Preprint 15-084

MINERAL DEPOSITS ASSOCIATED WITH TERTIARY ALKALINE IGNEOUS ROCKS IN NEW MEXICO

V. T. McLemore, New Mexico Bureau of Geology and Mineral Resources, Socorro, NM

ABSTRACT

Lindgren (1933) defined a belt of alkaline-igneous rocks associated with large quantities of gold and rare earth elements (REE) that extends from Alaska and British Columbia southward into New Mexico, Texas and eastern Mexico. The North American Cordilleran alkaline-igneous belt since has been exploited for numerous types of mineral deposits. In New Mexico, Mid-Tertiary alkaline to calc-alkaline rocks are found with seven types of deposits in these districts: (1) polymetallic epithermal/mesothermal veins, (2) gold-bearing breccias/quartz veins, (3) Cu-Au, Au and Mo porphyry deposits, (4) skarns and carbonate-hosted deposits, (5) iron skarns and replacement bodies (with some gold), (6) gold placers, and (7) Th-REE (with some U, Nb) epithermal veins. Some of New Mexico's largest gold and REE deposits are found within this belt. Their origin is not well understood, but a compilation of new data (age dates, isotopic and chemical analyses) allows for a better understanding. The diversity of igneous rocks and associated mineral deposits along this belt suggests that this region is characterized by highly fractionated and differentiated; multiple pulses of magmas and involves both upper mantle and lower crustal sources. Once magmas and metal-rich fluids reached shallow levels, local structures and wall rock compositions determined distribution of and final style of intrusions and resulting mineral deposits.

INTRODUCTION

Lindgren (1933) was one of the first geologists who noted that a belt of alkaline-igneous rocks extends from Alaska and British Columbia southward into New Mexico, Trans-Pecos Texas, and eastern Mexico (Fig. 1) and that these rocks contain relatively large quantities of gold, fluorine, zirconium, rare earth elements (REE), and other elements. Since then, the North American Cordilleran alkaline-igneous belt has been explored and exploited for numerous types of mineral deposits, especially gold. The North American Cordilleran alkaline belt is a north-south belt of alkaline igneous rocks and crustal thickening, roughly coinciding with the Great Plains physiographic margin with the Basin and Range (Rio Grande rift) and Rocky Mountains physiographic provinces (Mutschler et al., 1985, 1991; Bonham, 1988; Thompson, 1991a; Richards, 1995; McLemore, 1996; Jensen and Barton, 2000; Kelley and Luddington, 2002). Deposits within this belt have produced significant amounts of gold in the United States and Canada and include Cripple Creek, Colorado (702 metric tons of gold production), Black Hills, South Dakota (235 metric tons gold production) and Landsky-Zortman, Montana.

In New Mexico, the North American Cordilleran alkaline belt extends from the Sangre de Cristo Mountains near Raton, southward to the Cornudas Mountains, in the northern Trans-Pecos alkaline belt (Fig. 2). The alkaline-igneous related mineral deposits in New Mexico have been referred to as Great Plains Margin (GPM) deposits by North and McLemore (1986, 1988) and McLemore (1996, 2001). Alternative classifications by other workers include Au-Ag-Te veins (Cox and Bagby, 1986; Bliss et al., 1992; Kelley et al., 1998), alkalic-gold or alkaline-igneous related gold deposits (Fulp and Woodward, 1991a; Thompson, 1991a, b; Bonham, 1988; Mutschler et al., 1985, 1991; Richards, 1995), porphyry gold deposits, and the North American Cordilleran belt of alkaline igneous rocks (Woolley, 1987; Mutschler et al., 1991).

The purposes of this paper are to (1) summarize the geology, geochemistry, and mineral production of Tertiary alkaline igneous related mineral deposits in New Mexico, (2) discuss the age and formation of these deposits, and (3) comment on the future economic potential of mineral deposits in New Mexico. This work is part of ongoing studies of mineral deposits in New Mexico and includes updates and revisions of prior work by North and McLemore (1986, 1988) and McLemore (1996, 2001). Some of the data referred to in this paper is unpublished but available upon request.

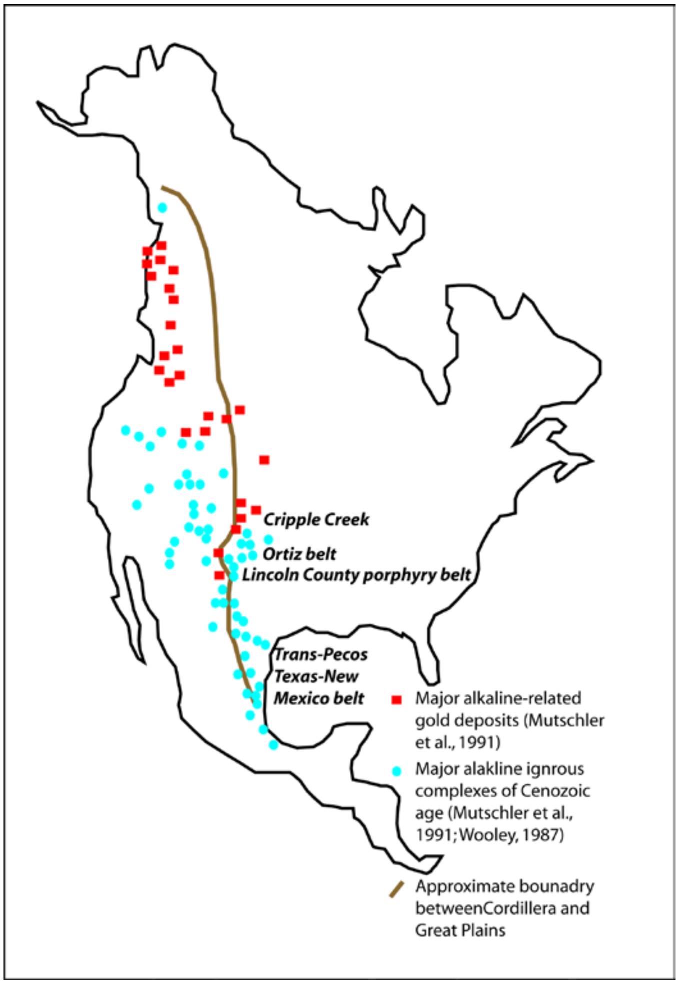

Figure 1. Extent of the North American Cordilleran alkaline belt (Woolley, 1987; Mutschler et al., 1991; McLemore, 1996).

