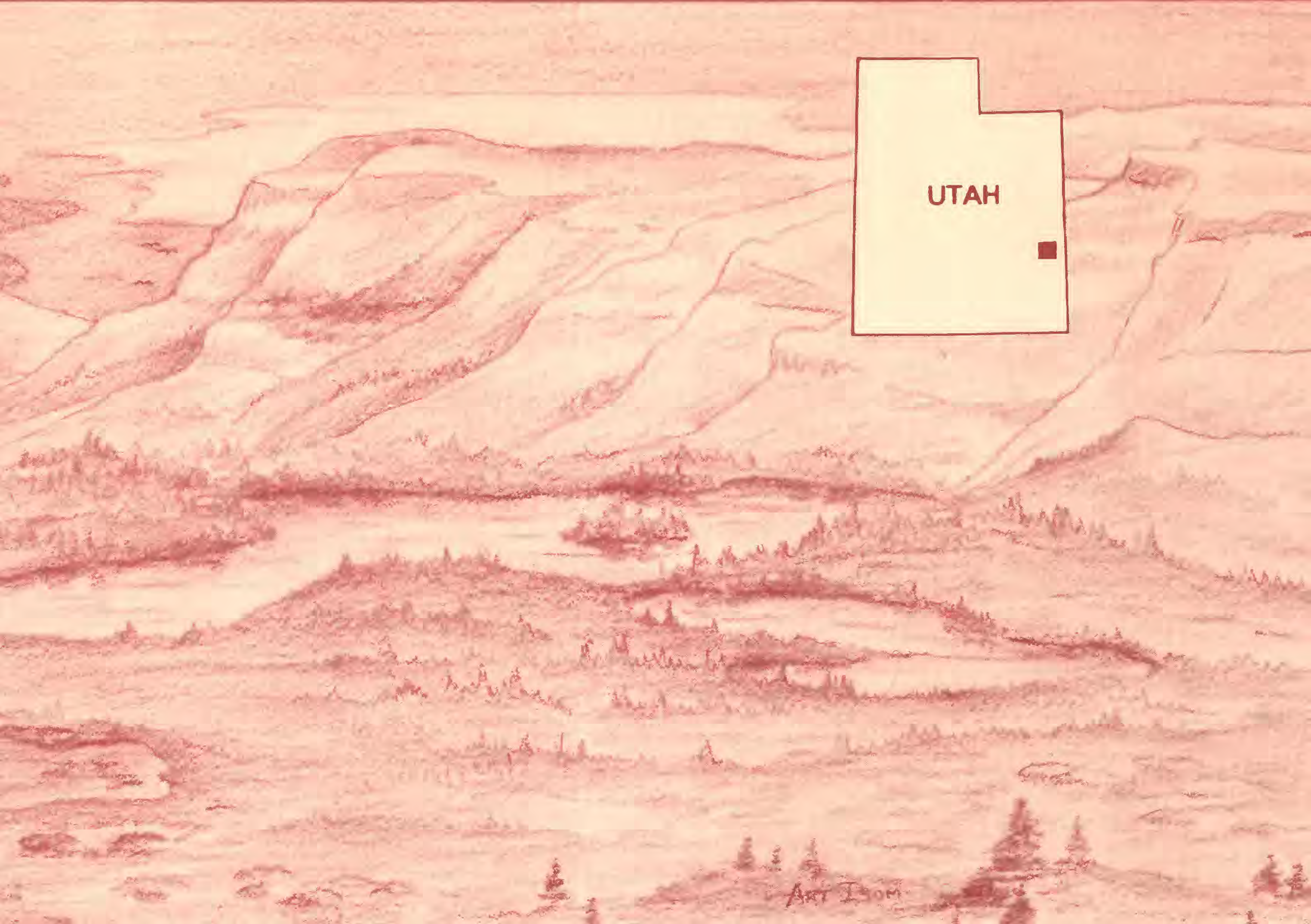
Mineral Resources of the Behind the Rocks Wilderness Study Area, Grand and San Juan Counties, Utah

U.S. GEOLOGICAL SURVEY BULLETIN 1754-B



Chapter B

Mineral Resources of the Behind the Rocks Wilderness Study Area, Grand and San Juan Counties, Utah

By CHARLES G. PATTERSON, MARGO I. TOTH,
JAMES E. CASE, GREGORY N. GREEN,
and HARLAN N. BARTON
U.S. Geological Survey

JOHN R. THOMPSON
U.S. Bureau of Mines

U.S. GEOLOGICAL SURVEY BULLETIN 1754

MINERAL RESOURCES OF WILDERNESS STUDY AREAS—
UPPER COLORADO RIVER REGION, UTAH

DEPARTMENT OF THE INTERIOR
DONALD PAUL HODEL, Secretary

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

UNITED STATES GOVERNMENT PRINTING OFFICE: 1988

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

Any use of trade names in this report is for descriptive purposes only and does not imply endorsement by the U.S. Geological Survey or the U.S. Bureau of Mines.

Library of Congress Cataloging-in-Publication Data

Mineral resources of the Behind the Rocks Wilderness Study Area, Grand and San Juan Counties, Utah.

(Mineral resources of wilderness study areas—upper Colorado River region, Utah ; ch. B) (U.S. Geological Survey bulletin ; 1754–B)
Bibliography: p.
Supt. of Docs. no.: I 19.3:1754–B
1. Mines and mineral resources—Utah—Behind the Rocks Wilderness.
2. Behind the Rocks Wilderness (Utah) I. Patterson, Charles G.
II. Series. III. Series: U.S. Geological Survey bulletin ; 1754–B.
QE75.B9 no. 1754–B 557.3 s [553'.09792'58] 88–600384
[TN24.U8]

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 Behind the Rocks Wilderness Study Area (UT–060–140A), Grand and San Juan Counties, Utah.

CONTENTS

PLATE

[Plate is in pocket]

FIGURES

Mineral Resources of the Behind the Rocks Wilderness Study Area, Grand and San Juan Counties, Utah

By Charles G. Patterson, Margo I. Toth, James E. Case,
Gregory N. Green, *and* Harlan N. Barton
U.S. Geological Survey

John R. Thompson
U.S. Bureau of Mines

ABSTRACT

The Behind the Rocks Wilderness Study Area (UT–060–140A) consists of 12,635 acres in Grand and San Juan Counties, Utah. The study area has inferred subeconomic resources of potash and halite in the subsurface, and sandstone on the surface. The study area has high potential for undiscovered resources of oil and gas, low potential for undiscovered uranium, copper, vanadium, gold, silver, other metals, and geothermal energy, and unknown potential for the rare-earth mineral, braitschite. There is no resource potential for potash or halite (beyond the previously mentioned inferred resources) or for coal.

SUMMARY

Character and Setting

The Behind the Rocks Wilderness Study Area consists of 12,635 acres in Grand and San Juan Counties, Utah. Moab, just northeast of the study area, is the nearest town. A joint mineral appraisal of the study area was conducted in 1986 and 1987 by the U.S. Bureau of Mines and the U.S. Geological Survey.

Access to the perimeter of the study area is by graded and unimproved roads leading from U.S. Highway 191 on the northeast, southeast, and south. The Kings Bottom road provides access on the north, west, and southwest, and the trail in Pritchett Canyon leads to the southwestern boundary. Travel within the study area is by foot only.

Manuscript approved for publication, July 22, 1988.

The Behind the Rocks Wilderness Study Area is in the Canyonlands section of the Colorado Plateaus physiographic province and the Paradox Basin fold-and-fault belt. This fold-and-fault belt is characterized by a series of mainly northwest-trending, salt-cored anticlinal or dome-shaped structures, many of which have collapsed crests that resulted from dissolution of the upper part of the salt core. The study area is on the southwestern limb of the Spanish Valley salt anticline, and the spectacular Moab Rim (fig. 1) is the fault scarp along the southwestern side of the collapsed crest of the anticline.

In the study-area vicinity, sedimentary rocks of the Lower Jurassic (see the geologic time chart in the Appendix) Glen Canyon Group overlie the Upper Triassic Chinle Formation, Lower Triassic Moenkopi Formation, and Lower Permian Cutler Formation. Rock units in the subsurface include more than 5,000 ft (feet) of Cambrian to Middle Pennsylvanian age rocks, which include the Middle Pennsylvanian Paradox Member of the Hermosa Formation and the Mississippian Leadville Limestone. The Paradox Member consists of several thousand feet of interbedded evaporites containing potash and clastic and carbonate rocks. The Leadville consists of a few hundred feet of limestone. Both formations contain porous zones and may be reservoirs for oil and gas, because oil and gas are produced from these horizons in nearby areas.

