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GEOLOGY AND MINERAL RESOURCES
IN THE ZUNI MOUNTAINS MINING DISTRICT,
CIBOLA COUNTY, NEW MEXICO: REVISITED

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ABSTRACT—The Zuni Mountains district is in the central and southern Zuni Mountains in north-central New Mexico. The earliest mining in the Zuni Mountains was by Native Americans, who recovered obsidian (eroded from the Mt. Taylor region), basalt, turquoise, malachite, azurite, and possibly fluorite for ornaments and stone tools. The major types of deposits in the Zuni Mountains include 1) veins and replacements in Proterozoic rocks, 2) stratabound, sedimentary-copper deposits, and 3) fluorite veins, although 4) REE (rare earth elements)-Th-U metasomatic bodies, 5) high-calcium limestone, 6) volcanic cinders (scoria), and 7) iron deposits also are found in the Zuni Mountains district. Total fluorite production exceeded 224,000 short tons of crude ore. Total reported metals production from the district amounts to more than 30,000 pounds copper, 260 oz silver, and 2 oz gold from 1923 to 1965; additional copper, gold, and silver production probably occurred during the late 1800s. There is some economic potential for gold, silver, and possibly copper in the veins and replacement deposits in Proterozoic Zuni and Mt. Sedgwick granites and metarhyolite. The Proterozoic dark syenite and amphibolite bodies and gold-silver veins in the Zuni Mountains should be geochemically evaluated for their platinum group metals (PGE) potential. It is unlikely that the stratabound, sedimentary-copper deposits or fluorite veins have any remaining significant economic potential, because the highest grades have been mined and remaining deposits appear to be discontinuous and low grade. The REE-Th-U metasomatic bodies and iron deposits also have low economic potential because of low grade and small size. The Zuni Mountains continue to have high economic potential for high-calcium limestone and volcanic cinders (scoria). The veins and replacement deposits appear to be Proterozoic in age and are associated with the Zuni and Mt. Sedgwick granites and metarhyolite, while the late Proterozoic epidysenites appear to be associated with the Mt. Sedgwick granite. The fluorite veins are much younger and perhaps associated with other Rio Grande rift barite-fluorite deposits in New Mexico.

INTRODUCTION

The Zuni Mountains mining district is in the central and southern parts of the Zuni Mountains, west and southwest of Grants in Cibola County, New Mexico (Fig. 1). After 1983, the Zuni Mountains were in Cibola County, which was created from the western portion of what was Valencia County. The major types of deposits in the Zuni Mountains include 1) veins and replacements in Proterozoic rocks, 2) stratabound, sedimentary-copper deposits, and 3) fluorite veins, although 4) REE (rare earth elements) -Th-U metasomatic bodies, 5) high-calcium limestone, 6) volcanic cinders (scoria), and 7) iron deposits also are found in the Zuni Mountains district. The only active mining in the Zuni Mountains is for limestone.

METHODS OF INVESTIGATION

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 et al. (1986), McLemore and McKee (1989), and McLemore (1983, 1989, 2001). Investigations of the mineral deposits and plutonic rocks in the Zuni Mountains by the author began in 1983 in order to assess their economic potential and tectonic setting (McLemore, 1983; McLemore and McKee, 1989). Continued investigations occurred in 1985-1986, as part of the evaluation of mineral resources within Cibola County (McLemore et al., 1986). During 2011-2012, the author resumed investigations in the area in order to understand the origin of the granitic and metasomatic rocks, the tectonic setting, and to evaluate the mineral resource potential.

Published and unpublished data were compiled and examined. Mineral occurrences, deposits, mines, prospects, and mills were identified, plotted on base maps (Fig. 2), and compiled in the New Mexico Mines Database (McLemore et al., 2005a, b). Igneous rock lithologies were characterized on the basis of mineralogy and chemistry. Types of deposits are from Cox and Singer (1986).
FIGURE 2. Simplified geologic map of the Zuni Mountains (modified by the author from field reconnaissance from Goddard, 1966), showing mines, occurrences, and sample locations (Tables 3, 4). Zuni granite includes metamorphic rocks and aplite.
and McLemore (2001). Production is in Tables 1 and 2. Selected samples were collected and analyzed by a variety of methods as explained in Tables 3 and 4.

MINING HISTORY AND PRODUCTION

The Zuni, Acoma, and Navajo people have lived, traveled, and hunted throughout the Zuni Mountains for centuries. Native Americans recovered obsidian (eroded from the Mt. Taylor region), basalt, turquoise, malachite, and azurite for ornaments and stone tools. Fluorite also may have been used by the Zunis for decorative ornaments (Lindgren et al., 1910; Oakes et al., 2006; Zamora, 2008).

Base and precious metals were found in the Zuni Mountains circa 1900 and at least one metals mill was built in the district. Total reported production from the district amounts to more than 30,000 lbs copper, 260 oz silver, and 2 oz gold from 1923 to 1965 (Table 1); additional copper, gold, and silver production probably occurred during the late 1800s.

