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CRITICAL MINERALS IN NEW MEXICO

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

ABSTRACT

Critical minerals are mineral resources that are essential to our economy and whose supply may be disrupted; many critical minerals are 100% imported into the U.S. Both uranium and potash are important commodities in NM and are considered critical minerals. Rare earth elements deposits are also found in NM. REE-Th-U veins are found in the Gallinas, Capitan, and Cornudas Mountains and Laughlin Peak-Chico Hills; all are associated with Tertiary alkaline igneous rocks. Disseminated Y-Zr deposits in Proterozoic nepheline syenite are known at Pajarito Mountain on the Mescalero Apache Indian Reservation near Ruidoso. Other critical minerals are associated with various mineral deposits in New Mexico. For example, vanadium and molybdenum, by-products of uranium mining, as well as selenium and REE, are associated with sandstone uranium deposits in the Grants uranium district. Rhenium is found in porphyry copper and porphyry molybdenum deposits in New Mexico. Coal deposits are abundant in the state and could be source of several critical minerals (REE, Se, V, Ge), but more work is needed to fully understand the distribution of critical minerals in New Mexico coal deposits.

INTRODUCTION

The growing market for alternative technologies like solar panels, wind turbines, batteries, electric cars, desalination plants, and carbon capture and storage require nontraditional elements for their manufacture (Table 1). In December 2017, President Trump signed an executive order (Presidential Executive Order (EO) No. 13817) that required the Departments of Interior and Defense to develop a list of critical minerals. In May 2018, the U.S. Department of the Interior published its final list of 35 critical minerals. As defined by EO No. 13817, "*a critical mineral is a mineral (1) identified to be a nonfuel mineral or mineral material essential to the economic and national security of the United States, (2) from a supply chain that is vulnerable to disruption, and (3) that serves an essential function in the manufacturing of a product, the absence of which would have substantial consequences for the U.S. economy or national security*". Many critical mineral**s** are 100% imported into the U.S. Critical minerals are mineral resources that are essential to our economy and whose supply may be disrupted (Committee on Critical Mineral Impacts of the U.S. Economy, 2008; Schulz et al., 2017). The criticality of a commodity changes with time as supply and society's needs evolve. As demands and supplies evolve, criticality of a commodity can change with time and geography. Disruptions of imports may occur because of natural disasters, labor strife, trade disputes, resource nationalism, armed conflict, and so on. Disruptions in supply chains can arise for any number of reasons, including natural disasters, labor strife, trade disputes, resource nationalism, conflict, and so on.

New Mexico has a wealth of mineral resources (McLemore et al., 2017) and some of these critical minerals are associated with various mineral and coal deposits in New Mexico (Fig. 1; McLemore, 2011, 2013, 2017, 2018; John and Taylor, 2016). For example, vanadium, a by-product of uranium mining, as well as commodities such as rare earth elements (REE), are associated with sandstone uranium deposits in the Grants uranium district (Breit, 2016). A number of the critical minerals on the draft list do not occur as distinct, economically viable mineral deposits, but rather as co-minerals of host or gateway minerals in deposits of the host or gateway minerals. For example, copper is the host or gateway mineral to at least four minerals on the list including, cobalt, rhenium, tellurium, and potentially REE. Gold is the gateway or host mineral to antimony and arsenic. Zinc and lead are the host or gateway minerals to indium, gallium, germanium, antimony, bismuth and tellurium. Nickel is host or gateway to cobalt and the platinum group metals.

Table 1. Critical minerals found in New Mexico.

