MINERAL-RESOURCE POTENTIAL OF PORTIONS OF SOUTHWESTERN 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. 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 U.S. Bureau of Land Management (BLM) to the New Mexico State Land Office (SLO). Then, in return, the SLO will transfer SLO lands to the BLM. This report assesses the mineral-resource potential of the BLM 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. Changing economics could also alter the mineral-resource potential in the future. Furthermore, this assessment is based upon a literature search and experience of the authors, but still requires field verification.

TABLE S. Summary of areas with high mineral-resource potential in southwestern New Mexico.

Area	**Mining District in Area (NM Mines Database)**	**Mineral-resource Potential**	**Reasonably Foreseeable Development**
Area 1	Cuchillo Negro, Chloride	high potential for W, Be, F, and Au, Mn, aggregate	Moderate-high
Area 2		high aggregate	S42, S44 high, otherwise none-low
Area 4	North Magdalena	high aggregate	
Area 5		high limestone	
Area 6		high gypsum, limestone, aggregate	
Area 7		high aggregate, limestone	
Area 8	Orogrande	high Cu, lode and placer Au, Ag, Fe, W, turquoise, garnet	high to moderate
Area 9		high aggregate	
Area 10		high limestone, aggregate, diatomite	moderate
Area 11	Lake Valley, Macho	high Au, Mn subsurface, perlite, aggregate	high to moderate
Area 12		high aggregate	
Area 13		high aggregate	
Area 15		high aggregate	
Area 16		high aggregate, scoria, basalt	
Area 17	Bound Ranch	high F	moderate
Area 18	White Signal	high Cu, lode Au, F	high to moderate
Area 19		high aggregate	
Area 20	Tortugas Mountains	high aggregate, F	moderate
Area 21	Organ Mountains	high Cu, F, Zn	high to moderate
Area 22		high aggregate	
Area 23		high aggregate	
Area 24		high aggregate	
Area 25	Tierra Blanca	high Sb, Ag, Pb, Zn	high to moderate
Area 26		high aggregate	

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INTRODUCTION

Purpose and scope of this assessment

The U.S. Bureau of Land Management (BLM) is developing an Environmental Assessment (EA) under provisions of the National Environmental Policy Act (NEPA), which requires the assessment of mineral-resource potential for federal surface and federal minerals for a land exchange. The proposed action is a land exchange that calls for transfer of state surface and minerals of parcels within and proximal to the Organ Mountains-Desert Peaks Monument from the New Mexico State Lands (SLO) to the BLM. Then, in return, the BLM will transfer BLM lands to the SLO. This report assesses the mineral-resource potential of certain BLM parcels in southwestern 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 from 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 GIS program ArcMap was the GIS program used to create the maps needed for this assessment.

Historic and Present Mineral and Energy Production

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 (Tables 1, 2). In 2023, New Mexico ranked 3rd in oil, 9th in natural gas, 13th in coal production, and 24th in nonfuel minerals production in the United States. New Mexico is ranked 6th in geothermal potential (U.S. Energy Information Administration, 2021), with focus on direct use applications (heating greenhouses, aquiculture, space heating, and spas). Most of the state’s nonfuel mineral production comes from 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 three major oil and gas basins and 246 mining districts and prospect areas (Fig. 2) described in New Mexico, summarized in Broadhead (2017) and McLemore (2017). Most of the geothermal resources in New Mexico are located along the Rio Grande rift or in the Basin and Range province in the southwestern part of the state (Witcher, 2007; Goff and Goff, 2017). A commercial geothermal power-plant capable of 4 MW of electrical production has been in operation since 2013 at

Lightning Dock near Lordsburg in southwestern New Mexico. The mining history of New Mexico is described by Jones (1904), Christiansen (1974), Broadhead (2017), McLemore (2017), McLemore et al. (2017) and other reports cited in McLemore (2017). Carbon dioxide (CO_2), another type of natural gas, has been produced from the Bravo Dome and other small fields in New Mexico since 1917. Helium, a natural gas as well as a critical mineral in previous lists, has been produced from eight small reservoirs in the state since 1943 (Broadhead, 2017).

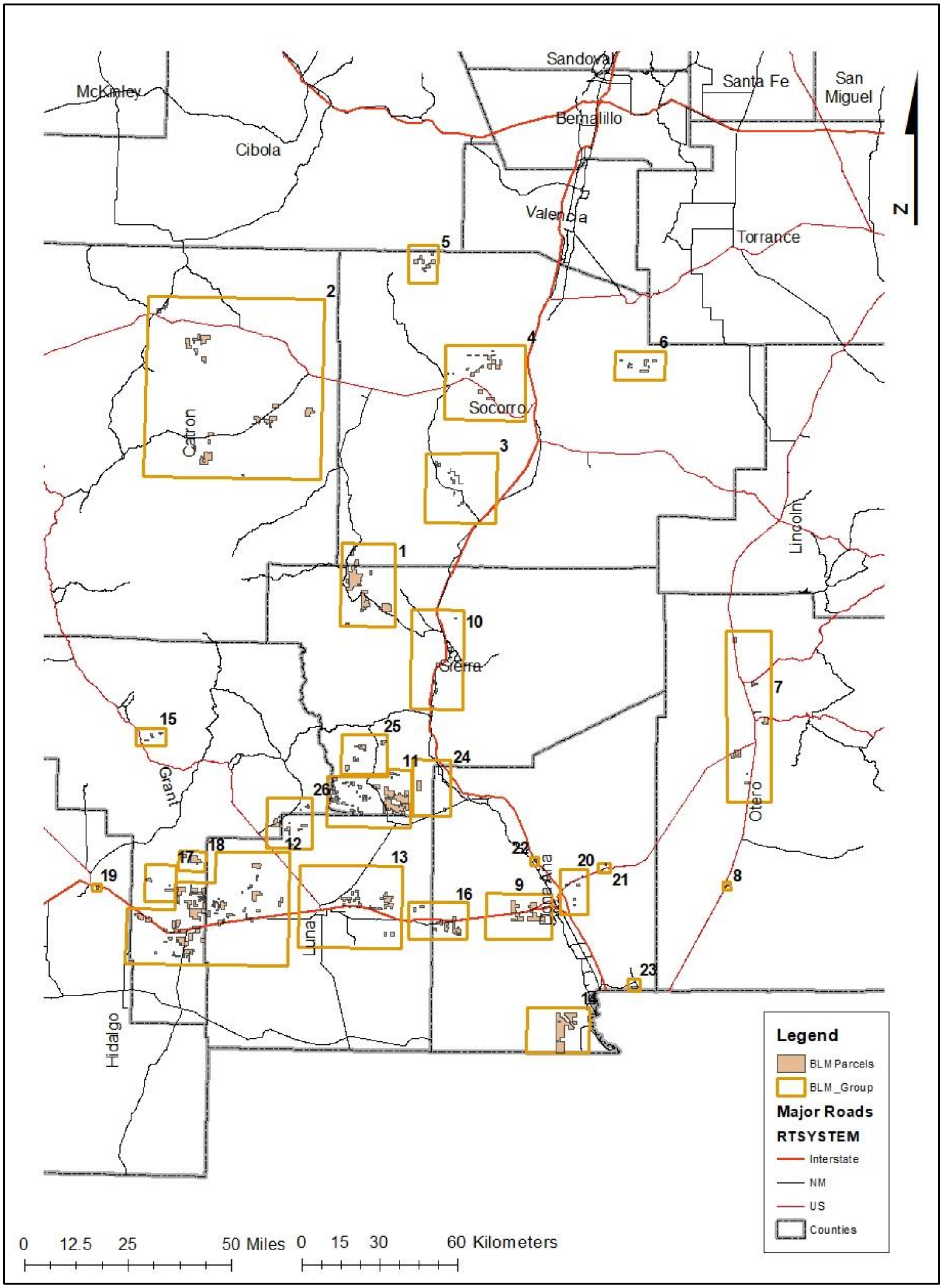

FIGURE 1. BLM areas of proposed lands in southwestern New Mexico to be transferred to the SLO (Appendix 1). Parcels were combined into groups for easier evaluation. See GIS data for more details.

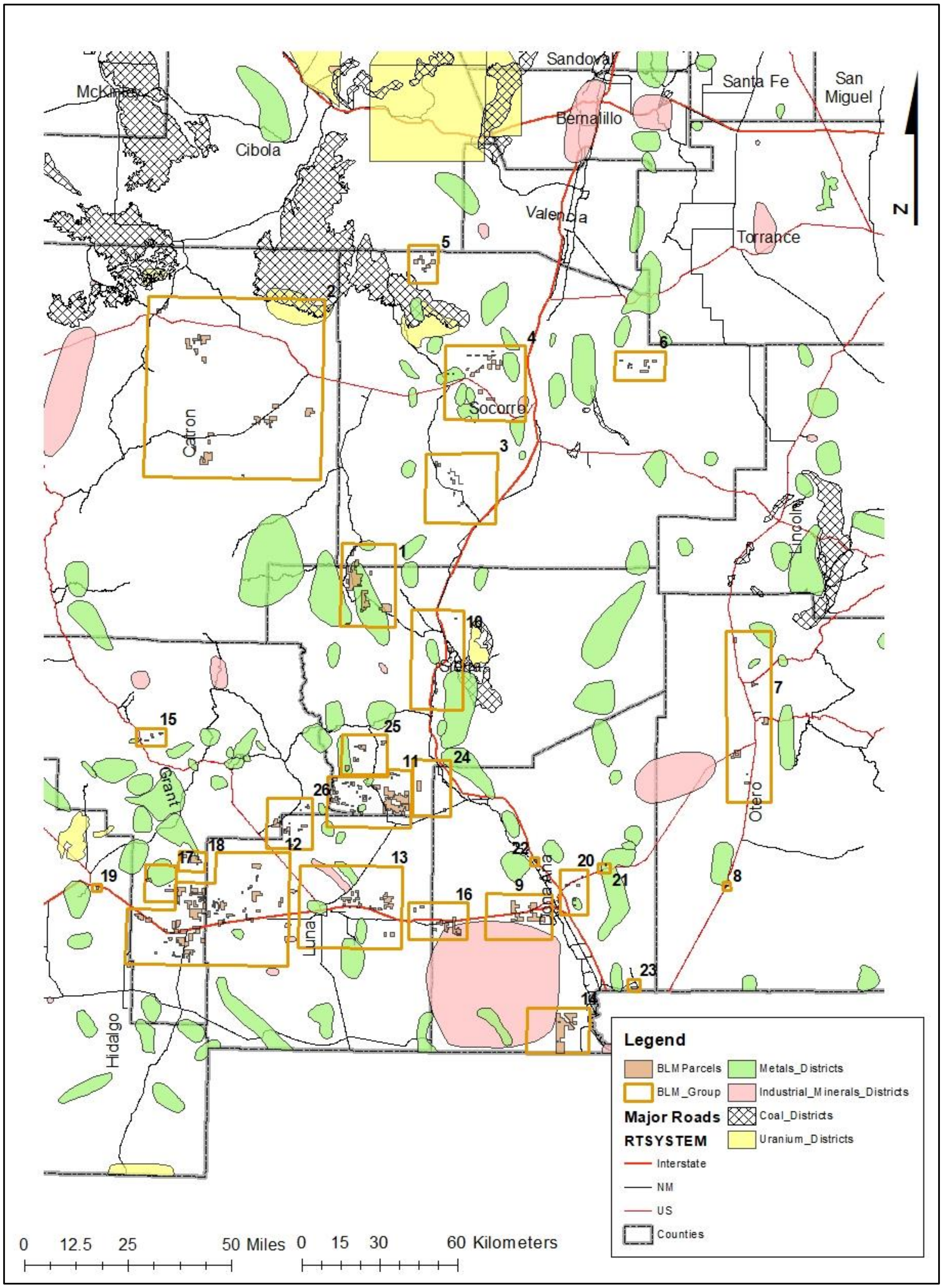

FIGURE 2. Areas of proposed lands, mining districts and prospect areas in southwestern New Mexico. Specific details on each mining district or prospect area, including names, are in the GIS data, McLemore (2017), and accompanying data found at http://geoinfo.nmt.edu/repository/index.cfml?rid=20170001.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

TABLE 1. Estimated total production of major commodities in New Mexico, in order of estimated cumulative value (data from U.S. Geological Survey (USGS), 1902–1927; USBM, 1927–1990; Kelley, 1949; Northrop, 1996; Harrer, 1965; USGS, 1965; Howard, 1967; Harben et al., 2008; Energy Information Administration, 2015-2022; New Mexico Energy, Minerals and Natural Resources Department, 1986–2024; 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 ($)
Natural Gas	1924-2020	7,530.581 MMBO	$180,979,000,000
Oil	1922-2020	82,087.06 BCF	$189,282,310,000
Coal	1882–2022	>1.5 billion short tons	>$23 billion
Copper	1804–2022	>201 million short tons	>$26.4 billion
Potash	1951–2022	124 million short tons	>$17 billion
Uranium	1948–2002	>347 million pounds	>$4.8 billion
Industrial minerals*	1997–2022	>57 million short tons	>$4 billion
Aggregates**	1951–2022	>757 short tons	>$3.4 billion
Molybdenum	1931–2013	>176 million pounds	>$852 million
Gold	1848–2022	>16 million troy ounces	>$592 million
Zinc	1903–1991	>1.51 million tons	>$337 million
Silver	1848–2022	>120 million troy ounces	>$309 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	1804–2020	—	>$78.4 billion

*Industrial minerals include the combined total of several industrial minerals (e.g., perlite, cement, decorative stone, pumice, zeolites, etc.), but exclude 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 2020, excluding oil and natural gas (New Mexico Energy, Minerals and Natural Resources Department, 2022, https://wwwapps.emnrd.state.nm.us/ocd/ocdpermitting/Reporting/Production/ProductionInjectionSummaryReport.aspx). na—not available.

Mineral	**Production in 2020**	**Rank in the U.S.**	**Production value in NM in 2020**	**Employment in NM (# full time jobs)**	**State revenue generated from extractive industries**	**Federal revenue generated from extractive industries**
Natural Gas	490,256,432 mcf		$55,026,602			
Oil	360,407,981 bbls		$965,697,556			
Copper	137,096,867 lbs	2	$383,799,937	1,348	$3,221,390	—
Coal	10,249,124 short tons	10	$453,218,459	705	$10,390,190	$5,748,892
Gold	2,495 troy oz	—	$4,416,096	—	$47,297	—
Industrial minerals	2,523,871 short tons	—	$197,466,323	607	$120,015	$363,253
Aggregates	13,293,701 short tons	—	$145,804,489	1,111	$5,202,347	—
Potash	409,277 short tons	1	$376,673,452	712	$3,384,612	$1,080,141
Silver	52,077 troy oz	—	$1,069,687	—	$10,629	—
CO2	66,149,735 mcf		$2,338,845			
Helium	13,602 mcf		$145,882			
Uranium	none	—	—	17	—	—
Total 2016	—	23 (excluding oil and gas)		4,500 (excluding oil and gas)	$22,376,480	$7,192,286

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 established 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 or unknown* 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. Petroleum fields are defined by oil and gas production and/or exploration (Broadhead, 2017), and can include production of additional natural gases such as carbon dioxide and helium as well as other commodities such as sulfuric acid. Known Geothermal Resource Areas (KGRA) were identified by the USGS during the 1970s (Stone and Mizell, 1977), but those designations are not in current use.

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. A *mineral system* is the grouping of mineral deposits by the geological processes necessary to form major mineral deposits and is not restricted to descriptive elements of a specific mineralization style (Hagemann et al., 2016; Hammarstrom et al., 2020; Hofstra et al., 2020, 2021).

Mineral deposits, including petroleum resources, 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 on 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.