Fluorite was discovered about 1908. A fluorite mill-concentrator was constructed in the 1910s, but was destroyed by fire in 1927 (Lasky and Wootton, 1933). In 1943, the Zuni Milling Co. (formerly Navajo Fluorspar Mines) opened a fluor spar mill in Los Lunas, where fluorite mined from the Zuni Mountains was processed. The lack of water and electricity prevented a mill from being built in the Zuni Mountains. The Los Lunas mill had a capacity of 100 short tons/day and could yield a 98% concentrate at 165 mesh (Kutnewsky, 1944). Chemical (93% fluorite), ceramic (95%) and metallurgical (85%) grades were shipped from the mill (Warner, 1947). In 1944, the mill increased its capacity, making it the third largest fluorite mill in the U.S. at the time (Kutnewsky, 1944; Messenger, 1979).

Other production has come from the Zuni Mountains (Table 2). In 1961-1962, U.S. Sericite produced 10 short tons of flake mica, worth approximately $255. An unknown amount of limestone and volcanic cinder also has been produced from the Zuni Mountains. Iron ore was found and prospected during WW II; production, if any, is unknown.

GEOLOGIC SETTING

The Zuni Mountains lie along the Jemez lineament (Fig. 1; Chapin et al., 1978; Aldrich et al., 1986) and geophysical data suggest that a mafic intrusion underlies the Zuni uplift (Ander and Huestis, 1982). The Jemez lineament is defined by north-east-trending alignment of late Cenozoic basaltic magmatism that extends from the Springerville volcanic field in Arizona to the Raton-Clayton volcanic field in northeastern New Mexico (Fig. 1). In New Mexico, much research has been focused on the association of magmatism, structure, and mineralization along the Jemez lineament (Mayo, 1958; Aldrich and Laughlin, 1984; Sims et al., 2002; Cather et al., 2006; Chamberlin, 2007).

Lineaments have played a role in localizing magmatic activity and can locally control mineralizing fluids; however, many volcanic and magmatic events and mining districts in New Mexico are not found along lineaments (Fig. 1). Many factors, such as surface topography, development of rift structural architecture, erosion and tectonic elimination of aquitards, unroofing of carbonate aquifers by karst formation, climate, rates of extension, basin sedimentation, subsidence, compaction, over-pressuring, and crustal magmatism, have all played roles in the location, types, and intensity of mineral deposit evolution at any particular site. As a result, deposits of different ages, size, temperature of formation, and accessory mineralogy are a common feature of the deposits found along lineaments. Lineaments, especially where they intersect other structural features could be viable exploration targets. At least two periods of magmatic activity have been focused along the Jemez lineament and are found within the Zuni Mountains (Proterozoic and Cenozoic; Goddard, 1966). The mineral deposits in the Zuni Mountains could be a result of this crustal feature.

Proterozoic granite and metamorphic rocks form the core of the Zuni Mountains (Fig. 2) that was uplifted during the Ancestral and Laramide orogenies (Aldrich et al., 1986). The oldest rocks are hornblende and serpentinized peridotite (1630.2±1.9 Ma, 40Ar/39Ar, Strickland et al., 2003), and a metahyolite with

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Reported production</th>
<th>Value (dollars)</th>
<th>Years Produced</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluorite</td>
<td>192,657 short tons</td>
<td>unknown</td>
<td>1946-1953</td>
<td>Additional production withheld 1953-1962</td>
</tr>
<tr>
<td>Mica</td>
<td>10 short tons</td>
<td>255</td>
<td>1909-1953</td>
<td>U.S. Sericite Co.</td>
</tr>
<tr>
<td>Scoria</td>
<td>unknown</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>High-calcium Limestone</td>
<td>unknown</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>

