MINERAL-RESOURCE POTENTIAL OF SABINOSO WILDERNESS AREA AND RIO GRANDE DEL NORTE NATIONAL MONUMENT IN NORTHEASTERN NEW MEXICO [1]

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SUMMARY

Mineral resources are the naturally occurring concentrations of materials (solids, gas, or liquid) in or on the earth's crust that can be extracted economically under current or future economic conditions. Most of the state's mineral production comes from oil, gas, coal, copper, potash, industrial minerals and aggregates. Oil and gas are the most important extractive industries in New Mexico in terms of production value and revenues generated, and are being evaluated in a separate report. The *mineral-resource potential* of an area is the probability or likelihood that a mineral will occur in sufficient quantities so that it can be extracted economically under current or future conditions, and includes the occurrence of undiscovered concentrations of metals, nonmetals, industrial materials, and energy resources. The mineral-resource potential is not a measure of the quantities of the mineral resources, but is a measure of the *potential* of occurrence. Factors that could preclude development of the resource, such as the feasibility of extraction, land ownership, accessibility of the minerals, or the cost of exploration, development, production, processing, permitting, bonding, or marketing, are not considered in assessing the mineral-resource potential. The proposed action is a land exchange that calls for transfer of state surface and minerals from the New Mexico State Land Office (SLO) to the Bureau of Land Management (BLM). Then, in return, the BLM will transfer BLM lands to the SLO. This report assesses the mineral-resource potential of the SLO lands, i.e., an assessment of selected economic mineral commodities that are most likely to be produced in the near future. The assessment for each area is below and for each individual parcel is in Appendix 1. As geologic mapping progresses at more detailed scales (i.e., 1:24,000), the mineral-resource potential in most areas of New Mexico will need to be updated. Furthermore, this assessment is based upon a literature search and experience of the author, but still requires field verification.

TABLE S1. Summary of mineral-resource assessment in the Sabinoso Wilderness Area and Rio Grande del Norte National Monument.

Area	Commodity	Mining District in Area (NM Mines Database)	Mineral-resource Potential	Level of Certainty	Geological units	Reasonably Foreseeable Development
Sabinoso Wilderness Area	Copper	DIS165	Low	Moderate	Trc	Low
	Uranium	DIS165	Low	Moderate	Trc	Low
	Uranium		Low	Low	Jm	Low
	Sand and gravel (aggregates)		Unknown	Low		High
Rio Grande del Norte	Placer gold	DIS239	Very high	High	Q	High
	Perlite	DIS235	Very high	High	Tv	High
	Pumice	DIS235	Very high	High	Tv	High
	Silica sand		Unknown	Low	P	High
	Stone		Very high	High		High
	Basalt		High	High	Tv	High
	Sand and gravel (aggregates)		High	High	Q	High

Trc=Chinle Formation, Jm=Morrison Fomration, Q=Quaternary sediments, Tv=volcanic rocks, P=Permian sandstones

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INTRODUCTION

Purpose and scope of this assessment

The New Mexico State Land Office (SLO) is developing an Environmental Assessment (EA) under provisions of the National Environmental Policy Act (NEPA), which requires the assessment of mineral-resource potential for state surface and state minerals for the land exchange. The proposed action is a land exchange that calls for transfer of state surface and minerals of parcels within the Sabinoso Wilderness Area and Rio Grande del Norte National Monument from the SLO to the Bureau of Land Management (BLM). Then, in return, the BLM will transfer BLM lands to the SLO (McLemore, 2018). This report assesses the mineral-resource potential of the SLO lands in the Sabinoso Wilderness Area and Rio Grande del Norte National Monument, New Mexico (Fig. 1; Appendix 1), and includes an assessment of selected economic mineral commodities that are most likely to be produced in the near future, for these federal lands that are available for land exchange with the SLO. The assessment for each individual parcel is in Appendix 1. Most of the effort for this report was synthesis and summary of previous work, and creation of various geodatabases and GIS layers for use by the New Mexico Bureau of Geology and Mineral Resources (NMBGMR), BLM and SLO in their evaluation efforts. The ESRI program ArcMap was the GIS program used to create the maps needed for this assessment.

Historic and Present Mining Activity

New Mexico's mineral wealth is among the richest of any state in the United States. Oil and gas are the most important extractive industries in New Mexico in terms of production value and revenues generated, and are being evaluated in a separate report. In 2016, New Mexico ranked 11th in coal production, and 20th in nonfuel minerals production in the United States. Most of the state’s mineral production comes from coal, copper, potash, industrial minerals and aggregates (Tables 1, 2). Other important commodities include a variety of industrial minerals (potash, perlite, cement, zeolites, etc.), sulfuric acid, molybdenum, gold, uranium, and silver. There are 246 mining districts and prospect areas described in New Mexico, summarized in McLemore (2017) and the geodatabase included with the GIS data (Fig. 2). Mining history of New Mexico is described by Jones (1904), Christiansen (1974), McLemore (2017), McLemore et al. (2017) and other reports cited in McLemore (2017).

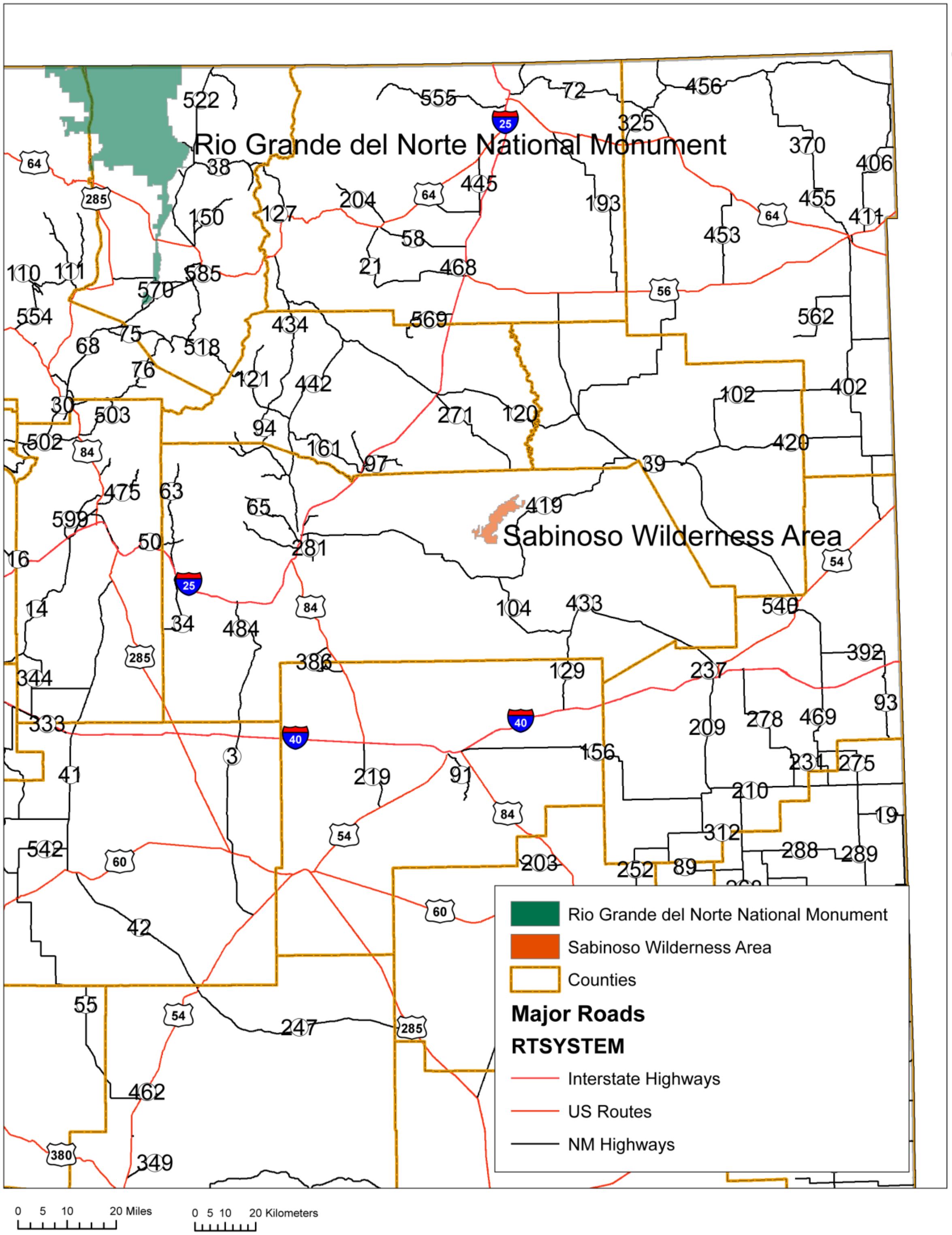

FIGURE 1. SLO areas of proposed lands in northeastern New Mexico to be transferred to the BLM (Appendix 1).

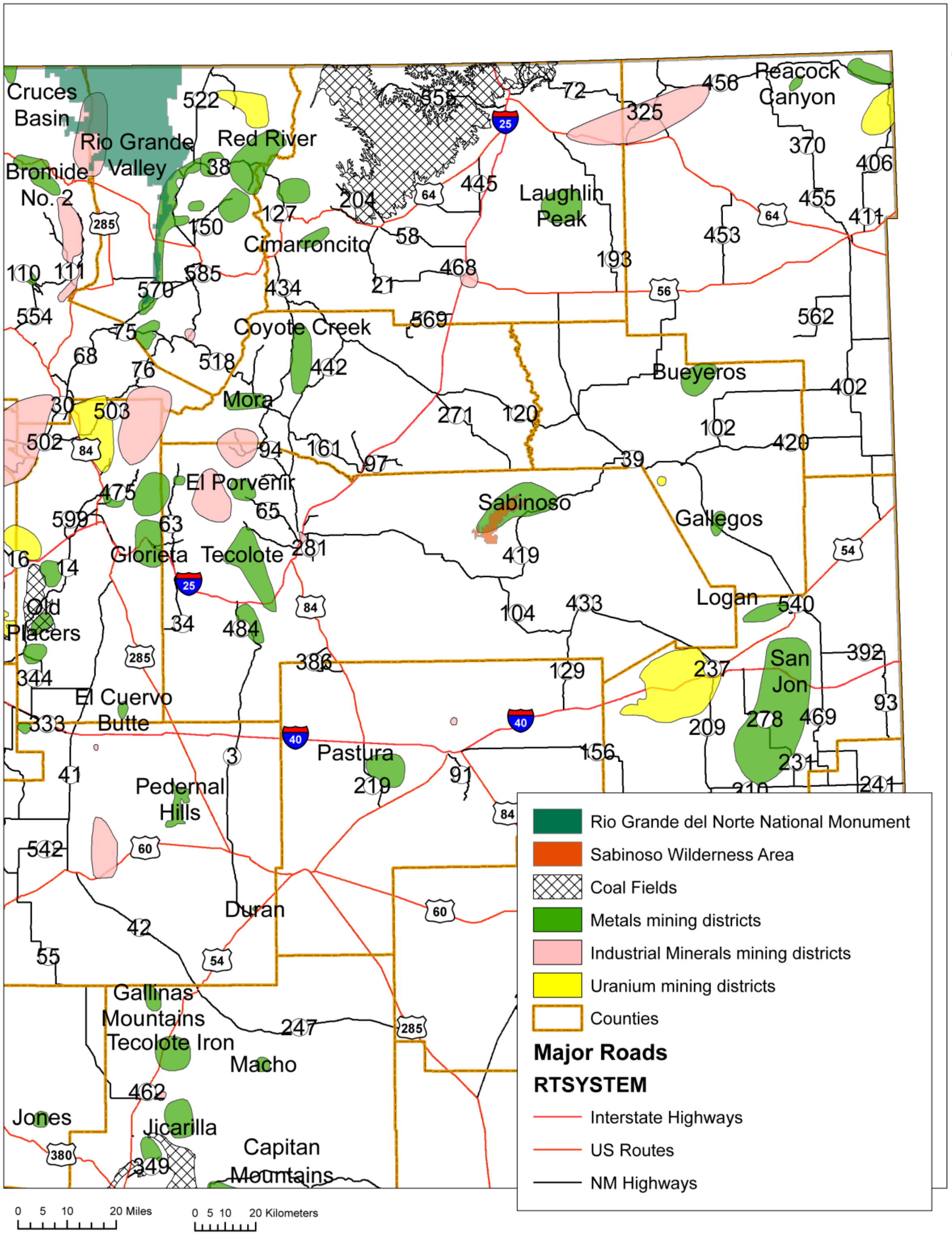

FIGURE 2. Coal fields, mining districts and prospect areas in northeastern New Mexico. Specific details on each mining district or prospect area, including names, are in the GIS data, McLemore (2017), and accompanying data found at http://geoinfo.nmt.edu/repository/index.cfml?rid=20170001.

TABLE 1. Estimated total production of major commodities in New Mexico, in order of estimated cumulative value (data from USGS, 1902–1927; USBM, 1927–1990; Kelley, 1949; Northrop, 1996; Harrer, 1965; USGS, 1965; Howard, 1967; Harben et al., 2008; Energy Information Administration, 2015; New Mexico Energy, Minerals and Natural Resources Department, 1986–2017; McLemore, 2017). Figures are subject to change as more data are obtained. Estimated cumulative value is in real, historic dollars at the time of production and is not adjusted for inflation.

