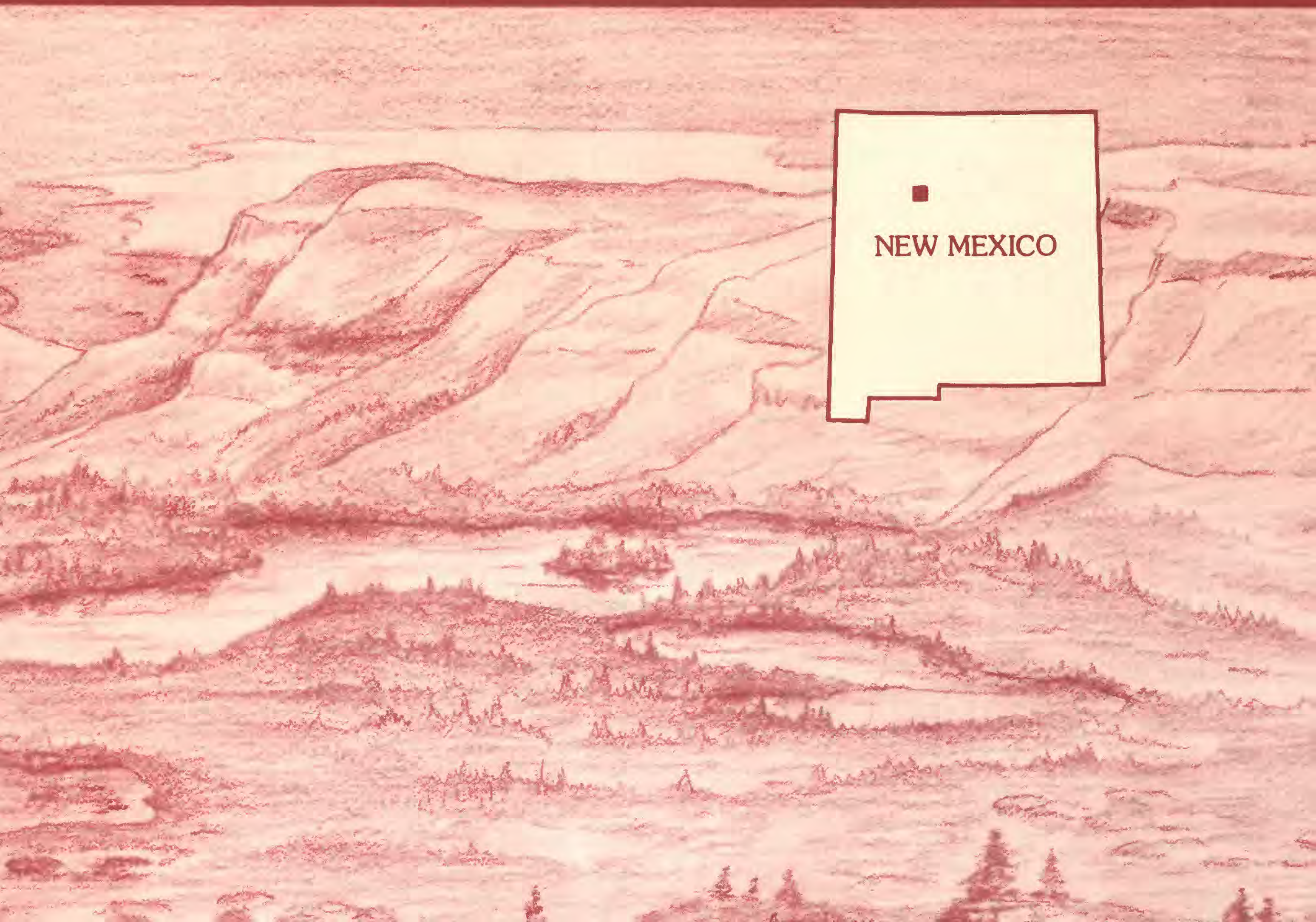
Mineral Resources of the Chamisa, Empedrado, and La Lena Wilderness Study Areas, Sandoval and McKinley Counties, New Mexico

U.S. GEOLOGICAL SURVEY BULLETIN 1733–E



Chapter E

Mineral Resources of the Chamisa, Empedrado, and La Lena Wilderness Study Areas, Sandoval and McKinley Counties, New Mexico

By PETER J. MODRESKI, GARY A. NOWLAN,
and WILLIAM F. HANNA
U.S. Geological Survey

RUSSELL A. SCHREINER
U.S. Bureau of Mines

U.S. GEOLOGICAL SURVEY BULLETIN 1733

MINERAL RESOURCES OF WILDERNESS STUDY AREAS—NORTHERN NEW MEXICO

DEPARTMENT OF THE INTERIOR
MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

UNITED STATES GOVERNMENT PRINTING OFFICE: 1990

For sale by the
Books and Open-File Reports Section
U.S. Geological Survey
Federal Center
Box 25425
Denver, CO 80225

Library of Congress Cataloging-in-Publication Data

Modreski, P.J.
Mineral resources of the Chamisa, Empedrado, and La Lena wilderness study areas, Sandoval and McKinley counties, New Mexico / by Peter J. Modreski, Gary A. Nowlan, and William F. Hanna.

p. cm.—(Mineral resources of wilderness study areas—northern New Mexico ; ch. E) (U.S. Geological Survey bulletin ; 1733-E)
Supt. of Docs. no.: I 19.3:1733-E
1. Mines and mineral resources—New Mexico—Chamisa Wilderness. 2. Mines and mineral resources—New Mexico—Empedrado Wilderness. 3. Mines and mineral resources—New Mexico—La Lena Wilderness. 4. Chamisa Wilderness (N.M.) 5. Empedrado Wilderness (N.M.) 6. La Lena Wilderness (N.M.) I. Nowlan, Gary A. II. Hanna, William F., 1938– . III. Title. IV. Series. V. Series: U.S. Geological Survey bulletin ; 1733-E.
QE75.B9 no. 1733-E
[TN24.N6]
557.3 s-dc20
[553'.09789'57] 89-600347
CIP

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 U.S. 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 the Chamisa (NM–010–021), Empedrado (NM–010–063), and La Lena (NM–010–063A) Wilderness Study Areas, Sandoval and McKinley Counties, New Mexico.

CONTENTS

PLATE

[Plate is in pocket]

FIGURES

TABLES

Mineral Resources of the Chamisa, Empedrado, and La Lena Wilderness Study Areas, Sandoval and McKinley Counties, New Mexico

By Peter J. Modreski, Gary A. Nowlan, *and*
William F. Hanna
U.S. Geological Survey

Russell A. Schreiner
U.S. Bureau of Mines

ABSTRACT

In 1985 and 1987–1988 the U.S. Bureau of Mines and the U.S. Geological Survey studied the Chamisa (NM–010–021) (16,582 acres), Empedrado (NM–010–063) (9,007 acres), and La Lena (NM–010–063A) (10,438 acres) Wilderness Study Areas in Sandoval and McKinley Counties, New Mexico. The study areas have measured resources of high-volatile-C bituminous coal totaling 27.2 million short tons, and indicated resources totaling 37.9 million short tons. The coal resources are mostly subeconomic because of the the thin and discontinuous nature of the coal beds. A private inholding between the study areas contains an inferred subeconomic resource of titaniferous/heavy mineral sand.

In the northern parts of the Empedrado and La Lena study areas, energy resource potential is high for additional coal resources adjacent to the identified coal resources, and the central part of the Chamisa study area has moderate energy resource potential for additional coal resources. All the study areas have moderate energy resource potential for undiscovered oil and gas, and low mineral resource potential for humate, for all undiscovered metals including uranium, barium, strontium, zinc, silver, and molybdenum, and for geothermal energy.

SUMMARY

Character and Setting

The three contiguous wilderness study areas are located about 50 mi (miles) northwest of Albuquerque, mostly in Sandoval County, New Mexico, with a corner of the Chamisa Wilderness Study Area extending into McKinley County (fig. 1). The Chamisa (NM–010–021) Wilderness Study Area, which comprises 16,582 acres, extends 10 mi to the west of Guadalupe, the Empedrado (NM–010-063) Wilderness Study Area, which comprises 9,007 acres, is about 4 to 12 mi northwest of Guadalupe, and the La Lena (NM–010–063A) Wilderness Study Area, which comprises 10,438 acres, is about 6 to 11 mi north of Guadalupe. Access is provided by unimproved roads west from New Mexico Highway 44. In the study areas, Upper Cretaceous (see geologic time chart in Appendix) continental and marine sedimentary rocks have been locally intruded and covered by Tertiary basalt. The sedimentary rocks, all of Late Cretaceous age, exposed in and immediately adjacent to the study areas are, in ascending order, the Gallup Sandstone, the Mulatto Tongue of the Mancos Shale, the Crevasse Canyon Formation, the Hosta Tongue of the Point Lookout Sandstone, the Satan Tongue of the Mancos Shale, the Point Lookout Sandstone, and the Cleary Coal and Allison Members of the Menefee Formation. Quaternary talus covers some hillslopes, and Quaternary alluvium fills stream channels.

Identified Resources

Lenticular coal beds as much as 8 ft (feet) thick, but averaging about 2.5 ft thick, are in the Cleary Coal

Manuscript approved for publication, October 26, 1989

Member of the Menefee Formation in the northern parts of the Empedrado and La Lena Wilderness Study Areas and the western part of the Chamisa Wilderness Study Area. The coal rank averages high volatile C bituminous. A measured coal resource at depths of 500 ft or less totals 27.2 million short tons and is distributed as 2.2 million short tons in the Chamisa study area, 3.9 million short tons in the Empedrado study area, and 21.1 short tons (including inholdings) in the La Lena study area. An indicated resource totaling 37.9 million short tons is distributed as 4.7 million short tons, 9.8 million short tons, and 23.4 million short tons, respectively, in the three areas. A small amount of coal (282 tons) was mined between 1933 and 1939 from the Tachias property, on an inholding between the Empedrado and La Lena study areas, and a larger amount (57,214 tons) was mined between 1979 and 1982 at the Arroyo #1 mine, 5 mi northeast of the La Lena study area.

As of 1987, Federal oil and gas leases had been issued over most of the Chamisa and La Lena study areas, and for a few sections in the Empedrado study area. A total of 36 holes have been drilled for oil and gas in and within 2½ mi of the study areas since 1923. Two holes have been drilled in the Empedrado, two in the La Lena, and one in the Chamisa, Wilderness Study Areas; all the holes have been dry. Small oil shows have been reported in one hole near the western boundary of the Empedrado study area, and in one hole near the eastern boundary of the Chamisa study area.

As of 1987, no mining claims were on file with the Bureau of Land Management, but in the late 1970's and early 1980's approximately 85 claims in the Chamisa study area, 270 in the Empedrado study area, and 500 in the La Lena study area had been located for uranium. Five holes have been drilled in and near the study areas to test the Jurassic Morrison Formation for uranium; apparently no significant uranium concentrations were found. Depth to the Morrison Formation, which contains major uranium deposits in the Grants Uranium Region, 20 mi to the south, was over 1,650 ft in one hole drilled in the Chamisa study area, and is inferred to be approximately 1,500 to 3,000 ft throughout the rest of the study areas.

A small paleo-beach-placer titaniferous sandstone deposit, which also contains small amounts of zircon, uranium, thorium, hafnium, niobium, and rare earths, is located in an inholding between the Empedrado and La Lena study areas (pl. 1). Economic mining is unlikely because of the small size of the deposit and the low concentration of metals.

Sand and gravel and sandstone are present in the study areas but have no current potential for development.

Mineral Resource Potential

Energy resource potential is high for discovery of additional coal resources in the northern parts of the Empedrado and La Lena study areas, in areas between and immediately adjacent to the identified coal resources. There is moderate energy resource potential for discovery of additional coal resources along the outcrop belt of the Cleary Coal Member of the Menefee Formation in the Chamisa study area, on the east slope of Mesa Chivato.

The study areas have moderate energy resource potential for undiscovered oil and gas. In the Miguel Creek oil fields, on the north flank of the Miguel Creek dome about 12 mi west of the Chamisa study area, oil has been produced from the Hospah sand (an informal unit of the Gallup Sandstone). Oil and gas have also been produced from the Mesaverde Group in the San Luis oil field and the Torreon gas field, about 10 mi north of the Chamisa and La Lena study areas.

The study areas have a low mineral resource potential for undiscovered uranium in the Morrison Formation. Geologic mapping and drill-hole data indicate that the Morrison Formation is present beneath the study areas, but there is no evidence for the presence of uranium in the study areas.

The study areas have low mineral resource potential for discovery of other metallic resources. Geochemical analysis of stream-sediment samples and concentrates has shown some anomalous concentrations of barium, strontium, silver, molybdenum, and zinc, and lesser anomalies of cobalt, nickel, and arsenic; however, the magnitudes of the anomalies are not large, and the geologic setting is not favorable for the occurrence of known types of ore deposits.

Humate (near-surface, leached and weathered coal, sometimes mined for use as a soil conditioner; Roybal and Barker, 1985) might occur within the outcrop or subcrop area of the Menefee Formation within the study areas. However, there is no definite indication of any specific areas with significant usable humate deposits, and in view of the generally thin and discontinuous nature of the known coal beds, the mineral resource potential of humate is low within the study areas.