mica, worth approximately $255. An unknown amount of limestone and volcanic cinder also has been produced from the Zuni Mountains. Iron ore was found and prospected during WW II; production, if any, is unknown.
TABLE 3. Chemical analyses of selected samples from the Zuni Mountains. Sample no. 7981 is from the Abo Formation; all other samples are from Proterozoic or fluorite veins. Analyses are from McLemore et al. (1986). Au and Ag were by fire assay and other elements by atomic adsorption spectroscopy (AA) at the NMBGMR laboratory.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Name</th>
<th>Mine Id</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Au oz/ton (ppm)</th>
<th>Ag oz/ton (ppm)</th>
<th>Cu%</th>
<th>Pb%</th>
<th>other</th>
<th>U3O8%</th>
<th>type of sample</th>
<th>type of deposit</th>
</tr>
</thead>
<tbody>
<tr>
<td>7977</td>
<td>Irene 2</td>
<td>NMCl0123</td>
<td>35.01655</td>
<td>-107.9853</td>
<td>0</td>
<td>0.26 (8.13)</td>
<td></td>
<td></td>
<td>no Pt, 16.5 CaF2%</td>
<td>0.12 BaSO4%</td>
<td>dump</td>
<td>fluorite vein</td>
</tr>
<tr>
<td>7978</td>
<td>21</td>
<td>NMCl0128</td>
<td>34.98971</td>
<td>-107.998</td>
<td>0.06 (1.88)</td>
<td>4.24 (133)</td>
<td></td>
<td></td>
<td>no Pt, 32.2 CaF2%</td>
<td>0.25 BaSO4%</td>
<td>dump</td>
<td>fluorite vein</td>
</tr>
<tr>
<td>8811</td>
<td>Fool's Gold Canyon</td>
<td>NMCl0124</td>
<td>35.00924</td>
<td>-107.985</td>
<td>0</td>
<td>0.02 (0.63)</td>
<td>26 ppm</td>
<td></td>
<td></td>
<td></td>
<td>South dump</td>
<td>Precambrian vein</td>
</tr>
<tr>
<td>8810</td>
<td>Fool's Gold Canyon</td>
<td>NMCl0124</td>
<td>35.00924</td>
<td>-107.985</td>
<td>0</td>
<td>0</td>
<td>62 ppm</td>
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<td></td>
<td></td>
<td>North dump</td>
<td>Precambrian vein</td>
</tr>
<tr>
<td>8801</td>
<td>Trail Canyon</td>
<td>NMCl0152</td>
<td>35.11212</td>
<td>-108.0749</td>
<td>0</td>
<td>0.02 (0.63)</td>
<td>26 ppm</td>
<td></td>
<td></td>
<td></td>
<td>dump</td>
<td>Precambrian vein</td>
</tr>
<tr>
<td>9017</td>
<td>Trail Canyon</td>
<td>NMCl0152</td>
<td>35.11212</td>
<td>-108.0749</td>
<td>0</td>
<td>0.18 (5.63)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>dump</td>
<td>Precambrian vein</td>
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<td>8805</td>
<td>Diener Canyon</td>
<td>NMCl0158</td>
<td>35.16149</td>
<td>-108.1257</td>
<td>0</td>
<td>0.28 (8.75)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>quartz vein</td>
<td>Precambrian vein</td>
</tr>
<tr>
<td>8806</td>
<td>Diener Canyon</td>
<td>NMCl0158</td>
<td>35.16149</td>
<td>-108.1257</td>
<td>0</td>
<td>1.36 (42.5)</td>
<td>2.94</td>
<td></td>
<td></td>
<td></td>
<td>quartz vein</td>
<td>Precambrian vein</td>
</tr>
<tr>
<td>8809</td>
<td>Diener Canyon</td>
<td>NMCl0158</td>
<td>35.16149</td>
<td>-108.1257</td>
<td>Trace (&lt;0.63)</td>
<td>0.74 (23.1)</td>
<td>1.14</td>
<td></td>
<td></td>
<td></td>
<td>quartz vein</td>
<td>Precambrian vein</td>
</tr>
<tr>
<td>8814</td>
<td>Diener Canyon</td>
<td>NMCl0158</td>
<td>35.1644</td>
<td>-108.1292</td>
<td>0</td>
<td>0.28 (8.75)</td>
<td>&lt;20 ppm</td>
<td></td>
<td></td>
<td></td>
<td>dump</td>
<td>Precambrian vein</td>
</tr>
<tr>
<td>8815</td>
<td>Diener Canyon</td>
<td>NMCl0154</td>
<td>35.16532</td>
<td>-108.1265</td>
<td>0</td>
<td>0.08 (2.5)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>quartz vein</td>
<td>Precambrian vein</td>
</tr>
<tr>
<td>9671</td>
<td>Diener Canyon</td>
<td>NMCl0154</td>
<td>35.16532</td>
<td>-108.1197</td>
<td>Trace (&lt;0.63)</td>
<td>Trace (&lt;0.63)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>quartz vein</td>
<td>Precambrian vein</td>
</tr>
<tr>
<td>7979</td>
<td>Mt. Sedgwick</td>
<td>35.17602</td>
<td>-108.1292</td>
<td>0</td>
<td>1.1 (34.4)</td>
<td>4.55</td>
<td>&lt;0.02</td>
<td>no Pt</td>
<td>0.003</td>
<td>dump</td>
<td>Precambrian vein</td>
<td></td>
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<tr>
<td>7980</td>
<td>Mt. Sedgwick</td>
<td>35.17602</td>
<td>-108.1292</td>
<td>0</td>
<td>0.74 (23.1)</td>
<td>3.5</td>
<td>&lt;0.02</td>
<td>no Pt</td>
<td>0.002</td>
<td>shear zone</td>
<td>Precambrian vein</td>
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</tr>
<tr>
<td>8049</td>
<td></td>
<td>35.17703</td>
<td>-108.1301</td>
<td>Trace (&lt;0.63)</td>
<td>0</td>
<td>0.06</td>
<td>&lt;0.02</td>
<td>0.006% Zn</td>
<td></td>
<td>shear zone</td>
<td>Precambrian vein</td>
<td></td>
</tr>
<tr>
<td>7982</td>
<td>Gabby</td>
<td>NMCl0154</td>
<td>35.19456</td>
<td>-108.1415</td>
<td>0</td>
<td>0.48 (15)</td>
<td>0.46</td>
<td>&lt;0.02</td>
<td></td>
<td></td>
<td>shear zone</td>
<td>Precambrian vein</td>
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<td>7982</td>
<td></td>
<td>NMCl0154</td>
<td>35.19456</td>
<td>-108.1415</td>
<td>0</td>
<td>0.48 (15)</td>
<td>103 ppm</td>
<td></td>
<td></td>
<td></td>
<td>dump</td>
<td>Precambrian vein</td>
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<tr>
<td>7981</td>
<td></td>
<td>NMCl0155</td>
<td>35.19967</td>
<td>-108.1444</td>
<td>0</td>
<td>1.02 (31.9)</td>
<td>3.7</td>
<td>&lt;0.02</td>
<td></td>
<td></td>
<td>sandstone</td>
<td>Precambrian vein</td>
</tr>
<tr>
<td>8058</td>
<td>McGaffey</td>
<td></td>
<td>0</td>
<td>1.62 (50.6)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>quartz vein</td>
<td>Precambrian vein</td>
</tr>
<tr>
<td>8050</td>
<td>McGaffey</td>
<td></td>
<td>0</td>
<td>0.22 (6.88)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>quartz vein</td>
<td>Precambrian vein</td>
</tr>
</tbody>
</table>
a U/Pb age of about 1655 Ma (Bowring and Condie, 1982). Strickland et al. (2003) also dated hornblende and biotite in two shear zones with $^{40}\text{Ar}/^{39}\text{Ar}$ ages of 1432±5.7 Ma and 1432.7±1.8 Ma. Other lithologies in the Zuni Mountains Proterozoic terrain include gneiss, schist, amphibolite, syenite, pegmatites, and diabase dikes (Goddard, 1966; Fitzsimmons, 1967; Lambert, 1983; Mawer and Bauer, 1989; Strickland et al., 2003). The diabase dikes are 1130±20 Ma ($^{40}\text{Ar}/^{39}\text{Ar}$, Strickland et al., 2003).