COMMODITY	YEARS OF PRODUCTION	ESTIMATED QUANTITY OF PRODUCTION	ESTIMATED CUMULATIVE VALUE ($)
Coal	1882–2016	>1.47 billion short tons	>$22 billion
Copper	1804–2016	>11.9million tons	>$22.5 billion
Potash	1951–2016	114 million short tons	>$15.8 billion
Uranium	1948–2002	>347 million pounds	>$4.8 billion
Industrial minerals*	1997–2016	>42.9 million short tons	>$2.8 billion
Aggregates**	1951–2016	>685 short tons	>$2.67 billion
Molybdenum	1931–2013	>176 million pounds	>$852 million
Gold	1848–2016	>3.3 million troy ounces	>$514 million
Zinc	1903–1991	>1.51 million tons	>$337 million
Silver	1848–2016	>119 million troy ounces	>$285 million
Lead	1883–1992	>367,000 tons	>$56.7 million
Iron	1888–2016	>6.7 million long tons	>$23 million
Fluorspar	1909–1978	>721,000 tons	$12 million
Manganese	1883–1963	>1.9 million tons	$5 million
Barite	1918–1965	>37,500 tons	>$400,000
Tungsten	1940–1958	113.8 tons (>60% WO_3)	na
Niobium-tantalum	1953–1965	34,000 pounds of concentrates	na
TOTAL	1804–2016	—	>$70 billion

*Industrial minerals include the combined total of several industrial minerals (e.g., perlite, cement, decorative stone, pumice, zeolites, etc.), but excluding potash and aggregates.
** Aggregates include only sand and gravel from 1951–1997, after 1997 aggregates include crushed stone and scoria. na–not available.

TABLE 2. Summary of mineral production in New Mexico in 2016, excluding oil and natural gas (New Mexico Energy, Minerals and Natural Resources Department, 2017, https://wwwapps.emnrd.state.nm.us/ocd/ocdpermitting/Reporting/Production/ProductionInjectionSummaryReport.aspx). na—not available.

MINERAL	PRODUCTION IN 2016	RANK IN THE U.S.	PRODUCTION VALUE IN NM IN 2016	EMPLOYMENT IN NM (# FULL TIME JOBS)	STATE REVENUE GENERATED FROM EXTRACTIVE INDUSTRIES	FEDERAL REVENUE GENERATED FROM EXTRACTIVE INDUSTRIES
Copper	383,618,474 lbs	2	$842,913,365	1,638	$6,820,883	—
Coal	14,681,937 short tons	11	$392,338,603	1,088	$13,642,134	$7,189,610
Gold	22,142 troy oz	—	$27,641,699	—	$230,525	—
Industrial minerals	1,288,684 short tons	—	$114,996,639	470	$225,813	$368,877
Aggregates	10,833,266 short tons	—	$84,059,547	1,044	$2,105,478	—
Other metals (iron, manganese)	24,702 short tons	—	$222,317	20	$1,083,176	—
Potash	631,154 short tons	1	$268,838,554	791	$4,267,331	$5,247,792
Silver	293,070 troy oz	—	$5,025,050	—	$24,217	—
Uranium	none	—	—	11	—	—
Total 2016	—	20 (excluding oil, gas, and coal)	$1,736,035,774	5,692	$28,399,557	$12,806,279

Definitions of Mineral Resources and Mineral-Resource Potential

In industry, *minerals* refer to any rock, mineral, or other naturally occurring material of economic value, including metals, industrial minerals, energy minerals, gemstones, and aggregates. *Mineral resources* are the naturally occurring concentrations of materials (solids, gas, or liquid) in or on the earth's crust that can be extracted economically under current or future economic conditions. Reports describing mineral resources vary from simple inventories of known mineral deposits to detailed geologic investigations.

A *mining district*, as used in this report and in McLemore (2017), is a group of mines and/or mineral deposits that occur in a geographically defined area (including coal fields) that are determined locally by geologic and other criteria (distribution of mines, mineral deposits and occurrences, mineralogy, faults, lithology, stratigraphic horizons, common mineralization processes, age, etc.) and has had some mineral production. A *prospect area* is an area defined by geologic criteria (distribution of mines deposits and occurrences, mineralogy, faults, lithology, stratigraphic horizons, age, etc.) that has had *no* mineral production. Mining districts and prospect areas are part of the New Mexico Mines Database, which consists of a finite collection of tables that are linked to one another through use of unique alphanumeric mining district identification number (*DISTRICT ID*). Each district and prospect area is identified by a unique *DISTRICT ID*, termed “primary key” in the database that allows for information to be queried, entered without redundancy, and reported as standard output. Mining districts, coal fields, and prospect areas are polygons in the accompanying GIS data.

A *mineral occurrence* is any locality where a useful mineral or material occurs. A *mineral prospect* is any occurrence that has been developed by underground or above ground techniques or by subsurface drilling. These two terms do not have any resource or economic implications. A *mine* is any opening or excavation in the ground for extracting minerals, even if no actual mineral production occurred, and includes excavations currently producing a useful mineral or commodity. A *quarry* is any open or surface working, usually for the extraction of sand and gravel, building stone, slate, limestone, etc. A *mineral deposit* is any occurrence of a valuable commodity or mineral that is of sufficient size and grade (concentration) for potential economic development under past, present, or future favorable conditions. An *ore deposit* is a well-defined mineral deposit that has been tested and found to be of sufficient size, grade, and accessibility to be extracted and processed at a profit over a specific time. Mineral deposits are not found just anywhere in the world. Instead, they are relatively rare and their formation and distribution depends upon specific natural geologic conditions or processes to form. Mineral deposits require a source of constituent elements, transport and concentration mechanisms, and preservation from geochemical and mechanical destruction. The requirement that an ore deposit must be extracted at a profit makes them even rarer. Mineral deposits also form at various geologic times through a combination of geological processes that are closely related in time. Thus, mineral deposits are commonly clustered in geological provinces (i.e., mineral or mining districts) in terms of both location and time. Since an ore deposit is a subset of a mineral deposit, we shall use mineral deposit in most instances in this report. Mineral deposits include *industrial minerals* and rocks, which are any rock, mineral, or other naturally occurring substance of economic value, excluding most metals and gemstones. Industrial minerals and rocks are used in the manufacture of many products, from ceramics to plastics and refractories to paper. Mines, prospects, occurrences, exploration sites, mills, tailings, processing facilities and locally waste rock piles are given a unique Mine Identification Number in the New Mexico Mines Database and are point data in the accompanying GIS data (see below for more discussion).

The *mineral-resource potential* of an area is the probability or likelihood that a mineral will occur in sufficient quantities so that it can be extracted economically under current or future conditions, including the occurrence of undiscovered concentrations of metals, nonmetals, industrial materials, and energy resources (Taylor and Steven, 1983; Goudarzi, 1984; McLemore, 1985). Mineral-resource potential is preferred in describing an area, whereas mineral-resource favorability is used in describing a specific rock type or geologic environment (Goudarzi, 1984). The mineral-resource potential is not a measure of the quantities of the mineral resources, but is a measure of the *potential* of occurrence. Factors that could preclude development of the resource, such as the feasibility of extraction, land ownership, accessibility of the minerals, or the cost of exploration, development, production, processing, permitting, bonding, or marketing, are not considered in assessing the mineral-resource potential. Mineral-resource potential is expressed as polygons in the accompanying GIS data.

On federal land, the Mining Act of 1872 and subsequent legislation designated minerals as locatable, leasable, or saleable (see definitions at http://www.blm.gov/id/st/en/prog/energy___minerals/minerals.html). *Locatable minerals* are any minerals on federal land that are not leasable or salable, and are managed under the Mining Act of 1872 and subsequent federal regulations. Typical locatable minerals are gold, silver, copper, lead, zinc, molybdenum, uranium, barite, gypsum, gemstones, and certain varieties of high calcium limestone. A locatable mining claim, also known as an unpatented mining claim, provides the right to extract minerals, but no land ownership is conveyed.

Leasable minerals on federal land include oil and gas, oil shale, geothermal resources, potash, sodium, native asphalt, solid and semisolid bitumen, bituminous rock, phosphate, sulfur, and coal that are managed by the BLM under the Mineral Leasing Act of 1920, other leasing acts, and BLM regulations. *Salable minerals*, also known as mineral materials, are common varieties of minerals and building materials such as sand, stone, gravel, pumice, pumicite, cinders, humate, and clay and are managed under the Materials Act of 1947, as amended by subsequent legislation.

In addition, minerals are owned by private individuals or companies and are typically obtained by actual miners by staking mining leases. *Patented mining claims* are previous locatable mining claims where the federal government has issued a mining patent, which gives the owner full title (ownership) to the land surface, minerals, and other resources on the claim, as specified under the Mining Act of 1872 and subsequent legislation. However, the Interior and Related Agencies Appropriation Act of 1994 included a moratorium on the acceptance of new mineral patent applications, starting October 1, 1994. Most federal homestead and other federal land patents did not include the federal ownership of the minerals and only the surface ownership was transferred; the mineral ownership remained with the federal government. These mixed ownership lands are known as *split-estate lands*.

Other types of mining leases exist on non-federal lands. The SLO offers mining leases to mining companies for minerals on state trust land (http://www.nmstatelands.org/). The various Native American tribes throughout New Mexico control their mineral resources and offer mining leases. Private landowners that also own the mineral rights can offer mining leases. Many mining companies also privately own some of the land with mineral resources.

Mineral economics

The process from initial discovery of a mineral occurrence to a profitable mine is long and involves many stages, which have changed over the years (Fig. 3). Most discoveries found during the prospecting or exploration stage never become mines. In order for a mineral occurrence to become a mine, it is necessary to define the location, geologic, geotechnical, geochemical, quantity, quality, and many more characteristics, especially the costs involved in the various stages of mining (exploration, development, closure and post closure). Today, most mines must have a mine closure plan and must be permitted before production can begin, which typically can take as long as ten years or even longer. Mining sites generally are very complex with a variety of specialized sampling and monitoring requirements. The lifetime of a mine extends from the exploration phase (occurrences, prospects, exploration sites) to development (mines) to closure and post-closure, and can involve a timeframe of many years.

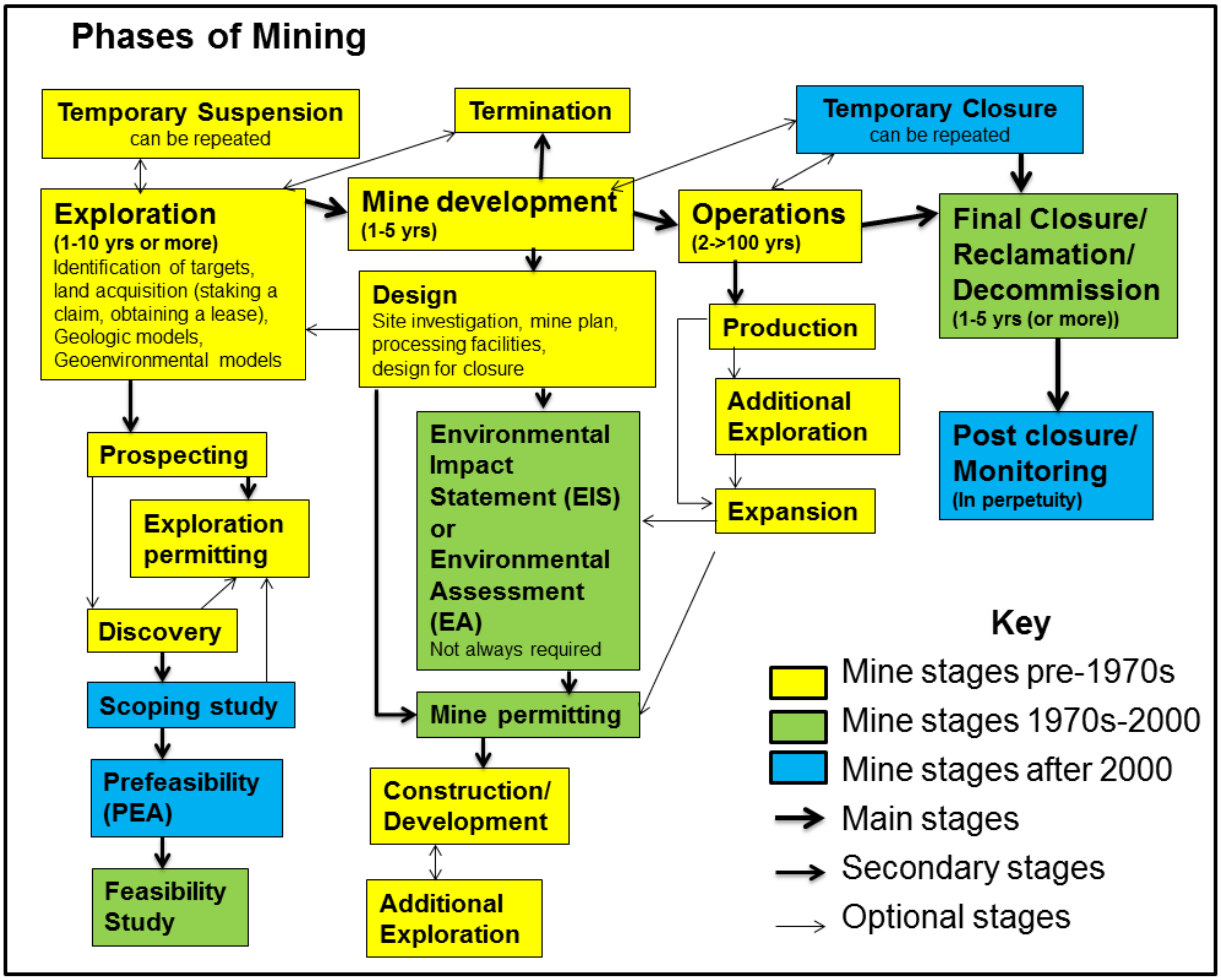

FIGURE 3. Stages of mining through history.

METHODS OF ASSESSMENT

Classification of mineral-resource potential

Classification of mineral-resource potential differs from the classification of mineral resources and reserves. Quantities of mineral resources are classified according to the availability of geologic data (assurance), economic feasibility (identified or undiscovered), and as economic or uneconomic. Mineral-resource potential is a qualitative judgement of the probability of the existence of a commodity and is classified as high, moderate, low, or no potential according to the availability of geologic data and relative probability of occurrence (Fig. 4).

DEFINITIONS OF LEVEL OF RESOURCE POTENTIAL

N **No mineral-resource potential** is a category reserved for a specific type of resource in a well-defined area with no evidence of mineral resources.

L **Low mineral-resource potential** is assigned to areas where geologic, geochemical, and geophysical characteristics indicate geologic environment where the existence of economic mineral resources is unlikely and is assigned to areas of no or dispersed mineralized rocks.

