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Introduction

Production of minerals and mineral fuels in New Mexico has decreased from $7.2 billion in 1981 to $6.5 billion in 1983 (Eveleth and Bieberman, 1984; Eveleth et al., 1984), but mineral resources are still vital to our state and national economies. New Mexico led the nation in the production of uranium, perlite, and potash in 1982, was second in the production of pumice, and was third in the production of copper. Significant quantities of natural gas (ranked fourth), molybdenum, gold, crude oil (all three ranked seventh), silver, and coal also were produced from New Mexico (Eveleth and Bieberman, 1984). Production of commodities such as sand and gravel, brick clay, limestone and clay for cement, and others are important to construction and other industries in New Mexico. Evaluation of mineral-resource potential helps us assess the future availability of these minerals.

Local, state, and federal officials are required to make decisions regarding use, acquisition, and restriction of federal, state, and other lands. These decisions may affect future exploration and development of mineral resources. Yet, adequate mineral-resource data are not always available in a usable form to policy makers who generally are not trained in geology but who must evaluate mineral-resource values as compared with other resources such as wildlife, timber, archaeology, wilderness, and agriculture. Furthermore, many resource assessments do not include evaluation of nonmetallic minerals. To alleviate these problems and provide data on future mineral availability, the New Mexico Bureau of Mines and Mineral Resources (NMBMMR), in cooperation with the U.S. Bureau of Land Management (BLM), has prepared a preliminary assessment of the mineral-resource potential of Torrance County (McLemore, 1984) and of the BLM's northern Rio Puerco resource area, which includes Sandoval and Bernalillo Counties and adjacent parts of McKinley, Cibola, and Santa Fe Counties (McLemore et al., 1984). Prior assessments of the mineral-resource potential of several areas have been completed by NMBMMR since 1970 (Table 1) although NMBMMR has been involved with evaluating mineral resources since the Bureau's formation in 1927.

Preliminary evaluations of the mineral-resource potential are useful not only for estimating mineral availability and helping government officials plan land use, but they also provide a basic background of geologic data, an index to geologic mapping, and an inventory of known mineral occurrences, prospects, deposits, mines, and oil and gas tests within the study area. In addition, NMBMMR evaluations delineate areas where more detailed geologic, geochemical, and geophysical work is needed. These reports, which outline exploration targets and identify known deposit types, are useful to exploration geologists.

Definitions

Many reports have been written in recent years that describe the mineral resources or mineral-resource potential of areas in New Mexico. However, the terms mineral resources or mineral-resource potential have rarely been defined. Usage of these terms varies from one report to another and some reports do not differentiate between them.

Mineral resources are the naturally occurring concentrations of materials (solid, 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 *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 *mineral deposit* is a sufficiently large concentration of a valuable or useful mineral or material that may be extracted under current or future economic conditions. A *mine* is any prospect that produced or is currently producing a useful mineral or material.

The *mineral-resource potential* of an area is the probability that a mineral will occur in sufficient quantities so that it can be extracted economically under current or future conditions (Taylor and Steven, 1983). 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 resources, such as the feasibility of extracting the minerals, land ownership, accessibility of the minerals, or cost of exploration, development, production, processing, or marketing, are not considered in assessing the mineral-resource potential even though these factors certainly affect the economics of extraction. Total evaluation of mineral-resource potential involves a complete understanding of the known and undiscovered mineral resources in a given area.

Classification

Classification of mineral resources differs from classification of the mineral-resource potential. Quantities of mineral resources are classified according to availability of geologic data (geologic assurance), economic feasibility (identified or undiscovered), and as economic or subeconomic (Fig. 1). Mineral-resource potential is a qualitative judgment of the probability of the existence of a commodity.

