Potential for Laramide porphyry copper deposits in southwestern New Mexico

Virginia T. McLemore

in:

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POTENTIAL FOR LARAMIDE PORPHYRY COPPER DEPOSITS IN SOUTHWESTERN NEW MEXICO

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ABSTRACT — New Mexico lies at the eastern edge of one of the world’s great metal-bearing provinces, where there are eight known Laramide porphyry copper deposits in New Mexico: Santa Rita, Tyrone (Burro Mountains district), Little Rock (Burro Mountains district), Copper Flat (Hillsboro district), Hanover-Hermosa Mountain (Fierro-Hanover district), Lone Mountain, Gold Lake (White Signal district), and McGhee Peak (Peloncillo Mountains). Additional Laramide skarn and polymetallic vein deposits in New Mexico formed in Paleozoic limestones and dolomitic limestones adjacent to calc-alkaline plutonic rocks emplaced during the Laramide compressional event; most of these areas have potential for additional porphyry copper deposits.

INTRODUCTION

New Mexico lies at the eastern edge of one of the world’s great metal-bearing provinces. Copper is particularly important with large, and in some cases, world-class deposits in Arizona, New Mexico, Utah, Nevada, and Sonora (Fig. 1). Gold and silver deposits are abundant in Nevada, and to a lesser extent, throughout the Southwest. Some of the largest molybdenum deposits in the world occur in central Colorado and northern New Mexico. Numerous geologists have examined the geology and mineral resource potential of these porphyry deposits over the last 50 years or more (Titley, 1982, 1997, 2001). Copper production from New Mexico has been significant (Table 1). However, most of the recent published reports emphasize the potential in Arizona only, or were not written in context of today’s current increase in demand for copper, as reflected by the recent increase in copper price and production (Table 1). Several porphyry copper deposits and other areas in New Mexico are currently being examined by mining and exploration companies for potential development. Additional potential exists in other districts in New Mexico.

The purpose of this paper is to provide an updated framework for exploration for porphyry copper deposits in southwestern New Mexico by identifying 1) the geologic criteria favorable for porphyry deposits, 2) areas of Laramide plutons in New Mexico, 3) known porphyry copper deposits in New Mexico, and 4) other mining districts with Laramide-age mineral deposits. This paper focuses on the Laramide-age rocks (40-80 Ma in age; Barton, 1996) in New Mexico and not on the younger mid-Tertiary deposits in central and northern New Mexico that also include some smaller porphyry copper deposits (although not all of the deposits discussed here have been dated). This paper is an update of the work by North and McLemore (1986) and McLemore (2001), who summarize the various gold and silver mineral deposits, including porphyry copper deposits in the state.

WHAT ARE PORPHYRY COPPER DEPOSITS?

Porphyry copper (molybdenum, gold) deposits are large, low-grade (<0.8% Cu) deposits that contain disseminated, breccias and stockwork veinlets of copper and molybdenum sulfides associated with porphyritic intrusions (Schmitt, 1966; Lowell and Guilbert, 1970; Kesler, 1973; Lowell, 1974; Titley and Beane, 1981; Cox and Singer, 1986; Seedorff et al., 2005). These copper deposits typically are found in and around relatively small porphyritic diorite, granodiorite, monzonite, and quartz monzonite plutons that were intruded at relatively high crustal levels, commonly within 1-6 km of the surface, and are surrounded by crudely concentric zones of hydrothermal alteration (Lowell and Guilbert, 1970; Seedorff et al., 2005). Volatiles, primarily steam and other gases, build up within the magma and ultimately there is enough pressure to fracture the solidified intrusive porphyry and adjacent host rocks above the magma chamber. Hydrothermal solutions are released through these fractures and react with the host rocks, altering them in a characteristic, concentric zonation. The outer hydrothermal zone (referred to as propylitic alteration) is typically characterized by epidote-chlorite-pyrite mineral assemblages. A quartz-sericite-pyrite (QSP) mineral assemblage alteration zone typically is found closer to the center and can overprint other zones. A central potassic zone of biotite-orthoclase-chalcopyrite mineral assemblage is commonly associated with most of the ore. This hydrothermal alteration can include numerous additional types of mineral assemblages that commonly overlap (Seedorff et al., 2005). However, in some deposits, the concen-
tronic zoning is destroyed and replaced by younger quartz-sericite alteration, such as at the Chino deposit.