COMMODITY	IS IT FOUND IN NEW MEXICO?	WAS IT PRODUCED FROM NEW MEXICO?
Aluminum (bauxite)	?	No
Antimony (Sb)	Yes	Yes
Arsenic	Yes	Yes
Barium (barite) (Ba)	Yes	Yes
Beryllium (Be)	Yes	Yes
Bismuth (Bi)	Yes	Yes
Cesium (Cs)	?	No
Chromium	?	No
Cobalt (Co)	?	No
Fluorine (fluorite) (F)	Yes	Yes
Gallium (Ga)	Yes	No
Germanium (Ge)	?	No
Graphite (carbon)	?	Yes
Hafnium (Hf)	?	No
Helium	Yes	Yes
Indium (In)	Yes	No
Lithium (Li)	Yes	Yes
Magnesium (Mg)	Yes	No
Manganese (Mn)	Yes	Yes
Niobium (Nb)	Yes	Yes
Platinum group elements (PGE: Pd, Pt, Os, Ir, Rh)	?	No
Potash (K)	Yes	Yes
Rare earth elements (REE), including yttrium (Y)	Yes	Yes
Rhenium (Re)	Yes	Yes
Rubidium (Rb)	?	No
Scandium (Sc)	Yes	No
Strontium (Sr)	?	No
Tantalum (Ta)	?	No
Tellurium (Te)	Yes	Yes
Tin (Sn)	Yes	Yes
Titanium (Ti)	Yes	No
Tungsten (W)	Yes	Yes
Vanadium (V)	Yes	Yes
Zirconium (Zr)	Yes	No
Uranium (U)	Yes	Yes

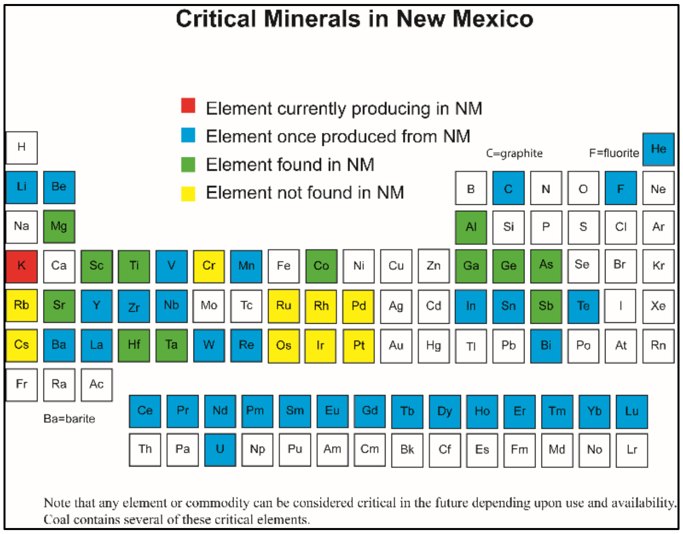
IMPORTANT CRITICAL MINERALS IN NEW MEXICO

It is beyond the scope of this paper to describe all of the critical mineral deposits found in New Mexico (Fig. 1) and only a few are summarized below. Most critical mineral deposits are described by McLemore and Austin (2017), McLemore and Lueth (2017), McLemore and Chenoweth (2017) and additional references cited in these reports.

Potash

The only critical mineral currently being produced in New Mexico is potash, which is used for fertilizer and in the chemical industry. The Carlsbad potash district is the largest potash producing area in the

U.S. (Fig. 2), and New Mexico is ranked number one in potash production yearly. Total production from the district is estimated as 115 million tons of salts from 1959-2016. Intreped Mining LLC and Mosaic Co. operate mines in the district from Permian bedded salt deposits and the important natural, commercial, soluble potassium salts are sylvite ($KC1$) and langbeinite (K_2SO_4-$2MgSO_4$). Sylvinite, a mixture of sylvite and halite, is the typical ore mined in the Carlsbad potash district (CPD) in southeastern New Mexico. Mining is by underground methods at depths of 800 to 1500 ft. The estimated potash reserves in the district amount to >553 million short tons.



Note that any element or commodity can be considered critical in the future depending upon use and availability. Coal contains several of these critical elements.

Figure 1. Periodic table showing critical minerals in New Mexico.