Existing data suggest four geographically and geochemically distinct granites are present in the Zuni Mountains (Figs. 2 and 3; Condie, 1978; Brookins and Rautman, 1978): Mt. Sedgwick granite (high calcium), Zuni granite (high silica), Cerro Colorado gneissic aplite (high silica), and Oso granite (high potassium). A fifth pluton in the northern Zuni Mountains has not been sampled. The megacrustic granite, the Mt. Sedgwick granite, has a $^{40}\text{Ar}/^{39}\text{Ar}$ age of 1432±1.9 Ma (Strickland et al., 2003). The metarhyolite is similar geochemically to the Oso granite and the Zuni and Cerro Colorado granites are geochemically similar. The Zuni Mountain granites are calcic to calc-alkaline and peraluminous granites. Condie (1978) suggested that the high-calcium granites were formed by partial melting of siliceous granulite in the lower crust and the high-silica and high-potassium granites formed by fractional crystallization of shallow high-calcium magmas.

The Proterozoic rocks are unconformably overlain by sedimentary deposits of Pennsylvanian and Permian age (Abo, Yeso and San Andres formations; Goddard, 1966). The youngest volcanic formations are Quaternary basalt flows and cinder volcanoes.

**DESCRIPTION OF THE MINERAL DEPOSITS**

**Vein and replacement deposits**

Copper veins with galena, silver, and gold are found in thin quartz veins along fault and shear zones and disseminated in Proterozoic Zuni and Mt. Sedgwick granites and metarhyolite (Fig. 2; Schrader, 1906; Lindgren et al., 1910; McLemore et al., 1986). None of the deposits are spatially associated with the Oso or Cerro Colorado granites. Minerals include malachite, azurite, chalcopyrite, chalcocite, native copper, bornite, galena, and sphalerite with trace turquoise, and some silver and gold. Pyrite and quartz are common. Platinum group elements (PGE) were not detected in any samples collected by McLemore et al. (1986); but recently prospectors have verified the presence of platinum assays and a platinum sulfide mineral in mafic portions of a shear zone. Some shear zones (mapped as faults in Fig. 2) are up to 243 m wide, several hundred meters long, and contain as much as 3-6% Cu, 156 to 313 ppm Ag and 0.94 to 3.44 ppm Au (Schrader, 1906; Lindgren et al., 1910). Individual mineralized veins are as much as 1 m wide and less than 100 m long. The mineralized areas are structurally controlled by shear and fault zones.

