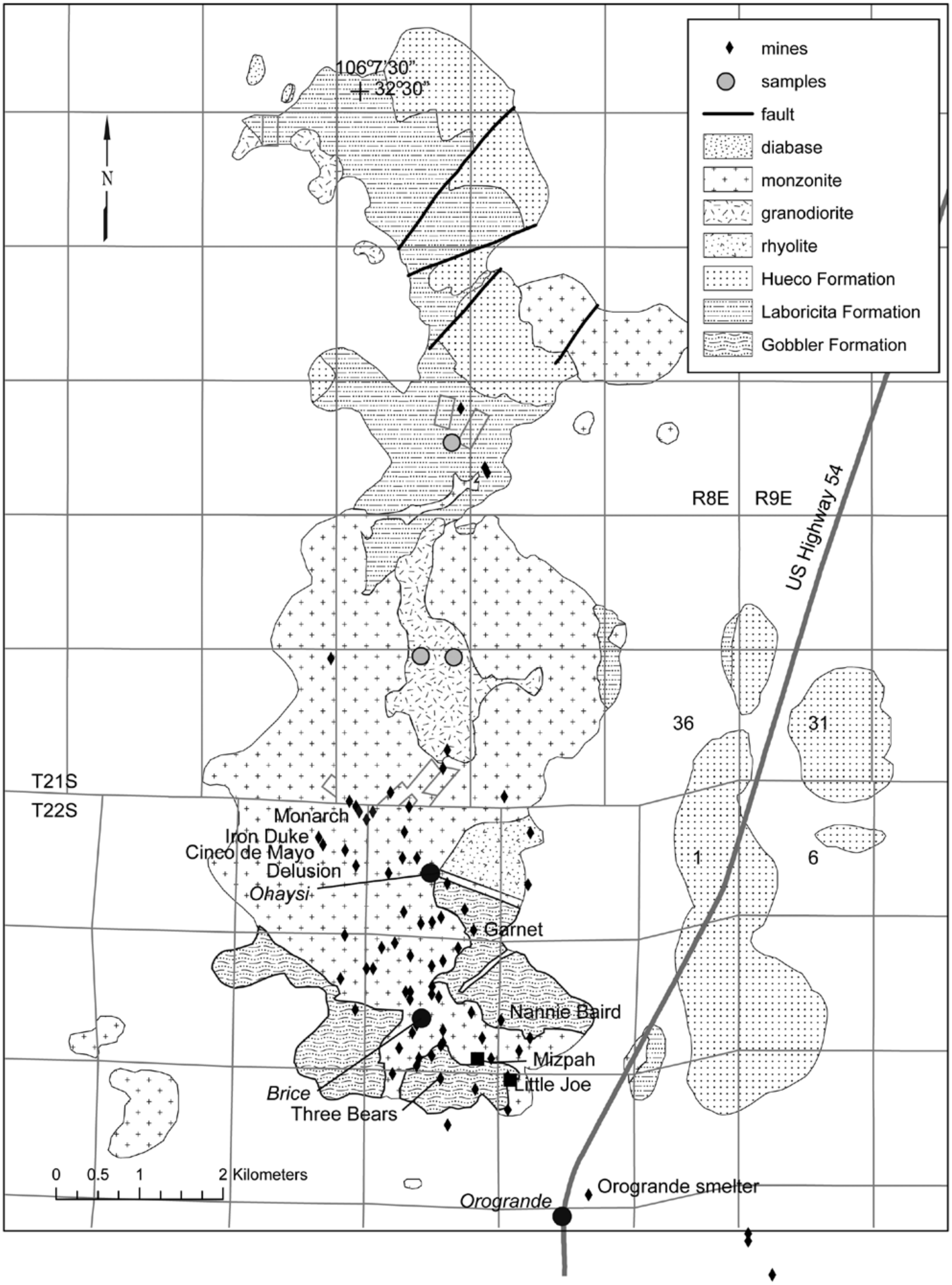

FIGURE 1. Simplified geologic map showing major mines and prospects in the Orogrande district of the Jarilla Mountains, Otero County. Geology simplified from Seager (1961) and Schmidt and Craddock (1964). Locations of mines and prospects in Appendix 1. (See also Color Plate 15)

33 additional patents soon followed (North, 1982; Appendix 1). Turquoise was again mined about 1891 when 50 kilos were produced (Weber, 1979). The lack of abundant water was a constant problem (North, 1982). Between 1898 and 1921, two mining camps were established; Brice and Ohaysi (Fig. 1; Heylmun, 1985). A railroad spur was built between the towns of Orogrande and Brice in 1898 and extended north to the iron mines in 1916.

In 1904, a 6.5 oz gold nugget was found on the Little Joe placer (NMOt0047) and exploration resumed. In 1905, the Southwest Smelting and Refining Co. consolidated many of the mining claims and built a 250-short ton copper matte smelter north of Orogrande in 1907 (Orogrande smelter, NMOt0060), but it closed in 1908 (Kelley, 1949; Anderson, 1957; McLemore, this volume). The smelter was sold to Orogrande Smelting Co. in 1909 and continued operating until 1910. The site is in SE 1/4 sec. 14, T22S, R8E and the ruins at the site include a cement water tower, approximately 6 m high, piles of cement, bricks, and fire bricks labeled St. Louis Laclede, a 24 m wide by 35 m long holding pond, and a slag pile. The Southwest Smelting and Refining Co. also built a pipeline, completed in 1907, bringing much-needed water to the district (Dodge, 2009; Rawling, this volume).

After the smelter closed, production was shipped to the ASARCO smelter in El Paso, Texas. Reported precious and base metal production is in Table 1. In 1916, 6,656 short tons of tungsten ore was produced from the district (Finlay, 1922).

The iron deposits were extensively mined about 1913–1929 by Colorado Fuel and Iron Co. The railroad was extended from Ohaysi to the Cinco de Mayo mine (NMOt0026), where iron was produced until 1921. Less than 217,000 short tons of iron ore worth approximately $500,000 were produced during that time (Table 2; Kelley, 1949; Harrer and Kelly, 1963). A jigging plant operated until 1921. A jigging plant is a processing machine that shakes the ore and separates the minerals based upon differences in weight. Total iron ore production in 1913–1929 was approximately 217,000 short tons.

As mineral production declined after 1953 (Table 1), many exploration programs were conducted in the district with favorable results, but no significant development occurred, except for small production from placer gold deposits and recent production of iron ore from waste rock piles. Anaconda drilled in the district in the 1940s, Earth Resources in 1960, Superior Oil Co. in 1964–1965, Leonard Minerals in the 1970s, Quintana Minerals Corp. in 1977, and Bear Creek Mining Co. in 1974–1976. In 1979, Anaconda Copper Co. discovered a low-grade porphyry copper-molybdenum deposit averaging 0.03% Mo. Later drilling by Santa Fe, Texaco, and Inspiration Gold, Inc. discovered tabular skarn deposits that contain 335,500 short tons of ore grading 0.05 oz/short ton Au and 0.7% Cu at depths of 26 m (Strachan, 1976).