Questa, Red River, and Organ Mountains districts are included in this paper as alkaline-related districts because of the presence of alkaline igneous rocks and proximity to the other deposits.

TYPES OF ALKALINE-RELATED DEPOSITS

Mid-Tertiary alkaline to subalkaline igneous rocks are found associated with mineral deposits in these districts (Table 1, see APPENDIX for all tables) and, in New Mexico, consist of seven deposit types: (1) polymetallic epithermal/mesothermal veins (Au, Ag, Cu, W, Te?), (2) gold-bearing breccias/quartz veins (W, Te?), (3) Cu-Au, Au and Mo porphyry deposits, (4) Cu, Pb/Zn, and Au skarns and carbonate-hosted deposits (W, Te?), (5) iron skarns and replacement bodies (with some Au), (6) gold placers, and (7) Th-REE (with some U, Nb) epithermal veins. Iron skarns and replacement replacements are found in most districts in New Mexico and iron has been produced from some districts (Table 2). Deposits of REE are found in several districts in New Mexico (Fig. 2), but are typically not found with significant gold deposits (Table 1).

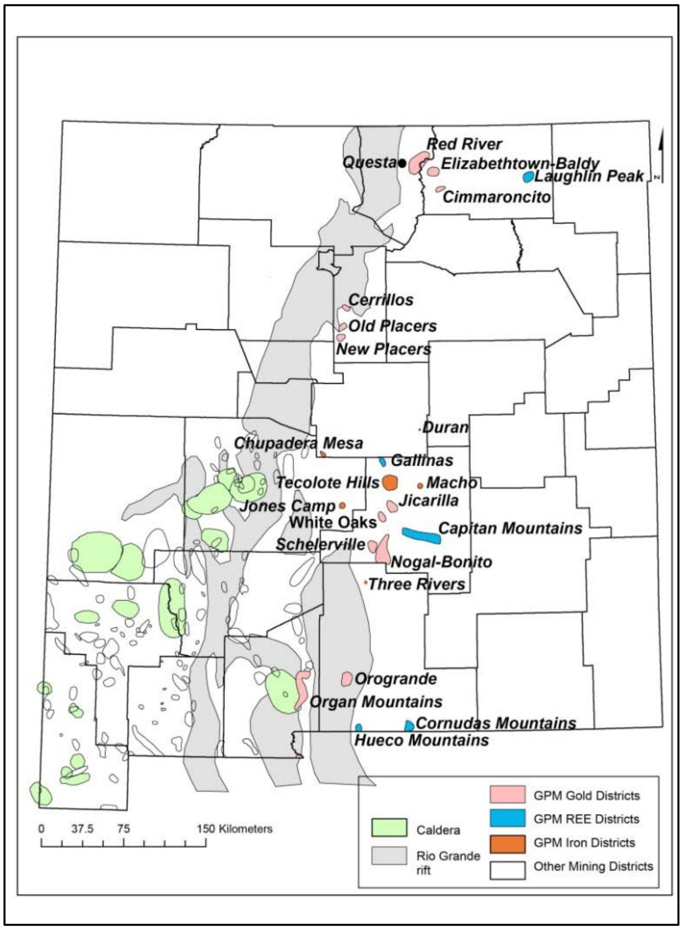

Figure 2. Mining districts related to the North American Cordilleran alkaline belt (GPM or Great Plains Margin deposits), Rio Grande rift, calderas, and other Tertiary mining districts in New Mexico (Chapin et al., 1978, 2004; McLemore, 1996, 2001; Sims et al., 2002; McLemore et al., 2005a, b). GPM districts are summarized in Table 1. Production is in Table 2.

PRODUCTION

Significant mineral production in New Mexico, especially gold, has come from deposits found within the North American Cordilleran alkaline belt (Table 2), although in many districts placer gold has accounted for much of the production. The Old Placers district, Santa Fe County is the largest alkaline-related district in gold production in the state (Table 2), including 250,000 ounces of gold produced from the Cunningham Hill mine in1979-1986. The Elizabethtown-Baldy district, Colfax County is the 2nd largest alkaline igneous-related district in New Mexico in gold production, with most of the production before 1920 (Howard, 1967).

AGE AND GEOCHEMISTRY OF ASSOCIATED IGNEOUS ROCKS

Mineral deposits in the North American Cordilleran alkaline belt are typically associated with alkaline to subalkaline igneous rocks. In some districts in New Mexico, older calc-alkaline igneous rocks are followed by younger alkaline volcanism, such as in the Old and New Placers (Maynard, 2014) and Nogal-Bonito (McLemore et al., 2014a) districts. The mineral deposits in New Mexico associated with Tertiary alkaline igneous rocks are found in small- to medium-sized volcanic fields or porphyry systems, with ages ranging from 22 to 46 Ma (Table 1) and were typically emplaced as multiple, compositionally diverse magmas, with periodic eruptions of varying volumes and wall rock assimilation (McLemore and Zimmerer, 2009).

The igneous rocks are typically calc-alkaline to alkaline, metaluminous to peraluminous intrusions, with light REE-enriched patterns with or without an Eu anomaly (data compiled by the author). Geochemically, the rocks plot as WPG (within-plate granites) to VAG (volcanic arc granites), and active continental margins to within plate volcanic zones, according to Pearce et al. (1984) and Schandl and Gordon (2002).

These volcanic systems formed during the transition at the end of Laramide subduction (continental arc) and beginning of extension (Rio Grande rift; Sauer, 1993; McLemore, 1996; Kelley and Luddington, 2002). The waning of Laramide compression was approximately at 37-43 Ma and rifting/extension began at approximately 33-36 Ma (McMillan et al., 2000; Chapin, 2012). Different melt regimes existed for Laramide compression and younger rifting/extension; Laramide magmas are derived from the mantle to lower crust, which shifted to intracrustal melting of heterogeneous sources during extension (McMillan et al., 2000; Anthony, 2005). Low Sr (Table 3) isotopes and low La/Nb and Zr/Nb of the igneous rocks suggests primitive mantle magma sources for the older rocks (McMillan et al., 2000).

DESCRIPTION AND GEOCHEMISTRY OF MINERAL DEPOSITS IN NEW MEXICO

The mineral deposits in New Mexico are typically structurally controlled and involve mixing and cooling of magmatic meteoric waters and leaching from host rocks (Table 4). Generally complex, magmatic-hydrothermal breccia pipes and porphyry deposits are older than hydrothermal veins and skarns (Maynard et al., 1990; McLemore, 2010). General paragenesis includes early base-metal veins followed by gold veins or Th-REE veins (Maynard et al., 1990; Douglass and Campbell, 1994, 1995; McLemore, 2010).

