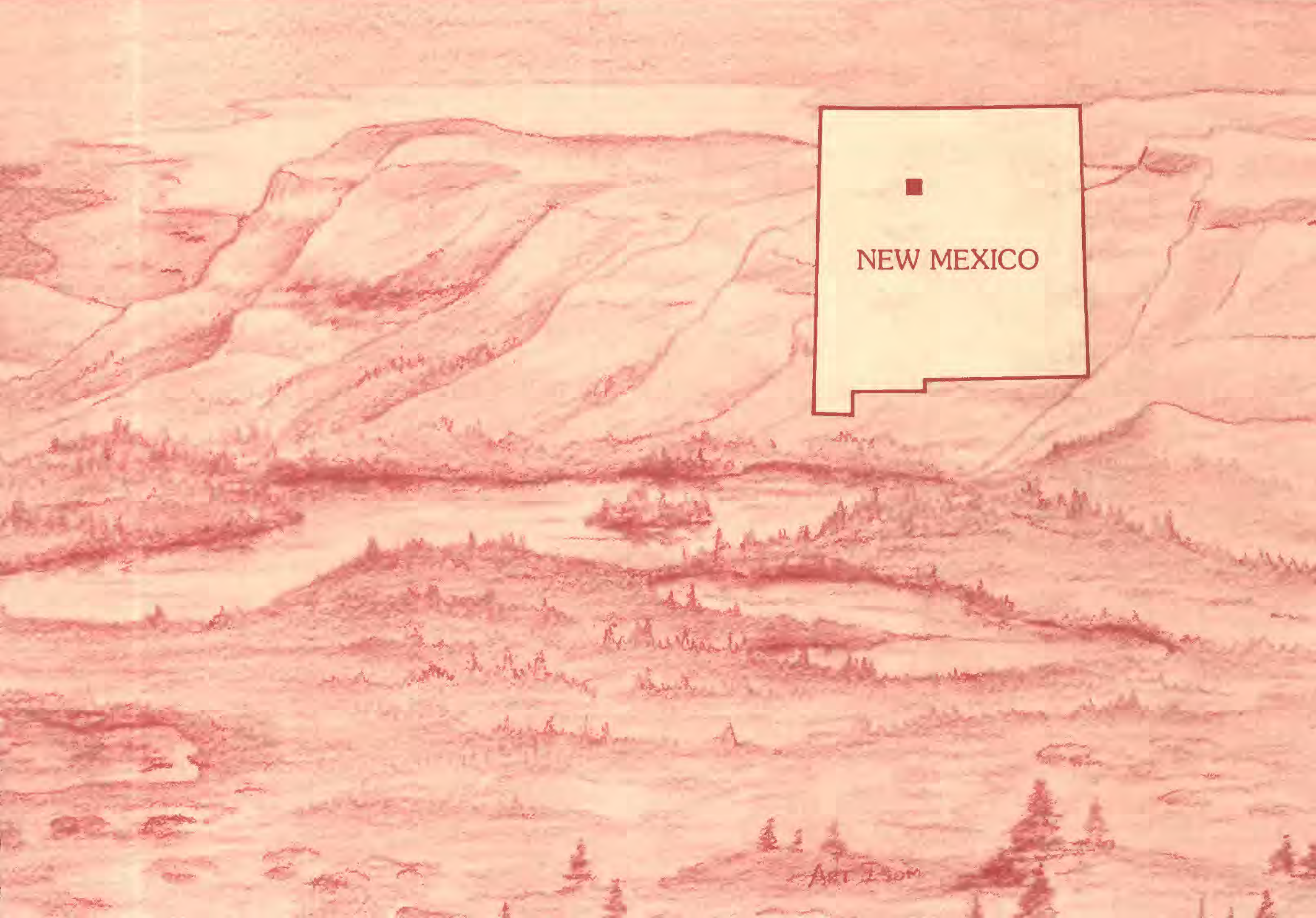
Mineral Resources of the Ojito and Cabezon Wilderness Study Areas, Sandoval County, New Mexico

U.S. GEOLOGICAL SURVEY BULLETIN 1733–B



Chapter B

Mineral Resources of the Ojito and Cabezon Wilderness Study Areas, Sandoval County, New Mexico

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U.S. GEOLOGICAL SURVEY BULLETIN 1733

MINERAL RESOURCES OF WILDERNESS STUDY AREAS—
NORTHERN NEW MEXICO

DEPARTMENT OF THE INTERIOR
DONALD PAUL HODEL, Secretary

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

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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 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 Ojito (NM–010–024) and Cabezon (NM–010–022) Wilderness Study Areas, Sandoval County, New Mexico.

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PLATE

[Plate is in pocket]

FIGURES

Mineral Resources of the Ojito and Cabezon Wilderness Study Areas, Sandoval County, New Mexico

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SUMMARY

In 1984 and 1985 the U.S. Geological Survey and the U.S. Bureau of Mines conducted investigations to assess the mineral resource potential and appraise the identified mineral resources of the Ojito (NM–010–024) and Cabezon (NM–010–022) Wilderness Study Areas. These investigations revealed that the Ojito study area has an identified subeconomic resource of gypsum and a moderate mineral resource potential for undiscovered uranium. The Ojito study area also has low mineral resource potential for undiscovered zeolite minerals. There are no identified mineral resources in the Cabezon study area, and mineral resource potential for undiscovered uranium is low. Both study areas have low mineral resource potential for all undiscovered metals and sand and gravel and low energy resource potential for undiscovered oil, gas, coal, and geothermal resources (fig. 1).

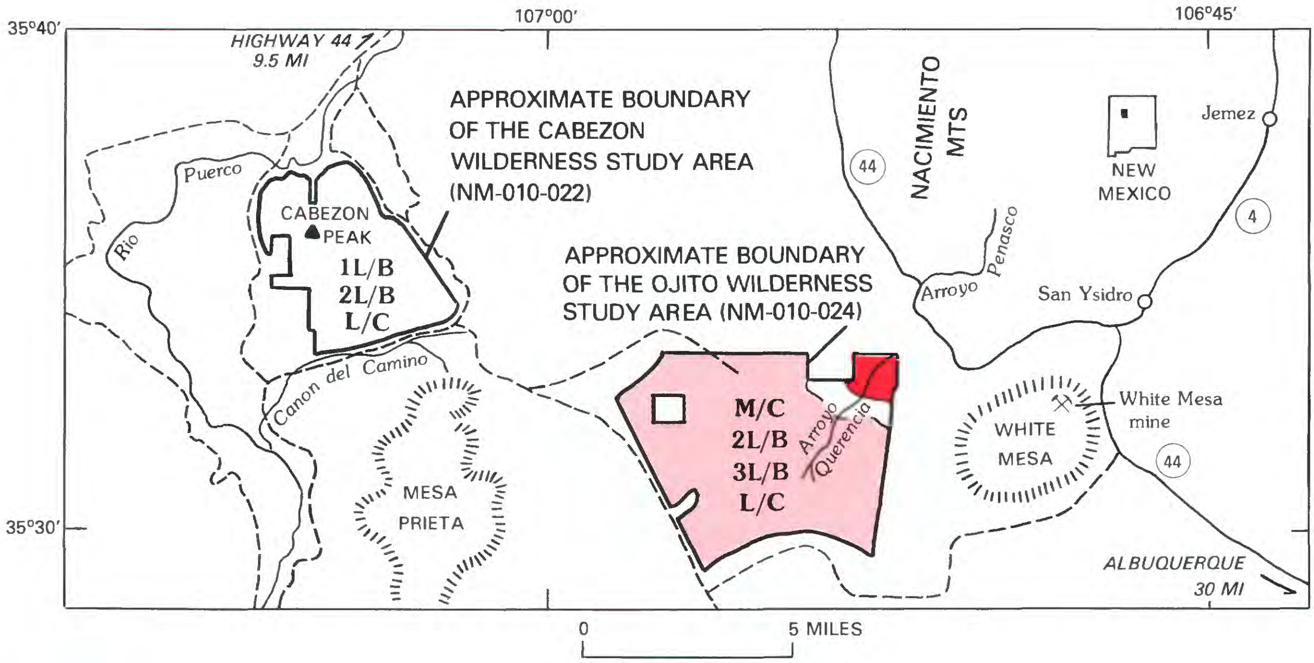
The Ojito (11,919 acres) and Cabezon (8,159 acres) Wilderness Study Areas are about 45 mi (miles) northwest of Albuquerque, in Sandoval County, N. Mex. They are on the southeastern edge of the San Juan Basin in the Colorado Plateaus physiographic province. Access is provided by unimproved roads west of New Mexico Highway 44. Elevations in the Ojito study area range from approximately 5,550 ft (feet) at the northeastern boundary to 6,261 ft in the northwestern part of the study area. In the Cabezon study area, elevations range from 6,000 ft at Canon del Camino to 7,785 ft at Cabezon Peak.