The mineral resource potential for titaniferous black-sand deposits within the study areas is low; the geological, geochemical, and geophysical studies give no indication suggesting the existence of any such deposits within the study areas.

No geothermal sources are known within the study areas, and no warm springs or other geothermal sources were noted during this investigation. The energy resource potential for undiscovered geothermal energy in all three study areas is therefore low.

INTRODUCTION

In 1985 and 1987–1988 the U.S. Geological Survey (USGS) and the U.S. Bureau of Mines (USBM) studied 16,582 acres of the Chamisa Wilderness Study Area (NM–010–021), 9,007 acres of the Empedrado Wilderness Study Area (NM–010-063), and 10,438 acres of the La Lena Wilderness Study Area (NM–010–063A). The study of this acreage was requested by the U.S. Bureau of Land Management (BLM). In this report, the studied areas are called the "wilderness study areas" or simply "the study areas." This report presents an evaluation of the mineral endowment (identified resources and mineral resource potential) of the study areas and was the product of several separate studies by the USBM and the USGS. Identified resources were classified according to the system of the U.S. Bureau of Mines and the U.S. Geological Survey (1980), which is shown in the Appendix. Identified resources were studied by the USBM. Mineral or energy resource potential is the likelihood of occurrence of undiscovered metals and nonmetals, industrial rocks and minerals, and energy sources (coal, oil, gas, oil shale, and geothermal). It was classified according to the system of Goudarzi (1984) shown in the Appendix. The potential for undiscovered resources was studied by the USGS.

The study areas are within 12 mi north and west of the mostly deserted village of Guadalupe and about 50 mi northwest of Albuquerque in Sandoval County and a small part of McKinley County, New Mexico (fig. 1). They are on the southeastern edge of the San Juan Basin in the Colorado Plateaus physiographic province. Access is provided by unimproved roads west from New Mexico Highway 44. The Chamisa study area includes the forested, lava-capped surface of Mesa Chivato to the west, and escarpment cliffs and steep, rugged slopes descending eastward from Mesa Chivato to gentler slopes dissected by arroyos which drain into the Rio Puerco. Elevations in the Chamisa study area range from approximately 5,880 ft where Guadalupe Canyon enters the Rio Puerco at the eastern edge of the study area, to approximately 8,120 ft on Mesa Chivato at the western edge of the study area. The Empedrado study area consists of low mesas dissected into badlands topography by arroyos and washes. Elevations in the Empedrado study area range from approximately 5,920 ft in Arroyo Chico in the southeast corner of the study area, to approximately 6,560 ft in the northwest corner. The La Lena study area consists of badlands and low mesas, dissected by numerous arroyos and washes. Elevations in the La Lena study area range from approximately 6,000 ft in Torreon Wash at the southwest corner of the study area, to approximately 6,662 ft in the northeast part of the study area. The Rio Puerco, a major drainage of the region with intermittent flowing water, runs generally north to south, east of the three study areas. A major tributary to the Rio Puerco, the Arroyo Chico, flows through the center of the Empedrado study area, and a major tributary to it, Torreon Wash, runs along the border between the Empedrado and La Lena study areas. The Empedrado and La Lena study areas each contain several inholdings of sections or partial sections of private and state land. The village of Guadalupe is located adjacent to the eastern margin of the Chamisa study area. The Chamisa study area includes two buttes, Cerro Chamisa Losa and Cerro del Ojo de las Yeguas, which are basaltic intrusive plugs, and several other such volcanic necks are located adjacent to the study areas.

Acknowledgments.—We thank Pat Hester and Brian Lloyd of the U.S. Bureau of Land Management, and Virginia McLemore of the New Mexico Bureau of Mines, for supplying information from their files about the study areas. Sandra Soulliere and Jean Dillinger of the USGS also provided helpful information about the geology of the study areas. Western Energy Company, Butte, Montana, provided drill hole data and coal analyses from their evaluation of the Chico Wash tract north and west of the study areas. The New Mexico Bureau of Mines and Mineral Resources, Socorro, NM, supplied additional drill hole, analytical, and other pertinent data from their files. Sandra Soulliere drafted maps for the report.

Investigation by the U.S. Bureau of Mines

In August 1985 and June 1987, the Bureau of Mines conducted a mineral survey of the Chamisa, Empedrado, and La Lena Wilderness Study Areas. Published and unpublished literature relating to the study areas was reviewed to obtain information pertaining to mineral occurrences and mining activity. Twenty-eight man days were spent in the field examination that included a reconnaissance flight by helicopter. A total of 10 samples was taken in the study areas.

Field work included mapping and channel sampling coal beds at 8 sites. Proximate and ultimate analyses, and calorific value determinations were made for all coal samples by Hazen Research Inc., Golden, CO, and Core Laboratories Inc., Denver, CO. In addition, a determination of the random vitrinite reflectance was made on five coal samples by Neely Bostick, USGS, Branch of Coal Geology, Denver, CO. The coal resource classification system of the U.S. Geological Survey (fig. 2; Wood and others, 1983) was used and modified in the following way due to the thin lenticular multiple beds in the Menefee Formation in the study areas. Measured coal resources were calculated from outcrop data of individual beds (all beds 1.2 ft in thickness or greater) projected to extend ¼ mi from the

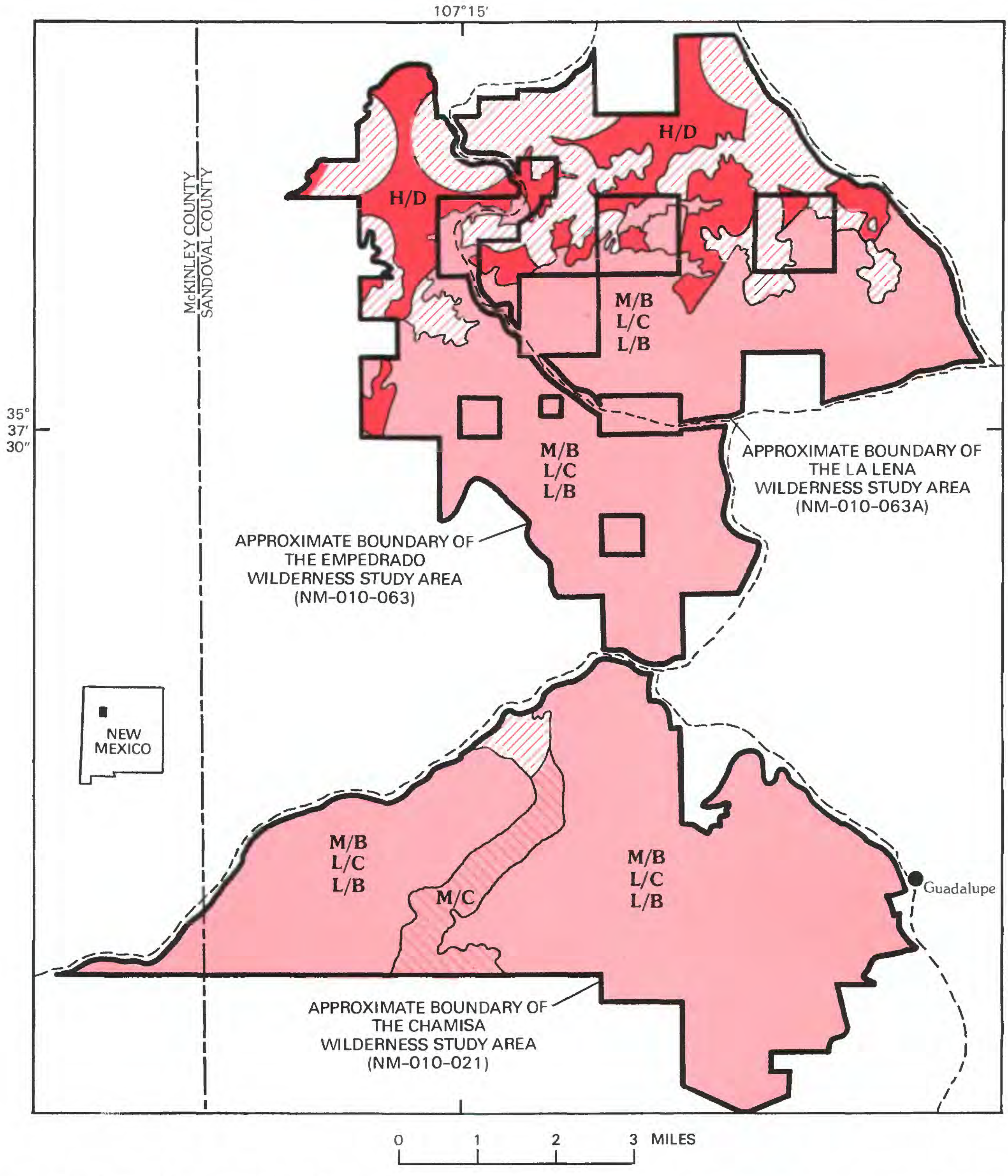


Figure 1 (above and facing page). Map showing location, identified resources, and mineral resource potential of the Chamisa, Empedrado, and La Lena Wilderness Study Areas. Dashed lines = roads.

outcrop; no indicated resources (¼ to ¾ mi) were projected from individual beds; because of their lenticular nature, they could not be assumed to be continuous over this distance. Calculation of coal resources from drill hole data was made using the total coal thickness (including all beds 1.2 ft in thickness or greater); measured resources were projected to extend in a ¼ mi radius from the drill site and indicated resources were projected to extend in a ¼ to ¾ mi radius from the drill site. An acre-foot of coal was assumed to weigh 1,800

EXPLANATION OF MINERAL RESOURCE POTENTIAL

- Area underlain by subeconomic coal resources; less than 500 ft overburden, includes measured and indicated resources
- **H/D** Geologic terrane having high energy resource potential for coal, with certainty level D
- **M/C** Geologic terrane having moderate energy resource potential for coal, with certainty level C—Applies to small area in Chamisa Wilderness Study Area
- **M/B** Geologic terrane having moderate energy resource potential for oil and gas, with certainty level B—Applies to entire acreage of all three study areas
- **L/C** Geologic terrane having low resource potential for coal (except as noted above), humate, all metals (except uranium), including barite, strontium, zinc, silver, molybdenum, and titanium, and geothermal energy—Applies to entire acreage of all three study areas except as noted
- **L/B** Geologic terrane having low resource potential for uranium, with certainty level B—Applies to entire acreage of all three study areas

short tons. Area determinations were made by planimeter on maps at a scale of 1:50,000. A report by Schreiner (1988, appendix A) contains location, depth to coal, thickness of beds, total coal thickness, year completed and reference for drill holes in and near the study areas.

Two chip samples from titaniferous sandstones were analyzed for 37 elements by instrumental neutron activation or X-ray fluorescence by Bondar-Clegg, Inc., Denver, CO.

Investigation by the U.S. Geological Survey

In 1987 and 1988, the USGS conducted an investigation to assess the potential for undiscovered mineral resources of the study areas. This investigation included a search for published and unpublished information about the area, a review and field checking of previous geological mapping, the collection of stream-sediment samples and panned concentrates for geochemical analysis and rock samples for petrographic examination, new geologic mapping of those parts of the study areas not covered by existing large-scale geologic maps, and a search for mineralized and altered areas.

APPRAISAL OF IDENTIFIED RESOURCES

By Russell A. Schreiner
U.S. Bureau of Mines

Previous Investigations

The New Mexico Bureau of Mines and Mineral Resources has evaluated the coal in and near the Chamisa, Empedrado, and La Lena Wilderness Study Areas; the results are given in reports by Tabet and Frost (1979a, b), Roybal (1984) and Campbell (1987).