Gold values in alkaline igneous deposits are generally higher than other deposits in New Mexico and have high gold/base-metal ratios and low silver/gold ratios, unlike other deposits in the state (North and McLemore, 1986, 1988; McLemore, 1996, 2001). Deposits of REE are found in several districts, but typically not with gold. Iron skarns and replacements are found in most districts, with high concentrations of gold and/or REE with the iron mineralization.

In New Mexico, the style of mineralization differs from that found in Colorado. Tellurium is found in most of the Colorado districts, but most districts in New Mexico have tungsten with little or no tellurium, except for a few districts (Kelly and Ludington, 2002; compilation by the author). However, tellurium analyses of samples from New Mexico districts are limited and tellurium could be found in specific zones within New Mexico districts.

RESOURCES AND FUTURE POTENTIAL

In the Old Placers district, the Carache Canyon breccia deposit is estimated to contain reserves of 11.7 million metric tons of 1.6 ppm Au and the Lukas Canyon skarn deposit is estimated to contain reserves of 13 million metric tons of 0.9 ppm Au. Santa Fe Gold Corp. is pursuing exploration and potential development in this area. In 1991-1992, USBM calculated an inferred resource of 0.487 million metric tons of total REE (grade of 2.95% total REE) in the Gallinas Mountains district.

Molybdenum resources remain at Questa and Nogal-Bonito (Griswold and Missaghi, 1964) districts, but they are unlikely to be developed in the near future. There is REE potential in the Laughlin Peak, Gallinas Mountains, and Cornudas Mountains districts (McLemore et al., 1988a, b) and exploration, including drilling, is on-going in the Gallinas and Cornudas Mountains. There is tellurium potential in the Organ Mountains (Lueth, 1998) and Nogal (ulp and Woodard, 1991b) district. Analyses for REE and tellurium as well as gold and other metals would be prudent in future exploration activities in any district.

ORIGIN OF DEPOSITS

The origin of these deposits is not well understood, but a compilation of new and past data, including new dates and isotopic and chemical analyses of igneous rocks and associated mineral deposits, allows for a better understanding of the origin of these deposits. The diversity of igneous rocks and associated mineral deposits along the boundary of the Great Plains with the Southern Rocky Mountain and Basin and Range provinces suggests that this region is characterized by highly fractionated and differentiated, multiple pulses of magmas. Both upper mantle and lower crustal source rocks may be involved, along with local hot spots. Deep-seated fracture systems or crustal lineaments probably channeled the magmas and hydrothermal fluids. Once magmas and metal-rich fluids reached shallow levels, local structures and wall rock compositions determined distribution of and final style of intrusions and resulting mineral deposits.

CONCLUSIONS

The North American Cordilleran alkaline igneous belt extends from Alaska and British Columbia southward into New Mexico, Trans-Pecos Texas, and eastern Mexico and contain relatively large quantities of gold, fluorine, zirconium, rare earth elements (REE), and other elements. In New Mexico, the belt extends from the Sangre de Cristo Mountains near Raton, southward to the Cornudas Mountains, in the northern Trans-Pecos alkaline belt. Significant mineral production in New Mexico, especially gold, has come from deposits found within this belt.

Mid-Tertiary alkaline to subalkaline igneous rocks are found associated with mineral deposits in these districts and, in New Mexico, consist of seven deposit types: (1) polymetallic epithermal/mesothermal veins, (2) gold-bearing breccias/quartz veins, (3) Cu-Au, Au and Mo porphyry deposits, (4) skarns and carbonate-hosted deposits, (5) iron skarns and replacement bodies (with some gold), (6) gold placers, and (7) Th-REE (with some U, Nb) epithermal veins. Some of New Mexico's largest gold and REE deposits are found within this belt. Gold values in alkaline igneous deposits are generally higher than other deposits in New Mexico and have high gold/base-metal ratios and low silver/gold ratios, unlike other deposits in the state. Deposits of REE are found in several districts, but typically not with gold.

The origin of these deposits is not well understood, but a compilation of new and past data, including new dates and isotopic and chemical analyses of igneous rocks and associated mineral deposits, allows for a better understanding of the origin of these deposits. The diversity of igneous rocks and associated mineral deposits along the boundary of the Great Plains with the Southern Rocky Mountain and Basin and Range provinces suggests that this region is characterized by highly fractionated and differentiated, multiple pulses of magmas. Both upper mantle and lower crustal source rocks may be involved, along with local hot spots. Deep-seated fracture systems or crustal lineaments probably channeled the magmas and hydrothermal fluids. Once magmas and metal-rich fluids reached shallow levels, local structures and wall rock compositions determined distribution of and final style of intrusions and resulting mineral deposits.

ACKNOWLEDGMENTS

This report is part of on-going studies of mineral resources in New Mexico, supported by the New Mexico Bureau of Geology and Mineral Resources (NMBGMR), a division of New Mexico Institute of Mining and Technology, L. Greer Price, Director and State Geologist. Recent geologic mapping of quadrangles in some districts was funded by the New Mexico State Map program and Otero County. The U.S. Geological Survey provided chemical analyses as (1) part of the resource evaluation of the Caballo Resource Area of the U.S. Bureau of Land Management and (2) evaluation of alkaline-gold deposits. Other chemical analyses are from cited references and unpublished data by the author. I also would like to acknowledge the numerous graduate students and colleagues who studied various mineral deposits this work is built upon.

REFERENCES

1. Allen, M. S. and Foord, E. E., 1991, Geological, geochemical and isotopic characteristics of the Lincoln County porphyry belt, New Mexico: Implications for regional tectonics and mineral deposits*:* NMGS (New Mexico Geological Society), Guidebook 42, p. 97-113

2. Allen, M. S. and McLemore, V. T., 1991, The geology and petrogenesis of the Capitan pluton, New Mexico: NMGS, Guidebook 42, p. 115-127.

3. Anthony, E. Y., 2005, Source regions of granites and their links to tectonic environment: examples from the western United States: Lithos, v. 80, p. 61-74

4. Bliss, J. D., Sutphin, D. M., Moiser, D. L., and Allen, M. S., 1992, Au-Ag-Te veins associated with alkalic rocks: USGS (U.S. Geological Survey), OF 92-208, 15 p.