Classification of mineral-resource potential varies from simple subjective schemes, like those used currently by NMBMMR, to complex quantitative and statistical methods (Harris and Euresty, 1969; Harris, 1969; Harris and Agterberg, 1981). However, it is rare that an adequate data base for all commodities is available for complex statistical treatment, especially for preliminary assessments. Furthermore, a simple classification scheme is more versatile for uses such as exploration for new deposits and land-use planning. Mineral-resource potential is classified at NMBMMR as high, moderate, low, very low,

↑ Increasing degree of economic feasibility	Identified			Undiscovered	
	Demonstrated		Inferred	Hypothetical	Speculative
	Measured	Indicated			
Economic	Reserves		Inferred reserves	Resources	
Marginally economic	Marginal reserves		Inferred marginal reserves		
Subeconomic	Subeconomic resources				
Other occurrences	Nonconventional and low-grade materials				

← Increasing degree of geologic assurance

FIGURE 1—Classification of mineral resources (modified from U.S. Bureau of Mines and U.S. Geological Survey, 1980).

or unknown according to availability of geologic data and relative probability of occurrence (Fig. 2).

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 class as well as identified deposits in known mining districts or in known areas of mineralization. Speculative deposits, such as reasonable extensions of known mining districts and identified deposits or partially known deposits within geologic trends or areas of mineralization, are classified as high mineral-resource potential when sufficient data indicate a high probability of occurrence. Information, such as quantity, quality, grade, past and present production, depth to deposit, and reserves, is important, although not always essential, in determining that an area has a high potential. Exploration may be in progress or expected to occur within 10 years.

Moderate mineral-resource potential is assigned to areas where geologic, geochemical, or geophysical data suggest a reasonable possibility that undiscovered deposits occur in formations or geologic settings known to contain economic deposits elsewhere. 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 assessment, 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 available data imply the occurrence of mineralization, but indicate a low probability for the occurrence of a 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. Additional geologic data may be needed to better classify such areas.

Very low mineral-resource potential is assigned to areas where sufficient information indicates that an area is unfavorable for economic deposits. This evaluation may include areas with dispersed but uneconomic mineral occurrences as well as areas that have been depleted of their mineral resources. Use of the very low potential classification requires a high level of geologic assurance to support such an evaluation, but it is assumed 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.

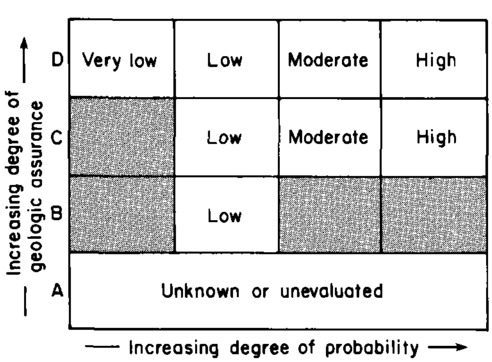

FIGURE 2—Classification of mineral-resource potential (modified from Taylor et al., 1984 and Goudarzi, 1984). A–D represent four levels of geologic assurance. By definition, shaded areas cannot be rated.

Unknown mineral-resource potential is reserved for 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. These areas should receive high priority for additional study.

The mineral-resource potential of some areas cannot be assessed because of lack of useful data. Detailed geologic mapping at a scale of 1:24,000 may be required before the mineral-resource potential can be assessed. The lack of data does not imply a very low mineral-resource potential. The difference between an *unknown* resource-potential classification and an *unevaluated* area is that some data exists in an area of unknown resource potential that implies the possibility of mineral-resource occurrences.

This classification scheme is similar to that used by Brobst and Goudarzi (1984) where a high mineral-resource potential corresponds to substantiated resource potential and a moderate mineral-resource potential corresponds to a probable resource potential. Goudarzi (1984), of the U.S. Geological Survey (USGS), proposed a classification scheme similar to the one used by NMBMMR.

In addition to evaluation of the mineral-resource potential, NMBMMR staff geologists assess the potential for development. The potential for development is classified simply as high, moderate, or low, and economic factors such as grade, tonnage, current market conditions, transportation, and operating status are taken into account. *High potential for development* indicates that a commodity is being produced currently or economic conditions suggest that production of the deposit is economically feasible currently or in the near future. *Moderate potential for development* indicates that production of the deposit would occur if certain geologic or economic conditions became favorable. *Low potential for development* indicates only a slight possibility, if any, for production of the deposit. The potential for development classification is a highly subjective judgment, but it does offer an evaluation of the economic feasibility of an area.