Exploration, Development, and Mining History

Coal

The northern half of the Empedrado study area (3,900 acres), and the northern two-thirds of the La Lena study area (7,400 acres), are part of a tract of land

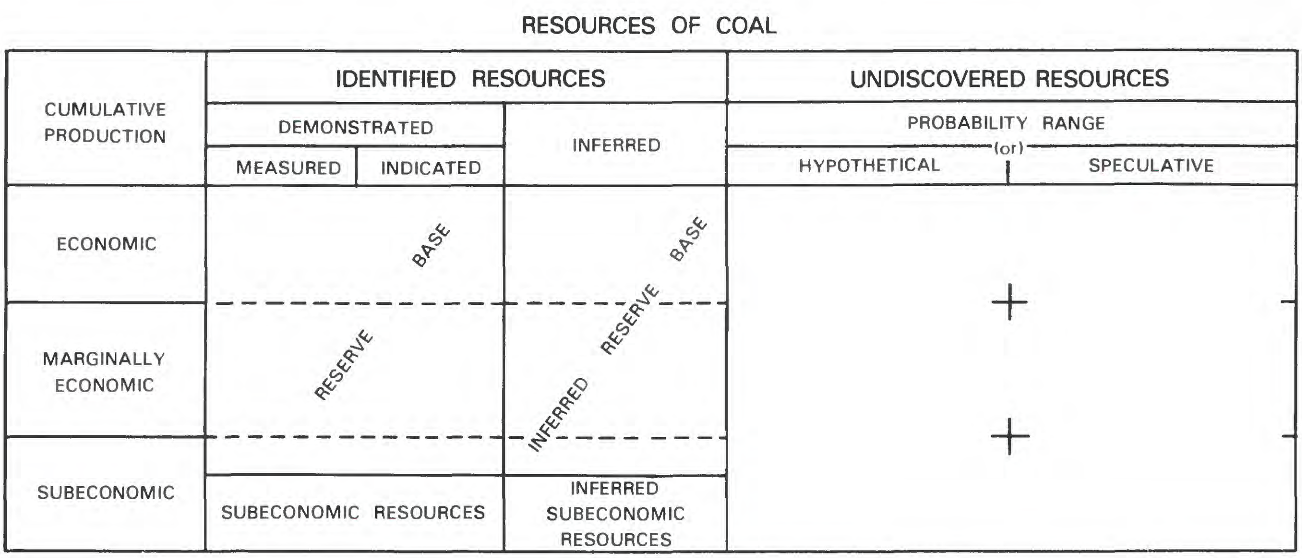


Figure 2. Format and classification of coal resources by reserve and inferred reserve bases and subeconomic and inferred subeconomic resources categories.

designated by the BLM as the La Ventana Known Recoverable Coal Resource Area (KRCRA) (BLM File Data, Albuquerque District Office, New Mexico). The La Ventana KRCRA is part of the Chacra Mesa and San Mateo coal fields as described by Roybal (1984, p. 223–226). Coal is exposed in the Cleary Member of the Menefee Formation in the KRCRA. Coal in the Cleary Member has been produced from three sites, and evaluated at another, near the study areas.

The Tachias property, within an inholding area of approximately 720 acres between the Empedrado and the La Lena study areas (N½ sec. 34, T. 17 N., R. 4 W.; pl. 1) produced 282.5 short tons of coal from 1933 to 1939 (U.S. Bureau of Land Management records, Farmington, New Mexico, and unpublished notes from Nickelson, H.B., 1979, History of Coal Mines in New Mexico, New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico). Coal was mined in two adits, which are now caved and inaccessible, from a 4-ft-thick bed.

The Arroyo #1 mine, 5 mi northeast of the La Lena study area (N½ sec. 16, T. 17 N., R. 3 W.), produced 57,214 short tons of coal from 1979 to 1982 (Roybal, 1984, p. 221). Coal was strip mined from two beds with a total thickness of 6 to 8 ft.

The Lee Ranch mine, 18 mi west of the Chamisa study area (secs. 21, 23, 25, 27, 29, 31, 32, 35, T. 16 N., R. 8 W., and sec. 19, T. 15 N., R. 7 W.), was producing approximately 2 million short tons of coal annually, as of August 1987. Coal is strip mined from multiple beds containing a minimum total thickness of 8 ft and averaging 16 ft. The average "as received" shipments of coal, to power plants for generation of steam, contain 16 percent moisture, 16 percent ash, 0.8 percent sulfur and 9,350 Btu/lb. (Robert Gray, Santa Fe Pacific Minerals, Albuquerque, N. Mex., oral commun., 1987.)

An exploration license was granted to Western Energy Company on the Chico Wash tract (T. 16 N., R. 5 W.) 3 mi west of the Empedrado study area. In 1983, the company drilled 29 holes to evaluate the coal and found the coal not economic due to the thin lenticular character of the beds and high ash content (Thomas Loberg, Western Energy Company, Butte, Mont., oral commun., 1986).

Uranium

As of 1987, no mining claims were on file with the BLM, but in the late 1970's and early 1980's approximately 85 claims in the Chamisa study area, 270 in the Empedrado study area, and 500 in the La Lena study area had been located for uranium (Roberts and others, 1982, p. 38–47).

Five holes are known to have been drilled in and near the study areas to test the Jurassic Morrison Formation. This formation hosts large uranium deposits in the Grants Uranium Region, a major domestic producing area, located approximately 20 mi to the south. Two sites within a mile of the Empedrado study area (secs. 31 and 33, T. 17 N., R. 4 W.) were drilled by United Nuclear/Teton Exploration, probably in the 1970's. Three sites in and along the boundary of the Chamisa study area were drilled for uranium by Pioneer Nuclear, Inc. in 1975 (sec. 34, T. 16 N., R. 4 W.) and by Homestake Mining Inc. in 1971 (sec. 36, T. 16 N., R. 4 W.) and in 1972 (sec. 6, T. 15 N., R. 3 W.). A geologic log from the 1972 Homestake hole shows the top of the Morrison Formation is over 1,650 ft deep (Steve Craigg, U.S. Geological Survey, Water Resources Division, Albuquerque, N. Mex., oral commun., 1978). Depths to the Morrison Formation are greater in the Empedrado and La Lena study areas. Apparently no significant uranium concentrations were penetrated in these drill holes and exploration activity was suspended in the early 1980's due to low uranium prices.

Oil and Gas

As of 1987, Federal oil and gas leases had been issued over most of the Chamisa, and La Lena study areas, and a few sections in the Empedrado study area (fig. 3). A total of 36 holes have been drilled for oil and gas in and within 2½ mi of the study areas since 1923. Two holes have been drilled in the Empedrado, two in the La Lena, and one in the Chamisa, study areas. All the holes have been dry. In the Miguel Creek oil fields on the north flank of the Miguel Creek Dome approximately 12 mi west of the Chamisa study area, hydrocarbons have been produced from the Hospah sand (informal unit) of the Cretaceous Gallup Sandstone. The North Miguel Creek Gallup oil field and the Miguel Creek Gallup oil field last produced in 1985 and have had a cumulative production of 8,995 and 46,919 barrels of oil, respectively (Ronald Broadhead, New Mexico Bureau of Mines and Mineral Resources, Socorro, N. Mex., written commun., 1988). Oil shows have been reported in the Cretaceous Menefee Formation from drill hole 41 near the western boundary of the Empedrado study area, and in the Cretaceous Dakota Sandstone from drill hole 64, 1 mile from the eastern boundary of the Chamisa study area (fig. 3 and pl. 1).

Ryder (1983, p. I–27) rated the hydrocarbon potential of the study areas as medium even though equivalent Jurassic and Upper Cretaceous rocks that occur in the study areas have produced hydrocarbons in nearby fields, have had oil shows in nearby drill holes, and have been shown to contain favorable reservoir rocks and stratigraphic traps.

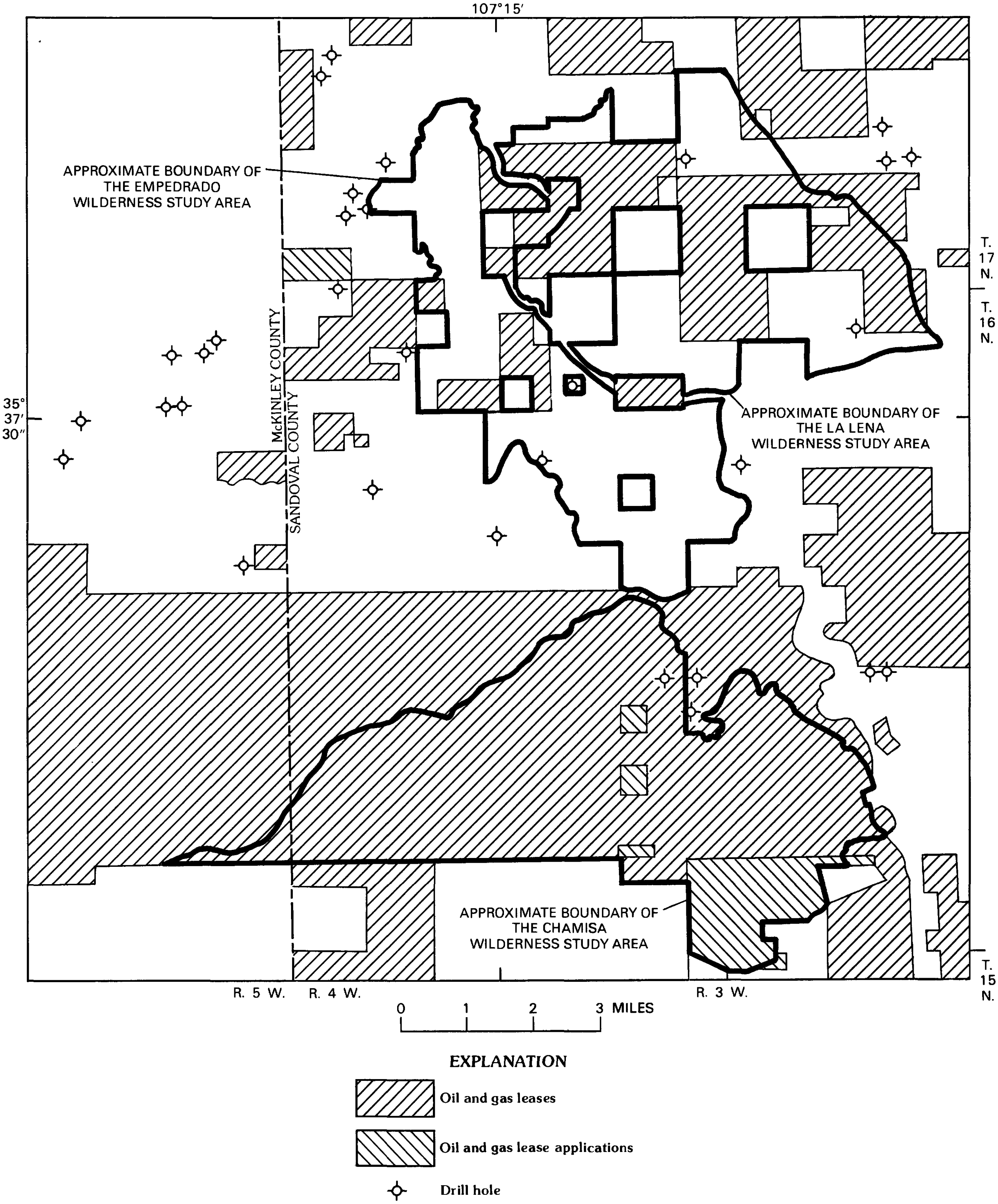


Figure 3. Map showing oil and gas leases and drill holes in and near the Chamisa, Empedrado, and La Lena Wilderness Study Areas.

Resource Appraisal

Coal

Coal occurs in the Cleary Member of the Menefee Formation in the study areas (fig. 4; Schreiner, 1988, pl. 1). The coal occurs as thin stringers and beds as thick as 8.0 ft including thin partings (no greater than 0.9 ft in thickness) of carbonaceous shale. Individual beds generally average 2.5 ft in thickness, are lenticular, and split and change in thickness over short distances. The beds can be grouped into coal zones (sections of thin lenticular multiple beds) that can be correlated for at least a few miles. Although coal zones appear to occur throughout the Cleary Member, the most laterally extensive zone, usually containing the thickest beds, is found at the base of the member, just above the Point Lookout Sandstone.

In the Chamisa Wilderness Study Area coal crops out along the steep escarpment of Mesa Chivato near Cerro Del Ojo De Las Yeguas (secs. 34 and 35, T. 16 N., R. 4 W.) in the northern part of the study area. Drill hole data indicate that additional coal beds are present under colluvial cover in the Chamisa study area and that the thickness of individual beds and the total coal thickness (minimum of 12 ft in thickness) at and near the base of the Cleary Member increases in this area.

Coal crops out in the northern part of the Empedrado study area (secs. 27 and 33, T. 17 N., R. 4 W. and secs. 3 and 4, T. 16 N., R. 4 W.) and in the northern two-thirds of the La Lena study area (secs. 4 and 5, T. 16 N., R. 3 W., secs. 21, 30, 31, 32, 33, T. 17 N., R. 3 W., and secs. 25, 26, 27, 34, 35, 36, T. 17 N., R. 4 W.). Good exposures of coal in the central part of the La Lena study area (secs. 34, 35, 36, T. 17 N., R. 4 W. and sec. 31, T. 17 N., R. 3 W.) and the adjacent part of the Empedrado study area (secs. 3 and 4, T. 16 N., R. 4 W.) contain relatively thick coal beds (one bed at least 4 ft in thickness) at the base of the Cleary Member.

Analytical Data

Eight channel samples from outcropping coal beds in the study areas averaged 12.57 percent moisture, 18.40 percent ash, 32.34 percent volatile matter, 36.69 percent fixed carbon, 0.40 percent sulfur, and 7,687 Btu/lb on an "as received" basis (table 1; from Schreiner, 1988). Apparent rather than a standard rank determination was made to classify the coal because outcrop samples are not permitted for use according to ASTM designation D–388–82 (American Society for Testing and Materials, 1982). Calculations of calorific values to determine the apparent rank of the samples were made on a moist (moisture questionable), mineral-matter-free (MMF) basis. Calculated calorific values range from 6,672 to 10,613 Btu/lb (British thermal units/pound) and average 9,689 Btu/lb. The apparent rank of the outcrop samples of coal in the study area is subbituminous.