![Diagram](image-url)

**FIGURE 3.** Granite samples plotted on Na$_2$O-CaO-K$_2$O and Rb-Sr diagrams. Geochemical fields shown after Condie (1978). Chemical analyses available upon request.
Several quartz veins subparallel to schistosity are mineralized, but typically are low in gold and silver (Table 3). The age of mineralization is uncertain, but presumed Proterozoic because the mineralized zones are found exclusively in the Proterozoic rocks and are associated with faults and shear zones of Proterozoic age (Goddard, 1966; Strickland et al., 2003), indicating deformation during the Proterozoic. Many mineralized veins and replacements are found along these shear zones. Most of the known mineral deposits are associated with mineralized veins and replacements are found along these shear zones. More work is needed to determine the origin of these deposits.

Mineral deposits in section 18, 30 T10N, R11W (northeast of Paxton Springs) also are found along shear zones in granite and samples assay up to a trace of gold, 191 ppm Ag, and 7.41% Cu with minor uranium, zinc, and lead (Table 3). These deposits are in the vicinity of fluorspar veins, but fluorspar is not present in the gold-silver veins (McLemore et al., 1986).

The age of mineralization is unknown, but presumed Proterozoic because mineralized bodies are found along Proterozoic structures and shear zones within Proterozoic rocks. Hornblende and biotite from two shear zones in the Zuni Mountains have 40Ar/39Ar ages of 1432±5.7 Ma and 1432.7±1.8 Ma (Strickland et al., 2003), indicating deformation during the Proterozoic. Many mineralized veins and replacements are found along these shear zones. Most of the known mineral deposits are associated with the Zuni and Mt. Sedgwick granites and metarhyolite (Fig. 2). More work is needed to determine the origin of these deposits.

**Stratabound, sedimentary-copper deposits**

Stratabound, sedimentary-copper deposits containing copper, silver, and locally gold, lead, zinc, uranium, vanadium, and molybdenum are found throughout New Mexico, including the
Zuni Mountains. These deposits have also been called “red-bed” or “sandstone” copper deposits by previous workers (Soulé, 1956; Phillips, 1960; Cox and Singer, 1986). They typically occur in bleached gray, pink, green, or tan sandstones, siltstones, shales, and limestones within or marginal to typical thick red-bed sequences of red, brown, purple, or yellow sedimentary rocks deposited in fluvial, deltaic or marginal-marine environments of Pennsylvanian, Permian, or Triassic age. The majority of sedimentary-copper deposits in New Mexico occur at or near the base of these sediments; some deposits, such as those in the Zuni Mountains districts, are in sedimentary rocks that unconformably overlie mineralized Proterozoic granitic rocks.

In the Zuni Mountains, stratabound, sedimentary-copper deposits are typically found in bleached pink or light gray sandstones, siltstones, and conglomerates of the Pennsylvanian (?)-Permian units deposited unconformably on the Proterozoic rocks near the Mirabel Copper mine in the Diener area. At one locality, the Proterozoic granite beneath the mineralized conglomerate consists of thin veinlets and disseminations of malachite and chalcocite. The deposits are predominantly in the Abo Formation (Permian), but some replacements of the Pennsylvanian rocks also are found. The mineralized bodies typically occur as lenses or blankets of disseminated and/or fracture coatings of copper minerals, predominantly chalcopyrite, chalcocite, malachite, and azurite with local uranium minerals, fracture coatings of copper minerals, predominantly chalcopyrite, typically occur as lenses or blankets of disseminated and/or fracture coatings of copper minerals, predominantly chalcopyrite, chalcocite, malachite, and azurite with local uranium minerals.

Fluorite veins

Some of the state’s largest fluorite veins in terms of production and potential are in the southern and central Zuni Mountains district. Total fluorite production exceeded 224,000 short tons of crude ore (Goddard, 1966). Fluorite was discovered in 1908 and produced in 1909. Significant fluorite production occurred in 1943 when Zuni Milling Co. (formerly Navajo Fluorspar Mines) opened a fluorspar mill in Los Lunas.

Fluorite veins are found along north-trending, steeply-dipping faults and fracture zones in Proterozoic and Permian rocks in three areas (Rothrock et al., 1946; Goddard, 1966): 1) Mirabel mine near Diener, 2) northeast of Paxton Springs in T10N, R11W and 3) sections 21 and 27 mines in southeastern Zuni Mountains. Most fluorite veins are in Proterozoic Zuni or Mt. Sedgwick granites, but a few veins cut sandstones of the Permian Abo Formation (Rothrock et al., 1946; Peters, 1958; Goddard, 1966; Williams, 1966; V.T.M. field notes). Locally, Quaternary basalt flows covered fluorite veins. Fluorite veins do not cut the basaltic lava (Rothrock et al., 1946; V.T.M. field notes), indicating that the fluorite veins are older than the basalt flows. Green, purple, colorless, and pink fluorite is found as open-space fillings with minor replacements and cementation of brecciated zones. Massive, crystalline fluorite is found in veins up to 0.5 m thick. A few veins are over 300 m long and have been explored to only a couple of hundred meters deep. The veins contain predominantly fluorite with varying amounts of calcite, quartz, aragonite, and wallrock fragments. Hematite alteration is common producing a reddening of the adjacent granite. Sulfide minerals are rare, although trace amounts of sphalerite, galena, and chalcopyrite are found in the Section 21 and 27 mines (Goddard, 1966). Barite is found locally in trace amounts, although a barite vein, up to 30 cm wide and a few hundred meters long, is found near the Mirabel mine near Diener and contained 78% BaSO₄ and some fluorite and malachite (Table 2, no. 8812).