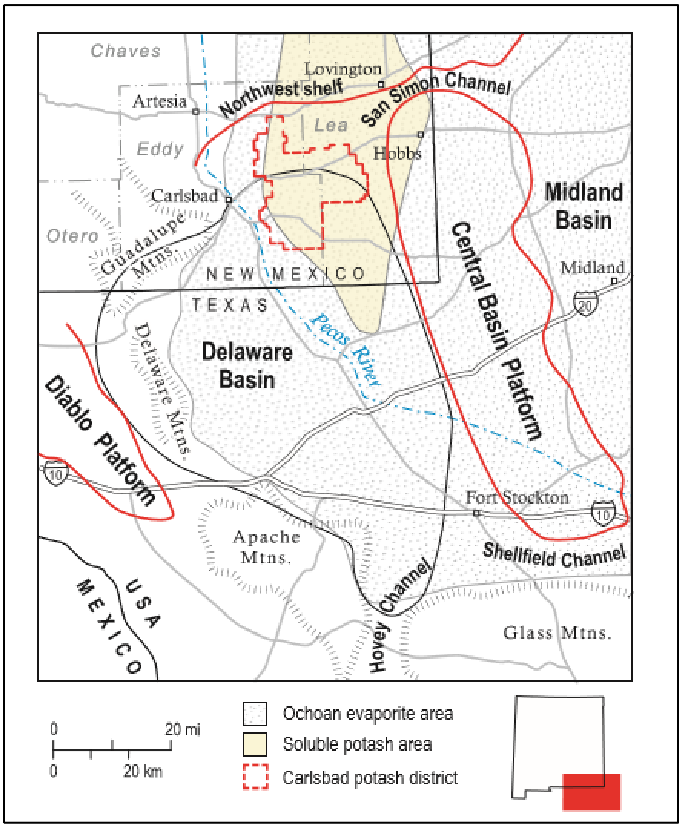


Figure 2. Location of the Carlsbad Potash district in the southwestern United States and its relation to the regional subsurface geology (after Barker and Austin, 1999 and Chemrox Technologies and Gustavson Associates LLC, 2009).

Rare earth elements (REE)

Rare earth elements (REE) include the 15 lanthanide elements (atomic numbers 57–71), yttrium (Y, atomic number 39), and scandium (Sc, atomic number 21). REE are enriched in the crust (known as lithophile elements) that have similar physical and chemical properties and, therefore, occur together in mineral deposits. However, REE are not always concentrated in easily mined economic deposits and only a few deposits in the world account for current production. In New Mexico, REE have been produced from a few pegmatite and vein deposits (Fig. 3; McLemore and Austin, 2017), and exploration has occurred recently in some areas containing carbonatites and REE veins.

The most economically-promising REE deposits in New Mexico are found in deposits associated with alkaline igneous rocks (Fig. 3; Great Plain margin deposits; McLemore, 2018), carbonatites (McLemore and Austin, 2017), and possibly episyenites (McLemore et al., 2018). Carbonatites are carbonate-rich rocks containing more than 50% magmatic carbonate minerals, less than 20% SiO_2, are of apparent magmatic derivation, and typically found in zoned complexes consisting of alkaline igneous and/or carbonatite stocks, ring dikes, and cone sheets. The term *episyenite* is used to describe altered rocks that were desilicified (subsolidus dissolution of quartz) and metasomatized by alkali-rich fluids. The metasomatic rocks in several areas in New Mexico, including the Caballo, Burro, and Zuni Mountains, Sevilleta Wildlife Refuge, and Lobo Hill (Fig. 3) were erroneously called syenites and alkali granites, but are actually metasomatic in origin and not primary igneous rocks (McLemore and Lueth, 2017; McLemore, 2018). Although REE are found in pegmatites and Cretaceous beach placer sandstone deposits in New Mexico, these deposits tend to be small and uneconomic at this time (McLemore and Austin, 2017). Additional unconventional mineral deposits that could be found in New Mexico include coal containing REE and REE in uraninite in sandstone uranium deposits of the Grants uranium district, and should be examined for their economic potential, especially if those deposits are mined in the future.