Moderate reserves of garnet are found on claims owned by the B.O.W. Corporation in the southern Orogrande district. These deposits were drilled and sampled in the late 1990s to early 2000s and again more recently, but no development has occurred. Metalline Mining Company leased the B.O.W. claims about 2002, but did not develop any deposits. Recently, Burrell Western Resources purchased patented and unpatented mining claims from Warren T. Burns Jr. and B.O.W. Corp. that total almost 2,400 acres; exploration is underway for garnet and other resources. Garnet is used as an abrasive, predominantly as sandblasting and in water jet cutting applications.

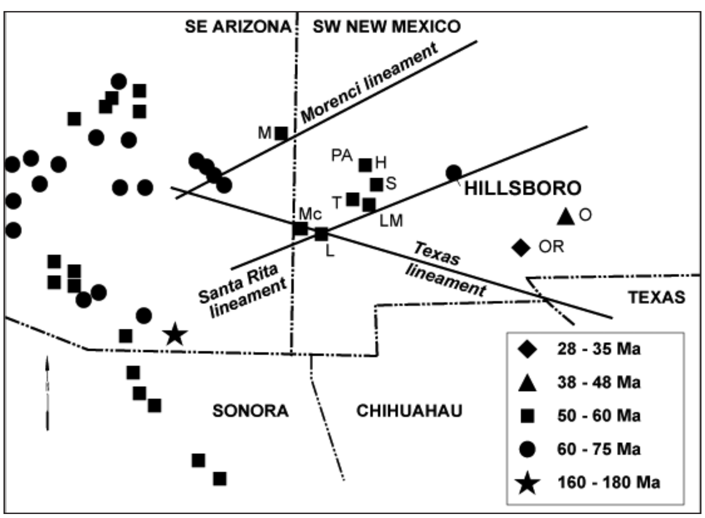

FIGURE 2. Arizona-New Mexico-Sonora porphyry copper province (from McLemore, 2008). PA-Piños Altos, H-Hanover Mountain, S-Santa Rita, T-Tyrone, LM-Lone Mountain, L-Lordsburg, Mc-McGee Peak, and M-Morenci are Laramide age. OR (Organ) and O (Orogrande) are younger Mid-Tertiary porphyry copper deposits.

FIGURE 3. Extent of the Rocky Mountain alkaline belt (Woolley, 1987; Mutschler et al., 1991; McLemore, 1996). Orogrande is just south of the Lincoln Co. porphyry belt and north of the Trans-Pecos Texas belt.

TABLE 1. Metals production in the Orogrande district (U.S. Geological Survey, 1900–1927; U.S. Bureau of Mines, 1927–1990; North, 1982; McLemore, 1991; NMBGMR, unpublished data).

YEAR	SHORT TONS ORE	GOLD (oz)	SILVER (oz)	COPPER (lbs)	LEAD (lbs)	VALUE ($)	IRON (long tons)
1902		3,200.00	146	117,520	—		—
1903		2,914.00	285	3,204	—		—
1904	170	126.70	164	14,400	—	4,557	—
1905	20	51.50	93	3,600	—	1,696	—
1906	78	20.50	163	11,166	—	2,689	—
1907	11,319	716.50	1,829	555,580	—	127,134	—
1908	21,901	1,726.70	4,205	710,780	—	131,742	—
1909	143	12.40	29	6,354	—	1,098	—
1910	536	415.10	2,007	38,858	5,841	14,857	—
1911	770	325.00	680	10,406	739	8,412	—
1912	2,553	630.80	1,011	119,740	—	33,418	—
1913	15,822	2,411.60	6,444	597,580	1,911	146,448	4,346
1914	11,009	1,860.60	5,376	387,211	2,027	93,010	25,623
1915	14,930	2,659.60	6,150	853,257	—	207,412	29,747
1916	20,195	1,925.90	7,403	1,077,492	638	309,787	20,671
1917	15,558	1,172.80	4,514	731,894	—	227,768	33,381
1918	6,210	246.50	2,048	253,405	—	69,735	40,128
1919	205	3.60	25	4,382	—	917	30,610
1921	500	253.00	32	—	—	5,262	17,336
1923	68	17.70	190	666	14,286	1,620	21,106
1924	499	1.00	397	4,046	129,286	11,160	—
1925	217	34.60	75	13,300	—	2,656	—
1927	372	19.20	60	7,847	—	1,458	—
1928	2,753	—	559	70,368	—	14,564	—
1929	4,927	357.70	1,285	127,192	—	30,464	—
1930	490	19.60	89	12,230	246	2,042	—
1932	11	2.61	—	—	—	54	—
1933	3	197.40	20	—	—	4,088	—
1934	—	130.00	11	—	—	4,584	—
1935	—	259.00	18	—	—	9,067	—
1936	—	94.00	9	—	—	3,304	—
1937	—	66.00	13	—	—	2,334	—
1938	—	12.00	1	—	—	407	—
1939	37	9.00	25	3,742	—	629	—
1940	86	29.00	173	13,900	—	3,640	—
1947	998	28.00	291	21,272	2,685	5,749	—
1953	1,136	—	—	32,738	—	9,428	—
1954		11.00	4	1,000	—	684	—
1957	4	1.00	5	3	2	41	—
1960	11	1.00	3	657	—	248	—
1966	288	—	76	10,000	—	3,715	—
TOTAL 1904–1966	133,819	15,848.61	45,477	5,695,066	157,661	1,497,878	222,948
ESTIMATED TOTAL 1879–1966		16,500	50,000	5,700,000	158,000	1,500,000	259,000

TABLE 2. Iron production from mines in the Orogrande district (from Kelley, 1949; Harrer and Kelly, 1963; NMBGMR files). Description of mines is in Appendix 1.

MINE	LOCATION	PRODUCTION (SHORT TONS)	%Fe_2O_3
Cinco de Mayo, Iron Duke, Iron King (NMOt0026, NMOt0038, NMOt0039)	4,T22S,R8E	158,862	54.32
Iron Queen (NMOt0041)	4,T22S,R8E	2,000	40–55
Iron Mask, Laura (NMOt0040, NMOt0042)	3,T22S,R8E	54,170	60.8
Cinnamon Bear (NMOt0071)	15,T22S,R8E	1,005	—
Total 1913–1929		216,037	40–60
Iron Duke and adjacent mines (2012–2013) (NMOt0038, NMOt0026, NMOt0093, NMOt0076)	3, 4 T22S R8E	~198,000	—
TOTAL (all mines)	—	414,037	

In 2012, Gulf Coast Mining Group, LLC obtained a mining permit from the New Mexico Mining and Minerals Division to mine iron ore from the Iron Duke (NMOt0038), Cinco de Mayo (NMOt0026), Virginia (NMOt0093), and Barbara (NMOt0076) waste rock piles. Approximately 198,000 short tons of iron ore were produced.

Much of the Orogrande district is covered by placer mining claims owned by recreational gold panners and clubs, and these small placer gold deposits are currently being worked by individuals. The gold production is not reported from these small deposits.