Several northeast-trending faults dissect the mostly flat lying Middle Jurassic through Upper Cretaceous (see geologic time chart in the appendix) sedimentary rocks exposed in the Ojito Wilderness Study Area. Rock units exposed in the Ojito study area include the Wanakah Formation, Morrison Formation, Dakota Sandstone, and Mancos Shale. These formations may underlie the Cabezon Wilderness Study Area.

The Cabezon Wilderness Study Area is about 5 mi northwest of the Ojito Wilderness Study Area. Cabezon Peak, the most prominent geologic feature in the Cabezon study area, is a volcanic neck emplaced during the late Tertiary or early Quaternary. It intrudes Upper Cretaceous sedimentary rocks that dip gently to the north. The exposed neck is cylindrical and its diameter is about 1,500 ft. Nearly vertical jointed columns of dense black basalt constitute the main body of the peak. No mineralized rock was associated with the basalt intrusion. Upper Cretaceous sedimentary rocks of the Point Lookout Sandstone and the Mancos Shale surround the peak and were neither disturbed nor altered by the intrusion.

There are no mines in the Ojito Wilderness Study Area; however, gypsum is mined by surface methods at the White Mesa mine, about 4 mi to the east. Prospects in and near the southwestern part of the Ojito Wilderness Study Area are trenches or bulldozer cuts in the Mancos Shale and alluvium. These prospects may have been dug during uranium exploration in the 1950's. No anomalous radioactivity or mineralized rock was found associated with these prospects during our investigations. One geothermal lease is within 1 mi of the Ojito study area boundary. Several drill holes, oil and gas leases, and land under application for lease are in and near both study areas. No mines, prospects, mineralized areas, or mining claims were identified in the Cabezon Wilderness Study Area.

An inferred subeconomic resource of 6 million tons of gypsum was calculated for the northeastern corner of the Ojito study area (fig. 1). The resource is subeconomic because large amounts of overburden



EXPLANATION

(red box)	Area of identified gypsum resources
M/C	**Geologic terrane having moderate mineral resource potential for uranium in the Jurassic Morrison Formation, with certainty level C**
1L/B	**Geologic terrane having low mineral resource potential for uranium, with certainty level B**—Applies to Cabezon study area
2L/B	**Geologic terrane having low mineral resource potential for oil, gas, coal, geothermal energy, and metals other than uranium, with certainty level B**—Applies to both study areas
3L/B	**Geologic terrane having low mineral resource potential for zeolite minerals, with certainty level B**—Applies to Brushy Basin Member of the Morrison Formation
L/C	**Geologic terrane having low mineral resource potential for sand and gravel, with certainty level C**—Applies to areas designated as Quaternary alluvium on plate 1
– – – –	**Unpaved road**

Levels of certainty

- **B** Data indicate geologic environment and suggest level of resource potential
- **C** Data indicate geologic environment and resource potential, but do not establish activity of resource-forming processes

Figure 1. Map showing location, identified resources, and mineral resource potential of the Ojito and Cabezon Wilderness Study Areas, Sandoval County, N. Mex.

would have to be stripped to mine most of the gypsum; this gypsum would not be economical in the foreseeable future. Large reserves of gypsum are available a few miles east of the study area and elsewhere in the United States.

Mineral resource potential for uranium in stratabound deposits is moderate for the Ojito study area and low for the Cabezon study area. The Westwater Canyon Member of the Morrison Formation is a known host rock for uranium elsewhere, and uranium is disseminated in small localized sites in mudstone and sandstone of the Westwater Canyon and Brushy Basin Members of the Morrison Formation throughout the Ojito Wilderness Study Area. However, the grade is far below that of economic deposits. The Morrison Formation may be present beneath the Cabezon Wilderness Study Area, where it probably has been intruded by volcanic rock. No uranium minerals were found at the surface of the Cabezon study area; no radioactive anomalies were found, and the geochemical analyses revealed no anomalous concentrations of uranium.

The energy resource potential for oil and gas is low for both study areas. Favorable reservoir rocks (Cretaceous sedimentary rocks) are exposed in both study areas and are susceptible to flushing by ground water. Pennsylvanian formations beneath both study areas are also favorable reservoir rocks. However, the Ojito study area has been tested to the Precambrian basement for oil and gas without success, and heating to the temperatures associated with the extensive Tertiary and Quaternary volcanism in the Cabezon study area probably destroyed any oil and gas present.

The resource potential for geothermal energy is low in both study areas. Approximately 2 sq mi (square miles) of the northeastern part of the Ojito Wilderness Study Area is included in the San Ysidro Known Geothermal Resource Area. Two thermal springs were discovered along the Nacimiento fault about 8 mi north and east of the Ojito study area. However, no hot springs are present in either study area.

No minerals have been produced and no surface evidence exists for metallic-mineral resources in either study area. Geological and geochemical evidence suggest a low mineral resource potential for all metals in both wilderness study areas.

Thin, lenticular coal beds of the Upper Cretaceous Crevasse Canyon Formation are exposed southwest of the study areas. Geologic mapping indicates that the Crevasse Canyon Formation may be present beneath the Cabezon study area, where it probably intertongues with the Cretaceous Mancos Shale. No coal beds were found at the surface in either study area. The mineral resource potential for coal is low in both study areas because coal beds of the Crevasse Canyon Formation are lenticular and discontinuous.

The area designated as Quaternary alluvium in both study areas has a low mineral resource potential for well-sorted sand and gravel.

The Ojito study area has a low mineral resource potential for zeolite minerals. Zeolitic siltstone beds were found about 10 mi north of the study area in the mudstone unit of the Brushy Basin Member of the Morrison Formation. These zeolitic siltstone beds may be present in the study area, where they possibly intertongue with sandstones of the Westwater Canyon Member of the Morrison Formation.

INTRODUCTION

The U.S. Geological Survey (USGS) and the U.S. Bureau of Mines (USBM) studied 11,919 acres of the Ojito Wilderness Study Area (NM–010–024) and 8,159 acres of the Cabezon Wilderness Study Area (NM–010–022). The study of these acreages was requested by the U.S. Bureau of Land Management (BLM). In this report the studied area is called the "wilderness study area," or simply the "study area." 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 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 of this report. Identified resources were studied by the USBM. Mineral 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 sources). It is classified according to the system of Goudarzi (1984), which also is shown in the appendix. Mineral resource potential was studied by the USGS.

The study areas are about 45 mi northwest of Albuquerque in Sandoval County, N. Mex. (fig. 1). Access is provided by unimproved roads west of New Mexico Highway 44. The Ojito Wilderness Study Area is dissected by numerous drainages forming a badlands-type topography of arroyos, cliffs, and small mesas. Elevations in the Ojito study area range from approximately 5,550 ft at the northeastern study area boundary to 6,261 ft in the northwestern part of the study area. The Cabezon Wilderness Study Area, about 5 mi northwest of the Ojito study area, is bounded on the north by the Rio Puerco and on the south by Canon del Camino. Tributaries of the Rio Puerco drain the Cabezon study area. Elevations in the Cabezon study area range from 6,000 ft at Canon del Camino to 7,785 ft at Cabezon Peak, the most prominent feature.

Acknowledgments—A.M. Leibold assisted in fieldwork and geochemical sampling. We thank Pat Hester and George Lasker of the U.S. Bureau of Land Management in Albuquerque for supplying information on the study areas from their files, and F.E. Lichte, P.H. Briggs, D.M. McKown, and R.B. Vaughn for analyses of the stream-sediment samples.

Investigations by the U.S. Bureau of Mines

U.S. Bureau of Mines personnel conducted a literature search for minerals information prior to field work. Oil and gas plats and geothermal plats were examined for leases; BLM records were checked for patented and current (1985) unpatented mining claims. Two USBM geologists conducted a field examination of both wilderness study areas in October 1984 (Tuftin, 1985). Foot traverses were made to examine prospects and mineralized outcrops in and near both wilderness study areas.

The USBM did not sample the Cabezon Wilderness Study Area. Seventeen rock chip samples were taken in and within 1 mi of the Ojito study area (numbers 1–17, pl. 1). Of these, five were gypsum samples taken from outcrops in and near the northeast corner of the study area (numbers 13–17, pl. 1) and tested for purity and combined water (water chemically part of the gypsum). The samples were washed before analysis because the outcrops are deeply weathered and contaminated by windblown sand. The washed samples are more representative of the gypsum at depth.