The grade of fluorspar varies throughout the district with the highest grades (85-93% fluorite) in the Sections 21 and 27 mines. Production varied from 17 to 86% CaF₂. Most fluorite veins do not have any precious- or base-metals, but two samples collected contained up to 133 ppm Ag and 1.88 ppm Au (Table 2). Rare earth (REE) minerals, likely bastnaesite, are reported in some fluorite veins (Zandra et al., 1952; Emanuel, 1982). The best concentrated sample contained 68% TREO (total rare earth oxides; Zandra et al., 1952) and could have included ore from the Gallinas Mountains.

Several studies have suggested that the Zuni Mountain fluorspar deposits are similar in origin and age as the uranium-fluorite
deposits found in the Todilto limestone in the Ambrosia Lake subdistrict of the Grants uranium district (Emanuel, 1982; Gilkey, 1953; Rapaport et al., 1952; Peters, 1956; Gableman, 1956; McLaughlin, 1963). Primary ore minerals in the Todilto deposits include uraninite, coffinite, and blue-black vanadium minerals, with accessory calcite, fluorite and barite. The disseminated and replacement fluorite found in the Todilto uranium deposits is quite different in character compared to the massive, structurally-controlled fluorite veins in the Zuni Mountains. The Todilto fluorite is typically found as small crystals or replacements in the limestone and is purple or colorless. The age of primary Todilto mineralization is estimated at 150-155 Ma based on concordant and nearly concordant U/Pb ages for uraninite (Berglof, 1989; McLemore, 2011a). The fluorite was deposited at the same time as the uranium minerals by uraniferous waters derived from a highland to the southwest migrated through the Entrada Sandstone. These waters were then drawn into the Todilto limestone through evapotranspiration or evaporative pumping. Uranium and fluorite precipitated in the presence of organic material within the intraformational folds and associated fractures and dissolution cavities in the limestone (Berglof, 1989; McLemore, 1983, 2011a).

North and McLemore (1986), McLemore et al. (1998), and McLemore (2001) suggested that the Zuni Mountains fluorite deposits are Rio Grande rift (RGR) deposits formed by low-temperature formation waters or basinal brines found within the Rio Grande rift and are similar to Mississippi Valley-type (MVT) deposits. Recent work by Partey et al. (2009) suggest that fluorite deposits in southern New Mexico are indeed related to the Rio Grande rift and the source of fluorine is consistent with an asthenospheric magma. The mafic magma body beneath the Zuni Mountains (Ander and Huestis, 1982) could be the source of the fluorite deposits found in the Zuni Mountains and the Jemez lineament would allow fluid migration. Uranium minerals are absent in the southern Zuni Mountains fluorite deposits, although the deposits near Diener are slightly radioactive (Goddard, 1966; McLemore, 1983), further supporting a different age and origin from the Todilto uranium deposits.

The Zuni Mountains fluorites contain fluid inclusions with relatively low to moderate homogenization temperatures (108-220°C) and moderate salinities (7-20.4 eq wt%) suggestive of basinal brines (Emanuel, 1982; Hill, 1994; Hill et al., 2000). Stable isotopes are consistent with formation by meteoric waters (Hill, 1994; Hill et al., 2000). Emplacement occurred at depths of approximately 2286 m (Emanuel, 1982). These characteristics suggest a formation similar to that described for RGR barite-fluorite-galena deposits (McLemore et al., 1998).

**POTENTIAL FOR OTHER COMMODITIES**

**REE-Th-U metasomatic bodies**

McLemore and McKee (1989) briefly described and mapped the known brick red, K-feldspar-rich metasomatic episyenite/syenite deposits east of Aragon in the Zuni Mountains. Another small body was found and mapped south of the known bodies. The term episyenite, as used by Leroy (1978), is used to describe rocks that were desilicated and metasomatized and are composed predominantly of alkali-feldspar formed by hydrothermal fluids. These rocks now resemble syenites. The metasomatic episyenites in the Zuni Mountains are discontinuous tabular bodies, narrow lenses, and breccia zones along faults, fractures, and shear zones in Proterozoic Mt. Sedgwick granite and metatyholite (McLemore and McKee, 1989). The bodies are slightly radioactive (2-4 times background), suggesting anomalous concentrations of U and Th. The similarity between the metasomatic episyenites in the Zuni Mountains to those found in the Caballos Mountains, which contain anomalous concentrations of REE, Th, and U (McLemore, 1986), suggested that the Zuni Mountains metasomatic episyenites also could contain anomalous concentrations of REE, Th, and U (McLemore et al., 1988a, b; McLemore, 2012). However, selected samples of episyenites in the Zuni Mountains contain <16 ppm Th, <4 ppm U, <14 ppm Nb, <174 ppm Y, <200 ppm total REE (Table 4), which are uneconomic. A feldspar from the metasomatic episyenite has a 40Ar/39Ar age between 700 and 1180 Ma (Strickland et al., 2003). More research is underway on these deposits by the author.