Copper minerals, to varying degrees, are deposited as a part of this interaction between hydrothermal solutions along fractures in solid rock. The copper minerals are found as disseminations along thin fractures, zones of brecciation, and within larger veins, called stockwork veins. Typically, these deposits are very large, some in excess of a billion tons of mineralized rock. Copper grade varies from less than 0.10% copper to over 1% copper, with 2-5% pyrite and varying amounts of gold, silver, molybdenum, uranium, and other metals and nonmetals. The important deposits in New Mexico at Chino and Tyrone had relatively low copper grade after this initial mineralization, but the grade was enhanced through supergene enrichment. Low concentrations of silver and gold are present in most deposits and can be recovered as byproducts by conventional milling techniques. Skarns and epithermal-vein deposits locally are spatially associated with porphyry copper deposits. A variety of different types of porphyry copper deposits are found as defined by the predominant metal content and composition of the porphyritic intrusions (Cox and Singer, 1986, 1992; Seedorff et al., 2005).

Supergene enrichment is a weathering process that occurs when rocks with high pyrite content come into contact with water in an oxidizing environment (Anderson, 1982; Chávez, 2000; Sillitoe, 2005). During this process, water, oxygen, and pyrite react to form sulfuric acid. This acid naturally leaches copper from chalcopyrite (CuFeS₂) and other copper-bearing minerals, putting copper into solution. Copper will stay in solution as long as the solution is acidic and oxidized. However, when the acidic solution is neutralized or evolves to reducing conditions, there is no longer free oxygen in the solution and copper is no longer soluble. In natural systems, conditions typically will become reducing just beneath the water table. When this happens, the copper in solution easily combines with reduced sulfur. This reduced sulfur is available in pyrite and the copper in solution will replace first chalcopyrite and then pyrite (FeS₂) with chalcocite (Cu₂S). This process preserves copper through chemical dissolution and subsequent enrichment rather than the loss of the metal through the erosion of copper-bearing rock by mechanical means. Without this process, deposits such as Tyrone would never have been economic, and the ore zone at Chino would be much smaller.

Skarn deposits of copper and other metals can form near the contact between hot magma intruded into limestone and other carbonate-bearing rocks. Skarn is a term for rocks that can have diverse origins, but with similar mineralogy, typically calcite-bearing variety of garnet and pyroxene (Einaudi et al., 1981; Einaudi and Burt, 1982). Whereas these types of deposits can form in a number of geological environments, they are most common in the southwestern U.S. in contact metamorphic aureoles, where hot, igneous rocks have intruded calcareous host rocks (Einaudi, 1982). Hydrothermal fluids exsolved from the igneous rocks metasomatize the calcareous wall rocks, converting them to garnet and pyroxene. Magnetite commonly also is present, especially in magnesian (dolomitic) host rocks. Although, chalcopyrite (CuFeS₂) and sphalerite (ZnS) are found in relatively small amounts, they are important ore minerals in this type of deposit. Polymetallic veins also are associated with some porphyry copper deposits, such as the Copper Flat deposit, Hillsboro district.

### GEOLOGIC CRITERIA FOR EXPLORATION OF PORPHYRY COPPER DEPOSITS

#### Tectonic Setting

Porphyry copper deposits are found along the margins of volcanic arcs in subduction zones (Sillitoe, 1972; Seedorff et al., 2005). Since Late Cretaceous time, southwestern United States and northern Mexico have undergone almost constant tectonic and volcanic activity related to motions of the lithospheric plates off the coast of present California. Laramide compressional deformation from Late Cretaceous to early Tertiary formed a series of northeast-to northwest-trending uplifts and broad shallow basins in southern New Mexico and Arizona (Drewes, 1991; Seager et al., 1997). The southwestern U.S. porphyry copper belt (Fig. 1) is generally attributed to Laramide (40-80 Ma in age; Barton, 1996; Keith and Swan, 1996) magmatism and compressional deformation, which extended as far eastward as south-central New Mexico, as evidenced by the Copper Flat igneous complex and porphyry copper deposit near Hillsboro (McLemore et al., 1999, 2000b) and volcanic-clast conglomerates in the McRae and Love Ranch Formations in the Jornada del Muerto near Truth or Consequences (Chapman-Fahy, 1996; Seager et al., 1997).