M **Moderate mineral-resource potential** is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for mineral-resource occurrence.

H **High mineral-resource potential** is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence and development. Assignment of high mineral-resource potential to an area requires some positive knowledge that mineral-forming processes have been active in at least part of the area.

DEFINITIONS OF LEVEL OF CERTAINTY

A Available information is not adequate for the determination of the level of mineral-resource potential.
B Low, available information suggests the level of mineral-resource potential.
C Moderate, available information gives a good indication of the level of mineral-resource potential.
D High, available information clearly defines the level of mineral-resource potential.

<table>
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INCREASING LEVEL OF RESOURCE POTENTIAL</td><td rowspan="5">U/A
Unknown Potential</td><td>H/B
High Potential</td><td>H/C
High Potential</td><td>H/D
High Potential</td></tr>
<tr><td>M/B
Moderate Potential</td><td>M/C
Moderate Potential</td><td>M/D
Moderate Potential</td></tr>
<tr><td>L/B
Low Potential</td><td>L/C
Low Potential</td><td>L/D
Low Potential</td></tr>
<tr><td rowspan="2">L/B
Low Potential</td><td rowspan="2">L/C
Low Potential</td><td>N/D
No Potential</td></tr>
<tr><td>N/D
No Potential</td></tr>
<tr><td colspan="5">***INCREASING LEVEL OF CERTAINTY*** →</td></tr>
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FIGURE 4. Classification of mineral-resource potential and certainty of assurance (from Goudarzi, 1984).

High mineral-resource potential is assigned to areas where there are known mines or deposits where the geologic, geochemical, or geophysical data indicate an excellent probability that mineral deposits occur. All active and producing properties fall into this category, and also includes active exploration projects that are in the permitting process. All identified deposits in known mining districts with significant past production or in areas of known mineralization fall into this category, unless mined out. Speculative deposits, such as reasonable extensions of known producing mining districts and identified deposits or partially defined deposits with past exploration within geologic trends are classified as high mineral-resource potential when sufficient data indicate a high probability of occurrence. This assignment, like other classifications, can be revised when new information, new genetic models, or changes in economic conditions develop. Some commodities and areas are assigned a very high mineral-resource potential in this report in order to designate current mineral production areas or areas likely to produce in the near future.

Moderate mineral-resource potential is assigned to areas where geologic, geochemical, or geophysical data suggest a reasonable probability that undiscovered mineral deposits occur in formations or geologic settings known to contain economic deposits elsewhere. Areas with multiple active or closed mining claims and areas of past exploration efforts would be included as having a moderate mineral-resource potential. Speculative deposits in known mining districts or mineralized areas are assigned a moderate potential if evidence for a high potential of economic deposits is inconclusive. This assignment, like other classifications, can be revised when new information, new genetic models, or changes in economic conditions develop.

Low mineral-resource potential is assigned to areas where limited available data imply the occurrence of mineralization, but the data are insufficient to indicate a high or moderate probability for the occurrence of an economic deposit. This includes speculative deposits in geologic settings not known to contain economic deposits, but which are similar to geologic settings of known economic deposits. Areas with scattered active or closed mining claims and areas with above-background chemical values are classified as having a low mineral-resource potential. Additional data are generally needed to better classify such areas.

No mineral-resource potential is assigned to areas where sufficient information indicates that an area is unfavorable for economic mineral deposits. This evaluation may include areas with dispersed, but uneconomic mineral occurrences as well as areas that have been depleted of their mineral resources. Areas with unfavorable geologic environments for specific mineral resources are assigned a no mineral-resource potential. Use of this classification implies a high level of geologic assurance to support such an evaluation, and it is assigned for potential deposits that are too deep to be extracted economically, even though there may not be a high level of geologic assurance. These economic depths vary according to the commodity, and current and future economic conditions.

Unknown mineral-resource potential is assigned to areas where necessary geologic, geochemical, and geophysical data are inadequate to classify an area otherwise. This assessment is assigned to areas where the degree of geologic assurance is low and any other classification would be misleading.

Methods of mineral-resource assessment

This report assesses the potential of mineral resources on the surface and within the subsurface within specific areas in New Mexico, excluding oil, gas, helium, and carbon dioxide potential (subject of a separate report). The evaluation of mineral-resource potential involves a complex process based on geologic analogy and probability of promising or favorable geologic environments with geologic settings (geologic models) that contain known economic deposits, as described in Goudarzi (1984) and McLemore (1985). Such subjective assessments or judgments depend upon available information concerning the area, as well as current knowledge and understanding of known deposits. The mineral resources were assessed by compilation and integration of all available published and unpublished geologic, geochemical, geophysical, and production data. Most commodities were evaluated at the mining district or prospect area scale (as defined by McLemore, 2017), although some industrial minerals have potential outside of known mining districts, which are identified by polygons indicating the mineral-resource potential. The mineral-resource potential described in this report is adequate to the district scale (approximately at a scale of 1:24,000), unless otherwise stated.

In general, the process of determining mineral-resource potential for each commodity is to identify favorable geologic settings, known mines, deposits, unmined deposits, mining claims and favorable areas, and then to identify areas of high, moderate, and low for a given resource.

Selection of Mineral Commodities

Although, a wide range of mineral commodities are found in New Mexico, due to time-constraints, this report focuses on selected minerals most likely to be economic under current or foreseeable economic conditions. Minerals evaluated for this report are generally those that are (1) currently being produced, (2) could support new mining activity, or (3) are considered critical minerals (see below). Favorable geology, type of mineral deposit, alteration, mining districts, mining claims, historical production and exploration data are among the most important factors in selection of these minerals. The other commodities should be evaluated in the future. Oil, gas, carbon dioxide, and helium mineral-resource potential is evaluated in a separate report. The selected commodities, including critical minerals, evaluated in this report are listed in Table 3.

TABLE 3. Commodities found in New Mexico selected for evaluation in this report. Critical minerals are designated by Schulz et al. (2017) and Department of Interior (2018-03219/draft-list-of-critical-minerals).

COMMODITY CLASS	COMMODITY	IS IT A CRITICAL MINERAL?
Metals	Copper (Cu)	
	Gold and silver (Au, Ag)	
	Molybdenum (Mo)	
	Platinum group elements (PGE: Pd, Pt, Os, Ir, Rh)	Yes
	Aluminum	Yes
	Antimony (Sb)	Yes
	Chromium	Yes
	Cobalt (Co)	Yes
Industrial minerals	Aggregate (sand and gravel)	
	Arsenic	Yes
	Barium (barite) (Ba)	Yes
	Beryllium (Be)	Yes
	Bismuth	Yes
	Cesium and rubidium	Yes
	Clay	
	Diatomite	
	Fluorine (fluorite)(F)	Yes
	Gallium (Ga)	Yes
	Garnet	Yes
	Germanium (Ge)	Yes
	Graphite (carbon)	Yes
	Gypsum	
	Hafnium (Hf)	Yes
	Helium	Yes
	Humate	
	Indium (In)	Yes
	Iron (Fe), iron oxide and magnetite (Fe)	

COMMODITY CLASS	COMMODITY	IS IT A CRITICAL MINERAL?
	Limestone and dolomite	
	Lithium (Li), strontium (Sr), bromine (Br), boron (B)	Yes
	Magnesium (Mg)	Yes
	Manganese (Mn)	Yes
	Mica	
	Niobium, tantalum (Nb, Ta)	Yes
	Perlite	
	Potash (K)	Yes
	Pumice	
	Rare earth elements (REE), including yttrium (Y)	Yes
	Rhenium (Re)	Yes
	Salt	
	Scandium (Sc)	Yes
	Selenium (Se)	Yes
	Silica sand	
	Stone	
	Tellurium (Te)	Yes
	Tin (Sn)	Yes
	Titanium (Ti)	Yes
	Tungsten (W)	Yes
	Vanadium (V)	Yes
	Zeolites	
	Zirconium (Zr)	Yes
Gemstones	Gemstones (including mineral collecting)	
Uranium	Uranium (U)	Yes
Coal	Coal	

Critical minerals

Our society is currently demanding more technologies like computers, cell phones, solar panels and wind turbines for electricity, batteries, and electric cars. Other technologies are being developed like water purification, desalination, carbon capture and storage, and even better light bulbs and they all require nontraditional minerals and commodities in their manufacture. Traditional commodities, like copper, iron for steel, and cement are required, but other nontraditional commodities, often called critical minerals, are also required. *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. (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.

Many of these minerals and commodities are not like traditional precious and base metals and energy minerals, where a market is already established and the commodity is traded world-wide. Many critical minerals and commodities are similar to industrial minerals and are dependent upon a specific market with customer-specified criteria being established. Some of these commodities do not require large quantities of production to meet the demand. For example, in the 1980s, approximately 12 elements were used to manufacture computer chips. Today more than 60 different elements are used in fabricating computer chips, and these same computer chips are essential in many everyday technologies that we depend upon. Substitution of other materials in many of these components is not an option. Although, recycling and conservation will play a part, most of these critical minerals will have to be mined, and some of these deposits are potentially found in New Mexico. Many challenges exist in mining these commodities, including potential environmental issues. Therefore, the mineral-resource potential of selected critical minerals is evaluated in this report as well as traditional commodities (Table 3).

FORMAT OF THIS REPORT AND ACCOMPANYING GIS DATA

This report differs from previous mineral-resource assessments in that support maps and other data are in accompanying GIS data. Specific information required to properly evaluate the mineral-resource assessment is organized in layers in the GIS data and described below. This report is organized by SLO areas (Sabinoso Wilderness Area and Rio Grande del Norte National Monument) instead of by commodities. The mineral-resource potential determinations for each of the individual parcels are in Appendix 1. The Reasonably Foreseeable Development (RFD) is discussed in a separate chapter in this report.

GIS Layers and sources of data

Sources of data

Data used in this report have been compiled from literature reviews, field examinations, and unpublished data by the author and include geologic maps, mineral occurrence records, mineral-resource assessments, production records, and evaluation of the NURE and other geochemical and geophysical data. Additional sources include:

- official government publications (including NMBGMR, U.S. Geological Survey (USGS), U.S. Bureau of Mines, BLM, U.S. Forest Service published reports)
- scientific journals
- N.M. Bureau of Geology and Mineral Resources mining archives
- university theses and other project works
- USGS MRDS database (https://mrdata.usgs.gov/mrds/)
- USGS prospect- and mine-related features on USGS topographic maps database (https://mrdata.usgs.gov/usmin/)
- USGS major mineral deposits database (https://mrdata.usgs.gov/major-deposits/)
- BLM official land records (https://glorecords.blm.gov/default.aspx)
- BLM LR2000 mining claims database (https://reports.blm.gov/reports.cfm?application=LR2000)
- NM Mining and Minerals Division mine registration database (http://www.emnrd.state.nm.us/MMD/mmdonline.html)
- New Mexico State Mine Inspector annual reports
- Mine Safety and Health Administration mines database

(https://arlweb.msha.gov/OpenGovernmentData/OGIMSHA.asp#msha-datasets)

- Office of Surface Mining Reclamation and Enforcement Abandoned Mine Land Inventory System (AMLIS; https://amlis.osmre.gov/QueryAdvanced.aspx)
- Office of Surface Mining Reclamation and Enforcement National Mine Map Repository (https://mmr.osmre.gov/MultiPub.aspx)
- U.S. Forest Service public GIS data
- county courthouse records
- other public information.

Several general reports describing the mineral resources of New Mexico, some including more detailed descriptions of many of the mining districts, can be found in Lindgren et al. (1910), Howard (1967), North and McLemore (1986), McLemore and Chenoweth (1989, 2017), McLemore (1984, 2001), Bartsch-Winkler and Donatich (1995), McLemore et al. (1984, 1986a, b, c, d, e, 1996a, 2001, 2002, 2005a, b), Bartsch-Winkler (1997), and numerous other reports listed in the references cited. Two additional publications were used in compiling this report that describes the types of deposits in New Mexico and their economic significance (McLemore, 2017; McLemore et al., 2017).

Mineral production by commodity from New Mexico is summarized in Table 1, and metals production by mining district is in the *Production* geodatabase included with the GIS data. However, mining and production records are generally poor, particularly for earliest mining activities, and many early records are conflicting. Nonetheless, these production figures are the best data available and were obtained from published and unpublished sources (USGS, 1902–1927; USBM, 1927–1990; New Mexico Energy, Minerals and Natural Resources Department, 1990–2017; NMBGMR unpubl. data). Historic production figures are subject to change as new data are obtained. Most resource or reserve data presented here are historical data and are provided for information purposes only and do not conform to Canadian National Instrument NI 43-101 requirements (http://web.cim.org/standards/documents/Block484_Doc111.pdf, accessed 10/8/14), unless otherwise stated. Historic and recent production and reserve/resource data are reported in metric or English units according to the original publication to avoid conversion errors.

Geology and deposit types

Layers from the state geologic map (New Mexico Bureau of Geology and Mineral Resources, 2003), which is at a scale of 1:500,000, are shown in the GIS data and used to identify favorable formations, where appropriate. Known areas of alteration are identified. As geologic mapping progresses at more detailed scales (i.e., 1:24,000), the mineral-resource potential in most areas of New Mexico will need to be updated.

Numerous classifications have been applied to mineral deposits to aid in exploration and evaluation of mineral resources (Lindgren et al., 1910; Lindgren, 1933; Eckstrand, 1984; Guilbert and Park, 1986; Cox and Singer, 1986; Roberts and Sheahan, 1988; Sheahan and Cherry, 1993; Dill, 2010; McLemore et al., 2017; McLemore, 2017). The USGS Mineral Deposit Models are "an organized arrangement of information describing the essential characteristics or properties of a class of mineral deposits. Models themselves can be classified according to their essential attributes (for example: descriptive, grade-tonnage models, genetic, geoenvironmental, geophysical, probability of occurrence, and quantitative process models)" (https://minerals.usgs.gov/products/depmod.html). They are a tool for assessing areas for undiscovered mineral deposits and were used in this assessment along with McLemore et al. (2017), and are summarized in Appendix 2.