Identified Resources

No evidence of past mining activity was found within the Behind the Rocks Wilderness Study Area. Just outside of the northwestern boundary of the study area, along the Kings Bottom road, large-diameter excavations were made into the Navajo Sandstone to provide storage for nearby land owners. Inferred subeconomic resources of sandstone,

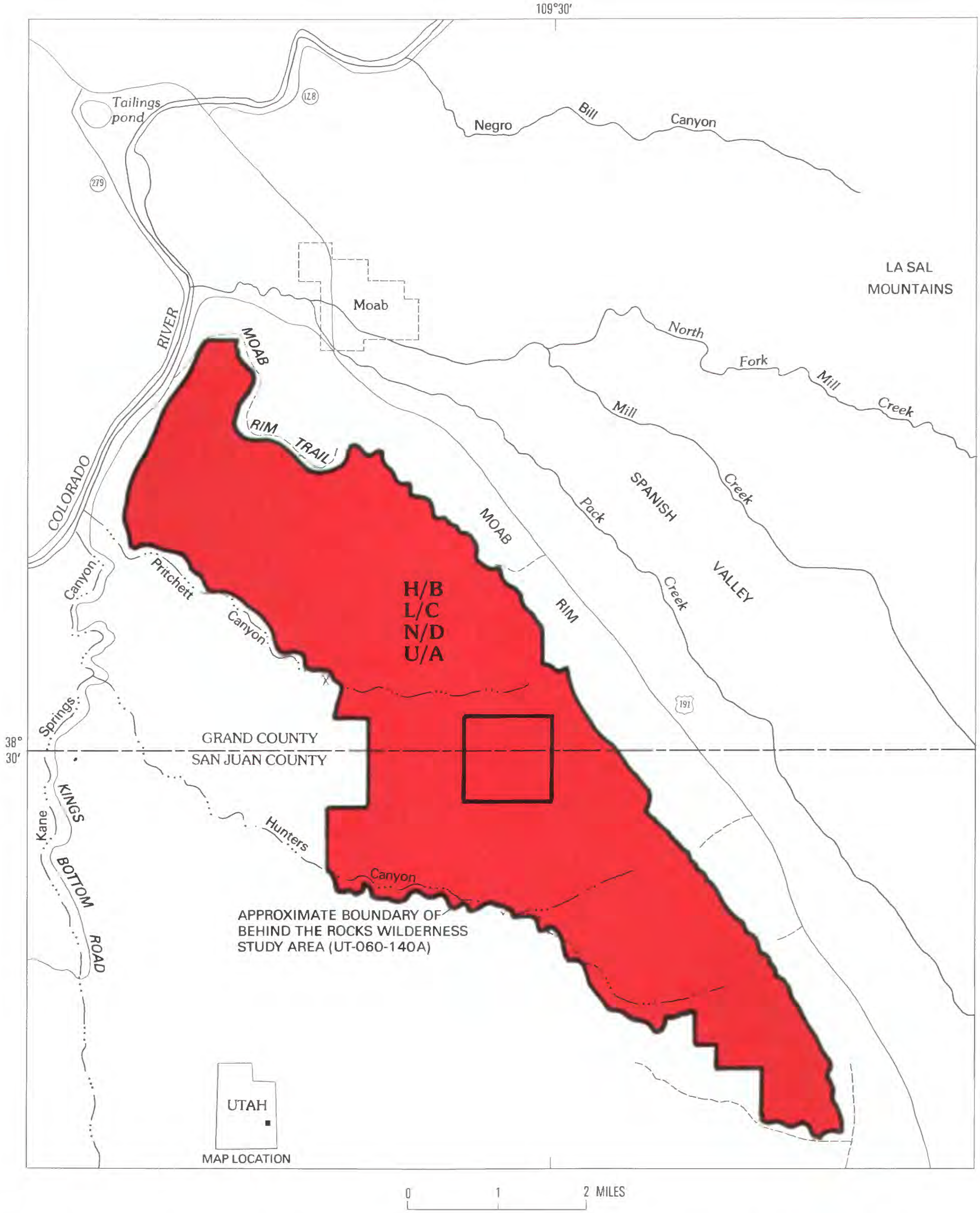


Figure 1 (above and facing page). Map showing mineral resource potential and location of the Behind the Rocks Wilderness Study Area, Utah.

EXPLANATION

[Entire wilderness study area has inferred subeconomic resources of potash and halite in the subsurface]

H/B	Geologic terrane having high resource potential for oil and gas with certainty level B—Applies to entire study area
L/C	Geologic terrane having low resource potential for uranium, copper, vanadium, gold, silver, other metals, and geothermal energy, with certainty level C—Applies to entire study area
N/D	Geologic terrane having no mineral resource potential for additional potash and halite, or coal, with certainty level D—Applies to entire study area
U/A	Geologic terrane having unknown mineral resource potential for rare-earth mineral braitschite, with certainty level A—Applies to entire study area
------	Unimproved road
X	Site of gold- and silver-bearing panned-concentrate sample
	Levels of certainty
A	Available information not adequate to define mineral resource potential
B	Available information suggests level of mineral resource potential
C	Available information gives good indication of level of mineral resource potential
D	Available information clearly defines level of mineral resource potential

suitable for construction purposes, exist in the study area. Sand and gravel have been produced from the Colorado River flood plain adjacent to the northern and northwestern boundaries of the study area, but only small sand and gravel occurrences unrelated to the Colorado River are found in the study area.

Potash leases are 2 to 3 mi (miles) west of the study area, where potash and halite are currently (1988) being mined from the Paradox Member of the Hermosa Formation at the Cane Creek mine. Potash and halite are produced by solution mining of evaporite beds that are between 3,000 to 3,500 ft deep and are dried by solar evaporation. Based on geologic evidence from oil-well drilling, inferred subeconomic resources of potash and halite underlie the study area.

Three blocks of unpatented lode claims were located for uranium in the study area. In the past, uranium was mined northwest, west, and southeast of the study area, but no uranium occurrences were found on the surface in the study area.

Potential for Undiscovered Resources

The potential for undiscovered resources was assessed by geologic, geochemical, geophysical, and remote-sensing studies. Rocks and stream-sediment samples from the study area and vicinity contained no anomalous concentrations of metals, with the exception of one stream-sediment sample taken from near Pritchett Natural Bridge outside the study area. This sample contained gold and silver; the gold was possibly from a paleoplacer deposit. Remote-sensing studies utilizing satellite imagery disclosed no false-color anomalies indicative of metallic deposits or of structures indicative of oil and gas accumulations.

The Behind the Rocks Wilderness Study Area has high resource potential for oil and gas. Favorable source beds, reservoir rocks, and structures lie beneath the study area. Some gas shows have been reported from a well adjacent to the northeastern boundary, but no production has occurred. No drilling has occurred within the study area, but part of the study area is under lease for oil and gas. Oil and gas have been produced south, west, and southeast of the study area, and the nearest producing field is less than 5 mi south.

The resource potential for uranium, copper, and vanadium is low, despite the presence of the Chinle and Cutler Formations, which host nearby deposits. No geochemical or radiometric anomalies were detected, and favorable host rocks for uranium are absent from the study area. The resource potential for gold and silver is low, based on the isolated occurrence of one geochemically anomalous sample. The resource potential for all other metals is low, based on geologic evidence and a lack of geochemical anomalies.

The resource potential for geothermal energy is low, based on low heat-flow values for the region and lack of thermal springs. There is no resource potential for coal, because no coal-bearing formations were found in the study area at the surface, and none are known or expected in the subsurface. The Paradox Member of the Hermosa Formation, which underlies the study area, is known to contain the rare-earth mineral braitschite elsewhere, but the resource potential for braitschite in the Paradox Member is considered to be unknown, based on lack of exploration and a suitable conceptual model of resource accumulation or formation in the study area. There is no resource potential for potash or halite, beyond the inferred resources mentioned above.

INTRODUCTION

The Behind the Rocks Wilderness Study Area consists of 12,635 acres in Grand and San Juan Counties, southeastern Utah (fig. 1). The study area is just southeast of the Colorado River and is southwest of Spanish Valley. The sheer northeast-facing cliff along the northeastern side of the study area is known as the Moab Rim. Rock fins, domes, and knobs, alternating with sandy stream washes, make up the topography of the rest of the study area. Elevations in the study area range from a high of 6,530 ft, above the cliff face, to a low of 3,990 ft, at the mouth of Pritchett Canyon.

No perennial streams are present in the study area. Dry washes drain into Pritchett and Hunters Canyons on the south and west, and bare rock surfaces slope northeast from the Moab Rim. The only permanent spring is in the west-central part of the study area, but several others, such as Kings Bottom Spring, are just outside the study-area boundary (pl. 1).

Vehicle access to the study area is limited to perimeter roads. U.S. Highway 191 is northeast of the study area in Spanish Valley, and several short graded dirt roads lead to the area boundary. The Moab Rim trail and Pritchett Canyon road, on the northern and western sides of the study area, may be reached by the powerline access road (Kings Bottom road), which ultimately becomes Kane Springs Canyon road. Few established foot trails are in the study area, because the rock fins are very steep.

This report presents an evaluation of the mineral endowment (identified resources and mineral resource potential) of the study area and is the product of several separate studies by the U.S. Bureau of Mines (USBM) and the U.S. Geological Survey (USGS). Identified resources are classified according to the system of the U.S. Bureau of Mines and U.S. Geological Survey (1980), which is shown in the Appendix of this report. Identified resources are studied by the USBM. Mineral resource potential is the likelihood of occurrence of undiscovered metals and nonmetals, industrial rocks and minerals, and of energy sources (coal, oil, gas, oil shale, and geothermal). It is classified according to the system of Goudarzi (1984) and is shown in the Appendix. Mineral resource potential is studied by the USGS.