A scintillometer was used in field investigations of the Ojito study area. Background radioactivity in the study area was determined to be 30 cps (counts per second); readings of 20 or more cps above background were considered to be anomalous. Twelve samples were collected from outcrops and a prospect emitting anomalous radioactivity (numbers 1–12, pl. 1). Uranium content was determined by fluorometric analysis. Assay data and analytical results are summarized by Tuftin (1985) and are available for public inspection at the U.S. Bureau of Mines, Intermountain Field Operations Center, Building 20, Denver Federal Center, Denver, CO 80225.

Investigations by the U.S. Geological Survey

In October 1985, the USGS conducted an investigation to assess the potential for undiscovered mineral resources of the Ojito and Cabezon Wilderness Study Areas. This investigation consisted of a search for published and unpublished information about the areas, a review of previous geologic mapping, the compilation of a geologic map at a 1:50,000 scale for the Cabezon study area, a collection of stream-sediment samples for geochemical analyses, a review of existing geophysical data, and a search for mines, prospects, and mineralized areas. Stream-sediment samples were collected from 27 sites in the Ojito study area (labeled JIT on pl. 1); eighteen samples were collected from sites in the Cabezon study area (labeled CP on pl. 1).

During a study of the uranium potential of Jurassic formations in northwestern New Mexico, Santos (1975) mapped the Ojito study area at a scale of 1:48,000. This map was field checked and modified to a scale of 1:50,000 for use in this study. Woodward and Ruetschilling (1976) mapped the geology of the San Ysidro 7½-minute quadrangle, which includes the southwestern corner of the Ojito study area. Preliminary assessments of mineral resources in the Ojito and Cabezon Wilderness Study Areas were written by Roberts, Krason, and Rizo (1982) and by McLemore and others (1984). A volume of work by Turner-Peterson and others (1986) summarizes the results of recent research in the San Juan Basin, focusing on the geology of the Morrison Formation and related uranium deposits. The potential for oil and gas was assessed by Ryder (1983) and Woodward (1983).

APPRAISAL OF IDENTIFIED RESOURCES

By Steven E. Tuftin
U.S. Bureau of Mines

Mines, prospects, and mining claims and leases

Ojito Wilderness Study Area

Prospects indicated on plate 1 in and near the southwestern part of the Ojito study area are trenches or bulldozer cuts in Mancos Shale and alluvium. The prospects might have been dug for uranium exploration in the 1950's, but no anomalous radioactivity or mineralized rock was found in these workings.

Drill-hole locations and oil and gas leases and lease applications in and near the study area are shown on figure 2. Drill holes east of the study area are in an anticlinal structure that is used for underground gas storage (Roberts and others, 1982).

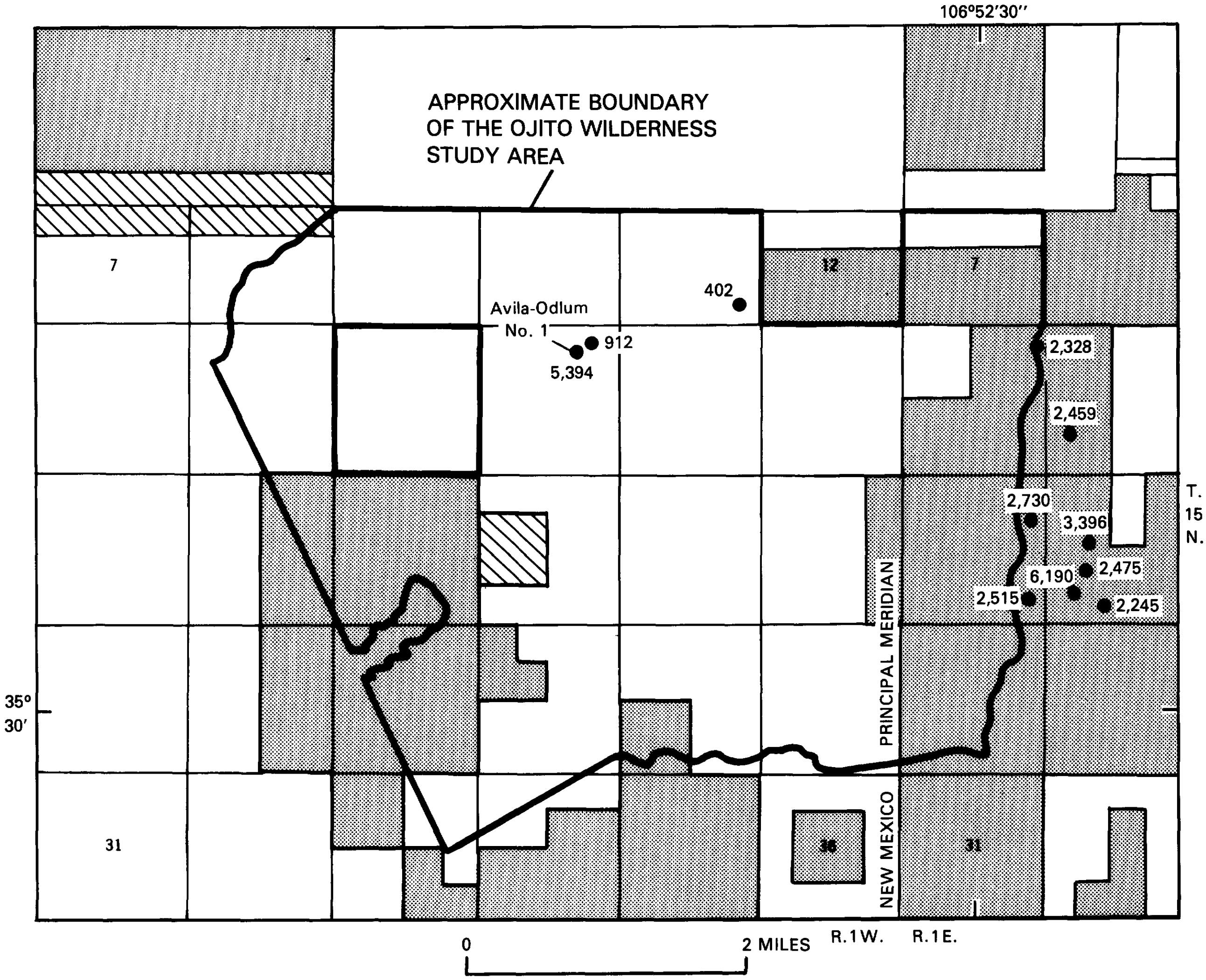
Approximately 2 sq mi of the northeastern part of the Ojito study area (fig. 3) is included in the San Ysidro Known Geothermal Resource Area. There are two thermal springs (23 °C and 29 °C; Swanberg, 1980) north and east of the study area (fig. 3). No geothermal resources were identified in the study area. One geothermal lease is within 1 mi of the study area boundary.

Cabezon Wilderness Study Area

No mining claims exist within the Cabezon study area and no mines, prospects, mineralized outcrops, or radioactive anomalies were found during the field investigation. No evidence of mineralization was found and no mineral resources were identified. The USBM did not sample the area. Oil and gas leases and lease applications in and near the study area are shown on figure 4. There are no geothermal leases or lease applications within or near the study area.

Reserves and Identified Resources

Gypsum and uranium occur within and near the Ojito Wilderness Study Area. No uranium resources were



EXPLANATION

Oil and gas leases

Oil and gas lease applications

5,394 ● **Drill hole**—Showing depth in feet (Data from Petroleum Information, Incorporated, Denver, Colo.)

Figure 2. Map showing oil and gas leases, lease applications, and drill-hole locations in and near the Ojito Wilderness Study Area, Sandoval County, N. Mex. Lease information from U.S. Bureau of Land Management files as of October 1984.