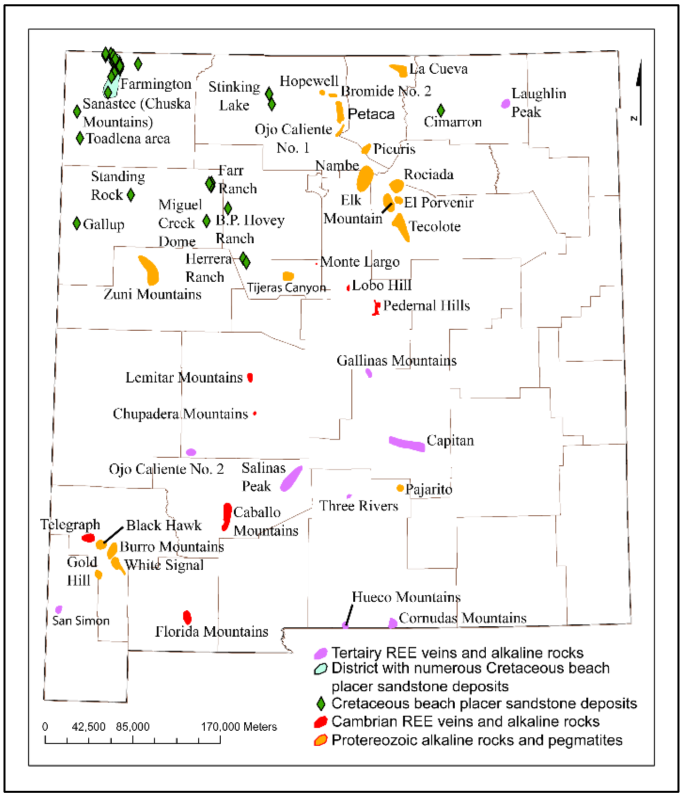


Figure 3. Mining districts in New Mexico that contain rare earth elements (REE) deposits (from McLemore and Austin, 2107). Summary of districts is in McLemore (2017, 2018).

Uranium (±V, Se, REE)

Today, uranium is used primarily in nuclear reactors to produce electricity via nuclear fission. Although no producing operations exist in New Mexico today, numerous companies have acquired uranium properties within the Grants, Hooks Ranch-Riley, and Red Basin-Pietown districts (Fig. 4) and plan to explore and develop deposits in the future. New Mexico has world-class uranium deposits in the Grants district and ranks 2nd in uranium reserves in the United States. These reserves amount to 64 million short tons of ore at 0.14% U_3O_8 (179 million pounds U_3O_8) at $50/pound. New Mexico has significant remaining resources that could be developed in the future if the price increases, number of nuclear generating plants increases, and environmental regulations allows for easier permitting uranium mines in the state (McLemore and Chenoweth, 2017). However, most of the uranium in the Grants district will require a mill for processing and only one mill is operating in the United States at Blanding, Utah, which would require expensive transportation costs.

The most important deposits in the state are within the sandstones of the Jurassic Morrison Formation in the Grants district. More than 348 million pounds of U_3O_8 have been produced from Morrison Formation deposits from 1948–2002, accounting for 97% of the total production in New Mexico and more than 30% of the total production in the U.S. Three types of uranium deposits are in the Westwater Canyon Member of the Morrison Formation: (1) primary, tabular (trend or blanket), (2) redistributed (roll-type or stack), and (3) remnant-primary sandstone. A fourth type, tabular sandstone uranium-vanadium deposits, is found in the Salt Wash and Recapture Members of the Morrison Formation in the western San Juan Basin. Other types of uranium deposits are found in New Mexico, but have not been major producers.

Vanadium was recovered from most of the uranium deposits in the Grants uranium district (McLemore and Chenoweth, 2017) and should be considered in future production. Selenium is found in several sandstone uranium deposits and also should be examined for potential recovery if uranium deposits once again are produced. REE are found in sandstone uranium deposits in uraninite and provide another potential recoverable mineral from these deposits (Breit, 2016).

Beryllium

Beryllium (Be) is a critical mineral because it is six times stronger than steel, has a high melting point, a high heat capacity, is non-sparking, is transparent to X-rays, and when alloyed with other metals it prevents metal fatigue failure, and is used in the defense, aerospace, automotive, medical, and electronics industries, in the cooling systems for nuclear reactors and as a shield in nuclear reactors. Beryllium deposits in New Mexico are small (Apache Warm Springs, 39,063 metric tons Be, grade <0.26% Be) and past production of beryl from New Mexico has been from pegmatites in Taos, Rio Arriba, Mora, San Miguel, and Grant Counties, with the majority of the beryl production from the Harding pegmatite, Taos County.

Three deposits in New Mexico have current potential for beryllium. Apache Warm Springs deposit in the Sierra Cuchillo is volcanogenic beryllium deposit, also known as Spor Mountain Be-U-F or epithermal volcanic-hosted deposit. The Iron Mountain deposit, also in the Sierra Cuchillo south of the Apache Warm Springs deposit, is a contact metasomatic W-Be-Sn-Fe deposit in limestones adjacent to Tertiary rhyolites and granite (Fig. 5). Beryllium also is found in the nepheline syenite at Wind Mountain, Otero County and in the molybdenum porphyry deposit at Questa, Taos County, although not in economic concentrations (Fig. 5).