In addition to the proximate and ultimate analysis and calorific determinations, a determination of the random vitrinite reflectance was made on four coal samples. Oxidation can directly affect calorific value and agglomeration characteristics used in the ASTM ranking of coals, but it usually does not affect the vitrinite reflectance which is comparable in accuracy to the above parameters for use in ranking coals. Samples 10, 11, 15, and 18 had random reflectance measurements of 0.56 percent, 0.54 percent, 0.52 percent, and 0.48 percent respectively. Random reflectance measurements of 0.50 percent are classified as bituminous; therefore, the coal ranks subbituminous A to high volatile C bituminous according to the oil reflectance limits of ASTM coal rank classes by McCartney and Teichmuller (1972).

Calculated calorific values (MMF) of non-oxidized samples from the Cleary Member from holes drilled in 1987 by the New Mexico Bureau of Mines along the northern boundary of the Empedrado and La Lena Wilderness Study Areas would place the coal in the high volatile C bituminous standard rank (Campbell, 1987, p. 67).

Considering all the above data, including the oxidation effects on the Bureau of Mines outcrop samples, the coal in the study areas would range in rank from subbituminous to bituminous, averaging high volatile C bituminous.

Resources

The USBM identified measured resources of 27.2 million short tons and indicated resources of 37.9 million short tons of coal at depths of 500 ft or less (Schreiner, 1988, pl. 2). Additional undetermined tonnages of coal resources exist outside of the areas of measured and indicated resources at depths of less than 500 ft and underneath Mesa Chivato at depths greater than 500 ft in the study areas. Coal resources could not be calculated in these areas due to insufficient data point spacing or an absence of data. Identified resources by study area are measured resources of 2.2 million short tons and indicated resources of 4.7 million short tons in the Chamisa Wilderness Study Area, measured resources of 3.9 million short tons and indicated resources of 9.8 million short tons in the Empedrado Wilderness Study Area, and measured resources (including inholdings) of 21.1 million short tons and indicated resources of 23.4 million short tons in the La Lena Wilderness Study Area. Calculated coal resources are further divided into thickness categories and inholdings are shown in table 2.

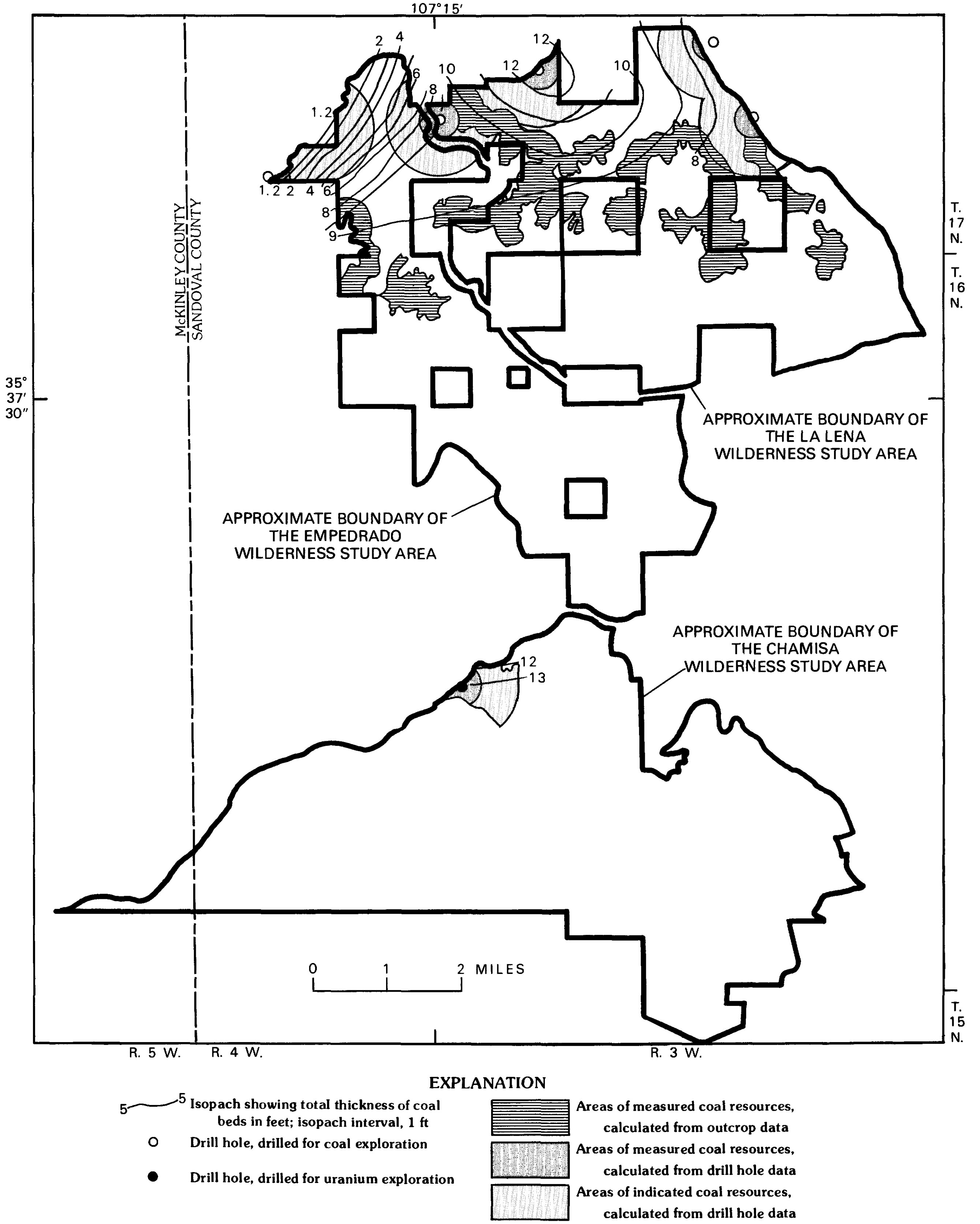


Figure 4. Coal resource map of the Chamisa, Empedrado, and La Lena Wilderness Study Areas, Sandoval and McKinley Counties, New Mexico.

Table 1. Proximate, ultimate, and calorific value analyses for coal samples taken from outcrops in the Chamisa, Empedrado, and La Lena Wilderness Study Areas, Sandoval and McKinley Counties, New Mexico

[Btu/lb, British thermal unit per pound; MMF Btu/lb, British thermal unit per pound on a mineral matter free basis; MAF Btu/lb, British thermal unit per pound on a moisture-ash free basis; nc, not calculated. All samples reported nonagglomerating. Sample locations are given in Schreiner (1988)]

Sample				Proximate analyses (%)				Ultimate analyses (%)					Heat value		
No.	Type	Length (ft)	Reporting basis	Moisture	Ash	Volatile matter	Fixed carbon	Carbon	Hydrogen	Nitrogen	Sulfur	Oxygen	Btu/lb	MMF Btu/lb	MAF Btu/lb
1	Channel	3.5	As received	8.43	30.67	29.71	31.19	42.39	2.98	0.82	0.46	14.25	6,942	10,484	nc
			Dry	.00	33.49	32.45	34.06	46.29	3.25	.90	.50	15.57	7,581	nc	11,398
2	do.	4.3	As received	9.30	21.12	33.86	35.72	47.27	3.10	.96	.34	17.91	7,443	9,700	nc
			Dry	.00	23.29	37.33	39.88	52.12	3.42	1.06	.37	19.74	8,206	nc	10,697
3	do.	1.7	As received	9.65	11.44	35.68	43.23	56.50	3.54	1.09	.39	17.39	9,273	10,613	nc
			Dry	.00	12.66	39.49	47.85	62.53	3.92	1.21	.43	19.25	10,263	nc	11,751
4	do.	4.1	As received	9.34	16.52	33.92	40.22	52.32	3.34	1.08	.38	17.02	8,402	10,273	nc
			Dry	.00	18.22	37.41	44.37	57.71	3.69	1.19	.42	18.77	9,367	nc	11,332
5	do.	3.5	As received	10.82	7.92	34.97	46.29	57.41	3.51	1.10	.47	18.77	9,300	10,193	nc
			Dry	.00	8.88	39.21	51.91	64.38	3.94	1.23	.53	21.04	10,429	nc	11,445
6	do.	1.5	As received	7.25	25.69	33.44	33.62	46.27	3.27	.95	.41	16.16	7,553	10,534	nc
			Dry	.00	27.70	36.05	36.25	49.89	3.53	1.03	.44	17.41	8,143	nc	11,263
7	do.	3	As received	14.39	24.45	28.42	32.74	41.67	2.73	.84	.47	15.45	6,604	9,039	nc
			Dry	.00	28.56	33.20	38.24	48.68	3.19	.98	.55	18.04	7,714	nc	10,798
8	do.	1.9	As received	31.37	9.40	28.71	30.52	39.41	2.27	.90	.25	16.40	5,980	6,672	nc
			Dry	.00	13.70	41.83	44.47	57.43	3.31	1.31	.37	23.88	8,714	nc	10,098

Tabet and Frost (1979a), using different criteria, calculated an indicated resource of 2.7 million short tons in the Empedrado study area, and 12.5 million short tons in the La Lena study area at depths of 250 ft or less.

Mineral Economics

Coal in the study areas averages less than 5 ft thick and is too thin to be mined by underground methods. In the San Juan Basin, criteria for economically surface minable coal (strippable reserve base coal) as of 1987 are defined as those coal beds (including one bed at least 2.3 ft thick) that must be covered by at least 20 ft of overburden, and the maximum amount of overburden cannot exceed a 15 to 1 stripping ratio (15 ft of overburden plus interburden for every foot of coal). These criteria are being used by the BLM to evaluate tracts of land for lease sale and are based on coal industry mining methods and practices in the San Juan Basin (Ralph Wilcox, BLM District Office, Albuquerque, N. Mex., oral commun., 1987). Most of the coal in the study areas is covered by overburden exceeding the 15 to 1 stripping ratio.

In the Chamisa study area, some of the outcropping coal beds would fall inside the 15 to 1 stripping ratio in a narrow belt up to approximately 200 ft wide around the edge of Mesa Chivato. This coal could be mined for limited local use, as in domestic heating.

In the central part of the La Lena study area (secs. 34, 35, and 36, T. 17 N., R. 4 W., and sec. 31, T. 17 N., R. 3 W.) and in the adjacent part of the Empedrado study area (secs. 3 and 4, T. 16 N., R. 4 W.) relatively thick beds of coal are exposed in a zone at the base of the Cleary Member (pl. 1). These sections contain at least one coal bed averaging 4 ft in thickness, with a total coal thickness up to 8.5 ft, and overburden generally around the 15 to 1 stripping ratio. This area appears to have the greatest potential for development of coal resources. Additional drilling would be required to determine the exact thickness and lateral continuity of the beds, and overburden thickness. Outcrop data can only be used as a general guide, since coal thickness appears to be less at outcrop than in drill hole data due to pinching of the beds by the overburden, and correlation of the beds is difficult when the Menefee-Point Lookout contact is not exposed.

This area could be developed if sufficient tonnages of coal are present within the 15 to 1 stripping ratio. Approximately 25 million tons are required to start up a mining operation that would produce over 1 million tons a year for a projected 20 year mine life, and would meet power plant requirements (Powell King, U.S. Bureau of Land Management, Santa Fe, N. Mex., oral commun., 1988).

Titaniferous Sandstone

A small paleo-beach-placer titaniferous sandstone deposit, the B.P. Hovey Ranch deposit, is in an inholding

Table 2. Calculated bituminous coal resources in short tons, by reliability and thickness of coal, with less than 500 ft of overburden in the Chamisa, Empedrado, and La Lena (including inholdings) Wilderness Study Areas, Sandoval and McKinley Counties, New Mexico

Geological assurance category	Coal thickness category (feet) 1.2 to 2.3	2.3 to 3.5	3.5 to 7.0	7.0 to 14.0
Chamisa Wilderness Study Area				
Measured	0	0	0	2,212,000
Indicated	0	0	0	4,693,000
Empedrado Wilderness Study Area				
Measured	819,000	133,000	2,540,000	377,000
Indicated	349,000	720,000	2,933,000	5,800,000
La Lena Wilderness Study Area				
Measured	1,808,000	2,969,000	6,221,000	5,582,000
Indicated	0	0	0	23,411,000
Inholding SW1/4 sec. 26, T. 17 N., R. 4 W.				
Measured	0	0	333,000	0
Inholding sec. 36, T. 17 N., R. 4 W.				
Measured	0	142,000	1,837,000	0
Inholding sec. 32, T. 17 N., R. 3 W.				
Measured	357,000	992,000	0	0
Inholding sec. 34, T. 17 N., R. 4 W.				
Measured	351,000	45,000	423,000	0

between the Empedrado and La Lena study areas in the west half of sec. 34, T. 17 N., R. 4 W. (pl. 1). The deposit consists of a lens of brown fine-grained sandstone, 4.5 ft in thickness at the middle and 500 ft in length, at the top of the Point Lookout Sandstone. Petrographic examination identified quartz, feldspar, anatase, and zircon cemented by hematite. Chemical analysis of sample 13 (Schreiner, 1988, table 3) taken from the center of the lense contained 5.48 percent titanium, 5.5 percent iron, and 0.58 percent zirconium. In addition, relatively high concentrations of cerium (520 ppm (parts per million)), lanthanum (300 ppm), hafnium (150 ppm), niobium (120 ppm), thorium (102 ppm), yttrium (100 ppm), and uranium (26 ppm) were present. McLemore and others (1984, p. 137) reported concentrations of 0.79 percent zircon, 0.013 percent uranium oxide (U_3O_8), 277 ppm niobium, 244 ppm yttrium, and 223 ppm thorium in a sample from the deposit.