Laramide deformation and magmatic activity extended as far southeast as the Red Hills intrusion in Trans-Pecos Texas (Fig. 1; Gilmer et al., 2003). The structural style of Laramide compressional deformation and magmatism is typically attributed to the low-angle subduction of the Farallon plate, which resulted in the locus of magmatic activity shifting eastward with time (Coney and Reynolds, 1977; Damon et al., 1983; McMillan et al., 2000). However, Duecker et al. (2001) suggests from teleseismic images of the upper mantle that movement of the North American plate sliding over the mantle could produce convection in the asthenosphere. The convection was localized by deep-seated Proterozoic basement structures and formed crustal melts, resulting in the Laramide intrusions common in the southwestern U.S.
Newly compiled magnetic and gravity maps have resulted in new interpretations of the tectonic setting of New Mexico and adjacent areas. Linear geophysical features appear to correlate with the alignment of mineral deposits in western U.S. (Hildenbrand et al., 2000; Kucks et al., 2001; Sims et al., 2002). Sims et al. (2002) define the New Mexico structure zone as a northeast-trending zone that is 250 km wide and roughly parallels the Colorado mineral belt. Although, most of the mineral deposits within this zone are mid-Tertiary in age, Sims et al. (2002) recognize that the southern Santa Rita zone is dominated by Late Cretaceous porphyry copper deposits in New Mexico and Arizona. Furthermore, Sims et al. (2002) showed that north-east trending magnetic anomalies are aligned along the northeast-trending New Mexico structural zone, which is most likely controlled by Proterozoic basement structures. These hypotheses dovetail nicely with the views of Titley (2001), suggesting that metals in the porphyry copper deposits are derived from Proterozoic basement sources.

**Composition of Associated Plutons**

Compositions of the Laramide intrusive rocks vary regionally and with time from early mafic and silica-poor dikes and monzonites to more siliceous and felsic monzogranites, quartz diorites, and monzogranites (Keith, 1986). They are typically calc-alkaline to mildly alkaline. Laramide volcanic rocks in New Mexico have arc-like chemical characteristics (Chapman-Fahey, 1996; Young, 1996; McLemore et al., 1999) and are consistent with generation by subduction processes triggered by dehydration of the subducted Farallon plate.

McMillan et al. (2000) documents a shift in magma source regions about the end of the Laramide from a subcontinental lithosphere source with contamination from distinct upper- and lower-crustal sources during the Laramide (at about 45 Ma) to an asthenosphere source with insignificant additions from the continental crust (late Tertiary). Lead isotope data from the Copper Flat deposit at Hillsboro indicates that the Copper Flat igneous system is derived from a similar source as the other porphyry copper deposits in New Mexico and the source is distinctly different from the younger mid-Tertiary mineral deposits (Stacey and Hedlund, 1983). The lead is relatively nonradiogenic, suggesting a lower crust or upper mantle source, which is consistent with the geochemical composition of the Copper Flat igneous rocks (McLemore et al., 1999, 2000b).

**KNOWN DEPOSITS IN NEW MEXICO**

**Porphyry copper, copper-molybdenum (= gold) deposits**

There are eight known Laramide porphyry copper deposits in New Mexico (Fig. 1; Table 2): Santa Rita, Tyrone (Burro Mountains district), Little Rock (Burro Mountains district), Copper Flat (Hillsboro district), Hanover-Hermosa Mountain (Fierro-Hanover district), Lone Mountain, Gold Lake (White Signal district), and McGhee Peak (Peloncillo Mountains). Many other areas in the state have potential for porphyry copper deposits, as discussed below.