Mining districts

Mining districts and prospect areas are defined by McLemore (2017), shown in Figure 2 and the GIS data. However, not all sand and gravel, crushed stone, and dimension stone operations are located in a specific mining district or prospect area, even if they were actually mined, because these low-value commodities are not constrained by criteria that defines a mining district. Undoubtedly new occurrences of metals, industrial minerals and energy minerals will be located that also are not in a mining district or prospect area designated in this resource map and new mining districts or prospect areas will be added in the future. File and Northrop (1966) recognized a Guadalupe Mountains district in Otero County, but there is no evidence of mineral deposits in that exact area and that district is no longer included as a district in this report.

Names of mining districts are generally from File and Northrop (1966), McLemore and Chenoweth (1989, 2017), McLemore (2001), McLemore et al. (2002, 2005a, b), McLemore and Lueth (2017), McLemore and Austin (2017), and McLemore (2017). The naming of a mining district or prospect area is a complex and sometimes an arbitrary and emotional issue. File and Northrop (1966) found five factors that enter into the naming of a mining district or prospect area: (1) lode and placer mining claim names, (2) survey names, (3) post office names, (4) agency names, and (5) names from other sources. These are in themselves complicating factors, and become more so when local custom imposes a local name for a place officially named something else on a topographic map or in the official government records. Some of the challenges in identifying a unique mining district and prospect area name include synonyms or aliases, spelling variations, confusion with names of mining camps and subdistricts, legislative changes in the county boundaries, and the same name applied to different areas. Thus the DISTRICT ID becomes important to uniquely identify a particular mining district. Most of the known synonyms or aliases are in the district details geodatabase in the GIS data and are in McLemore (2017).

There are five categories of coal fields, mining districts and prospect areas:

- **Metals** that are economically important in New Mexico include copper, gold, silver, and molybdenum. Gold and silver resources are described by McLemore (2001) and all of the metallic deposits are described by McLemore and Lueth (2017). Metals are locatable minerals under the federal classification system.
- **Industrial minerals** are described by McLemore and Austin (2017). Many industrial minerals are locatable minerals under the federal classification system; leasable commodities include potash, sodium, native asphalt, solid and semisolid bitumen, bituminous rock, phosphate, and sulfur. Salable minerals include common varieties of minerals and building materials such as stone, pumice, pumicite, cinders, and clay. Gemstones, locatable minerals, are included in the database as industrial minerals.
- **Aggregates**, as used in this report, refers to any of several hard, inert materials, such as sand, gravel, slag, or crushed stone, used for mixing with a cementing material to form concrete, mortar, or plaster; or used alone, as in railroad ballast or graded fill (McLemore and Austin, 2017). Aggregate is used predominantly for construction purposes and there are three general types: (1) construction sand and gravel, (2) crushed stone, and (3) lightweight aggregate (Austin and Barker, 1990). Aggregates are some of the most abundant natural resources and are a major basic raw material used by construction, agriculture, and industries employing complex chemical and metallurgical processes. The largest demand for aggregates in New Mexico is for

highway construction and then for building construction. Some aggregates are also considered industrial minerals and rocks. Aggregates, including sand, gravel, and crushed stone, are salable minerals under the federal classification system.

- **Uranium** districts are described in McLemore and Chenoweth (1989; 2017). Uranium is a locatable mineral under the federal classification system.
- **Coal** fields are described in Hoffman (1996, 2014, 2017). Coal is a leasable mineral under the federal classification system.

New Mexico Mines Database

The NMBGMR maintains the New Mexico Mines Database, which is a relational database that includes information on active and historical mines, prospects, occurrences, exploration sites, mills, tailings, processing facilities and locally waste rock piles in New Mexico (McLemore et al., 2002, 2005a, b; McLemore, 2017). Mines, prospects, occurrences, exploration sites, mills, tailings, processing facilities and locally waste rock piles are given a unique Mine Identification Number in the New Mexico Mines Database and are point data in the accompanying GIS data in New Mexico and consists of a prefix NM (for New Mexico), two letter abbreviation that represents the county followed by a unique number. Locations of mines were obtained from sources listed above.

Active mines

The New Mexico Mining and Minerals Division (NMMMD) maintains a database of active mines (http://www.emnrd.state.nm.us/MMD/mmdonline.html). These data were incorporated into the New Mexico Mines Database and shown in Figure 5. The mine identification numbers, prefixed by NM, are from the New Mexico Mines Database (McLemore et al., 2002, 2005a, b; McLemore, 2017) and refer to the mines listed in the text and in the accompanying GIS data.

Exploration areas (past, active)

Past and current active exploration areas are included as mines with unique mine identification numbers in the New Mexico Mines Database and are shown in Figure 5. The New Mexico Mining and Minerals Division (NMMMD) maintains a database of active permits in

New Mexico (http://www.emnrd.state.nm.us/MMD/mmdonline.html), which are included in this study. NMMMD data were supplemented with additional exploration projects that have not yet applied for exploration permits with NMMMD, but are reported by various companies as areas of active exploration.

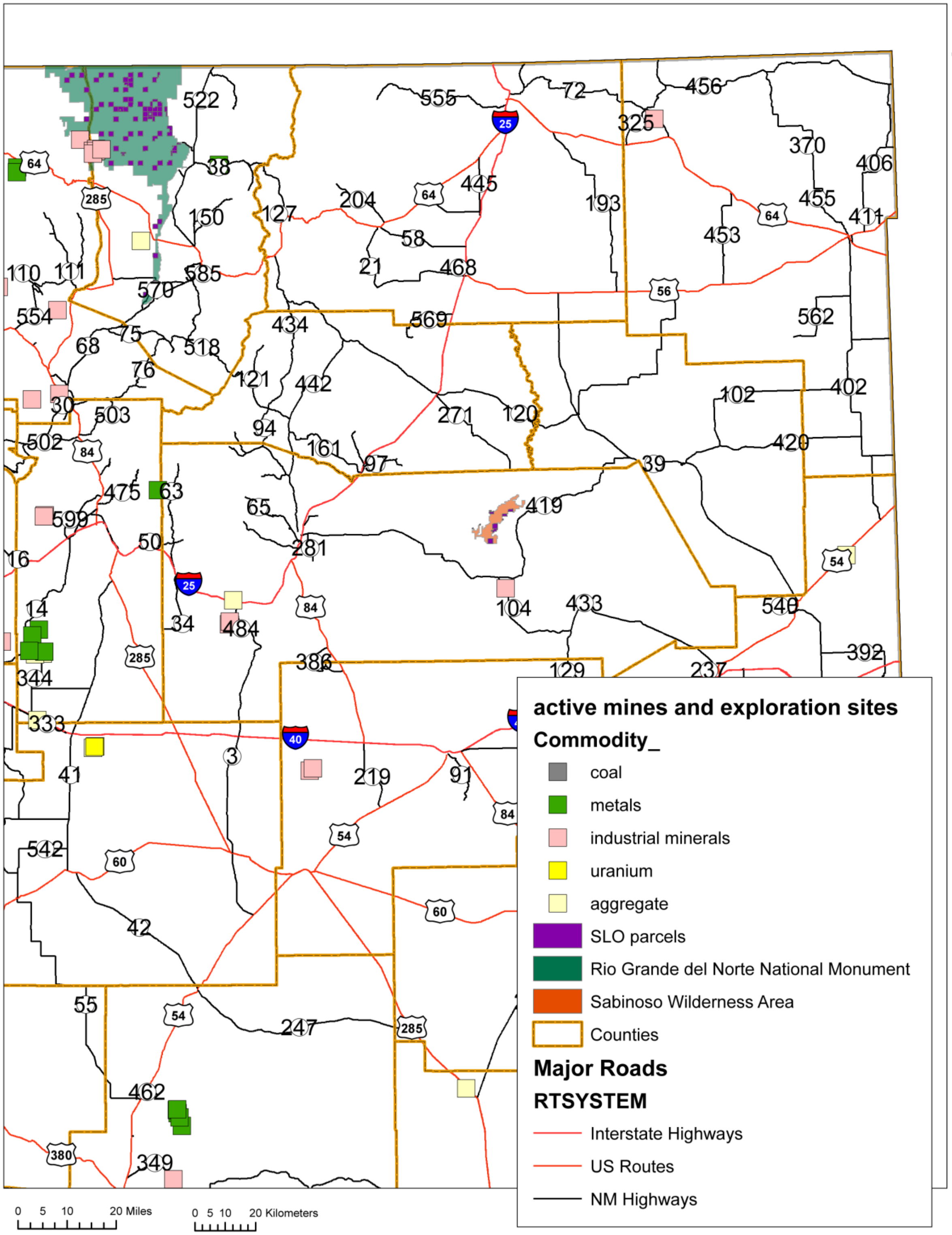

FIGURE 5. Active mines and exploration sites in northeastern New Mexico. Exploration sites are defined in this study as areas where a company or prospector is exploring for a commodity (including but not limited to permitted sites with NMMMD; see text). Not all aggregate

producers are shown. Specific details on each mine**,** including names, are in the GIS data and McLemore (2017).

Mining claims

The presence of mining claims indicates that someone had indications that some locatable commodity could be present; however most mining claims do not indicate any economic potential without significant exploration efforts. Locations of historical and active mining claims were obtained from the USGS (Causey and Frank, 2006; Causey, 2011) and the BLM LR2000 (https://www.blm.gov/lr2000/). However, the LR2000 database only identifies township, range, and sections that contain mining claims. The BLM converted the township, range and section of mining claims into latitude and longitude for entering into GIS. The actual location description of individual mining claims can only be obtained from the actual claim owner or from each county courthouse.

Geodatabases

Three geodatabases are included with the GIS data, which are from McLemore (2017): DistrictDetails, Production, and DistrictEvolution. The DistrictDetails geodatabase describes the mining districts and prospect areas in New Mexico. Fields are described in Appendix 3. The Production geodatabase includes reported and estimated base and precious metals production by district (non-confidential data). The DistrictEvolution geodatabase describes the evolution of the definition of mining districts in New Mexico through time. Number refers to the number listed by that author. Note that the coal fields are not included in the DistrictDetails geodatabase, but are included as a separate layer in the GIS coal fields shapefile. These data are also included in the data repository for McLemore (2017; http://geoinfo.nmt.edu/repository/index.cfml?rid=20170001).

MINERAL-RESOURCE POTENTIAL

Specific mineral-resource assessment by commodity for each area (Fig. 1) is briefly described below. Known mineral resources in New Mexico are described by references listed in the references cited and in McLemore (2017), Hoffman (2017), McLemore and Lueth (2017), McLemore and Austin (2017), and McLemore and Chenoweth (2017), and references cited within those reports. Selected maps are included in the discussions below; more details are in the GIS data.

Sabinoso Wilderness Area

The Sabinoso Wilderness Area is known for its spectacular canyons and mesas near Truijillo and Sabinoso, east of Las Vegas in San Miguel County (Fig. 1). Canon Largo enters the Canadian River at Sabinoso. Most of the area is within the Sabinoso mining district (DIS165) and numerous mines and prospects are present (Fig. 6). Sedimentary-copper deposits and sandstone uranium deposits are found within the Chinle Formation and sandstone uranium deposits potentially are found within the Morrison Formation in the Sabinoso Wilderness Area (McLemore and Menzie, 1983; McLemore, 1983; Almquist, 1986; Leibold et al., 1987; McLemore and Chenoweth, 1989, 2017; McLemore and Lueth, 2017). Uranium production is in Table 4. Mining claims have been staked in the area.

Although Leibold et al. (1987) classifies the mineral-resource potential for uranium in the Chinle Formation in the Sabinoso area as moderate, this report re-evaluates the mineral-resource potential for uranium and copper in the Chinle Formation in the Sabinoso area as low with a moderate level of certainty. The uranium-copper deposits in the district are low grade, small and not economic (McLemore and Menzie, 1983; McLemore and Chenoweth, 1989). The mineral-resource potential for potential sandstone uranium in the Morrison Formation in the Sabinoso area is low with a low level of certainty (Fig. 7). There are sand and gravel mines surrounding the Sabinoso Wilderness Area, and without field investigation, the mineral-resource potential for sand and gravel in the wilderness area is unknown with a low level of certainty.

TABLE 4. Uranium production for the Sabinoso mining district in New Mexico. Production prior to 1971 is from atomic Energy Commission (AEC) production records (McLemore, 1983). DISTRICT ID is from the New Mexico Mines Database.