In addition to the B.P. Hovey Ranch deposit, irregular lenses of black fine-grained sandstone, 0.5 ft in thickness, occur in the Cleary Member of the Menefee Formation in an inholding in the La Lena study area in sec. 36, T. 17 N., R. 4 W. Petrographic examination identified quartz and feldspar with minor anatase and zircon, within a hematite matrix. Chemical analysis of sample 16 taken from one of the lenses contained 31 percent iron and only 0.13 percent titanium, 2.0 ppm uranium, less than 500 ppm zirconium, and less than 10 ppm cerium (Schreiner, 1988, table 3).

Mining of heavy-mineral concentrations for titanium, zirconium, and iron with rare-earth and related metals as byproducts, has occurred in unconsolidated beach-placer deposits where crushing, grinding, and removal of overburden is minimal. In 1987, two companies produced metals from beach sands in Florida (U.S. Bureau of Mines, Mineral Commodity Summaries, 1988). The beneficiation required, the small size (10,000 short tons) and low concentrations of metals in the B.P. Hovey Ranch deposit precludes economic mining.

Common Industrial Minerals

Sand and gravel and sandstone are present in the study area, but because of the abundance of these materials in the region, the distance from markets, and their lack of unique properties, they have no current potential for development.

Conclusions

Coal resources averaging high volatile C bituminous in rank, at depths of 500 ft or less, occur in the Cleary Member of the Menefee Formation in the study areas. The USBM identified measured resources of 27.2 million short tons and indicated resources of 37.9 million short tons. Additional undetermined tonnages of coal resources exist outside of the areas of measured and indicated resources at depths of less than 500 ft and underneath Mesa Chivato at depths greater than 500 ft in the study areas. Identified resources by study area are measured resources of 2.2 million short tons and indicated resources of 4.7 million short tons in the Chamisa study area, measured resources of 3.9 million short tons and indicated resources of 9.8 million short tons in the Empedrado study area, and measured resources (including inholdings) of 21.1 million short tons and indicated resources of 23.4 million short tons in the La Lena study area. Most of the coal in the study areas is subeconomic (due to the large amounts of overburden), except for the narrow belt around Mesa Chivato in the Chamisa study area, and the central part of the La Lena study area and the adjacent part of the Empedrado study area. The La Lena and Empedrado areas have the greatest potential for the development of coal resources, possibly containing sufficient tonnages within the 15 to 1 stripping ratio, to make a mining operation feasible. Additional drilling is required to determine the exact thickness and lateral continuity of coal, and overburden thickness in this area.

Inferred subeconomic resources of titanium, zirconium, and iron with rare-earth and related metals occur in a titaniferous sandstone deposit in an inholding between the La Lena and Empedrado study areas. The cost of beneficiation required for these type deposits, their small size, and the low concentrations of metals precludes economic mining.

Sand and gravel and sandstone have no current potential for development.

ASSESSMENT OF POTENTIAL FOR UNDISCOVERED RESOURCES

By Peter J. Modreski, Gary A. Nowlan, and William F. Hanna
U.S. Geological Survey

Geology

The following description of geologic setting and rock units of the Chamisa, Empedrado, and La Lena Wilderness Study Areas is modified from Tabet and Frost (1979a, b), and Soulliere and others (1988), plus field observations by the authors. Some information is also drawn from Chapman, Wood, and Griswold, Inc. (1979), Dane and Bachman (1957), Fassett (1974), Holzle (1960), Hunt (1936), Molenaar (1977), Roberts and others (1982), Soulliere and others (1987), U.S. Geological Survey (1979a, b, c), and Wyant and Olson (1978). Upper Cretaceous marine and continental sedimentary rocks exposed in the study areas are, in ascending order, the Gallup Sandstone (Kg), the Mulatto Tongue of the Mancos Shale (Kmm), the Crevasse Canyon Formation (Kcc), the Hosta Tongue of the Point Lookout Sandstone (Kph), the Satan Tongue of the Mancos Shale (Kms), the Point Lookout Sandstone (Kpl), and the Cleary Coal (Kmfc) and Allison (Kmfa) Members of the Menefee Formation. These strata have a northeasterly strike and dip about 1–5 degrees to the northwest. They have been intruded locally or are overlain by Tertiary basaltic rocks (Ti, Tb) related to the Mount Taylor volcanic field to the southwest (pl. 1). The rocks are cut by northeast-trending normal faults that generally have only a few tens of feet of displacement; maximum displacement is about 150 ft. Basaltic dikes in the area reflect the same northeast-trending fracture pattern. Quaternary alluvium (Qal) of poorly sorted sand, silt, and gravel fills major drainages, and basaltic talus (Qt) mantles and obscures contacts on the slopes of Mesa Chivato and the intrusive plugs.

Jurassic and Cretaceous sedimentary rocks are present beneath the study areas and are important to this assessment because of their potential as host rocks for uranium and oil and gas. The Upper Jurassic Morrison Formation underlies the study areas at depths estimated to range from approximately 1,500 to 3,000 ft and is a favorable host for uranium elsewhere. Upper Cretaceous nearshore marine sandstones, in particular the Dakota and Gallup Sandstones, and the Jurassic Entrada Sandstone are favorable reservoir rocks for oil and gas.

Description of Rock Units

During Cretaceous time, transgressive and regressive sequences of sediments were deposited in intertonguing offshore-marine, nearshore-marine, and continental environments. This has produced an intertonguing sequence of the presently exposed sedimentary rocks, including the Gallup Sandstone, Mancos Shale, Crevasse Canyon Formation, Point Lookout Sandstone, and Menefee Formation. The Gallup Sandstone is a light-gray to yellowish-tan, very fine to medium-grained, crossbedded sandstone, 20 to 60 ft thick in and adjacent to the study areas. It is exposed only at the extreme southeastern end of the Chamisa study area, near the town of Guadalupe. This is near the northeastern-most known extent of the Gallup Sandstone in the San Juan Basin (Molenaar, 1974), and it represents the northeastern limit of the marine regression that deposited the Gallup Sandstone.

The Mulatto Tongue of the Mancos Shale consists of light- to dark-gray, silty, laminated marine shale. Near the south end of the Chamisa study area it intertongues into nearshore-marine and continental shale and sandstone of the Crevasse Canyon Formation. The Crevasse Canyon Formation, composed of intertonguing shale and sandstone, is exposed only near the southern border of the Chamisa study area; this is close to the extreme northeastward exposure of this unit in the San Juan Basin, and this represents the maximum extent of the marine regression that deposited the Crevasse Canyon Formation. The thickness of the Crevasse Canyon Formation exposed in and immediately to the south of the Chamisa study area is approximately 100 to 200 ft. Mapping of the intertonguing upper, lower, and lateral contacts of this unit (pl. 1) is approximate. Farther south and west in the San Juan Basin, the Crevasse Canyon Formation is thicker, and includes the Dilco Coal Member, the Dalton Sandstone Member, and the Gibson Coal Member. The beds of the Crevasse Canyon Formation exposed in and near the Chamisa study area probably correlate with the Dalton Sandstone Member; no coal beds are seen in the exposed section.

The Hosta Tongue of the Point Lookout Sandstone is a tan to brown, fine-grained, even-bedded to crossbedded, cliff-forming sandstone, 20 to 100 ft thick. It is not exposed farther north than the southern half of the Empedrado study area. The Satan Tongue of the Mancos Shale is similar in lithology to the underlying Mulatto Tongue; it is conformable with the overlying, regressive marine, main body of the Point Lookout Sandstone. The Satan Tongue and the Point Lookout Sandstone have a transitional contact, characterized by a series of sandstone and shale interbeds. The sandstone beds thicken upward into a massive, tan to light-gray to white, fine-grained, cliff-forming sandstone.

The Menefee Formation is conformable with the Point Lookout Sandstone and consists of interbedded shale, siltstone, sandstone, and coal. Two members of the Menefee Formation are exposed in the study areas: the basal coal-bearing Cleary Coal Member and the sandy Allison Member. These units underlie the western half of the Chamisa Wilderness Study Area, and the northern portions of the Empedrado and La Lena Wilderness Study Areas. The contact between the two members is gradational and not easily distinguished, and often poorly exposed; on the geologic map (pl. 1) it is shown as an inferred contact in the southern half of the Chamisa study area. Tabet and Frost (1979a) placed the contact at the base of a thick, cliff-forming channel sandstone sequence that overlies the uppermost major coal horizon of the Cleary. The Cleary Coal Member is a fine-grained paludal (marsh) deposit consisting of gray to dark-brown carbonaceous shale that contains abundant organic debris, lenticular sandstone, and coal beds. It is about 200–300 ft thick. The Allison Member consists of fine- to medium-grained, crossbedded sandstone and tan to light-gray shale and is about 400–550 ft thick. Rocks of the Allison Member have very little organic debris, but thin coal beds and some brown humic shales occur locally, generally comprising less than 5 percent of the Allison.

Tertiary basalt flows, about 100 ft thick, cap Mesa Chivato in the western part of the Chamisa study area. Some basaltic dikes cut through the sedimentary rocks below the basalt in and near the Chamisa study area. Two plugs of basaltic intrusive rock occur near the eastern edge of Mesa Chivato in the Chamisa study area, and a number of other plugs occur adjacent to the study areas to the east, south, and west. Most of the plugs contain ultramafic xenoliths of peridotite and pyroxenite, and pyroxene megacrysts. Sedimentary rocks surrounding the intrusive plugs show little or no alteration.

Geochemistry

Sampling Methods

A reconnaissance geochemical survey of the Chamisa, Empedrado, and La Lena Wilderness Study Areas was conducted during July and August, 1987. Samples of drainage sediment were collected at 63 sites on streams draining the wilderness study areas and vicinity; sample locations are given in Bullock and others (1989). Stream-sediment samples represent a composite

Table 3. Statistics for selected elements in drainage samples collected in and near the Chamisa, Empedrado, and La Lena Wilderness Study Areas, Sandoval County, New Mexico

[Results based on 63 samples. Concentrations determined by emission spectrography except As-i and Zn-i determined by inductively coupled plasma spectroscopy. N, not detected at lower limit of determination; L, detected but below lower limit of determination; G10,000, greater than upper limit of determination of 10,000 ppm Ba (see Bullock and others, 1989)]

Elements	Lower limit of determination, ppm	Range, ppm		Percentiles, ppm		Threshold concentration, ppm	Number of samples with anomalous concentrations
		Minimum	Maximum	50th	90th		
Stream-sediment samples							
As-i	5	L	13	L	8	10	2
Ba	20	200	5,000	500	1,000	1,500	1
Co	10	N	50	N	10	15	1
Zn-i	2	20	69	37	52	57	2
Concentrate samples							
Ag	1	N	1	N	L	L	8
Ba	50	700	G10,000	G10,000	G10,000	10,000	36
Mo	10	N	30	N	13	L	9
Ni	10	L	500	70	150	300	2
Sr	200	N	10,000	L	4,000	700	12
Zn	500	N	500	N	L	L	7

of material eroded from the drainage basin of the stream sampled. Panned-concentrate samples derived from stream sediment contain selectively concentrated minerals that may include ore-related elements that are not easily detected in stream-sediment samples.

Two samples were collected at each site. One of the samples was air dried and then sieved through an 80-mesh (0.18-mm) stainless-steel sieve to obtain a "stream-sediment sample." The portion that passed through the screen was later pulverized to minus-100 mesh (0.15 mm) prior to analysis. For the second sample from each site, about 20 lb of sediment were collected and later panned to remove most of the quartz, feldspar, clay-sized material, and organic matter. Treatment with bromoform (specific gravity 2.8) removed the remaining quartz and feldspar. Finally, a magnetic separation removed the magnetite and any other strongly magnetic minerals to produce a "concentrate sample." A magnetic separation to remove paramagnetic minerals, such as ferromagnesian silicates and iron oxides, was omitted because of the paucity of heavy minerals. Therefore, the concentrate sample includes most nonmagnetic ore minerals, ferromagnesian silicates, iron and manganese oxides, and accessory minerals, such as sphene, zircon, apatite, and rutile. Prior to analysis the concentrate samples were pulverized to minus-100 mesh.

Analytical Methods

The stream-sediment and concentrate samples were analyzed by emission spectrography for 35 elements. In addition, the concentrate samples were analyzed by emission spectrography for platinum and palladium. Also, the stream-sediment samples were analyzed for uranium by ultraviolet fluorimetry and for antimony, arsenic, bismuth, cadmium, and zinc by inductively coupled plasma spectroscopy (ICP). Analytical data, sampling sites, and references to analytical methods are presented by Bullock and others (1989).

