Mineral Resources of the Sierra Ladrones Wilderness Study Area, Socorro County, New Mexico

U.S. GEOLOGICAL SURVEY BULLETIN 1734–F

Chapter F

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MINERAL RESOURCES OF WILDERNESS STUDY AREAS—
WEST-CENTRAL NEW MEXICO

DEPARTMENT OF THE INTERIOR
DONALD PAUL HODEL, Secretary

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STUDIES RELATED TO WILDERNESS

Bureau of Land Management Wilderness Study Areas

The Federal Land Policy and Management Act (Public law 94-579, October 21, 1976) requires the U.S. Geological Survey and the Bureau of Mines to conduct mineral surveys on certain areas to determine the mineral values, if any, that may be present. Results must be made available to the public and be submitted to the President and the Congress. This report presents the results of a mineral survey of a part of the Sierra Ladrones (NM-020-016) Wilderness Study Area, Socorro County, New Mexico.

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[Plate is in pocket]

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Mineral Resources of the Sierra Ladrones Wilderness Study Area, Socorro County, New Mexico

By Samuel L. Moore, Michael S. Allen, *and* Carl L. Long
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ABSTRACT

In 1986 the U.S. Bureau of Mines and U.S. Geological Survey conducted investigations to appraise the identified (known) resources and assess the mineral resource potential (undiscovered) of a part of the Sierra Ladrones (NM–020–016) Wilderness Study Area in central New Mexico. Inferred subeconomic resources of limestone, travertine, and sand and gravel are present, but these investigations revealed no identified metallic mineral resources. Five areas in the wilderness study area have moderate potential for undiscovered resources of various commodities: (1) tungsten, bismuth, molybdenum, and lead in the northern and east-central parts; (2) silver and gold in the northeastern part; (3) fluorite and tungsten in the east-central part; (4) manganese, cobalt, nickel, tungsten, and molybdenum in the southeastern part; and (5) manganese, cobalt, nickel, and molybdenum in the southwestern part. Except where the resource potential is moderate for the metals listed above, the entire wilderness study area has a low potential for undiscovered resources of all metals. The entire wilderness study area has a low potential for undiscovered resources of coal, uranium, oil and gas, and geothermal energy.

SUMMARY

At the request of the U.S. Bureau of Land Management, 31,804 acres of the Sierra Ladrones (NM–020–016) Wilderness Study Area were studied. In this report the studied area is called the "wilderness study area" or simply "study area."

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The Sierra Ladrones Wilderness Study Area is about 25 air miles north-northwest of the city of Socorro in west-central New Mexico (fig. 1). The study area is about 12 mi (miles) long and ranges from 1.5 to 7 mi wide and includes most of the Sierra Ladrones (these mountains are also known as the Ladron Mountains). The crest and the east and west escarpments of the wilderness study area are an elevated thrust-faulted block of Precambrian (see geologic time chart in Appendix) metavolcanic schist and gneiss, metasedimentary quartzite gneiss, granite gneiss, and granite. The imbricated Precambrian crystalline metamorphic rocks are flanked on the west by the near-vertical Ladron fault, which has downthrown Pennsylvanian limestone against the Precambrian rocks, and on the east slopes by the Jeter fault, which has thrust Paleozoic, Mesozoic, and Cenozoic strata westward over Precambrian granite gneiss.

Early mining activity in the study area occurred from about 1879 to 1887 and 1895 to 1897 when prospecting for lead and silver was carried out in the eastern and northeastern parts of the Sierra Ladrones; however, no lead or silver was produced. In 1926 the Juan Torres fluorite prospect was developed north of Cerro Colorado in the south-central part of the study area (fig. 2). This mine reportedly produced one carload of metallurgical-grade fluorspar. Manganese was produced from the Black Mask mine and the Rio Salado mine in the western and southern parts of the study area. An estimated 610 tons of manganese ore was mined from about 1952 to 1955. Uranium production from 1954 to 1958 from the Jeter mine located just outside the northeastern boundary of the study area (fig. 2) totaled about 58,562 lb (pounds) of uranium oxide (U_3O_8). Inferred subeconomic resources of Pliocene limestone (travertine), Pennsylvanian limestone, and Quaternary sand and gravel are abundant along the flanks of the Sierra Ladrones. Abundant supplies of similar material are available much closer to railheads and population centers, and the distance to market

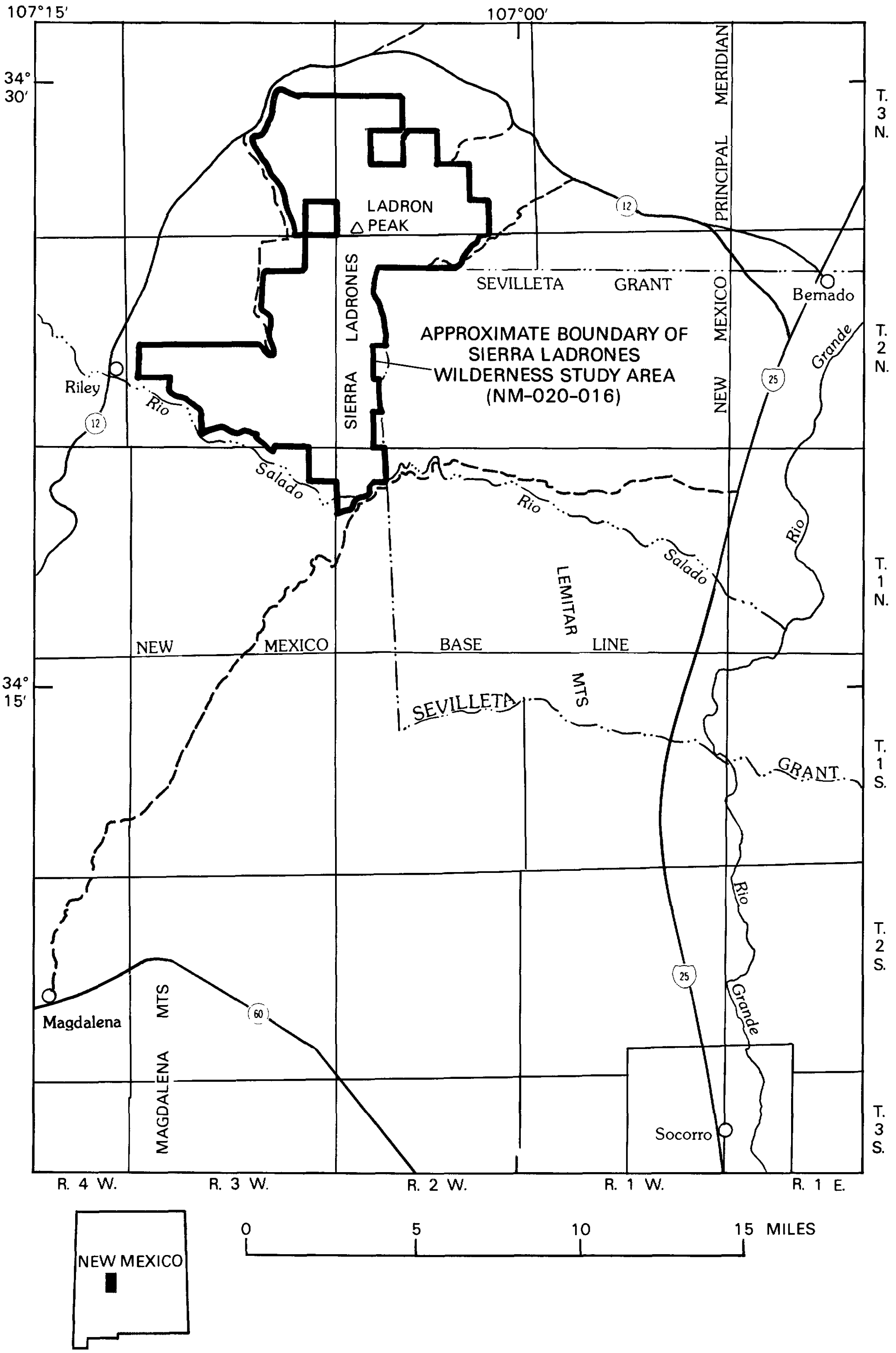

Figure 1. Index map showing location of the Sierra Ladrones Wilderness Study Area, Socorro County, New Mexico. The Sierra Ladrones are also known as the Ladron Mountains.

makes development of these commodities in the study area unlikely.

Aeromagnetic studies indicated that the faulted Precambrian granite, metavolcanic, and metasedimentary rocks of the Sierra Ladrones are possibly a shallow unit that has a structural floor; however, the thickness of the Precambrian unit is unknown. Gravity data are sparse from the study area, but regional gravity data suggest that the Sierra Ladrones are possibly an uplifted fault block. A gamma-ray spectroscopy study of the wilderness study area indicates an overall moderate radioactivity; there are no radiometric anomalies within the study area.

As a part of this study, 51 stream sites were sampled by the U.S. Geological Survey and analyzed for 31 elements. The concentrations of barium and strontium are generally high over the entire area and are related to mineralized rock in the northeast and to low-level amounts of disseminated barite in the southwest. Zinc concentrations were anomalous in two areas and appear to be unrelated to any known geologic features. In the northern part of the area, a well-defined multielement anomaly is defined by drainage basins with anomalous concentrations of at least three of the elements tungsten, molybdenum, bismuth, and lead.