W-Mo-Be skarn/vein deposits in Paleozoic dolostones, limestones, and sandstones were discovered in the Victorio Mountains, Luna County in the early 1900s. Gulf Minerals Resources, Inc. drilled 71 holes in 1977-1983 and delineated a porphyry Mo and W-Mo-Be skarn deposits northwest of Mine Hill and south of Middle Hills. At a cut-off grade of 0.02% WO_3, resources were estimated as 57,703,000 tons of 0.129% Mo and 0.142% WO_3. Open pit resources were estimated as 11,900,000 tons of 0.076% WO_3 and 0.023% Be. Galway Resources Ltd. acquired the Victorio Mountains deposit in the late 1990s.

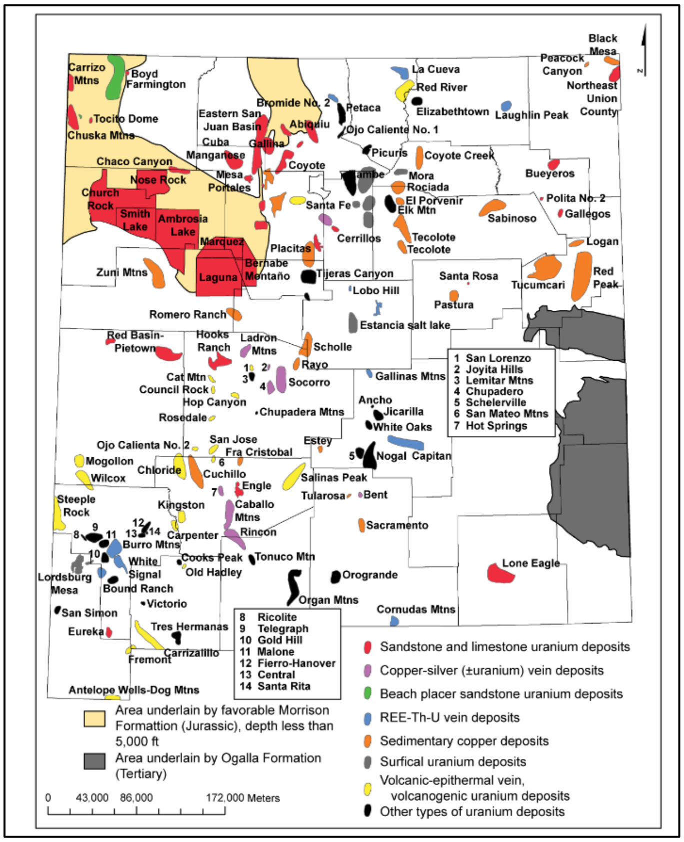


Figure 4. Mining districts that have uranium deposits and other areas favorable for uranium in New Mexico (modified from McLemore and Chenoweth, 2017). Each district is color-coded according to the predominant type of deposit; other types of uranium deposits are found in most districts.

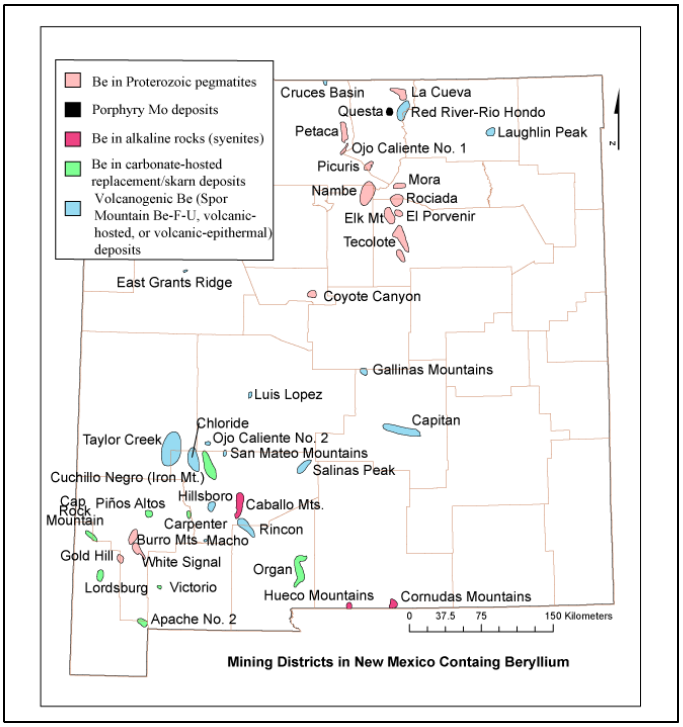


Figure 5. Mining districts in New Mexico that contain beryllium (Be). Summary of districts is in McLemore (2010a).