The largest porphyry copper deposit in New Mexico is the Chino deposit in the Santa Rita district, where copper sulfides occur in the upper part of a highly fractured quartz-monzodiorite to granodiorite and adjacent metamorphosed sedimentary rocks. Liqueous activity at Chino began about 60-59 Ma with the intrusion of dioritic to quartz diorite sills into the Precambrian basement. The intrusion of multiple stages of the quartz-monzodiorite to granodiorite dikes and stocks followed (Rose and Baltose, 1966; Audéat and Petteke, 2006). Reported ages of the stock range from 64.6 to 59.7 Ma (K-Ar, biotite; Schwartz, 1959; McDowell, 1971), but unpublished 40Ar/39Ar data by NMBGMR indicates the age of the stock is slightly younger, at 58.6 Ma (Table 2). The stock had a high oxygen fugacity and was enriched in sulfur (Audéat and Petteke, 2006). Most of the mineralization occurred shortly after intrusion of the dikes and stock. Potassic, phyllic, argillic, and propylitic alteration zones are present, but are not everywhere concentric (Nielsen, 1968, 1970). Several periods of supergene enrichment have further concentrated the ore (Cook, 1994; Cook and Porter, 2005). Adjacent copper skarns are becoming increasingly more important economically. The mine has produced more than 5.9 million tons Cu, 500,000 oz Au, and 5.36 million oz Ag plus some molybdenum and iron ore from 1911 to 2006 (Long, 1995; McLemore et al., 1996; V.T. McLemore, this guidebook). Estimated milling reserves at the Chino mine in December 2006 are 53.9 million tons of 0.68% copper and 0.03% molybdenum, and estimated leaching reserves are 120.5 million tons of 0.43% Cu (Phelps Dodge Corporation, 2007). Accordingly, the Chino mine in the Santa Rita district is the largest copper and gold district in New Mexico and ranked ninth in silver production in terms of total metal production.

The Tyrone porphyry copper deposit in the Burro Mountains district occurs within a quartz-monzonite laccolith and adjacent Proterozoic rocks (Kolessar, 1970, 1982). The ore contains minor amounts of gold and silver, especially in the enriched zones. The age of the Tyrone stock is 54.5 Ma (NMBGMR unpublished data). At least two cycles of supergene enrichment have concentrated the ore at 16.2-19.4 Ma and 4.6-8.7 Ma (Cook, 1994; Mach, 2004). Approximately 300 million short tons of ore grading 0.81% Cu were processed by the concentrator at Tyrone from 1969 to 1992. Approximately 425 million short tons of ore grading 0.35% Cu have been leached. In addition, silver and gold were recovered from 1903 to 1992. The mine has produced more than 5.3 million tons Cu, 500,000 oz Au, and 5.36 million oz Ag, plus some molybdenum and iron ore from 1911 to 2006 (Long, 1995; McLemore et al., 1996; V.T. McLemore, this guidebook).

The Little Rock deposit (Ohio mine) is a historic open pit mine near the Tyrone mine that was mined and leached in the late 1960s and early 1970s. In 1970-1972, U.S. Natural Resources, Inc. removed and stockpiled approximately 1 million tons of leach material. If it goes into production, Freeport McMoRan Inc. will extract copper from the existing open pit and leach piles.

The Copper Flat deposit in the Hillsboro district consists of copper, gold, and silver disseminated in a quartz-monzonite stock and in quartz veins (Kuellmer, 1955; Dunn, 1982, 1984; Hedlund, 1985b; McLemore et al., 1999, 2000b). Unlike the Santa Rita and Tyrone deposits, there is no significant supergene enrichment.
TABLE 2. Laramide porphyry copper deposits in southwestern New Mexico. References for age determinations are in Table 3. * reported reserves are recoverable copper reserves as reported by the company (not always 43-101 compliant). ** skarn or carbonate-hosted replacement deposits also present. Mine identification number is from the New Mexico Mines Database (McLemore et al., 2005a, b).

<table>
<thead>
<tr>
<th>Mine Identification Number</th>
<th>Porphyry Deposits</th>
<th>District</th>
<th>County</th>
<th>Latitude (decimal degrees)</th>
<th>Longitude (decimal degrees)</th>
<th>Year of Discovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>NMGR0029</td>
<td>Chino**</td>
<td>Santa Rita</td>
<td>Grant</td>
<td>32.791667</td>
<td>108.06667</td>
<td>1909</td>
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<tr>
<td>NMGR0084</td>
<td>Tyrone</td>
<td>Burro Mountains</td>
<td>Grant</td>
<td>32.643889</td>
<td>108.36722</td>
<td>1903</td>
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<td>NMSI0610</td>
<td>Copper Flat**</td>
<td>Hillsboro</td>
<td>Sierra</td>
<td>32.806667</td>
<td>108.12222</td>
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<td>NMGR0478</td>
<td>Gold Lake</td>
<td>Grant</td>
<td>Grant</td>
<td>32.55270</td>
<td>108.32957</td>
<td>1970s</td>
</tr>
<tr>
<td>NMGR0208</td>
<td>Hanover Mountain</td>
<td>Fierro-Hanover</td>
<td>Grant</td>
<td>32.833</td>
<td>108.083</td>
<td>1970s</td>
</tr>
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<td>NMGR0409</td>
<td>Lone Mountain**</td>
<td>Lone Mountain</td>
<td>Grant</td>
<td>32.718056</td>
<td>108.17667</td>
<td>1970s</td>
</tr>
<tr>
<td>NMGR0160</td>
<td>Little Rock (Ohio)</td>
<td>Burro Mountains</td>
<td>Grant</td>
<td>32.646698</td>
<td>108.40675</td>
<td>1070s</td>
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<tr>
<td>NMMH0327</td>
<td>Steins</td>
<td>McGhee Peak</td>
<td>Hidalgo</td>
<td>32.186111</td>
<td>109.02083</td>
<td>1970s</td>
</tr>
</tbody>
</table>