Rock samples were also collected and analyzed for 31 elements and, additionally, for low concentrations of gold, silver, and tungsten. Three samples contained anomalous tungsten concentrations: a sample from the Rio Salado mine, a sample from the Juan Torres prospect, and a sample from a fault in the northeastern part of the study area. None of these samples contained detectable gold or silver.

Five areas within the Sierra Ladrones study area have moderate mineral resource potential for various undiscovered commodities (fig. 2). The northern and east-central parts of the study area have stream-sediment concentrate samples with anomalous concentrations of tungsten, bismuth, molybdenum, and lead; these parts of the study area have a moderate potential for undiscovered resources of these metals. In the northeastern part of the study area, rock samples collected from steeply dipping quartz veins in a faulted block of altered Precambrian granite gneiss, quartz monzonite, and amphibolite have anomalous concentrations of silver and gold. This area has a moderate potential for undiscovered mineral resources of silver and gold. In the east-central part of the study area around the Juan Torres prospect, pods and veins of fluorite and quartz are present in a faulted block of Precambrian granite gneiss; one rock sample from the Juan Torres prospect contained anomalous concentrations of tungsten. This area has a moderate potential for undiscovered mineral resources of fluorite and tungsten. In the southeastern and southwestern parts of the study area vein samples from the Rio Salado and Black Mask mines contain anomalous concentrations of cobalt, nickel, and molybdenum, and the Rio Salado mine additionally contains anomalous concentrations of tungsten. The area of the Rio Salado mine has moderate potential for undiscovered mineral resources of manganese, cobalt, nickel, tungsten, and molybdenum. The area of the Black Mask mine has moderate potential for undiscovered mineral resources of manganese, cobalt, nickel, and and molybdenum. Except for these areas and metals for which there is moderate mineral resource potential, the entire wilderness study area has low mineral resource potential for all metals.

Uranium was produced from the Jeter mine just a few hundred yards east of the study area; however, all previous studies in the study area did not indicate any anomalous concentrations of uranium. There is low potential for undiscovered mineral resources of uranium in the study area. No coal beds of Cretaceous or Pennsylvanian age are present within the study area, and therefore there is low potential for undiscovered resources of coal within the study area. Oil and gas leases partially cover the northern, northeastern, and eastern parts of the study area, but no holes have been drilled for oil and gas in the study area. In the northern and northeastern parts of the area, the leased areas are underlain by unconsolidated Tertiary sediments that are probably deposited on Precambrian granite. In the eastern part of the study area the leased area is underlain mostly by thrust-faulted Precambrian metasedimentary gneiss, metavolcanic gneiss, and granitic gneiss with only a minor area of Pennsylvanian rock resting unconformably on Precambrian rocks. Thus there is low potential for undiscovered energy resources of oil and gas in the study area. There are no hot or warm water springs or wells in the study area, and there is low resource potential for undiscovered geothermal energy.

INTRODUCTION

The Sierra Ladrones (NM–020–016) Wilderness Study Area is about 25 air miles north-northwest of Socorro in central New Mexico (fig. 1). The study area is named for the north-south-trending rugged Sierra Ladrones (Thieves Mountains). The wilderness study area is about 12 mi long from north to south and about 1–7 mi wide from east to west. Access to the eastern parts of the study area is from County Road 12 that leads west-northwest from Interstate Highway 25 at Bernardo around the northern end of the Sierra Ladrones. Elevations in the study area range from about 5,200 to 9,176 ft (feet). Access to the western part of the area is also from County Road 12 which curves around the northern end of the Sierra Ladrones and leads south-southwest to the village of Riley. Access to the southern parts of the area is from County Road 67 (not shown on fig. 1) and ranch roads that lead north and northeast from the town of Magdalena to the village of Riley and ranches along the Rio Salado.

Faulted and thrust-faulted Precambrian granite gneiss, metavolcanic gneiss and schist, and metasedimentary quartzite gneiss underlie the higher ridges and peaks of the study area. The western escarpment of the Sierra Ladrones is flanked by a down-faulted block of north-trending west-dipping Pennsylvanian limestone beds. The southern end of the Sierra Ladrones is traversed by the Rio Salado which cut a gorge through the

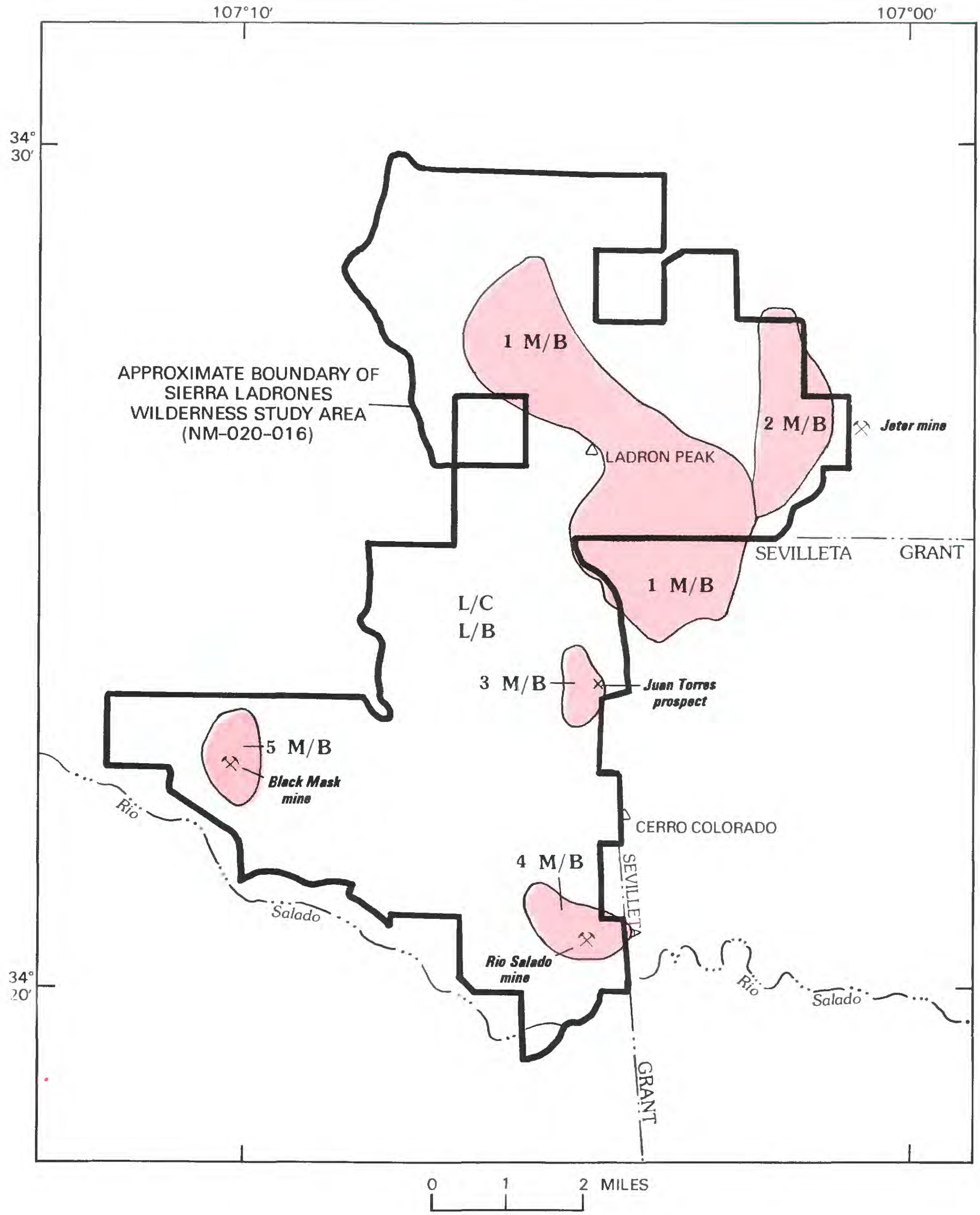

Figure 2 (above and facing page). Map showing mineral resource potential of the Sierra Ladrones Wilderness Study Area.

southernmost part of the study area. The northern end of the Sierra Ladrones ends on a low ridge of Pennsylvanian limestone at County Road 12.

This report presents an evaluation of the mineral endowment (identified resources and mineral resource potential) of the study area and is the product of several separate studies by the U.S. Bureau of Mines (USBM) and the U.S. Geological Survey (USGS). Identified resources are classified according to a modification of the system described by McKelvey (1972) and the U.S. Bureau of Mines and U.S. Geological Survey (1980) which is shown in the Appendix of this report. Identified

EXPLANATION

[Entire study area has low mineral resource potential for all metals (except as outlined below) and geothermal energy, at certainty level B, and for coal, uranium, and oil and gas, at certainty level C]

M/B	Geologic terrane having moderate mineral resource potential for the commodities listed below, with certainty level B

Commodities

1 Tungsten, bismuth, molybdenum, and lead

2 Silver and gold

3 Fluorite and tungsten

4 Manganese, cobalt, nickel, tungsten, and molybdenum

5 Manganese, cobalt, nickel, and molybdenum

Levels of certainty

B Available information suggests the level of mineral resource potential

C Available information gives a good indication of the level of mineral resource potential

⚒ Mine

× Prospect

resources are studied by the USBM. Mineral resource potential is the likelihood of occurrence of undiscovered metals and nonmetals, industrial rocks and minerals, and of undiscovered energy sources (coal, oil, gas, oil shale, and geothermal sources). It is classified according to the system of Goudarzi (1984) and is shown in the Appendix. Undiscovered resources are studied by the USGS.