Tellurium

There are no primary tellurium mines in the world; most tellurium production comes from the anode slimes generated in metal refining, primarily from copper porphyry deposits. Tellurium is used as an alloying agent in iron and steel, as catalysts, and in the chemical industry. However, future demand and production could increase because tellurium is increasingly used in thin film cadmium-tellurium solar panels and some electronic devices. In New Mexico, anomalous amounts of tellurium are found associated with porphyry copper deposits, as well as with gold-silver vein deposits, but were not considered important exploration targets in the past (Fig. 6). The only tellurium production from New Mexico has been from the Lone Pine deposit (Wilcox district, Fig. 6) in the Mogollon Mountains, where approximately 5 tons of tellurium ore were produced. Gold-tellurides are found with gold, silver, pyrite, and fluorite in fracture-filling veins in rhyolite at Lone Pine, with reported assays as much as 5,000 ppm Te. Tellurium-bearing deposits also are found in the Organ Mountains, Sylvanite, Tierra Blanca, Grandview Canyon, and Hillsboro districts.

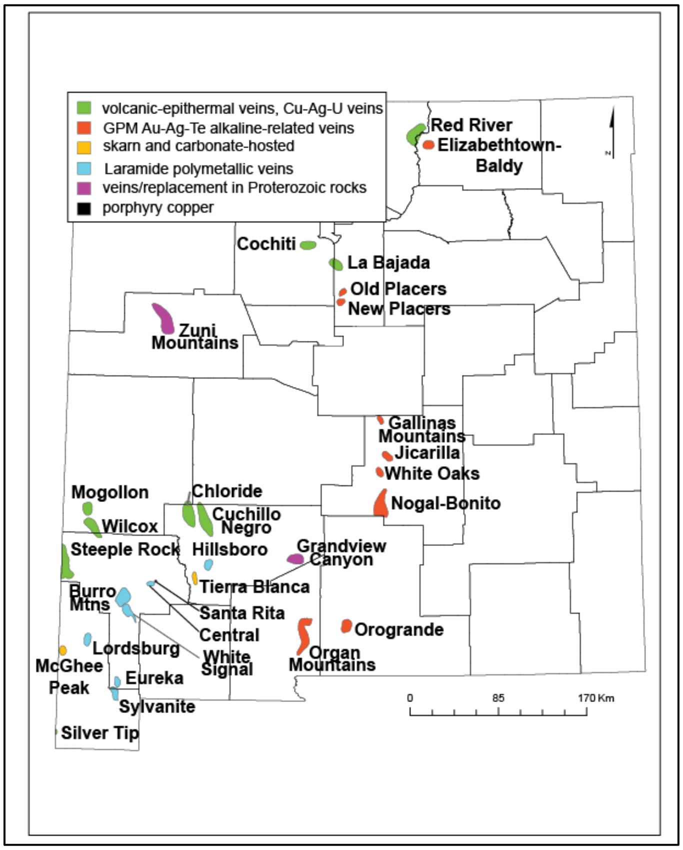


Figure 6. Mining districts in New Mexico with reported tellurium-bearing minerals or with >20 ppm Te in analyzed samples (McLemore, 2016). County boundaries shown as black lines. GPM=Great Plains Margin deposits.

Lithium

Lithium has become an important commodity because it is now used in lithium batteries to power a variety of electronic devices. Lithium was once produced from pegmatites in New Mexico, although most of the known pegmatites in the state are small and uneconomic (Fig. 7; McLemore and Austin, 2017; McLemore and Lueth, 2017).

Several NURE water samples near playa lakes in the northern Estancia Basin (Torrance County) and Lordsburg (Hidalgo County; Fig. 7), contain anomalously high lithium (as much as 624 ppb Li, McLemore, 2010b). The Estancia Basin is a closed basin bounded on the east by the Pedernal Hills and on the west by the Sandia and Manzano Mountains. The Lordsburg playa is one of several playas found in southern New Mexico and Arizona that could have potential for lithium.