Investigations by the U.S. Bureau of Mines

The Behind the Rocks Wilderness Study Area was examined by the USBM in 1986 (Thompson, 1987). In November 1985, prior to the field investigation, a detailed literature search was made for pertinent geologic, mining, and land-status information. U.S. Bureau of Land Management records were checked for the location of patented and unpatented claims, and for oil and gas leases and potash leases in or near the study area.

Field studies included investigations of prospects, claims, and geologic structures. A total of six rock samples were taken from tunnels in the Navajo Sandstone and outcrops of Kayenta Sandstone. Samples were analyzed for uranium by fluorimetry and for vanadium by inductively coupled plasma-atomic emission spectroscopy; analyses were by Bondar-Clegg of Lakewood, Colo. Detailed information and sample data are available from the U.S. Bureau of Mines, Intermountain Field Operations Center, Building 20, Denver Federal Center, Denver, Colo.

Investigations by the U.S. Geological Survey

A mineral resource assessment of the study area was conducted by the USGS in 1986 and 1987. This assessment consisted of preparation of a geologic map at a scale of 1:50,000 (modified from Huntoon and others, 1982; Weir and others, 1961; and Baker, 1933), rock and stream-sediment sampling, ground radiometric surveys, stratigraphic and sedimentologic analysis, remote-sensing study, and geophysical studies of regional gravity and magnetism.

Acknowledgments.—We gratefully acknowledge the assistance and cooperation of personnel in the U.S. Bureau of Land Management offices in Moab and the staff of Arches National Park. A.M. Leibold, A.M. Wilson, D.J. Maloney, G.A. Desborough, R.B. Vaughn and J.M. Nishi of the U.S. Geological Survey provided valuable assistance in various phases of the study. Local residents, particularly Libby Nance of Moab, provided assistance in locating trails and access to the study area.

APPRAISAL OF IDENTIFIED RESOURCES

By John R. Thompson
U.S. Bureau of Mines

Mining History

The Behind the Rocks Wilderness Study Area is in the Moab uranium district. This district is divided into smaller areas of different uranium-containing formations that have produced ore near the study area. Vanadium and uranium minerals were first recognized in the Salt Wash Member of the Morrison Formation in 1909, and the first recorded production was of vanadium in 1911. Five miles southeast of the study area, 87,000 tons of ore having an average grade of 1.6 percent V_2O_5 and 0.27 percent U_3O_8 were mined from the Salt Wash Member of the Morrison Formation. Uranium deposits were discovered in other formations in 1948. Nine miles northwest of the study area, 206,000 tons of ore having an average grade of 0.26 percent U_3O_8 were produced from the Shinarump Member of the Chinle Formation. Eight miles west of the study area, somewhat less than 100,000 tons of ore were mined from deposits in the Moss Back Member of the Chinle Formation. (See Chenoweth, 1975.)

Potash was discovered in the Paradox Basin of southeastern Utah in 1924. The potash deposits occur in the "saline facies" of the Paradox Member of the Hermosa Formation of Pennsylvanian age. Exploration for potash was concentrated on folds such as the Cane Creek anticline (fig. 2), the northwestern part of the Moab Valley anticline, and the Lisbon Valley anticline. The Cane Creek mine, of Texasgulf, Inc., is on the northeastern flank of the Cane Creek anticline, about 3 mi west of the study area. The potash bed is at depths of 3,000 to 3,500 ft (Raup and others, 1967, p. C38).

The Cane Creek mine was started by sinking a shaft in 1964 and began ore production in 1965. In 1971, the mining operation was converted from conventional room and pillar to solution mining because of methane gas, high temperature, and a contorted, undulating potash bed. By 1975 the mine was producing at a rate of about 1,000 tons per day (Phillips, 1975). The estimated annual capacity from the mine is 110,000 metric tons of K_2O equivalent (Searls, 1985, p. 619).

The Paradox Basin, which underlies the Behind the Rocks Wilderness Study Area, contains salt deposits, including potash and halite, of Pennsylvanian age and also oil and gas in places. Oil and gas leases (fig. 3) cover about 1,750 acres of the study area, and oil and gas wells have been drilled nearby. Twelve oil fields are in the region. West of the study area, wells in six of the fields reach the petroliferous Pennsylvanian Hermosa Formation at average depths of 7,500 ft. One of the fields is producing, one is shut in, and four are abandoned. Twelve miles southeast of the study area, wells in six of the fields reach the petroliferous Mississippian Leadville Limestone at average depths of 7,000 ft. Five of these fields are producing and one is shut in. The oil and gas traps are structural and stratigraphic. (See Clem and Brown, 1984.)

Placer gold currently is being recovered as a byproduct from sand-and-gravel operations on the flood plain of the Colorado River near Moab. These gold-bearing gravels lie outside the study area, and only small sand-and-gravel occurrences, unrelated to the Colorado River, are in stream beds in the study area.

Mineral Appraisal

Potash and Halite

Salt deposits, including potash and halite, occur in the "saline facies" of the Paradox Member of the Hermosa Formation. The areal extent of the "saline facies" is about 11,000 square miles, nearly two-thirds of which contains potash at depths ranging from 1,700 to 14,000 ft below the surface. (See Hite, 1961, p. D135.)

According to the stratigraphic column of Huntoon and others (1982), the "saline facies" may underlie the Behind the Rocks Wilderness Study Area at a depth greater than 4,500 ft. Folding and faulting in the region have exposed salt formations in the Spanish Valley, adjacent to the Behind the Rocks Wilderness Study Area. Folding in the area may have thickened the potash bed and brought it closer to the surface. Potash and halite in the subsurface of the study area are rated as inferred subeconomic resources because of geologic evidence. To accurately determine if resources of potash and halite are buried under the study areas, drilling would be required to prove thickness and depth of beds.

The structural complexities are a formidable barrier to underground mining. For reasons of economics, depths to potash cannot exceed 4,000 ft, and the potash beds should be thick enough (more than 8 ft) to accommodate mechanized operations. Two areas near Moab that meet the above conditions are the Spanish Valley and Gibson Dome (Ritzma and Doelling, 1969, p. 31). Spanish Valley abuts the northeast boundary of the Behind the Rocks Wilderness Study Area.

Because solution mining of potash is currently (1988) being done at the Cane Creek mine, this method of mining is a viable means of recovering potash below practical mining depths. Problems with development would be water supply, conflict with oil and gas operations, and the relatively low price of potash from Canada. In 1986, the United States produced 1,100,000 metric tons of K_2O, worth about $140 million. The United States imported 4,400,000 metric tons (about 78 percent of its needs) in 1986, mostly from Canada. The average price per metric ton in 1986 was $92 (Searls, 1987, p. 120–121).

Uranium

The Behind the Rocks Wilderness Study Area contains parts of three blocks of mining claims, according to records on file with the Bureau of Land Management as of May 1985.

The YCW claims in the southern end of the study area are on Navajo Sandstone and uranium-bearing Salt Wash and Brushy Basin Members of the Morrison Formation. The part of the claims underlain by the Morrison Formation lies outside the study area in a northeast-trending, down-dropped fault block. The Morrison Formation (and any uranium minerals within it) has been eroded from the study area. Scintillometer readings of the Navajo Sandstone in this area were not significantly higher than background.

The Cobre claims in the southwestern part of the study area, in Hunters Canyon, are on the Kayenta Formation. Scintillometer readings in the canyon ranged from a background level of 45 cps (counts per second) to 210 cps in the bottom of the canyon. A sample of sandstone from the Kayenta contained 2 ppm (parts per million) uranium and 22 ppm vanadium, which are normal for this formation.

The Osage claims in the northern part of the study area are on Navajo Sandstone. Scintillometer readings of the sandstone ranged from a background level of 55 cps to 185 cps. Openings in the Navajo Sandstone, along the Kings Bottom road by the Colorado River, were made for storage by local landowners. Four chip samples from the tunnels ranged from 0.8 to 3 ppm uranium and 13 to 34 ppm vanadium, which are average background amounts