Investigations by the U.S. Bureau of Mines

Prior to the field investigation, a background search of published and unpublished reports and USBM files was made to gather data pertinent to the geology and mining history of the study area. U.S. Bureau of Land Management files were searched for mining claim and oil and gas lease information.

Field work in the Sierra Ladrones Wilderness Study Area, which required 58 employee-days, included examining and sampling mineralized areas, mines, and prospects in and within ½ mi of the study area. Limestone samples were collected to test for purity and precious-metal content. In addition, minus-80-mesh stream-sediment samples were taken to determine the extent of mineralized areas. Sample localities are shown in Neubert (1986).

All samples were analyzed for gold and silver by the fire assay or the fire assay/inductively coupled plasma (ICP) technique. In addition, most samples were analyzed semiquantitatively, either for 40 elements using an optical emission spectrograph or for 33 elements by ICP. Arsenic content was determined by atomic absorption and ICP; antimony and tin by atomic absorption; bismuth, cobalt, copper, lead, manganese, molybdenum, and zinc by ICP; uranium by fluorimetry; barium by X-ray fluorescence; fluorite by wet chemistry; and mercury by a cold-vapor procedure.

Investigations by the U.S. Geological Survey

The Sierra Ladrones were part of a National Uranium Resource Evaluation (NURE) study of the Socorro 1°×2° quadrangle in New Mexico by Pierson and others (1980). The field study of the geology and mineral occurrences of the Sierra Ladrones Wilderness Study Area was done by Samuel L. Moore during 1985 and 1986, and it consisted of traverses and collecting of stream-sediment samples, mineral samples, and rock samples.

Acknowledgments

Special thanks are extended to Charles Headen, owner of the Lawrence Lode patented claim, and to Lionel Ortega, local landowner, for allowing access to and sampling of their lands. The regional geochemical stream-sediment samples were evaluated by Michael S. Allen; the geophysical data were evaluated by Carl L. Long.

APPRAISAL OF IDENTIFIED RESOURCES

By John T. Neubert
U.S. Bureau of Mines

Mining History

The northeastern part of the Sierra Ladrones study area is within the Ladron (or Hanson) mining district, where silver and gold were the principal targets. The first mineral discovery in the district was in 1868, and peak activity was between 1879 and 1897. Numerous workings (mainly prospect pits) remain in the northeastern part of the study area (Neubert, 1986). Production, if any, was low.

In 1926 one carload of metallurgical-grade fluorspar was mined from the Juan Torres prospect in the eastern part of the study area (fig. 3). From 1952 to 1955, small, high-grade manganese deposits along the northern slopes of the Rio Salado in the study area (fig. 3) yielded about 610 tons of ore that contained 22–42 percent manganese. The Black Mask mine was the principal producer, although the Rio Salado mine may have had minor production.

The Jeter mine, about 500 ft east of the northeastern boundary of the study area (fig. 3), was the largest uranium producer near the study area. The mine operated from 1954 to 1958 and produced 58,562 lbs of U_3O_8 from about 9,000 tons of ore. In the mid-1970's, Gulf Minerals, Inc., drilled near the Jeter mine, but no further mining resulted (Chamberlin, 1982).

In 1980, Silver King, Inc., filed a mining plan to extract silver from the Silver King claim just west of the Headen Ranch in the northeastern part of the study area in the Ladron district (fig. 3). Although the plan was filed, no development or mining occurred. About 60 unpatented and 1 patented lode mining claims exist within the study area; however, none of the claims were being mined in 1985.

Oil and Gas Activity

Oil and gas leases and lease applications cover parts of the study area (fig. 3). No drilling has been done for hydrocarbons in the study area; the nearest test hole was drilled about 4 mi northwest of the northern boundary of the study area. The hole was 201 ft deep and intersected Precambrian granite (New Mexico Geological Society, 1983).

Results of Field Investigation

The most heavily prospected area within and near the study area is the northeastern part, where uranium was mined at the Jeter mine and silver was prospected for west of that mine. Other commodities mined within the study area include fluorite at the Juan Torres prospect and manganese at the Black Mask and Rio Salado mines. Pliocene travertine limestone of relatively high purity is abundant throughout much of the western part of the area.

Metals in the Northeastern Part of the Study Area

The greatest density of workings within the study area is centered around the Lawrence Lode patented claim (fig. 3). Workings are generally on quartz veins and range in size from shallow pits to shafts; the deepest shaft is about 47 ft. Two short adits were also driven; the longest is about 50 ft.

Precambrian granite and amphibolite dikes are the dominant rock types in the Silver King prospect area near the Headen Ranch (Condie, 1976). The granite is generally fine to medium grained with limonite, sericite, partially kaolinized feldspar, and local epidote and chlorite. The amphibolite is extremely fine grained and contains abundant chlorite and hornblende.

North- to northwest-striking, steeply dipping, limonitic quartz veins in Precambrian granite gneiss contain low concentrations of precious (silver and gold) and base (copper, lead, and zinc) metals. Gangue minerals are quartz, calcite, barite, and sparse fluorite. Ore minerals identified in the veins are galena, malachite, and sparse chalcopyrite. Maximum width of the veins is about 15 ft; the average width is 2–3 ft. The veins are discontinuous; the longest is traceable for about 600 ft (Neubert, 1986).

Field observations suggest at least two ages of mineralization. A mineralized, limonitic fault-breccia zone is cut off by an amphibolite dike to the southeast of the sampled site. This amphibolite is cut by a weakly mineralized quartz vein. The field relationships suggest the breccia zone predates the emplacement of the amphibolite, which in turn predates the quartz vein.

Sixty-one of 139 rock samples from the Silver King and Lawrence Lode claims in the area contain detectable silver and (or) gold. Maximum silver content is 6.9 oz/t (ounces/ton) (237 ppm (parts per million)), in a sample from the collar of a 27-ft-deep shaft on the Lawrence Lode. Maximum gold content was 0.01 oz/t (0.344 ppm) from a chlorite- and limonite-rich amphibolite. Most of the detected silver concentrations were below 2 ppm; only four samples contained gold above 0.1 ppm.

Three of 52 sediment samples contained detectable silver and (or) gold; maximum silver concentration was about 3.1 ppm, and maximum gold concentration was 0.025 ppm. Two of eight panned-concentrate samples contained silver. One sample (0.680 ppm) is from a drainage northeast of the Lawrence Lode, and the other sample (24.79 ppm) is from a major arroyo which drains the Lawrence Lode and numerous other prospects.