Results of Study

Table 3 lists selected elements determined to have anomalous concentrations in each sample type, the lower and upper limits of determination, the range of concentrations, the 50th and 90th percentile concentrations, the threshold (highest background) concentrations, and the number of samples with anomalous concentrations of the selected elements. Threshold concentrations were established by visual and statistical examination of the data and by reference to median bedrock concentrations listed by Rose and others (1979, p. 549–581).

Only one or two samples contain anomalous concentrations of zinc (as determined by the more sensitive ICP method) or of arsenic, cobalt, or nickel. Arsenic is mildly anomalous in two stream-sediment samples (table 3) from the central part of the sampled area. These arsenic concentrations of 12 and 13 parts per million (ppm) might represent the upper end of the normal range of concentrations for arsenic in shale. According to Rose and others (1979, p. 550), the median concentration for arsenic in shale is 12 ppm. However, the zinc concentrations of the same two samples are also mildly anomalous (64 and 69 ppm), and the concentrate sample from one of the sites has just detectable silver.

The cobalt concentration of the stream-sediment sample from one site at the north end of the Empedrado Wilderness Study Area is 50 ppm and definitely anomalous. Barium in the concentrate sample from the same site is anomalously high but appears to be part of a pattern of anomalous barium values in concentrate samples. The nickel concentration in concentrate samples from each of two sites in the south part of the Chamisa Wilderness Study Area is 500 ppm, a mildly anomalous concentration because ferromagnesian minerals, which commonly contain elevated amounts of nickel, were not separated from the concentrate samples.

These instances of isolated and generally mild anomalies of arsenic, zinc, cobalt, and nickel are difficult to evaluate but are probably not significant, based on the nature of bedrock in the sampled area and the lack of known mineralization in the vicinity of the study areas.

Patterns of anomalous concentrations are given by silver, barium, molybdenum, strontium, and zinc in concentrate samples. In the case of silver, molybdenum, and zinc, the associations of anomalous concentrations may be more significant than the magnitudes of individual concentrations, which are low.

The patterns of anomalous silver and zinc concentrations occur in and near the southeast parts of the Empedrado and La Lena Wilderness Study Areas. The patterns of anomalous silver (maximum 1 ppm) and zinc (maximum 500 ppm) overlap and are spatially associated with areas underlain by the Satan Tongue of the Mancos Shale. The pattern of anomalous molybdenum concentrations (maximum 30 ppm) is in the southeast part of the Chamisa Wilderness Study Area and is spatially associated with the Mulatto Tongue of the Mancos Shale. The sources of anomalous concentrations of silver, molybdenum, and zinc are probably slightly elevated concentrations of these elements in these rock units. The concentrate samples contain manganese-iron oxides, which commonly scavenge silver (Chao and Anderson, 1974), molybdenum, and zinc (Nowlan, 1976), when the elements are available. Shale (Rose and others, 1979, p. 562, 573, 580) and coal (Rankama and Sahama, 1950, p. 628, 706, 714) are both enriched in silver, molybdenum, and zinc compared to other common rock types. The anomalous samples lie downstream or downslope of exposed coal beds in the Menefee Formation, so it is possible that erosion of the coal-bearing strata is the source of the anomalous metals. An alternative explanation is that leakage from some unknown source at depth has taken place along faults within the sampled area. However, no relation between faults and anomalous geochemical patterns is evident.

Barium concentrations are highly anomalous in all three wilderness study areas. Thirty-six out of the total of 63 concentrate samples contain greater than 10,000 ppm barium and are classed as anomalous. Five additional concentrate samples contain 10,000 ppm barium. One stream-sediment sample contains an anomalously high 5,000 ppm barium. Flat barite particles as large as 0.2 inch in diameter were observed when the samples were panned. Twelve of the concentrate samples containing anomalous barium concentrations also contain anomalous concentrations of strontium, indicating the presence of the barite-celestite solid-solution series. Small (about 0.2 inch) barite crystals were also observed by P.J. Modreski in amygdules in a basaltic dike in sec. 22, T. 15 N., R. 4 W., about 1.3 mi outside the southern border of the Chamisa study area (pl. 1).

Anomalous concentrations of barium and strontium could represent bedded barite deposits. However, small concentrations of barite are a common feature of rocks in the region of New Mexico containing the study areas (Sandra Soulliere, pers. commun., 1989); the barite may exist as veinlets, concretions, and precipitated crystals in the sedimentary rocks. Because of its high specific gravity (4.5) and chemical stability in the weathering environment, barite can be selectively enriched during fluvial processes and in panning. The barite detected in these geochemical studies is unlikely to be present in quantities that can be exploited.

Chemical analysis of nine samples of basalt lava and basaltic intrusive plugs (Soulliere and others, 1988) from the Ignacio Chavez Wilderness Study Area, which adjoins the present study areas on the west and contains the same igneous rock types, showed no anomalous concentrations of any element.

Geophysics

The Chamisa, Empedrado, and La Lena Wilderness Study Areas are covered by regional gravity and more detailed aeromagnetic surveys, the latter having sufficient resolution to define anomalies of 1 or more square miles in areal extent. These data provide information on surface and subsurface distribution of rock masses and structural features.

Gravity Data

Gravity data are in the form of a terrain-corrected Bouguer gravity anomaly map (Defense Mapping Agency, 1974, 1975), slightly modified from compilations of Keller and Cordell (1984) and Cordell, Keller, and Hildenbrand (1982), and are based largely on 30 observations within or adjacent to the study area (8 within the map area of pl. 1). The gravity data (fig. 5) show a smooth gradient, with values increasing southeastward across the study area. The highest values over the southeastern part of the area fringe a broad high which borders the Rio Grande depression east of the study area. This broad high associated with the rifted depression is inferred by Cordell, Keller, and Hildenbrand (1982) to be caused by high-density mantle-derived material intermediate in depth between low-density sediments which fill the grabens of the depression and low-density zones of partially melted upper mantle which deeply underlie the depression. The separation of contour lines immediately southwest of 35° 37.5' N. lat., 107°, 7.5' W. long. manifests a small-amplitude gravity high which may be associated with mafic intrusive rocks also having a magnetic expression. The absence of a gravity feature over the basalt field in the southwest part of the study area suggests that the flows are too thin or too vesicular, or both, to generate a broad high in this sparsely surveyed region.

Aeromagnetic Data

Aeromagnetic data are in the form of an anomaly map (U.S. Geological Survey, 1980) contoured from measurements made along 12 flight lines in a north-south direction spaced 1 mile apart at an average altitude of 1,000 ft above ground.

The aeromagnetic anomaly data (fig. 6) generally show a strong correlation with mapped geology and a weak correlation with topography. The southwestern part of the area is dominated by a group of short-wavelength, large-amplitude highs and lows characteristic of basaltic flows with which they correlate. The average anomaly field associated with this group of anomalies is notably negative, suggesting that some, if not many, of the basaltic flows possess reversely directed total magnetization. Immediately to the east and north of this group of anomalies, several isolated short-wavelength highs and lows correlate with mapped exposures of mafic intrusive plugs. One especially salient cluster of these isolated anomalies occurs within the "–200 gamma" contour line just southwest of 35°, 37.5′ N. lat., 107°, 7.5′ W. long. This cluster of highs generally correlates with a previously mentioned small-amplitude gravity high, suggesting that both the magnetic and gravity features are generated by a shallow distribution of mafic intrusive rocks.

Less conspicuous than the short-wavelength anomalies, a broad small-amplitude high is largely confined to within a "–200 gamma" contour in the west-central part of the area. The source of this long-wavelength high is unknown. The lack of a gravity feature over this broad magnetic high, however, suggests that its source is a deeply buried igneous intrusive body of intermediate composition having an average density similar to the sedimentary rocks which it intrudes. If the magnetic feature is caused by an intrusive body, heat associated with such a body may have activated any hydrocarbons originally hosted by the intruded sedimentary rocks.

Radiometric Data

From 1975 to 1983, the U.S. Department of Energy contracted for aerial gamma-ray surveys that covered almost all of the United States. Aerial gamma-ray spectroscopy is a technique that allows estimates of the near-surface (0-50 cm depth) concentrations of potassium (K, in percent), equivalent uranium (eU, in ppm), and equivalent thorium (eTh, in ppm). These data (K, eU, eTh) provide a partial geochemical representation of the near-surface materials (J.S. Duval, written commun., 1986).

Data from the aerial gamma-ray survey (J.S. Duval, written commun., 1986) indicate that the Empedrado Wilderness Study Area has overall moderate radioactivity with concentrations of 1.7–2.1 percent K, 2.3–3.5 ppm eU, and 9.5–11 ppm eTh. The La Lena Wilderness Study Area has overall moderate radioactivity with concentrations of 1.7–2.1 percent K, 2.3–3.5 ppm eU, and 9.5–11 ppm eTh. The Chamisa Wilderness Study Area (Duval, 1988) has overall moderate radioactivity with concentrations of 1.6–1.8 percent K, 2.3–3.5 ppm eU, and 8–10 ppm eTh. There are no major anomalies in or near any of the study areas, although there is a weak, broad maximum in the eU pattern (maximum 3.5 ppm eU) centered on the east edge of the Chamisa study area.

Mineral and Energy Resources

The mineral resource potential for the three study areas was assessed by comparing the geological, geochemical, and geophysical characteristics of each study area with those of nearby mineralized areas and with resource deposit models.

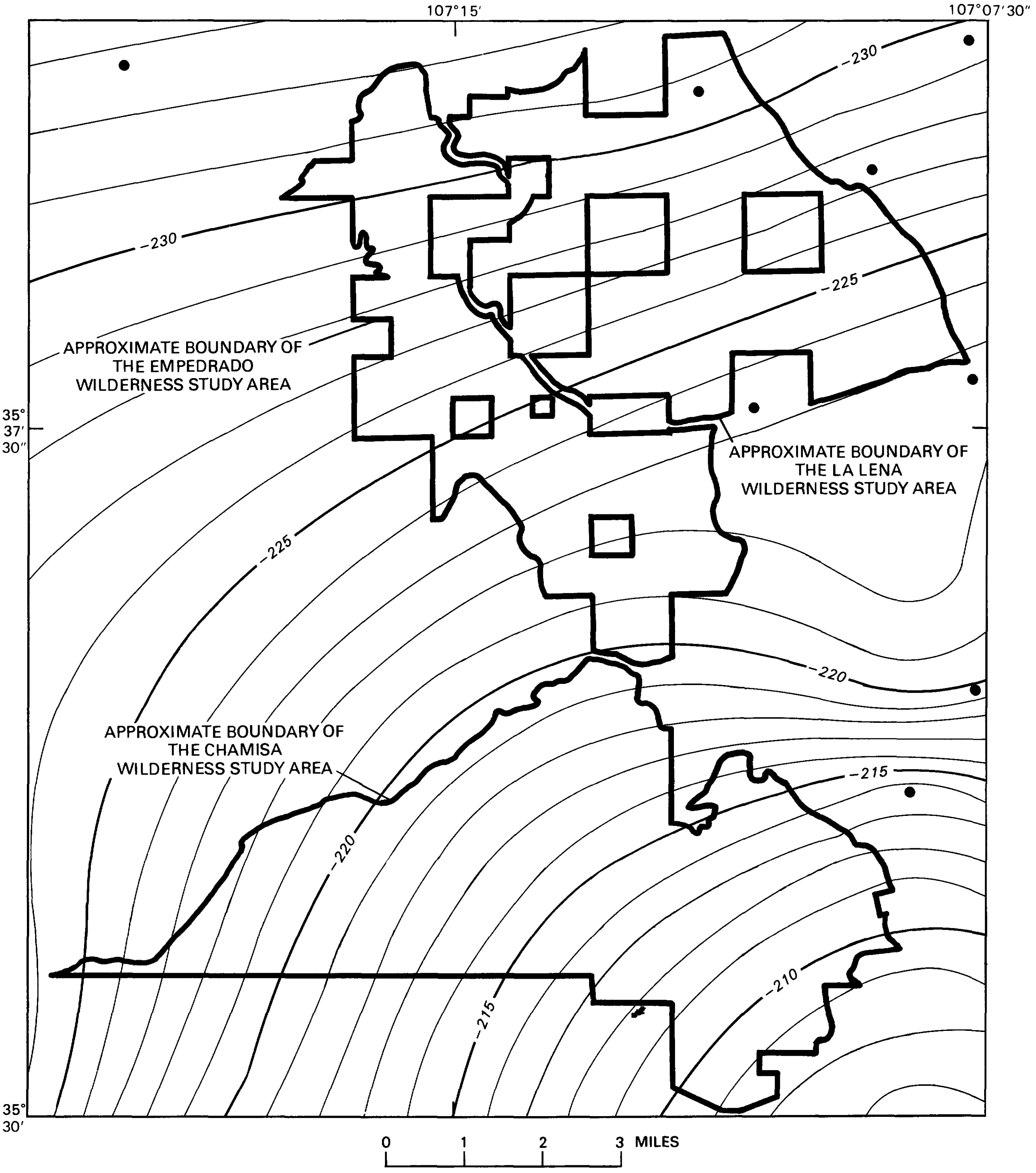


Figure 5. Map showing Bouguer gravity of the Chamisa, Empedrado, and La Lena Wilderness Study Areas. Contour interval 1 milligal. Dots = gravity stations.