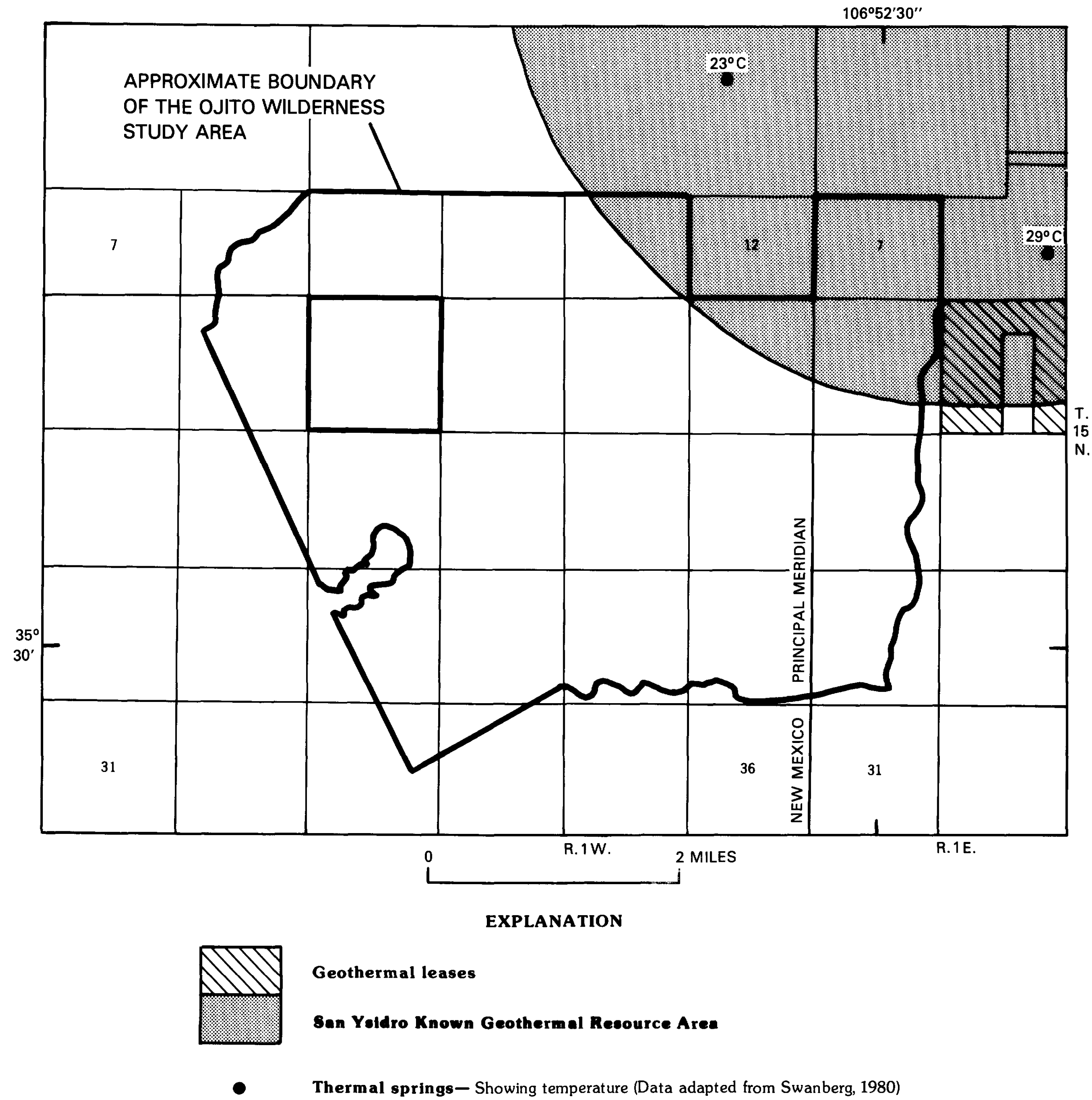


Figure 3. Map showing Known Geothermal Resource Area and geothermal leases within 1 mi of the Ojito Wilderness Study Area, Sandoval County, N. Mex. Lease information from U.S. Bureau of Land Management files as of October 1984.

identified; however, a subeconomic resource of gypsum was identified in the Ojito study area. No mineral resources were identified in the Cabezon Wilderness Study Area.

Gypsum

A 90-ft-thick gypsum bed crops out where Arroyo Querencia crosses the northeastern boundary of the Ojito study area (pl. 1). The bed occurs in the Todilto Limestone Member of the Wanakah Formation and dips about 7° west. Five chip samples were collected from these gypsum outcrops and analyzed for purity. The analyses indicated that the gypsum is 97–99 percent pure calcium sulfate combined with water. Drill-core data, subsurface sampling, and sample analysis are necessary to determine the minable thickness, the ratio of gypsum to anhydrite, and the overburden thickness.

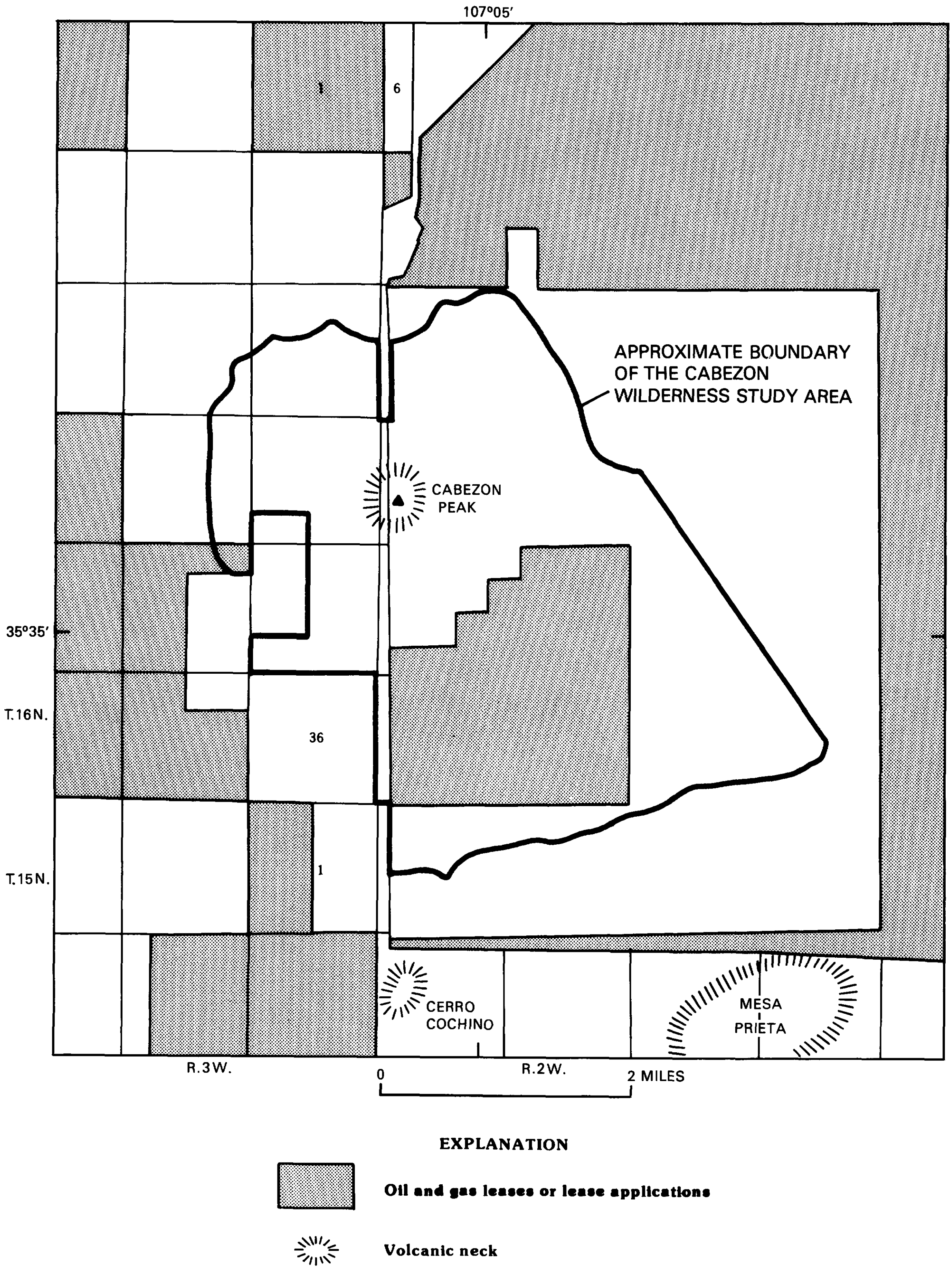


Figure 4. Map showing oil and gas leases and lease applications in and near the Cabezon Wilderness Study Area, Sandoval County, N. Mex. Lease information from U.S. Bureau of Land Management files as of October 1984.