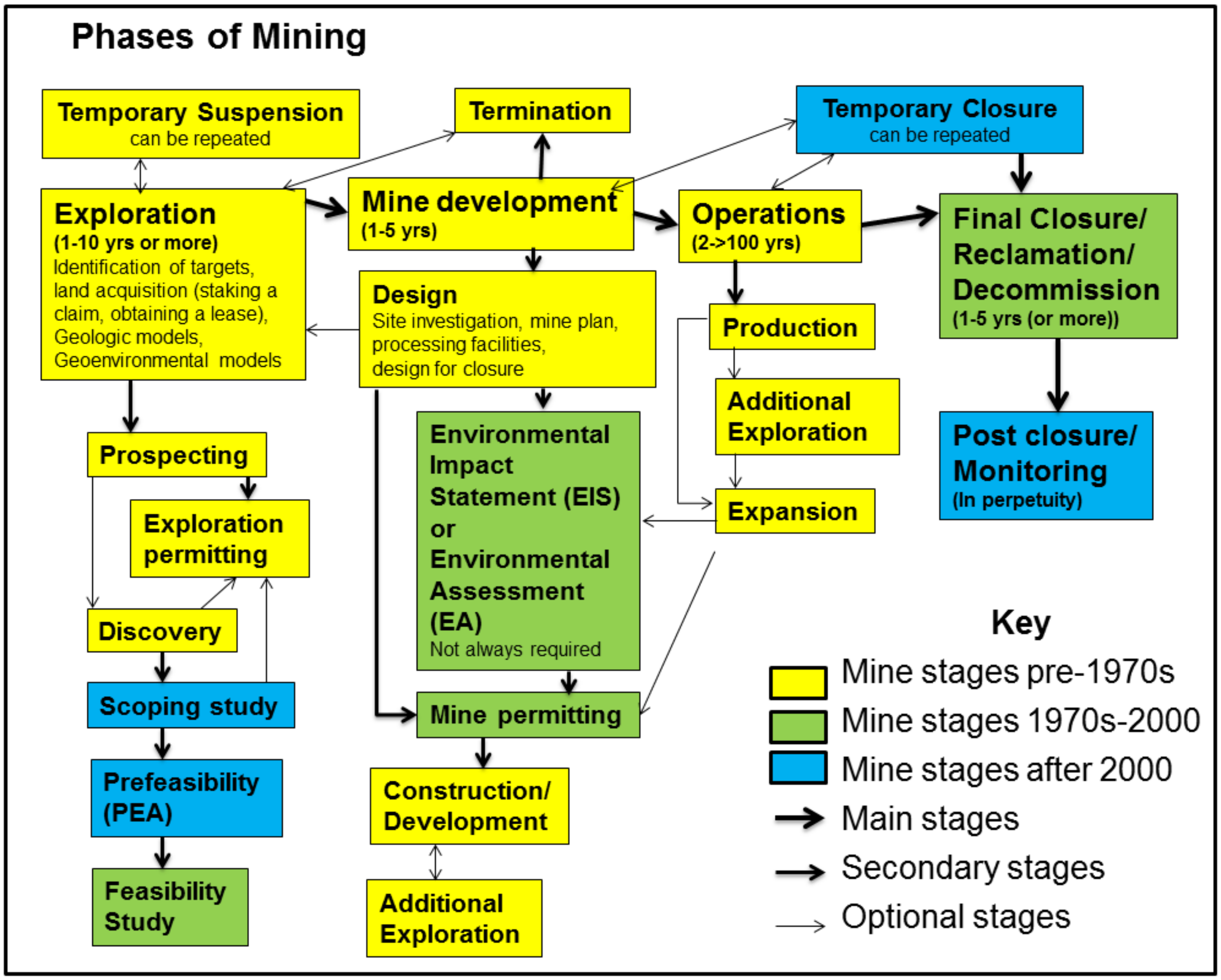

FIGURE 3. Stages of mining through history.

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>
<tr><td rowspan="5">↑
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.

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, including geothermal, oil, gas, helium, and carbon dioxide potential. 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 regions with potential geologic processes to form mineral deposits; known mines, deposits, unmined deposits, mining claims and favorable areas; and then to identify areas of high, moderate, and low for a given resource. A minerals systems approach was used, where geologic models of deposits were grouped by a mineral system. Mineral systems are defined by Hofstra et al. (2020, 2021) and summarized in Appendix 1. Mineral deposits are described by USGS models (Cox and Singer, 1986 and subsequent reports) and summarized by McLemore and Lueth (2019), McLemore and Austin (2019), Hoffman (2019) and McLemore and Chenoweth (2019), and are in Appendix 2.

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 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 (2022-04027-final-list-of-critical-minerals).

Commodity class	**Commodity**	**Is it a critical mineral?**
Metals	Copper (Cu)	Yes under DOE
	Gold and silver (Au, Ag)	
	Zinc (Zn)	Yes
	Molybdenum (Mo)	
	Platinum group elements (PGE: Pd, Pt, Os, Ir, Rh)	Yes
	Aluminum (Al)	Yes
	Antimony (Sb)	Yes
	Chromium (Cr)	Yes
	Cobalt (Co)	Yes
Industrial minerals	Aggregate (sand and gravel)	
	Arsenic (As)	Yes
	Barium (barite) (Ba)	Yes
	Beryllium (Be)	Yes
	Bismuth (Bi)	Yes
	Cesium and rubidium (Cs, Rb)	Yes
	Clay	
	Diatomite	
	Dolomite	
	Fluorine (fluorite)(F)	Yes
	Gallium (Ga)	Yes
	Garnet	Yes
	Germanium (Ge)	Yes
	Graphite (carbon)	Yes
	Gypsum	
	Hafnium (Hf)	Yes
	Helium (He)	Former in 2020
	Humate	
	Indium (In)	Yes
	Iron (Fe), iron oxide and magnetite (Fe)	

Commodity class	**Commodity**	**Is it a critical mineral?**
	Limestone and dolomite (crushed stone)	
	Lithium (Li), strontium (Sr), bromine (Br), boron (B)	Yes
	Magnesium (Mg) (including dolomite)	Yes
	Manganese (Mn)	Yes
	Mica	
	Niobium, tantalum (Nb, Ta)	Yes
	Perlite	
	Potash (K)	
	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)	Former in 2020
Coal	Coal	
Geothermal	Geothermal	
Petroleum and related commodities	Oil and gas	
	Helium (He)	
	CO_2	

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 mostly imported from other countries. The supply chains of these minerals can be easily 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. As of 2022, zinc has been added to the list of critical minerals, and uranium, helium, and potash have been removed (Applegate, 2022). Recent geopolitical instability and supply chain concerns may see these elements added back to the list or added to other lists designated by the federal government.

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 established by customer-specified criteria. 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, in addition to traditional commodities (Table 3).

The U.S. Geological Survey has defined mineral systems and focus areas for the United States where geologic terranes are favorable for hosting the various critical minerals. Focus areas for REE, aluminum, cobalt, graphite, lithium, niobium, platinum-group elements, tantalum, tin, titanium, tungsten are described in Hammarstrom et al. (2020). A preliminary data release on focus areas for the remaining critical minerals was used in this report.

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 and a summary tables and spreadsheets. Specific information required to properly evaluate the mineral- and energy-resource assessment is organized and analyzed using layers in ArcMap. This report is organized by SLO areas instead of by commodities or energy resource, but the GIS data are arranged by commodities or energy resource. The mineral-resource potential determinations for each of the individual parcels are in Appendix 1 and the energy resource potential evaluations of the grouped parcels are also summarized in Tables 4-7. First, mineral resources are discussed, followed by assessments of oil, gas, carbon dioxide, and helium. Geothermal resource analysis is presented last. Finally, the Reasonably Foreseeable Development (RFD) is discussed in a separate chapter in this report.

Mineral Resources

Sources of data

Data used in this report have been compiled from literature reviews, field examinations, and unpublished data by the authors and include geologic maps, mineral occurrence records, mineral-resource assessments, production records, and evaluation of the NURE and other geochemical and geophysical data. Specific references for the areas and parcels are listed in Appendix 1. Additional sources include:

- Official government publications (including NMBGMR, 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 reports
- 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, including types of deposits in New Mexico 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), McLemore (2017), McLemore and Lueth (2017), McLemore and Austin (2017), Goff and Goff (2017), Broadhead (2017), and numerous other reports listed in the references cited.

Mineral production by commodity from New Mexico is summarized in Table 1, and metals production by mining district is in McLemore (2017) and updated production statistics are at https://geoinfo.nmt.edu/staff/mclemore/MineralProductionfromNewMexico.html. 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, 1990–2022; 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 to host mineral deposits, 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 1.

The USGS also has used a mineral systems approach to identify prospective areas for exploration of critical minerals (Hofstra and Kreiner, 2020). The mineral systems approach is based upon current understanding of the formation of ore deposits and the relationship to broader geologic frameworks and the tectonic history of the Earth. The mineral systems approach is appropriate for mineral-resource assessments because mineral systems are larger than individual ore deposits and they have geologic features that can be used with the topographic, geologic, geochemical, and geophysical techniques used to determine mineral-resource potential. The USGS mineral systems are listed in Appendix 1 for each SLO area.

Mining districts

Mining districts and prospect areas are defined by McLemore (2017), shown in Figure 2 and the GIS data. However, not all critical minerals (i.e. magnesium, helium), 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 commodities are not constrained by criteria that defines a mining district. Undoubtedly new occurrences of metals, industrial minerals, critical 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), North and McLemore (1986, 1988), 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 are locatable minerals and 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.

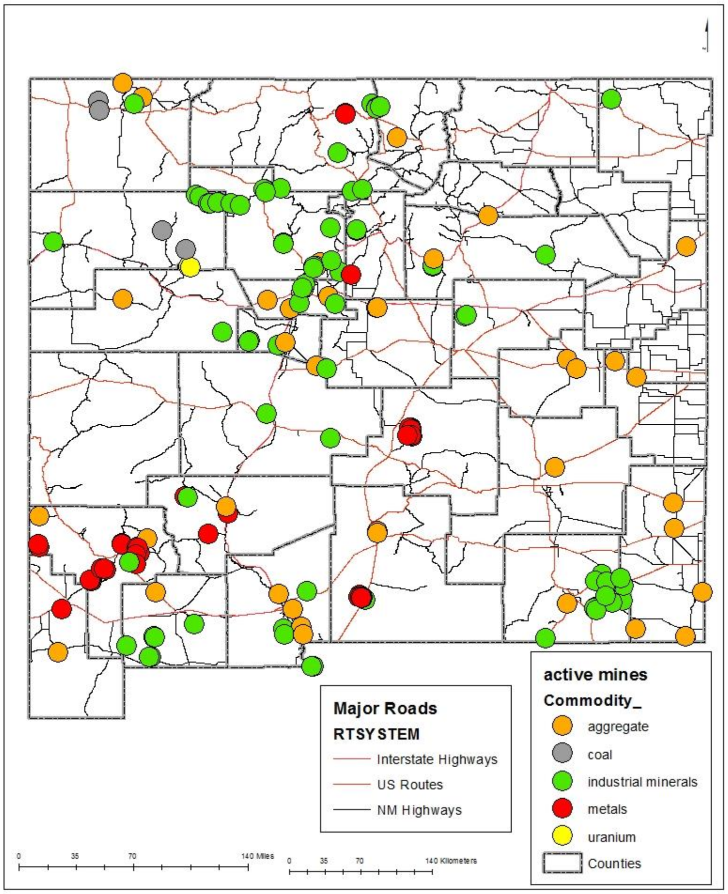

FIGURE 5. Active mines and exploration sites in southwestern New Mexico. Exploration sites are defined in this study as areas where a company or prospector is exploring for a commodity (including but not limited to permitted sites with NMMMD; see text). Not all aggregate producers are shown. Specific details on each mine**,** including names, are in the GIS data and McLemore (2017).

Exploration areas (past, active)

Past and current 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.

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/). The LR2000 database only identifies township, range, and sections that contain mining claims. However, the BLM New Mexico State Office creates spatial data for the more recent mining claims, which were evaluated for this report.

Geodatabases

Three geodatabases from McLemore (2017) 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 mineral commodity for each area (Fig. 1) is briefly described below. Known mineral resources in New Mexico are described in references listed in the references cited in this report and in Broadhead (2017), McLemore (2017), Hoffman (2017), McLemore and Lueth (2017), McLemore and Austin (2017), and McLemore and Chenoweth (2017. Selected maps are included in the discussions below; more details are in the GIS data and Appendix 1. There is no coal or uranium potential in these parcels.

Metals, industrial minerals, critical minerals, uranium and coal

Area 1

Area 1 is in southern Socorro and northern Sierra Counties, includes portions of the Ojo Caliente No. 2, Cuchillo Negro, and Chloride mining districts, and parcels L1, L2, L3, L4, L5, L6, L9, S66, and S70. Parcels are in the Cuchillo Negro and Chloride districts. Active mining claims are found in parcels L1, L3, L5, L6, S66, and S70. Three USGS mineral systems overlap Area 1: chemical weathering (supergene manganese), porphyry Cu-Mo-Au (S-R-V tungsten; all parcels); and magmatic REE (fluorite in southern portion of Area 1).

Parcels L2, eastern part of L3, L4, L6 and S70 have high potential for aggregate (sand and gravel). L2 has unknown gold and silver potential. Parcels S70 and L2 have unknown potential for tungsten and manganese.

Parcels (S66, L3, L5, L1, and L6) are in the Cuchillo Negro district and have high potential for tungsten, manganese, beryllium, and gold; moderate potential for alunite, antimony, fluorite, and zeolite; and low potential for copper, molybdenum, garnet, iron, tellurium, tin, zinc, and uranium. Parcels L5 and L6 also have high potential for fluorite.

Parcel L9 is in the southern Chloride district and has a high potential for gold and silver, moderate potential for fluorite, tungsten, beryllium, antimony, and low potential for copper, molybdenum, garnet, manganese, iron, tellurium, tin, uranium, and zinc. Although the Chloride district has a very high potential for zeolites and active mining is occurring at the St. Cloud Stone House zeolite mine east of parcel L9, the zeolite potential does not extend into parcel L9. Therefore, the potential for zeolite in parcel L9 is low.

Area 2

Area 2 is in Catron County and includes the Red Basin-Pie Town uranium district and the Datil Mountains coal field, which extends into the northeastern corner of the area; but none of the specific parcels are in the mining district or coal field. Parcel L23 is adjacent to mining claims. Three USGS mineral systems overlap Area 2: chemical weathering (supergene manganese deposits), porphyry Cu-Mo-Au (S-R-V tungsten deposits), and meteoric recharge (sandstone uranium); there is no mineral-resource potential for these deposits in the parcels within Area 2.

There is no mineral resource potential in parcels southern S11, S13, S14, S15, S23, S42, S44, S48, S50, S77, S53, and S77. Parcels S10, northern part of S11, S12, S16, S39, S40, S41, S43, S53, and S76 have high potential for aggregates (sand and gravel). Parcel S45 has a high potential for aggregate in areas of Quaternary deposits and no mineral-resource potential where rhyolites are present.

Area 3

Area 3 is in central Socorro County and includes parcels S51, S52, S54, S55, S56, S57, S58, S59, S60, S61, S62, S91, and S92. Parcels L56, L57, and L58 are adjacent to mining claims. USGS mineral systems porphyry Cu-Mo-Au and chemical weathering overlaps Area 3, but there is no mineral-resource potential for these deposits in Area 3.

There are manganese mines in the northern portion of Area 3, and this area has moderate potential for manganese. However, there are no mines, mining districts, or mining claims on the parcels within Area 3, therefore there is no metals, including manganese, or uranium potential in the parcels. There is some aggregate potential in Area 3, but no significant aggregate potential is found on any of the parcels.

Area 4

Area 4 is in Socorro County and includes parcels S17, S18, S19, S20, S21, S22, S26, S27, S28, S29, S30, S31, S32, S33, S34, S38, and S99. Portions of the Lemitar Mountains, San Lorenzo, Luis Lopez, Hop Canyon, Water Canyon, Magdalena and North Magdalena mining districts are in Area 4, but only parcels S32 and S33 are in the North Magdalena district; none of the other parcels are in any mining districts. There are active mining claims in parcel S33. USGS focus areas that overlap Area 4 include magmatic REE (carbonatite), meteoric recharge (sandstone uranium), porphyry Cu-Mo-Au (S-R-V tungsten deposits), volcanogenic seafloor (Sangre de Cristo VMS), and chemical weathering (supergene manganese), but there is no potential for these deposits in Area 4.

The North Magdalena district (parcels S32 and S33) has a low potential for copper and zinc and moderate potential for lode gold and vanadium. All of the parcels have a high potential for aggregate.