A dual rating classification has been proposed by Oak Ridge National Laboratory (Voelker et al., 1979), which is being used by the USGS (Taylor et al., 1984; Goudarzi, 1984) and the BLM. This system involves rating the geologic environment as high, moderate, low, or none (or as 1–4 with 4 the highest rating) and rating separately the certainty or availability of geologic data (expressed as 1–4 or A–D with 4 and D the highest degrees of certainty). Therefore, a high mineral-resource potential corresponds to a 4/4 or 4/D and a very low potential corresponds to a 1/4 or 1/D. However, this classification scheme can be awkward to use. The availability of geologic data has been incorporated into the NMBMMR classification scheme (Fig 2).

Evaluation process

The evaluation of mineral-resource potential involves a complex process based on geologic analogy of promising or favorable geologic environments with geologic settings (geologic models) that contain known economic deposits. Such subjective assessments or judgments depend not only on the available information concerning the area to be evaluated, but also on the current knowledge and understanding of known deposits. Assessments of the resource potential also depend on the experience and knowledge of the researchers and the date of the assessment. Therefore, mineral-resource potential is assessed by a team of NMBMMR geologists who specialize in specific commodities and then the assessment is reviewed by other commodity specialists. Not all mineral-resource assessments by other agencies involve teamwork or subsequent review.

The process of evaluating mineral-resource potential used currently by NMBMMR is similar to that used by the USGS (Shawe, 1981; Goudarzi, 1984) and Oak Ridge National Laboratory (Voelker et al., 1979). However, little field investigation is incorporated into NMBMMR assessments because of time constraints imposed by the BLM. Additional data provided by future field investigations will help refine these preliminary evaluations.

The most important stage in any geologic investigation, and especially in these evaluations, is compilation of all available published and unpublished information. A complete bibliography of geologic references and an index to geologic mapping are essential. Evaluation of mineral-resource potential involves integration and interpretation of several data sets maintained by various federal and state agencies, including: 1) MRDS (Mineral Resources Data Systems; formerly CRIB, Computerized Resource Information Bank, and MILS, Mineral Industry Location System); 2) DMEA (Defense Minerals Exploration Administration); 3) NURE (National Uranium Resource Evaluation) data, including HSSR (Hydrogeochemical and Stream Sediment Reconnaissance) and ARMS (Aerial Radiometric and Magnetic Survey); 4) NCRDS (National Coal Resource Data System); 5) AML (Abandoned Mine Lands); and 6) various file data from state and federal agencies. Using these data, known mineral occurrences, prospects, mines, deposits, and oil and gas tests are identified and plotted on topographic maps. Geochemical and geo- ☞

physical anomalies are identified and described.

After compilation of all available geologic data, the types of mineral deposits and favorable geologic environments are identified and compared with appropriate geologic models. It is important to include all types of metallic, nonmetallic, and energy-fuel deposits in the area. A preliminary evaluation of the mineral-resource potential is performed by using all available data and then determining what additional data are required for assessment. A number of factors must be evaluated, including: 1) host-rock "favorability," 2) structural controls, 3) evidence of mineralization, 4) previous mining and production, 5) geochemical and/or geophysical anomalies, 6) regional geologic setting, 7) time of mineralization, 8) alteration, 9) mineralogy and mineral assemblages, 10) processes affecting mineralization since their formation, and 11) geologic history. Lack of data in a particular area does *not* imply no potential, but should be classified as unknown or not evaluated.

The evaluation of the preliminary mineral-resource potential should be followed by field investigations and more detailed mapping, geochemical sampling, and geophysical studies. Preliminary assessments are essential for determining which areas need additional work and what types of data are needed.

Repeated evaluation of the mineral-resource potential is required. New data on the study area should be incorporated into the data base. New geologic concepts and models and more sophisticated exploration techniques could drastically alter the assessments. New technologies that require different commodities and changes in mining, milling, and processing could allow exploration and development of lower-grade or new types of deposits. Political and economic conditions change rapidly and can transform today's mineral curiosity into tomorrow's mineral deposit. Therefore, mineral-resource potential assessments must be revised periodically and updated on a timely basis.