Coal

In addition to the measured and indicated resources of coal described as identified resources in this report (fig. 4), the energy resource potential of the Empedrado and La Lena study areas is high, with a certainty level of D (see Appendix), for additional coal resources in the parts of the study areas between and adjacent to the identified coal resources (fig. 1, and pl. 1).

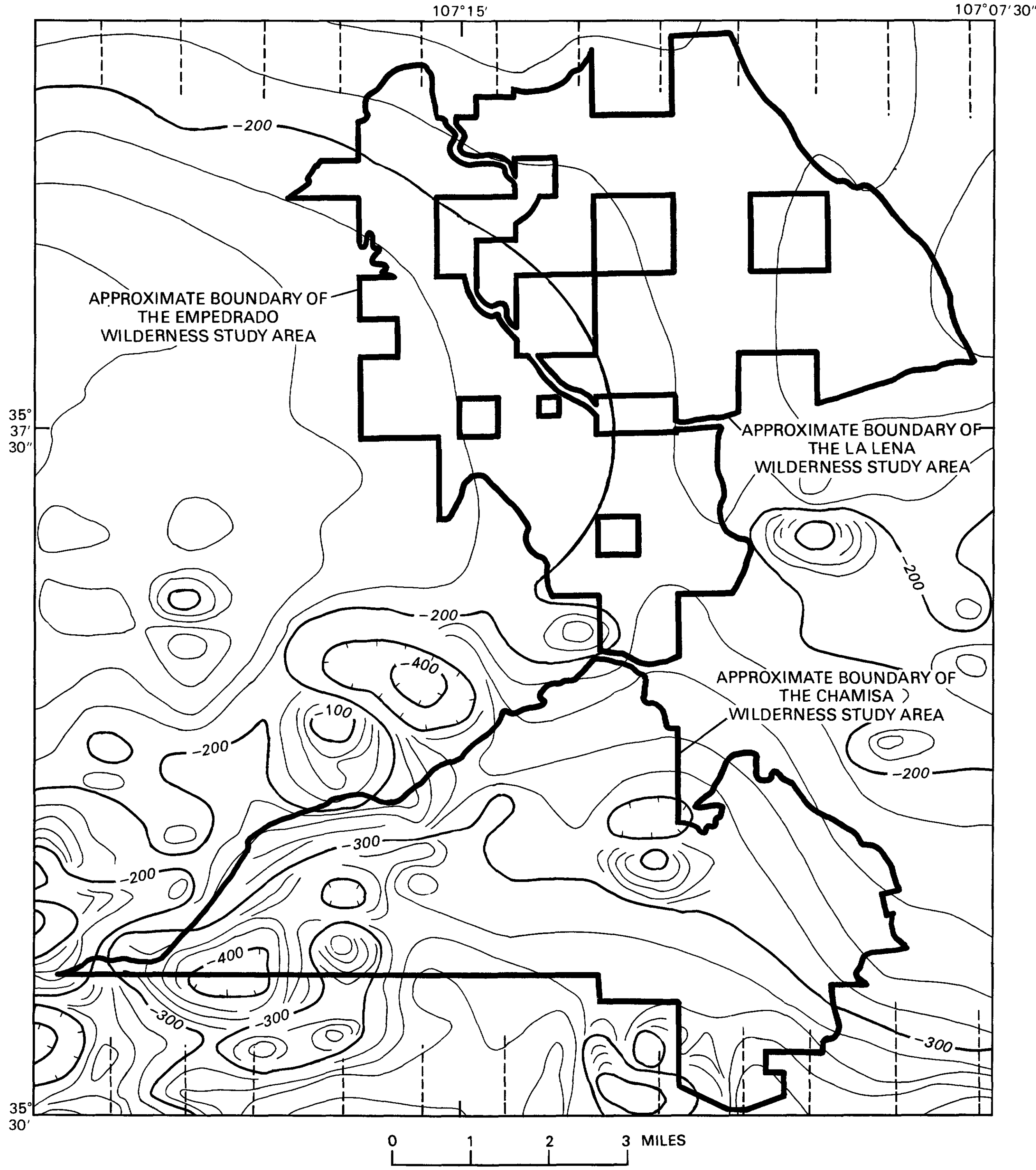


Figure 6. Map showing aeromagnetic intensity contours of the Chamisa, Empedrado, and La Lena Wilderness Study Areas. Contour intervals 20 and 100 gammas. Dotted vertical lines indicate flight lines spaced 1 mile apart.

These areas, in the northern part of the Empedrado and La Lena study areas, are those in which the Cleary Coal Member of the Menefee Formation crops out or lies close to the surface. There is moderate energy resource potential, with a certainty level of C, for discovery of additional coal resources in a north-south belt through the center of the Chamisa study area. This area, extending south from the identified coal resources in the Chamisa study area, represents the section from the base of the Cleary Coal Member of the Menefee Formation, to the point at which the coal-bearing horizons are covered by 500 ft of overburden beneath the slope of Mesa Chivato.

Other parts of the study areas have a low energy resource potential for additional coal resources, with a certainty level of C. Beneath the western part of Mesa Chivato in the Chamisa study area, the Cleary Coal Member of the Menefee Formation lies at depths of 1,200 or more below the surface. Thin coal beds may also exist in the subsurface within the Crevasse Canyon Formation. Where it is thicker to the south and west in the San Juan Basin, the Crevasse Canyon Formation contains two coal-bearing members, the Gibson Coal Member and the stratigraphically lower Dilco Coal Member. Geologic mapping (pl. 1) shows that sandstone and shale of the Crevasse Canyon Formation crop out in and near the southern border of the Chamisa study area; this appears to represent the northeasternmost extent of the formation, making it unlikely that Crevasse Canyon beds exist beneath the surface rocks of the Empedrado and La Lena study areas. There is no indication of coal beds in surface exposures of the Crevasse Canyon Formation in and adjacent to the Chamisa study area, and if subsurface coal-bearing members did exist in the western part of the Chamisa study area, they would lie at depths of 500 to 1,600 ft below the surface.

Humate

Humate suitable for mining might occur within the near-surface portions of the known coal beds in the Menefee Formation. Humate deposits in the Menefee have been mined farther south near San Ysidro, and to the north between La Ventana and Cuba (Siemers and Wadell, 1977). However, no humate deposits are known within or adjacent to the study areas, and the mineral resource potential for humate is low, with a certainty level of C.

Oil and Gas

The three study areas have a moderate energy resource potential for oil and gas, with a certainty level of B. Ryder (1983) rated the potential for oil and gas as medium in the study area (roughly equivalent to the moderate potential rating of Goudarzi, 1984). This rating was based on the presence of Jurassic and Upper Cretaceous oil fields about 10 mi to the north, Cretaceous Miguel Creek oil fields 12 mi to the west, oil shows in nearby drill holes, and favorable reservoirs and stratigraphic traps in Upper Cretaceous nearshore marine sandstones (Dakota and Gallup Sandstones) and the Jurassic Entrada Sandstone. These formations are present beneath the three study areas. Oil shows were found in two nearby drill holes; however, five holes drilled within the study areas were dry. The resource potential is only moderate because the rocks are intruded by volcanic plugs, especially in the Empedrado and Chamisa study areas, that may have raised the temperature of reservoir rocks above the limit for preservation of gas and oil, and because of possible flushing of reservoir rocks by groundwater from surface exposures of these strata flanking the Nacimiento and Zuni uplifts to the northeast and southwest.

Titaniferous Sandstone

Mineral resource potential for titaniferous heavy-mineral sandstone deposits is low, with certainty level C, in all three study areas. The deposit in the privately owned section between the Empedrado and La Lena Wilderness Study Areas (Schreiner, 1988; McLemore, 1983; McLemore and others, 1984; Brookins, 1977) is small and of low grade, and the smaller occurrence noted in another private inholding is much poorer in its content of heavy minerals and rare elements. There is no specific geologic, geochemical, or geophysical evidence for the occurrence of other such deposits within the study areas.

Uranium

The mineral resource potential is low for uranium in all three study areas, with a certainty level of B. Uranium minerals in the Grants Uranium region, about 20 mi to the south, are associated with organic material in the fluvial sandstone of the Upper Jurassic Morrison Formation. Ore in the Grants region is typically confined to the upper part of the Westwater Canyon Member and the Jackpile Sandstone Member of the Morrison Formation (Santos, 1963; Owen and others, 1984). Mineralization is localized at oxidation-reduction boundaries. Criteria favorable for uranium mineralization in the Morrison Formation include thick beds of sandstone, abundant organic material, high sandstone to mudstone ratio, and the presence of greenish-gray mudstone thought to be a source of organic material (Turner-Peterson, 1986).

Geological mapping (Turner-Peterson and Fishman, 1986) and sparse drill-hole data by Pioneer Nuclear, Inc., and Homestake Mining, Inc. (Schreiner, 1988), indicate that the Morrison Formation is present beneath the study areas. The top of the Morrison is over 1,650 ft deep in one drill hole, and estimated to be between 1,500 and 3,000 ft deep throughout the entire study areas. No uranium appears to have been found in the drill holes. No information was found regarding the sandstone to mudstone ratio or the presence or absence of organic material in the Morrison Formation beneath the study areas. More information on the subsurface stratigraphy is needed in order to raise the level of certainty; however, the study areas lie well outside the limit of known deposits in the Morrison Formation within the Grants Uranium district. The nearest identified ore deposit is 24 mi south of the study areas, and the nearest area of uranium mineralization inferred from drill holes is 14 mi south of the study area (Chapman, Wood, and Griswold, Inc., 1979). For these reasons, the resource potential for uranium is low at certainty level B in all three study areas.

The aerial gamma-ray data indicate that the area has moderate radioactivity. These data only provide information on near-surface materials. The "black sand" sandstone bed enriched in heavy minerals, located on a private inholding between the Empedrado and La Lena study areas, is the only location found to have enhanced radioactivity. No other radioactive anomalies were found, and the geochemistry data revealed no anomalous concentrations of uranium.

Other Commodities

Mineral resource potential for all other metals other than uranium is low in the Chamisa, Empedrado, and La Lena Wilderness Study Areas, with a certainty level of C. Barium, strontium, silver, molybdenum, and zinc were detected in anomalous amounts in geochemical analyses of stream-sediment samples. However, the magnitudes of the anomalies are not great, and appear to be explainable by weak concentration processes in the shales and other sedimentary rocks which host them, with relatively little likelihood of their being associated with a significant deposit. There are no known geologic models which would predict a significant deposit that would produce these types of metal anomalies in the rock types found in the study areas, and there are no known related ore deposits in the adjacent region of New Mexico. No metallic minerals have been produced and no surface evidence was found to indicate metallic-mineral resources. The isolated anomalies reported for arsenic, cobalt, and nickel are probably not significant; they do not correspond to any likely occurrence model for these metals in the rocks of the study areas. The arsenic anomaly probably represents the upper part of the range of the element normally found in shale. The nickel anomaly may be related to weak concentration of this metal in ferromagnesian minerals from the basalt or from ultramafic xenoliths known to occur in the basaltic intrusive plugs, and these sources are unlikely to result in economically significant mineralization.

The energy resource potential for geothermal energy is low in the three study areas, with a certainty level of C. No geothermal sources are known within the study areas, nor were warm springs or other geothermal sources found during this investigation.

REFERENCES CITED

American Society for Testing and Materials, 1982, Standard classification of coals by rank (ASTM Designation D–388–82): 1982 Annual book of ASTM standards, pt. 26, p. 242–246.

Brookins, D.G., 1977, Upper Cretaceous black sand deposits of the San Juan Basin: Supplement to New Mexico Geological Society Guidebook, 28th Field Conference, San Juan Basin III, p. 31–33.

Bullock, J.H., Jr., Roemer, T.A., and Nowlan, G.A., 1989, Analytical results and sample locality map for stream-sediment and heavy-mineral-concentrate samples from the Chamisa (NM–010–021), Empedrado (NM–010–063), and La Lena (NM–010–063A) Wilderness Study Areas, Sandoval and McKinley Counties, New Mexico: U.S. Geological Survey Open-File Report 89–8, 15 p.

Campbell, F.W., 1987, Description of combustion analysis, *in* Quality assessment of strippable coals in New Mexico, Year II, Phase II, Fruitland, Menefee, and Crevasse Canyon Formation coals in the San Juan Basin of northwestern New Mexico: New Mexico Research and Development Institute, NMRDI 2–74–4331, p. 64–85.

Chao, T.T., and Anderson, B.J., 1974, The scavenging of silver by manganese and iron oxides in stream sediments collected from two drainage areas of Colorado: Chemical Geology, v. 14, p. 159–166.

Chapman, Wood, and Griswold, Inc., 1979, Geologic map of Grants uranium region: New Mexico Bureau of Mines and Mineral Resources, Geologic Map 31 *rev*.