At the White Mesa mine, about 4 mi east of the Ojito study area (fig. 1), gypsum is being mined by surface methods to a depth of about 60 ft. Below 60 ft, nodular anhydrite appears in significant quantities (Logsdon, 1982), making this part of the Todilto unusable for gypsum production. Elston (1967) reports that the average purity of raw gypsum at the White Mesa mine is 98.1 percent. This deposit is under a 5- to 8-ft overburden of gypsite (a mixture of gypsum and clay). The overburden and minable thicknesses may compare with gypsum deposits in the study area. By assuming a minable thickness of 45 ft and overburden thickness of 10 ft, the USBM estimated an inferred subeconomic resource of 6 million tons of gypsum within the northeastern corner of the Ojito study area.

Vast amounts of developable gypsum are available about 4 mi outside the Ojito study area at the White Mesa mine. The White Mesa mine has reported reserves of more than 220 million tons of gypsum (Elston, 1967), which would supply the entire United States yearly demand of about 20–25 million tons per year for 9–11 years. In the United States, gypsum resources are centered near three main areas, the Great Lakes area, California, and the Texas-Oklahoma area. In Michigan alone, the resources of gypsum have been estimated as practically inexhaustible (Reed, 1975).

Uranium

In the Ojito study area, localized sites in the Morrison Formation were found to have radiation levels as high as 64 cps. The anomalously radioactive sites are small, on the order of 8 by 12 ft or less, and are in mudstone and sandstone. Twelve samples were taken from a bulldozer cut and from anomalously radioactive outcrops in and near the study area (pl. 1); the highest uranium value determined chemically was 12 ppm (parts per million; 0.0012 percent uranium). To be economic, uranium deposits must average at least 0.3 percent U_3O_8 (0.255 percent uranium; George Grandbouche, geologist, U.S. Department of Energy, Grand Junction, Colo., oral commun., 1986).

Conclusions

The northeastern part of the Ojito Wilderness Study Area contains an inferred subeconomic resource of 6 million tons of gypsum. Large quantities of developable gypsum are available near the study area and elsewhere in the United States; gypsum in the Ojito study area probably will not be developed in the near future.

Isolated occurrences of disseminated uranium are found throughout the Ojito study area in mudstone and sandstone of the Westwater Canyon and Brushy Basin Members of the Morrison Formation. Assays, however, indicate the grade of the uranium in the study area is far below the grade of commercial deposits.

No mines, prospects, mineral occurrences, or signs of mineralization were found during the investigation of the Cabezon Wilderness Study Area. No mineral resources were identified. There are oil and gas leases in and near both study areas.

ASSESSMENT OF POTENTIAL FOR UNDISCOVERED RESOURCES

By Sandra J. Soulliere and Carl L. Long
U.S. Geological Survey

Geology

Both study areas are on the southeastern edge of the San Juan Basin in the Colorado Plateaus physiographic province. The study areas are along the Jemez lineament, a northeast-trending zone of late Cenozoic volcanic fields that extends northeastward across Arizona and northern New Mexico (Mayo, 1958).

Ojito Wilderness Study Area

The eastern edge of the San Juan Basin is marked by folds and faults along the Nacimiento uplift, about 2 mi east of the Ojito study area. These folds and faults are about 0.5–1 mi east of the study area. In the Ojito study area, mostly flat-lying Middle Jurassic through Upper Cretaceous sedimentary rocks are exposed and, mostly in the western part of the study area, are dissected by several northeast-trending faults (pl. 1). Geologic mapping (pl. 1) and the following description of map units were modified from Santos (1975). This geologic mapping indicates that the Jurassic Entrada Sandstone, the Triassic Chinle Formation, and the Pennsylvanian Madera Formation are present beneath the study area. Jurassic rocks that crop out in the study area are the Wanakah Formation and the overlying Morrison Formation. The Upper Cretaceous Dakota Sandstone and Mancos Shale crop out above the Morrison Formation.

The Todilto Limestone Member of the Wanakah Formation (unit **Jwt**, pl. 1) consists of a thin limestone unit and an overlying thick gypsum unit. The member ranges from 5 to 125 ft in thickness. The limestone unit is yellowish brown to light gray, silty, and thinly laminated. Thin seams of gypsum are interbedded with the limestone in some places. The gypsum unit is light gray to nearly white, massive, and structureless. Drill-hole data indicate that the unit is largely anhydrite in the subsurface. Strata from the upper part of the Wanakah Formation (unit **Jw**, pl. 1), 40–50 ft thick, conformably overlie the Todilto. The upper part consists of interbedded brown and grayish-green mudstone, claystone, siltstone, and grayish-pink, fine-grained sandstone. Limestone and gypsum are locally interbedded near the base and top of the upper part.

The three members that make up the Morrison Formation are, in ascending order, the Recapture Member (unit Jmr, pl. 1), the Westwater Canyon Member (unit Jmw, pl. 1), and the Brushy Basin Member (units Jmb, Jmj, pl. 1). The Jackpile sandstone (Jmj) is a discontinuous unit in the top of the Brushy Basin. The Recapture Member conformably overlies the Wanakah Formation and consists of approximately 100 ft of pink to red, banded silty sandstone and a few beds of sandy siltstone and mudstone. Overlying the Recapture Member is the cliff- and slope-forming sandstone of the Westwater Canyon Member. This member is approximately 100 ft thick and consists of buff to pale-orange sandstone and a few mudstone interbeds. The Brushy Basin Member consists of a basal mudstone unit (Jmb) of thick clayey and silty beds and thin sandstone and conglomerate lenses. The upper, sandstone unit of the Brushy Basin is the Jackpile sandstone. The Jackpile sandstone is white, pinkish gray, or yellowish gray and may be as much as 165 ft thick. It is fine to coarse grained, poorly to moderately sorted, and crossbedded.

Late Cretaceous rocks of the Dakota Sandstone and Mancos Shale are exposed in the western and southwestern parts of the study area. The lower part of the Mancos Shale has been mapped together with the Dakota Sandstone because strata from both these formations intertongue (unit Kmd, pl. 1). The upper part of the Mancos Shale (unit Km, pl. 1) has been mapped separately; it consists of gray, fossiliferous shale and a few sandstone interbeds.

Cabezon Wilderness Study Area

The most prominent feature in the study area is Cabezon Peak (7,785 ft), a volcanic plug emplaced during the late Tertiary or early Quaternary. Cabezon Peak is one of about 50 basalt and brecciated basalt necks of the Rio Puerco valley in the northeastern part of the Mount Taylor volcanic field (Hunt, 1938). Extensive erosion has exposed these volcanic necks.

Cabezon Peak is the highest and most impressive of the necks and consists of dense black basalt (unit QTb, pl. 1), jointed with columnar structure and capped with scoriaceous basalt. The jointed columns range from a few feet to 8 feet in diameter (Hunt, 1938). A talus slope of broken columns of weathered basalt (unit Qt, pl. 1) obscures the base of the neck. According to Hunt (1938), the basalt of Cabezon Peak consists of about 60 percent calcic plagioclase, 15 percent olivine, 20 percent augite, and 5 percent magnetite. It is dark gray on fresh surface and weathers brown-black. The scoriaceous basalt cap weathers red (probably due to the oxidation of magnetite). No mineralized rocks were found associated with the intrusion.

Upper Cretaceous sedimentary rocks surround the peak and were undisturbed and unaltered by the emplacement of the volcanic plug. The sedimentary formations exposed include the Mancos Shale and the Point Lookout Sandstone (units Kmu and Kp, pl. 1). In the study area these two formations intertongue and dip gently to the north. The Hosta Tongue (unit Kph, pl. 1) of the Point Lookout Sandstone consists of yellowish-orange to grayish-white, fine-grained, crossbedded sandstone. It is medium bedded and approximately 100–150 ft thick. The Hosta Tongue is separated from the main body of the Point Lookout Sandstone by the Satan Tongue (unit Kms, pl. 1) of the Mancos Shale. The Satan Tongue consists mostly of gray-black shale and siltstone and a few yellow sandstone beds. The Satan Tongue forms slopes and is approximately 400 ft thick. The main body of the Point Lookout Sandstone consists of very pale orange to light-gray, cliff-forming sandstone approximately 200 ft thick. Below the Point Lookout is the lower part of the Mancos Shale (Kmu); the various tongues of this part of the formation were not differentiated. The Mancos Shale consists of dark-gray to black, fissile shale interbedded with brownish-gray siltstone and pale-yellowish-brown sandstone. Geologic mapping indicates that the Crevasse Canyon Formation may be present beneath the study area, where it probably intertongues with the Mancos Shale. The Gibson Coal Member of the Crevasse Canyon Formation contains thin, lenticular coal beds (McLemore and others, 1984).