Area 5

Area 5 is in northern Socorro County and includes parcels S1, S2, S3, S4, S5, S6, S7, and S8. There are no mining districts, mines, or mining claims in Area 5. There are no USGS focus areas that overlap Area 5, although an area designated as basin brine path (sediment-hosted copper deposits) is just to the east of Area 5. There is no metals or uranium potential in Area 5. There is some aggregate potential in Area 5, but no significant aggregate potential is found on any of the parcels. Furthermore, the parcels are too far from existing roads to be developed in the near future. Parcels S1 and S4 have high potential for limestone.

Area 6

Area 6 is in eastern Socorro County and includes parcels S24, S25, S78, S79, S80, S81, S82, S83, S84, and S85. There are no mines, mining districts, or mining claims in Area 6, therefore there is no metals or uranium potential.

Small, uneconomic stratabound, sedimentary-copper deposits (USGS mineral system basin brine path) in the Scholle and Rayo mining districts, north of Area 6, are restricted predominantly to the lower member of the Abo Formation, with minor occurrences in the upper member of the Bursum Formation and the Mesita Blanca Sandstone Member of the Yeso Formation (McLemore, 1984; 2016b). The Abo, Bursum, and Yeso formations are found in Area 6, either in the subsurface or at the surface and could have potential for similar sedimentary-hosted deposits. Therefore, the mineral-resource potential is low with a moderate level of certainty for copper, silver, and gold in sedimentary-copper deposits in Area 6 (parcels S24, S25, S85, and S84). However, the reasonably foreseeable development is low because of remoteness of Area 6 and these deposits do not typically have exploration potential because they generally are small, low grade, and not economic. Chemical analyses of ore samples are required to assess the mineral-resource potential for cobalt, gallium, germanium, PGE, and rhenium, potential commodities found in some stratabound, sedimentary-copper deposits.

There is high aggregate potential in Area 6 (parcels S80, S81, S83, southern half of S85, S25, and the northern and eastern parts of S84). Parcels S78, S79, S80, and S82 have high potential for gypsum. Parcels S78, S79, S80, S82, S84, and S85 have a high potential for limestone.

Area 7

Area 7 is in Otero County and includes parcels L11, L19, L20, L23, L33, L34, L41, L49, and L50. Area 7 includes the Three Rivers and Tularosa mining districts, but none of the parcels are within these districts. USGS magmatic REE, basin brine path, Climax-type, and alkalic porphyry mineral systems overlaps area 7, but there is no mineral-resource potential for these deposits in area 7. Parcel L23 has a high potential for limestone. Parcels L23, L34, L41, L49, and L50 have moderate potential for gypsum. There is some aggregate potential in Area 7 (parcels L11, L33, L34, L41, L49, and L50). Magmatic REE, basin brine path, Climax-type, and alkalic porphyry deposits overlaps area 7, but there is no mineral-resource potential for these deposits in area 7.

Area 8

Area 8 is in southern Otero County, in the southern portion of the Orogrande district, and includes parcels L122 and L217. USGS magmatic REE (peralkaline syenite/granite/rhyolite/alaskite/pegmatite), climax-type, and alkalic porphyry mineral systems overlaps area 8. The Orogrande district has a high potential for copper, lode gold, silver, placer gold, iron, tungsten, turquoise, and garnet; moderate potential for molybdenum; and low potential for manganese, tellurium, zinc, uranium, tellurium, and REE.

Area 9

Area 9 is in southern Doña Ana County and includes parcels L184, L163, L177, L176, L178, and L186. The Aden district (scoria) lies within the area but south of the parcels. USGS porphyry Cu-Mo-Au (S-R-V tungsten), volcanogenic seafloor, and chemical weathering (supergene manganese) mineral systems overlaps area 9; none of these deposits are known in Area 9, except for L163. Parcels L163 and L177 have a high potential for aggregate. Parcel L163 has a moderate potential for manganese.

Area 10

The Caballo and Hot Springs mining districts are in area 10, in Sierra County, although the parcels lie outside the mining districts. Area 10 incudes parcels L8, L12, L13, L14, L16, L17, L18, and L22. USGS mineral systems that overlap Area 10 include magmatic REE, porphyry Cu-Mo-Au (S-R-V tungsten), chemical weathering (supergene manganese), and volcanic seafloor (Sangre de Cristo VMS), but none of these deposits are found in the parcels, except for L14.

The northern part of Parcel L14 has a high potential for limestone (as both crushed rock and dimension stone) and moderate potential for manganese. Parcel L8 has a high potential for diatomite. Parcels L8, L17, L18, L22, and L16 have a high potential for aggregate.

Area 11

Area 11 is in Sierra County. Area 11 includes parcels L39, L40, L42, L43, L44, L48, L51, L52, L53, L54, L55, L56, L57, L58, L59, L60, L61, L62, L63, L64, L65, L66, L67, L68, L69, L70, L71, L72, L73, L74, L75, L76, L78, L79, L82, L83, L84, and L85. Lake Valley and Macho mining districts are in Area 11, but only parcels L84 and L78 are in the Macho district. Parcel L55 is adjacent to the Lake Valley district. USGS mineral systems that overlap Area 11 include chemical weathering (all parcels), porphyry Cu-Mo-Au (multiple systems), magmatic REE, and basin brine path.

Parcel L55 has a low potential for copper and molybdenum, and high potential for manganese in the subsurface. Parcels L84 and L78 have high potential for gold and low potential for molybdenum, manganese, and zinc. Parcel L60 has a high potential for perlite. Parcels L68, L69, L79, L85, L76, L65, and western portion of L62 have a high potential for aggregate.

Area 12

Area 12 is in Luna County; the Victorio mining district is in Area 12 but none of the parcels are in the mining district. Area 12 includes parcels L103, L108, L123, L125, L127, L128, L129, L132, L133, L135, L137, L141, L142, L145, L146, L147, L150, L151, L152, L153, L154, L155, L156, L159, L161, L162, L165, L168, L172, L173, L174, L179, L180, L181, L182, L183, L185, L188, L189, L190, L191, L192, L194, L198, L199, L200, L204, L205, L206, L207, L208, L209, L210, L211, and L212. USGS mineral systems that overlap Area 12 include chemical weathering, porphyry Cu-Mo-Au (Middle Tertiary W skarns of southwestern New Mexico and southeastern Arizona, southwest Laramide porphyry belt), marine evaporite (In group, high Mg dolomites; Florida Mountains); none of the parcels have any potential for these deposits. All of the parcels in Area 12 have high potential for aggregate.

Area 13

Area 13 is in Luna County. Fluorite Ridge, Cooks Range manganese, Deming, Little Florida and Florida mining districts are in area 13, but none of the parcels are in these districts. Parcels L130, L131, L134, L136, L138, L139, L140, L143, L148, L149, L157, L158, L164, L167, L169, L170, L201, and L202 are in area 13. There are active mining claims on L169. USGS mineral systems that overlap Area 13 include Chemical weathering, Porphyry Cu-Mo-Au (all parcels), volcanogenic seafloor, hybrid magmatic REE/basin brine path, magmatic REE, marine evaporite (High Mg Dolomite), porphyry Cu-Mo-Au (Deming Mills); but there is no potential for these deposits in any of the parcels. All of the parcels have high potential for aggregate.

Area 14

Area 14 is in southern Doña Ana County and includes parcels L215 and L216. There are no mines, mining districts, or mining claims in Area 14, therefore there is no metals or uranium potential. Although the USGS focus area for chemical weathering (supergene manganese deposits) overlaps area 14, there is no potential in the parcels for these deposits. There is high potential for scoria in the western portion of area 14, but there is no potential for scoria in the parcels.

Area 15

Area 15 is in Grant County and includes parcels L25, L26, L27, L28, and L29. The eastern portion of the Cora Miller mining district is in Area 15, but none of the parcels are within that district. USGS mineral systems that overlap Area 15 include lacustrine evaporite, chemical weathering, and porphyry Cu-Mo-Au (Southwest belt and Middle Tertiary skarns); but there is no potential for these deposits in the parcels. Parcel L28 has high potential for aggregate. There is no other resource potential in the other parcels.

Area 16

Area 16 is in Luna and Doña Ana Counties. Parcels L166, L171, L193, L195, L196, L197, L203, and L203 are in Area 16. USGS mineral systems that overlap Area 16 include chemical weathering, porphyry Cu-Mo-Au, lacustrine evaporite; but there is no potential for these deposits in the parcels. Although much of Area 16 is in the Aden mining district, which has a high potential for scoria (decorative stone and volcanic cinder), only parcels L195, L196, and L203 have a high potential for scoria and L195 has a high potential for basalt (crushed stone). Parcels L166, northern L171, L193, northern L195, eastern L196 and L203 have high potential for aggregate.

Area 17

Area 17 is in Grant County and includes parcels L111, L121, and L126. USGS mineral systems that overlap Area 17 include lacustrine evaporite, volcanogenic seafloor, chemical weathering, porphyry Cu-Mo-Au (Southwest belt and mid tertiary skarns) and, magmatic REE. The Bound Ranch mining district is found in the area and parcel L111 is in the district. Parcel

L111 in the Bound Ranch district has a low potential for copper and lode gold, high potential for fluorite, and moderate potential for tungsten.

Area 18

Area 18 is in Grant County and includes parcels L99, L101, and L98. USGS mineral systems that overlap Area 18 include chemical weathering (supergene manganese), porphyry Cu-Mo-Au (southwest belt and Middle Tertiary skarns). The southern portion of the White Signal mining district overlaps parcel 99. Parcel 99 in the White Signal district has a high potential for copper, lode gold and fluorite, moderate potential for beryllium, cobalt, garnet and placer gold, and low potential for antimony, tellurium, zinc and mica.

Area 19

Area 19 is in Hidalgo County and includes parcel L124. USGS mineral systems that overlap Area 19 include lacustrine evaporite, chemical weathering, porphyry Cu-Mo-Au; but there is no potential for these deposits in the parcels. The area has high potential for aggregates.

Area 20

Area 20 is in Dona Ana County and includes parcels L112, L120, L107, L118, L160, L144, L115, L107, and L118. The Tortugas mining district is in Area 20 and includes parcels L160 and L144. USGS mineral systems that overlap Area 20 include chemical weathering (supergene manganese), porphyry Cu-Mo-Au (Mid Tertiary skarns), and hybrid magmatic REE/basin brine path. The Tortugas district (parcels L160 and L144) has a high potential for fluorite and a low potential for manganese. Parcels L107 and L160 have high potential for aggregate. Parcel L107 has a moderate potential for gypsum.

Area 21

Area 21 is in the Organ Mountains district, in Doña Ana County, and includes parcels L102 and L106. The USGS mineral systems that overlap Area 21 include porphyry Cu-Mo-Au, tungsten, chemical weathering and basin brine path. The parcels have high potential for copper, fluorite, and zinc; moderate potential for gold, tellurium, and garnet, and low potential for antimony, beryllium, molybdenum, iron, manganese, and REE. The parcels have high potential for aggregate.

Area 22

Area 22 is in Doña Ana County and includes parcel L100. Parcel L100 has a high potential for aggregate.

Area 23

Area 23 is in southern Doña Ana County and includes parcel L214. There are no mines, mining districts, or mining claims in Area 23, therefore there is no metals or uranium potential. Although the USGS mineral systems focus area for volcanogenic seafloor deposits (Hofstra and Kreiner, 2020) overlaps area 23, there is no potential in parcel L214 for these deposits. There is high aggregate potential in Area 23, but not in parcel L214.

Area 24

Area 24 includes L81 and L37. A portion of the Rincon mining district is in the upper northeastern corner of the area, but the parcels are outside of the district. L37 has a high aggregate potential. There is no mineral potential in parcel L81.

Area 25

Area 25 is in Sierra County and includes parcels L30, L31, L32, L35, L36, L38, L39, L40, and L42. The Tierra Blanca mining district is in the western portion of area 25 and includes parcel L38. USGS mineral systems that overlap Area 25 include chemical weathering (supergene manganese), porphyry Cu-Mo-Au (Middle Tertiary skarns, southwest Laramide), and porphyry Cu-Mo-Au; but the potential is restricted to the Tierra Blanca district. The Tierra Blanca district has high potential for antimony, silver, lead, and zinc, and moderate potential for lode gold, tellurium, tungsten, and copper.

Area 26

Area 26 is in Grant and Luna Counties and includes parcels L88, L93, L89, L86, L91, L80, L92, L218, L95, and L87. Parcels L91, L92, L95 and L87 have a high aggregate potential.

Oil and Gas Potential

Methodology for Oil and Gas Evaluation

In New Mexico, a century-long record of oil and gas exploration has spanned fluctuating commodity prices and technologic gains with exploration wells drilled in many areas of the state (Broadhead, 2017). As such, New Mexico can be readily defined by its currently producing areas and those with varying degrees for hydrocarbon potential.

The BLM land parcels were evaluated using resources available through the technical publications, records from the New Mexico Bureau of Geology and Mineral Resources Subsurface Library, and records from the New Mexico Oil Conservation Division. The current BLM land parcel evaluation builds upon previous resources assessments developed for BLM field offices (Broadhead and Cather, 2018; Engler and Cather, 2014; Engler and others, 2013). Statewide basin and petroleum system characteristics were referenced Broadhead (2017). Also, this evaluation draws upon the work of Thompson (1982) in characterizing the BLM parcels in the southwestern part of the state.

The BLM land parcels were characterized by the elements of the petroleum system: source rock, reservoir rock, seal, and trap (Table 4). Source rock parameters include organic richness, organic material type, and thermal maturity, which are catalogued in the New Mexico Petroleum Source Rock Database (Broadhead et al., 1998). Source rock information for many BLM parcels was referenced from the Thompson (1982) study of exploration wells in southwestern New Mexico. Potential reservoir, seal, and trap are described in the BLM parcels utilizing the subsurface mapping of Broadhead et al. (2009). Also, the structural framework for basin and uplifts boundaries were obtained from Plate 1 of Broadhead et al. (2009). This study utilizes the state-wide maps designating areas of low, medium, high, and high (producing) hydrocarbon potential, created by Cather and Broadhead (2018), based on geological evidence for the presence/absence of reservoir, seal, source rock, trap, and proximity to known production or shows while drilling.

For an area to be classified as high potential, offset wells must have flowed substantial volumes of oil or gas and there must be continuous reservoirs and seals along the migration pathway of the source rocks. In New Mexico, the areas of high potential coincide with currently active oil and gas wells (Fig. 6). Areas of moderate potential have more limited data, but contain exploratory wells with documented hydrocarbons shows and are characterized by favorable reservoir, seal, source and trap. The low potential designation is given to areas were the parameters required for a petroleum system are not present.

In addition to potential, the level of certainty for parcels was evaluated using the criteria described in BLM Policy Manual 3031 – Energy and Mineral Resource Assessment. The four categories of certainty are defined as:

> A – The available data are insufficient and/or cannot be considered as direct or indirect evidence to support or refute the possible existence of mineral resources within the respective area.
>
> B – The available data provide indirect evidence to support or refute the possible existence of mineral resources.

C – The available data provide direct evidence but are quantitatively minimal to support or refute the possible existence of mineral resources.

D – The available data provide abundant direct and indirect evidence to support or refute the possible existence of mineral resources.

None of the BLM parcels in the current evaluation are in actively producing parts the state, as such the parcels of interest are considered to be located in "frontier" areas with low to moderate hydrocarbon potential (Fig. 6, Table 4).