5. Bonham, H. F., Jr., 1988, Models for volcanic-hosted epithermal precious metal deposits; *in* Bulk mineable precious metal deposits of the western United States: Geological Society of Nevada, Symposium Proceedings, p. 259-271.

6. Briggs, J. P., 1983, Mineral investigation of an addition to the White Mountain Wilderness, Lincoln County, New Mexico: USBM (U.S. Bureau of Mines), MLA-33-83, 11 p.

7. Campbell, A. R., Banks, D. A., Phillips, R. S., and Yardley, B. W. D., 1995, Geochemistry of the Th-U-REE mineralizing fluid, Capitan Mountains, New Mexico, USA: Economic Geology, v. 90, p. 1273-1289.

8. Campbell, A. R., Porter, J. A., and Scott E. Douglass, S. E., 1991, Fluid inclusion investigation of the mid-Tertiary Helen Rae gold mine, Nogal district, New Mexico*:* NMGS, Guidebook 42, p. 317-321.

9. Chamberlin, R. M., McIntosh, W. C., and Peters, L., 2009, $^{40}Ar/^{39}Ar$ Geochronlogy of the Jones Camp Dike, central New Mexico: an eastward projection of the Magdalena Radial Dike Swarm from under the Oligocene Socorro-Magdalena Caldera Cluster*:* NMGS, Guidebook 60, p. 337-346.

10. Chapin, C. E., 2012, Origin of the Colorado mineral belt: Geosphere, v. 8, p. 28-43.

11. Chapin, C. E., Jahns, R. H., Chamberlin, R. M., and Osburn, G. R., 1978, First day road log from Socorro to Truth or Consequences via Magdalena and Winston; *in* Field Guild to selected caldrons and mining districts of the Datil-Mogollon volcanic field, New Mexico: NMGS, Special Publication no. 7, p. 17-19.

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

13. Cikoski, C. T., Koning, D. J., Kelley, S. A., and Zeigler, K. E., 2011. Preliminary geologic map of the Church Mountain quadrangle, Lincoln County, New Mexico: NMBGMR (New Mexico Bureau of Geology and Mineral Resources), Open-file geologic map OF-GM-215: scale 1:24,000.

14. Constantopoulos, J., 2007, Geochemistry of the Bonito Lake stock, Lincoln County, New Mexico: Petrogenesis and hydrothermal alteration: Rocky Mountain Geology, v. 42, p. 137 - 155.

15. Cox, D. P. and Bagby, W. C., 1986, Descriptive models of Au-Ag-Te veins; in Cox, D. P., and Singer, D. A., eds., 1986, Mineral deposit models: USGS, Bulletin 1693, p. 124.

16. Douglass, S. E., 1992, Characterization of alkaline rock-hosted precious and base metal mineralization in the Nogal mining district, Lincoln County, New Mexico [M.S. thesis]: New Mexico Institute of Mining and Technology, Socorro, 122 p.

17. Douglass, S. E. and Campbell, A. R., 1994, Characterization of alkaline rock-related mineralization in the Nogal mining district, Lincoln County, New Mexico: Economic Geology, v. 89, p. 1306-1321.

18. Douglass, S. E. and Campbell, A. R., 1995, Characterization of alkaline rock-related mineralization in the Nogal mining district, Lincoln County, New Mexico, Reply: Economic Geology, v. 90, p. 985-987.

19. Dunbar, N. W., Campbell, A. R., and Candela, P. A., 1996, Physical, chemical, and mineralogical evidence for magmatic fluid migration within the Capitan pluton, southeastern New Mexico: GSA (Geological Society of America) Bulletin, v. 108, p. 318-333.

20. File, L., and Northrop, S. A., 1966, County, township, and range locations of New Mexico's mining districts: NMBMMR, Circular 84, 66 p.

21. Fulp, M. S. and Woodward, L.A., 1991a, Mineral deposits of the New Mexico alkalic province (abstr.): GSA, Abstracts with Programs, v. 23, p. 23.

22. Fulp, M. S. and Woodward, L. A., 1991b, The Mudpuppy-Waterdog prospect, an alkalic copper-gold porphyry system in the Nogal-Bonito mining district, Lincoln County, New Mexico: NMGS, Guidebook 42, p. 327-328.

23. Gander, M. J., 1982, The geology of the northern part of the Rialto stock, Sierra Blanca igneous complex, New Mexico [M.S. thesis]: Fort Collins, Colorado State University, 132 p.

24. Giles, D. L., 1991, Gold mineralization in the Cerrillos district, New Mexico (abstr.): GSA, Abstracts with Programs, v. 23, p. 24.

25. Giles, D. L. and Thompson, T. B., 1972, Petrology and mineralization of a molybdenum-bearing alkalic stock, Sierra Blanca, New Mexico: GSA Bulletin, v. 83, p. 2129 - 2148.

26. Goff, F., Kelley, S. A., Lawrence, J. R., Cikiski, C., Krier, D. J., Goff, C. J., and McLemore, V. T., 2011, Preliminary geologic map of the Nogal Peak quadrangle, Lincoln and Otero Counties, New Mexico: New Mexico Bureau of Geology and Mineral Resources, Open-file Geologic Map OF-GM-134, 81 p

27. Goff, F., Roback, R. C., McIntosh, W. I., Goff, C. J., and Kluk, E. C., 2014, Geochemistry and geochronology of intrusive and volcanic rocks of the Three Rivers stock, Sierra Blanca, New Mexico: NMGS, Guidebook 65, p. 183-196.

28. Grainger, J. R., 1974, Geology of the White Oaks mining district, Lincoln County, New Mexico [M.S. thesis]: University New Mexico, Albuquerque, NM, 69 p.

29. Griswold, G. B., 1959, Mineral deposits of Lincoln County, New Mexico: NMBMMR (New Mexico Bureau of Mines and Mineral Resources), Bulletin 67, p. 1-117.

30. Griswold, G. B. and Missaghi, F., 1964, Geology and geochemical survey of a molybdenum deposit near Nogal Peak, Lincoln County, New Mexico: NMBMMR, Circular 67, 29 p.

31. Howard, E. V., 1967, Metalliferous occurrences in New Mexico: Phase 1, state resources development plan: State Planning Office, Santa Fe, 270 p.