District Id	District or occurrence area	Production* (lbs U_3O_8)	Typical grade of production (% U_3O_8)	Period of production (yrs)	Type of deposit (Appendix 2)
DIS165	Sabinoso district	81	0.08	1956	Sedimentary copper, sandstone uranium

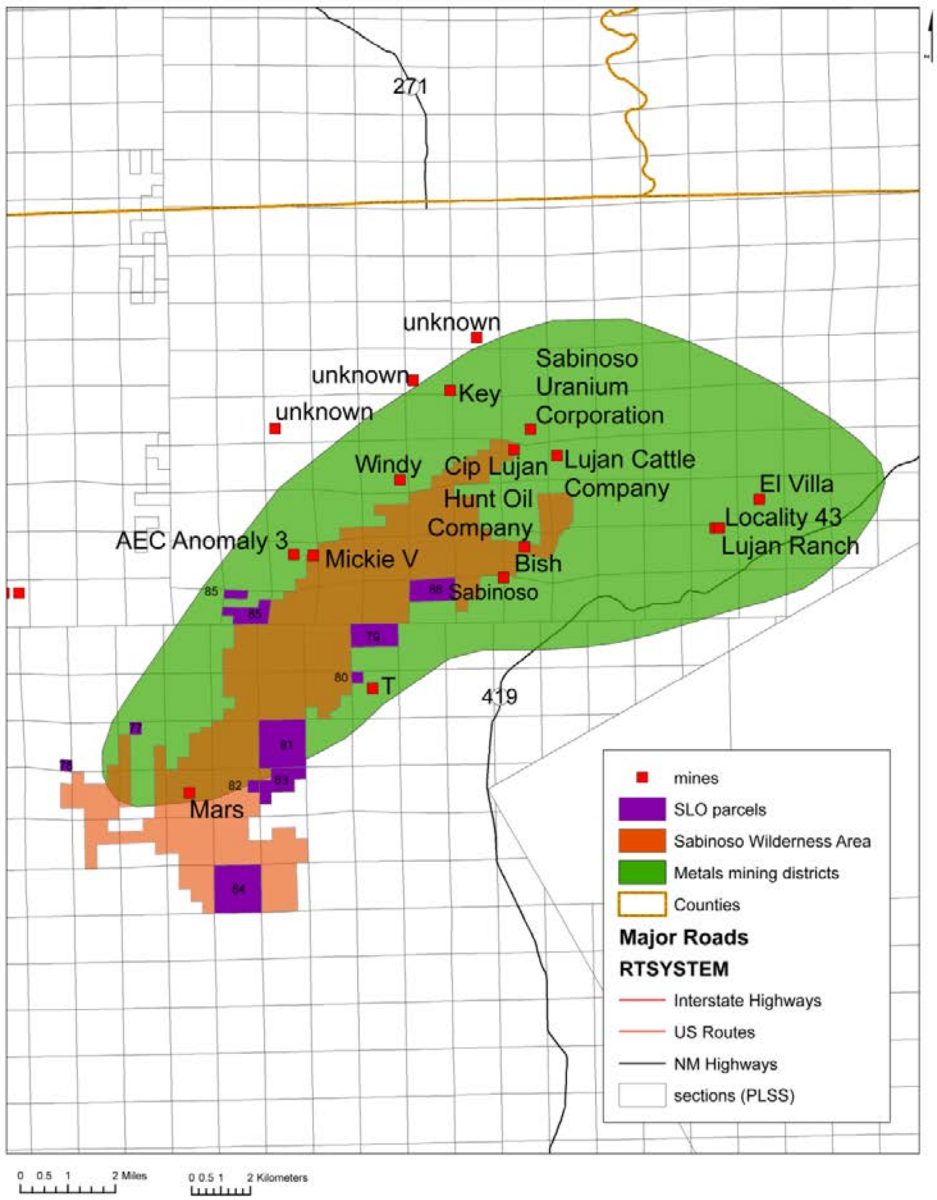

FIGURE 6. Mines, prospects, and SLO parcels in the Sabinoso Wilderness Area. The location of the Sabinoso Wilderness area is shown in Figure 1. Note that some of the colors are different from the legend because of the transparency function in ARCMAP.

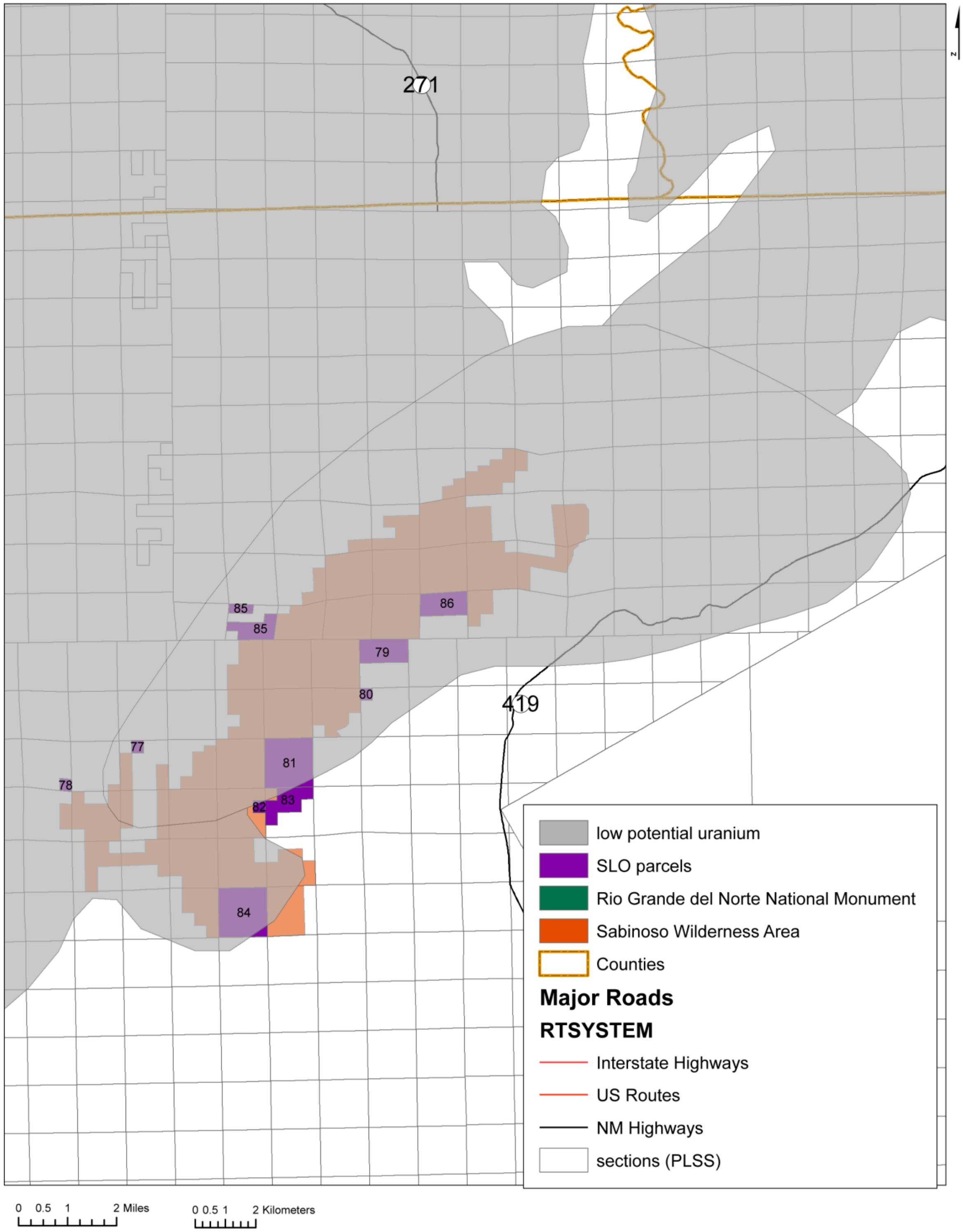

FIGURE 7. Uranium mineral-resource potential in the Sabinoso Wilderness Area. The location of the Sabinoso Wilderness area is shown in Figure 1. Note that some of the colors are different from the legend because of the transparency function in ARCMAP.

Rio Grande Del Norte National Monument

The Rio Grande del Norte National Monument lies within northern Rio Arriba and Taos Counties and was established on March 25, 2013 (https://www.blm.gov/programs/national-conservation-lands/new-mexico/rio-grande-del-norte-national-monument). The area comprises rugged, wide open plains, dotted by volcanic cones, and cut by steep canyons, including the Rio Grande. The National Monument includes the Rio Grande Gorge and the Rio Grande Wild and Scenic River. Ute Mountain is the highest volcanic peak, reaching to 10,093 ft. Two mining districts are found in the Rio Grande del Norte National Monument: No Agua (DIS235) and Rio Grande Valley (DIS239) (Fig. 8). Placer gold deposits are found in the Rio Grande Valley district (Johnson, 1972; McLemore, 1994, 2001; McLemore, 2017). Perlite and pumice are found in the No Agua district (McLemore, 2017). Numerous mines and prospects, including active mines in the No Agua district, are found in the National Monument. Mining claims also are found in the National Monument area.

The mineral-resource potential for placer gold in the Rio Grande and perlite and pumice in the No Agua district is very high with a high level of certainty (Fig. 9, 10). The mineral-resource potential for silica sand is unknown with a low level of certainty (Fig. 10). The mineral-resource potential for stone in the No Agua district is very high and for basalt in most of the National Monument is high with a high level of certainty (Fig. 11). The mineral-resource potential for sand and gravel (aggregates) is high with a high level of certainty along the eastern border of the National Monument (Fig. 12).

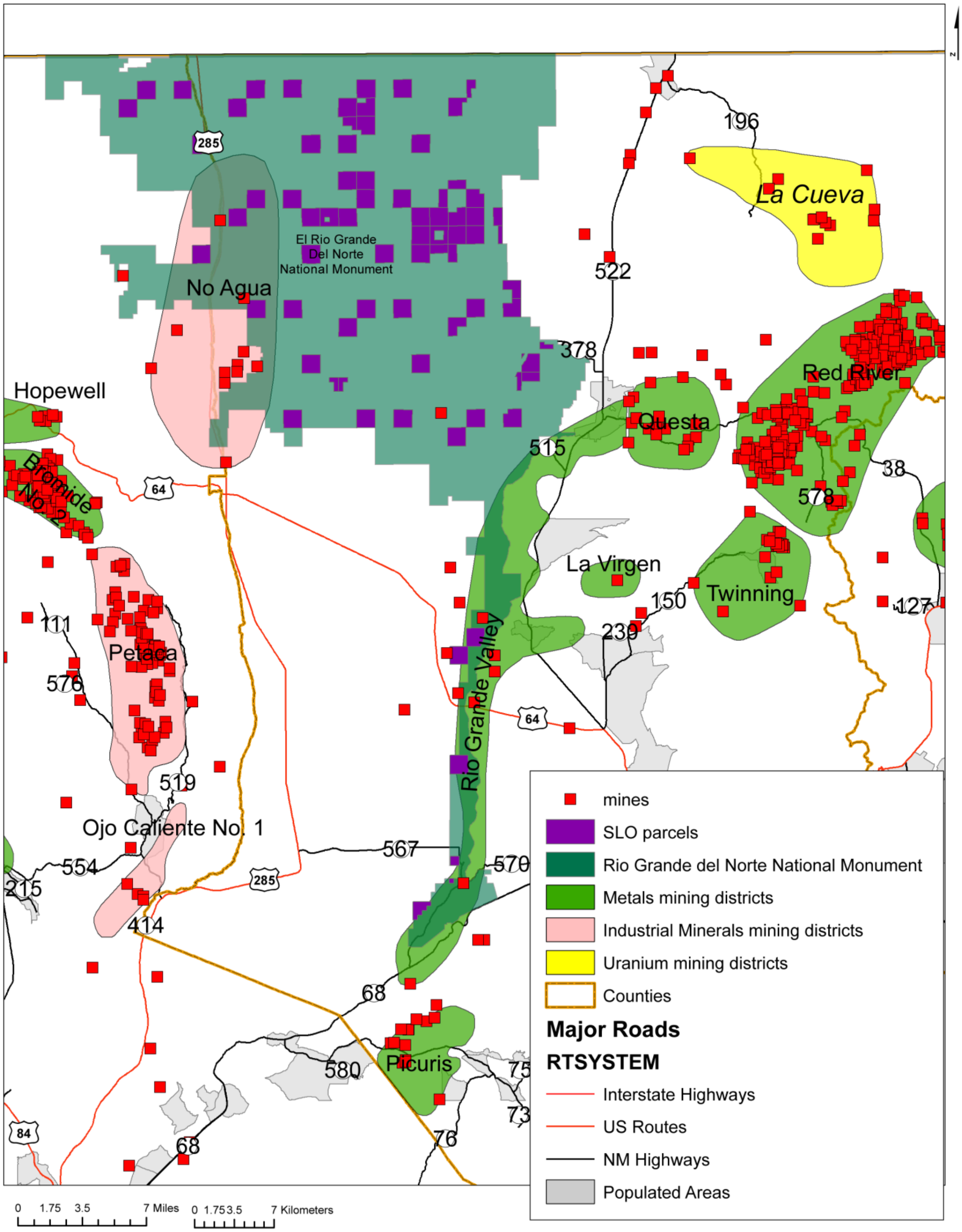

FIGURE 8. Mining districts, mines, prospects, and SLO parcels in the Rio Grande del Norte National Monument. The location of the Rio Grande del Norte National monument is shown in Figure 1. Note that some of the colors are different from the legend because of the transparency function in ARCMAP.