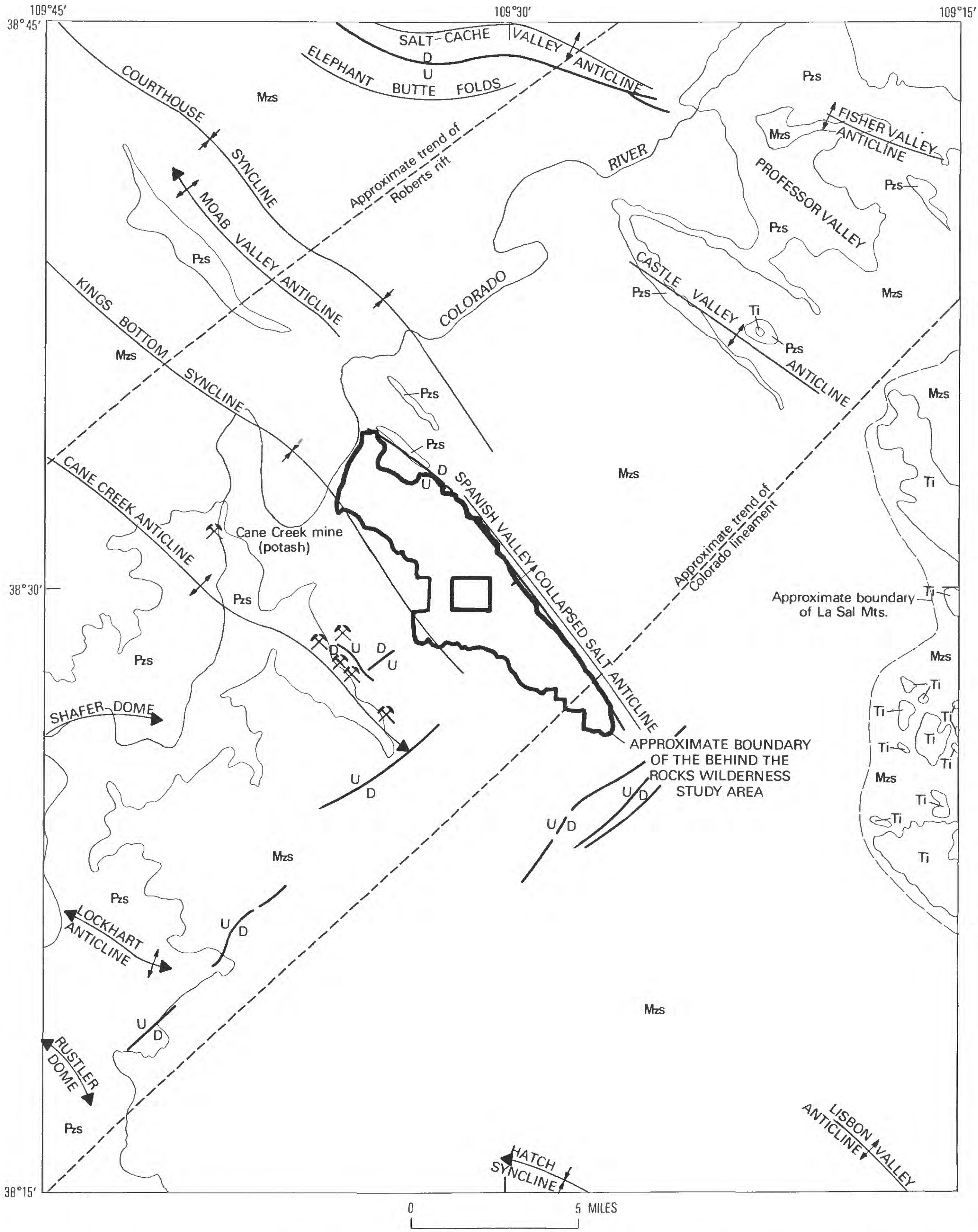


Figure 2 (above and facing page). Map showing generalized geology of the Behind the Rocks Wilderness Study Area, Utah. From Williams (1964).

EXPLANATION

Ti	Tertiary igneous rocks
Mzs	Mesozoic sedimentary rocks
Pzs	Paleozoic sedimentary rocks
	Contact
U / D	Fault—Dashed where approximately located; U, upthrown side; D, downthrown side
	Anticline—Showing direction ot plunge
	Syncline—Showing direction of plunge

for this rock type. Neither the Kayenta Formation nor the Navajo Sandstone are known to be uranium bearing. No uranium resource was identified.

Common Industrial Materials

Inferred subeconomic resources of sandstone exist in the study area, but similar sandstone, suitable for construction purposes, exists throughout the region. Terrace and flood-plain deposits of sand and gravel occur just outside the northern and northwestern boundaries of the study area along the Colorado River.

ASSESSMENT OF POTENTIAL FOR UNDISCOVERED RESOURCES

By Charles G. Patterson, Margo I. Toth, James E. Case, Harlan N. Barton, and Gregory N. Green
U.S. Geological Survey

Geology

Beginning with the classic work of J.W. Powell (1875), the Colorado Plateaus physiographic province has been the subject of many geologic studies. The geology of the study area was described by Baker (1933), Kelly (1955), Cater (1970), and Lohman (1974, 1975). Compilations include work edited by Wiegand (1981) and Fassett (1975). Compilations of regional mapping include Williams (1964) and Huntoon and others (1982).

The study area is within the salt anticline region of the Paradox Basin (Kelley, 1955; Cater, 1970) subdivision of the Canyon Lands District of the Colorado Plateaus province (Fenneman, 1931).

Rocks exposed in the study area consist primarily of the Lower Jurassic Glen Canyon Group[1] (Litwin, 1986; Pipiringos and O'Sullivan, 1978), which consists, in ascending order, of the Wingate Sandstone, the Kayenta Formation, and the Navajo Sandstone. These overlie the Upper Triassic Chinle Formation. Rocks in the subsurface probably include the Lower and Middle(?) Triassic Moenkopi Formation, the Lower Permian Cutler Formation, the Middle and Upper Pennsylvanian Hermosa Formation, including the Paradox Salt Member and the Molas Formation, the Lower Mississippian Leadville Limestone, and a section of lower Paleozoic limestone, sandstone, and shale. The entire section is 5,000–6,000 ft thick and overlies a lithologically heterogeneous Precambrian crystalline basement (Case and Joesting, 1972).

Of primary economic interest in the study area is the Paradox Member of the Hermosa Formation. The saline facies of the Paradox Member consists of about 29 evaporite cycles. A single complete cycle consists of, in order of deposition, (1) limestone, (2) dolomite, (3) anhydrite, and (4) halite, with or without potassium salts. This sequence repeats in reverse order to complete the cycle. Black shale, mudstone, and siltstone also occur as interbeds. All cycles are not complete, and due to shifting of the depocenter of the basin, the boundaries of the halite and (or) potash-bearing zone may shift from cycle to cycle. Chemical sedimentation proceeded to the point of potash deposition in 18 of the 29 recorded cycles.

Structural features of the study area trend northwest and northeast and reflect regional structural trends that probably originated in the Early Proterozoic. Northwest-trending fractures may be part of the Olympic-Wichita lineament (Baars and Stevenson, 1981). Northeast-trending fractures, known locally as the Roberts rift, are probably part of the Colorado lineament (Warner, 1978; Hite, 1975). These Precambrian lineaments have subsequently been reactivated, perhaps several times.

Geologic structures in and near the study area consist of salt structures (domes or swells and collapsed anticlines) and several kinds of igneous intrusions, all superimposed on the relatively flat-lying strata of the Colorado Plateau. The study area is on the southwestern limb of the Spanish Valley collapsed salt anticline (fig. 2). Plastic flow of great thicknesses of salt at depth, coupled with dissolution of near-surface salt, produced this feature. Depositional thickness of the salt in the salt

[1] The age of the Glen Canyon Group (Wingate, Navajo, and Kayenta Formations) has been under study for many years. Current work indicates the Group is entirely of Early Jurassic age (Pipiringos and O'Sullivan, 1978; Litwin, 1986).

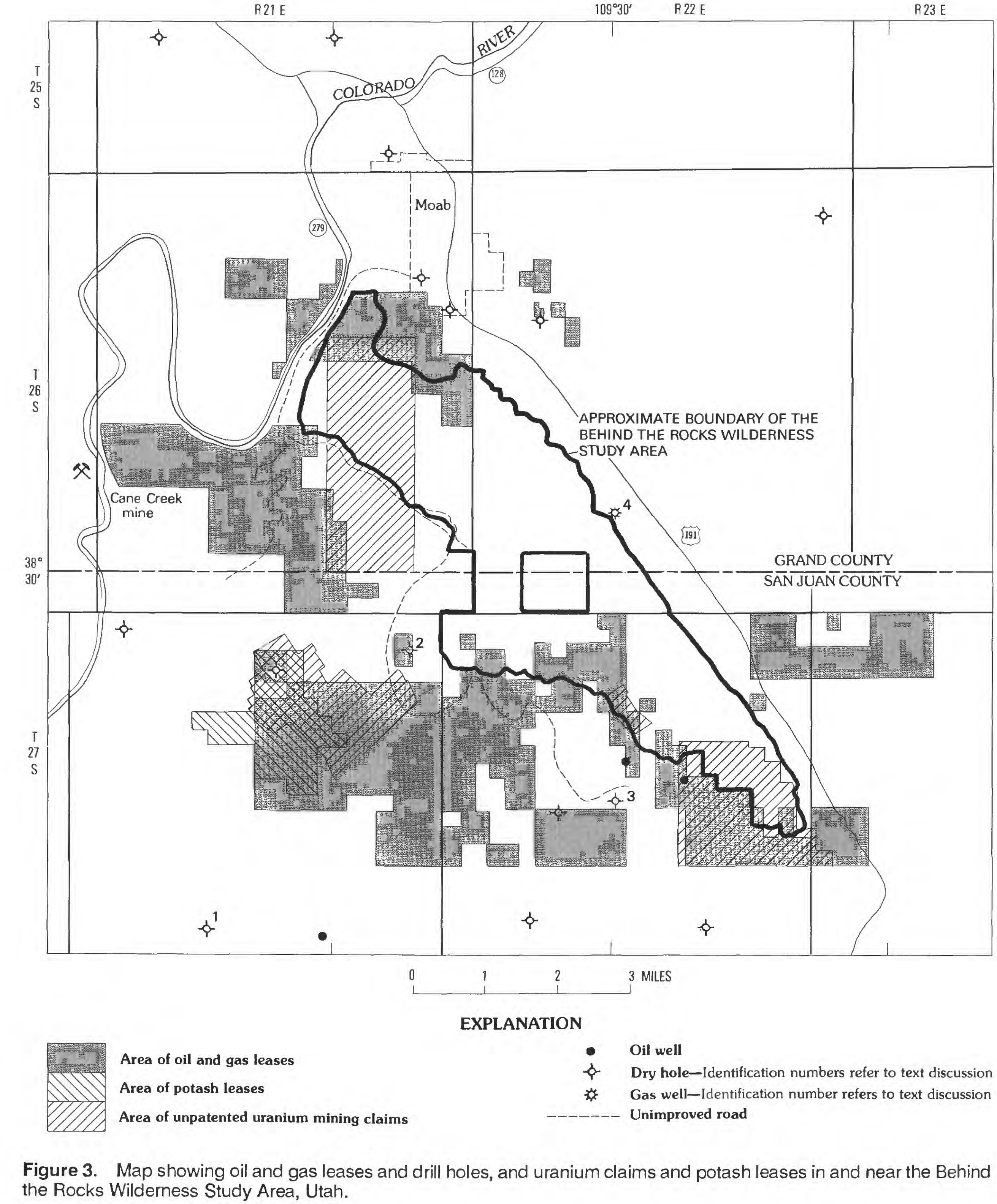


Figure 3. Map showing oil and gas leases and drill holes, and uranium claims and potash leases in and near the Behind the Rocks Wilderness Study Area, Utah.

structures is difficult to assess, but total thickness may have exceeded 5,000 ft in deeper parts of the depositional basin, especially the northeastern part (Hite and Lohman, 1973).