zone at Copper Flat. The Copper Flat porphyry is dated at 75 Ma (McLemore et al., 1999, 2000b). Approximately 7 million pounds of copper was produced in 1982 prior to closure of the mine. Reserves are estimated at 56.5 million tons of ore at grades of 0.432% Cu, 0.004 oz/ton Au, 0.064 oz/ton Ag, and 0.014% Mo (Alta Gold Co., Form 10K, December 13, 1997).

Supergene-enriched copper zones are found near the Continental (Cobre) skarn deposits, at Hanover and Hermosa Mountains in the Fierro-Hanover district (Hillesland et al., 1994, 1995). The tabular zones contain fine-grained calc-silicate along fractures within the Colorado Formation (Cretaceous) and are 15-152 m thick. Age dates of intrusive rocks in the Fierro-Hanover district range from 70.4 to 57.1 Ma (K-Ar, McDowell, 1971). A granodiorite porphyry sample collected from the Continental pit was dated more precisely as 57.55 Ma (40Ar/39Ar, McLemore et al., 1995). Drilling in the 1970s and 1990s has delineated 80 million short tons of geologic resources of 0.38% Cu at Hanover Mountain, northeast of the Continental mine (Hillesland et al., 1994, 1995). The deposit at Hermosa Mountain, southwest of the Continental mine, has not been characterized. Drilling in 1975-1989 and in 2006-2007 northwest of the carbonate-hosted silver deposits in Lone Mountain delineated a weakly mineralized quartz latite to quartz monzonite stock surrounded by an upper copper oxide zone and two deeper, stratiform, copper and lead-zinc skarn bodies, ranging in depth from 30 to 915 m (Moore and Moran, 2006). Copper oxide horizons are approximately 30 m thick at grades of 0.1% to 0.2% Cu, with rare intercepts to 0.6%. Skarn grades in the Lake Valley horizon, while variable, typically assay 1.5 to 3.0% Cu, 3 to 5% Zn, 1.0 to 2.0% Pb, 0.01 to 0.02 oz/ton Au, and 1.0 to 3.0 oz/ton Ag. The intrusions have been dated at 51.5-50.6 Ma (P. B. Hubbard et al., 1987). The deposit at Lone Mountain, northeast of the Continental mine, has not been characterized. The deposit at Lone Mountain, northeast of the Continental mine, has not been characterized.

Laramide copper and lead/zinc skarn deposits

Laramide skarn deposits in New Mexico are contact-metasomatic deposits that formed in Paleozoic limestones and dolomitic limestones adjacent to calc-alkaline plutonic rocks emplaced during the Laramide compressional event (McLemore and Lueth, 1996). Three types of Laramide skarns occur in southern New Mexico: copper (typically associated with porphyry copper deposits; Einaudi et al., 1981; Einaudi, 1982; Lueth, 1984), lead-zinc (proximal and vein-type deposits; Einaudi et al., 1981; Meijer, 1987; Turner and Bowman, 1993; Lueth, 1996), and iron skarns (Einaudi et al., 1981; Lueth, 1984, 1996). These skarns, except the iron type, are either copper- or zinc-rich with lead and silver produced as by-products. The largest lead-zinc skarns are in the Fierro-Hanover and Piños Altos districts. Laramide iron skarns are found throughout southwestern New Mexico (Fig. 2, Table 3).