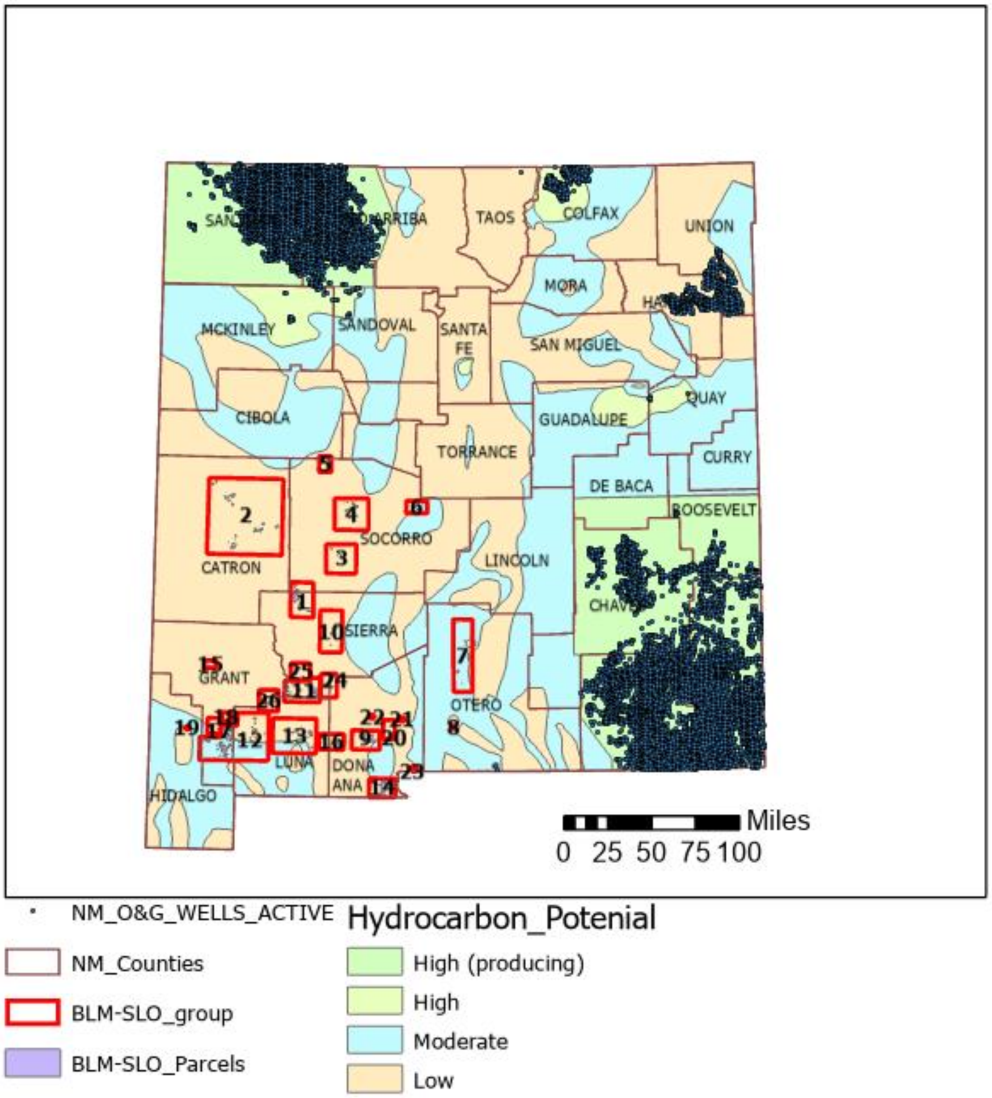

FIGURE 6. BLM-SLO evaluation parcels and groups with petroleum potential map (modified from Cather and Broadhead, 2018) and surface hole locations of active oil and gas wells (New Mexico Oil Conservation Division, 2022).

TABLE 4. Summary of subject land parcel groups and description of reservoir, seal, source rock, trap, and proximity to known production or hydrocarbon shows.

BLM group	OG_Reservoir	OG_Seal	OG_Source	OG_Trap	OG_Prod_Show	OG_certainty	OG_Potential
1	Pennsylvanian and Permian Sandstone	very faulted, reservoir rocks at surface	Overmature or not charged	Not likely, very faulted, reservoir rocks at surface	None	D	L
2	Cretaceous Sandstone, Permian and Pennsylvanian Sandstone	Pennsylvanian shales, micritic limestones, Tertiay Volcanic	Immature Cretaceous, Moderate to Mature Permian San Andres, Yeso, Abo	stratigraphic, structural at basin edge	Weak Gas shows in mudlog, Water recovered in drill stem test	C	L
3	Permian and Pennsylvanian Sandstone	Pennsylvanian shales, micritic limestones, Tertiay Volcanic	Overmature or not charged	stratigrphic, structural	None	C	L
4	Permian and Pennsylvanian Sandstone,	Pennsylvanian shales, micritic limestones, Tertiay Volcanic	Overmature or not charged	stratigraphic, structural	None	C	L
5	Cretaceous Sandstone ,Permian and Pennsylvanian Sandstone	Pennsylvanian shales, micritic limestones, Tertiay Volcanic	Overmature or not charged	stratigraphic, structural	None	C	L
6	Cretaceous Sandstone, Permian, and Pennsylvanian Sandstone	Pennsylvanian shales, micritic limestones	Pennsylvanian shales (1-2% TOC in some strata, thermally mature, oil & gas prone kerogens)	stratigraphic	no shows in this area. shows oil & gas In Pennsylvanian strata on Oscura anticline to southeast	B	L
7	Upper Penn sandstones; Lower Penn sandstones; Mississippian limestones	Pennsylvanian shales; Mississippian shales	Pennsylvanian & Mississippian shales	stratigraphic; combination pinchouts & regional dip	gas in Upper & Lower Pennsylvanian sandstones to east of L19&L20	C	M
8	Upper Penn sandstones; Lower Penn sandstones; Mississippian limestones	Pennsylvanian shales; Mississippian shales,	Pennsylvanian & Mississippian shales, Overmature?- Tertiary Intrusives outcrop at surface	Pemian Outcrop at surface with Tertiary Intrusives	None	C	L
9	Cretaceous Sandstone (v. poor - fair), Permian Sandstone, Pennsylvanian Sandstone and Carbonate (poor - fair), Mississippian-Ordivician Carbonate (poor - fair), U. Cambrian Sandstone (poor)	Cretaceous Shale	Cretaceous Shale (good) and limestone (fair), Permian and Pennsylvanian carbonate (fair-good), Pennsylvanian and Permian Carbonate (faird to good), Mississippian-U. Cambrian Carbonate (poor - fair)	stratigraphic, structural	Shows in Penn section ~10 miles to south	C	L
10	Permian Sandstone, Mississippian- Ordivician Carbonate, U. Cambrian Sandstone	micritic limestones	no offset data available	stratigraphic, structural	No shows in near offset wells	C	L
11	Cretaceous Sandstone Permian Sandstone Pennsylvanian Sandstone and Carbonate	Faulted area, Paleozoic section outcrops at surface	poor - fair Cretacous to Permian, Fair - good Pennsylvanian	stratigraphic, structural	No offset data available	B	L
12	Permian Sandstone, Pennsylvanian Sandstone and Carbonate (poor - fair), Mississippian- Ordivician Carbonate (poor - fair), U. Cambrian Sandstone (poor)	Cretaceous Shale, Pennsylvanian shales, micritic limestones	poor - fair Cretacous to Permian, Fair - good Pennsylvanian	stratigraphic, structural	None	B	L
12-south (parcels >L179)	Permian Sandstone, Mississippian- Ordivician Carbonate (poor - fair), U. Cambrian Sandstone (poor)	Cretaceous Shale, Pennsylvanian shales, micritic limestones	poor - fair Cretacous to Permian, Fair - good Pennsylvanian , Mississippian	stratigraphic, structural	No oil or gas encountered in well drilled near parcel L211,	A	L

BLM group	OG_Reservoir	OG_Seal	OG_Source	OG_Trap	OG_Prod_Show	OG_certainty	OG_Potential
13	Cretaceous Sandstone (v. poor - fair), Permian Sandstone, Mississippian-Ordivician Carbonate (poor - fair), U. Cambrian Sandstone (poor)	Cretaceous Shale	Cretaceous Shale (good) and limestone (fair), Permian carbonate (fair-good), , Mississippian-U. Cambrian Carbonate (poor - fair)	stratigraphic, structural	none	C	L
14	Cretaceous Sandstone (v. poor - fair), Permian Sandstone, Pennsylvanian Sandstone and Carbonate (poor - fair), Mississippian-Ordivician Carbonate (poor -	Cretaceous Shale	Cretaceous Shale (good) and limestone (fair), Permian and Pennsylvanian carbonate (fair-good), Mississippian-U. Cambrian Carbonate (poor - fair)	stratigraphic, structural	none	C	L
15	Permian Sandstone, Pennsylvanian Sandstone and Carbonate (poor - fair), Mississippian- Ordivician Carbonate (poor - fair), U. Cambrian Sandstone (poor)	Cretaceous Shale, Pennsylvanian shales, micritic limestones	poor - fair Cretacous to Permian, Fair - good Pennsylvanian	stratigraphic, structural	None	B	L
16	Cretaceous Sandstone (v. poor - fair), Permian Sandstone, Pennsylvanian Sandstone and Carbonate (poor - fair), Mississippian-Ordivician Carbonate (poor - fair), U. Cambrian Sandstone	Cretaceous Shale	Cretaceous Shale (good) and limestone (fair), Permian and Pennsylvanian carbonate (fair-good), , Mississippian-U. Cambrian Carbonate (poor - fair)	stratigraphic, structural	Shows in Penn section ~10 miles to north	C	L
17	Cretaceous Sandstone (v. poor - fair), Permian Sandstone (poor - fair), Mississippian- Ordivician Carbonate (poor - fair), U. Cambrian Sandstone (poor)	Cretaceous Shale, Pennsylvanian shales, micritic limestones	poor - fair Cretacous to Permian, Fair - good Pennsylvanian	stratigraphic, structural	No offset data available	B	L
18	Cretaceous Sandstone (v. poor - fair), Permian Sandstone (poor - fair), Mississippian- Ordivician	Cretaceous Shale, Pennsylvanian shales, micritic limestones	poor - fair Cretacous to Permian, Fair - good Pennsylvanian	stratigraphic, structural	No offset data available	B	L
19	Cretaceous Sandstone Permian Sandstone Pennsylvanian Sandstone and Carbonate Mississippian carbonate	Cretaceous Shale, Pennsylvanian shales, micritic limestones	poor - fair Cretacous to Permian, Fair - good Pennsylvanian , Mississippian	stratigraphic, structural	None	B	L
20	Cretaceous Sandstone (v. poor - fair), Permian Sandstone, Pennsylvanian Sandstone and Carbonate (poor - fair), Mississippian-Ordivician Carbonate (poor - fair), U. Cambrian Sandstone (poor)	Cretaceous Shale,Pennsylvanian shales, micritic limestones	Cretaceous Shale (good) and limestone (fair), Permian and Pennsylvanian carbonate (fair-good), Mississippian-U. Cambrian Carbonate (poor - fair)	stratigraphic, structural	Shows in Penn section ~10 miles to south	C	L
21	Permian Sandstone, Pennsylvanian Sandstone and Carbonate (poor - fair), Mississippian- Ordivician Carbonate (poor - fair), U. Cambrian Sandstone (poor)	Faulted area, Permian and Mississippian section outcrops at surface	Cretaceous Shale (good) and limestone (fair), Permian and Pennsylvanian carbonate (fair-good), Mississippian-U. Cambrian Carbonate (poor - fair)	Faulted area, Permian and Mississippian section outcrops at surface	No offset data available	B	L
22	Cretaceous Sandstone (v. poor - fair), Permian Sandstone, Pennsylvanian Sandstone and Carbonate (poor - fair), Mississippian-Ordivician Carbonate (poor - fair), U. Cambrian Sandstone (poor)	Cretaceous Shale,Pennsylvanian shales, micritic limestones	Cretaceous Shale (good) and limestone (fair), Permian and Pennsylvanian carbonate (fair-good),, Mississippian-U. Cambrian Carbonate (poor - fair)	stratigraphic, structural	Shows in Penn section ~15 miles to south	C	L
23	Permian Sandstone, Pennsylvanian Sandstone and Carbonate (poor - fair), Mississippian- Ordivician Carbonate (poor - fair), U. Cambrian Sandstone (poor)	Faulted area, Permian and Mississippian section outcrops at surface	Cretaceous Shale (good) and limestone (fair), Permian and Pennsylvanian carbonate (fair-good),Mississippian-U. Cambrian Carbonate (poor - fair)	Faulted area, Permian and Mississippian section outcrops at surface	No offset data available	B	L
24	Permian Sandstone, Mississippian- Ordivician Carbonate, U. Cambrian Sandstone	micritic limestones	no offset data available	stratigraphic, structural	No offset data available	B	L
25	Cretaceous Sandstone (v. poor - fair), Pennsylvanian Sandstone and Carbonate (poor - fair), Mississippian-Ordivician Carbonate (poor - fair), U. Cambrian Sandstone (poor)	Faulted area, Paleozoic section outcrops at surface	Cretaceous Shale (good) and limestone (fair),Pennsylvanian carbonate (fair-good), Mississippian-U. Cambrian Carbonate (poor - fair)	Faulted area, Paleozoic section outcrops at surface	None	B	L
26	Cretaceous Sandstone (v. poor - fair), Pennsylvanian Sandstone and Carbonate (poor - fair), Mississippian-Ordivician Carbonate (poor - fair), U. Cambrian Sandstone (poor)	Cretaceous Shale	Cretaceous Shale (good) and limestone (fair),Pennsylvanian carbonate (fair-good), Mississippian-U. Cambrian Carbonate (poor - fair)	stratigraphic, structural	None	B	L

Methodology for Carbon Dioxide (CO_2) and Helium Evaluation

To evaluate the potential for carbon dioxide (CO_2) and helium within the BLM land parcels, gas concentration and the potential for accumulation within the geologic play elements of reservoir, seal, and trap were reviewed. Each land parcel was assigned a designation of high, medium, or low CO_2 and helium potential

CO_2 resource potential in New Mexico is extensively considered in New Mexico Bureau of Geology and Mineral Resources Open-file Report 514 (Broadhead et al., 2009) and utilized in this study. The economic threshold to produce carbon dioxide commercially, is 98 mol percent CO_2, unless CO_2 is coproduced with other economically viable gases such as methane or helium. CO_2 content within a reservoir can be less than 60 mol percent when coproduced with methane and as low as 30 mol percent when coproduced with sufficient amounts of helium (Broadhead et al., 2009).

Helium resource potential is extensively considered in Broadhead and Gillard (2004) and utilized in this study. Economic concentration of helium is considered to be greater than 1 mol percent, unless it is coproduced with other economically viable gases such as methane or CO_2. When helium is coproduced within hydrocarbon reservoirs, concentrations can be as low as 0.3 mol percent (Broadhead and Gillard, 2004).

Cather and Broadhead (2018) created state-wide maps for helium and CO_2 designating areas of medium and high potential, based local geological evidence for the presence/absence of reservoir, seal, trap, and proximity to known production or shows while drilling. For the resource potential of either helium or CO_2 to be rated as high in a given area there must be elevated concentrations of that particular gas recovered or produced. The area must also have documented flows or test flows to show production potential of the gas. The boundaries of the area of high potential are delineated by the geologic model elements necessary for the storage and production of the particular gas (Cather and Broadhead, 2018). For CO_2 these elements include a source rock of Tertiary or Quaternary-age volcanic, a reservoir for gas accumulation, a seal to restrict the gas to the reservoir, and an adequate trap to prevent the gas from leaking out of the reservoir (Broadhead et al., 2009). In the case of helium, these elements include a pathway, consisting of faults or fractures, for migration from Precambrian rock or the mantle to reservoir rock, constrained by a seal and trap (Broadhead and Gillard, 2004). For an area to qualify as having moderate resource potential for helium or CO_2 the area must have the above-mentioned geologic elements for trapping the gas of interest and show elevated gas concentrations from a compositional analysis. The low potential designation is given to areas where there is a lack of the geologic elements for trapping, areas off of structural trends associated with elevated helium or CO_2, or areas that lack an elevated helium or CO_2 concentrations from a compositional analysis. In addition to potential, the level of certainty for parcels was evaluated using the criteria described in BLM Policy Manual 3031 – Energy and Mineral Resource Assessment and outlined in the previous "Methodology for Oil and Gas evaluation" section.

One group of the BLM parcels in the current evaluation is in a moderate potential area with respect to CO_2 (Fig. 7, Table 5). None of the subject parcels in this study are in moderate or high potential Helium areas (Fig. 8, Table 6).