Salt structures are of two types: diapiric, which pierce the overlying strata, and nondiapiric. Diapiric structures brought salt to the surface. Subsequent dissolution of salt has left remnant deposits of less soluble gypsum and fragments of siltstone, shale, and dolomite, and has led to collapse of the crests of these structures, resulting in northwest-trending valleys whose walls are the boundary faults of the collapsed crest. The boundary faults are not thought to extend below the level of the salt. Salt thickness in the core of the anticlines may exceed 10,000 ft, and the salt shows complex deformation and internal faulting (Hite and Lohman, 1973; Cater, 1970). Collapse of the crests may have occurred as late as early Pleistocene time but not earlier than Miocene time, in response to regional uplift and dissolution of near-surface salt (Cater, 1970; Richmond, 1962; Kitcho, 1981, Sugiura and Kitcho, 1981; Biggar and others, 1981). Structures of this type include Spanish Valley along the northeastern side of the study area, Salt-Cache Valley, Fisher Valley anticline, Castle Valley anticline and Lisbon Valley (fig. 2).

Upheaval Dome, in Canyonlands National Park, is apparently a salt diapir in which salt did not reach the surface (Mattox, 1975). Nondiapiric structures, or salt swells, have less deformed salt cores but still show thickening of salt, and salt has moved closer to the surface in these features (Hite and Lohman, 1973). Examples of this type of structure include Shafer Dome, Cane Creek anticline, and Rustler Dome (fig. 2).

Other possible salt-related collapse structures are so-called "breccia pipes." These are subcircular, vertical structures along which upward movement of brine has stoped overlying beds, causing their collapse. These pipes now appear topographically as mounds of brecciated rock fragments derived from stratigraphic levels above those of the surrounding rocks. Structures such as these are mineralized with uranium-copper ores in the vicinity of the Grand Canyon (Huntoon and Richter, 1979; Sugiura and Kitcho, 1981).

The La Sal Mountains, just east of the study area, consist of igneous rock intruded during Miocene time (Witkind, 1975; Hunt, 1958). Pebbles of diorite porphyry typical of the La Sal Mountains found on the Moab Rim indicate transport by streams that flowed across what is now Spanish Valley, prior to the collapse of the Spanish Valley salt anticline.

Geochemistry

Methods

A reconnaissance geochemical survey was conducted in the Behind the Rocks Wilderness Study Area during the summer of 1986. Minus-80-mesh stream sediments and panned concentrates of heavy minerals contained in stream sediments were the primary sample media. Stream-sediment samples represent a composite of rock and soil exposed in the drainage basin upstream from the sample site. Their analysis provides information that helps to identify those basins containing unusually high concentrations of elements that may be related to mineral occurrences.

Chemical analysis of heavy minerals concentrated from stream sediments permits the determination of certain elements in the concentrate that may not be detectable in bulk stream sediments by the analytical methods available. Some of these elements, in turn, may result from, and therefore indicate that, ore-forming processes have occurred.

Both types of samples, bulk stream sediment and heavy-mineral concentrate, were collected from alluvium along stream courses at 17 first- or second-order stream sites to give a sampling density of one per 1.4 square miles.

A gamma radiation detector was used to assess radiation levels at all sampling sites to determine the presence of possible uranium or thorium minerals.

The dry stream-sediment samples were sieved through 80-mesh stainless steel sieves, and the minus-80-mesh portion was saved for analysis. To produce the heavy-mineral concentrates, bulk stream sediment was first sieved through a 10-mesh screen. Approximately 10 pounds of the minus-10 mesh portion was panned to remove most of the quartz, feldspar, clays, and organic materials. The panned concentrate was separated into light and heavy fractions using bromoform (heavy liquid of specific gravity 2.8), and the light fraction was discarded. Magnetic minerals were then separated from the heavy fraction on the basis of magnetic susceptibility, and the nonmagnetic fraction was hand ground and analyzed.

Rock samples were collected from four sites in the study area. Samples that appeared unaltered were collected to provide information on geochemical background values. Altered and mineralized samples were collected to determine suites of elements associated with the alteration or mineral deposition.

Stream-sediment, heavy-mineral-concentrate, and rock samples were analyzed for 31 elements using a semiquantitative emission spectrographic method (Grimes and Marranzino, 1968). In addition, stream-sediment samples were analyzed for arsenic, antimony, bismuth, cadmium, gold, uranium, and zinc by specific chemical methods (Crock and others, 1987). Analytical data, sample sites, and a detailed description of the sampling and analytical techniques are given in Bullock and Barton (1987).

Results

Anomalous concentrations, defined as those above the upper limit of normal background levels, were determined for each element in the various sample media by inspection of the analytical data. Few samples (17 each of stream sediment and heavy-mineral concentrate) were taken, and many elements had only a few measurable concentrations. Uranium analyses show a normal distribution of values. One heavy-mineral concentrate contained 30 ppm silver and 200 ppm gold; the sample site was just outside the study area in Pritchett Canyon, 0.6 mi north of Pritchett Natural Bridge. This stream sediment may have been derived from or represent a paleoplacer gold occurrence; the likely source of the silver is unknown.

A heavy-mineral concentrate from a site near the northwestern boundary of the Behind the Rocks Wilderness Study Area contained 5,000 ppm lead. The sample site is 300 yards south-southwest of Kings Bottom Spring in a small drainage about 2 mi long near its confluence with the Colorado River. The site is accessible by vehicle and is in an area used for camping, and the anomalous lead concentration may be due to contamination. No anomalous values were found in any of the rock samples.

Geophysics

Interpretation of Regional Magnetic Data

East-west magnetic traverses were flown over the western part of the study area (fig. 4) at an elevation of about 8,500 ft above sea level and at a spacing of about 1 mi. The survey of the eastern part of the study area was flown at an elevation of 12,500 ft at spacings of 1–2 mi in connection with the La Sal Mountains survey (Case and others, 1963). The magnetic data were subsequently continued upward mathematically and merged by Hildenbrand and Kucks (1983) to an elevation of 12,500 ft. Additional magnetic surveys were flown as part of the National Uranium Resource Evaluation Program (NURE) along flight lines spaced about 3 mi apart and about 400 ft above the surface (Johnson, 1983), but the widely spaced data provide few details pertinent to this report.

Because the sedimentary rocks are regarded as virtually nonmagnetic, most of the anomalies of the region arise from contrasts in magnetization within the Precambrian basement or from changes in depth of the basement. Magnetic heterogeneity of the Precambrian rocks of the region was determined by studies of exposed rocks on the Uncompahgre uplift (Case, 1966).

Just south of the study area, a 200-nT (nanotesla) ovoid magnetic high is interpreted to be produced by a highly magnetic body within the Precambrian basement. Diameter of the body is about 3 mi. Available drill-hole data indicate that the body also lies partly on a northeast-trending basement structural high (Case and Joesting, 1972). An associated gravity high is also present in this area, indicating that the body is probably mafic in composition. In the region of the wilderness study area itself, the magnetic field trends about east-west, and the magnetic values increase smoothly northward, despite the northward increase in depth of the Precambrian basement. As discussed at length by Case and Joesting (1972), these circumstances indicate that the regional magnetization of the Precambrian basement must increase substantially toward the north and northeast. A similar conclusion was drawn by Johnson (1983) from the widely spaced NURE data.

Interpretation of Regional Gravity Data

No gravity stations have been established in the wilderness study area, but stations in immediately adjacent areas provided data on the gravity in the study area (fig. 5). A reduction density of 2.5 g/cm^3 (grams per cubic centimeter) was used for the data, and the gravity interpretation is from Hildenbrand and Kucks (1983).