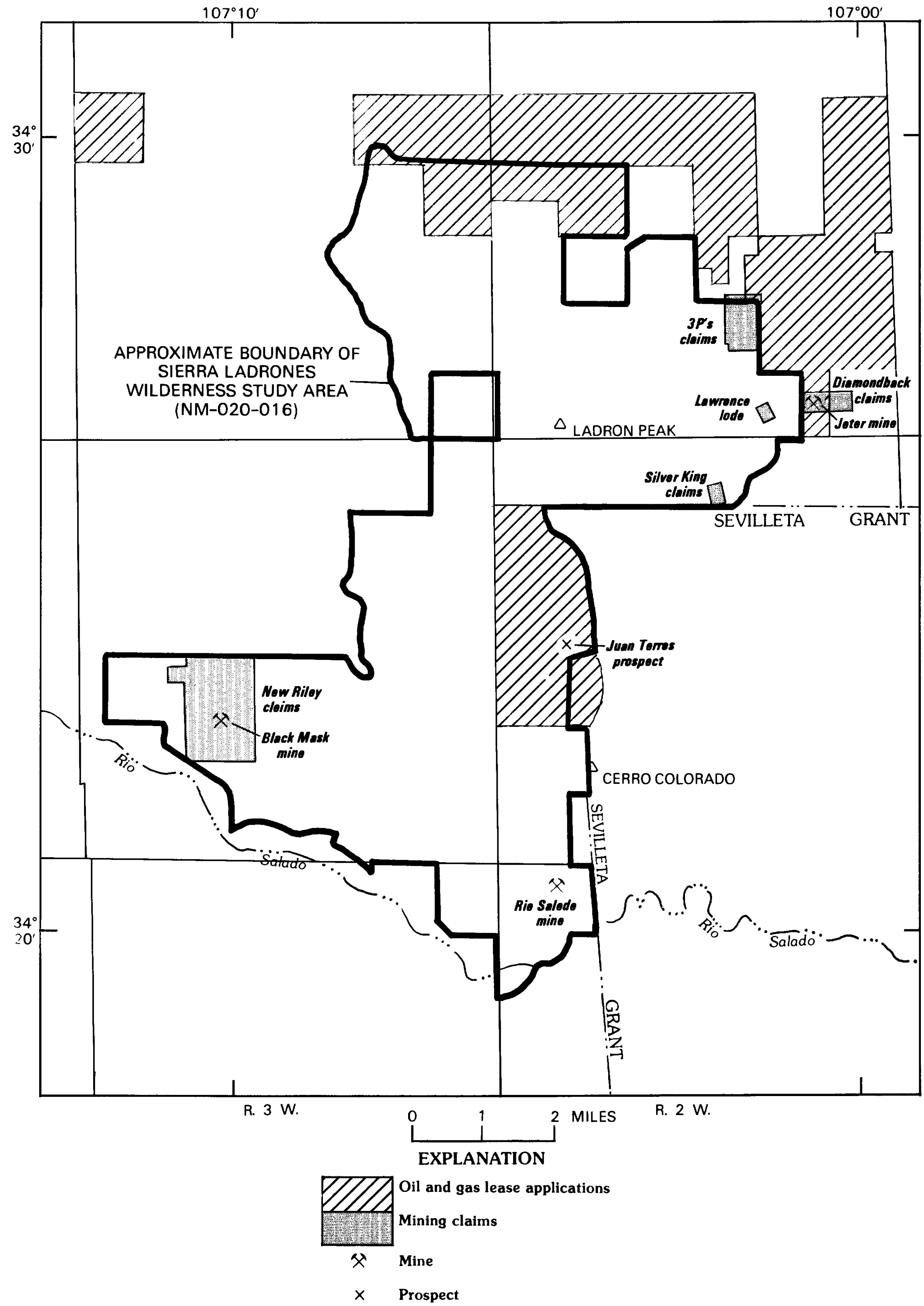

Figure 3. Map showing oil and gas leases, lease applications, mining claims, mines, and prospects in the Sierra Ladrones Wilderness Study Area.

Lead, copper, and zinc were detected in many of the rock samples. Maximum values were 5.6 percent lead and 1.00 percent zinc in a select sample from a quartz-barite-galena vein at the Silver King shaft and 2.7 percent copper in a select sample of malachite-coated granite. The majority of the base-metal concentrations were much lower than these values.

Barium was detected in most of the samples from the northeastern part of the study area, the maximum being 38 percent in a discontinuous quartz-barite lens. Typical barium concentrations ranged from about 0.01 to 0.2 percent.

Metals in the Remainder of the Study Area

Large areas of the northern part of the study area are underlain by Precambrian metavolcanic rocks. A quartz vein and gouge zone that parallels foliation was prospected near the head of Canon del Alamito. Samples from the prospect contained as much as 5.6 ppm silver, 1.1 percent copper, 0.41 percent lead, and 0.31 percent zinc. Gold and silver were detected in two stream-sediment samples from an arroyo that drains schist and amphibolite. Other sediments from schistose terrane were barren of precious metals. Concentrations of cobalt, arsenic, and antimony, indicators of sulfide orebodies, are low or below detection limits (Neubert, 1986).

An area on the west side of the range, about 1 mi west of Ladron Peak, was explored by a 200-ft-long adit driven in sheared limestone and granite, slightly west of the Ladron fault. Assays of samples from the adit were low, although a sample collected at the portal contained 0.04 ppm gold; maximum lead content was 38 ppm. Stream-sediment samples from this area contained no anomalous element concentrations. No metallic resources were identified in limestone west of Ladron Peak.

Numerous, scattered, small, precious-metal, base-metal, and barite occurrences are in the northeastern part of the study area (area 1 M/B and area 2 M/B, fig. 2); however no resources were identified. Sample concentrations were generally low; highest concentrations were confined to select samples or samples from discontinuous veins or lenses. An argentiferous base-metal occurrence is present in the northeast part of the study area in schist in Canon del Alamito; however, no resources were identified at this site or within the schist in the study area.

Jeter Uranium Mine

Uranium was mined at the Jeter mine, about 500 ft east of the northeastern boundary of the study area (pl. 1). The Jeter mine consists of an open pit and a 300-ft-long, 25°-E.-dipping decline along the Jeter fault (McLemore, 1983). The Jeter fault is a major north-striking, east-dipping structure that separates Precambrian granite gneiss in the footwall to the west from Tertiary sedimentary rocks, Tertiary Santa Fe Group, and Paleozoic rocks in the hanging wall to the east. At the mine, the fault contains uranium (mainly coffinite) and minor amounts of copper (Collins and Nye, 1957). Samples from the Jeter mine contained as much as 430 ppm uranium (Neubert, 1986).

A northeast-trending fault intersects and displaces the Jeter fault 1 mi north of the Jeter mine (pl. 1). Samples collected within the study area near the Jeter fault trace contained as much as 10.5 ppm uranium. The area of the projection of the fault trace north of the Jeter mine is covered with colluvium and alluvium which precludes direct observation of fault continuity and makes sampling impossible. Scintillometer readings near the mapped fault trace were not above background.

The origin of the uranium and copper mineralization along the Jeter fault is speculative. Collins and Nye (1957) suggested a hydrothermal origin of ascending mineralized solutions. More recently, Chamberlin (1982) suggested a supergene origin by descending mineralized waters.

Juan Torres Fluorite Prospect

A small amount of fluorite was mined at the Juan Torres prospect within the eastern boundary of the study area. Five prospect pits and an 18-ft-deep shaft are present. Quartz and fluorite pods (maximum width 5 ft) are hosted in a medium- to coarse-grained granite. Fluorite crystals as much as 1.5 in. (inches) across were observed; fluorite crystals were clear, white, green, and purple. White, clear, and smoky quartz crystals (maximum 4 in. long) were also observed. The highest fluorite content in samples from the Juan Torres prospect area was about 6 percent in a discontinuous 10-ft-long pod of quartz-fluorite; most samples contained less than 0.5 percent fluorite. Because of low fluorite content and the small, discontinuous nature of the occurrences, no fluorite resources are identified at the surface.

Manganese Mines

Small manganese prospects and mines are in the southern part of the study area near the Rio Salado. The major manganese producer in the area was the Black Mask mine, although the Rio Salado mine may have had minor production. The podlike manganese deposits are hosted in silicified conglomerates of the Tertiary Santa Fe Group. The ore is massive (locally leafy) black psilomelane and (or) pyrolusite. The highest manganese content (39 percent) is in samples from the Black Mask mine; the weighted average from this mine is 26 percent manganese. Manganese content in samples from other prospects is considerably lower than in those from the Black Mask mine. The examined manganese deposits appeared to be virtually mined out; therefore no identified manganese resources are present at the surface in the study area.

Limestone

Pennsylvanian limestone and Pliocene travertine are exposed in the western and southwestern parts of the study area. Many of the Pennsylvanian carbonate beds are impure; however, some contain as much as 95.6 percent calcium carbonate. The travertine at the western and southwestern parts of the area is as much as 110 ft thick, covers about 7 mi^2 (square miles) of the study area, and is reported to be 99 percent calcium carbonate (Chamberlin, 1982). Three travertine samples collected for this study averaged 94 percent calcium carbonate. Travertine limestones of these compositions are suitable for cement, agricultural use, and, marginally, for use in chemical lime; however, the closest railhead is at Bernardo, N. Mex., about 25 mi away by unpaved roads. Other sources of limestone, closer to transportation and markets, make development of these limestones unlikely in the foreseeable future.

Sand and Gravel

The flanks of the Sierra Ladrones, within the study area, contain abundant alluvial and colluvial deposits of sand and gravel. Most of the material is suitable for general construction purposes. However, abundant supplies of sand and gravel are available in the Rio Grande Valley, much closer to railheads and population centers. Quarrying of sand and gravel in the study area is unlikely in the foreseeable future.

ASSESSMENT OF POTENTIAL FOR UNDISCOVERED RESOURCES

By Samuel L. Moore, Michael S. Allen, and Carl L. Long

Geology

Structure

The Sierra Ladrones Wilderness Study Area is part of a regional uplifted triangular block of faulted and thrust-faulted crystalline Precambrian granite gneiss, metavolcanic schist and gneiss, and metasedimentary quartzite gneiss that are intruded by three Precambrian plutons of the granite gneiss, and quartz monzonite (1.3 b.y. (billion years), Anderson, 1983). The Sierra Ladrones jut from the plains of Tertiary basin fill along the western margin of the Rio Grande trench, and they lie north of the Lemitar and Magdalena Mountains. The western escarpment of the Sierra Ladrones is bounded by the north-northwest-trending near-vertical Ladron fault which has downthrown and juxtaposed Pennsylvanian Magdalena Group on the west against an imbricated thrust complex of Precambrian granite gneiss, metavolcanic gneiss, and metasedimentary quartzite gneiss along the northern and central parts of the western escarpment of the Sierra Ladrones (pl. 1). Along the southern part of the Sierra Ladrones, the Ladron fault has downthrown and juxtaposed Precambrian metasedimentary quartzite gneiss, metavolcanic gneiss, and granite gneiss against rocks of similar age and lithology in the Cerro Colorado area (pl. 1). The southern extension of the Ladron fault merges with the northeast-trending and 20°–30°-E.-dipping Jeter thrust fault 1 mi east of the summit of Cerro Colorado (pl. 1).