**Limestone (crushed stone and high-calcium limestone)**

Limestone in the Permian San Andres Formation has been quarried throughout the Zuni Mountains for crushed stone for road construction and for stack scrubbers. The Escalante Plant used limestone from the El Morro quarries in the Zuni Mountains in the stack scrubber system (McLemore et al., 1986; Kottlowski and Armstrong, 1995). Only local areas are high enough in calcium (i.e., >95%) to be suitable for high-calcium end uses (McLemore et al., 1986; Kottlowski and Armstrong, 1995). A sample from Nutria, NM (west of Sawyer) contained 94.2% CaCO3, 1.04% CaO, 0.18% K2O, 0.78% Na2O, 0.16% Fe2O3, 0% Al2O3, 3.26% SiO2, 0.23% H2O and 0.01% S and is marginal for high-calcium limestone use (C.H. Maxwell and L.G. Nonini, written communication, 1977). The San Andres limestone is 30-100 meters thick and found along the northeast and southwest limbs of the Zuni Mountains (Goddard, 1966). Detailed sampling of the San Andres limestone is required to properly assess the potential for high-calcium limestone.

**Scoria**

Scoria is a highly vesicular, dark-colored volcanic rock of mafic composition (commonly basalt or basaltic andesite), generally found in volcanic cinder cones and on the surface of lava flows. In industrial usage, scoria is known as volcanic cinders. Scoria differs from pumice by a more mafic composition, darker color, higher density, coarser vesicles (gas cavities), more crystalline texture, and generally higher strength and ranges in color from black to brown to red (Clippinger, 1946). Uses of scoria include natural lightweight concrete aggregate, road surfacing aggregate, railroad ballast, and decorative stone for landscaping. Scoria used in lightweight aggregate provides less weight reduction accompanied by higher strength than pumice. The vesicular
nature of scoria provides excellent insulating properties for heat, cold, and sound and the glassy composition is fireproof. Scoria used in concrete, road surfacing, and ballast must meet the same specifications as any other aggregate material, including abrasion resistance, immersion disintegration, and aggregate degradation. Most scoria is friable and fragmental and can be ripped with little blasting, resulting in lower production costs than nonvesicular rock that must be crushed (Presley, 2006; Bush et al., 2006). Red scoria is locally desired for landscaping. The difference in color is a result of differences in magma temperatures in the vent that causes oxidation (Osburn, 1980, 1982).

Scoria was produced from several pits northeast and northwest of Bandera Crater, along U.S. Highway 53 in the southern Zuni Mountains (Fig. 2), and is used mostly for road material.

Iron deposits

Precambrian iron formations are stratigraphic units composed of layered, bedded rocks that contain 15% or more iron mixed with quartz, chert, and/or carbonate and are among the largest iron ore deposits mined for steel in the world (Bekker et al., 2010), although known deposits in New Mexico are quite small in comparison (McLemore, 2011b).

Several small deposits of iron oxides are found in the Zuni Mountains, but there has not been any reported production (Kelley, 1949; Harrer and Kelly, 1963; McLemore et al., 1986). The Smelter Gulch deposit in section 16, T11N, R12W (Fig. 2) consists of small veins (less than a meter wide) of limonite, hematite, and magnetite in a sheared and brecciated zone in Proterozoic rocks, and could be indicative of Precambrian iron formations at depth.

The Kirchan deposit in section 11, T13N, R15W (northern Zuni Mountains) consists of a hematite replacement in limestone of the Chupadera Formation (D.A. Carter and D.G. Ellingwood, unpublished report, NMBGMR files, 1960) and is only a few meters wide and a few meters long. Similar deposits are found in limestones throughout the Zuni Mountains. All of the iron deposits in the Zuni Mountains are small, isolated, and uneconomic.

Mica

Muscovite is common throughout the Proterozoic rocks in the Zuni Mountains district, especially in the Proterozoic schists. In 1961-1962, U.S. Sericite produced 10 short tons of sericite valued at $255 from an open pit in section 16, T11N, R12W, north of Diener (McLemore et al., 1986). Horst and Bhappu (1969) evaluated a separate sample of sericite from the Mount Sedgwick area and found it to be suitable for roofing-grade mica. However the mica from the Zuni Mountains typically is too dark and impure for most commercial applications, such as paint. Also, the mica deposits in the Zuni Mountains are small and discontinuous (lenses or pods few hundreds of meters in diameter). Mica is used as functional filler in building materials and in the manufacture of numerous industrial and consumer products such as joint compound, paints, automotive sound deadening materials, thermoplastics, coatings, and even cosmetics because of its unique physical characteristics, including color, flexibility, durability, thermal properties, and weight.