32. Hollister, V. F., 1978, Porphyry molybdenum deposits; *in* A. Sutukov (ed.), International molybdenum encyclopedia 1778-1978, v. 1, Resources and production: Santiago, Chile, Alexander Sutukov, Internet Publications, p. 270-288.

33. Jensen, E. P. and Barton, M. D., 2000, Gold deposits related to alkaline magmatism: Society of Economic Geologists Reviews, v. 13, p. 279-314

34. Johnson, M. G., 1972, Placer gold deposits of New Mexico: USGS, Bulletin 1348, 46 p.

35. Kay, B. D., 1986, Vein and breccia gold mineralization and associated igneous rocks at the Ortiz mine, New Mexico, USA [M.S. thesis]: Colorado School of Mines, Golden, CO, 179 p.

36. Kelley, K. D. and Luddington, S., 2002, Cripple Creek and other alkaline-related gold deposits in the southern Rocky Mountains, USA: influence of regional tectonics: Mineralium Deposita, v. 37, p. 38-60.

37. Kelley, K. D, Romberger, S. B., Beaty, D. W., Pontius, J. A., Snee, L. W., Stein, H. J., and Thompson, T. B., 1998, Geochemical and geochronological constraints on the genesis of Au-Te deposits at Cripple Creek, Colorado: Economic Geology, v. 93, p. 981-1012.

38. Kelley, S., Koning, D. J., Goff, F., Cikoski, C., Peters, L., and McIntosh, W., 2014, Stratigraphy of the northwestern Sierra Blanca volcanic field: NMGS, Guidebook 65, p. 197-208.

39. Kish, S. A., Ragland, P. C., and Cannon, R. P., 1990, Petrochemistry of the Palisades sheet, Cimarron Pluton, northern New Mexico: NMGS, Guidebook 41, p. 341-347.

40. Laughlin, A. W. Rehrig, W.A. and Mauger, R.L., 1969, K-Ar chronology and sulfur and strontium isotope ratios at the Questa mine, New Mexico: Economic Geology, v. 64, p. 903-909.

41. Lindgren, W., 1933, Mineral deposits, 4th edition: New York, McGraw-Hill, 930 p.

42. Lindgren, W., Graton, L.C., and Gordon, C. H., 1910, The ore deposits of New Mexico: USGS, Professional Paper 68, 361 p.

43. Lueth, V. W., 1998, Tellurium mineralization in the northern Organ district, Dona Ana County, New Mexico: NMGS, Guidebook 49, p. 265-269.

44. Lueth, V.W. and McLemore, V.T., 1998, A reinterpretation of ore zoning in the Organ district, Doña Ana County, New Mexico: NMGS, Guidebook 49, p. 279-285.

45. Maynard, SR., 2014, Geology and mineral resources of the Ortiz Mine Grant, Santa Fe County, New Mexico: NMBGMR, Open-file Report 560.

46. Maynard, S.R., Martin, K.W., Nelson, C.J., and Schutz, J.L., 1989, Geology and gold mineralization of the Ortiz Mountains, Santa Fe County, New Mexico: SME, Preprint No. 89-43, 9 p.

47. Maynard, S.R., Nelson, C.J., Martin, K.W., and Schutz, J.L., 1990, Geology and gold mineralization of the Ortiz Mountains, Santa Fe County, New Mexico: Mining Engineering, August, p. 1007-1011.

48. McLemore, V. T., 1984, Preliminary report on the geology and mineral-resource potential of Torrance County, New Mexico: NMBGMR, OF-192, 211 p.

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

50. McLemore, V.T., 2001, Silver and gold resources in New Mexico: NMBMMR, Resource Map 21, 60 p.

51. McLemore, V. T., 2002, Geology and geochemistry of the Mid-Tertiray alkaline to calc-alkaline intrusions in the northern Hueco Mountains and adjacent areas, McGregor Range, southern Otero County, New Mexico: NMGS Guidebook 52, p. 129-137.