The eastern and southeastern escarpment of the Sierra Ladrones is bounded by the N. 20°–30°–E.-trending and 20°–30°–SE.-dipping Jeter thrust fault (Black, 1964; pl. 1). The Jeter thrust fault can be traced from south of the Rio Salado northeastward for more than 11 mi, and Pennsylvanian and Permian strata, Tertiary Santa Fe Group rocks, and volcanic sedimentary rocks are thrust westward over altered Precambrian granite gneiss along the central and southern escarpments of the Sierra Ladrones (pl. 1). The Precambrian metavolcanic gneiss and metasedimentary quartzite gneiss crop out in the central and southern parts of the Sierra Ladrones as a pile of imbricated slices that are thrust northwestward over a sole of vertically faulted and high-angle to vertical schistose and gneissic metavolcanics in the northern part of the Sierra Ladrones. The aeromagnetic map of faulted Precambrian intrusive plutons of granite gneiss, quartz monzonite, metavolcanic gneiss, and metasedimentary quartzite gneiss indicates that (1) the Precambrian rocks are not rooted, (2) the Sierra Ladrones may have a structural floor that dips to the southeast, and (3) the entire Precambrian crystalline block of the Sierra Ladrones may be a rootless allochthonous block that has been thrust north-northwestward. The thrust faults that displace the slices of granite gneiss, metavolcanic schist and gneiss, and metasedimentary quartzite gneiss contain quartz veins with specular hematite; locally the quartz veins are pegmatitic and contain pink orthoclase crystals.

Stratigraphy

The rocks of the Sierra Ladrones study area range in age from Precambrian metasedimentary, metavolcanic, and metaigneous rocks that are about 1.6 b.y. old (Anderson, 1983) through upper Paleozoic and Mesozoic sedimentary rocks, to Tertiary and Quaternary deposits of conglomerate, fanglomerate, sandstone, and travertine. Geology of the study area and vicinity is shown on plate 1.

The Precambrian rocks are, from oldest to youngest, (1) granite gneiss (unit p€g) that underlies the Cerro Colorado area; (2) quartzite and conglomeratic quartzite schist and gneiss (unit p€qc) that are present in an imbricated thrust complex; (3) schistose and gneissic rhyolite and dacite flows and ash flows (unit p€mv) that underlie the northern and northeastern parts of the Sierra Ladrones and the Cerro Colorado area; and (4) interbedded amphibolite and quartz-muscovite schist (unit p€asp)

The metavolcanic and metasedimentary rocks are intruded by three plutons of Precambrian granitic rocks that are about 1.3 b.y. old (Anderson, 1983). These granitic rocks are, from oldest to youngest, (1) granite and granite gneiss (unit p€gg), (2) granite gneiss (unit p€g), and (3) quartz monzonite (unit p€qm).

Sedimentary rocks of Paleozoic age are, from oldest to youngest, (1) dolomitic limestone and crinoidal light-gray limestone of the Mississippian Kelly Formation (unit Mk); (2) limestone, sandstone, and siltstone of the Pennsylvanian Magdalena Group (unit IPmu); (3) red siltstone, sandstone, and minor limestone of the Lower Permian Abo Formation (unit Pa); (4) siltstone, sandstone, gyspum, and limestone of the Lower Permian Yeso Formation (unit Py); (5) Lower Permian Glorieta Sandstone (unit Psg); and (6) Lower Permian San Andres Limestone (unit Psa).

Mesozoic sedimentary rocks that crop out in the study area are, from oldest to youngest, (1) reddish-purple siltstone, shale, and fine-grained sandstone of the Upper Triassic Chinle Formation (unit ₮c); and (2) the undivided Cretaceous rocks (unit Kdmu). These undivided rocks are, from oldest to youngest, the Dakota Sandstone, Rio Salado shale tongue of the Mancos, Tres Hermanos Formation, D–Cross Tongue of the Mancos, and the uppermost Gallup Sandstone.

Tertiary sedimentary rocks that crop out in the study area are the middle Miocene to Pliocene Santa Fe Group and Pliocene travertine. The Santa Fe rock units are, from oldest to youngest, (1) crudely bedded conglomerate, fanglomerate, and sandstone (unit Tscs); (2) sandstone and volcanic ash beds of the Popotosa Formation (unit Tsp); (3) andesite flows intercalated with andesite conglomerates (unit Tsv); (4) fanglomerate composed of well-rounded pebbles, cobbles, and some boulders of Precambrian granite, quartz monzonite, metavolcanics, and metasedimentary rocks (unit Tsfg); and (5) conglomerate (unit Tscg). Pliocene travertine (unit Tt) unconformably overlies the upper conglomerate of the Santa Fe. Late Oligocene monzonite dikes, dike swarms, and plugs (unit not mapped) intrude the Triassic and Cretaceous sedimentary rocks in the southwestern part of the study area. Pliocene travertine is deposited on an erosional surface cut on the Lower Permian Abo Formation, Yeso Formation, Upper Triassic Chinle Formation, and the Pliocene conglomerate of the Santa Fe.

Quaternary rocks in the map area are (1) Pleistocene piedmont slope deposits (unit Qp) composed of silt and gravel that were deposited on terraces cut on Tertiary sedimentary rocks and on Precambrian rocks along the eastern slopes of the Sierra Ladrones; (2) Pleistocene and Holocene alluvium and colluvium (unit Qac), talus deposits (unit Qt), and landslide deposits (unit Ql); and (3) Holocene alluvium (unit Qal).

Geophysical Studies

Aeromagnetic and gravity data were obtained from existing data files as part of the mineral resource evaluation of the Sierra Ladrones Wilderness Study Area. These data provide information on regional surface and subsurface distribution of rock masses and structural features.

Aeromagnetic Data

The aeromagnetic data are extracted from a compilation of magnetic data for the state of New Mexico by Cordell (1984) and are shown on figure 4. The Sierra Ladrones aeromagnetic survey was flown at a constant barometric elevation of 10,000 ft, and the flight lines were oriented east-west at a spacing of about 1 mi. The significant magnetic features of the study area are twin enclosed magnetic highs that coincide with exposed Precambrian granitic rocks and metavolcanic rocks. A region of low magnetic values nearly encircles these magnetic highs, and the magnetic field increases at the southwest corner of the study area. The regionally small, short wavelengths of the twin magnetic anomalies suggest that the Precambrian granitic, metavolcanic, and metasedimentary rocks of the Sierra Ladrones are possibly a shallow thrust-faulted crystalline complex. Most of the existing geophysical models suggested high-angle normal faulting, and some have been interpreted as showing mainly listric faults. The solution to this structurally complex area may be a combination of all the above observations and interpretations; however, the geophysical data in the study area are not sufficient to reach a final conclusion on the thickness of the Precambrian core of the Sierra Ladrones.

The magnetic low that surrounds the central core of the range reflects the low magnetic content of the thick sedimentary rocks in these areas. The –100 gamma enclosed low near the southeastern edge of the study area boundary (fig. 4) possibly represents an anomaly that is near the arcuate-trending mineralized zone in Pennsylvanian limestone in the vicinity of the Rio Salado manganese mine and could possibly indicate the source of the mineralization. On the east side of the Sierra Ladrones, the magnetic values gradually decrease toward the thickening of the Tertiary sedimentary rocks in the hanging wall of the eastward-dipping Jeter thrust fault.

Gravity Data

Gravity data were obtained from a file managed by the Department of Defense (NOAA National Geophysical Data Center). Bouguer gravity anomaly values were computed using the 1967 gravity formula (International Association of Geodesy, 1967) and a reduction density of 2.67 g/cm³ (grams per cubic centimeter). Terrain corrections were made by computer for a radial distance of 100 mi from each station using the method of Plouff (1977); the data are shown on figure 5. Although the gravity station density is sparse in the study area, regional