Geochemistry

Analytical Methods

In 1985, stream-sediment samples were collected from 27 sites in the Ojito study area (sample localities labeled JIT on pl. 1): and from 18 sites in the Cabezon study area (CP on pl. 1). All samples were taken from intermittent streams that drain the study areas. At each of these sites, a sieved fraction of silt and clay was collected to be analyzed for the presence of fine-grained minerals and metals that may have adsorbed onto clay minerals. Stream-sediment samples were sieved to minus-100 mesh (0.15 mm) to obtain the silt and clay fraction. The USGS analyzed these fine-grained samples by inductively coupled plasma atomic-emission spectroscopy (ICP) for 44 elements following the methods of Taggart and others (1981) and by delayed neutron activation for uranium and thorium following the techniques of Millard and Keaton (1982).

Eleven rock samples (localities not shown) of the basalt intrusions in the area, including Cabezon Peak, were collected in 1985. All rock samples were crushed and pulverized in the laboratory to minus-100 mesh (0.15 mm) and analyzed for 31 elements by semiquantitative optical-emission spectrography.

Results of Study

Anomalous concentrations vary with each element and are dependent on the statistical data for that element. For this data set, two to three times the mean abundance of the element was used to define anomalous values. None of the samples from either study area was anomalous in uranium, and no sample exceeded 6 ppm uranium. Six samples from the Ojito study area (JIT1, 3, 4, 6, 12, 17, pl. 1) contained low-level concentrations of silver (2–5 ppm; detection limit 2 ppm). These samples were from localities scattered throughout the study area and were not specific to one geologic formation. It is probable that mineralizing processes operated only weakly in the study area and were sufficient to cause a weak anomaly. The low-level anomalies do not present clear patterns of element enrichment. This lack of pattern is due in part to the reconnaissance nature of the sampling. Chemical analyses of stream-sediment samples from both study areas revealed no anomalous concentrations of any other element indicative of mineralization.

The analysis of basalt from Cabezon Peak revealed no anomalous concentrations of any element. The composition of this basalt is no different from other basalt intrusions in this area.

Geophysics

Aeromagnetic and gravity data were obtained from existing data files as part of the mineral resource evaluation of the Ojito and Cabezon Wilderness Study Areas. These data provide information on general surface and subsurface distribution of rock masses and structural features.

Aeromagnetic Data

The aeromagnetic data shown on figure 5 are from two different data sets and are from a compilation of magnetic data for the state of New Mexico by Cordell (1984). The Cabezon area magnetic survey was flown at 1,000 ft above ground level, and the flight lines were oriented north-south and spaced approximately 1 mi apart. The Ojito area magnetic survey was flown at a constant barometric elevation of 9,000 ft, and flight lines were oriented east-west and spaced approximately 1 mi apart. Magnetic values vary from −180 nT (nanoteslas) over the Ojito Wilderness Study Area to +160 nT over the Cabezon Wilderness Study Area. The symmetrical magnetic high near Cabezon Peak reflects the highly magnetic basalt of Cabezon Peak. Decreasing magnetic values toward the Ojito area probably reflect a thickening of nonmagnetic sedimentary rocks that would be consistent with a structural low in the basement rocks near the center of the study area. East of the Ojito study area, a steep, increasing, east-west magnetic gradient probably indicates the structural change along a mapped north-south fault near the front of the Nacimiento Mountains.

Gravity Data

Gravity data were obtained from a file collected by the U.S. Department of Defense (National Oceanic and Atmospheric Administration National Geophysical Data Center). We computed complete Bouguer gravity anomaly values using the 1967 gravity formula (International Association of Geodesy, 1967) and a reduction density of 2.67 g/cm^3 (grams per cubic centimeter). We made terrain corrections by computer for a distance of 100 mi from each station using the method of Plouff (1977). The data are shown on figure 6.

Gradation of the Bouguer values in a generally northwest direction from −202 mGal (milligals) south of the Ojito study area to −220 mGal at the northwest corner of the Cabezon study area indicates a thickening of the sedimentary section toward the San Juan Basin. At the southeast corner of the Ojito study area, a gravity high is aligned in a northeasterly direction and suggests a high basement feature that may be related to the Jemez lineament.

Results of Study

Analysis of the gravity and magnetic data did not reveal any anomalies. More detailed geophysical methods might provide information on subsurface stratigraphy that would aid in assessing the likelihood of occurrence and possibly the definition of prospective exploration targets.

Aerial Gamma-Ray 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 us with 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 Ojito Wilderness Study Area has overall low radioactivity with concentra-

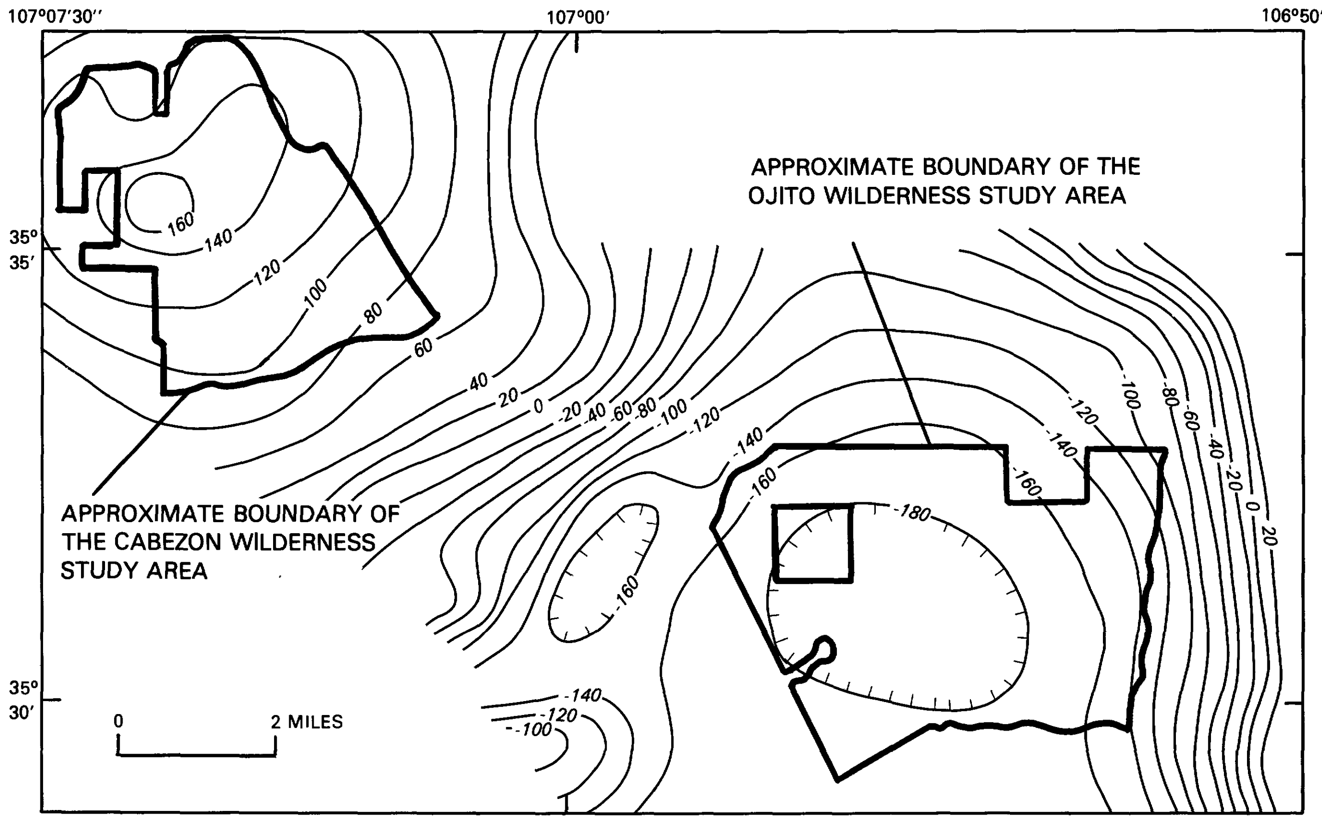


Figure 5. Map showing lines of aeromagnetic intensity in the Ojito and Cabezon Wilderness Study Areas, Sandoval County, N. Mex. Contour interval 20 nT (nanoteslas). Hachures indicate areas of magnetic lows.

tions of 1.3–2.3 percent K, 1.8–2.0 ppm eU, and 6–9 ppm eTh. The Cabezon Wilderness Study Area has overall moderate radioactivity with concentrations of 1.4–1.7 percent K, 2.3–2.5 ppm eU, and 8.5–10 ppm eTh. There are no anomalies in or near either study area.