The region has three patterns of gravity anomalies: (1) an east-west zone of steepened gradient, south and west of the study area, whose source is principally related to density contrasts within the Precambrian basement and northward thickening of salt (Joesting and others, 1966, fig. 3); (2) a northeast-striking zone of steepened gradient near the La Sal Mountains, which is related to deep-seated contrasts in density between Precambrian and lower Paleozoic rocks and to less dense salt and Mesozoic rocks (Case and others, 1963); and (3) the northwest-trending gravity low associated with the Moab Valley-Spanish Valley salt anticline. Regionally, the gravity field decreases northward by about 40 mGal (milligals) from Lockhart anticline to the flank of Castle Valley anticline (fig. 5), a change which is consistent with increasing thickness of the sedimentary sequence toward the deepest part of the Paradox Basin.

A gravity model for the region just northwest of the study area was constructed by Joesting and others (1966) to provide constraints on the configuration and dimensions of the Moab Valley salt anticline (fig. 5). The shape of the southwestern flank of the anticline and the salt thickness are especially pertinent to evaluation of the mineral and energy resource potential for the Behind the Rocks Wilderness Study Area because of the possibilities for the occurrence of oil and gas on the flank and potash-rich evaporite deposits. Within the constraints of our assumption that the regional gravity field is planar across Moab Valley and Spanish Valley, a residual gravity low of about 22 mGal can be isolated across the Moab Valley salt anticline. Because the evaporites crop out in the valley floor, the upper width of the anticline must be about 6,000 ft and it must increase

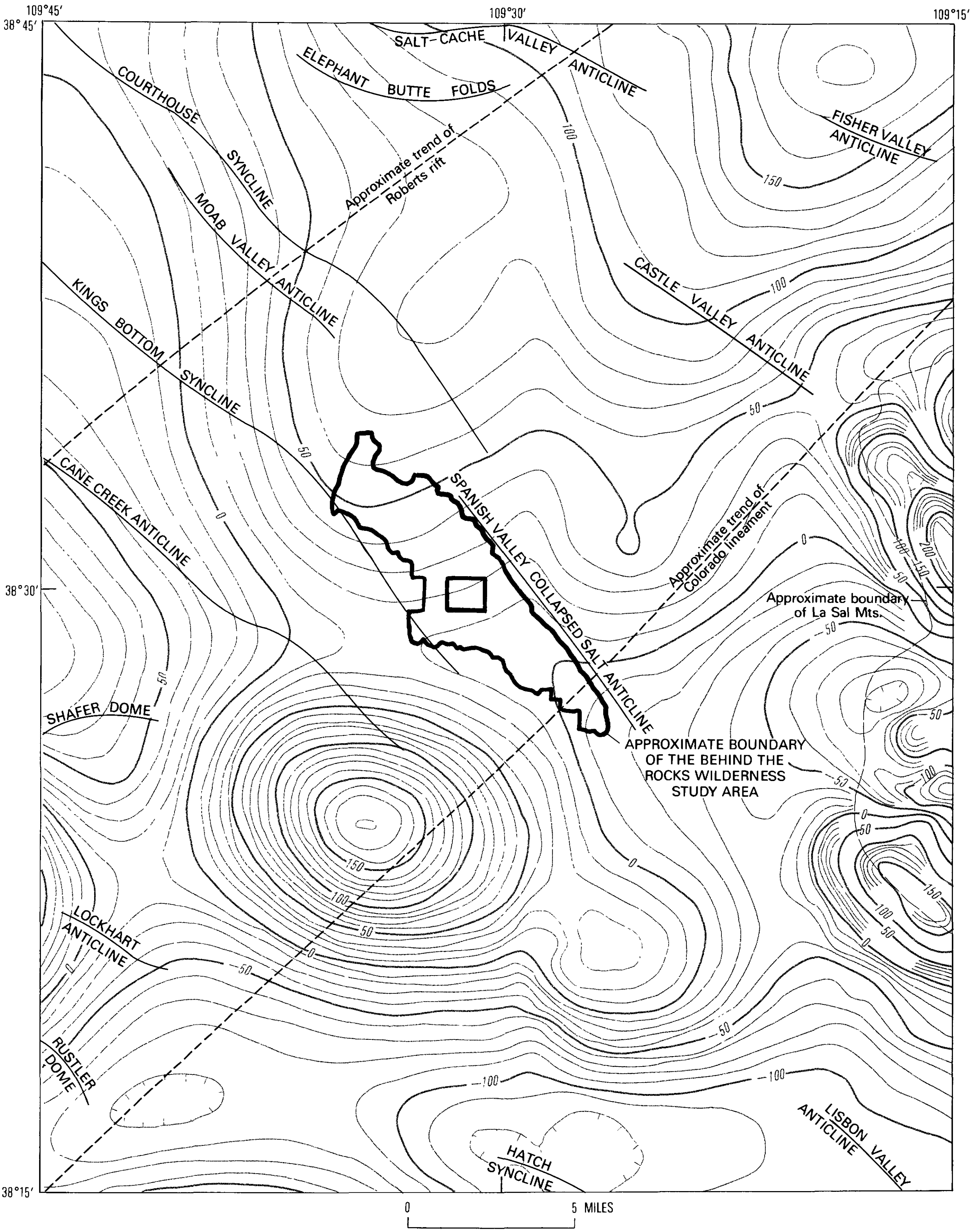


Figure 4. Residual total-intensity aeromagnetic map of the Behind the Rocks Wilderness Study Area and vicinity, Utah. Contour interval 10 gammas. Hachures show closed areas of lower magnetic intensity. Original magnetic data continued upward to an elevation of 12,500 ft. From Hildenbrand and Kucks (1983).

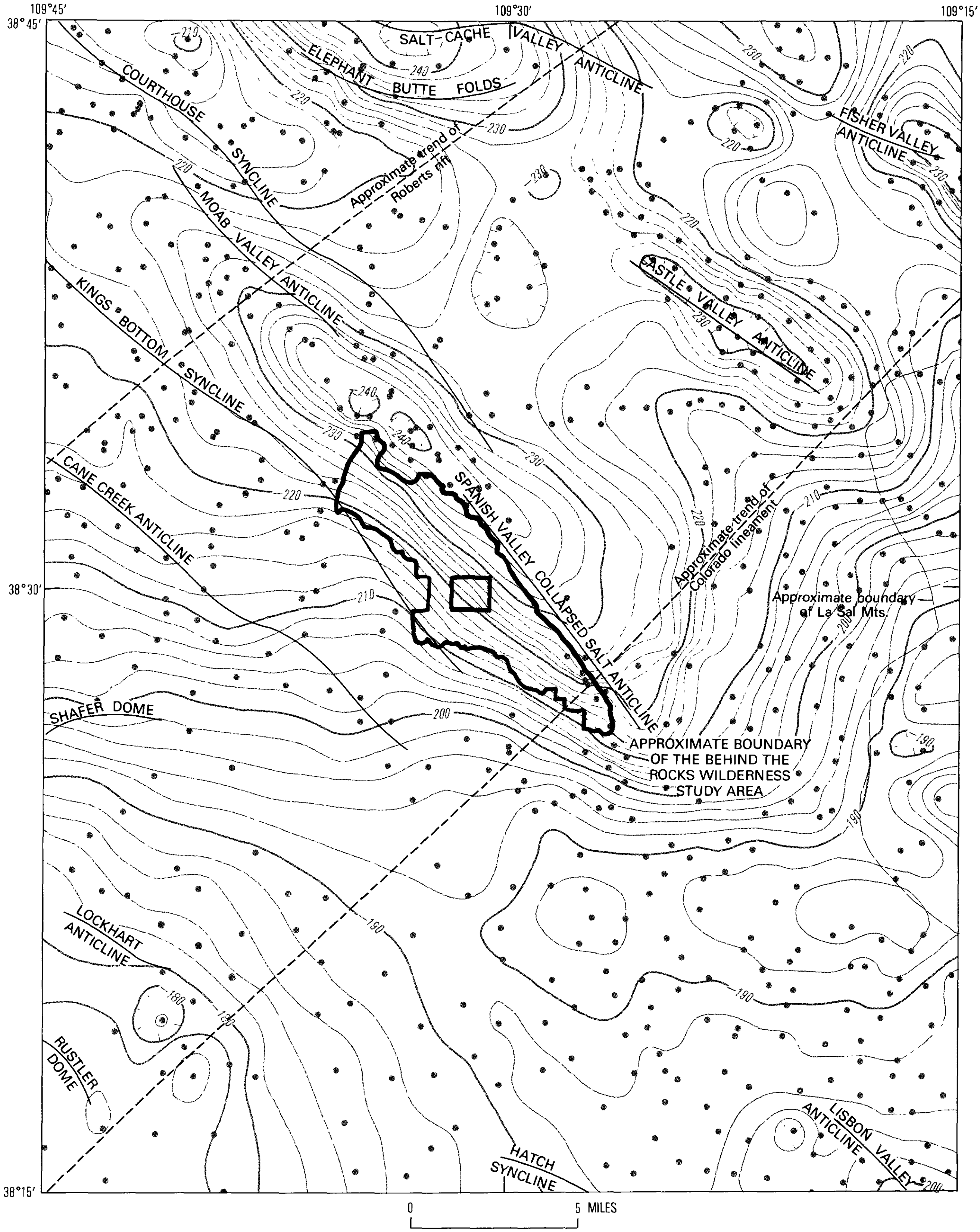


Figure 5. Bouguer anomaly map of the Behind the Rocks Wilderness Study Area and vicinity, Utah. Contour interval 2 milligals. Hachures show closed areas of lower gravity values. Dots are gravity stations. Some surficial structural features shown. Modified from Hildenbrand and Kucks (1983).

in width with depth to 13,000–15,000 ft. The thickness of the salt core above the top of the little-deformed salt sequence would be 8,000 ft, which gives a density contrast of -0.35 g/cm^3 between the salt and enclosing rocks. Such a contrast would exist if the evaporites have a mean density of 2.2 g/cm^3 and the enclosing rocks a mean density of 2.55 g/cm^3 (Case and Joesting, 1972). If the density contrast were greater, 0.4 g/cm^3, for example, the thickness or amplitude of the salt core must be less.