52. McLemore, V.T., 2009, Geologic Setting and Mining History of the Questa mine, Taos County, New Mexico: NMBGMR, OF-515, 29 p.
53. McLemore, V.T., 2010, Geology and mineral deposits of the Gallinas Mountains, Lincoln and Torrance Counties, New Mexico; preliminary report: NMBGMR, Open-file report OF-532, 92 p.
54. McLemore, V.T., 2014, Geology of the Three Rivers mining district: NMGS, Guidebook 65, p. 45-47.
55. McLemore, V.T., Dunbar, N., Heizler, L., and Heizler, M., 2014b, Geology and mineral deposits of the Orogrande mining district, Jarilla Mountains, Otero County, New Mexico: NMGS, Guidebook 65, p. 247-259.
56. McLemore, V. T., Goff, F., And McIntosh, W., 2014a, Geology and mineral resources of the Nogal-Bonito mining district, Lincoln County, New Mexico: NMGS, Guidebook 65, p. 235-246.
57. McLemore, V. T., Lueth, V. W., Pease, T. C., and Gulinger, J. R., 1996, Petrology and mineral resources of the Wind Mountain laccolith, Cornudas Mountains, New Mexico and Texas: Canadian Mineralogist, v. 34, pt. 2, pp. 335-347.
58. McLemore, V. T., Hoffman, G., Smith, M., Mansell, M., and Wilks, M., 2005a, Mining districts of New Mexico: NMBMMR, OF-494, CD-ROM.
59. McLemore, V. T., Krueger, C. B., Johnson, P., Raugust, J. S., Jones, G.E., Hoffman, G.K. and Wilks, M., 2005b, New Mexico Mines Database: Mining Engineering, February, p. 42-47.
60. McLemore, V. T., North, R. M., and Leppert, S., 1988a, Rare-earth elements (REE), niobium and thorium districts and occurrences in New Mexico: NMBMMR, OF-324, 28 p.
61. McLemore, V. T., North, R. M., and Leppert, S., 1988b, Rare-earth elements (REE) in New Mexico: New Mexico Geology, v. 10, p. 33-38.
62. McLemore, V. T., Ouimette, M., and Eveleth, R. W., 1991, Preliminary observations on the mining history, geology and mineralization of the Jicarilla mining district, Lincoln County, New Mexico: NMGS, Guidebook 42, p. 311-316.
63. McLemore, V.T. and Phillips, R.S., 1991, Geology of mineralization and associated alteration in the Capitan Mountains, Lincoln County, New Mexico: NMGS, Guidebook 42, p. 291-298.
64. McLemore, V.T. and Zimmerer, M., 2009, Magmatic Activity and Mineralization along The Capitan, Santa Rita, And Morenci Lineaments in the Chupadera Mesa Area, central New Mexico: NMGS, Guidebook 60, p. 375-386.
65. McMillan, N. J., Dickin, A. P. and Haag, D., 2000, Evolution of magma source regions in the Rio Grande rift, southern New Mexico: GSA Bulletin, v. 112, p. 1582-1593.
66. Mutschler, F. E., Griffin, M. E., Stevens, D. S. and Shannon, S. S., Jr., 1985, Precious metal deposits related to alkaline rocks in the North American Cordillera-an interpretive review: Transactions GSA, v. 88, p. 355-377.
67. Mutschler, F. E., Mooney, T. C., and Johnson, D. C., 1991, Precious metal deposits related to alkaline igneous rocks-a space-time trip through the Cordillera: Mining Engineering, v. 43, p. 304-309.
68. New Mexico Bureau of Mines and Mineral Resources, New Mexico State University Southwest Technology Institute, and TRC Mariah Associates, Inc., 1998, Mineral and energy resource assessment of the McGregor Range (Fort Bliss), Otero County, New Mexico: NMBMMR OF- 458, 543 p.
69. North, R. M., 1982, Geology and ore deposits of the Orogrande mining district, Otero County, New Mexico: NMBMMR, OF-370, 23 p.
70. North, R. M., and McLemore, V. T., 1986, Silver and gold occurrences in New Mexico: NMBMMR, Resource Map 15, 32 p., scale 1:1,000,000.
71. North, R. M., and McLemore, V. T., 1988, A classification of the precious metal deposits of New Mexico; *in* Bulk mineable precious metal deposits of the western United States Symposium Volume: Geological Society of Nevada, Reno, Symposium held April 6-8, 1987, p. 625-660.
72. Pearce, J. A., Harris, N. B. W. and Tindle, A.G., 1984, Trace element discrimination diagrams for the tectonic interpretation of granitic rocks: Journal of Petrology, v. 24, p. 956–983.
73. Pearson, J. B., 1955, A New Mexico gold story--The Elizabethtown-Red River area, Ph. D. dissertation, University Texas, Austin, TX, p. 1-534.
74. Perhac, R. M., 1970, Geology and mineral deposits of the Gallinas Mountains, Lincoln and Torrance Counties, New Mexico: NMBMMR, Bulletin 95, 51 p.
75. Potter, L. S., 1988, Petrology and petrogenesis of Tertiary igneous rocks, Chico Hills, New Mexico [M.S. thesis]: Iowa State University, Ames, IA, 179 p.
76. Rawling, G. C., 2011, Geology of the Capitan and Nogal quadrangles, Lincoln County, New Mexico: NMBGMR, Open-file Report 538.
77. Rawling, G. and Koning, D, 2011, Geologic map of the White Oaks South quadrangle, Lincoln County, New Mexico: NMBGMR, Open-file Geologic Map, OF-GM 216.
78. Rawson, D. E., 1957, Geology of the Tecolote Hills area, Lincoln County, New Mexico [M.S. thesis]: University New Mexico, Albuquerque, NM, 77 p.
79. Richards, J. P., 1995, Alkalic-type epithermal gold deposits—a review; *in* Thompson, J.F.H. (ed.), Magmas, fluids, and ore deposits: Mineralogical Association of Canada, Short Course Series, v. 23, p. 367-400.
80. Roberts, T. T., Parkison, G. A., and McLemore, V. T., 1990, Geology of the Red River district, Taos County, New Mexico: NMGS, Guidebook 41, p. 375-380.
81. Ross, P. S., Jebrak, M., and Walker, B. M., 2002, Discharge of hydrothermal fluids from a magma chamber and concomitant formation of a stratified breccia zone at the Questa porphyry molybdenum deposit, New Mexico: Economic Geology, v. 97, p. 1679-1699.
82. Rowe, A., 2012, Ore genesis and fluid evolution of the Goat Hill orebody, Questa Climax-type porphyry-Mo system, New Mexico and its comparison to the Climax-type deposits of the Colorado mineral belt [Ph.D. dissertation]: New Mexico Institute Mining Technology, Socorro, NM, 286 p.
83. Ryberg, G. E., 1991, Geology of the Vera Cruz mine and breccia pipe, Lincoln County, New Mexico: NMGS, Guidebook 42, p. 329-332.
84. Sauer, R. R., 1999, Petrochemistry and geochronology of plutons relative to tectonics in the San Pedro-Ortiz porphyry belt, New Mexico [M.S. thesis]: University Colorado, Boulder, CO, 115 p.
85. Schreiner, R. A., 1993, Mineral investigation of the rare-earth-element-bearing deposits, Red Cloud Mining district, Gallinas Mountains, Lincoln County, New Mexico: USBM, MLA 99-93, 189 p.
86. Schutz, J. Leroy, 1995, Gold mineralization associated with alkaline intrusives at the Carache Canyon breccia pipe prospect, Ortiz Mountains, New Mexico: NMGS, Guidebook 46, p. 167-173.