DATA SETS AND METHODS OF STUDY

The geology and mineralization of the Orogrande district in the Jarilla Mountains has been described in numerous reports (Jones, 1904; Lindgren et al., 1910; Seager, 1961; Schmidt and Craddock, 1964; Howard, 1967; Beane et al., 1975; Bloom, 1975; Jaramillo, 1973; Strachan, 1976; Morley, 1977; North, 1982; Heylmun, 1985; New Mexico Bureau of Mines and Mineral Resources et al., 1998) and is only summarized in this report. Names of types of mineral deposits are from Cox and Singer (1986), North and McLemore (1986, 1988), and McLemore (2001). Mineral occurrences, deposits, mines, prospects, and mills were identified, plotted on base maps, described, and compiled in the New Mexico Mines Database (McLemore et al., 2005a, b). Appendix 1 includes the locations of the major mines.

Mineral production is presented in Tables 1 and 2. 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.

Igneous rock samples were collected, analyzed, and compared with published data (Appendix 2). Different terminologies of the igneous rocks have been used by previous workers in the Jarilla Mountains and are summarized in Table 3. Igneous rock lithologies were identified on the basis of mineralogy and chemistry as defined by LeMaitre (1989). According to the definition of volcanic and plutonic rocks proposed by LeMaitre (1989), the igneous rocks in the Jarilla Mountains are mostly plutonic (i.e. coarse-grained rock), and not volcanic (i.e. aphanitic texture).

Additional geochemical data for this area consists of mineralized samples that were collected and analyzed for various elements by Korzeb and Kness (1994), Korzeb et al. (1995), and New Mexico Bureau of Mines and Mineral Resources et al. (1998) and are provided in Appendix 3.

Three samples of plutonic rocks were collected in 2013 in order to determine their age and were analyzed by furnace incremental heating $^{40}Ar/^{39}Ar$ age spectrum method by the New Mexico Geochronological Research Laboratory at NMBGMR (Table 4; Appendix 4). Laboratory methods are described in Appendix 4 and at http://geoinfo.nmt.edu/labs/argon/home.html.

Samples of placer gold obtained by panning by John Estess from the Nannie Baird placer gold mine and were examined using a Cameca SX-100 electron microprobe located at New Mexico Institute of Mining and Technology in order to examine chemical variability within and between individual placer gold particles. The analysis began with backscattered electron (BSE) imaging of the gold particle to determine if chemical zonation was present within individual gold particles. Following BSE imaging, qualitative scans were carried out in order to determine the major components of the gold particles. These scans indicated that Au and Ag are the major components. Qualitative analyses were carried out on gold particles as well as small pyrite inclusions within the gold. For the gold particles, elements Au, Ag, Cu, As, Pb, Fe, and S were analyzed. For pyrite, analyses included S, Fe, Cu, As, Pb, and Zn. For both analytical setups, the elements present at high abundances were analyzed with a 20 nA probe current with 10–20 second count times. Elements that are present at low abundance were analyzed with a 200 nA probe current, with count times between 60 and 300 seconds. All analyses were carried out using an accelerating voltage of 15 kV.

TABLE 3. Lithology and mineralogy (in percent) of the igneous rocks in the Jarilla Mountains (Seager, 1961; Schmidt and Craddock, 1964; Beane et al., 1975; Morley, 1977). Total area in percent represents approximate surface area of the lithology based on the geologic map by Schmidt and Craddock (1964) as determined by Morley (1977). Chemical analyses of selected samples are in Appendix 2. Plag=plagioclase, ortho=orthoclase, mag=magnetite, bio=biotite, horn=hornblende, chl=chlorite.

Lithology (Schmidt and Craddock, 1964)	Lithology (Seager, 1961)	Lithology (Beane et al., 1975)	quartz	plag	Ortho/ K-feldspar	Augite/ diopside	forsterite	mag	Bio	Horn/ actinolite	Chl	Total area
basalt	Olivine basalt			40		30	15	15				
Biotite syenodiorite	Biotite granodiorite	granodiorite	5–30	55–65	10–30	8		2	5–15	4–8		12
Monzonite adamellite	Hornblende adamellite	monzonite	Tr-15	20–45						5–15		76
leucorhyolite	Quartz latite	Leucocratic quartz latite	25–30	10–20	60							3
Orthoclase adamellite	Monzonite porphyry	Orthoclase quartz monzonite	10–20	20–40	40				0–5	5–30	6–10	9

TABLE 4. Summary of $^{40}Ar/^{39}Ar$ results. OR6 62261–02 through 12 represent single crystal ages. Latitude and longitude are in decimal degrees, NAD27. Complete analytical data are in Appendix 4.

Sample	Latitude	Longitude	Lithology	Age Ma	Mineral
OR6	32.4426633	106.109642	Granodiorite/ syenodiroite	45.12 ±0.09	K-feldspar
OR8	32.4425196	106.105471	monzonite porphyry	41.2642 ±0.082	hornblende
OR5	32.4657184	106.105754	hornblende monzonite	45.643 ±0.054	K-feldspar

Representative analyses are shown in Table 5 (detailed analytical conditions shown as in Appendix 5 footnotes). Complete quantitative data are in Appendix 5.

GEOLOGY

The Jarilla Mountains consist of approximately 2,000 m of upper Paleozoic sedimentary rocks belonging to the Devonian Percha Shale, Pennsylvanian Gobbler Formation, Pennsylvanian-Permian Laboricita Formation (mapped and described as Panther Seep Formation by Seager, 1961 and Lucas and Krainer, 2002), and Permian Hueco Formation (Seager, 1961; Schmidt and Craddock, 1964; Strachan, 1976). The limestones and shales adjacent to the intrusions have been metamorphosed to three types of skarns: pyroxene-scapolite-garnet adjacent to granodiorite, epidote-garnet-calcite adjacent to the monzonite, and pyroxene-scapolite-garnet-epidote-calcite adjacent to dikes and granodiorite (Beane et al., 1975). Xenoliths and/or roof pendants are common within the granodiorite and also are metamorphosed. Marble is common (Seager, 1961).

The sedimentary rocks are intruded by rhyolite, granodiorite to syenodiorite and monzonite to quartz monzonite stocks, dikes and sills (Fig. 1; Seager, 1961; Schmidt and Craddock, 1964; Beane et al., 1975; Bloom, 1975). The rhyolite (quartz latite of Seager, 1961 and Beane et al., 1975) is white to pink, aphanitic, and has phenocrysts of plagioclase, K-feldspar, and quartz. The granodiorite to syenodiorite is in the central and northwestern parts of the Jarilla Mountains and is dark-gray, massive, and fine- to medium-grained. Age relationships between the rhyolite and granodiorite are not clear. The monzonite to quartz monzonite is gray, typically porphyritic, and variable in composition. In the southern part of the Jarilla Mountains, the monzonite intrudes the rhyolite and granodiorite. A large number of granodiorite to syenodiorite, monzonite, andesite, rhyolite and diabase dikes and sills cut the larger intrusions and the surrounding sedimentary rocks.