Lithium also is found in ancient closed basins in the form of high-lithium clays, hectorite, and bentonite (Asher-Bolinder, 1991a, b). In New Mexico, lithium-rich tuffs in the Popotosa Formation contain lithium values as high as 3,800 ppm Li (Fig. 7; McLemore and Austin, 2017). No lithium has been produced from these deposits.

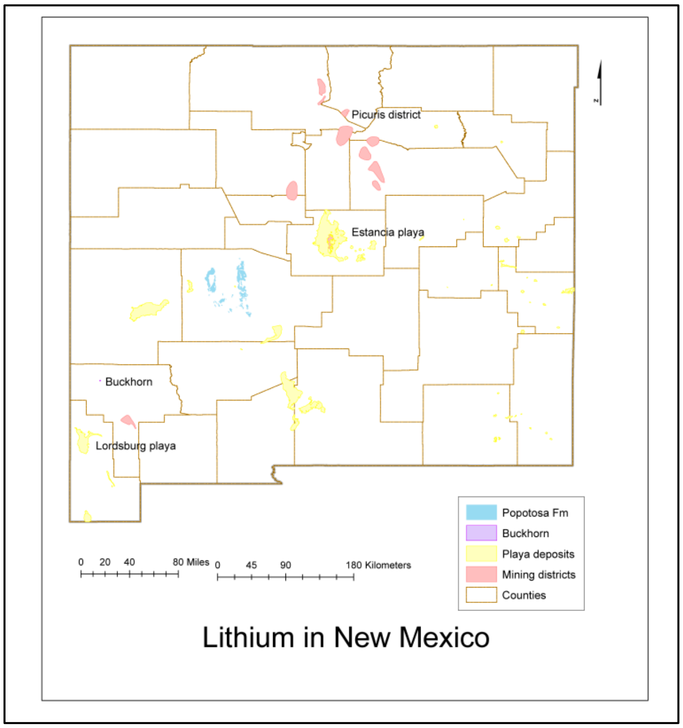


Figure 7. Geologic units and mining districts with lithium resources in New Mexico.

Critical minerals found in porphyry copper deposits in New Mexico

Porphyry copper and copper-molybdenum (±gold) deposits are large, low-grade (<0.8% copper) deposits that contain disseminated copper minerals, breccias, and stockwork veinlets of copper and molybdenum sulfides associated with porphyritic intrusions (McLemore and Lueth, 2017). 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 0.6–3.7 mi of the surface, and are surrounded by crudely concentric zones of hydrothermal alteration (Fig. 8). Hydrothermal solutions are released through these fractures and react with the host rocks, altering them in a characteristic, concentric zonation. Other types of deposits are commonly found near porphyry copper deposits, including skarns, polymetallic veins, and carbonate-hosted deposits. Precious metals (gold, silver) and critical minerals, including PGEs, tellurium, indium, germanium, and gallium, can be recovered from the anode slimes remaining after copper is refined (John and Taylor, 2016). They occur as particles of native species and as solid solutions or exsolved species in sulfide minerals. However, until the mine actually receives financial credit for these elements, production is geared towards recovering copper, gold, silver, and molybdenum, rather than the critical minerals. Most of the porphyry copper deposits in New Mexico are part of the Southwestern United States copper porphyry belt (Fig. 9).

WHAT ARE THE CHALLENGES IN PRODUCING CRITICAL MINERALS?

There are many challenges in producing many of the critical minerals.

Meeting the demand

Are there enough critical minerals in the pipeline to meet the demand for these technologies and other uses? There is much speculation in determining what the future demands will be for critical minerals. Geologists know where potential deposits are, and companies will explore for these minerals and conduct feasibility studies, once the price is high enough for investors to fund these projects. Some of these critical minerals must be mined in higher amounts than ever before. Substitution, recycling, and technological developments can affect demand. Knowing exactly what supplies are available and what is needed is difficult.