87. Sims, P. K., Stein, H. J., and Finn, C. A., 2002, New Mexico structural zone—an analogue of the Colorado mineral belt: Ore Geology Reviews, v. 21, p. 211-225.
88. Staatz, M. H., 1985, Geology and description of the thorium and rare-earth veins in the Laughlin Peak area, Colfax County, New Mexico: USGS, Professional Paper 1049-E, 32 p.
89. Stroud, J. R., 1997, The geochronology of the Raton-Clayton volcanic field, with implications for volcanic history and landscape evolution [M.S. thesis]: New Mexico Institute of Mining and Technology, Socorro, p. 1-70 p.
90. Thompson, T. B, 1991a, Genesis of gold associated with alkaline igneous rocks (abstr.): GSA, Abstracts with Programs, v. 23, p. 99-100.
91. Thompson, T. B., 1991b, The Bonito-Nogal district, Lincoln County, New Mexico (abstr.): GSA, Abstracts with Programs, v. 23, p. 99.
92. USBM (U.S. Bureau of Mines), 1927-1990, Mineral yearbook: Washington, D.C., U.S. Government Printing Office, variously paginated.
93. USGS (U.S. Geological Survey, 1902-1927, Mineral resources of the United States (1901-1923): Washington, D.C., U.S. Government Printing Office, variously paginated.
94. Vance, Z., 2013, Mineralogy, Geochemistry and Genesis of the Hydrothermal Ree-Fluroite-AG-PB-CU Ore Deposits of the Gallinas Mountains, New Mexico [M.S. thesis]: Socorro, New Mexico Institute of Mining and Technology, 219 p.
95. Verplanck, P. L., Farmwe, G. L., McCurry, M., and Mertzman, S. A., 1999, The chemical and isotoic differentiation of an epizonal magma body: Organ Needle pluton, New Mexico: Journal of Petrology, v. 40, p. 653-678.
96. Williams-Jones, A. E., Samson, I. M., and Olivo, G. R., 2000, The genesis of hydrothermal fluorite-REE deposits in the Gallinas Mountains, New Mexico: Economic Geology, v. 95, no. 2, pp. 327-341.
97. Woolley, A. R., 1987, Alkaline rocks and carbonatites of the world, Part 1: North and South America: University of Texas Press, Austin.
98. Zimmerer, M. J. and McIntosh, W. C., 2012, The geochronology of volcanic and plutonic rocks at the Questa caldera: constraints on the origin of caldera-related silicic magmas: GSA, Bulletin, v. 124, p. 1394-1408.
99. Zimmerer, M. J. and McIntosh, W. C., 2013, Geochronologic evidence of upper-crustal in situ differentiation: Silicic magmatism at the Organ caldera complex, New Mexico: Geosphere, v. 9, p. 155-169.

APPENDIX

Table 1. Mining districts related to the North American Cordilleran alkaline belt in New Mexico (also known as GPM districts). Names of districts are after File and Northrop (1966) wherever practical, but many former districts have been combined and new districts added. The district id number refers to the New Mexico Mines Database district number (McLemore et al., 2005a, b). Districts are shown in Figure 2. Types of deposits, indicated by number in parenthesis, are described in text.

District Id	Name	Associated volcanic field	Selected elements	Age Ma	Veins (1)	Breccia pipes (2)	Porphyry (3)	Other skarns (4)	Fe skarns (5)	Gold placers (6)	Th-REE veins (7)	Selected references
DIS237	Questa	Latir	Mo, Be	22.7-28.5	x	x	x					McLemore (2009), Zimmerer and McIntosh (2012)
DIS238	Red River	Latir	Au, Ag, Cu, Be, Te	24.9	x					x		Roberts et al. (1990), Zimmerer and McIntosh (2012)
DIS018	Cimarroncito	Cimarron porphyry	Au, Ag	29.1	x					x		Lindgren et al. (1910), Kish et al. (1990)
DIS019	Elizabethtown-Baldy	Cimarron porphyry	Au, Ag, W, Te	29.1	x			x	x	x		Laughlin et al. (1910), Pearson (1955), Kish et al. (1990)
DIS020	Laughlin Peak	Laughlin Peak-Chico Hills	REE, Th, U	22.8-32.3	x	x					x	Stroud (1997), Staatz (1985), Potter (1988)
DIS180	Cerrillos	Ortiz porphyry belt	Au, Ag, Cu	28.9	x		x					Giles (1991), Maynard (2014)
DIS186	New Placers	Ortiz porphyry belt	Au, Ag, Cu, Te	33.7-33.9	x			x		x		Sauer (1994), Maynard (2014)
DIS187	Old Placers	Ortiz porphyry belt	Au, Ag, Cu, W, Te	29.6-43.2	x	x	x	x		x		Kay (1986), Maynard (2014), Maynard et al. (1989, 1990)
DIS091	Capitan Mountains	Lincoln County porphyry belt	REE, Th, U, Fe, Be	28.3	x				x		x	McLemore and Phillips (1991), Allan and McLemore (1991), Campbell et al. (1995), Dunbar et al. (1996)
DIS092	Gallinas Mountains	Lincoln County porphyry belt	REE, Th, U, Te	29.2	x	x			x		x	Perhac (1970), Schreiner (1993), McLemore (2010), Vance (2013)
DIS093	Jicarilla	Lincoln County porphyry belt	Au, Ag, Fe	39.45-40.72	x				x	x		McLemore et al. (1991)
DIS098	Tecolote Iron	Lincoln County porphyry belt	Fe						x			Rawson (1957)
DIS099	White Oaks	Lincoln County porphyry belt	Au, Ag, W, Te		x				x	x		Grainger (1974), Rawling and Koning (2011)
DIS271	Duran	Lincoln County porphyry belt	Fe						x			McLemore (1984)
DIS095	Nogal-Bonito	Lincoln County porphyry belt, Sierra Blanca	Au, Ag, Cu, Mo, Fe, Te, REE(?)	26-33	x	x	x		x	x	?	Griswold (1959), Giles and Thompson (1972), Gander (1982), Briggs (1983), Constantopoulos (2007), McLemore et al. (2014a), Goff et al. (2011, 2014)
DIS096	Schelerville	Lincoln County porphyry belt, Sierra Blanca	Au, Ag	26-33	x							Goff et al. (2011, 2014), Kelley et al. (2014), Cikoski et al. (2011),
DIS132	Three Rivers	Lincoln County porphyry belt, Sierra Blanca	Fe (Au, Ag, REE?)	26-33	x				x			Goff et al. (2014), Kelley et al. (2014), McLemore (2014)
DIS216	Jones Camp	Chuadera Mesa (Magdalena radial dike swarm)	Fe (Au)	28.88					x			Chamberlin et al. (2009)
DIS241	Chupadera Mesa	Chudaera Mesa dikes	Fe (Au)						x			McLemore (1984)
DIS129	Orogrande	Jarilla plutons	Cu, Au, Ag, Fe, Te	45.6-41.4	x		x	x	x	x		North (1982), McLemore et al. (2014b)
DIS030	Organ Mountains	Organ (Mogollon-Datil)	Cu, Pb, Zn, Au, Ag, Te, Be	36.0-36.45	x		x	x				Lueth (1998), Lueth and McLemore (1998), Zimmerer and McIntosh (2013)
DIS128	Cornudas Mountains	Trans-Pecos volcanic field	REE, Th, U, Be	36.3	x	x					x	McLemore et al. (1996), New Mexico Bureau of Mines and Mineral Resources et al. (1998)
DIS255	Hueco Mountains	Trans-Pecos volcanic field	Fe, REE, Th, U	34.5-34.7					x		?	McLemore (2002)

APPENDIX (cont'd)

Table 2. Reported and estimated base and precious metals production by district. — no reported production. * estimated, ** includes placer production. W withheld or not available. From USGS (1902-1927), USBM (1927-1990) Mineral Yearbooks, Howard (1967), Johnson (1972), McLemore (2001), and NMBMG unpublished information. District and mine id number from the New Mexico Mines Database (McLemore et al., 2005a, b). 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.