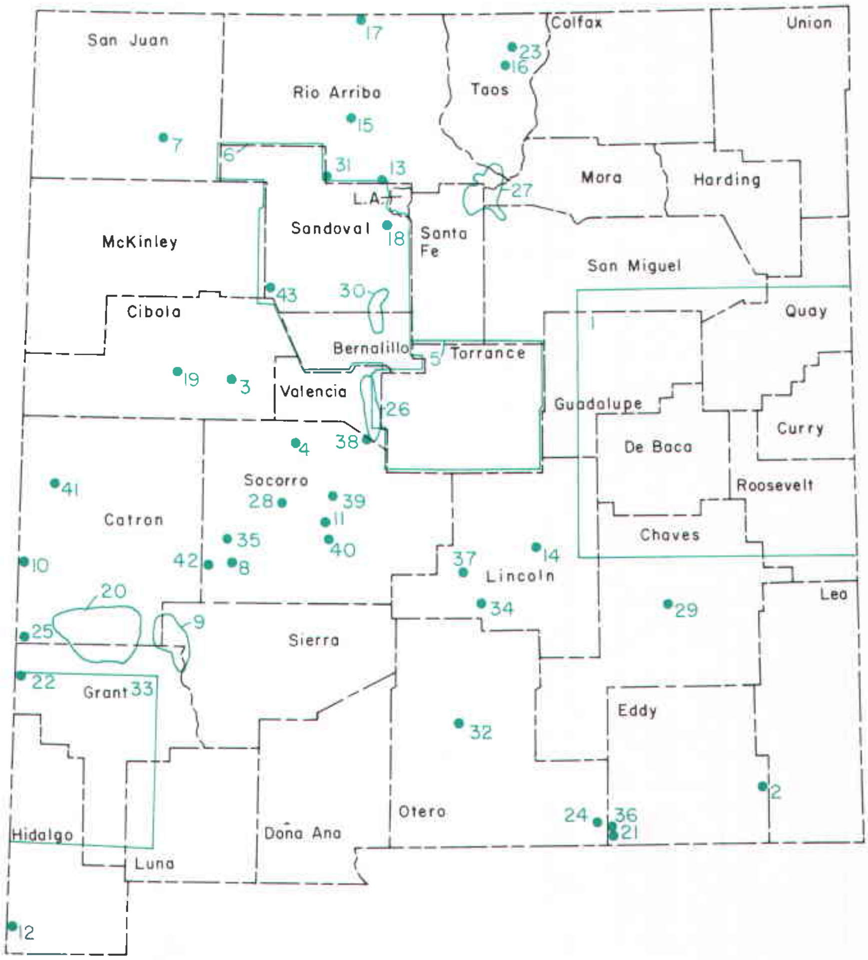

FIGURE 3—Approximate locations of mineral-resource potential assessments in New Mexico. Numbers refer to location of areas listed in Tables 1–3.

Available assessments in New Mexico

A number of mineral-resource-potential evaluations for parts of New Mexico have been completed by NMBMMR (Table 1; Fig. 3), USGS (Table 2), U.S. Bureau of Mines (Table 2), and BLM (Table 3). NMBMMR has been involved with assessments of two wilderness study areas, the WIPP (Waste Isolation Pilot Plant) site, and several regional evaluations (Table 1; Fig. 3). Some of the wilderness areas, wilderness study areas, roadless areas, and national wildlife refuges were evaluated by the USGS and the U.S. Bureau of Mines (Table 2; Fig. 3). The BLM has assessed several wilderness areas as well as other BLM lands (Table 3, Fig. 3). The remaining wilderness areas not evaluated previously are being assessed currently or will be assessed in the future.

The USGS also evaluated the Silver City 1° × 2° quadrangle as part of CUSMAP (Conterminous United States Mineral Assessment Program). Results of CUSMAP include numerous reports concerning the geology, mineral deposits, geochemistry, and geophysical characteristics of the area.

Summary

Although it is difficult to compare mineral resources with other resources such as timber, wildlife, and others, government officials are required to make decisions regarding these resources. Mineral availability and exploration programs also require a knowledge of mineral resources. One means of fulfilling these needs is to assess the mineral-resource potential of an area for all types of minerals.

Assessment of the mineral-resource potential depends on the available geologic, geochemical, and geophysical data and the experience and knowledge of the researchers evaluating the area. NMBMMR uses a simple classification scheme, which is based on increasing degree of probability of occurrence and geologic assurance. The potential is classified as unknown, very low, low, moderate, or high. Some areas cannot be evaluated because data are lacking or insufficient.