Mineral and Energy Resources

The mineral resource potential for both wilderness 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.

The area designated as Quaternary alluvium (unit Qal; pl. 1) in both study areas is underlain by heterogeneous, poorly sorted sand and gravel. These areas have a low mineral resource potential for deposits of monomineralic or well-sorted sand and gravel for specialized uses, with a certainty level of C.

Ojito Wilderness Study Area

The mineral resource potential is moderate for uranium in the Ojito Wilderness Study Area, with a certainty level of C. Uranium mineralization in the Grants uranium region, about 25 mi to the southwest, is 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 to sandstone units of the Brushy Basin Member, including the Jackpile sandstone (Santos, 1963). The ore bodies either "float" within sandstone layers or terminate against impermeable mudstone. Mineralization is localized at oxidation-reduction boundaries. Criteria favorable for uranium mineralization in the Upper Jurassic 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)). On a smaller scale, uranium ore tends to follow zones of clay rip-up clasts along scour surfaces.

Some of the characteristics associated with the uranium ore deposits of the Grants region are common in the study area. The thick-bedded sandstone and mudstone members of the Morrison are present here. However, very little organic material exists in exposures of the Morrison Formation in the study area (Santos, 1975). This does not rule out occurrences of organic material in unexposed

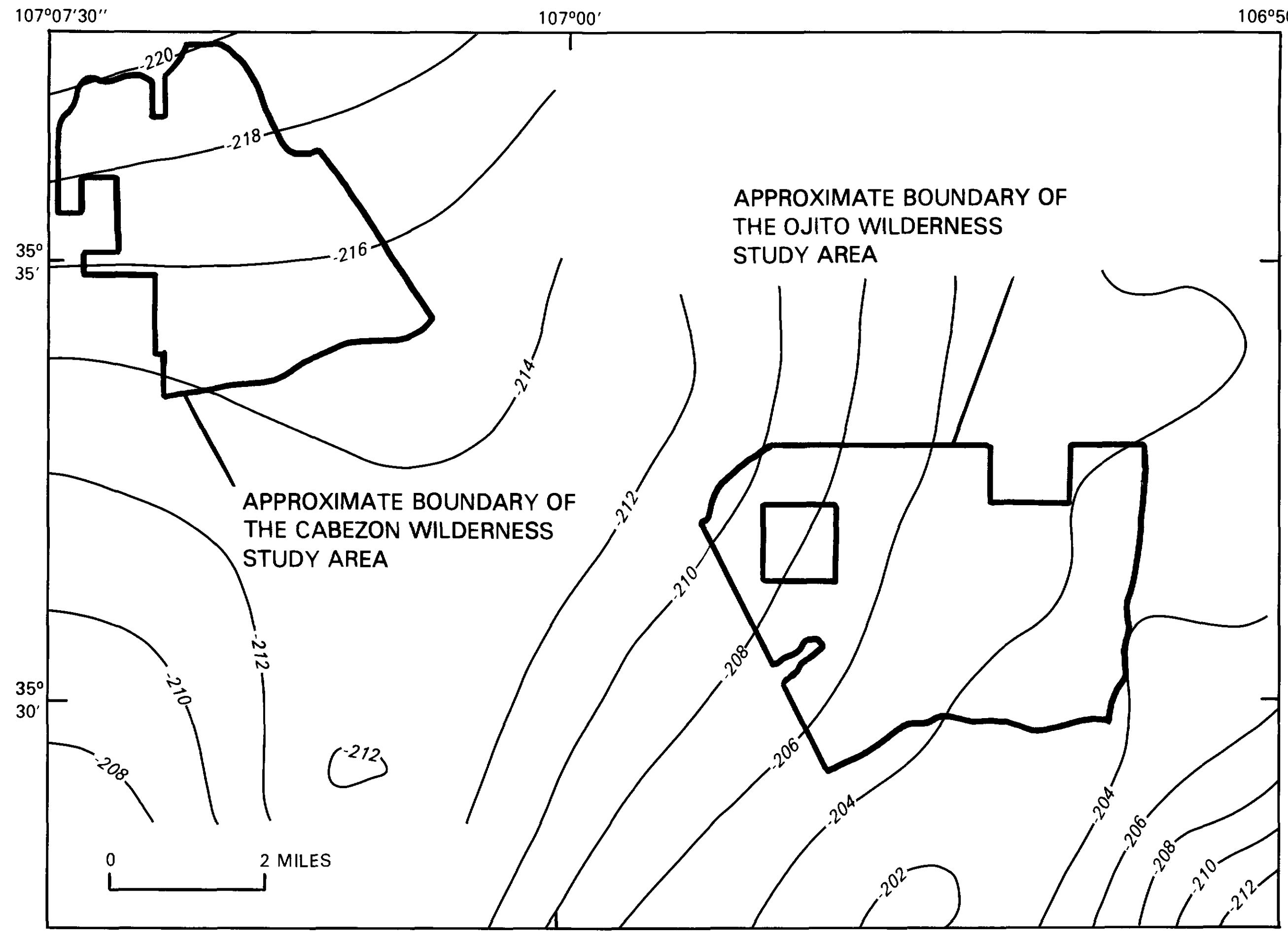


Figure 6. Map showing complete Bouguer gravity of the Ojito and Cabezon Wilderness Study Areas, Sandoval County, N. Mex. Contour interval 2 mGals (milligals).

Morrison Formation. Small localized sites in mudstone and sandstone of the Morrison Formation throughout the study area have radiation levels almost twice the background (Tuftin, 1986). The gamma-ray survey indicated that the study area has low radioactivity, and no anomalous amounts of uranium were detected in the geochemical sampling survey. Exploration for uranium has been extensive and, as of 1985, unsuccessful in and near the study area; small pits and bulldozer trenches were excavated and many holes drilled (Chenoweth, 1974; Santos, 1975).

The energy resource potential for oil and gas is low in the Ojito study area, with a certainty level of B. The study area has favorable reservoir rocks for oil and gas but lacks structural traps sufficient for accumulation. Cretaceous marine shales of the Mancos Shale formation are favorable reservoir rocks for oil and gas elsewhere in the San Juan Basin. However, these strata are exposed in the study area and are therefore susceptible to possible flushing by groundwater (Ryder, 1983). The Jurassic Entrada Sandstone and the Pennsylvanian Madera Formation are also favorable reservoir rocks for oil and gas and are present beneath the study area. According to Woodward (1983), the potential for oil and gas would be most promising where the formations are truncated by thrust and reverse faults. However, Ryder (1983) stated that formations underlying the study area have been tested without success to the Precambrian basement, and Woodward (1983) reported that the Avila Oil Corporation's No. 1 Odlum well, which is in the study area (sec. 15, T. 15 N., R. 1 W., fig. 2), encountered only a slight oil show throughout the Entrada Sandstone.

The resource potential for geothermal energy is low in the Ojito study area, with a certainty level of B. Approximately 2 sq mi of the northeastern part of the Ojito study area is included in the San Ysidro Known Geothermal Resource Area (Tuftin, 1986). There are thermal springs along Arroyo Penasco, 3–4 mi northeast of the study area (Woodward and Ruetschilling, 1976). However, no hot springs are present in the study area.

Mineral resource potential for copper and silver in the Chinle Formation is low in the subsurface of the Ojito study area, with a certainty level of B. Northeast of the study area, at the Jemez Springs and Nacimiento mining districts, copper and silver were mined from the Agua Zarca Sandstone Member of the Triassic Chinle Formation. The deposits, formed by replacement of organic material, occur as discontinous lenticular bodies in ancient stream channels (Elston, 1967). The Chinle Formation may be present beneath the study area, where it is possible that copper and silver mineralization occurred. However, more information regarding the subsurface stratigraphy is needed in order to raise the level of certainty for this type of resource.

Mineral resource potential for all other metals is low for the study area, with a certainty level of B. No minerals have been produced and no surface evidence was found to indicate metallic-mineral resources. The geochemical analyses of samples revealed no anomalous concentrations of any element indicative of mineralization.

Thin, lenticular coal beds of the Upper Cretaceous Crevasse Canyon Formation are exposed south and southwest of the study area. The Crevasse Canyon is not present in the study area. No coal beds were found at the surface of the study area. The mineral resource potential for coal is low in the study area, with a certainty level of B.