District (DIS) or Mine (NM) Id	County	District	Period of production	Ore (short tons)	Copper (pounds)	Gold (troy ounces)	Silver (troy ounces)	Lead (pounds)	Zinc (pounds)	Iron (short tons)
DIS018	Colfax	Cimmaroncito*	1896-1940	—	W	100	1,000	—	—	—
DIS019	Colfax	Elizabethtown-Baldy**	1866-1968	—	—	471,400	—	—	—	—
DIS030	Dona Ana	Organ Mountains*	1849-1961	—	4,636,000	11,500	820,000	25,000,000	1,700,000	—
DIS092	Lincoln	Gallinas Mountains	1909-1955	5,367	385,418	7	23,723	1,797,838	17,344	11,540
DIS093	Lincoln	Jicarilla**	1912-1957	53,307	4,201,474	22,857	37,561	2,665	—	8,000
DIS095	Lincoln	Nogal-Bonito*	1868-1965	—	—	17,000	20,000	—	—	—
DIS096	Lincoln	Schelerville		—	W	W	W	W	—	—
DIS099	Lincoln	White Oaks*	1850-1942	—	1,000	163,500	1,100	—	—	—
DIS129	Otero	Orogrande*	1879-1966 (Fe til 2012)	—	5,700,000	16,500	50,000	158,000	—	456,765
DIS180	Santa Fe	Cerrillos	1907-1957	27,670	229,395	2,594	28,030	1,583,440	1,897,527	—
DIS186	Santa Fe	New Placers*	1839-1968	—	17,000,000	117,000	308,000	—	—	—
DIS187	Santa Fe	Old Placers*	1828-1986	—	2,000	450,000	1,000	6,000	—	—
NMSF0108	Santa Fe	Cunningham Hill	1979-1986	6,000,000		250,000	—	—	—	—
DIS238	Taos	Red River*	1902-1956		17,000	365	8,051	—	—	—

Table 3. Summary of Sr isotope data of selected alkaline igneous rocks.

District Id	Name	Sr isotopes	Sr reference
DIS237	Questa	0.7076-0.7069	Laughlin et al. (1969)
DIS019	Elizabethtown-Baldy	0.70617	Kish et al. (1990)
DIS020	Laughlin Peak	0.7044, 0.7039-0.7060	Potter (1988)
DIS091	Capitan Mountains	0.70801	Allen and Foord (1991)
DIS092	Gallinas Mountains	0.7061	Allen and Foord (1991)
DIS093	Jicarilla	0.70565-0.70578	Allen and Foord (1991)
DIS098	Tecolote Iron	0.70490-0.70513	Allen and Foord (1991)
DIS099	White Oaks	0.70673	Allen and Foord (1991)
DIS095	Nogal-Bonito	0.7067	Allen and Foord (1991)
DIS216	Jones Camp	0.70715	Allen and Foord (1991)
DIS030	Organ Mountains	0.7085 to 0.7060	Verplanck et al. (1999)
DIS128	Cornudas Mountains	0.7041	Barker et al. (1977)

Table 4. Summary of fluid inclusion and stable isotope data.

Name	Temperature degrees C	Salinities	Delta D per mil	Delta ^{18}O per mil	Delta ^{34}S per mil	Conclusion	Reference
Questa	550		–138 to –110 (phlogopite)	2.8 to 5.7 for phlogopite, 6.8 to 10.3 for quartz		little or no meteoric fluids	Ross et al. (2002)
Questa	62-560	0-63 eq wt% NaCl + KCl + CaCl2	-89 to -63	3.8-7.4	0.4-2.3, 1.6-2.5, and 6.6-10.0	evolved magmatic-hydrothermal fluid	Rowe (2012)
Capitan	600	84 eq wt% NaCl + KCl	-54 to -80	7.1 to 8		magmatic fluids	Campbell et al. (1995)
Nogal	230-540	6-50 eq wt% NaCl		0.9 ± 3.9 gold, -2.6 ± 2.3 Ag-Pb-Zn	-1.7 ± 0.8	Au magmatic-meteoric fluid,Ag-Pb-Zn meteoric fluids	Douglass (1992), Campbell et al. (1991), Douglass and Campbell (1994, 1995)
Gallinas	400	15 eq wt% NaCl				meteoric fluid, with REE magmatic	Williams-Jones et al. (2000)
Gallinas	200-310			15.0 to 23.8	-21.1 to 1.5, 9.6 to 13.3	hydrothermal	Vance (2013)
Cunningham Hill, Ortiz	324-445 (quartz, scheelite)	>40 eq wt% NaCl					Kay (1986)
Carache Canyon, Ortiz	275->400	25-46 eq wt% NaCl					Schutz (1995)
Organ	178->300	0-6 eq wt% NaCl					Lueth (1998)

APPENDIX (cont'd)

Table 5. Alkaline-related gold deposits in New Mexico with reported, historic (non 43-101 compliant) resources.

Mine Id	Name of deposit	Tons of ore	Au grade (ppm)	Ag grade (ppm)	Cu grade %	Mo grade %	Year of estimate	Reference
NMLI0068	Vera Cruz	207,450 (assured)	4.5				1938	Ryberg (1991)
		435,000 (probable)	3.9					
		934,000 (possible)	3.9					
NMLI0207	Great Western	3,600,000	18.7				1992	NMBGMR file data
NMLI0271	Parsons	44,000	16.1				1991	Thompson (1991a, b)
NMLI0121	Rialto	30 million short tons				0.05-0.18%	1978	(Hollister, 1978)
NMLI0008	Bonito	1.7 million short tons	1.6	16.1			1989	NMBGMR file data
NMSF0116	Carache Canyon	11.7 million metric tons	1.58				2012	10K (http://www.sec.gov/Archives/edgar/data/851726/000106299313004849/form10k.htm)
NMSF0117	Lucas Canyon	13 million metric tons	0.91		0.142		2012	10K (http://www.sec.gov/Archives/edgar/data/851726/000106299313004849/form10k.htm)
	Florencio	3,000,000	0.65				?	Maynard (2014)