GEOCHEMISTRY OF IGNEOUS ROCKS

The igneous rocks in the Jarilla Mountains are subalkaline to alkaline, metaluminous to peraluminous, and plot as monzonite to quartz monzonite to granodiorite to syenodiorite according to the diagram by de la Roche et al. (1980) (Fig. 4). They are classified as volcanic arc granites (VAG) to within-plate granites (WPG) using the classification of Pearce et al. (1984). The chondrite-normalized rare earth element (REE) patterns of four samples exhibit light REE-enriched patterns with either a slightly negative or no Eu anomaly, which is typical of granitic rocks associated with porphyry copper deposits (Fig. 4).

TABLE 5. Quantitative electron microprobe analyses of two Orogrande placer gold nuggets from the Nannie Baird placer mine (NMOt0409). Complete analytical data are in Appendix 5. sd=standard deviation

	Weight %	Ag	Au	Cu	As	Pb	Fe	S	Total
Au 1 rim	OR1-01	1.16	97.85	0.08	0.01	0.00	0.00	0.01	99.10
	OR1-02	4.87	96.49	0.07	0.00	0.00	0.00	0.01	101.45
	OR1-03	0.53	98.84	0.03	0.00	0.00	0.00	0.01	99.41
	mean	2.19	97.73	0.06					
	sd	2.34	1.18	0.03					
Au 2 rim	OR1-07	0.76	99.91	0.04	0.00	0.00	0.01	0.01	100.72
	OR1-08	3.03	96.80	0.05	0.01	0.00	0.00	0.01	99.89
	OR1-09	0.17	99.11	0.04	0.00	0.00	0.01	0.01	99.34
	OR1-010	1.65	97.64	0.04	0.00	0.00	0.00	0.01	99.34
	mean	1.40	98.37	0.04					
	sd	1.25	1.40	0.01					
Au 1 core	OR1-04	35.72	64.06	0.02	0.00	0.00	0.01	0.00	99.81
	OR1-05	35.94	64.11	0.02	0.00	0.00	0.00	0.01	100.08
	OR1-06	36.37	64.38	0.03	0.00	0.00	0.00	0.00	100.79
	mean	36.01	64.18	0.02					
	sd	0.33	0.17	0.00					
Au 2 core	OR1-011	20.90	79.59	0.04	0.00	0.00	0.00	0.00	100.54
	OR1-012	21.00	79.03	0.03	0.00	0.00	0.00	0.00	100.06
	OR1-013	20.97	78.77	0.02	0.00	0.00	0.00	0.01	99.77
	OR1-014	20.89	79.09	0.03	0.01	0.00	0.01	0.00	100.02
	mean	20.94	79.12	0.03					
	sd	0.05	0.34	0.01					
Pyrite inclusions	OR1-015			0.00	1.33	0.15	45.90	52.99	100.36
	OR1-016			0.02	1.56	0.14	45.42	53.06	100.21
	mean			0.01	1.45	0.14	45.66	53.02	
	sd			0.01	0.16	0.00	0.33	0.05	

AGE

Three K/Ar ages have been reported from the Jarilla Mountains. The granodiorite to syenodiorite exposed in the Jarilla Mountains was dated at 48.3 ±1.8 Ma (K/Ar, biotite; Beane et al., 1975). A rhyolite (quartz latite porphyry) gave a hornblende K/Ar age of 42.6 ±2.2 Ma (Kelley and Chapin, 1997). Phlogopite from a copper skarn was dated at 42.8 ±1.6 Ma (K/Ar, unpublished report by R.K. Andrews, J.I. Lyons, and M.P. Martineau, Bear Creek Mining Co., January 1976, NMBMMR file data).

These K/Ar ages are consistent with new high precision $^{40}Ar/^{39}Ar$ ages reported here for samples collected from Water Canyon and Monte Carlo Gap in the northern Jarilla Mountains (Table 4; Fig. 5A, B, C). Igneous rocks in the southern Jarilla Mountains are too altered for $^{40}Ar/^{39}Ar$ dating. K-feldspar from sample OR 5 from the monzonite yielded a climbing age spectrum

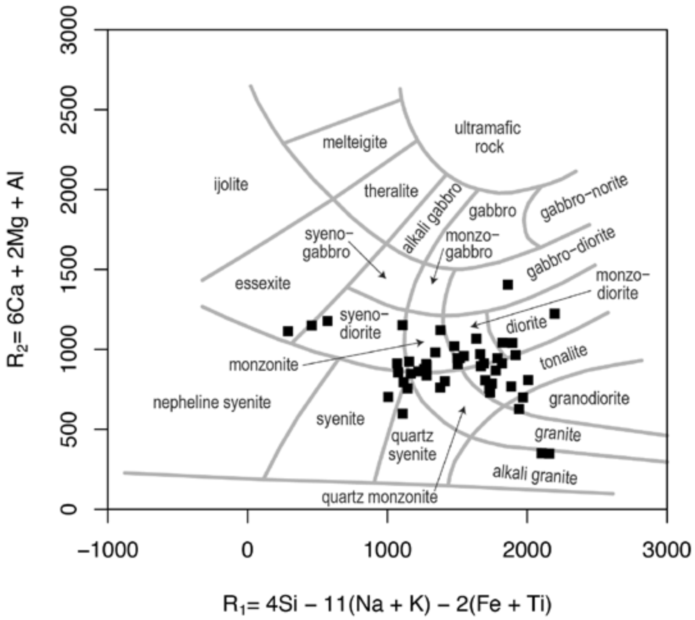

FIGURE 4A. R1–R2 plot of de la Roche et al. (1980) showing most samples plot as monzonite to granodiorite to syenodiorite.

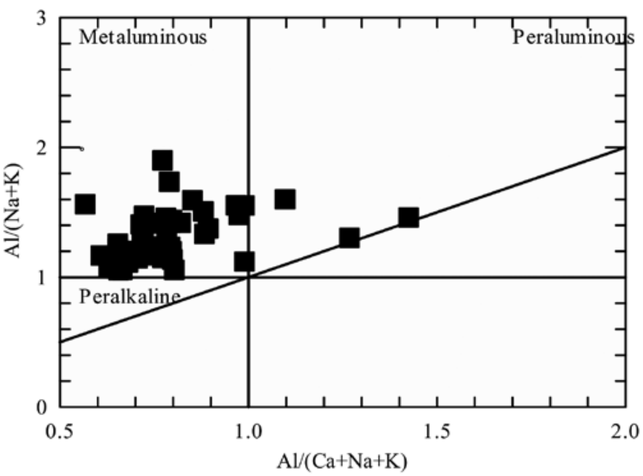

FIGURE 4B. Plot showing samples are metaluminous to peraluminous (Shand, 1943).