The Ojito study area has a low potential for zeolite minerals, with a certainty level of B. Zeolitic siltstone beds (generally less than 6 in. thick) were found about 10 mi north of the study area in the mudstone unit of the Brushy Basin Member (Jmb) of the Morrison Formation. Santos (1975) found that these siltsone beds contain as much as 75 percent zeolite minerals; the red siltstone contains mainly clinoptilolite, and the greenish-gray siltstone contains mainly analcime. Santos also found that the zeolitic siltstone beds are prevalent about 10 mi north of the study area and decrease to the south. Zeolitic siltstone beds of the Brushy Basin may be present in the study area, where they possibly intertongue with sandstone of the Westwater Canyon Member of the Morrison Formation. More extensive sampling and X-ray diffraction analysis is necessary to raise the level of certainty for zeolites in the study area.

Cabezon Wilderness Study Area

The Cabezon Wilderness Study Area has low mineral resource potential for all metals; certainty level is B. No mineralized outcrops were found, and the geochemistry revealed no anomalous concentrations of any elements indicative of mineralization.

The mineral resource potential is low for uranium in the Cabezon study area, with a certainty level of B. The same criteria favorable for uranium mineralization in the Ojito study area also apply to the Cabezon study area. The geologic mapping indicates that the Morrison Formation may be present beneath the study area, where it has been intruded by volcanic rock. The aerial gamma-ray survey indicated that the area has moderate radioactivity. However, no radioactive anomalies were found and the geochemistry revealed no anomalous concentrations of uranium.

Although favorable host rocks (Pennsylvanian strata) may be present beneath the surface of the study area, the mineral resource potential for oil and gas is low, with a certainty level of B. These favorable reservoir rocks were intruded by a volcanic plug (late Tertiary and early Quaternary) that probably raised the paleotemperature above the limits for the preservation of oil and gas. Cretaceous marine shales, also favorable as reservoirs, are exposed in the study area and are therefore susceptible to possible flushing by ground water (Ryder, 1983).

The Cretaceous Gibson Coal Member of the Crevasse Canyon Formation may be present beneath the study area, where it probably intertongues with the Mancos Shale. Southwest of the study area, the coal beds in the Gibson Coal Member are thin and lenticular (McLemore and others, 1984). The mineral resource potential for coal is low in the study area because coal beds in the Gibson are discontinuous; certainty level is B.

No hot springs or other geothermal sources were noted during this investigation. The energy resource potential is low for geothermal sources, with a certainty level of B.

REFERENCES CITED

Chenoweth, W.L., 1974, Uranium occurrences of the Naciemento-Jemez region, Sandoval and Rio Arriba Counties, New Mexico: New Mexico Geological Society Guidebook, 25th Field Conference, Ghost Ranch, p. 309–313.

Cordell, Lindrith, 1984, Composite residual total intensity aeromagnetic map of New Mexico: National Oceanic and Atmospheric Administration Geothermal Resources of New Mexico, Scientific Map Series, scale 1:500,000.

Elston, W.E., 1967, Summary of the mineral resources of Bernalillo, Sandoval, and Santa Fe Counties, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 81, 81 p.

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.

Hunt, C.B., 1938, Igneous geology and structure of the Mount Taylor volcanic field, New Mexico: U.S. Geological Survey Professional Paper 189–B, 79 p.

International Association of Geodesy, 1967, Geodetic Reference System, 1967: International Association of Geodesy Special Publication No. 3, 116 p.

Logsdon, M.J., 1982, Gypsum resources of New Mexico, *in* Austin, G.S., ed., Industrial rocks and minerals of the Southwest: New Mexico Bureau of Mines and Mineral Resources Circular 182, p. 43–48.

Mayo, E.B., 1958, Lineament tectonics and some ore districts of the Southwest: American Institute of Mining, Metallurgy, and Petroleum Engineers Transcript, p. 1169–1175.

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.

Millard, H.T., Jr., and Keaton, B.A., 1982, Precision of uranium and thorium determinations by delayed neutron counting: Radioanalytical Chemistry Journal, v. 72, p. 489–500.

Plouff, Donald, 1977, Preliminary documentation for a FORTRAN program to compute gravity terrain corrections based on topography digitized on a geographic grid: U.S. Geological Survey Open-File Report 77–535.

Reed, A.H., 1975, Gypsum, *in* Mineral facts and problems: U.S. Bureau of Mines Bulletin 667, p. 469–477.

Roberts, D.B., Krason, Jan, and Rizo, J.A., 1982, Geology, energy, and mineral (GEM) resources assessment of the San Luis Area, New Mexico: Geoexplorers International, Inc., Denver, Colo.; prepared for the U.S. Department of the Interior, Bureau of Land Management, 75 p.; unpublished report available from U.S. Bureau of Land Management, Albuquerque District Office, P.O. Box 6770, Albuquerque, NM 87107.

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, p. I1–I32.

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.

———1975, Lithology and uranium potential of Jurassic formations in the San Ysidro–Cuba and Majors Ranch areas, northwestern New Mexico: U.S. Geological Survey Bulletin 1329, 22 p.

Swanberg, C.A., 1980, Geothermal resources of New Mexico: Las Cruces, N. Mex., Energy Institute at New Mexico State University, scale 1:500,000.

Taggart, J.E., Jr., Lichte, F.E., and Wahlberg, J.S., 1981, Methods of analysis of samples using X-ray fluorescence and induction-coupled plasma spectroscopy, *in* Lipman, P.W., and Mullineaux, D.R., eds., The 1980 eruptions of Mount St. Helens, Washington: U.S. Geological Survey Professional Paper 1250, p. 683–687.

Tuftin, S.T., 1985, Mineral investigation of the Cabezon Wilderness Study Area (NM–010–022), Sandoval County, New Mexico: U.S. Bureau of Mines Open File Report MLA–60–85, 7 p.

———1986, Mineral investigation of the Ojito Wilderness Study Area (NM–010–024), Sandoval County, New Mexico: U.S. Bureau of Mines Open File Report MLA–20–86, 11 p.

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, no. 22, p.47–76

Turner-Peterson, C.E., Santos, E.S., and Fishman, N.S., 1986, A basin analysis case study—The Morrison Formation, Grants uranium region, New Mexico: American Association of Petroleum Geologists Studies in Geology, no. 22, 391 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.

Woodward, L.A., 1983, Potential oil and gas traps along the overhang of the Nacimiento uplift, Northwestern New Mexico, *in* Lowell, J.D., ed., Rocky Mountain foreland basins and uplifts: Denver, Colo., Rocky Mountain Association of Geologists, p.213–218.

Woodward, L.A., and Ruetschilling, R.L., 1976, Geology of San Ysidro quadrangle, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 37, scale 1:24,000.

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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.

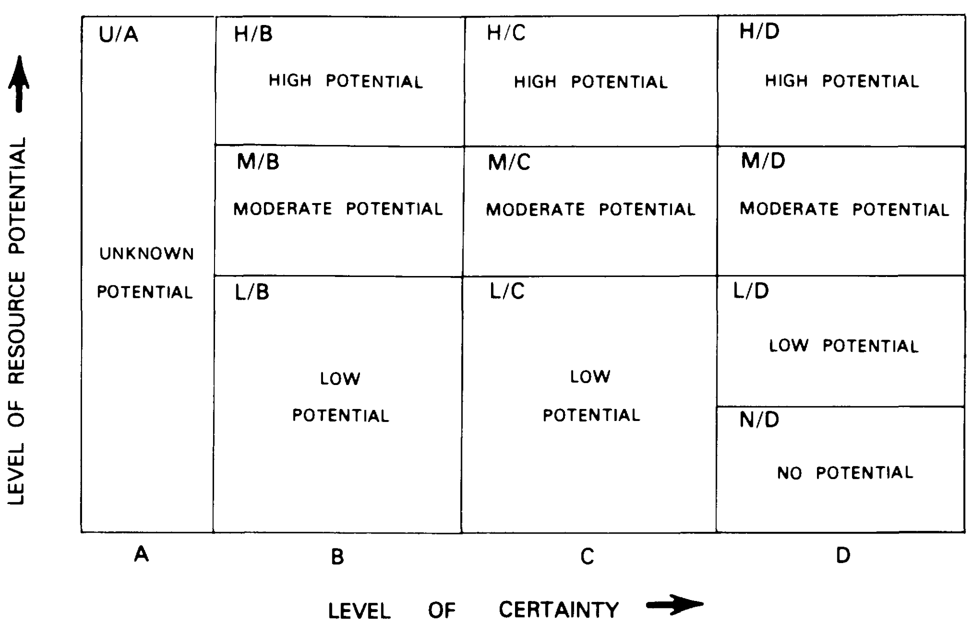
MODERATE mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence, where interpretations of data indicate a reasonable likelihood of resource accumulation, and (or) where an application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

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 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.