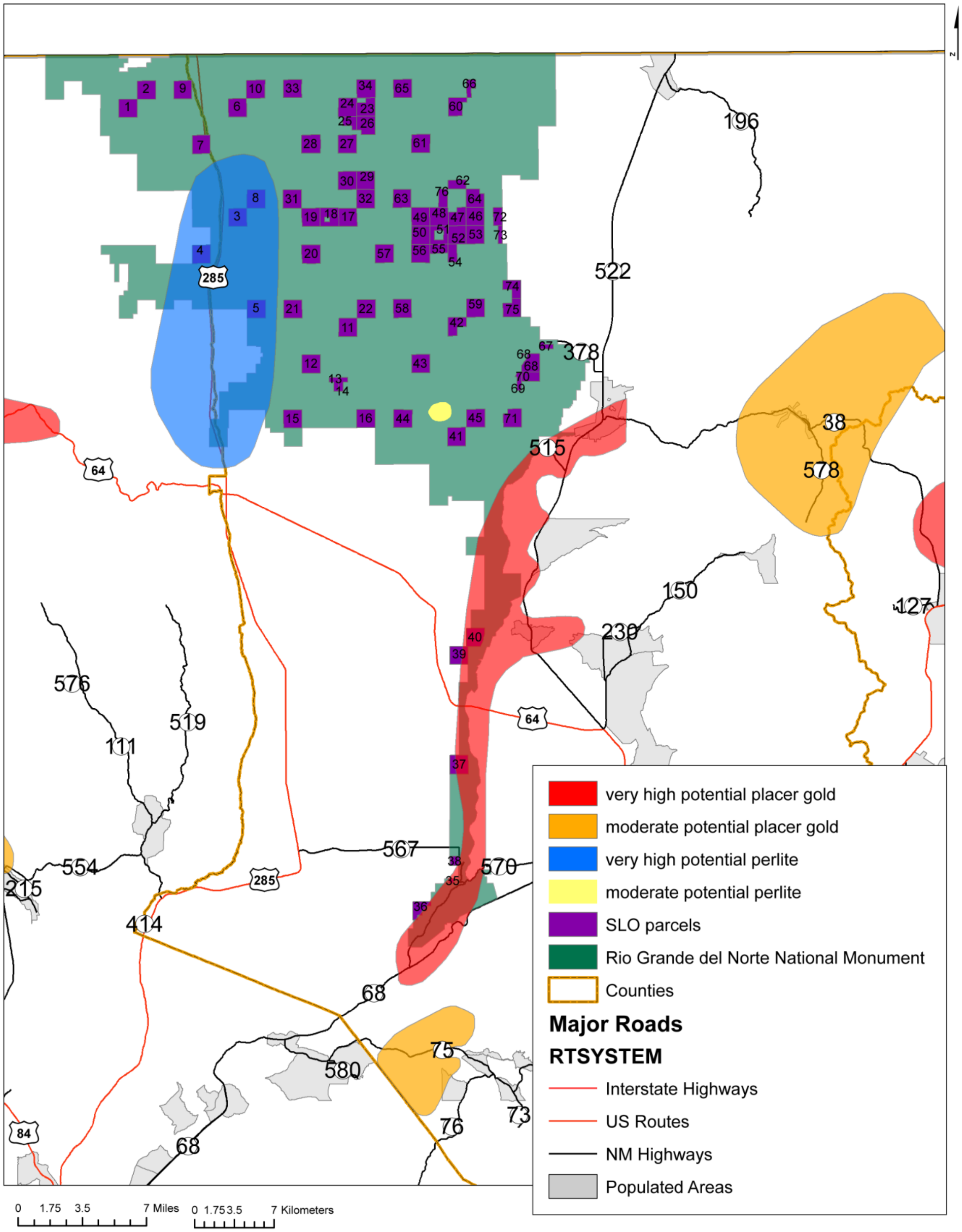

FIGURE 9. Mineral-resource potential for placer gold and perlite in the Rio Grande del Norte National Monument. The location of the Rio Grande del Norte National monument is shown in Figure 1. Note that some of the colors are different from the legend because of the transparency function in ARCMAP.

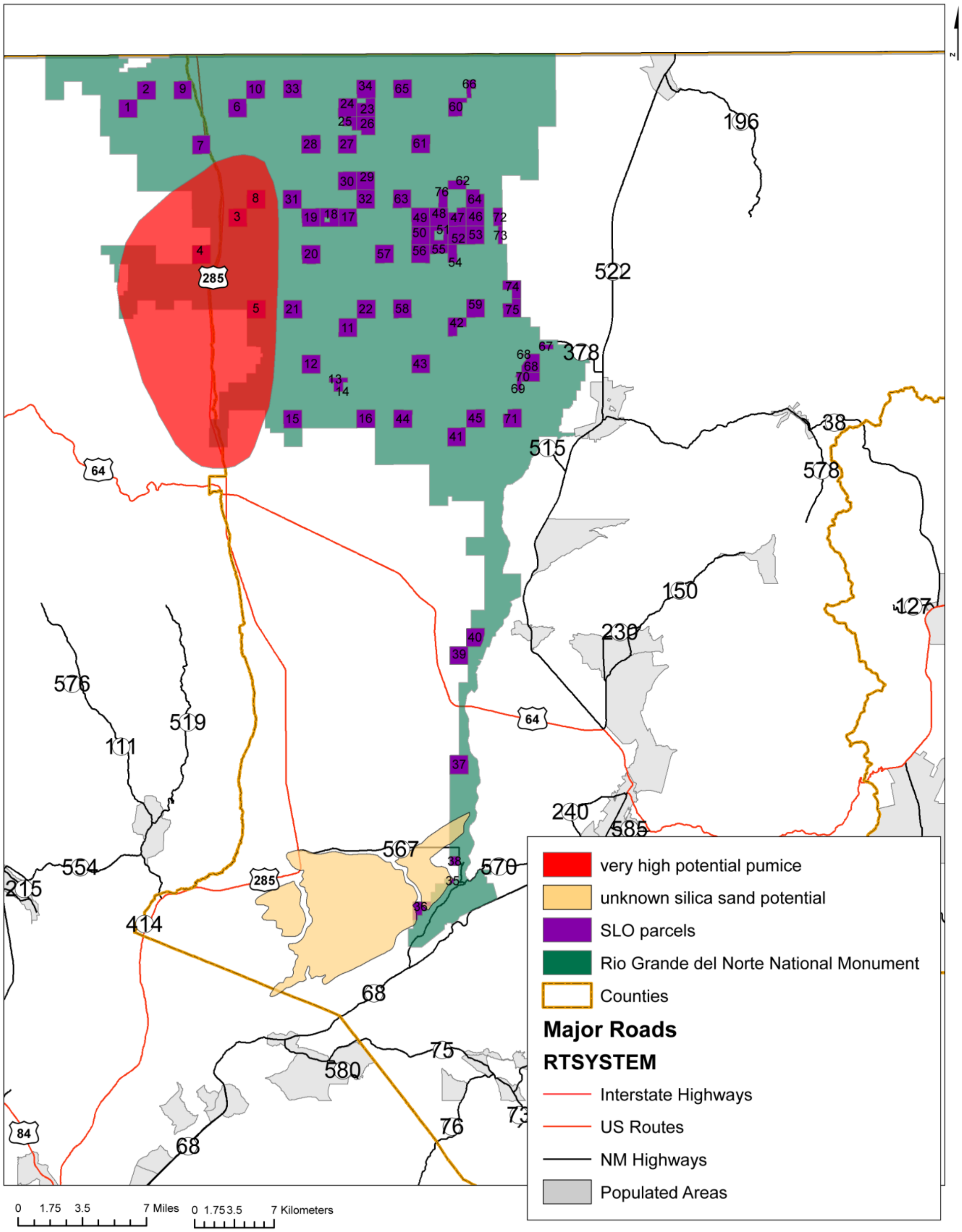

FIGURE 10. Mineral-resource potential for pumice and silica sand in the Rio Grande del Norte National Monument. The location of the Rio Grande del Norte National monument is shown in

Figure 1. Note that some of the colors are different from the legend because of the transparency function in ARCMAP.

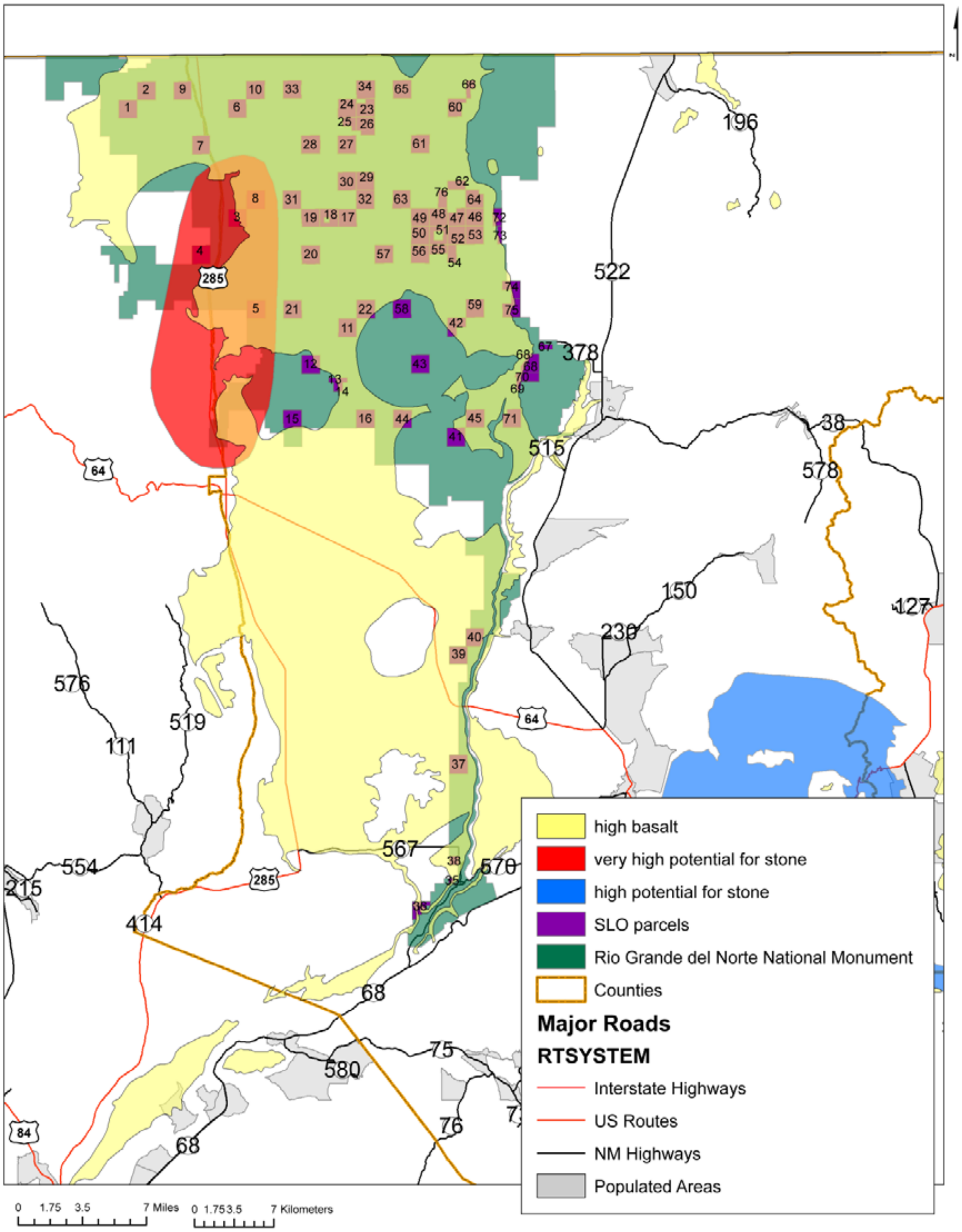

FIGURE 11. Mineral-resource potential for stone in the Rio Grande del Norte National Monument. The location of the Rio Grande del Norte National monument is shown in Figure 1.

Note that some of the colors are different from the legend because of the transparency function in ARCMAP.

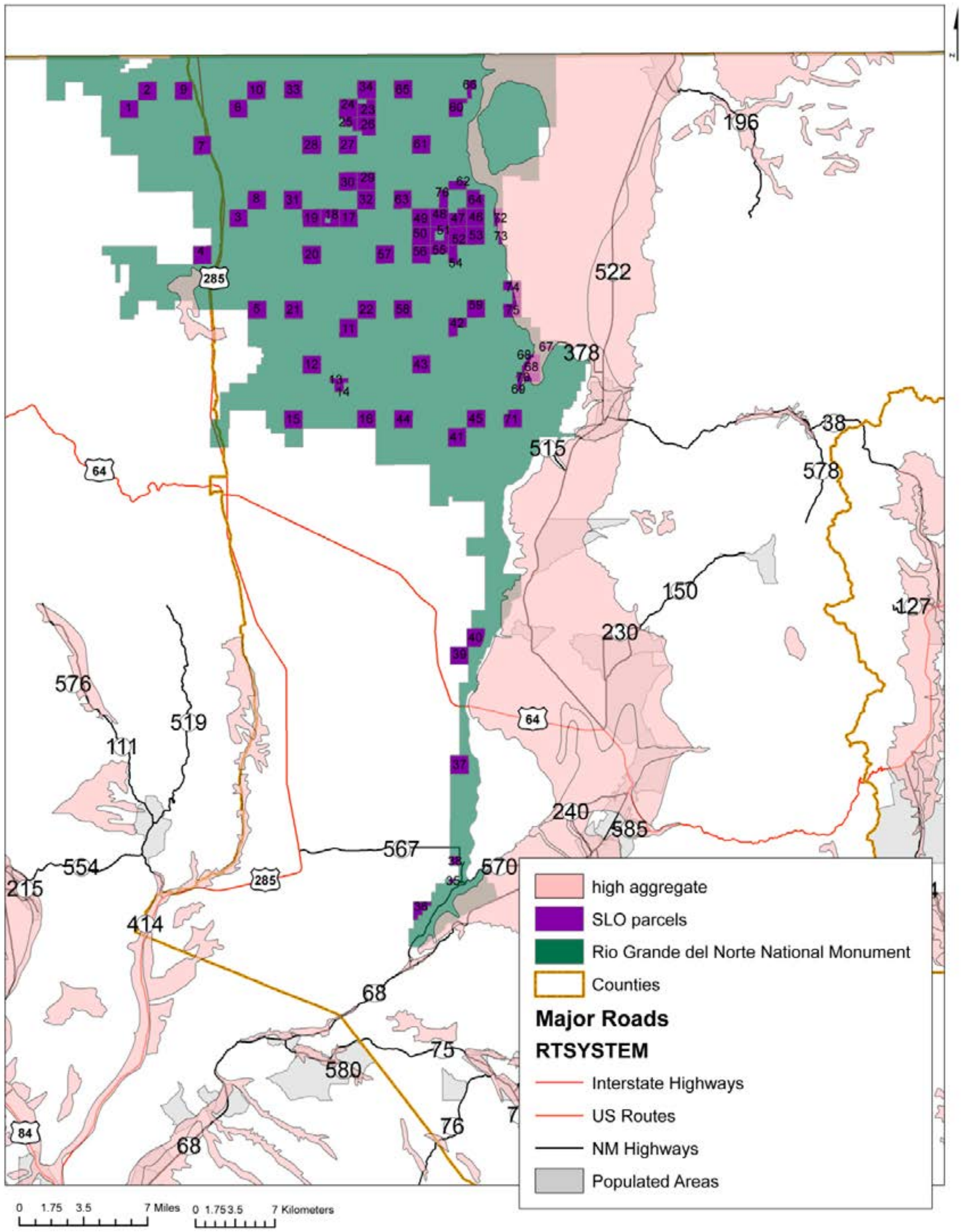

FIGURE 12. Mineral-resource potential for aggregates (sand and gravel) in the Rio Grande del Norte National Monument. The location of the Rio Grande del Norte National Monument is shown in Figure 1. Note that some of the colors are different from the legend because of the transparency function in ARCMAP.