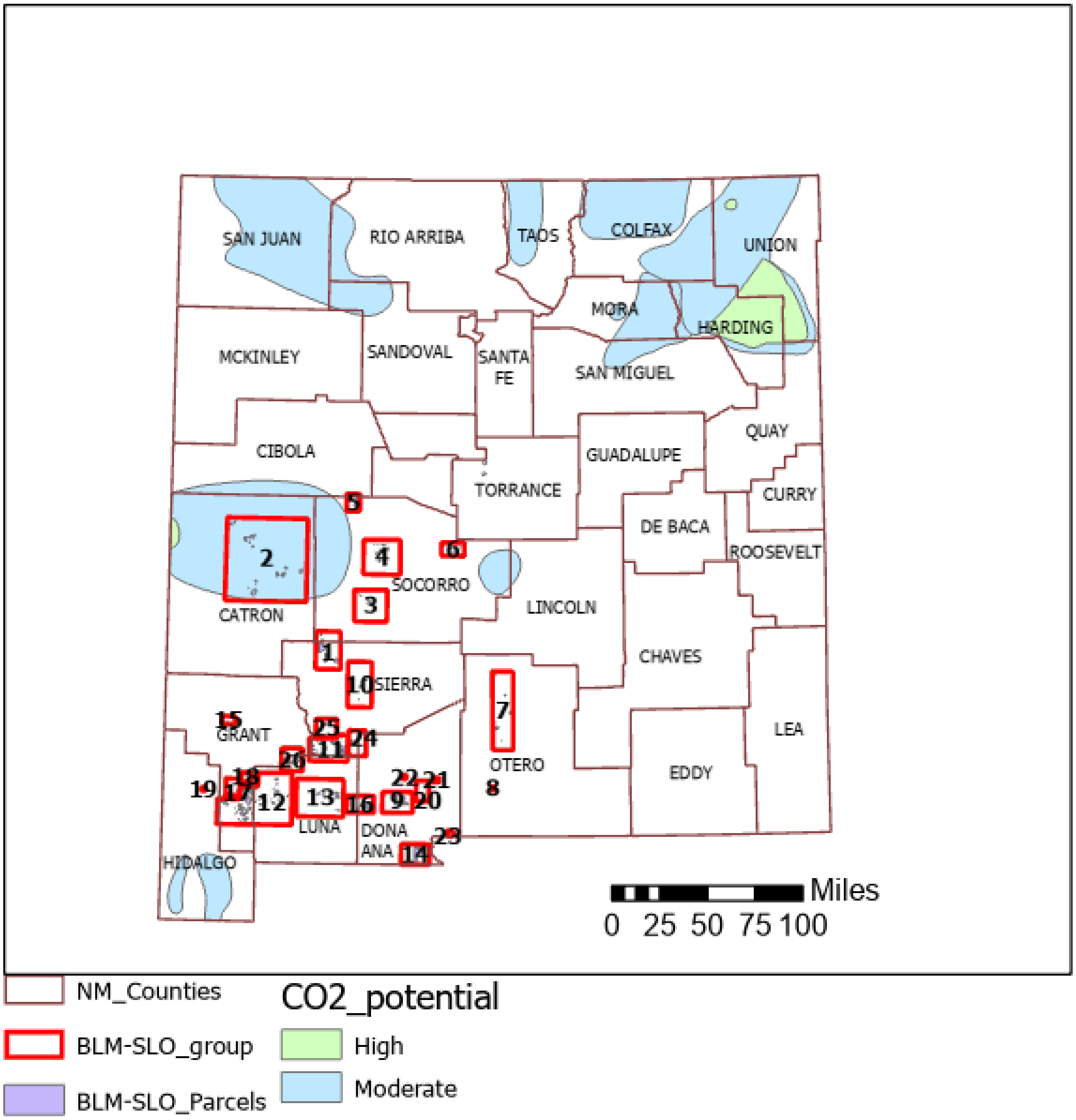

FIGURE 7. CO_2 potential subject land parcels (modified from Cather and Broadhead, 2018).

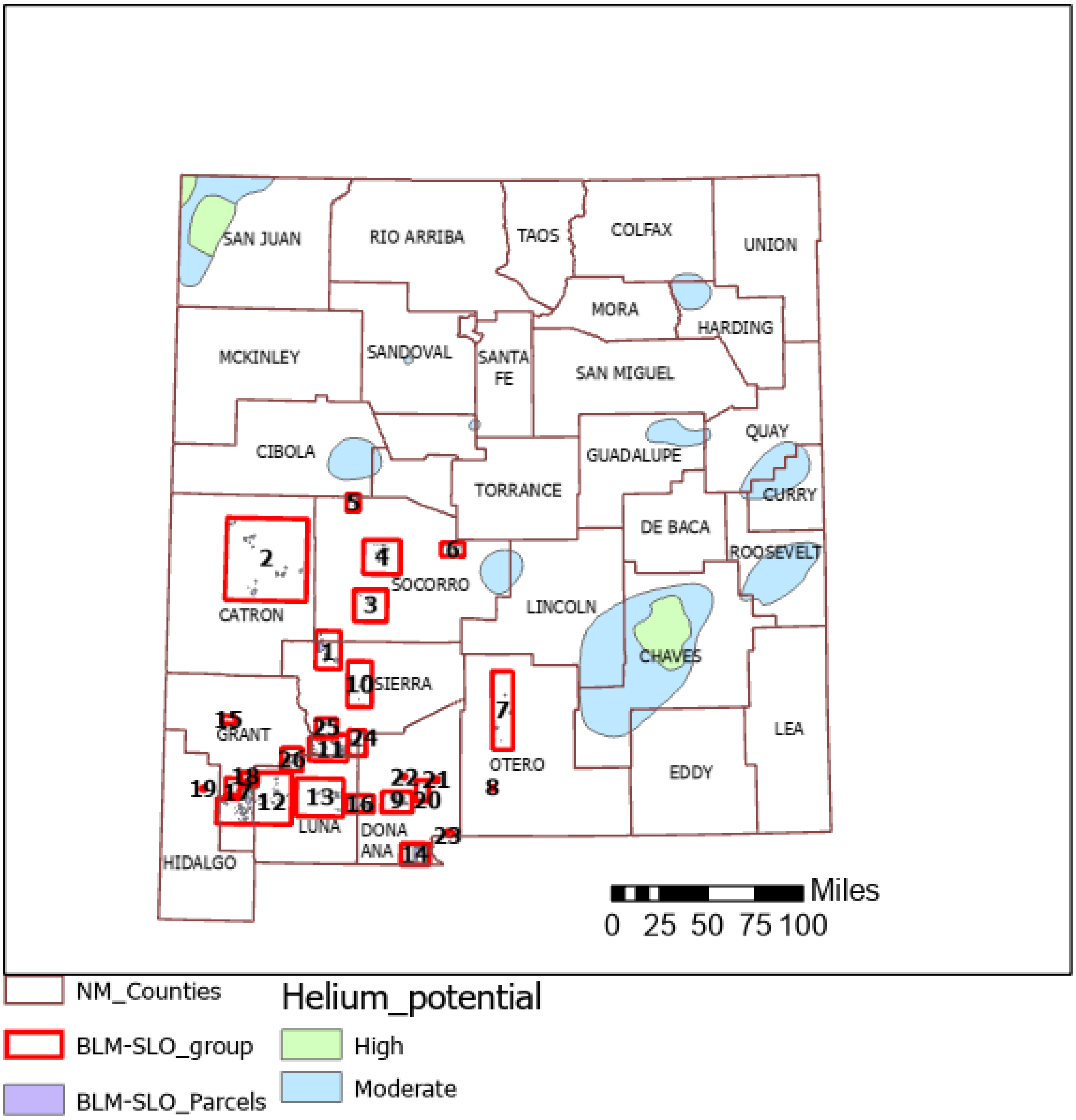

FIGURE 8. Helium potential of subject land parcels (modified from Cather and Broadhead, 2018).

TABLE 5. Summary of subject land parcel groups with respect to CO$_2$.

BLM group	C02_Reservoir	C02_Seal	CO2_concentration	CO2_Trap	CO2_indicators	CO2_Potential	CO2_Certainty
1	Pennsylvanian and Permian Sandstone	very faulted, reservoir rocks at surface	no wells in area with gas composition analyses	Not likely, very faulted, reservoir rocks at surface	area not along structural trends associated with elevated He content of gases	L	A
2	Cretaceous Sandstone, Permian and Pennsylvanian Sandstone	Pennsylvanian shales, micritic limestones, Tertiay Volcanic	He 0.2 mole %and C02 98 mole % on AZ border (4-1N-21W), wells in 1S-13W with no gas analysis, but reported non-combustable gas	stratigraphic, structural at basin edge	down dip of the He and CO2 discoveries in Holbrook Basin, AZ	M	C
3	Permian and Pennsylvanian Sandstone	Pennsylvanian shales, micritic limestones, Tertiay Volcanic	no wells in area with gas composition analyses	stratigrphic, structural	no wells in area with gas composition analyses	L	B
4	Permian and Pennsylvanian Sandstone,	Pennsylvanian shales, micritic limestones, Tertiay Volcanic	no wells in area with gas composition analyses	stratigraphic, structural	no wells in area with gas composition analyses	L	B
5	Cretaceous Sandstone ,Permian and Pennsylvanian Sandstone	Pennsylvanian shales, micritic limestones, Tertiay Volcanic	C02 95 mole % and He .13 mole % tests from wells in 7N-7W, C02 92 mole % and He .6 mole % in 6N-3W (>20 miles north)	stratigraphic, structural	C02 95 mole % and He .13 mole % tests from wells in 7N-7W, C02 92 mole % and He .6 mole % in 6N-3W (>20 miles north)	L	C
6	Cretaceous Sandstone, Permian, and Pennsylvanian Sandstone	Pennsylvanian shales, micritic limestones	C02 92 mole % and He 2.0 mole % in 4S-9E (~25 miles east)	stratigraphic	C02 92 mole % and He 2.0 mole % in 4S-9E (~25 miles east)	L	B
7	Upper Penn sandstones; Lower Penn sandstones; Mississippian limestones	Pennsylvanian shales; Mississippian shales	gas from nearby well in T14S R10E is 98% methane and apparently no He	stratigraphic; combination pinchouts & regional dip	strong flows of gas in Upper & Lower Pennsylvanian sandstones in nearby wells	L	A
8	Upper Penn sandstones; Lower Penn sandstones; Mississippian limestones	Pennsylvanian shales; Mississippian shales,	no wells in area with gas composition analyses	Pemian Outcrop at surface with Tertiary Intrusives	no wells in area with gas composition analyses	L	A
9	Cretaceous Sandstone (v. poor - fair), Permian Sandstone, Pennsylvanian Sandstone and Carbonate (poor - fair), Mississippian- Ordivician Carbonate (poor - fair), U. Cambrian Sandstone (poor)	Cretaceous Shale	no wells in area with gas composition analyses	stratigraphic, structural	no wells in area with gas composition analyses	L	A
10	Permian Sandstone, Mississippian- Ordivician Carbonate, U. Cambrian Sandstone	micritic limestones		stratigraphic, structural	no wells in area with gas composition analyses	L	A
11	Cretaceous Sandstone Permian Sandstone Pennsylvanian Sandstone and Carbonate	Faulted area, Paleozoic section outcrops at surface	no wells in area with gas composition analyses	stratigraphic, structural	no wells in area with gas composition analyses	L	A
12	Permian Sandstone, Pennsylvanian Sandstone and Carbonate (poor - fair), Mississippian- Ordivician Carbonate (poor - fair), U. Cambrian Sandstone (poor)	Cretaceous Shale, Pennsylvanian shales, micritic limestones	no wells in area with gas composition analyses	stratigraphic, structural	no wells in area with gas composition analyses	L	A
12-south (parcels >L179)	Permian Sandstone, Mississippian- Ordivician Carbonate (poor - fair), U. Cambrian Sandstone (poor)	Cretaceous Shale, Pennsylvanian shales, micritic limestones	no wells in area with gas composition analyses	stratigraphic, structural	no wells in area with gas composition analyses	L	A

2022 BLM group	C02_Reservoir	He_Seal	CO2_concentration	He_Trap	CO2_indicators	CO2_Potential	CO2_Certainty
13	Cretaceous Sandstone (v. poor - fair), Permian Sandstone, Mississippian- Ordivician Carbonate (poor - fair), U. Cambrian Sandstone (poor)	Cretaceous Shale	no wells in area with gas composition analyses	stratigraphic, structural	no wells in area with gas composition analyses	L	A
14	Cretaceous Sandstone (v. poor - fair), Permian Sandstone, Pennsylvanian Sandstone and Carbonate (poor - fair), Mississippian- Ordivician Carbonate (poor - fair), U.	Cretaceous Shale	no wells in area with gas composition analyses	stratigraphic, structural	no wells in area with gas composition analyses	L	A
15	Permian Sandstone, Pennsylvanian Sandstone and Carbonate (poor - fair), Mississippian- Ordivician Carbonate (poor - fair), U. Cambrian Sandstone (poor)	Cretaceous Shale, Pennsylvanian shales, micritic limestones	no wells in area with gas composition analyses	stratigraphic, structural	no wells in area with gas composition analyses	L	A
16	Cretaceous Sandstone (v. poor - fair), Permian Sandstone, Pennsylvanian Sandstone and Carbonate (poor - fair), Mississippian- Ordivician Carbonate (poor - fair), U. Cambrian Sandstone (poor)	Cretaceous Shale	no wells in area with gas composition analyses	stratigraphic, structural	no wells in area with gas composition analyses	L	A
17	Cretaceous Sandstone (v. poor - fair), Permian Sandstone (poor - fair), Mississippian- Ordivician Carbonate (poor - fair), U. Cambrian Sandstone (poor)	Cretaceous Shale, Pennsylvanian shales, micritic limestones		stratigraphic, structural	no wells in area with gas composition analyses	L	A
18	Cretaceous Sandstone (v. poor - fair), Permian Sandstone (poor - fair), Mississippian- Ordivician Carbonate (poor - fair), U.	Cretaceous Shale, Pennsylvanian shales, micritic limestones	no wells in area with gas composition analyses	stratigraphic, structural	no wells in area with gas composition analyses	L	A
19	Cretaceous Sandstone Permian Sandstone Pennsylvanian Sandstone and Carbonate Mississippian carbonate	Cretaceous Shale, Pennsylvanian shales, micritic limestones	no wells in area with gas composition analyses	stratigraphic, structural	no wells in area with gas composition analyses	L	A
20	Cretaceous Sandstone (v. poor - fair), Permian Sandstone, Pennsylvanian Sandstone and Carbonate (poor - fair), Mississippian- Ordivician Carbonate (poor - fair), U. Cambrian Sandstone (poor)	Cretaceous Shale,Pennsylvanian shales, micritic limestones	no wells in area with gas composition analyses	stratigraphic, structural	no wells in area with gas composition analyses	L	A
21	Permian Sandstone, Pennsylvanian Sandstone and Carbonate (poor - fair), Mississippian- Ordivician Carbonate (poor - fair), U. Cambrian Sandstone (poor)	Faulted area, Permian and Mississippian section outcrops at surface	no wells in area with gas composition analyses	Faulted area, Permian and Mississippian section outcrops at surface	no wells in area with gas composition analyses	L	A
22	Cretaceous Sandstone (v. poor - fair), Permian Sandstone, Pennsylvanian Sandstone and Carbonate (poor - fair), Mississippian- Ordivician Carbonate (poor - fair), U. Cambrian Sandstone (poor)	Cretaceous Shale,Pennsylvanian shales, micritic limestones	no wells in area with gas composition analyses	stratigraphic, structural	no wells in area with gas composition analyses	L	A
23	Permian Sandstone, Pennsylvanian Sandstone and Carbonate (poor - fair), Mississippian- Ordivician Carbonate (poor - fair), U. Cambrian Sandstone (poor)	Faulted area, Permian and Mississippian section outcrops at surface	no wells in area with gas composition analyses	Faulted area, Permian and Mississippian section outcrops at surface	no wells in area with gas composition analyses	L	A
24	Permian Sandstone, Mississippian- Ordivician Carbonate, U. Cambrian Sandstone	micritic limestones	no wells in area with gas composition analyses	stratigraphic, structural	no wells in area with gas composition analyses	L	A
25	Cretaceous Sandstone (v. poor - fair), Pennsylvanian Sandstone and Carbonate (poor - fair), Mississippian- Ordivician Carbonate (poor - fair), U. Cambrian Sandstone (poor)	Faulted area, Paleozoic section outcrops at surface	no wells in area with gas composition analyses	Faulted area, Paleozoic section outcrops at surface	no wells in area with gas composition analyses	L	A
26	Cretaceous Sandstone (v. poor - fair), Pennsylvanian Sandstone and Carbonate (poor - fair), Mississippian- Ordivician Carbonate (poor - fair), U. Cambrian Sandstone (poor)	Cretaceous Shale	no wells in area with gas composition analyses	stratigraphic, structural	no wells in area with gas composition analyses	L	A