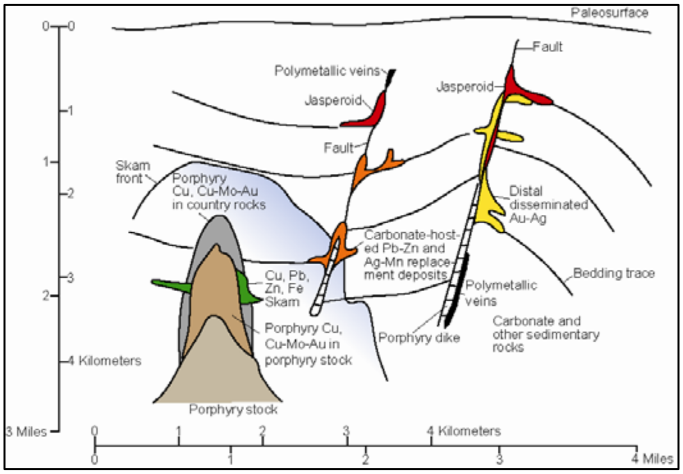


Figure 8. Simplified settings of porphyry copper and associated deposit types (modified from John, 2010). Distal disseminated Au-Ag deposits have not been found associated with porphyry copper deposits in New Mexico and are shown here as potential future exploration targets.

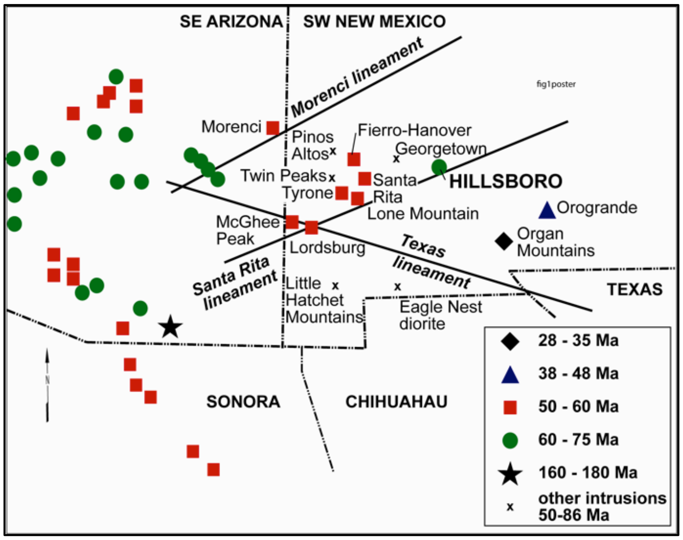


Figure 9. Laramide porphyry copper deposits in southwestern United States and northern Mexico. The Copper Flat porphyry copper deposit is in the Hillsboro district.

Environmental issues

Nearly all of these critical minerals will be mined and environmental issues will be identified and addressed during production. For example, REE deposits nearly always occurs with some quantities of uranium and thorium, generally not in enough concentrations that can be economically recovered, but in high enough concentrations to be of a concern in the radioactive waste rock remaining after mining and processing. If nuclear reactors that use thorium are built, then thorium may be recovered economically as a by-product from some deposits.

Other challenges to producing these commodities

There are additional challenges to overcome in producing critical minerals. Financing for both exploration/mining and development of new products is now competitive on a global scale. In the past, mining companies would respond to an increase in demand and shortage in supply by increasing production, but today, mining companies may not always be able to meet the quick change in supply and demand. Mining companies must engage the local community and obtain a social license to operate; without community support, production delays are inevitable. Mining companies must meet new regulations and pay new taxes. Mining companies, regulating agencies, universities, and all of us are now recognizing the shortage in trained personnel as the aging, experienced workforce is retiring. Planning for natural disasters (volcanic activity, earthquakes, droughts, floods) and even forecasts of changes in climate is becoming harder, but lowering standards is not an option. Local infrastructure in many areas of the United States and throughout the world is in need of maintenance and repair, and mining companies are often the only means of improvement.

CONCLUSIONS

New Mexico has a wealth of mineral resources and is currently producing copper, coal, potash, and a variety of industrial minerals, and has potential to produce one or more critical minerals in the future, besides potash. Although, numerous deposits in New Mexico have been explored for potential critical mineral resources in recent years, the lack of adequate exploration funding and the drive of exploration companies to capture investment dollars, has resulted in the exploration of some deposits to be based upon criteria for cheaper, less regulated minimal impact exploration status rather than having exploration governed by geologic criteria. Most of the favorable areas in New Mexico require additional regional and district geologic mapping, along with geophysical and geochemical studies to properly define exploration drilling programs. However, many of the critical minerals do not have sustainable economic futures, which makes investment dollars even scarcer.

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