FIGURE 4A-E. Geochemical plots of selected samples from the Jarilla Mountains. Chemical analyses are in Appendix 2.

with a relatively flat segment at 45.64 ±0.05 Ma. Several single K-feldspar crystals from OR 6 for the granodiorite to syenodiorite were analyzed using low resolution laser step-heating. The spectra are highly variable with integrated ages ranging between about 57.3 to 45.5 Ma. Overall, old grains are likely contaminated with excess argon with the youngest population near 45.12 Ma, potentially representing a minimum emplacement age. OR 8 hornblende from the monzonite porphyry yielded a plateau age of 41.26 ±0.08 Ma and likely records the time of intrusion. Although K-feldspar has a lower argon closure temperature than hornblende (~250°C compared to ~500°C, respectively) the apparent ages conform to field relationships where the granodiorite to

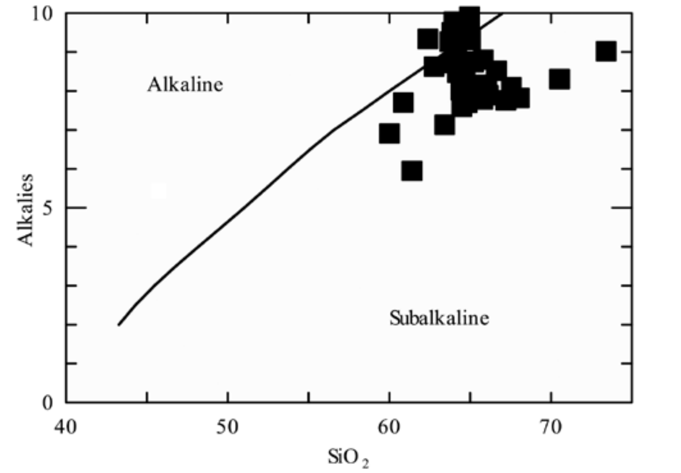

FIGURE 4C. Plot showing samples are subalkaline to alkaline (Irvine and Baragar, 1971).

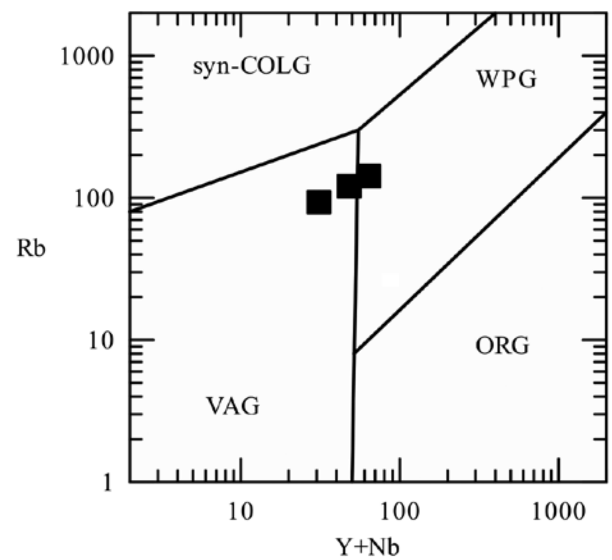

FIGURE 4D. They are classified as volcanic arc granites (VAG) to within-plate granites (WPG) using the classification of Pearce et al. (1984).

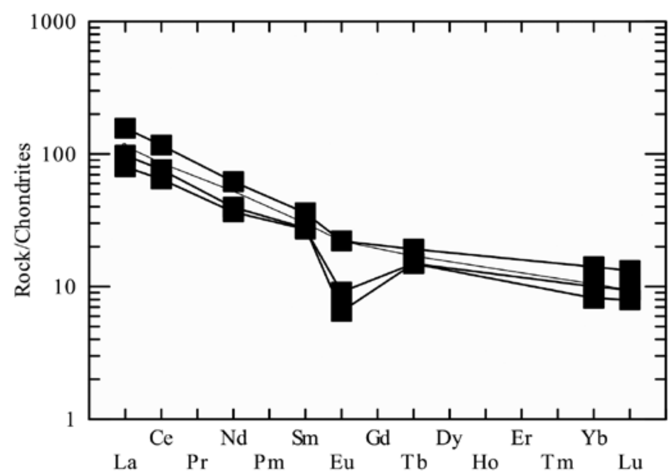

FIGURE 4E. Chondrite-normalized plots of selected samples from Jarilla Mountains. Chondrite values from Nakamura (1974).

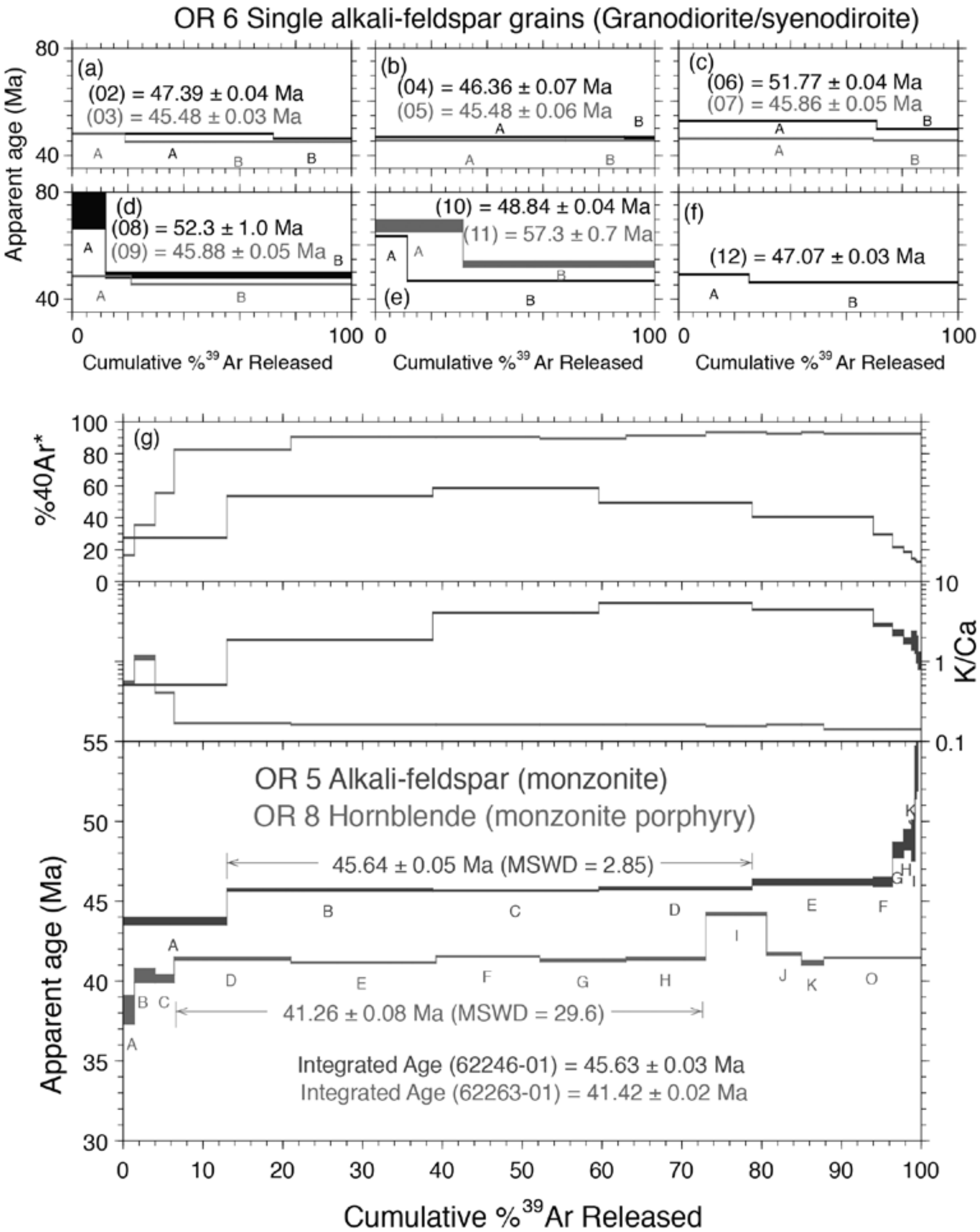

FIGURE 5. $^{40}Ar/^{39}Ar$ plots of three samples from the Jarilla Mountains. Locations of samples are in Table 4 and analytical data are in Appendix 4.