BLM group	He_Reservoir	He_Seal	He_concentration	He_Trap	He_indicators	He_Potential	He_Certainty
1	Pennsylvanian and Permian Sandstone	very faulted, reservoir rocks at surface	no wells in area with gas composition analyses	Not likely, very faulted, reservoir rocks at surface	no wells in area with gas composition analyses	L	A
2	Cretaceous Sandstone, Permian and Pennsylvanian Sandstone	Pennsylvanian shales, micritic limestones, Tertiay Volcanic	He 0.2 mole %and C02 98 mole % on AZ border (4-1N-21W), wells in 1S-13W with no gas analysis, but reported non-combustable gas	stratigraphic, structural at basin edge	down dip of the He and CO2 discoveries in Holbrook Basin, AZ	M	B
3	Permian and Pennsylvanian Sandstone	Pennsylvanian shales, micritic limestones, Tertiay Volcanic	no wells in area with gas composition analyses	stratigrphic, structural	no wells in area with gas composition analyses	L	B
4	Permian and Pennsylvanian Sandstone,	Pennsylvanian shales, micritic limestones, Tertiay Volcanic	no wells in area with gas composition analyses	stratigraphic, structural	no wells in area with gas composition analyses	L	B
5	Cretaceous Sandstone ,Permian and Pennsylvanian Sandstone	Pennsylvanian shales, micritic limestones, Tertiay Volcanic	C02 95 mole % and He .13 mole % tests from wells in 7N-7W, C02 92 mole % and He .6 mole % in 6N-3W (>20 miles north)	stratigraphic, structural	C02 95 mole % and He .13 mole % tests from wells in 7N-7W, C02 92 mole % and He .6 mole % in 6N-3W (>20 miles north)	L	C
6	Cretaceous Sandstone, Permian, and Pennsylvanian Sandstone	Pennsylvanian shales, micritic limestones	2% He show in Carrizozo Basin to 30 miles to the east	stratigraphic	2% He show in Carrizozo Basin to east	L	C
7	Upper Penn sandstones; Lower Penn sandstones; Mississippian limestones	Pennsylvanian shales; Mississippian shales	gas from nearby well in T14S R10E is 98% methane and apparently no He	stratigraphic; combination pinchouts & regional dip	area not along structural trends associated with elevated He content of gases	L	A
8	Upper Penn sandstones; Lower Penn sandstones; Mississippian limestones	Pennsylvanian shales; Mississippian shales,	no wells in area with gas composition analyses	Pemian Outcrop at surface with Tertiary Intrusives	no wells in area with gas composition analyses	L	A
9	Cretaceous Sandstone (v. poor - fair), Permian Sandstone, Pennsylvanian Sandstone and Carbonate (poor - fair), Mississippian- Ordivician Carbonate (poor - fair), U. Cambrian Sandstone (poor)	Cretaceous Shale	no wells in area with gas composition analyses	stratigraphic, structural	no wells in area with gas composition analyses	L	A
10	Permian Sandstone, Mississippian-Ordivician Carbonate, U. Cambrian Sandstone	micritic limestones		stratigraphic, structural	no wells in area with gas composition analyses	L	A
11	Cretaceous Sandstone Permian Sandstone Pennsylvanian Sandstone and Carbonate	Faulted area, Paleozoic section outcrops at surface	no wells in area with gas composition analyses	stratigraphic, structural	no wells in area with gas composition analyses	L	A
12	Permian Sandstone, Pennsylvanian Sandstone and Carbonate (poor - fair), Mississippian- Ordivician Carbonate (poor - fair), U. Cambrian Sandstone (poor)	Cretaceous Shale, Pennsylvanian shales, micritic limestones	no wells in area with gas composition analyses	stratigraphic, structural	no wells in area with gas composition analyses	L	A
12-south (parcels >L179)	Permian Sandstone, Mississippian-Ordivician Carbonate (poor - fair), U. Cambrian Sandstone (poor)	Cretaceous Shale, Pennsylvanian shales, micritic limestones	no wells in area with gas composition analyses	stratigraphic, structural	no wells in area with gas composition analyses	L	A

BLM group	He_Reservoir	He_Seal	He_concentration	He_Trap	He_indicators	He_Potential	He_Certainty
13	Cretaceous Sandstone (v. poor - fair), Permian Sandstone, Mississippian-Ordivician Carbonate (poor - fair), U. Cambrian Sandstone (poor)	Cretaceous Shale	no wells in area with gas composition analyses	stratigraphic, structural	no wells in area with gas composition analyses	L	A
14	Cretaceous Sandstone (v. poor - fair), Permian Sandstone, Pennsylvanian Sandstone and Carbonate (poor - fair), Mississippian- Ordivician Carbonate (poor - fair), U. Cambrian Sandstone (poor)	Cretaceous Shale	no wells in area with gas composition analyses	stratigraphic, structural	no wells in area with gas composition analyses	L	A
15	Permian Sandstone, Pennsylvanian Sandstone and Carbonate (poor - fair), Mississippian- Ordivician Carbonate (poor - fair), U. Cambrian Sandstone (poor)	Cretaceous Shale, Pennsylvanian shales, micritic limestones	no wells in area with gas composition analyses	stratigraphic, structural	no wells in area with gas composition analyses	L	B
16	Cretaceous Sandstone (v. poor - fair), Permian Sandstone, Pennsylvanian Sandstone and Carbonate (poor - fair), Mississippian- Ordivician Carbonate (poor - fair), U. Cambrian Sandstone (poor)	Cretaceous Shale	no wells in area with gas composition analyses	stratigraphic, structural	no wells in area with gas composition analyses	L	A
17	Cretaceous Sandstone (v. poor - fair), Permian Sandstone (poor - fair), Mississippian- Ordivician Carbonate (poor - fair), U. Cambrian Sandstone (poor)	Cretaceous Shale, Pennsylvanian shales, micritic limestones		stratigraphic, structural	no wells in area with gas composition analyses	L	A
18	Cretaceous Sandstone (v. poor - fair), Permian Sandstone (poor - fair), Mississippian- Ordivician Carbonate (poor - fair), U. Cambrian Sandstone	Cretaceous Shale, Pennsylvanian shales, micritic limestones	no wells in area with gas composition analyses	stratigraphic, structural	no wells in area with gas composition analyses	L	A
19	Cretaceous Sandstone Permian Sandstone Pennsylvanian Sandstone and Carbonate Mississippian carbonate	Cretaceous Shale, Pennsylvanian shales, micritic limestones	no wells in area with gas composition analyses	stratigraphic, structural	no wells in area with gas composition analyses	L	A
20	Cretaceous Sandstone (v. poor - fair), Permian Sandstone, Pennsylvanian Sandstone and Carbonate (poor - fair), Mississippian- Ordivician Carbonate (poor - fair), U. Cambrian Sandstone (poor)	Cretaceous Shale,Pennsylvanian shales, micritic limestones	no wells in area with gas composition analyses	stratigraphic, structural	no wells in area with gas composition analyses	L	A
21	Permian Sandstone, Pennsylvanian Sandstone and Carbonate (poor - fair), Mississippian- Ordivician Carbonate (poor - fair), U. Cambrian Sandstone (poor)	Faulted area, Permian and Mississippian section outcrops at surface	no wells in area with gas composition analyses	Faulted area, Permian and Mississippian section outcrops at surface	no wells in area with gas composition analyses	L	A
22	Cretaceous Sandstone (v. poor - fair), Permian Sandstone, Pennsylvanian Sandstone and Carbonate (poor - fair), Mississippian- Ordivician Carbonate (poor - fair), U. Cambrian Sandstone (poor)	Cretaceous Shale,Pennsylvanian shales, micritic limestones	no wells in area with gas composition analyses	stratigraphic, structural	no wells in area with gas composition analyses	L	A
23	Permian Sandstone, Pennsylvanian Sandstone and Carbonate (poor - fair), Mississippian- Ordivician Carbonate (poor - fair), U. Cambrian Sandstone (poor)	Faulted area, Permian and Mississippian section outcrops at surface	no wells in area with gas composition analyses	Faulted area, Permian and Mississippian section outcrops at surface	no wells in area with gas composition analyses	L	A
24	Permian Sandstone, Mississippian-Ordivician Carbonate, U. Cambrian Sandstone	micritic limestones	no wells in area with gas composition analyses	stratigraphic, structural	no wells in area with gas composition analyses	L	A
25	Cretaceous Sandstone (v. poor - fair), Pennsylvanian Sandstone and Carbonate (poor - fair), Mississippian-Ordivician Carbonate (poor - fair), U. Cambrian Sandstone (poor)	Faulted area, Paleozoic section outcrops at surface	no wells in area with gas composition analyses	Faulted area, Paleozoic section outcrops at surface	no wells in area with gas composition analyses	L	A
26	Cretaceous Sandstone (v. poor - fair), Pennsylvanian Sandstone and Carbonate (poor - fair), Mississippian-Ordivician Carbonate (poor - fair), U. Cambrian Sandstone (poor)	Cretaceous Shale	no wells in area with gas composition analyses	stratigraphic, structural	no wells in area with gas composition analyses	L	A

Geothermal Resources

The purpose of this project is to evaluate the geothermal potential of several blocks of BLM land scattered across southwestern and south-central New Mexico. With the exception of Lightning Dock southwest of Lordsburg, most of the known geothermal systems in this part of the state are low temperature, ranging from 40–100°C, and thus are most suitable for direct-use applications (e.g., space heating, heating greenhouses, and recreational soaking).Geothermal resource evaluation commonly involves compiling thermal information (heat flow, spring and well discharge temperature), conservative ion (boron, lithium) concentrations, and structural information (earthquake location and magnitude, Quaternary fault locations, dike locations). Here, in addition to the standard analysis, we utilized a subcrop map developed by Los Alamos National Laboratory (2015) as part of a DOE-funded Play Fairway analysis of the geothermal potential of southwestern New Mexico. In addition, the Play Fairway analysis of Bennett and Nash (2017) in the Tularosa Basin was incorporated into this evaluation.

The geothermal systems in southwestern New Mexico are gravity-driven, with meteoric water recharge in the highlands and groundwater discharge at low elevation (Smith and Chapman, 1983). These gravity-driven systems pick up heat and chemical constituents along their flow paths in fractured rocks at depth. The fluids are heated by the elevated heat flow within the thinned crust of the Rio Grande rift. Crustal heat flow in this region ranges from 70 to 105 mW/m^2 (Reiter et al., 1975). In some situations, the groundwater discharges at the surface as a warm spring. Discharge hydrogeologic windows associated with springs are zones at relatively low elevation where regional or local aquitards are thinned or breached by faulting, erosion, or fractured intrusions, allowing relatively rapid vertical flow of geothermal water toward the surface (Witcher, 1988; Figure 1). An example of a surface discharge window is at Radium Springs, NM along the Rio Grande, where hot (100 °C) water is flowing upward through a fractured rhyolite dike that had cut through the Palm Park volcaniclastic aquitard (Figure 9; Witcher, 2001). Sometimes heated water comes up through a hydrogeologic window and is trapped in the subsurface by younger aquitards (playa deposits in the Santa Fe Group) to form a blind geothermal system. For example, the breaching of the Palm Park aquitard across a permeable fault zone forces 85°C fluids into a shallow blind outflow plume below playa deposits in the Santa Fe Group at Rincon, NM (Witcher, 1998).

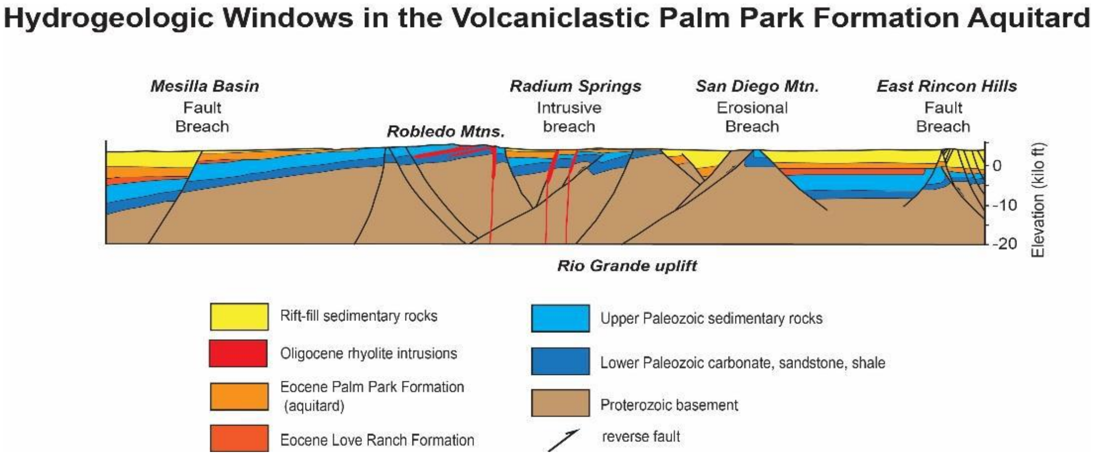

FIGURE 9. A diagrammatic cross-section modified from Seager et al. (1987) showing three types of hydrogeologic windows. The location of the cross-section is on Figure 2.

In southwestern New Mexico, compressional Laramide deformation began in late Cretaceous time and reached its peak during Eocene time, forming northwest-trending uplifts and basins that followed the trend of an earlier Jurassic to Cretaceous rifting event. Many of the NW-trending normal faults associated with Jurassic rifting were reactivated as reverse faults during Laramide deformation (Lawton, 2000). Large andesitic stratovolcanic centers developed in the Mogollon-Datil volcanic field at 38 Ma, shedding debris flow and laharic aprons that form low permeability aquitards on top of the older Laramide highlands and basins. Los Alamos National Laboratory (2015) developed a subcrop map of the contact between the buried structures and overlying younger rocks, building on previous unpublished work by Witcher (Figure10). This map was used to locate the places where regional aquitards (fine-grained volcaniclastic units in the Eocene-Oligocene Palm Park or Rubio Peak formations) have been stripped by erosion or penetrated by faults or intrusions.