Uranium in granitic rocks

Brookins and Rautman (1978) and Brookins (1982) examined the Proterozoic granitic rocks to determine if these rocks would constitute a large in situ uranium deposit and if there could be any geothermal potential. Their data does not support any uranium or thorium potential. The average uranium content of 57 samples is 3.75 ppm U (range 1.82-7.37 ppm U) and the average thorium content of 25 samples is 17.5 ppm Th (range 4.07-41.76 ppm Th). The geothermal potential is beyond the scope of this paper.

Volcanogenic massive-sulfide deposits

Volcanogenic massive-sulfide (VMS) deposits are volcanogenic, polymetallic, stratabound deposits formed by stratiform accumulations of sulfide minerals that precipitated from circulating hydrothermal fluids associated with submarine volcanism on and below the seafloor (Sangster and Scott, 1976; Franklin et al., 2005; Barrie and Hannington, 1999; Stix et al., 2003), and consists of at least 50% sulfides, generally copper, lead, and zinc with some precious metals (Sangster and Scott, 1976; Franklin et al., 2005). In New Mexico, VMS deposits are rare and are restricted to Precambrian greenstone terrains; production has occurred only from the Pecos mine in the Willow Creek district in Santa Fe County (Robertson et al., 1986; McLemore, 2001). The mineralized metamorphosed volcaniclastic rocks in the Zuni Mountains district are suggestive of VMS deposits at depth (Robertson et al., 1986), but detailed mapping, geochemical analyses and drilling should be performed to examine this similarity and determine genesis of the deposits.

Proterozoic syenite/gabbro-hosted platinum group elements (PGE) deposits

Platinum group elements (PGE) typically occur in economic concentrations in ultramafic and associated mafic rocks (Eckstrand, 1984; Cox and Singer, 1986; Macdonald, 1988). PGE includes platinum, palladium, osmium, ruthenium, iridium, and rhodium. The average concentration of platinum in unmineralized mafic and ultramafic rocks is approximately 10 ppb, ranging from 0.1 to 500 ppb (Macdonald, 1988). Combined PGE content of most ore deposits ranges from 1 to 20 ppm (Eckstrand, 1984). PGE ore occurs as conformable layers or lenses near the base of layered ultramafic and mafic complexes, thin stratiform layers, and irregular pipe-like bodies within ultramafic and mafic complexes. Although, none of these features are found in the Zuni dark syenite and amphibolite, which are fine- to medium-grained and massive, the Proterozoic dark syenite and amphibolite bodies and gold-silver veins in the Zuni Mountains should be geochemically evaluated for their PGE potential. Proterozoic amphibolites (gabbro) from the Caballo Mountains contained 1-3 ppb Pt and 1-2 ppb Pd (McLemore et al., 2012). Similar Proterozoic gabbro/amphibolite from the Sacramento Mountains contained 1 ppb
Pt and 66 ppb Pd (New Mexico Bureau of Mines and Mineral Resources et al., 1998). There are no PGE proved reserves or ore deposits known in New Mexico that contain high enough concentrations of significant volume to be mined economically for PGE, including the mafic rocks in the Zuni Mountains (McLemore et al., 1989).

CONCLUDING REMARKS

There is some economic potential for gold, silver, and possibly copper in the veins and replacement deposits in Proterozoic Zuni and Mt. Sedgwick granites and metarhyolite and prospecting is underway by several individuals. The Proterozoic darksyenite and amphibolite bodies and gold-silver veins in the Zuni Mountains should be geochemically evaluated for their PGE potential. It is unlikely that the stratabound, sedimentary-copper deposits or fluorite veins have any remaining significant economic potential, because the highest grades have been mined and remaining deposits appear to be discontinuous and low grade. The REE-Th-U metasomatic bodies and iron deposits also have low economic potential because of low grade and small size. The Zuni Mountains continues to have high economic potential for high-calcium limestone and volcanic cinders (scoria). The veins and replacement deposits appear to be Proterozoic in age and are associated with the Zuni and Mt. Sedgwick granites and metarhyolite, while the late Proterozoic episyenites appear to be associated with the Mt. Sedgwick granite. The fluorite veins are much younger (younger than the Permain Abo Formation) and perhaps associated with other Rio Grande rift barite-fluorite deposits in New Mexico.

FUTURE WORK

One of the most important future research activities is detailed mapping, geochemical analysis, and precise dating of the various granitic rocks, veins, and shear zones to determine the relationship between the different granites, deformation, and vein mineralization. Fluid inclusion and isotopic studies are required to constrain temperatures of formation and other geochemical conditions of mineralization of the fluorite veins and of the fluorites found in the Todilto limestone deposits to determine their origin. Detailed mapping of the Proterozoic terrain west of Goddard’s (1966) map also is required.

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