syenodiorite is older than the monzonite porphyry (cf. Beane et al., 1975). This suggests that the igneous rocks were emplaced at shallow crustal levels thereby facilitating rapid cooling and allowing K-feldspar to record near emplacement argon ages.

DESCRIPTION OF MINERAL DEPOSITS

Placer gold deposits

Placer gold deposits have been worked along several arroyos and the southeastern slopes on alluvial fans and pediment surfaces. The stream gravels are reported to assay \$1/yd^3 (Anderson, 1957) or approximately 0.05–0.2 oz/yd^3 (Heylmun, 1985). The largest gold nugget reported from the district was collected in 1904, weighed 6.5 oz, and was valued at \$123 (Jones, 1904). The best gold values are found in red- to brown-stained, caliche-cemented stream gravels lying directly on bedrock or caliche hardpan (Johnson, 1972; Heylmun, 1985; McLemore, 1994). Most streams in the central and southern Jarilla Mountains carry some placer gold, but the higher-grade deposits are downstream of gold-rich skarn and vein deposits. Some trenches are as much as 4.5 m deep, which is probably the average thickness of the gold-bearing alluvial deposits.

Small placer gold nuggets collected from the Nannie Baird placer mine (NMOt0409, also known as Mannie Baird) were examined by electron microprobe, using both back-scattered electron imaging (BSE) and quantitative analysis. Based on BSE imaging, two notable features were present. First, the BSE intensity around the margins of the nuggets was higher (indicating average higher mean atomic number, Z) than that observed for the nugget cores (Fig. 6A). Furthermore, a number of small cubic inclusions were observed in the nuggets (Fig. 6B). Qualititive analysis indicated that these inclusions are composed largely of Fe and S, suggesting that they are pyrite (Appendix 5). The chemical composition of the higher and lower mean Z areas of the gold nuggets, as well as the pyrite, was quantitatively measured (Table 5). The cores of two nuggets for which quantitative analysis was carried out contain around 36 and 21 wt% Ag, respectively. The core concentration was quite consistent within each nugget, with standard deviations of 0.33 and 0.05 wt% Ag, respectively. The higher Z rims of the nuggets, are composed dominantly of Au and contain a much lower relative concentration of Ag, between 0.2 and 4.8 wt%. The Cu content of the rims is as high as 800 ppm, although most analyses are close to the detection limit of Cu, which is between 200 and 300 ppm. Other elements, including As, Pb, Fe, and S, are all below detection limits (see details in footnote of Appendix 5). The BSE images showing Ag-poor zones forming higher Z rims of variable thickness around lower Z nugget cores and adjacent to interior fractures and voids, suggests that the zonation may be related to a weathering process, whereby Ag is leached from rims and interior void areas of the nuggets, leaving a relatively higher abundance of Au.

Finally, a number of very small pyrite inclusions were identified within the Orogrande gold nuggets. Analyses of two of these inclusions suggest pyrite composition, with significant levels of As and Pb (see Table 5 and Appendix 5), but with Cu and Zn below detection limits. Virgil Lueth also reports the presence of magnetite inclusions in some of the gold nuggets from the Nannie Baird placer mine (V. Lueth, personal commun. 2014).

Skarn and replacement deposits

Most skarn and replacement deposits contain predominantly garnet, magnetite and hematite, and locally, copper and gold. The metal-rich skarns can be classified as calcic copper skarns according to Einaudi and Burt (1982). Individual skarns range in size from a few metric tons to over 500,000 metric tons. Until 1949, the average geochemical analyses of iron ore produced from the Orogrande district was 55.8% Fe, 0.051% P, 9.8% SiO_2, 0.23% Mn, 0.50% Al_2O_3, 3.81% CaO, 0.51% MgO, 0.91% S, and 0.09% Cu (Kelley, 1949).

Spectacular outcrops of skarn are exposed at the Cinco de Mayo (NMOt0026) and Iron Duke (NMOt0038) open cuts and adits in NE ¼ sec. 4, T22S, R8E. Alternating beds of black magnetite-hematite, white marble, and green garnet that are 1–3 m thick are found in 15–39.6 m thick zones. Iron was produced from the mine, although chalcopyrite and malachite also are common. The garnet-rich zones contain as much as 50% calcite, iron oxides, pyrite, actinolite, quartz, chalcopyrite, and malachite. The magnetite-hematite-rich layers also contain garnet, pyrite, actinolite, calcite, fluorite, and chalcopyrite. An average analysis of ore shipments contains 54.35% Fe, 0.056% P, 10.55% SiO_2, 0.31% Mn, 0.66% Al_2O_3, 4.51% lime, 0.58% Mg, 1.08% S, and 0.11% Cu (Kelley, 1949). Geochemical analyses of samples collected from the various workings on the claims contain as much as 3,380 ppb Au and 11.8 ppm Ag (Appendix 3).

The Garnet-Shoe Fly-Providence (NMOt0036) group of mines is one of many copper-gold and copper-gold-lead skarns in the district and is located in sec. 34, T21S, R8E. Historical production from 1905–1939 from the mine includes 19,525 short tons of ore grading 0.12 oz/short ton Au, 0.47 oz/short ton Ag, and 3.22% Cu worth $15,000. Geochemical analyses of samples collected from the various workings on the claims contain as much as 9,830 ppb Au and 29.6 ppm Ag (Appendix 3). At the surface there are two levels; the upper level consists of two open and hazardous shafts, approximately 61 m deep. The lower level consists of a shaft and decline. A 5.8-m adit also exposes the skarn at the lower level. A garnet skarn is exposed at the lower level workings, which is 13 m long, 6.7 m thick, and a minimum of 7 m thick. The skarn consists predominantly of garnet with trace amounts of malachite, pyrite, chalcopyrite, calcite, and chert. The upper and middle dumps are highly oxidized and eroded, poorly sorted, and contain 40–60% rust-colored sand, silt, and clay sized material (predominantly iron oxides), 5–15% pyrite, 1% malachite, 1% chert, 1% garnet, and trace amounts of chalcopyrite, fluorite, and calcite. The upper dump is approximately 61 m long, 6–12 m wide, and 15 m high at a 40° slope. The middle dump is approximately 48.7 m long, 4.6 m wide, and