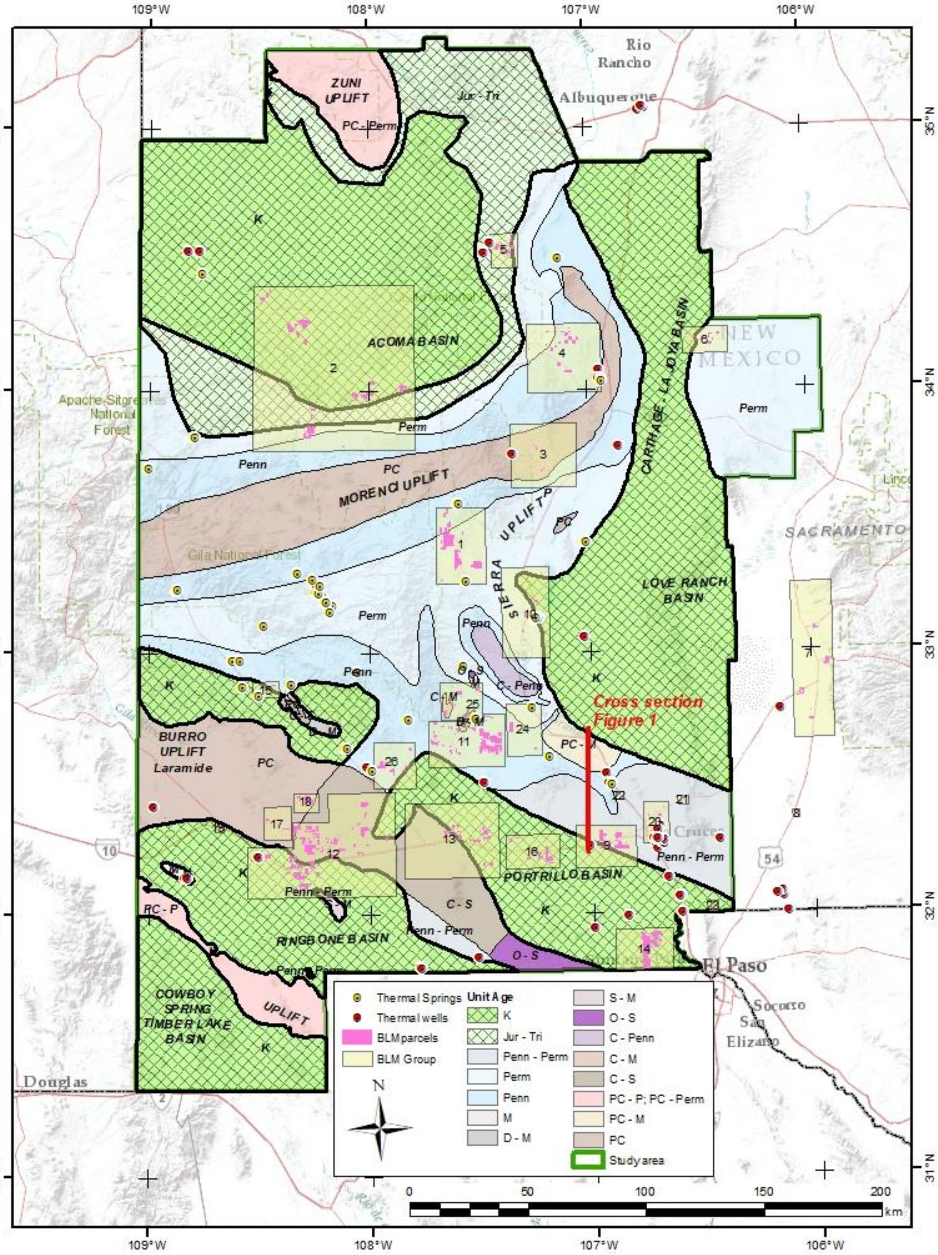

FIGURE 10. Subcrop map depicting the landscape at the end of Laramide deformation, just prior to deposition of Eocene to Oligocene volcanic and volcaniclastic rocks from the Mogollon-Datil volcanic field. The various colors depict the rock unit or units that lie below the unconformity. The NW-striking fabric of southwestern New Mexico is inherited in part from Jurassic rifting associated with the formation of the Bisbee Basin. The green cross-hatched areas are Laramide basins that preserve fine-grained Cretaceous sedimentary rocks that act as aquitards. These areas hold little geothermal potential. Note that thermal springs (yellow dots) coincide with the erosional hydrogeologic windows where the volcaniclastic material has been removed. The red dots are thermal wells of various depths. The white areas encompass several small BLM blocks of interest (lavender areas). Modified from Los Alamos National Laboratory (2015).

Evaluation of thermal data

The most direct evidence of the presence of a geothermal system is thermal data. Heat flow data for the state of New Mexico largely come from two sources: (1) published data from wells >200 m deep (e.g. Reiter et al., 1975) that measure the regional-scale background heat flow, and (2) industry data (AMAX, Hunt, Phillips, etc.) from measurements in abandoned wells and thermal gradient holes wells <200 m deep (commonly <100 m). Most of the heat flow data in the vicinity of the BLM parcels is from shallow wells (<100 m) that can be disturbed by shallow hydrologic affects, particularly lateral groundwater flow or upwelling groundwater flow, that mask the deeper subsurface thermal structure (e.g., Pepin et al., 2022, fig.2, and references therein). Consequently, the possibility of disturbance makes the elevated heat flow from shallow wells difficult to extrapolate to depths with temperatures associated with low-temperature geothermal resources (40–100°C). Two areas of high heat flow in the vicinity of the BLM parcels of interest are truly indicative of a geothermal resource. One is located in Area 20 in Figure 11on the west side of Tortugas Mountain (Las Alturas) and one is located to the west of Area 14 along the east side of the East Potrillo Mountains.

The modern geothermal system in the vicinity of Tortugas Mountain was originally found when the Clary and Ruther State 1 oil test produced steam and hot water in 1949 and when warm salty water in shallow wells was noted during the construction of the Las Alturas neighborhood (Witcher et al., 2002). Early studies revealed temperatures of 62.5°C at depth of 300 m. New Mexico State University decided to develop the geothermal system during the mid-1970s to early 1980s to save on heating costs. Subsequent drilling encountered a maximum temperature of 65.6 °C at 300 m. A direct-use heating system was built in 1981–1982 to heat athletic buildings and other facilities on the east side of campus. Greenhouse and aquiculture business incubators were added to the system in 1985. This was one of the first attempts to use a geothermal resource to directly heat large facilities (e.g., the basketball arena) on a university campus. Because the use of this resource was ground-breaking, several mistakes in the initial design led to maintenance problems in later years (Millennium Energy, 2006). The heating system was taken offline in 2001, but the geothermal resource remains viable. This system coincides with a horst that separates the Mesilla Basin to the west from the Jornada del Muerto Basin; the horst extends from the Doña Mountains to the north to the New Mexico-Texas state line to the south. Thus, the shallow system at Las Alturas likely is present at greater depths to the north and south along the horst; this geothermal resource is called the East Mesa system by Witcher (1995).

An undeveloped low-temperature geothermal system is located on the east side of the East Potrillo Mountains along a fault zone (Snyder, 1986) several kilometers to the west of the Sunland Park parcels in Area 14. Hunt Energy Corporation and Anadarko Industries did extensive exploration on the West Mesa in the late 1970s to early 1980s.Three deep geothermal wells drilled for Hunt Energy Corp in 1980 and one oil and gas well indicate the presence of a karstic and fractured aquifer developed in Lower Cretaceous and Middle Permian sedimentary rocks along the southeastern margin of the East Potrillo Mountains. Two of the geothermal wells were 620 m deep and encountered 55–60°C water and one was drilled to 310 m and hit 60°C water. All three geothermal wells showed curved temperature depth profiles indicating strong upflow (Pepin et al., 2022). The oil well was drilled several kilometers north of the geothermal wells and had a geothermal gradient of 26°C/km and a heat flow of 73mW/m^2. This well did not encounter the geothermal system, but it did penetrate fractured and karstic rock.

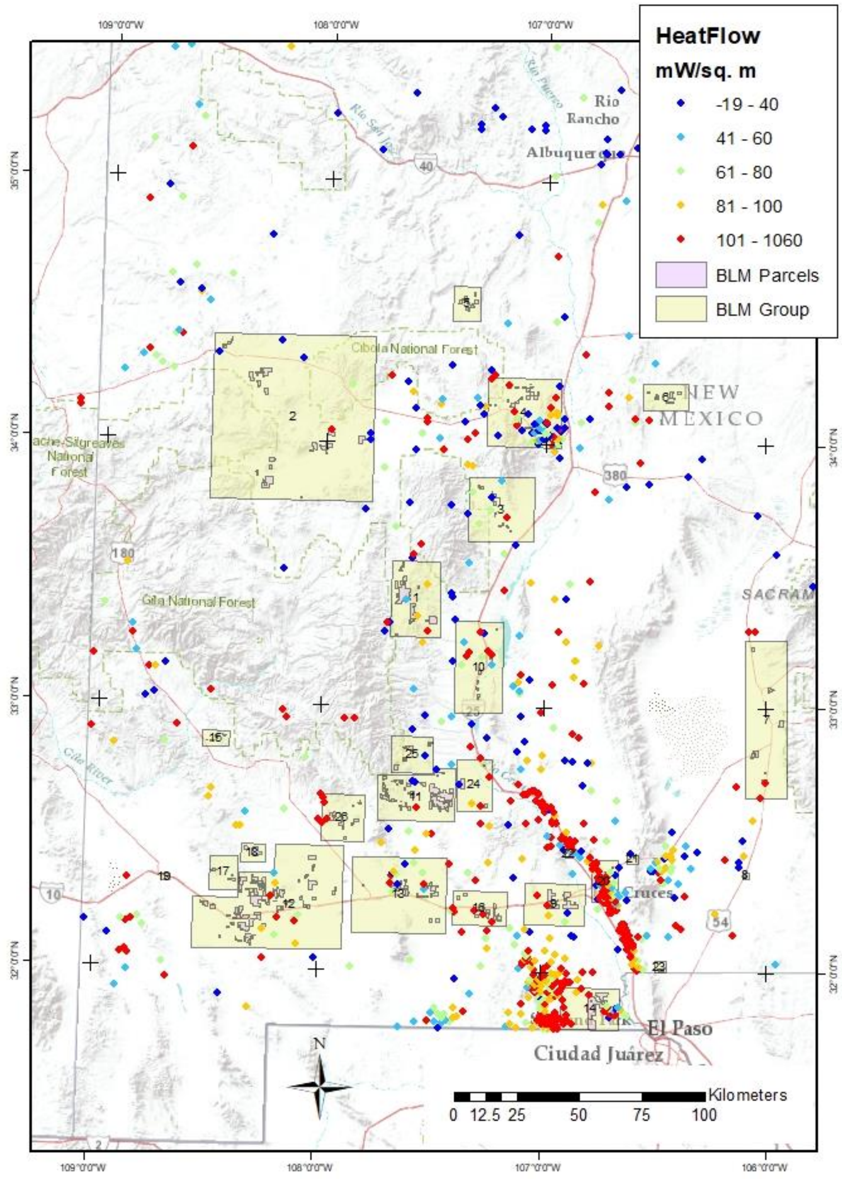

FIGURE 11. Heat flow data in southwestern New Mexico.

Another source of thermal information comes from measuring the discharge temperature of springs and wells. Discharge temperatures greater than 30°C are considered evidence of geothermal activity. The locations of thermal springs and wells are plotted on Figure 10. Note that thermal springs (yellow dots) coincide with the erosional hydrogeologic windows where the volcaniclastic material has been removed.

Evaluation of groundwater geochemistry

Conservative trace element analysis is regularly used in geothermal exploration because rock-water geochemical reactions at temperatures above 100°C liberate these elements into groundwater (Arehart and Donelick, 2006). Boron and lithium are among the trace elements associated with chloride-dominated geothermal waters (Arehart and Donelick, 2006). Boron does not absorb onto mineral surfaces and thus remains in solution as groundwater flows down gradient away from a geothermal source. Concentrations diminish as solutes disperse while the fluids move down gradient. This dilution likely occurs within about 10 km of the source region. Boron measurements are utilized in agricultural assessments because boron is toxic to certain plants (Hem, 985); thus, this element is analyzed during routine water quality investigations. Like boron, lithium does not absorb onto minerals once released into solution and this element is also toxic to certain plants. The source of the groundwater geochemistry data used in this project is described in Los Alamos National Laboratory (2015). The dataset was updated during this project using data collected from the NMBGMR Aquifer Mapping program between 2015 and 2020. In general, the boron and lithium groundwater concentrations are low (<1 mg/L), suggesting that the presence of thermal waters upwelling from depth is largely masked by dilution by meteoric waters (Fig. 12, 13). Exceptions are in the Acoma Basin (Goff et al., 1988; Kelley et al., 2016), north of Parcel Group 5 outside the area of interest.

The chalcedony geothermometry data from Los Alamos National Laboratory (2015) was examined for this report, but as noted in the Los Alamos National Laboratory (2015) analysis, high values of estimated reservoir temperature in this region are controlled more by the presence of silica-rich volcanic rocks as opposed to interactions of hot water with rock at depth. Thus, these estimates probably do not reflect true subsurface reservoir temperatures. This data was not considered during the current evaluation.

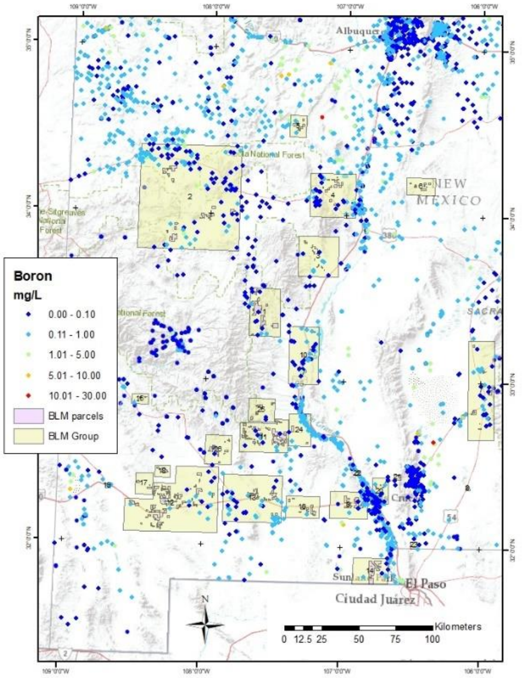

FIGURE 12. Map of boron concentration

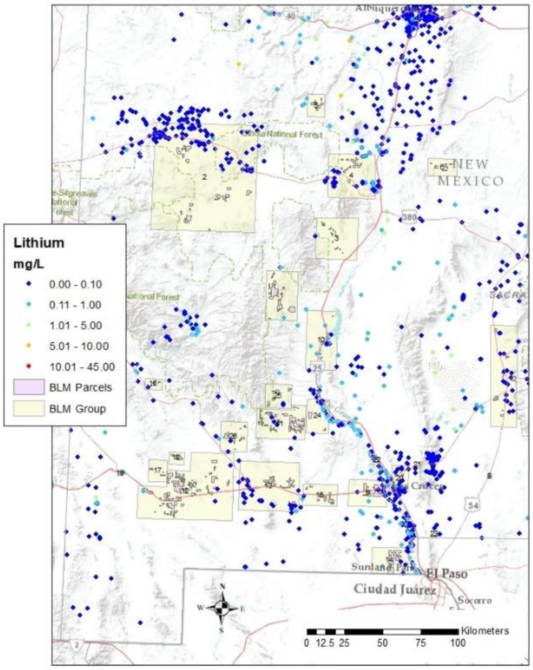

FIGURE 13. Map of lithium concentration.

Evaluation of geologic structures

Faults and fault intersections commonly act as conduits for geothermal waters in the Basin and Range (Faulds and Hinz, 2015). Fractured dikes can also serve as a path from deep geothermal reservoirs to the surface (Witcher, 2001). Earthquakes can enhance or change the plumbing of geothermal systems. Because all these features are associated with geothermal potential, a series of ArcGIS layers that include Quaternary faults and fault density, Cenozoic dikes, and historic earthquakes were constructed for structural analysis (Fig. 14). The resulting map was examined to identify possible paths of high vertical permeability in the vicinity of hydrogeologic windows and the BLM parcels.

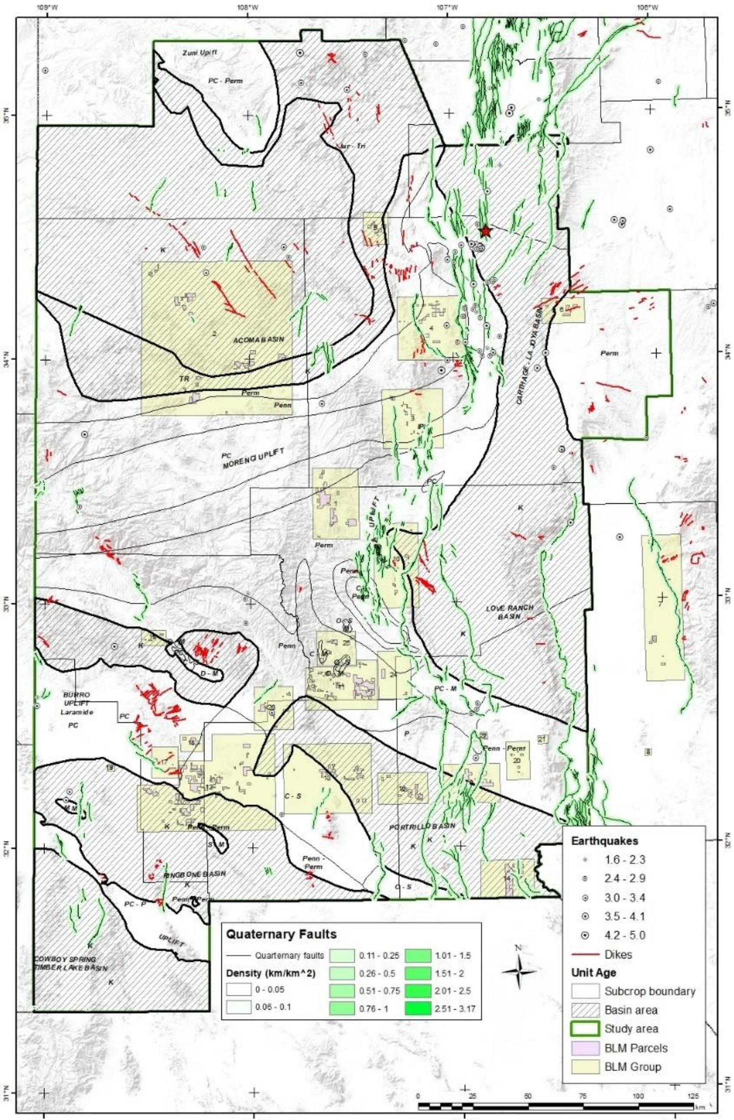

FIGURE 14. Historic earthquakes, Quaternary fault location and density, and Cenozoic dikes superimposed on the subcrop map.