Interpretation of subsequent drill-hole data requires some modifications in the conjectured deep structure along the profile constructed by Case and Joesting (1972). (1) The Pennzoil Co. No. 27A Hatch Point (well 1, sec. 27, T. 27 S., R. 21 E., fig. 3) penetrated about 3,300 ft of the Paradox on the southern flank of the Cane Creek anticline. (2) The Skyline Oil Co. No. 1 Hunters Canyon Unit (well 2, sec. 1, T. 27 S., R. 21 E., fig. 3) bottomed in Devonian rocks 1,831 ft below the surface, and the May Petroleum, Inc., No. 1 Hunters Canyon-State (well 3, sec. 16, T. 27 S., R. 22 E., fig. 3) bottomed in Mississippian rocks 1,665 ft below the surface. The depth of rocks of Mississippian age (before salt deposition) is about 500 to 1,000 ft less than at the Cane Creek anticline, so the Mississippian rocks are higher beneath the Kings Bottom syncline, south of the wilderness study area. (3) The No. 1 Hunters Canyon Unit well penetrated 638 ft of evaporites, so that complete flowage of salt out of the Kings Bottom syncline and into the adjacent anticlines may not have occurred as postulated by Case and Joesting (1972). (4) The Cities Service No. 1 (well 4, sec. 28, T. 26 S., R. 22 E., fig. 3) penetrated 5,800 ft of evaporites on the southern side of the core of the Moab Valley and Spanish Valley anticlines and bottomed in Mississippian rocks at 3,523 ft below the surface. Thus, the thickness of the salt core is probably somewhat less than calculated by Case and Joesting (1972) along their profile to the northwest at Moab Valley, and the position of the postulated pre-Pennsylvanian (before salt deposition) fault, if one exists, must lie farther northeast than originally thought.

Unfortunately, the available well data are not sufficient to permit accurate configuration of the surface below the salt, underneath the Moab Valley and Spanish Valley anticlines. A pre-Pennsylvanian scarp along a fault downthrown to the northeast has been postulated from analogy with other major salt anticlines of the region where drill-hole control exists. Also, by analogy with other salt anticlines of the region, Joesting and others (1966) and Case and Joesting (1972) inferred that the salt may have flowed completely into the Moab Valley and Cane Creek anticlines, leaving an area without salt beneath part of the southern extension of the Kings Bottom syncline (fig. 2), but the more recent drilling indicates that some salt is present just south of the study area.

Remote Sensing

Landsat multispectral scanner (MSS) data were processed digitally to map variations in surface limonite and to map lineaments. These data were interpreted by Lee (1988). The MSS data were used to identify hydrothermally altered areas associated with mineralized rock and to identify limonite anomalies associated with either uranium deposition or hydrocarbon seepage. MSS data also were used as the basis for a lineament analysis of a large area of western Colorado and eastern Utah. Linear features recognized on the images were interpreted to make up longer trends of parallel linear features called lineaments. Lineaments were studied, along with geophysical surveys and deep drilling data, as possible indicators of basement structures. The methods used are described more fully in Lee (1988).

The Behind the Rocks Wilderness Study Area is bounded by three northeast-trending major lineaments (fig. 2). One, consisting of faults just to the southwest of the wilderness study area, at the Cane Creek uranium mines (fig. 2), controlled deposition of uranium in the Permian Cutler Formation. Another lineament, on the southern end of the study area, reflects a series of Precambrian basement faults that make up the Colorado lineament (Warner, 1978). The third lineament, north of the study area, is known as the Roberts rift (Hite, 1975).

Reverse limonite anomalies (areas of low limonite concentration within limonitic rocks) that might correspond to areas of hydrocarbon seepage or uranium deposition were sought on the Landsat images. One such anomaly was identified, but field examination indicated that the lack of limonite was caused by an extensive grass cover, and samples collected showed no anomalous radiation.

Aerial Gamma-ray Data

Aerial gamma-ray spectroscopy is a technique that provides estimates of the near-surface (0 to 20 in. (inches) depth) concentrations of potassium, equivalent uranium, and equivalent thorium. Because the uranium and thorium measurements utilize radioactive daughter nuclei that are chemically distinct from the parent nuclei, the results are given in equivalent concentrations. These concentrations indicate a partial chemical composition of the near-surface materials. For a typical aerial survey, each measurement gives average concentrations for a surface area of about 634,000 square feet to an average depth of about 12 in. The regional surveys that include the wilderness study area were flown in 1975–83. The flight-line spacing of the surveys was 3 mi. The study area has generally low radioactivity with concentrations of 1.2–2.0 percent potassium, 0.5–2.0 ppm equivalent uranium, and 1–4 ppm equivalent thorium. No gamma-ray anomalies were recognized within or near the wilderness study area (Joe Duval, written commun., 1987).

Mineral and Energy Resources

Uranium, Vanadium, and Copper

Uranium deposits containing variable amounts of vanadium and copper occur in the vicinity of the study area at Kane Creek, Lisbon Valley, Indian Creek, and the Seven-Mile Canyon area. Host rocks for these deposits are fluvial sandstone and conglomerate of the Moss Back Member of the Chinle Formation or other sandstone units in the Chinle and the Cutler Formations. Deposits in the Chinle contained 93 percent of the ore produced in the Moab uranium district. The deposits are tabular, structurally controlled, or a combination of the two types (Johnson and Thordarson, 1966; Chenoweth, 1975).

Tabular deposits are generally nearly parallel to bedding in the host sandstone, although in detail they may be irregular in form. Thickness of ore bodies ranges from a few inches to 20 ft or more, and widths from a few feet to a few thousand feet. Some deposits are irregular in plan view, but most are elongate parallel to sandstone paleochannels. Favorable ground for ore deposits consists of sandstone bodies, especially the Moss Back Member, which contain coalified wood (carbonaceous trash) or green mudstone in the Chinle Formation, and altered or bleached zones in sandstone units in the Cutler Formation. In the Chinle, deposits are at or near the basal contact with the Moenkopi or Cutler. Favorable zones in the Cutler are in areas of marine-fluvial intertonguing (Campbell, 1981); deposits in this type of favorable zone include the Seven-Mile Canyon and Kane Creek deposits in the Moss Back Member, and in the Cutler Formation at Indian Creek.

Structurally controlled deposits are in Kane Springs Canyon, where uranium minerals occur in a series of nearly vertical, northwest-trending faults along the crest of the Cane Creek anticline. The ore is mainly in the Cutler Formation, but minor amounts are in the Moenkopi and Chinle Formations (Chenoweth, 1975).

The deposits of the Lisbon Valley mining area occur along the flank of a northwest-trending salt anticline in the Moss Back Member and the Cutler Formation. These are the most productive deposits in the canyonlands area of eastern Utah and have yielded more than 60 million pounds of U_3O_8, or 78 percent of the total production of the area as of 1975 (Chenoweth, 1975). The uranium-bearing fluids appear to have been localized along the southwestern flank of the anticline near the crest (Wood, 1968).

Primary ores in the uranium districts around the wilderness study area consist of uraninite (uranium oxide) and coffinite (uranium silicate); pyrobitumen, a uraniferous organic material; several vanadium silicates; and copper as the sulfides chalcopyrite, bornite, and chalcocite. Oxidized ores are brightly colored compared to the primary ores, which are dark. They include carnotite and tyuyamunite (yellow uranium vanadates); malachite and azurite (green and blue copper carbonates); and a wide variety of less common uranium and copper oxides, carbonates, sulfates, phosphates, arsenates, and silicates, and also vanadium silicates. Pyrite and marcasite, both iron disulfide, are common in primary ore. Upon weathering, they produce rusty red iron oxides (limonite).

The grade of uranium in the deposits ranges from 0.2 to 0.5 percent U_3O_8. The fracture-controlled ore contains little vanadium, but other ores average 1 to 2 percent. Copper values increase to the west, from a few thousandths of a percent at Lisbon Valley to 1 or 2 percent in mines in the White Canyon district, 75 mi southwest of the study area (Johnson and Thordarson, 1966).

Investigations for uranium, vanadium, and copper resources in the study area consisted of stream-sediment sampling, especially of the minus-80-mesh fraction, upon which uranium will adsorb (Wenrich-Verbeek, 1977). Additional studies consisted of stratigraphic and sedimentologic analysis, traverses with a hand-held scintillometer, especially over fracture zones, and visual examination for mineralized areas.