Copper skarns are intimately associated with Laramide plutons (e.g. Santa Rita, Piños Altos), whereas the lead-zinc skarns are typically distal from igneous rocks. Some lead-zinc skarns occur
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along faults distal from intrusive rocks (e.g., Groundhog, southwestern deposits at Piños Altos, Eureka). The Laramide skarns in New Mexico formed from variable, but higher temperature and saline fluids compared to carbonate-hosted lead-zinc replacement deposits in New Mexico (McLemore and Lueth, 1996). Most deposits probably formed from mixing of meteoric and magmatic fluids (Ahmad and Rose, 1980; Abramson, 1981; Lueth, 1984; Turner and Bowman, 1993). Grades and tonnages vary (McLemore and Lueth, 1996). District-scale zoning of metals is common in most areas with copper adjacent to the intrusive rocks grading outwards to zinc-lead, lead-zinc, lead-silver, and locally, lead-silver-manganese (Meinert, 1987; McLemore and Lueth, 1996).

Polymetallic vein deposits

Polymetallic vein deposits of probable Laramide age (Late Cretaceous-early Eocene, 75-40 Ma) occur in a number of districts in New Mexico (Table 2, Fig. 2). These vein deposits exhibit variations in textures and mineralogy, but are similar in form and age. In some districts with Laramide polymetallic vein deposits, Laramide skarns are locally present and economically important. Lindgren (1933) classified these veins as polymetallic veins and Cox and Singer (1986) classified them as mesothermal veins. The most important districts in New Mexico are Hillsboro, Piños Altos, Bayard, and Lordsburg.