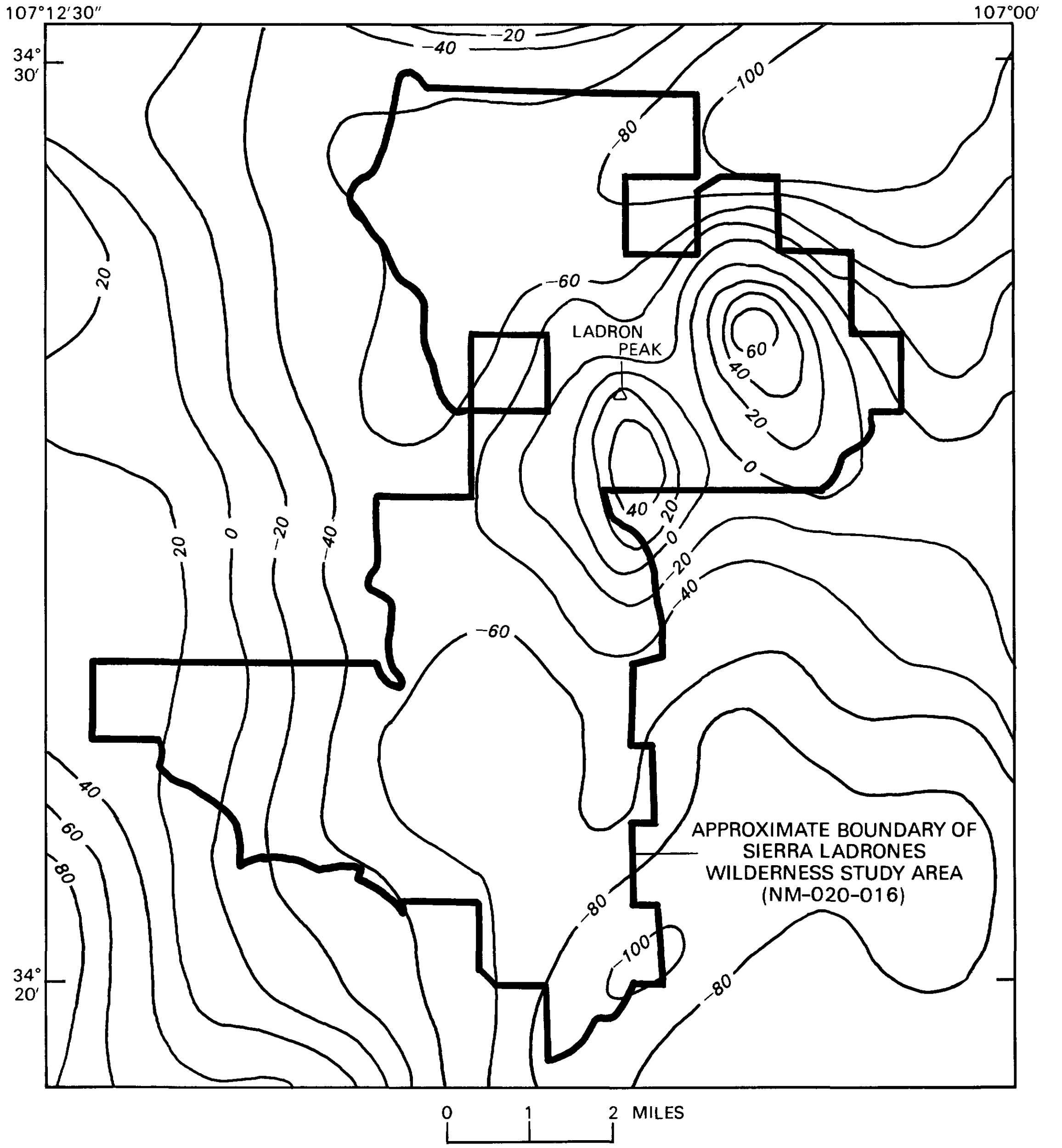

Figure 4. Map showing lines of total aeromagnetic intensity in the Sierra Ladrones Wilderness Study Area; regional gradient has been removed. Contour interval 20 gammas.

gravity values of the area do define a rather large mass of dense rocks beneath the Sierra Ladrones; most of the small structures in the area are unresolvable with the existing data. A gravity model (Birch, 1982) suggests the Sierra Ladrones are possibly a basement horst. The gravity values decrease toward the Rio Grande valley to the east as would be expected due to the thickening of less-dense Tertiary sedimentary rocks in that direction in the hanging-wall block of the Jeter thrust fault (pl. 1).

Aerial Gamma-Ray Spectroscopy

J.S. Duval, U.S. Geological Survey (written commun., 1986), used an aerial gamma-ray survey to estimate near-surface (0–20 in. depth) concentrations of percent potassium (K), parts per million equivalent uranium (eU), and parts per million equivalent thorium (eTh). These data (K, eU, eTh) provide a partial geochemical representation of the near-surface

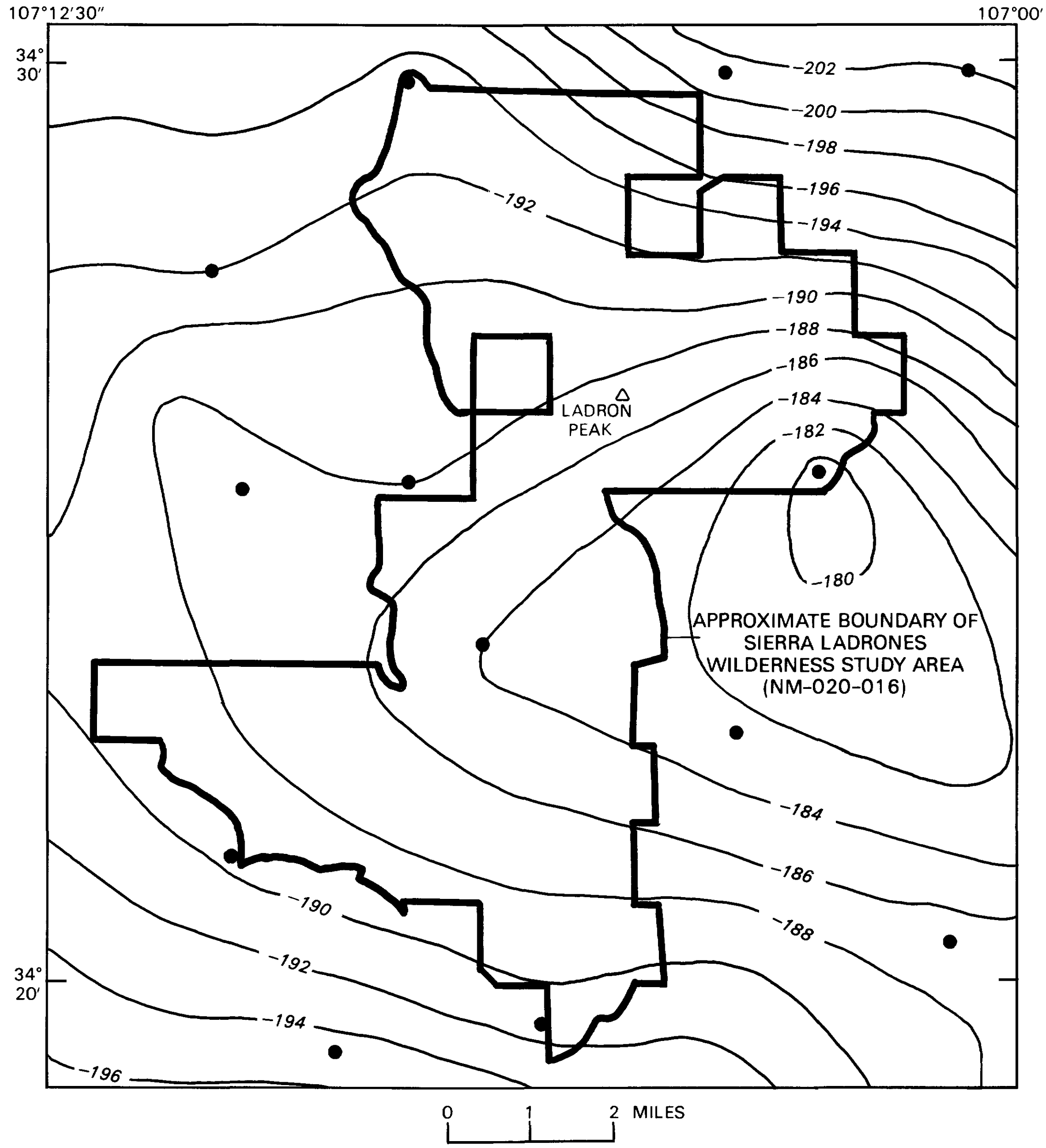

Figure 5. Map showing complete Bouguer gravity of the Sierra Ladrones Wilderness Study Area. Contour interval 2 milligals. Dots are gravity stations from this study.

materials. For a typical aerial survey each measurement reflects average concentrations for a surface area on the order of about 70,000 square yards to an average depth of about 10 in. The definition of an anomaly requires that the element concentration as well as its ratios to the other two elements all be relatively high values. The Sierra Ladrones Wilderness Study Area has overall moderate radioactivity with concentrations of 1.2–3.5 percent K, 1.8–4.0 ppm eU, and 7–16 ppm eTh. There are no anomalies within or near the study area.

Geochemistry

Methods

A regional reconnaissance stream-sediment sampling program was conducted during November 1984 by Rick Graff and Alan Phillips; sample locations are shown on plate 1. Emission spectrographic analyses were done by G. Day, and interpretation of the data was the responsibility of Michael S. Allen. Rock samples were collected by Samuel L. Moore.

Fifty-one stream sites were sampled along the base of the mountain front in this reconnaissance study (pl. 1). The drainage basins that were sampled ranged from 0.5 to 3 mi^2 in area, and sample density was approximately one site every 1.5 mi^2. The sample medium for this study was the nonmagnetic fraction of panned concentrates of drainage sediment. The heavy-mineral-concentrate samples were collected from active sediment in drainage channels. Each sample was composited from several localities within an area that may extend as much as 60 ft from the site plotted on the map. Each sample was sieved through a 2-mm (10 mesh) screen to remove coarse material. The minus-2-mm material was panned to remove most of the quartz, feldspar, organic material, and clays. The panned concentrates were air dried and then put through a bromoform (specific gravity 2.8) separation to remove the remaining quartz and feldspar. The heavy fraction was then separated into three fractions using a modified Frantz Magnetic Separator. The three fractions produced include: C1, dominated by magnetite and ilmenite; C2, dominated by heavy rock-forming minerals, such as garnet and hornblende; and C3, dominated by heavy accessory minerals, such as zircon and apatite, and the majority of ore minerals such as cassiterite, scheelite, and most sulfides. Only the C3 fraction was analyzed for this study. Due to insufficient quantities, a split of the C3 fraction was not available for mineralogical analysis.