REASONABLY FORESEEABLE DEVELOPMENT

Reasonably foreseeable development (RFD) is defined as the potential for the occurrence and likelihood for future development (i.e. mining) of mineral resources. The evaluation of RFD involves the evaluation of the potential of the occurrence of the resource based on geologic factors (i.e. mineral resource classification described above) and the evaluation of the potential for future exploitation of that resource based upon economic factors. Economic factors include future supply and demand, future prices, costs of production and processing, and changes due to new technologies. The best approach is to assess past production, supply, demand, and prices and predict changes in the future. Local economic factors also have a role in determination of RFD. McLemore (2017) and McLemore et al. (2017) include production tables and graphs showing the production of numerous commodities produced from New Mexico, which are used in the evaluation of the RFD.

In this report the RFD has been designated as high, low, unknown, and none. High RFD refers to areas where future production is likely. Low RFD refers to areas where production is not as likely because of economic factors. Unknown refers to areas where not enough data are available to properly asses the RFD. None refers to areas where there are no known resources in the area.

The near-term future mineral production of many commodities, especially metals, in New Mexico is uncertain at best because of many complex, interrelated issues, including permitting issues, land access, available water, environmental concerns, and negative perceptions of mining within the state. It typically takes 10-15 years to permit a mine in the U.S. The Copper Flat mine in Hillsboro, Sierra County has been in the permitting process for about 15 years and a record of decision from the BLM is pending (https://www.blm.gov/programs/planning-and-nepa/plans-in-development/new-mexico/copper-flat-eis) and, if permitted, would be the first new major metal mine to be permitted under the New Mexico Mining Act of 1993 (http://www.emnrd.state.nm.us/MMD/MARP/documents/MiningAct.PDF). Some communities view mining as unfavorable and are against any mining, even of sand and gravel or other aggregates. Without community support, obtaining permits to mine are difficult and take years of negotiating and ultimately are resolved by the courts. Areas adjacent to (or even near) wilderness areas, wilderness study areas, national and state parks and monuments, and wildlife refuges typically face similar opposition to mining. Some land owners depend upon other uses of their land (such as grazing, farming, hunting) and are fearful mining is high risk and could negatively impact those other more reliable income sources. The environmental issues are addressed in that most mines today must have approved closure plans before final permits are issued (see Fig. 3 for the typical mine life cycle). Mining companies are reluctant to invest in exploration and potential development in New Mexico because these issues add to the high risk of return of investment in a reasonable time period. Some additional specifics of economic factors for each commodity or commodity group are explained below.

TABLE 3. Commodities found in the Sabinoso Wilderness Area and the Rio Grande del Norte National Monument, northeastern New Mexico selected for evaluation in this report. Critical minerals are designated by Schulz et al. (2017).

COMMODITY CLASS	COMMODITY	IS IT A CRITICAL MINERAL?	AREA COMMODITY IS PRESENT	REASONABLY FORESEEABLE DEVELOPMENT
Metals	Copper (Cu)		Sabinoso	Low
	Placer gold (Au, recreational miners)		Rio Grande del Norte	High
Industrial minerals	Sand and gravel (aggregates)		Sabinoso Rio Grande del Norte	High
	Perlite		Rio Grande del Norte	High
	Pumice		Rio Grande del Norte	High
	Silica sand		Rio Grande del Norte	High
	Stone		Rio Grande del Norte	High
Uranium	Uranium (U)	Yes	Sabinoso	Low

Copper

New Mexico has been a significant producer for copper, primarily from the Silver City area (McLemore, 2017; McLemore and Lueth, 2017). The reasonably foreseeable development for copper in the Sabinoso Wilderness Area is low because of the small size of known deposits, access issues, environmental regulations, and potential permitting delays.

Gold and silver

The reasonably foreseeable development for placer gold in the Rio Grande Valley district is high for recreational gold miners (McLemore and Lueth, 2017). The reasonably foreseeable development for commercial development of placer is high.

Sand and Gravel (Aggregates)

The reasonably foreseeable development for sand and gravel (aggregates) near highway construction and larger cities is high (McLemore and Austin, 2017).

CONCLUSIONS

Energy (coal, uranium), metal, and industrial minerals resources are broadly distributed throughout New Mexico and are found in many mining districts that are scattered throughout the state (Table 3; Fig. 2). Distribution of mineral deposits is highly dependent on the geological conditions and processes necessary for concentration of the commodity in question. The assessment for each individual parcel is in Appendix 1. As geologic mapping progresses at more detailed scales (e.g., 1:24,000), the mineral-resource potential in most areas of New Mexico will need to be updated. Furthermore, this assessment is based upon a literature search and experience of the author, but still requires field verification.

TABLE 4. Summary of mineral-resource assessment in the Sabinoso Wilderness Area and Rio Grande del Norte National Monument.

Area	Commodity	Mining District in Area (NM Mines Database)	Mineral-resource Potential	Level of Certainty	Geological units	Reasonably Foreseeable Development
Sabinoso Wilderness Area	Copper	DIS165	Low	Moderate	Trc	Low
	Uranium	DIS165	Low	Moderate	Trc	Low
	Uranium		Low	Low	Jm	Low
	Sand and gravel (aggregates)		Unknown	Low		High
Rio Grande del Norte	Placer gold	DIS239	Very high	High	Q	High
	Perlite	DIS235	Very high	High	Tv	High
	Pumice	DIS235	Very high	High	Tv	High
	Silica sand		Unknown	Low	P	High
	Stone		Very high	High		High
	Basalt		High	High	Tv	High
	Sand and gravel (aggregates)		High	High	Q	High

Trc=Chinle Formation, Jm=Morrison Fomration, Q=Quaternary sediments, Tv=volcanic rocks, P=Permian sandstones

RECOMMENDATIONS

- Much of New Mexico has not been mapped at 1:24,000 scale, which is needed to fully understand the geology, structure, hydrology, and mineral-resource potential of the area.
- A complete inventory of historic and inactive mines, occurrences, and prospects is needed.
- Areas with active claims should be field checked.
- Regional geophysical data should be better incorporated into this assessment in order to identify areas in the subsurface that could have potential mineral resources.
- Refine this assessment to a more detailed scale (at least 1:12,000).

ACKNOWLEDGMENTS

The U.S. Bureau of Land Management (BLM) and the New Mexico State Land Office (SLO) requested and provided partial funding for this project. Additional funding was provided by the NMBGMR and other related projects in the past. Numerous mining companies provided some production and reserve data over the years used in this report. Mark Mansell and Adam Read assist with formatting the GIS data. Amy Trivett assisted with reorganizing and formatting the New Mexico Mines Database and providing data from the NMBGMR mining archives. Much of this report is based upon McLemore et al. (2017) and Stacey Timmons and Brigitte Felix assisted with those reports. Gretchen Hoffman, NMBGMR emeritus coal geologist, provided an assessment of the coal resources in New Mexico, which was used in this report. Marcus Silva, John Asafo-Akowuah, William Zutah, John Durica, and Bon Durica provided technical support.

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APPENDIX 1

MINERAL-RESOURCE POTENTIAL OF 87 SLO PARCELS

Trc=Chinle Formation, Jm=Morrison Fomration, Q=Quaternary sediments, Tv=volcanic rocks, P=Permian sandstones

Township	Range	Section	SLO_MOU_ID (SLOID_MOU)	LARGE_GROUP_ID (Group2)	Commodity	Mining District in Area (NM Mines Database)	Mineral-resource Potential	Level of Certainty	Geological units
0310N	0100E	01	23	A	basalt		high	high	Tv
0310N	0100E	02	24	A	basalt		high	high	Tv
0310N	0100E	11	25	A	basalt		high	high	Tv
0310N	0100E	12	26	A	basalt		high	high	Tv
0310N	0100E	14	27	A	basalt		high	high	Tv
0310N	0100E	16	28	A					
0320N	0100E	32	33	A	basalt		high	high	Tv
0320N	0100E	36	34	A	basalt		high	high	Tv
0310N	0110E	02	60	A	basalt		high	high	Tv
0310N	0110E	16	61	A	basalt		high	high	Tv
0320N	0110E	32	65	A	basalt		high	high	Tv
0320N	0110E	36	66	A	basalt		high	high	Tv
0310N	0080E	02	1	B	basalt		high	high	Tv
0320N	0080E	36	2	B	basalt		high	high	Tv
0300N	0090E	02	3	B	perlite	DIS235	very high	high	Tv
			3		pumice	DIS235	very high	high	Tv
			3		basalt		high	high	Tv
			3		stone	DIS235	high	high	Tv
0300N	0090E	16	4	B	perlite	DIS235	very high	high	Tv
			4		perlite	DIS235	very high	high	Tv
			4		stone	DIS235	high	high	Tv
0310N	0090E	02	6	B	basalt		high	high	Tv
0310N	0090E	16	7	B	basalt		high	high	Tv
0310N	0090E	36	8	B	perlite	DIS235	very high	high	Tv
			8		pumice	DIS235	very high	high	Tv
			8		basalt		high	high	Tv
			8		stone	DIS235	high	high	Tv
0320N	0090E	32	9	B	basalt		high	high	Tv
0320N	0090E	36	10	B	basalt		high	high	Tv
0300N	0100E	02	17	C	basalt		high	high	Tv
0300N	0100E	03	18	C	basalt		high	high	Tv
0300N	0100E	04	19	C	basalt		high	high	Tv
0300N	0100E	16	20	C	basalt		high	high	Tv
0310N	0100E	25	29	C	basalt		high	high	Tv
0310N	0100E	26	30	C	basalt		high	high	Tv
0310N	0100E	32	31	C	basalt		high	high	Tv
0310N	0100E	36	32	C	basalt		high	high	Tv

Township	Range	Section	SLO_MOU_ID (SLOID_MOU)	LARGE_GROUP_ID (Group2)	Commodity	Mining District in Area (NM Mines Database)	Mineral-resource Potential	Level of Certainty	Geological units
0300N	0110E	01	46	C	basalt		high	high	Tv
0300N	0110E	02	47	C	basalt		high	high	Tv
0300N	0110E	03	48	C	basalt		high	high	Tv
0300N	0110E	04	49	C	basalt		high	high	Tv
0300N	0110E	09	50	C	basalt		high	high	Tv
0300N	0110E	10	51	C	basalt		high	high	Tv
0300N	0110E	11	52	C	basalt		high	high	Tv
0300N	0110E	12	53	C	basalt		high	high	Tv
0300N	0110E	14	54	C	basalt		high	high	Tv
0300N	0110E	15	55	C					
0300N	0110E	16	56	C					
0300N	0110E	18	57	C					
0310N	0110E	26	62	C	basalt		high	high	Tv
0310N	0110E	32	63	C	basalt		high	high	Tv
0310N	0110E	36	64	C	basalt		high	high	Tv
0300N	0120E	06	72	C	sand and gravel		high	high	Q
			72		basalt		high	high	Tv
			72						
0300N	0120E	07	73	C	sand and gravel		high	high	Q
			73		basalt		high	high	Tv
0310N	0110E	34	76	C	basalt		high	high	Tv
0280N	0110E	02	41	D	basalt		high	high	Tv
0290N	0110E	02	42	D	basalt		high	high	Tv
0290N	0110E	16	43	D					
0290N	0110E	32	44	D	basalt		high	high	Tv
0290N	0110E	36	45	D	basalt		high	high	Tv
0300N	0110E	32	58	D					
0300N	0110E	36	59	D	basalt		high	high	Tv
0290N	0120E	10	67	D	sand and gravel		high	high	Q
			67		basalt		high	high	Tv
0290N	0120E	16	68	D	sand and gravel		high	high	Q
			68		basalt		high	high	Tv
0290N	0120E	20	69	D	basalt		high	high	Tv
0290N	0120E	21	70	D	sand and gravel		high	high	Q
0290N	0120E	32	71	D	basalt		high	high	Tv
0300N	0120E	29	74	D	sand and gravel		high	high	Q
			74		basalt		high	high	Tv
0300N	0120E	32	75	D	sand and gravel		high	high	Q
			75		basalt		high	high	Tv
0300N	0090E	36	5	E	perlite	DIS235	very high	high	Tv
			5		pumice	DIS235	very high	high	Tv
			5		stone	DIS235	high	high	Tv
0290N	0100E	02	11	E					
0290N	0100E	16	12	E					
0290N	0100E	22	13	E					

Township	Range	Section	SLO_MOU_ID (SLOID_MOU)	LARGE_GROUP_ID (Group2)	Commodity	Mining District in Area (NM Mines Database)	Mineral-resource Potential	Level of Certainty	Geological units
0290N	0100E	23	14	E					
0290N	0100E	32	15	E	basalt		high	high	Tv
0290N	0100E	36	16	E	basalt		high	high	Tv
0300N	0100E	32	21	E					
0300N	0100E	36	22	E					
0250N	0110E	02	37	F	placer gold	DIS239	very high	high	Q
0260N	0110E	02	39	F	placer gold	DIS239	very high	high	Q
			39		basalt		high	high	Tv
0270N	0110E	36	40	F	placer gold	DIS239	very high	high	Q
			40		basalt		high	high	Tv
0240N	0110E	02	35	G	placer gold	DIS239	very high	high	Q
			35		silica sand		unknown	low	
			35		basalt		high	high	Tv
0240N	0110E	16	36	G	silica sand		unknown	low	
			36		basalt		high	high	Tv
0250N	0110E	35	38	G	basalt		high	high	Tv
0160N	0220E	13	77	H	uranium, copper	DIS165	low	low	Trc, Jm
0160N	0220E	15	78	H	uranium, copper	DIS165	low	low	Trc, Jm
0160N	0230E	02	79	H	uranium, copper	DIS165	low	low	Trc, Jm
0160N	0230E	11	80	H	uranium, copper	DIS165	low	low	Trc, Jm
0160N	0230E	16	81	H	uranium, copper	DIS165	low	low	Trc, Jm
0160N	0230E	20	82	H	uranium, copper	DIS165	low	low	Trc, Jm
0160N	0230E	21	83	H	uranium, copper	DIS165	low	low	Trc, Jm
0160N	0230E	32	84	H	uranium, copper	DIS165	low	low	Trc, Jm
0170N	0230E	32	85	H	uranium, copper	DIS165	low	low	Trc, Jm
0170N	0230E	36	86	H	uranium, copper	DIS165	low	low	Trc, Jm

APPENDIX 2

MINERAL DEPOSIT TYPES IN NEW MEXICO

TABLE A2-1. Types of mineral deposits in New Mexico, in order of perceived age (oldest to youngest), excluding coal deposits (modified from North and McLemore, 1986, 1988; Cox and Singer, 1986; McLemore and Chenoweth, 1989, 2017; McLemore and Lueth, 1996, 2017; McLemore, 1996a, 1996b, 1996c, 2001; McLemore and Austin, 2017). USGS (U.S. Geological Survey) classification from Cox and Singer (1986) and subsequent reports (see http://minerals.usgs.gov/products/depmod.html). PGE=platinum group metals. REE=rare earth elements. See Table A2-3 for definitions of abbreviations.