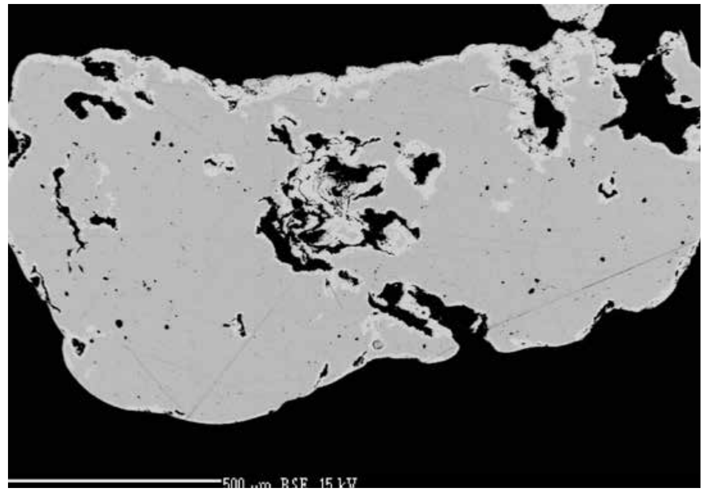

FIGURE 6A. Backscattered Electron (BSE) microprobe image of placer gold nugget showing Ag-poor (hi-Z) zonations of variable thickness along perimeter and surrounding interior voids and fractures.

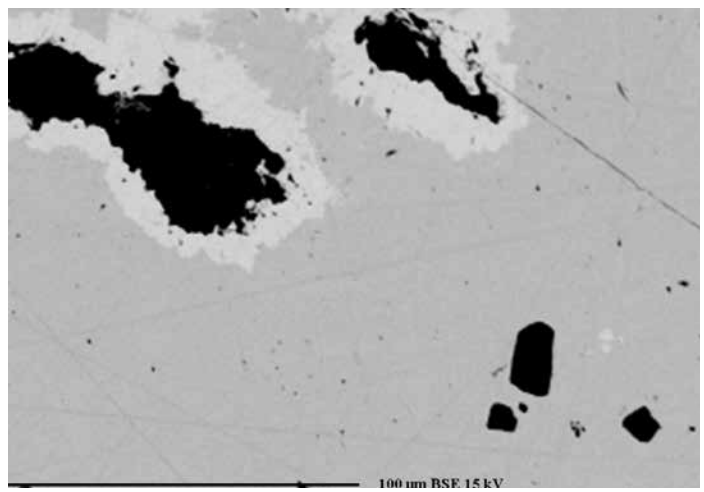

FIGURE 6B. Closeup BSE image showing pyrite inclusions (black crystals in lower right of image) and Ag-poor zonations surrounding interior voids.

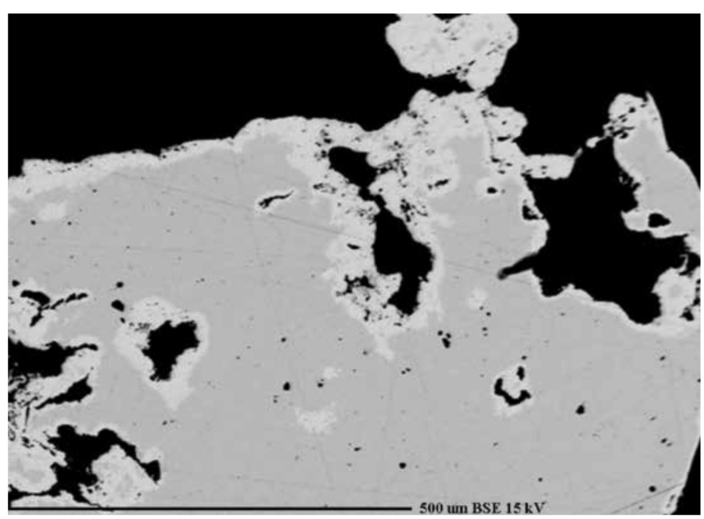

FIGURE 6C. Closeup BSE image showing Ag leached areas (AU-enrichment/replacement?) surrounding euhedral grains (former pyrite)?

7.6–9 m high at a 40° slope. The lower dump is approximately 44 m long, 4.6 m wide, and 3–7.6 m high and consists of garnet, limestone, and soil.

The Three Bears mine (NMOt0071), also known as Grizzly Bear, Cinnamon Bear, and Little Bear, is a shaft 160 m deep with five levels and extensive underground workings. The shaft was driven along a garnet skarn, which also is exposed along the western hillside. The dump is heterogeneous and poorly sorted, and consists of limestone, garnet, malachite, calcite, chalcopyrite, pyrite, iron oxides, chert, monzonite, and quartz. The skarn along the western hillside is approximately 18 m wide. The dump is approximately 19.8 m wide, 21 m long, and 15 m high with a slope of 40°. Production is unknown. Geochemical analyses of samples collected from the various workings on the claims contain as much as 1,180 ppb Au and 34.6 ppm Ag (Appendix 3).

Workings at the Mizpah mine (NMOt0054) in SE ¼ sec. 10, T22S, R8E consist of a 22.8 m cut, adits, and pits. Less than 500 short tons Au, Ag, and Cu ore were produced in 1915–1916. In the cut, garnet skarn is exposed that is approximately 2.4–4.6 m thick, but the garnet skarn thins and splits into three or four garnet zones down dip, as exposed in the adits. The garnet zones are <0.3–1 m thick and separated by limestone and marble. The dump contains predominantly garnet, chert, limestone, and iron oxides. Geochemical analyses of one sample collected from the claims contain 226 ppb Au and 15.1 ppm Ag (Appendix 3).

The Delusion mine (NMOt0032) is in NE ¼ sec. 4, T22S, R8E and consists of cuts and several adits leading into extensive underground workings. Less than 10,000 short tons of Cu, Ag, and Au ore were mined intermittently in 1907–1947. The dumps are rust colored and consist of iron oxides, pyrite, chalcopyrite, malachite, turquoise, and trace garnet, calcite, and quartz. Geochemical analyses of two samples collected from the claims contain 39 and 200 ppb Au and no detectable Ag and 7 ppm Ag (Appendix 3). Drilling by Inspiration Gold Inc. encountered several favorable zones assaying as much as 0.028 oz/ton Au, 0.08 oz/ton Ag, and 0.88% Cu (NMBGMR file data).

Garnet skarns are common throughout the district and contain trace to major amounts of magnetite and hematite (Lueth, 1996). Pyrite and chalcopyrite are found in the garnet-scapolite skarns adjacent to the monzonite, with abundant magnetite locally. Garnet comprises up to 80%. Garnet is typically fine-grained and is found in irregular tabular zones that pinch and swell. Most industrial uses of garnet require coarse-grained garnet that can be mined without blasting. Only a few unmined deposits in the Orogrande district consist of this grade of garnet. However, many of the dumps can be reprocessed for garnet.