Overall geothermal evaluation

The overall assessment of the parcel groups is summarized in Table 6. Bennett and Nash (2017) used a combination estimated critical stress on the Alamogordo fault and locally elevated heat flow, as shown on the heat flow map in Figure 3 of this report, to assign a moderate prospectively to an area just north of Tularosa in Parcel Group 7. In addition to potential, the level of certainty for parcels was evaluated using the criteria described in BLM Policy Manual 3031 – Energy and Mineral Resource Assessment and outlined in the previous "Methodology for Oil and Gas evaluation" section.

For this evaluation, elevated heat flow, the presence or absence of thermal springs or known geothermal resources, the occurrence of Quaternary faults, and the presence of Laramide basins underlain by fine-grained Cretaceous rocks on the subcrop map were the principal factors used to assign potential. To some degree subjective expert knowledge of the area was considered, as well. In several areas, the lack of data makes accurate assignment of potential challenging.

TABLE 6. Geothermal potential of the BLM parcel groups.

BLM group	**General area**	**Heat Flow (low<80; high >80)**	**Thermal springs and wells T>30°C**	**Boron (low <1 mg/L; moderate 1–5 mg/L)**	**Lithium (low <1 mg/L)**	**Earthquakes**	**Quaternary faults**	**Cenozoic dikes**	**Hydrologic window?**	**Geothermal potential of the small parcels**
1	Monticello -Chloride	low to high; high HF in shallow wells	nearby, but not on parcels	low	low	no	no	no	yes	low
2	Plains of San Agustin	low to high; high HF in shallow well (S#39)	none	low; 1–1.3 mg/L near Quemado	low	nearby	no	no	northern parcels, no; southern parcels, yes	low
3	Milligan Gulch	low; one high HF in shallow well	nearby, but not on parcels	low	low	nearby	nearby	no	yes	low
4	La Jencia basin	low	nearby, but not on parcels	low	low	yes	nearby	no	yes, but younger playa deposits serve as the aquitard	low

5	Sierra Lucero	no data	nearby, but not on parcels	low; 15.3 mg/L 18.5 km to the east	low; 8.7 mg/L 18.5 km to the east	no	no	no	no	low
6	Quebradas	no data; high HF in shallow wells 8–9 km south	none	no data	no data	no	no	yes	west parcels, no; east parcels yes	low
7	Eastern Tularosa basin	high HF in shallow wells just N and S	none	low	low	no	yes, cross the parcels	no	not applicable because no volcanics	parcel north of Tularosa rated moderate by Bennett and Nash (2017); areas to the south are low
8	Jicarilla	low	none	no data	no data	no	no	no	not applicable because no volcanics	low
9	West Mesa Las Cruces	low to high; high HF in shallow wells	nearby, but not on parcels	low	low	yes, nearby	yes, cross the parcels	no	yes, all but the SW parcel	moderate
10	Truth or Consequences	high HF; hot springs and wells 40–43°C	nearby, but not on parcels	low to moderate	low	no	yes, crosses a parcel	no	yes, all but the NWparcel	low
11	Macho Valley	low to high; high HF in shallow wells	nearby, but not on parcels	low	low	no	no	no	yes	low
12	Lordsburg	low to high; high HF in shallow wells	nearby, but not on parcels	low	low	no	no	no	northern parcels, yes; southern parcels, no	low
13	Florida Mtns.	low to high; high HF in shallow wells; warm water reported in irrigation wells on N side of the Floridas	none	low	low	no	nearby	no	no, except for westernmost	moderate

14	Sunland Park	many high HF values; Hunt Exploration Co. never developed the resource	none	low	low	no	yes, cross the parcels	no	no	low
15	Mangus Spring	no data	nearby, but not on parcels	low	low	no	no	no	on boundary	low
16	I-10 Luna-Doña Co. line	high HF in shallow wells	none	low	low	no	no	no	no	low
17	NE of Lordsburg	no data	none	no data	no data	no	yes, crosses a parcel	no	yes	low
18	NW of Lordsburg	no data	none	no data	no data	no	no	no	yes	low
19	I10-Highway 90	no data	none	low	low	no	no	no	no	low
20	Tortugas Mtn.	high heat flow; known geothermal resource	yes, several near southern parcels, none on northern parcels	low	low	no	no	no	yes	southern parcels high; northern parcels moderate
21	Organ Pass	low heat flow	none	low	low	no	no	no	yes	low
22	W of Doña Ana Mtns.	low to high; high HF in shallow wells	nearby, but not on parcels	low	low	no	no	no	yes	low
23	NE El Paso	no data	none	no data	low	no	nearby	no	no	low

24	Derry-Hatch	low to high; high HF in shallow wells	nearby, but not on parcels	low	low	no	nearby	no	yes	low
25	Berrenda Creek	low except along fault; discahrge T or 32°C	nearby, but not on parcels	low	low	no	no	no	yes	low
26	Faywood Hot Springs	high heat flow; known geothermal resource	nearby, but not on parcels	low	low	yes	nearby	no	yes	moderate

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 (Appendix 1). 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 and critical minerals, 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 (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 7. Commodities found in the southwestern New Mexico selected for evaluation in this report. Critical minerals are designated by Schulz et al. (2017) and Department of Interior (2022-04027-final-list-of-critical-minerals).

Commodity Class	**Commodity**	**Is It A Critical Mineral?**	**Area Commodity Is Present**	**Reasonably Foreseeable Development**
Metals	Copper (Cu)		1, 4, 8, 11, 17, 18, 21, 25	High
	Gold and silver (Au, Ag)		1, 4, 8, 11, 17, 18, 21, 25	High
	Zinc (Zn)	Yes	1, 4, 8, 11, 18, 21, 25	Low
	Molybdenum (Mo)		1, 4, 8, 11, 21	Moderate
	Aluminum (Al)	Yes		Low
	Antimony (Sb)	Yes	1, 18, 21, 25	Low
	Chromium (Cr)	Yes		Low
	Cobalt (Co)	Yes	18	low
Industrial minerals	Aggregate (sand and gravel)		1, 2, 4, 6, 7, 9, 10, 11, 12, 13, 15, 16, 19, 20, 21, 22, 23, 24, 26	High
	Arsenic (As)	Yes		Low
	Barium (barite) (Ba)	Yes		Moderate
	Beryllium (Be)	Yes	1, 18, 21	Low
	Bismuth (Bi)	Yes		Low
	Cesium and rubidium (Cs, Rb)	Yes		Low

Commodity Class	**Commodity**	**Is It A Critical Mineral?**	**Area Commodity Is Present**	**Reasonably Foreseeable Development**
	Clay			Low
	Diatomite		10	Low
	Dolomite		10, 11, 12, 13, 25	Low
	Fluorine (fluorite)(F)	Yes	1, 17, 18, 20, 21	Low
	Gallium (Ga)	Yes		Low
	Garnet	Yes	1, 8, 18, 21	Low
	Germanium (Ge)	Yes		Low
	Gypsum			Low
	Hafnium (Hf)	Yes		Low
	Indium (In)	Yes		Low
	Iron (Fe), iron oxide and magnetite (Fe)		1, 8, 21	Moderate
	Limestone and dolomite (crushed stone)		5, 6, 7, 10	High
	Lithium (Li), strontium (Sr), bromine (Br), boron (B)	Yes		Low
	Magnesium (Mg) (including dolomite)	Yes	12, 13	Low
	Manganese (Mn)	Yes	1, 8, 9, 10, 11, 20, 21	Low
	Niobium, tantalum (Nb, Ta)	Yes		Low
	Perlite		11	High
	Pumice			High
	Rare earth elements (REE), including yttrium (Y)	Yes	8, 21	Low
	Rhenium (Re)	Yes		Low
	Scandium (Sc)	Yes		Low
	Selenium (Se)	Yes		Low
	Silica sand			Moderate
	Stone		16, 21	High
	Tellurium (Te)	Yes	1, 8, 18, 21, 25	Low
	Tin (Sn)	Yes	1	Low
	Titanium (Ti)	Yes		Low
	Tungsten (W)	Yes	1, 8, 17, 25	Low
	Vanadium (V)	Yes	4	Low
	Zeolites		1	Low
	Zirconium (Zr)	Yes		Low
Gemstones	Gemstones (including mineral collecting)		8	Low
Uranium	Uranium (U)		1, 8	Low
Geothermal	Geothermal		See geothermal report	Moderate to low
Petroleum and related commodities	Oil and gas		See Oil and gas report	Low
	Helium			Low
	CO_2		2	Low

Metals, industrial minerals, critical minerals, uranium and coal

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 areas where copper occurs is high although access issues, environmental regulations, and potential permitting delays will hamper development and could decrease the RFD to moderate or low.

Gold and silver

The reasonably foreseeable development for placer gold in areas where gold occurs is high for gold, especially for recreational gold miners (McLemore and Lueth, 2017). The reasonably foreseeable development for commercial development of placer gold is high.

Aggregates (Sand and Gravel)

The reasonably foreseeable development for aggregates (sand and gravel) near highway construction and larger cities is high (McLemore and Austin, 2017). However, there is no reasonably foreseeable development for aggregates (sand and gravel) in remote areas from highway construction and cities, except along future electrical transmission sites.

Critical minerals

There is currently a boom in sales price of many critical minerals due to supply chain concerns and interest in renewable energy, and this is expected to continue in the near future. Market conditions will continue to determine the RFD of these commodities and are subject to change. Areas with high mineral-resource potential for critical minerals are assigned a high reasonably foreseeable development until additional data indicate a lower mineral-resource assessment.

Reasonably Foreseeable Development for Oil and Gas

Over the last two decades, the petroleum industry has developed and applied technologies, such as horizontal drilling and fracture stimulation, which have improved hydrocarbon recovery and opened new areas for production across the world. In the mid-2000s, New Mexico saw a reversal in decline of oil and gas production, resulting from the horizontal completion of low permeability reservoirs. In addition to new technologies, there have been periods of high commodity pricing for oil and gas in the last two decades which drove both exploratory and production-scale drilling (Broadhead, 2017).

In New Mexico, the main areas of hydrocarbon drilling and production continue to be in the northern and southeast parts of the state (Fig. 1). Barring new technology advances or changes beyond the historic commodity price fluctuations, the areas in New Mexico currently in production are likely to remain the only areas developed for oil and gas. Thus, the parcels included in this study, located in areas of low and moderate potential, are not likely to be developed for oil and gas in the foreseeable future (Fig.1, Table 1).

Reasonably Forseeable Development for Carbon Dioxide (CO_2) and Helium Evaluation

Only one area in the current BLM parcel evaluation has potential for the existence of CO_2 (Fig. 2, Table 2). Area 2 has a moderate potential for the existence of CO_2, possibly continuous with a high potential area on the Arizona border, approximately 50 miles to the west. There are no gas concentration analyses in plugged and abandoned offset wells in Area 2, where non-flammable gas shows were reported. Area 2 has no existing infrastructure for gas development and is not likely to be developed for CO_2.

In New Mexico the production of helium has historically been in conjunction with natural gas in the Four Corners area in the NW part of the state (Broadhead and Gillard, 2004). In the current BLM parcel evaluation there are no parcels on which oil or gas, nor helium are likely to be developed in the foreseeable future (Fig. 3, Table 3). Helium was taken off the 2022 critical minerals list (Applegate, 2022), however, supply chains or market conditions may change, and helium could be added once again.

CONCLUSIONS

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, and the areas with high mineral-resource potential are summarized in Table 8. The probability of mineral development is summarized above in table 7. None of the parcels contain any notable known mineral value under current conditions. 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. Economics could also alter the mineral-resource potential in the future. Furthermore, this assessment is based upon a literature search and experience of the authors, but still requires field verification.

TABLE 8. Summary of areas with high mineral-resource potential in southwestern New Mexico.

Area	Commodity	Mining District in Area (NM Mines Database)	Mineral-resource Potential	Level of Certainty	Geological units	Reasonably Foreseeable Development
1	W, Be, F, Au, Mn, aggregate	Cuchillo Negro, Chloride	high	high to moderate	MC, IPma, Pa, Psy, Kd, Ti, Tla, Tlv, Tpb, Tnr, Turf, QTs	Moderate-high
2	aggregate		high	high	Tfl, Tps, Tvs, Tlrp, Tual, Tvs, QTp, Qp, Qoa, Qa	S42, S44 high
4	aggregate	North Magdalena	high	high	Turp, Ti, Tsf, QTs, Qp	high
5	limestone		high	high	TRc, Psa, Tim, Qa	
6	gypsum, limestone, aggregate		high	high	Pg, Py, Psa, Qp	
7	aggregate, limestone		high	high	IP, Pb, Pa, Qp	
8	Cu, lode and placer Au, Ag, Fe, W, turquoise, garnet	Orogrande	high	high to moderate	QTs	high to moderate
9	aggregate		high	high	QTs, Qp	
10	Limestone, aggregate, diatomite		high	high	OC, D, IP, QTs, Qp	moderate
11	Au, Mn subsurface, perlite, aggregate	Lake Valley, Macho	high	high to moderate, high (aggregate)	Tlv, Tla, Tual, Tlrp, QTg, QTs, Qp	
12	aggregate		high	high	Yg, Tlrp, Tlrf, Tla, QTg, Qp, Qa	
13	aggregate		high	high	Qp, Qa	
15	aggregate		high	high	Tlrp, Ti, QTg, Qa	
16	aggregate, scoria, basalt		high	high	Tvs, QTs, Qb, Qp	
17	F	Bound Ranch	high	high to moderate	Yg, QTg	moderate
18	Cu, lode Au, F	White Signal	high	high to moderate	Yg, QTg	high to moderate
19	aggregate		high	high	Qp	
20	aggregate, F	Tortugas Mountains	high	high	QTs, Qp	moderate

Area	Commodity	Mining District in Area (NM Mines Database)	Mineral-resource Potential	Level of Certainty	Geological units	Reasonably Foreseeable Development
21	Cu, F, Zn	Organ Mountains	high	high to moderate	Ti QTs, Qp	high to moderate
22	aggregate		high	high	Qp, Qa	
23	aggregate		high	high	QTs	
24	aggregate		high	high	QTs, Qp	
25	Sb, Ag, Pb, Zn	Tierra Blanca	high	high to moderate	MC, IP, Pa, Tla, Tlrf, Tlrp, Tual, QTs	high to moderate
26	aggregate		high	high	Tlrf, Tlrp, Tlrf, Tla, QTg, Qp	

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.
- Areas with potential for critical minerals should be re-examined as market conditions evolve. Some of these areas could be developed in the near future if enough grade and tonnage are found. Existing mine wastes could also be of future potential.

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APPENDIX 1

MINERAL-RESOURCE POTENTIAL OF 26 BLM PARCELS

See attached spreadsheet.

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

NMBGMR Classification	**USGS Classification (USGS Model Number)**	**Commodities**	**Perceived Age of Deposit in New Mexico**	**Area the Deposit Type is Found**
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
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

NMBGMR Classification	**USGS Classification (USGS Model Number)**	**Commodities**	**Perceived Age of Deposit in New Mexico**	**Area the Deposit Type is Found**
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