The deposits at Hillsboro provide a good model for the description of Laramide vein deposits that are associated with porphyry copper deposits. Polymetallic veins, many of which are hosted by latite dikes, extend radially outward from the Copper Flat porphyry copper deposit. Distal carbonate-hosted replacement deposits containing Ag, Pb, Mn, V, Mo, Zn are found in the southern and northern parts of the district. Geological, geochronological, and geochemical evidence suggests that the mineral deposits found in the Hillsboro district are zonally related and were formed by large, convective magmatic-hydrothermal
<table>
<thead>
<tr>
<th>District number, District</th>
<th>Year of Discovery</th>
<th>Estimated Cumulative Production</th>
<th>Type of deposits</th>
<th>Pluton and age in million years (dating method)</th>
<th>Reference for isotopic ages</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIS043 Bayard</td>
<td>1858</td>
<td>$60,000,000</td>
<td>Laramide vein, placer Au</td>
<td>Twin Peaks monzonite, 72.5 (K/Ar)</td>
<td>Hedlund (1978)</td>
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<tr>
<td>DIS044 Black Hawk</td>
<td>1881</td>
<td>$1,000,000</td>
<td>Laramide vein, placer W</td>
<td></td>
<td></td>
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<tr>
<td>DIS045 Bound Ranch</td>
<td></td>
<td>$97,000</td>
<td>Laramide vein, fluorite veins</td>
<td></td>
<td></td>
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<tr>
<td>DIS046 Burro Mountains</td>
<td>1871</td>
<td>$2,000,000,000</td>
<td>Laramide vein, placer Au, W veins, porphyry Cu</td>
<td>Tyrore stock, 54.5 ($^{40}$Ar/$^{39}$Ar)</td>
<td>NMBGMR unpublished data</td>
</tr>
<tr>
<td>DIS049 Carpenter</td>
<td>1891</td>
<td>$1,360,000</td>
<td>Cu-Pb-Zn skarn, carbonate-hosted Pb-Zn (Cu, Ag)</td>
<td>Copper Flat stock, 55.4 (K/Ar)</td>
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<td>DIS050 Chloride Flat</td>
<td>1870</td>
<td>$13,000,000</td>
<td>Carbonate-hosted Ag-Mn(Pb) replacement</td>
<td>Hidalgo Formation (basaltic andesite), 71.4 ($^{40}$Ar/$^{39}$Ar)</td>
<td>Lawton et al. (1993)</td>
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<td>DIS053 Eureka</td>
<td>1871</td>
<td>$1,590,000</td>
<td>Laramide vein, Cu-Pb-Zn skarn, placer Au</td>
<td>汉诺瓦-费耶罗 (赫莫萨) 炉, 57.55 ($^{40}$Ar/$^{39}$Ar)</td>
<td>McLemore et al. (1996)</td>
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<td>DIS054 Fierro-Hanover</td>
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<td>DIS056 Georgetown</td>
<td>1866</td>
<td>$3,500,000</td>
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<td>Granodiorite porphyry dikes, 71 ($^{40}$Ar/$^{39}$Ar)</td>
<td>McLemore (1998)</td>
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<td>DIS059 Lone Mountain</td>
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<td>Laramide skarn, carbonate-hosted Ag-Mn (Pb) replacement</td>
<td>Lone Mountain stock, 51.5 (K/Ar)</td>
<td>P. B. Hubbard and P. G. Dunn, unpublished report, 1983</td>
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<td>DIS060 Malone</td>
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<td>DIS062 Piños Altos</td>
<td>1800</td>
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<tr>
<td>DIS065 Santa Rita</td>
<td>1800</td>
<td>$2,000,000,000</td>
<td>Porphyry Cu, Laramide skarn</td>
<td>Santa Rita stock, 58.3 ($^{40}$Ar/$^{39}$Ar)</td>
<td>NMBGMR unpublished data</td>
</tr>
<tr>
<td>DIS067 Telegraph</td>
<td>1881</td>
<td>$482,000</td>
<td>Laramide vein</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DIS068 White Signal</td>
<td>1880</td>
<td>$165,000</td>
<td>Laramide vein, placer Au</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DIS075 Apache No. 2</td>
<td>1879</td>
<td>$107,000</td>
<td>Laramide vein, carbonate-hosted Pb-Zn (Cu, Ag) replacement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DIS076 Big Hatchet Mountains</td>
<td>1917</td>
<td>$2,000</td>
<td>Carbonate-hosted Pb-Zn (Cu, Ag) replacement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DIS077 Fremont</td>
<td>1860</td>
<td>$17,000</td>
<td>Carbonate-hosted Pb-Zn (Cu, Ag) replacement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DIS080 Granite Gap</td>
<td>1875</td>
<td>$1,950,000</td>
<td>Carbonate-hosted Pb-Zn (Cu, Ag) replacement, Cu-Pb-Zn skarn</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DIS082 Lordsburg</td>
<td>1854</td>
<td>$60,000,000</td>
<td>Laramide vein, placer Au</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DIS083 McGhee Peak</td>
<td>1894</td>
<td>$1,171,500</td>
<td>Porphyry Cu, Laramide vein, Cu-Pb-Zn skarn</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Late Cretaceous-early Tertiary mineral deposits in southwestern New Mexico. District number is from the New Mexico Mines Database (McLemore et al., 2005a, b). Names of mining districts are after File and Nothrop (1966) wherever practical, but many districts have been combined and added. Estimated value of production is in original cumulative dollars and includes all commodities in the district. Production data compiled from Lindgren et al. (1910), Anderson (1957), U.S. Geological Survey (1902-1927), U.S Bureau of Mines Mineral Yearbooks (1927-1994), Energy, Minerals and Natural Resources Department (1986-2007). Types of deposits are after North and McLemore (1986) and McLemore (2001).
systems related to the Copper Flat volcanic/intrusive complex (McLemore et al, 1999, 2000b).

Many of these veins display multiple episodes of opening and mineralization. Proterozoic rocks are a common host rock, although Cretaceous volcanic and plutonic rocks also are host rocks in some districts (i.e. Lordsburg, Hillsboro). Paleozoic and Cretaceous sedimentary rocks host the veins in the Bayard district. Laramide veins were typically worked for both base and precious metals and locally contain U, W, Te, and Be. Mineral and metal associations are diverse, even within a district. Despite these differences, these deposits are grouped together because of similar form, association with Laramide intrusive rocks, and perceived origin at moderate to high temperatures and moderate depths.

SUMMARY OF MINERAL RESOURCE POTENTIAL FOR PORPHYRY COPPER DEPOSITS IN NEW MEXICO

Many areas in New Mexico have potential for porphyry copper deposits, but more exploration is needed to verify their occurrence. Development of these deposits will depend upon the copper market. Exploration has occurred north of the Lordsburg and Eureka districts for porphyry copper deposits, but the results are unknown. Both districts are known for Laramide vein deposits as well as alteration suggestive of porphyry copper mineralization. The potential for discovering additional skarns in the districts in southwestern New Mexico is excellent. Cobre Mining Co. reported reserves at the Continental mine in the Fierro-Hanover district of over 10 million short tons of 0.92% Cu (Hillesland et al., 1994, 1995). Significant copper skarns also are mined at the Chino mine in the Santa Rita district (Nielsen, 1968, 1970; McLemore, 1996). The ores from Laramide veins have potential for siliceous flux for copper smelters. Nearly two million tons of mineralized siliceous flux have been shipped from veins in the Lordsburg district. Early exploration is occurring in several other districts in southwestern New Mexico. Some of the more favorable areas are associated with Laramide vein and Laramide skarn deposits (Table 3).