Reassessment of the mineral-resource potential will be required periodically as new technologies are developed, different commodities are required, and new exploration or development techniques are found. Political and economic conditions may alter these assessments. Repeated evaluation of the mineral-resource potential is essential for land-use planning, mineral availability, or planning for exploration programs.

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TABLE 1—Assessments of mineral-resource potential by NMBMMR; **OF** = Open-file report.

No. on Fig. 3	Mineral-resource area	NMBMMR reference
1	East-central New Mexico	OF–28A (1970)
2	Waste Isolation Pilot Plant (WIPP) site	OF–87 (1978)
3	Petaca Pinta Wilderness study area	OF–161 (1981)
4	Sierra Ladrones Wilderness study area	OF–179 (1982)
5	Torrance County	OF–192 (1984)
6	Northern Rio Puerco resource area	OF–211 (1984)
—	Valencia, Cibola, McKinley, San Juan, and western Rio Arriba Counties	in preparation

TABLE 2—Detailed mineral-resource potential studies of wilderness areas, wilderness study areas, national wildlife refuges, and roadless areas by the U.S. Geological Survey (USGS) and the U.S. Bureau of Mines (USBM). * Mineral-resource potential is summarized in Marsh et al. (1984); **MF**, Miscellaneous Field Studies; **Bull.**, Bulletin; **OF**, Open-file report.

No. on Fig. 3	Mineral-resource area	USGS reference	USBM reference
7	Ah-shi-sle-pah	OF 83–889	MLA 40–83
8	Apache Kid	—	MLA 72–83
7	Bisti	OF 83-889	MLA 40–83
9	*Black Range	Bull. 1319E (1970)	—
10	*Blue Range	Bull. 1261E (1969)	—
11	Bosque del Apache	Bull. 1260B (1967)	—
12	*Bunk Robinson Peak	MF 1425–B (1983)	—
13	*Caballo	MF 1516 (1983)	—
14	Capitan Mountains	—	MLA 20–84
15	*Chama River Canyon	MF 1523B (1983)	MLA 108–82
16	*Columbine–Hondo	MF 1570A (1983)	MLA 143–82
17	Cruces Basin	—	MLA 15–84
7	De-na-zin	OF 83–889	MLA 40–83
18	Dome	—	MLA 106–83
19	El Malpais	OF 81–557 (1981)	—
20	*Gila	Bull. 1451 (1979)	—
21	*Guadalupe Escarpment	MF 1560A (1983)	MLA 41–83
22	*Hells Hole	MF 1344E (1982)	MLA 137–82
23	Latir Peak	—	MLA 102–83
24	*Little Dog and Pup Canyons	MF 1468 (1983)	—
25	*Lower San Francisco	MF 1463C (1982)	MLA 13–82
26	*Manzano	MF 1464C (1983)	MLA 116–82
27	*Pecos	OF 80–382	—
13	*Polvadera	MF 1516 (1983)	—
28	*Ryan Hill	MF 1634A (1984)	MLA 78–82
29	Salt Creek (Bitter Creek)	Bull. 1260A (1967)	—
30	*Sandia Mountains	MF 1631A (1984)	MLA 119–82
31	*San Pedro Parks	Bull. 1385C (1975)	—
32	Sacramento Mts. (west face)	—	MLA 27–83
33	Silver City 1°×2° quadrangle (CUSMAP)	OF 83–924 (1983)	—
16	*Wheeler Peak	—	MLA 127–82
34	*White Mountain	Bull. 1453 (1979)	MLA 33–83
34	White Mountain addition	OF 83–594	—
12	*Whitmire Canyon	MF 1425B (1983)	—
35	Withington	—	MLA 72–83

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TABLE 3—Assessments of mineral-resource potential contracted by the U.S. Bureau of Land Management (BLM).

No. on Fig. 3	Mineral-resource area	BLM reference
36	Humphrey Canyon	Cruver et al., 1982
37	Carrizozo	Krason, Cruver, and Wodzicki, 1982
38	Manzano	Krason, Wodzicki, and Cruver, 1982a
39	Socorro	Krason, Wodzicki, and Cruver, 1982b
40	Armendaris	Krason, Wodzicki, and Cruver, 1982c
41	Salt Lake	Roberts et al., 1982a
42	San Augustin	Roberts et al., 1982b
43	San Luis	Roberts and Rizo, 1982