Cordell, L.E., Keller, G.R., and Hildenbrand, T.G., 1982, Complete Bouguer gravity anomaly map of the Rio Grande rift, Colorado, New Mexico, and Texas: U.S. Geological Survey Geophysical Investigations Map GP–949, scale 1:1,000,000.

Dane, C.H., and Bachman, G.O., 1957, Preliminary geologic map of the northwestern part of New Mexico: U.S. Geological Survey Miscellaneous Geologic Investigations Map I–224, scale 1:380,160.

Defense Mapping Agency Aerospace Center, 1974, World relative gravity reference network, North America, Part 2: Defense Mapping Agency Aerospace Center Reference Publication 25, with supplement updating gravity values to the International Gravity Standardization Net 1971, 1635 p.

______ 1975, Holding, storage, and retrieval of gravity data: Defense Mapping Agency Aerospace Center Publication RP–75–003, 33 p.

Duval, J.S., 1988, Aerial gamma-ray contour maps of regional surface concentrations of uranium, potassium, and thorium in New Mexico: U.S. Geological Survey Geophysical Investigations Map GP–979, scale 1:750,000.

Fassett, J.E., 1974, Cretaceous and Tertiary rocks of the eastern San Juan Basin, New Mexico and Colorado: New Mexico Geological Society Guidebook, 25th Field Conference, Ghost Ranch (Central-Northern N.M.), p. 225–230.

Goudarzi, G.H., compiler, 1984, Guide to preparation of mineral survey reports on public lands: U.S. Geological Survey Open-File Report 84–787, 42 p.

Holzle, A.F., 1960, Photogeologic map of the Cabezon-3 quadrangle, McKinley and Sandoval Counties, New Mexico: U.S. Geological Survey Miscellaneous Geologic Investigations Map I–317, scale 1:62,500.

Hunt, C.B., 1936, Geology and fuel resources of the southern part of the San Juan Basin, New Mexico, Part 2, The Mount Taylor coal field: U.S. Geological Survey Bulletin 860–B, 80 p.

Keller, G.R., and Cordell, L.E., 1984, Bouguer gravity anomaly map of New Mexico: National Oceanic and Atmospheric Administration Geothermal Resources of New Mexico, Scientific Map Series, scale 1:500,000.

McCartney, J.T., and Teichmuller, Marlies, 1972, Classification of coals according to degree of coalification by reflectance of the vitrinoid components: Fuel, v. 51, p. 64–68.

McLemore, V.T., 1983, Uranium and thorium occurrences in New Mexico—distribution, geology, production, and resources, with selected bibliography: New Mexico Bureau of Mines and Mineral Resources Open-File Report 183, 950 p.

McLemore, V.T., Roybal, G.H., Broadhead, R.F., Chamberlin, Richard, North, R.M., Osburn, J.C., Arkell, B.W., Colpitts, R.M., Bowie, M.R., Anderson, Kent, Barker, J.M., and Campbell, Frank, 1984, Preliminary report on the geology and mineral resource potential of the northern Rio Puerco Resource Area in Sandoval and Bernalillo Counties and adjacent parts of McKinley, Cibola, and Santa Fe Counties, New Mexico: New Mexico Bureau of Mines and Mineral Resources Open-File Report 211, 817 p.

Molenaar, C.M., 1974, Correlation of the Gallup Sandstone and associated formations, Upper Cretaceous, eastern San Juan and Acoma Basins, New Mexico: New Mexico Geological Society Guidebook, 25th Field Conference, Ghost Ranch (Central-Northern N.M.), p. 251–258.

_____ 1977, Stratigraphy and depositional history of Upper Cretaceous rocks of the San Juan Basin area, New Mexico and Colorado, with a note on economic resources: New Mexico Geological Society Guidebook, 28th Field Conference, San Juan Basin III, p. 159–166.

Nowlan, G.A., 1976, Concretionary manganese-iron oxides in streams and their usefulness as a sample medium for geochemical prospecting: Journal of Geochemical Exploration, v. 6, p. 193–210.

Owen, D.L., Walters, L.J., Jr., and Beck, R.G., 1984, The Jackpile Sandstone Member of the Morrison Formation in west-central New Mexico—a formal definition: New Mexico Geology, v. 6, no. 3, p. 45–52.

Rankama, Kalervo, and Sahama, T.G., 1950, Geochemistry: Chicago, University of Chicago Press, 912 p.

Roberts, D.B., Krason, J., and Rizo, J., 1982, Geology, energy and mineral resources of the San Luis area, New Mexico: Geoexplorers International Inc., Denver, Colorado, unpublished report prepared for the Bureau of Land Management, 75 p. [available at Albuquerque, NM BLM District office].

Rose, A.W., Hawkes, H.E., and Webb, J.S., 1979, Geochemistry in mineral exploration, 2nd edition: London, Academic Press, 657 p.

Roybal, G.H., 1984 Coal resources, *in* Preliminary report on the geology and mineral resource potential of the northern Rio Puerco Resource Area in Sandoval and Bernalillo Counties and adjacent parts of McKinley, Cibola and Santa Fe Counties, New Mexico: New Mexico Bureau of Mines and Mineral Resources Open File-Report no. 211, p. 202–231.

Roybal, G.H., and Barker, J.M., 1985, Geology and production of humate and weathered coal in New Mexico: Society of Mining Engineers of AIME preprint 85–408, 11 p.

Ryder, R.T., 1983, Petroleum potential of wilderness lands, New Mexico, *in* Miller, B.M., ed., Petroleum potential of wilderness lands in the Western United States: U.S. Geological Survey Circular 902–I, 33 p.

Santos, E.S., 1963, Relation of ore deposits to the stratigraphy of the Ambrosia Lake area, *in* Kelley, V.C., ed., Geology and technology of the Grants uranium region: New Mexico Bureau of Mines and Mineral Resources Memoir 15, p. 53–59.

Schreiner, R.A., 1988, Mineral Resources of the Chamisa (NM–010–021), Empedrado (NM–010–063), Ignacio Chavez (NM–010–020), and La Lena (NM–010–063A) Wilderness Study Areas, McKinley and Sandoval Counties, New Mexico: U.S. Bureau of Mines Open-File Report MLA–33–88, 35 p.

Siemers, C.T., and Wadell, J.S., 1977, Humate deposits of the Menefee Formation (Upper Cretaceous), northwestern New Mexico: Supplement to New Mexico Geological Society Guidebook, 28th Field Conference, San Juan Basin III, p. 1–22.

Soulliere, S.J., Long, C.L., and Schreiner, R.A., 1988, Mineral resources of the Ignacio Chavez Wilderness Study Area, McKinley and Sandoval Counties, New Mexico: U.S. Geological Survey Bulletin 1733–D, 13 p.

Soulliere, S.J., Long, C.L., and Tuftin, S.E., 1987, Mineral resources of the Ojito and Cabezon Wilderness Study Areas, Sandoval County, New Mexico: U.S. Geological Survey Bulletin 1733-B, 14 p.

Tabet, D.E., and Frost, S.J., 1979a, Environmental characteristics of the Menefee coals in the Torreon Wash area: New Mexico Bureau of Mines and Mineral Resources Open-File Report 102, 134 p.

_____ 1979b, Coal geology of the Torreon Wash area: New Mexico Bureau of Mines and Mineral Resources Geologic Map 49, 1:24,000 scale.

Turner-Peterson, C.E., 1986, Fluvial sedimentology of a major uranium-bearing sandstone—a study of the Westwater Canyon Member of the Morrison Formation, San Juan basin, New Mexico, *in* Turner-Peterson, C.E., Santos, E.S., and Fishman, N.S., eds., A basin analysis case study—The Morrison Formation, Grants Uranium region, New Mexico: American Association of Petroleum Geologists Studies in Geology 22, p. 47–76.

Turner-Peterson, C.E., and Fishman, N.S., 1986, Geologic synthesis and genetic models for uranium mineralization in the Morrison Formation, Grants uranium region, New

Mexico, *in* Turner-Peterson, C.E., Santos, E.S., and Fishman, N.S., eds., A basin analysis study—the Morrison Formation, Grants uranium region, New Mexico: American Association of Petroleum Geologists Studies in Geology 22, p. 357–388.

U.S. Bureau of Mines, 1988, Mineral Commodity Summaries 1988, 193 p.

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, 5 p.

U.S. Geological Survey, 1979a, Federal coal resource occurrence and coal development potential maps of the Arroyo Empedrado 7½-minute quadrangle, Sandoval County, New Mexico: U.S. Geological Survey Open-File Report 79–1045, 26 p., 13 plates.

_____ 1979b, Federal coal resource occurrence and coal development potential maps of the Canada Calladita 7½-minute quadrangle, McKinley and Sandoval Counties, New Mexico: U.S. Geological Survey Open-File Report 79–626, 25 p., 19 plates.

_____ 1979c, Federal coal resource occurrence and coal development potential maps of the Cerro Parido 7½-minute quadrangle, McKinley and Sandoval Counties, New Mexico: U.S. Geological Survey Open-File Report 79–627, 20 p., 8 plates.

_____ 1980, Aeromagnetic map of northeast Arizona and northwest New Mexico: U.S. Geological Survey Open-File Report 80–614, 4 sheets, scale 1:250,000.

Wood, G.H., Jr., Kehn T.M., Carter, M.D., and Culbertson, W.C., 1983, Coal resource classification system of the U.S. Geological Survey: U.S. Geological Survey Circular 891, 65 p.

Wyant, D.J., and Olson, Annabelle, 1978, Preliminary geologic map of the Albuquerque 1 by 2 degree quadrangle, northwestern New Mexico: U.S. Geological Survey Open-File Report 78–467, 7 p., 1 sheet, scale 1:250,000.

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.

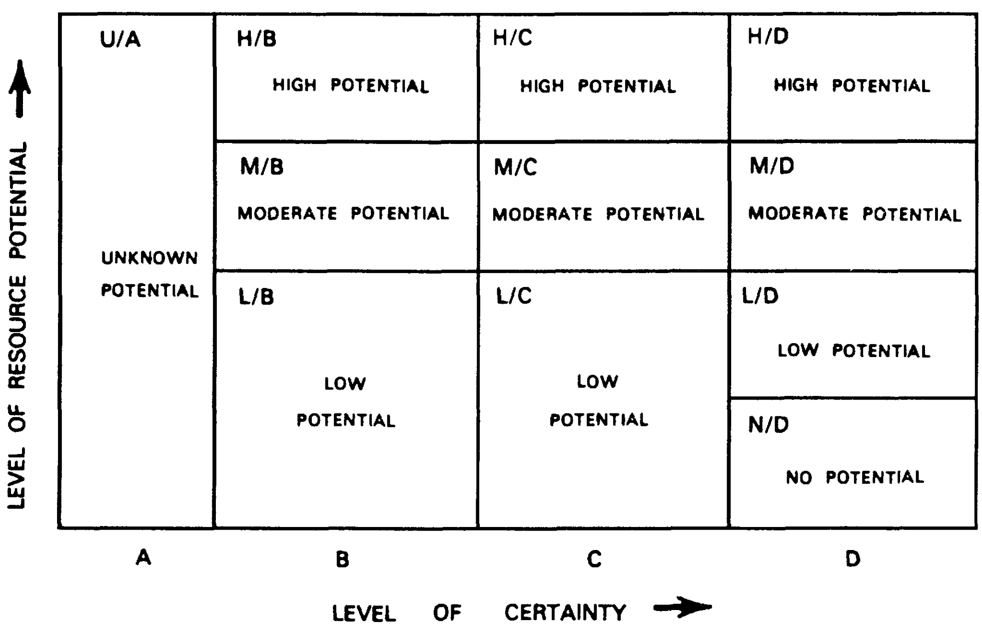
MODERATE mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence, where interpretations of data indicate a reasonable likelihood of resource accumulation, and (or) where an application 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.

Goudarzi, G. H., compiler, 1984, Guide to preparation of mineral survey reports on public lands: U.S. Geological Survey Open-File Report 84–0787, p. 7, 8.

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
				Pleistocene	1.7
		Tertiary	Neogene Subperiod	Pliocene	5
				Miocene	24
			Paleogene Subperiod	Oligocene	38
				Eocene	55
				Paleocene	66
	Mesozoic	Cretaceous		Late	96
				Early	138
		Jurassic		Late Middle Early	205
		Triassic		Late Middle Early	~ 240
	Paleozoic	Permian		Late Early	290
		Carboniferous Periods	Pennsylvanian	Late Middle Early	~ 330
			Mississippian	Late Early	360
		Devonian		Late Middle Early	410
		Silurian		Late Middle Early	435
		Ordovician		Late Middle Early	500
		Cambrian		Late Middle Early	~ 570[1]
Proterozoic	Late Proterozoic				900
	Middle Proterozoic				1600
	Early Proterozoic				2500
Archean	Late Archean				3000
	Middle Archean				3400
	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.

☆U.S. GOVERNMENT PRINTING OFFICE: 1990-773-047/06043

Mineral Resources of Wilderness Study Areas— Northern New Mexico

This volume was published
as separate chapters A–E

U.S. GEOLOGICAL SURVEY BULLETIN 1733

CONTENTS

[Letters designate the chapters]