ACKNOWLEDGMENTS

This paper is part of an on-going study of the mineral resources of New Mexico at NMBGMR, Peter Scholle, Director and State Geologist. This manuscript was reviewed by Eric Seedorff, Miles Silberman, and Tom Gibson, and their comments were helpful and greatly appreciated. I would also like to thank some of my former students (Daniel Hack, Eric Munroe, Kelly Donahue, Steve Raugst) who studied in detail some of these porphyry copper and carbonate-hosted deposits and compiled some of the data presented here.

REFERENCES


TABLE 3. Continued.

<table>
<thead>
<tr>
<th>District number, District</th>
<th>Year of Discovery</th>
<th>Estimated Cumulative Production</th>
<th>Type of Deposits</th>
<th>Pluton and age in million years (dating method)</th>
<th>Reference for isotopic dating</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIS088 Sylvanite</td>
<td>1871</td>
<td>$315,000</td>
<td>Laramide vein, Cu-Pb-Zn skarn, placer Au</td>
<td>Hidalgo Formation (basaltic andesite), 71.4 ($^{40}Ar/^{39}Ar$)</td>
<td>McLemore et al. (1993)</td>
</tr>
<tr>
<td>DIS102 Camel Mountain - Eagle Nest</td>
<td>None</td>
<td>Carbonate-hosted Pb-Zn (Cu, Ag) replacement, Cu-Pb-Zn skarn</td>
<td>Diorite, 86.3 ($^{40}Ar/^{39}Ar$)</td>
<td>McLemore et al. (2001)</td>
<td></td>
</tr>
<tr>
<td>DIS191 Chloride</td>
<td>1879</td>
<td>$20,000,000</td>
<td>Laramide skarn, placer Au</td>
<td>Copper Flat, 75 ($^{40}Ar/^{39}Ar$)</td>
<td>McLemore et al. (1999, 2000b)</td>
</tr>
<tr>
<td>DIS192 Cuchillo</td>
<td>1879</td>
<td>$205,000</td>
<td>Cu-Pb-Zn skarn</td>
<td>nepheline monzodiorite, 59.9±2.4 Ma (K–Ar, nepheline)</td>
<td>Lamarre (1974)</td>
</tr>
<tr>
<td>DIS197 Hillsboro</td>
<td>1877</td>
<td>$8,500,000</td>
<td>Porphyry Cu, Laramide skarn, Laramide veins</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DIS254 Salado Mountains</td>
<td>1970</td>
<td>None</td>
<td>Fluorite veins</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Many areas in New Mexico have potential for porphyry copper deposits, but more exploration is needed to verify their occurrence. Development of these deposits will depend upon the copper market. Exploration has occurred north of the Lordsburg and Eureka districts for porphyry copper deposits, but the results are unknown. Both districts are known for Laramide vein deposits as well as alteration suggestive of porphyry copper mineralization. The potential for discovering additional skarns in the districts in southwestern New Mexico is excellent. Cobre Mining Co. reported reserves at the Continental mine in the Fiero-Hanover district of over 10 million short tons of 0.92% Cu (Hillesland et al., 1994, 1995). Significant copper skarns also are mined at the Chino mine in the Santa Rita district (Nielsen, 1968, 1970; McLemore, 1996). The ores from Laramide veins have potential for siliceous flux for copper smelters. Nearly two million tons of mineralized siliceous flux have been shipped from veins in the Lordsburg district. Early exploration is occurring in several other districts in southwestern New Mexico. Some of the more favorable areas are associated with Laramide vein and Laramide skarn deposits (Table 3).
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Nielsen, R.L., 1968, Hypogene texture and mineral zoning in a copper-bearing
McLemore, V. T., Peters, L. and Heizler, M. T., 2000a, Geochemistry and 