NMBGMR CLASSIFICATION	USGS CLASSIFICATION (USGS MODEL NUMBER)	COMMODITIES	PERCEIVED AGE OF DEPOSIT IN NEW MEXICO	AREA THE DEPOSIT TYPE IS FOUND
Volcanogenic massive sulfide (VMS)	Volcanogenic massive sulfide (24a,b, 28a)	Au, Ag, Cu, Pb, Zn	1650-1600 Ma	none
Pegmatite	Pegmatite (13a-h)	Be, Li, U, Th, REE, Nb, Ta, W Sn, Zr, Hf	Probably 1450-1400 Ma, 1100-1200? Ma, some Tertiary	none
Vein and replacement deposits in Proterozoic rocks (formerly Precambrian veins and replacements)	Polymetallic veins, fluorite veins (22c, 26b)	Au, Ag, Cu, Pb, Zn, Mn, F, Ba	Proterozoic to Tertiary	none
Proterozoic iron formation	Volcanic hosted magnetite (25i)	Fe, Au	Proterozoic	none
Syenite/gabbro-hosted Cu-Ag-PGE	Gabbroid-associated Ni-Cu (7a)	Cu, Ag, PGE	Probably 1450-1400 Ma, could be older	none
Disseminated Y-Zr deposits in alkaline rocks	Alkaline complex associated zircon (11c)	Y, Zr, REE, U. Th, Hf	1100-1200 Ma	none
Carbonatites	Carbonatite and peralkaline intrusion-related REE deposits (10)	REE, U, Th, Nb, Ta, Zr, Hf, Fe, Ti, V, Cu, apatite, barite	400-600 Ma, one about 22 Ma	none
Episyenites and REE-Th-U veins	Th-REE veins (10b, 11d)	REE, U, Th, Nb, Ta	400-600 Ma	none
Sedimentary iron deposits	Oolitic iron (34f)	Fe	Cambrian-Ordovician	none
Sedimentary-copper deposits	Sediment-hosted copper (30b)	Cu, Ag, Pb, Zn, U, V	Pennsylvanian-Permian, Triassic	Sabinoso Wilderness Area
Uraniferous collapse-breccia pipe (including clastic plug deposits)	Solution-collapse breccia pipe U deposits (32e)	Cu, Ag, U, Co, Se, REE?	Triassic, Jurassic	none
Limestone uranium deposits	none	U, V, Se, Mo	Jurassic	none
Sandstone uranium deposits	Sandstone uranium (30c)	U, V, Se, Mo, REE?	Pennsylvanian-Permian-Miocene	Sabinoso Wilderness Area
Beach placer sandstone deposits	Shoreline placer Ti (39c)	Th, REE, Zr, Hf, Ti, U, Fe, Nb, Ta	Cretaceous	none
Replacement iron	Iron skarn (18d)	Fe	Cretaceous-Miocene (75-50 Ma)	none
Porphyry Cu, Cu-Mo (±Au)	Porphyry copper (17, 20c, 21a)	Cu, Mo, Au, Ag	75-50 Ma	none
Cu, Pb, Zn, Fe skarn	Skarn (18a, 18c, 19a)	Au, Ag, Cu, Pb, Zn	75-40 Ma	none

NMBGMR CLASSIFICATION	USGS CLASSIFICATION (USGS MODEL NUMBER)	COMMODITIES	PERCEIVED AGE OF DEPOSIT IN NEW MEXICO	AREA THE DEPOSIT TYPE IS FOUND
Polymetallic vein	Polymetallic veins (22c)	Au, Ag, Cu, Pb, Zn	75-40 Ma	none
Porphyry Mo (±Cu, W)	Porphyry Mo-W (16, 21b)	Mo, W, Au, Ag, Be, Cu	Probably 35-25 Ma	none
Carbonate-hosted W-Be replacement and skarn (Mo-W-Be, F-Be, Fe-Mn)	W-Be skarns (14a)	Mo, W, Be, Pb, Zn, Cu, F, Mn	Probably 35-25 Ma	none
Carbonate-hosted Pb-Zn (Cu, Ag) replacement	Polymetallic replacement (19a)	Pb, Zn, Cu, Ag	75-25 Ma	none
Carbonate-hosted Ag-Mn (Pb) replacement	Polymetallic replacement, replacement manganese (19a, b)	Ag, Mn, Pb, Zn	75-25 Ma	none
Great Plains Margin (GPM or alkaline-related) deposits (including polymetallic epithermal to mesothermal veins; gold-bearing breccias and quartz veins; porphyry Cu-Mo-Au; Cu, Pb/Zn, and Au skarns and carbonate-hosted replacement deposits; Fe skarns and replacement bodies; Th-REE-fluorite (with U and and Nb) epithermal veins)	Porphyry copper, polymetallic veins, copper skarns, iron skarns, placer gold (17, 22c, 18a,b, 18d, 39a), Th-REE veins (10b, 11d)	Au, Ag, Cu, Pb, Zn, Mo, Mn, Fe, F, Ba, Te, REE, Nb, Zr, U, Th	47-25 Ma	none
Volcanic-epithermal veins	Quartz-adularia, quartz-alunite, epithermal manganese (25b,c,d,e,g, 26b, 35[a])	Au, Ag, Cu, Pb, Zn, Mn, F, Ba	35-16 Ma or younger	none
Rhyolite/granite-hosted tin (topaz rhyolites)	Rhyolite-hosted tin (25h)	Sn, Be, REE	28 Ma	none
Tin skarns	Tin skarns (15c, 14b, 14c)	Sn		none
Volcanogenic Be (volcanic-hosted replacement, volcanic-epithermal, Spor Mountain Be-F-U deposits)	Volcanogenic Be deposits	Be, F, U	Miocene-Pliocene	none
Carbonate-hosted Mn replacement	Replacement Mn (19b)	Mn	Miocene-Pliocene	none
Copper-silver (±U) vein deposits	Polymetallic veins (22c)	Cu, Ag, U	Miocene-Pliocene	none
Mississippi Valley-type (MVT) (here restricted to Permian Basin)	Mississippi Valley-type (MVT) (32a-d)	Cu, Pb, Ag, Zn, Ba, F	Oligocene-Pliocene	none
Surficial uranium deposits	none	U	Miocene-Recent	none
Rio Grande Rift (RGR) Epithermal Mn	Epithermal Mn (25g)	Mn	Miocene-Recent	none
Rio Grande Rift (RGR) barite-fluorite veins	Fluorite and barite veins, polymetallic replacement (IM26b, c, 27e, 19a)	Ba, F, Pb, Ag, U	12 Ma-Recent	none
Placer tungsten	None	W	Pliocene-Recent	none
Placer tin	Stream placer tin (39e)	Sn	Pliocene-Recent	none
Placer gold	Placer gold-PGE (39a)	Au, Ag	Pliocene–Recent	Rio Grande del Norte

TABLE A2-2. Types of industrial minerals and rocks deposits in New Mexico, in alphabetical order (modified from Cox and Singer, 1986; Dill, 2010; McLemore and Austin, 2017). USGS classification from Cox and Singer (1986) and subsequent reports (see http://minerals.usgs.gov/products/depmod.html). Some deposits are listed in Table 2 because they are also considered to be metallic mineral resources as well as industrial minerals and rocks. Gems are included in this table, but are generally not considered industrial minerals and rocks. See Table A2-3 for definitions of abbreviations.

NMBGMR CLASSIFICATION	USGS CLASSIFICATION (USGS MODEL NUMBER)	AREA THE DEPOSIT TYPE IS FOUND
Adobe and earthen construction		Not evaluated
Aggregate (sand and gravel)		Rio Grande del Norte
Alunite and alum		none
Asbestos	Serpentine hosted asbestos (8d)	none
Barium minerals (Ba)	Bedded barite (31b), vein barite (31b, 27e)	none
Bauxite		none
Beryllium minerals (Be)		none
Boron and borates	Lacustrine borates (35b.3)	none
Bromide	Bromine brines (35an)	none
Chromite		none
Clay	sedimentary clay (31K), hydrothermal bentonite (251.1), hydrothermal kaolin (251.2), sedimentary bentonite (28e.1, 28e.2), sedimentary kaolin (31k.1, 31k.2, 31k.3), palygoskite (34e), residual kaolin (38h)	Not evaluated
Diatomite	Lacustrine diatomite (31s)	none
Evaporate		none
Feldspar	Feldspar in pegmatite (13e)	none
Fluorspar	Fluorite veins (26b)	none
Gallium		none
Garnet		none
Gems (mineral collecting)		Not evaluated
Gilsonite		none
Glauconite		none
Graphite	Amorphous graphite (18k)	none
Gypsum and anhydrite	bedded gypsum (35ae), lacustrine gypsum (35b.4)	none
Iron, iron oxide and magnetite		none
Kyanite, sillimanite, and andalusite		none
Lime		none
Limestone and dolomite	Limestone (32g)	none
Lithium	Lithium brines (35bm), lithium in smectites (251c)	none
Magnesium Minerals and Compounds (excluding dolomite)	Metasomatic and metamorphic replacement magnesite (1981)	none
Manganese	Sedimentary Mn (34b)	none
Mica		none
Nepheline syenite		none
Nitrogen and nitrates (guano)		none
Olivine		none
Perlite		Rio Grande del Norte
potash	potash bearing-bedded salt (35ab)	none
Pozzolans and supplementary cementitious materials		Not evaluated

NMBGMR CLASSIFICATION	USGS CLASSIFICATION (USGS MODEL NUMBER)	AREA THE DEPOSIT TYPE IS FOUND
Pumice, pumicite, and scoria (volcanic cinder)	pumice scoria-volcanic cinders (IM25kb)	Rio Grande del Norte
Pyrophyllite		none
Rare earth elements (REE)	Thorium-rare earth veins (11d)	none
Salt	bedded salt, marine evaporate (35ac), lacustrine halite (35b.5)	none
Silica	Sandstone/quartzite silica (30e), silica sand (39i)	unknown
Soda ash	Sodium carbonate (35ba)	none
Sodium sulfate		none
Soil amendments (including humate)		none
Stone (crushed, dimension)		Rio Grande del Norte
Strontium minerals		none
Sulfur	Fumarolic sulfur (25)	none
Talc	Metasomatic and metamorphic talc (18m)	none
Tellurium		none
Titanium		none
Vermiculite		none
Wollastonite	Wollastonite skarn (18g)	none
zeolites	Sedimentary zeolites (25oa, 25ob)	Not evaluated

TABLE A2-3. Abbreviations of elements used in this report.

As arsenic	Au gold
Ag silver	Ba barium
Be beryllium	Bi bismuth
Br bromine	Cd cadmium
Co cobalt	Cr chromium
Cu copper	F fluorine
Fe iron	Ga gallium
Ge germanium	Mn manganese
Mo molybdenum	Ni nickel
Pb lead	REE Rare earth elements
PGM Platinum group elements	Sb antimony
Sn tin	Th thorium
U uranium	V vanadium
W tungsten	Zn zinc

APPENDIX 3
DESCRIPTION OF FIELDS IN THE DISTRICT DETAILS GEODATABASE

DistrictDetails: Mining districts and prospect areas in New Mexico (updated and modified from Lindgren et al., 1910; File and Northrop, 1966; Howard, 1967; North and McLemore, 1986; McLemore and Chenoweth, 1989; McLemore, 2001, 2017). Districts and prospect areas are in alphabetical order by county then by district name. Estimated production is in dollars at the time of production. Types of deposits are summarized by McLemore (2017). Summary of metals production is in Production. REE=rare earth elements, PGE=platinum group elements, VMS=volcanic massive sulfide, MVT=Mississippi Valley type, RGR=Rio Grande rift, GPM=Great Plains Margin. Names in italics are prospect areas with no production. Note that the Grants uranium district consists of several subdistricts as indicated by McLemore and Chenoweth (1989).

District Id: Key, unique district identification number with prefix of DIS

District: Mining district, coal field, prospect area, or the geographical area as defined by File and Northrop (1966), North and McLemore (1986), McLemore and Chenoweth (1989), Hoffman (1996), and McLemore (2001)

Prospect Area: Prospect area defined as no production

County: County in which district is found in

Commodity category (major commodity): Unique commodity category, only the major commodity category is listed even though some districts may have more than one category (uranium, coal, metals, industrial minerals, aggregate)

Aliases: Other names associated with this district, including common misspellings.

Year of Discovery: Year district was discovered

Year of Initial Production: First year of known production in district

Year of Last Production: Last year of known production in district

Estimated Cumulative Production: Best estimate of total cumulative production in actual dollars at time of production, includes all commodities except aggregate and crushed stone

Commodities produced: Commodities produced from the district

Other commodities: Commodities found in the district, but never produced

Deposit type: After North and McLemore (1986), McLemore (2001), McLemore and Lueth (2017), McLemore and Austin (2017), https://minerals.usgs.gov/products/depmod.html

Description: description of district

Source for district name: Source for name of mining district

Selected references: selected references further describing the district