The C3 fraction was analyzed for 31 elements using a semiquantitative, direct-current arc emission spectrographic method (Grimes and Marranzino, 1968). Concentrations of elements are estimated based on visual comparison of sample spectra against standard-derived spectra and are reported geometrically over any order of magnitude in the series 10, 15, 20, 30, 50, 70, 100, and so forth. The precision of the method is approximately plus or minus one reporting interval at the 83 percent confidence level and plus or minus two intervals at the 96 percent confidence level (Motooka and Grimes, 1976). Concentrations determined for the elements iron, magnesium, calcium, and titanium are reported in weight percent, whereas all others are reported in parts per million (micrograms/gram). Note that sample methods, sample processing, and analytical methods differ from the methods used by the USBM in their assessment of known resources; this results in some disparity in analyses of sediments from the same areas in the wilderness study area.

Rock samples from the Black Mask and Rio Salado mines were analyzed for 31 elements by emission spectrography and were additionally analyzed for gold, silver, and tungsten by atomic absorption. Samples from the northeast part of the study area and the Juan Torres prospect were analyzed for gold, silver, and tungsten by atomic absorption.

Results

Stream-Sediment Samples

The data used in the interpretation that is presented in this report are listed in detail in Allen and others (1988). The elements arsenic, gold, cadmium, and antimony were not detected in any of the samples due to the high detection limits of the methods used. The elements silver, cobalt, and thorium were each detected in only one sample; only the silver value (10 ppm) was of geochemical significance. The distributions of the other elements were studied through the calculation of statistical parameters, review of histograms, and plotting of data. The distributions of the elements boron, beryllium, chromium, copper, lanthanum, niobium, scandium, vanadium, yttrium, and zircon indicated no apparent geologic or geochemical feature, largely due to insignificant variation. The distributions of calcium, iron, magnesium, manganese, and titanium appear to be governed by lithologic variations.

The concentrations of barium and strontium are generally high over the whole area. The highest values occur east of Ladron Peak and in a large area west of Cerro Colorado underlain by Paleozoic carbonate rocks, whereas the lowest concentrations occur northwest and north of Ladron Peak in areas underlain by siliceous metavolcanics. Barium values average more than 5,000 ppm and range from 200 to greater than 10,000 ppm. Strontium contents average over 1,000 ppm and range from not detected at 100 ppm to 10,000 ppm.

The concentrations of barium and strontium in the heavy-mineral concentrates suggests that their presence is in minerals in which they are primary constituents (for example, barite and celestite), and the high correlation of these two elements may indicate a single phase, such as strontium-bearing barite. The origin of barium in the northeastern part of the study area is probably in Tertiary veins as described by Black (1964), Condie (1976), and Neubert (1986) in the faulted and altered Precambrian granite gneiss and quartz monzonite. The anomalous barium and strontium in the southwestern part of the study area is probably related to low-level amounts of disseminated barite in the underlying Paleozoic carbonate rocks.

Although zinc was rarely detected (7 samples at a lower limit of 500 ppm), two anomalous areas are suggested; however, the form and source of the zinc are unknown. The two areas appear to be unrelated to any mapped geologic features; one area is underlain predominantly by metavolcanic rocks, and the other is underlain by Paleozoic sedimentary rocks.

A multielement anomaly is present in a north-south trend underlain by Precambrian quartz monzonite, metasediments, metavolcanic rocks, and granite gneiss. The anomaly is defined by drainage basins having anomalous concentrations of three or more of the elements tungsten, molybdenum, bismuth, and lead (table 1). A few anomalous concentrations for boron, barium, and yttrium also correspond to sites with anomalous concentrations of these elements. Within the northern part of the area (fig. 6), the anomaly is the strongest for tungsten, molybdenum, bismuth, and lead (table 1).

The tungsten and molybdenum are thought to be present in scheelite and powellite because these minerals were observed in concentrates before grinding and analysis. These minerals were not observed in any rocks; thus the nature of their occurrence is unknown. The minerals that contain bismuth and lead in association with the tungsten and molybdenum are unknown due to the unavailability of mineralized splits. Although bismuth may substitute in scheelite (Dana, 1951), the high concentrations of bismuth in these samples suggest that the bismuth may be a major constituent in a widely disseminated mineral.

Rock Samples

An analysis of a manganese vein sample from the Rio Salado mine yielded anomalous amounts of cobalt (500 ppm), nickel (300 ppm), molybdenum (150 ppm), strontium (300 ppm), tungsten (12 ppm), and arsenic (2,000 ppm), and weakly anomalous amounts of zinc (300 ppm) and copper (80 ppm). A similar sample of a manganese vein from the Black Mask mine yielded anomalous amounts of cobalt (700 ppm), nickel (100 ppm), and molybdenum (10 ppm), and weakly anomalous amounts of chromium (30 ppm), copper (20 ppm), and lead (15 ppm). The sample from the Juan Torres prospect contained 19 ppm tungsten.

Analyses of 15 samples from faults in the northeast part of the study area yielded tungsten values that range from less than 0.5 ppm to 6.1 ppm; these faults crosscut multilithologic units. Neither scheelite nor powellite were observed in the rock samples.

Table 1. Ranges and anomalous values for selected elements in nonmagnetic-fraction heavy-mineral-concentrate samples

Element	Range (ppm)	Anomalous values (ppm)	Number of anomalous samples
Entire Sierra Ladrones Wilderness Study Area (51 samples total)			
Bismuth	<20–>2,000	>200	10
Molybdenum	<10–100	10	10
Lead	<20–700	>100	12
Tin	<20–1,500	20	5
Tungsten	<100–20,000	150	18
Northern anomalous area of Sierra Ladrones Wilderness Study Area (10 samples total)			
Bismuth	20–>2,000	>200	7
Molybdenum	<10–100	10	8
Lead	<20–700	>100	7
Tungsten	500–20,000	>1,000	8

Mineral and Energy Resource Potential

Metals

Five areas of potential mineral resource in the Sierra Ladrones study area are shown on figure 2 and plate 1.

Tungsten, Bismuth, Molybdenum, and Lead

A multielement anomaly is present in the heavy-mineral panned concentrates in the drainage basins in the northern part of the Sierra Ladrones study area and in the east-central part of the study area from the Headen Ranch southwestward to Mule Canyon (pl. 1). The range of these anomalous concentrations is shown in table 1. These drainage basins are underlain by multilithologic thrust-faulted slices and faulted blocks of Precambrian granite gneiss, quartz monzonite, siliceous metavolcanic gneiss and schist, and quartzite gneiss and schist. The source of the tungsten, molybdenum, bismuth, and lead is unknown, and it could be a disseminated phase in any one or all of the Precambrian rock units. It is also possible that these elements are concentrated along some of the faults, especially in the northeastern part of the study area. The source of these anomalies is unknown. The area near Ladron Peak (1 M/B on fig. 2 and pl. 1) has a moderate resource potential for undiscovered tungsten, bismuth, molybdenum, and lead, with certainty level B.

Silver and Gold

The northeastern part of the Sierra Ladrones study area (2 M/B on fig. 2 and pl. 1) is underlain mostly by faulted blocks of altered Precambrian granite gneiss, quartz monzonite, metavolcanic quartz latite schist, and amphibolite dikes. The Precambrian granite gneiss is displaced by numerous north- to northeast- and northwest-trending, near-vertical faults that served as channels for veins of galena and minor chalcopyrite and fluorite in quartz-calcite-barite gangue. Neubert (1986) of the USBM analyzed 139 samples from these veins and breccia zones; 48 of these samples contained detectable silver and 13 contained detectable gold. Silver values ranged from 2 to 237 ppm, and gold values ranged from less than 0.1 ppm to a maximum value of 0.34 ppm in one locality. Four panned concentrates of the stream sediments from arroyos that drain the Ladron Peak area and faulted veins from this area were analyzed by the USGS, and neither gold nor silver was detected in these samples. The vein system of this area (2 M/B) has a moderate resource potential for undiscovered silver and gold, with certainty level B.

Fluorite and Tungsten

Veins and pods of fluorite and smoky, clear, milky, and amethystine quartz were mined from the Juan Torres prospect area located near the head of Mule Canyon in the east-central part of the study area (3 M/B on fig. 2 and pl. 1). A sample from the prospect contained 19 ppm tungsten. The fluorite and quartz veins and pods crop out in Precambrian granite gneiss and are about 1–4 ft wide and about 10–20 ft long. These discontinuous pods and lenses of fluorite and quartz occur in an area west of Ladron fault and east of a hogback of Pennsylvanian limestone (pl. 1). The Juan Torres prospect area (3 M/B) has a moderate resource potential for undiscovered fluorite and tungsten, with certainty level B.

Manganese, Cobalt, Nickel, Tungsten, and Molybdenum

About 610 tons of manganese ore was produced from the Rio Salado mine in the southeastern part of the study area and the Black Mask mine in the southwestern part of the study area (4 M/B and 5 M/B on fig. 2 and pl. 1); most of the manganese ore was produced from the Black Mask mine.

The Rio Salado mine is developed on a faulted brecciated zone in Pennsylvanian limestone. The manganese mineralization in the matrix of the brecciated limestone is variable in grade and discontinuous. An analysis of the manganese minerals in the matrix of the limestone breccia yielded moderately strong anomalous cobalt, nickel, tungsten, and molybdenum, and weakly anomalous zinc and copper. These polymetalliferous anomalies may suggest a hydrothermal mineral system that may be localized along the arcuate fault system that traverses the Rio Salado mine area.