A nearly pure garnet-magnetite skarn crops out at on the Monarch claims (NMOt0056) in NW ¼ sec. 3, T22S, R8E and several shallow pits and an adit expose the skarn. The outcrop is faulted, with a displacement of approximately 3 m, and is approximately 244 m long and 6–18 m thick. The garnet is predominantly fine-grained and is found in irregular zones ranging in thickness from a few centimeters to several meters. Coarse-grained garnet is rare. The Monarch skarn is in contact with the monzonite along the upper surface. The skarn contains iron oxides, chert, and a trace of pyrite. Geochemical analyses of one sample collected from the claims contain 30 ppb Au and no detectable Ag (Appendix 3).

Vein deposits

Vein deposits are variable in extent and composition from calcite veins along faults (Nannie Baird mine) to mineralized zones of veinlets and disseminations of chalcopyrite and pyrite within altered monzonite. One vein contains chalcopyrite and wulfenite (Schilling, 1965).

Porphyry copper deposits

Porphyry copper deposits are found in monzonite as disseminated and stockwork veinlets of copper and molybdenum sulfides. Distribution of mineralization and alteration led Beane et al. (1975) to suggest that a larger porphyry copper deposit may lie at depth, which was confirmed by exploration drilling. Potassic alteration is found near the Cinco de Mayo mine and consists of intensely fractured monzonite cut by quartz and K-feldspar veinlets; fractures are typically coated with secondary copper minerals. Phyllic alteration locally overlaps the potassic alteration and is characterized by quartz-sericite replacements and veinlets; mafic minerals are typically altered beyond recognition.

Turquoise

Turquoise is found in over 50 localities in the district (Pogue, 1915; Weber, 1979; Crook and Lueth, this volume). The turquoise is associated with kaolin, limonite, pyrite, gypsum, jarosite, and other clay minerals in thin seams along fractures and as nodules in altered quartz monzonite or monzonite and is typically within 7.6 m of the surface. Colors ranged from blue to green and some deep blue stones tended to fade with time (Weber, 1979). Crook and Lueth (this volume) indicate that the turquoise deposits are supergene, formed by cold waters during weathering.

DISCUSSION

The ages of the igneous rocks in the Jarilla Mountains are 41.4 to 45.6 Ma, which are among the youngest ages of the Arizona-Sonora-New Mexico porphyry copper province (Fig. 2; Keith and Swan, 1996; Barton, 1996; McLemore, 2008) and are similar in age to the older deposits found within the Rocky Mountain alkaline belt (Mutschler et al., 1985, 1991; Allen and Foord, 1991; McLemore, 1996). The Jarilla Mountains subalkaline to alkaline igneous rocks are older than the alkaline igneous rocks in the nearby Hueco (34.5–34.7 Ma; McLemore, 2002) and Cornudas Mountains (36.32 ±0.15 Ma; New Mexico Bureau of Mines and Mineral Resources et al., 1998) in the northern Trans-Pecos alkaline province of the Rocky Mountain alkaline belt (Fig. 3). The Jarilla Mountains igneous rocks also are older than most of the igneous rocks in the Lincoln County porphyry belt (also part of the Rocky Mountain alkaline belt), which range from 40 to 25 Ma (Allen and Foord, 1991; McLemore and Zimmerer, 2009; McLemore et al., this volume). New, unpublished ages of calc-alkaline to alkaline igneous rocks from the Jicarilla Mountains in the northern Lincoln County porphyry belt range from 39.45 ±0.02 and 40.72 ±0.04 Ma ($^{40}Ar/^{39}Ar$, V.T. McLemore, unpubl. 2014).

McMillan et al. (2000) suggests that arc-magmatism related to subduction occurred in southern New Mexico from about 50 to 36 Ma, and that Rio Grande rift extension began as early as 36 Ma. Thus, the 41.4 to 45.6 Ma igneous rocks in the Jarilla Mountains were likely emplaced during the transition between Laramide subduction of the Farallon plate (i.e., the time of emplacement of the porphyry copper deposits of the Arizona-Sonora-New Mexico porphyry copper province) and mid-Tertiary extension (i.e., the time of emplacement of the Rocky Mountain alkaline belt). Several studies have attributed changes in the chemistry and source of the magmas to tectonic transition between Laramide subduction and mid-Tertiary extension (Anthony, 2005). Richards (2009) suggests that the igneous rocks associated with the porphyry Cu-Au deposits in the Arizona-Sonora-New Mexico porphyry copper province are related to remelting of subduction-modified lithosphere generated after subduction beneath the arc ceased. McMillan et al. (2000) further suggest that this transition is a shift of magma source from lithosphere to asthenosphere. Therefore, the igneous rocks in the Jarilla Mountains and associated mineral deposits could represent the transition between arc-magmatism forming the porphyry copper deposits and the shift to extension-related alkaline magmas and related mineral deposits, such as those found in the Rocky Mountain alkaline belt. More geochemical studies of the igneous rocks in the Jarilla Mountains are required to better understand the source and tectonic setting of this area.

OUTLOOK FOR MINERAL RESOURCE POTENTIAL IN THE FUTURE

Gold, silver, base metals

Many companies have explored the Orogrande district looking for gold, silver and base metals. However, no significant production has occurred since 1966 (Table 1), other than unreported placer gold production. However, as the price of gold and copper increases, companies will continue to re-examine the Orogrande district because:

- Some gold, silver, and base metals have been produced in the past (Table 1)
- Porphyry copper and gold-bearing skarn deposits have been found that have not yet been mined, and could be in the future
- Geochemical analyses indicate moderate to high values of gold, silver, molybdenum, tungsten, tellurium, and other metals are present (Appendix 3).

Detailed geochemical and geophysical surveys are recommended to delineate potential drilling sites for additional undiscovered deposits.

The mineral resource potential for small placer gold deposits is high, but large-scale mining of these placers is unlikely because of the lack of abundant water and the scattered, discontinuous nature of the placer gold deposits. The potential for porphyry Cu-Mo deposits is high, but no reserves have been delineated.

Garnet and iron ore

The potential for garnet and iron ore in skarns and waste rock piles is high. However, metallurgical tests (New Mexico Bureau of Geology and Mineral Resources, unpubl. 1996) indicate that the garnet breaks into fine-sand size when crushed, which could be too fine grained for the abrasives industry. Howard (1967) reported iron resources of 216,000 short tons averaging 40–50% Fe and recent production has occurred from the waste rock piles at the Iron Duke mine. Geophysical surveys should be conducted to delineate additional skarn deposits in the subsurface.

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 as a constituent of 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. Limited data from this study indicates tellurium concentrations are moderate to low in most analyzed samples; one sample assayed 323 ppm Te, which is close to ore grade (Appendix 3). However, additional geochemical analyses of the deposits including tellurium are recommended as other investigations are conducted.

Tungsten

The Orogrande district had past production of tungsten and limited data from this study indicates tungsten concentrations are moderate to low in the analyzed samples; one sample assayed 759 ppm W (Appendix 3).

Rare Earth Elements

Available geochemical studies and known mineralogy throughout the Orogrande district indicate the REE concentrations are not high enough to warrant additional exploration in this district at this time (Fig. 4E; Appendix 3).

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