The Black Mask mine is developed on branching veins in silicified, indurated conglomerate of the Pliocene Santa Fe. An analysis of the manganese oxide veins of the Black mask mine yielded moderately high anomalous cobalt, nickel, and molybdenum, and weakly anomalous chromium, copper, and lead concentrations.

The area of the Rio Salado mine (4 M/B) has a moderate resource potential for undiscovered manganese, cobalt, nickel, tungsten and molybdenum with certainty level B. The area of the Black Mask mine (5 M/B) has a moderate resource potential for undiscovered manganese, cobalt, nickel, and molybdenum, with certainty level B.

Except where the mineral resource potential is moderate for the metals listed above, the wilderness study area has low mineral resource potential for all metals, with certainty level B.

Coal

No coal beds of either Cretaceous or Pennsylvanian or of any other age are present within the study area. Lower Cretaceous coal beds are present in the Mesaverde Formation about 1 mi southwest of the study area. The Pennsylvanian rocks in the study area and the region are all marine in origin and do not contain coal beds. There is a low energy resource potential for undiscovered coal in the study area, with certainty level C.

Uranium

All the uranium production in the region was from the Jeter mine which lies a short distance east of the eastern boundary of the study area (fig. 1); mineralization at this mine occurred in fault gouge of the Jeter fault. Uranium occurrences were not recognized in the study area by Pierson and others (1980) in their National Uranium Resource Evaluation (NURE) study. According to J.S. Duval's (written commun., 1987) airborne gamma-ray spectroscopy survey of the Sierra Ladrones study area, the area showed a low potential for uranium near-surface occurrences. There is a low mineral resource potential for undiscovered uranium in the study area, with certainty level C.

Oil and Gas

Oil and gas leases and lease applications that partially cover the northern, northeastern, and eastern parts of the map area are shown on figure 3. The oil and gas leasing activity in the northern and northeastern parts of the study area is in an area where the surface rocks are unconsolidated Tertiary sedimentary rocks that probably were deposited on Precambrian granitic rocks. The oil and gas leases along the eastern part of the map area north of Cerro Colorado are underlain mostly by thrust plates of Precambrian granite gneiss, metavolcanic schist, and metasedimentary quartzite gneiss, and only a small area of limestone of the Pennsylvanian Magdalena Group crops out in the western part of the leased area. Thus the Sierra Ladrones study area has a low energy resource potential for undiscovered oil and gas, with certainty level C.

Geothermal Energy

The Sierra Ladrones Wilderness Study Area is located about 20 mi north of the Socorro Peak Geothermal Resource Area. There are no known geothermal leases in the study area, and no warm springs or wells were noted during the study of the map area. The wilderness study area therefore has a low resource potential for undiscovered geothermal energy, with certainty level B.

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APPENDIX

DEFINITION OF LEVELS OF MINERAL RESOURCE POTENTIAL AND CERTAINTY OF ASSESSMENT

Definitions of Mineral Resource Potential

LOW mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics define a geologic environment in which the existence of resources is unlikely. This broad category embraces areas with dispersed but insignificantly mineralized rock as well as areas with few or no indications of having been mineralized.

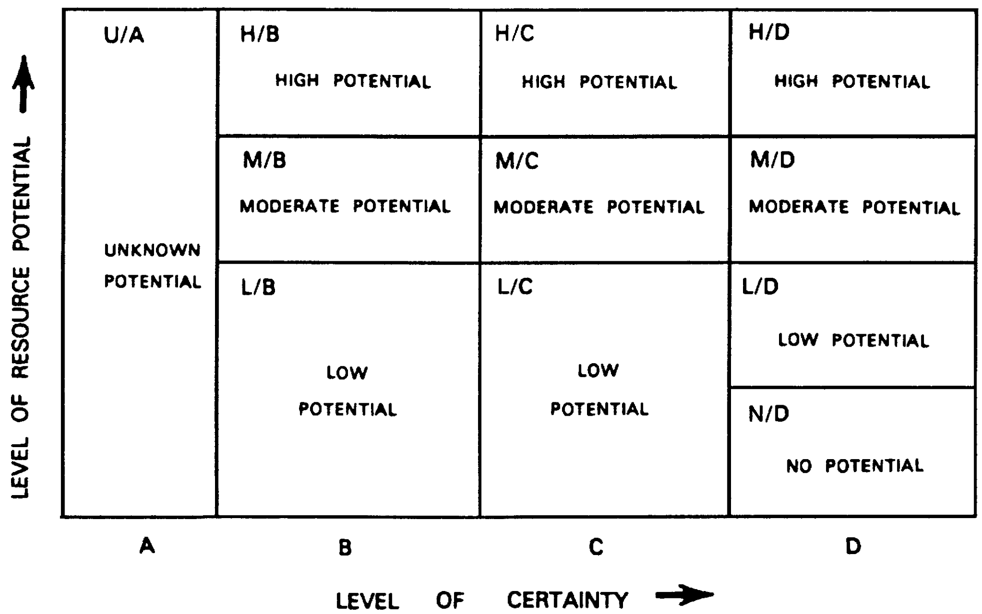
MODERATE mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence, where interpretations of data indicate a reasonable likelihood of resource accumulation, and (or) where an application of mineral-deposit models indicates favorable ground for the specified type(s) of deposits.

HIGH mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence, where interpretations of data indicate a high degree of likelihood for resource accumulation, where data support mineral-deposit models indicating presence of resources, and where evidence indicates that mineral concentration has taken place. Assignment of high resource potential to an area requires some positive knowledge that mineral-forming processes have been active in at least part of the area.

UNKNOWN mineral resource potential is assigned to areas where information is inadequate to assign low, moderate, or high levels of resource potential.

NO mineral resource potential is a category reserved for a specific type of resource in a well-defined area.

Levels of Certainty



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

Abstracted with minor modifications from:

Taylor, R. B., and Steven, T. A., 1983, Definition of mineral resource potential: Economic Geology, v. 78, no. 6, p. 1268–1270.

Taylor, R. B., Stoneman, R. J., and Marsh, S. P., 1984, An assessment of the mineral resource potential of the San Isabel National Forest, south-central Colorado: U.S. Geological Survey Bulletin 1638, p. 40–42.

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RESOURCE/RESERVE CLASSIFICATION

	IDENTIFIED RESOURCES			UNDISCOVERED RESOURCES	
	Demonstrated		Inferred	Probability Range (or)	
	Measured	Indicated		Hypothetical	Speculative
ECONOMIC	Reserves		Inferred Reserves		
MARGINALLY ECONOMIC	Marginal Reserves		Inferred Marginal Reserves		
SUB-ECONOMIC	Demonstrated Subeconomic Resources		Inferred Subeconomic Resources		

Major elements of mineral resource classification, excluding reserve base and inferred reserve base. Modified from McKelvey, 1972, Mineral resource estimates and public policy: American Scientist, v.60, p.32-40, and U.S. Bureau of Mines and U.S. Geological Survey, 1980, Principles of a resource/reserve classification for minerals: U.S. Geological Survey Circular 831, p.5.

GEOLOGIC TIME CHART

Terms and boundary ages used in this report

EON	ERA	PERIOD		EPOCH	BOUNDARY AGE IN MILLION YEARS
Phanerozoic	Cenozoic	Quaternary		Holocene	0.010
Phanerozoic	Cenozoic	Quaternary		Pleistocene	1.7
Phanerozoic	Cenozoic	Tertiary	Neogene Subperiod	Pliocene	5
Phanerozoic	Cenozoic	Tertiary	Neogene Subperiod	Miocene	24
Phanerozoic	Cenozoic	Tertiary	Paleogene Subperiod	Oligocene	38
Phanerozoic	Cenozoic	Tertiary	Paleogene Subperiod	Eocene	55
Phanerozoic	Cenozoic	Tertiary	Paleogene Subperiod	Paleocene	66
Phanerozoic	Mesozoic	Cretaceous		Late	96
Phanerozoic	Mesozoic	Cretaceous		Early	138
Phanerozoic	Mesozoic	Jurassic		Late Middle Early	205
Phanerozoic	Mesozoic	Triassic		Late Middle Early	~ 240
Phanerozoic	Paleozoic	Permian		Late Early	290
Phanerozoic	Paleozoic	Carboniferous Periods	Pennsylvanian	Late Middle Early	~ 330
Phanerozoic	Paleozoic	Carboniferous Periods	Mississippian	Late Early	360
Phanerozoic	Paleozoic	Devonian		Late Middle Early	410
Phanerozoic	Paleozoic	Silurian		Late Middle Early	435
Phanerozoic	Paleozoic	Ordovician		Late Middle Early	500
Phanerozoic	Paleozoic	Cambrian		Late Middle Early	~ 570[1]
Proterozoic	Late Proterozoic				900
Proterozoic	Middle Proterozoic				1600
Proterozoic	Early Proterozoic				2500
Archean	Late Archean				3000
Archean	Middle Archean				3400
Archean	Early Archean				3800?
pre-Archean[2]					4550

[1] Rocks older than 570 m.y. also called Precambrian, a time term without specific rank.

[2] Informal time term without specific rank.

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