The studies revealed no geochemical anomaly indicating uranium, vanadium, and copper mineralization; all absolute values of uranium, as determined by delayed-neutron activation (Millard, 1976), were below 3 ppm, and no other elements of interest were detected by semiquantitative spectroscopy (Bullock and Barton, 1987). Scintillometer readings never rose much above background (25–50 cps) except over isolated sandstone lenses in the Chinle, just outside the northeastern boundary of the study area, for which counts were 2 or 3 times background levels, but not indicative of mineralized rock. Measured paleocurrent vectors suggest that these small sandstone bodies might extend at depth under the study area. Only the uppermost part of the Chinle is exposed near the study area; stratigraphic studies indicate that the Moss Back Member of the Chinle, which normally is found at the base of the Chinle in this region and is the most favorable host for uranium, is not present under the study area (Johnson and Thordarson, 1966). Green, reduced mudstone, also considered favorable for uranium and byproduct vanadium and copper minerals, may possibly be present in the Chinle under the study area. Structurally, the study area is similar to the Lisbon Valley area, but the Moss Back Member is not present to be a host rock. The Cutler Formation, if present, lies many hundreds of feet beneath the study area.

Because of the absence of geochemical or radiometric anomalies and the suspected lack of favorable host rocks in the Chinle, the mineral resource potential for uranium, vanadium, and copper in the Behind the Rocks Wilderness Study Area is rated as low, with certainty level C.

Oil and Gas

The Behind the Rocks Wilderness Study Area is in a region historically productive of oil and gas. Fields in the vicinity include, as of 1987, Bartlett Flat (abandoned), Big Flat (shut in), Big Indian (producing), Cane Creek (abandoned in favor of potash mining), Hook and Ladder (shut in), Lisbon (producing), Long Canyon (producing), Little Valley (producing), Lion Mesa (shut in), Little Grand Wash (abandoned), Salt Wash (producing), South Pine Ridge (producing), Shafer Canyon (abandoned), and Wilson Canyon (producing).

The Lisbon field has yielded 98 percent of production from the region, mainly from reservoirs in the upper, porous zone of the Leadville Limestone, but also from the Cane Creek marker, an informally named clastic unit in the lower part of the Paradox Member, and from the Upper Devonian McCracken Sandstone Member of the Elbert Formation (Clem and Brown, 1984; Spencer, 1975; Parker, 1981). Big Flat, Big Indian, Little Valley, and Salt Wash fields also produce from the Leadville.

Traps typically consist of a combination of stratigraphic and structural elements. The principal structures of the region are salt domes and anticlines, many of which trend northwest. Impermeable salt encases tilted porous zones, forming traps for oil and gas (Parker, 1981). Oil source beds are thought to consist of dark, organic-rich shale within the Paradox Member, but oil may also have been generated from the Devonian and Mississippian rocks. Drill cuttings from most reservoir rocks within the Paradox Basin show oil. This oil is thought to be a residuum from the passage of oil into, through, and out of beds as tilting of the basin caused extensive migration of hydrocarbons (Spencer, 1975).

The structural setting of the Lisbon Valley field is similar to that of the wilderness study area, and a similar reservoir may exist in the study area. Production would be from the Cane Creek marker or the Leadville Limestone. It was previously conjectured that the Paradox salt had flowed completely from under the study area, which would reduce the possibility of an oil and gas reservoir. However, recent drilling indicates the presence of some salt just south of the study area.

Eleven wildcat wells have been drilled close to the study area, including two test wells for the Texasgulf, Inc., potash-mining operation. All had extensive shows of gas, and some had shows of oil. An example is the Union Oil/Cities Service well drilled on the northwestern boundary of the study area, which, due to slant-hole drilling, tested formations 8,300 ft below and 2,400 ft within the study area. This well had large but short-lived shows of gas from unknown clastic intervals within the extensively faulted and deformed Paradox. No productive horizon was found, and the well was shut in. The Mississippian Leadville Limestone beneath the study area has not been fully tested. Molenaar and Sandberg (1983) have rated this area as having a medium resource potential for oil and gas.

The energy resource potential for oil and gas in the Behind the Rocks Wilderness Study Area is rated as high, with a certainty level of B. Suitable source rocks, trapping mechanism, and shows of gas and oil indicate the presence of oil and gas deposits, but complex structure and lack of production from wildcat wells suggest a low certainty rating.

Gold and Silver

An anomalous concentration of gold and silver was found in one panned-concentrate sample from near Pritchett Natural Bridge just outside the study area. Possible sources for these metals include (1) sedimentary rocks underlying the basin of the stream-sediment-sample site (Butler and others, 1920); and (2) an unknown vein under the wilderness study area related to the La Sal Mountains or northeast-trending fractures similar to the Roberts rift (Hite, 1975). Additional sources for gold include (3) gold deposits in the La Sal Mountains, from which gold was eroded and deposited by streams flowing across what is now Spanish Valley, prior to its collapse; and (4) gold-bearing gravels of the Colorado River, deposited there during an earlier stage of erosion of the area.

There is no evidence for sources 1 or 2, and these are thought to be unlikely. Sources 3 and 4 are considered to be equally likely. Small clasts of diorite porphyry from the La Sal Mountains found on Moab Rim could have been emplaced by either method. In either case, the isolated, singular occurrence of this anomaly gives little suggestion of a possible gold or silver resource in the Behind the Rocks Wilderness Study Area. Therefore, the mineral resource potential for gold and silver is low, with certainty level C.

Other Metals

No evidence of deposition of other metals related to fractures of the Roberts rift type (Hite, 1975; Fischer, 1937) or from breccia pipes was detected. Therefore, the mineral resource potential for other metals in the study area is low, with certainty level C.

Geothermal Energy

No sign of geothermal activity was noted during the investigation, and no geothermal springs or sources were found within the region. Regional heat flow is low (National Oceanic and Atmospheric Administration, 1980). Therefore, the potential for geothermal energy is low, with certainty level C.

Coal

Any coal-bearing formations have been eroded from the study area, and no coal-bearing formations exist in the subsurface. Therefore, there is no resource potential for coal, with certainty level D.

Braitschite (Rare-Earth Mineral)

Braitschite, a rare-earth borate mineral, was described by Raup and others (1967) from the saline facies of the Paradox Member, which is probably at least 1,500 ft beneath the study area. Whether this mineral occurs under the study area, especially in concentrations sufficient to constitute resources, is unknown, with certainty level A.

Potash and Halite

Potash and halite resources were discussed previously (see the section on "Appraisal of Identified Resources"). There is no mineral resource potential, with certainty level D, for undiscovered potash or halite resources beyond the inferred subeconomic resources described in that section.

Suggestions for Further Work

Oil and gas potential beneath the study area could be more adequately evaluated by a seismic survey of the study area, particularly the northern part near the Colorado River.

REFERENCES CITED

Baars, D.L., and Stevenson, G.M., 1981, Tectonic evolution of the Paradox Basin, Utah and Colorado, *in* Wiegand, D.L., ed., Geology of the Paradox Basin: Rocky Mountain Association of Geologists, 1981 Field Conference, Guidebook, p. 23–31.

Baker, A.A., 1933, Geology and oil possibilities of the Moab district, Grand and San Juan Counties, Utah: U.S. Geological Survey Bulletin 841, 95 p.

Biggar, N.E., Harden, D.R., and Gillam, M.L., 1981, Quaternary deposits of the Paradox Basin, *in* Wiegand, D.L., ed., Geology of the Paradox Basin: Rocky Mountain Association of Geologists, 1981 Field Conference, Guidebook, p. 129–147.

Bullock, J.H., Jr., and Barton, H.N., 1987, Analytical results and sample locality map of stream-sediment and heavy-mineral-concentrate samples from Behind the Rocks, Indian Creek, Bridger Jack Mesa, and Butler Wash Wilderness Study Areas, San Juan and Grand Counties, Utah: U.S. Geological Survey Open-File Report, in press.

Butler, B.S., Loughlin, G.F., and Heikes, V.C., 1920, The ore deposits of Utah: U.S. Geological Survey Professional Paper 111, 672 p.

Campbell, J.A., 1975, Lower Permian depositional system, northern Uncompahgre Basin, *in* Baars, D.L., ed., Permian lands: Four Corners Geological Society, 9th Field Conference, Guidebook, p. 13–21.

——— 1981, Uranium mineralization and depositional facies in the Permian rocks of the northern Paradox Basin, Utah and Colorado, *in* Wiegand, D.L., ed., Geology of the Paradox Basin: Rocky Mountain Association of Geologists, 1981 Field Conference, Guidebook, p. 187–194.

Case, J.E., 1966, Geophysical anomalies over Precambrian rocks, northwestern Uncompahgre Plateau, Utah and Colorado: American Association of Petroleum Geologists Bulletin, v. 50, p. 1423–1443.

Case, J.E., and Joesting, H.R., 1972, Regional geophysical investigations in the central Colorado Plateau: U.S. Geological Survey Professional Paper 736, 31 p.

Case, J.E., Joesting, H.R., and Byerly, P.E., 1963, Regional geophysical investigations in the LaSal Mountains, Utah and Colorado: U.S. Geological Survey Professional Paper 316–F, 116 p.

Cater, F.W., 1970, Geology of the Salt Anticline region in southwestern Colorado: U.S. Geological Survey Professional Paper 637, 80 p.

Chenoweth, W.L., 1975, Uranium deposits of the Canyonlands area, *in* Fassett, J.E., ed., Canyonlands country: Four Corners Geological Society, 8th Field Conference, Guidebook, p. 253–260.

Clem, K.M., and Brown, K.W., 1984, Petroleum resources of the Paradox Basin: Utah Geological and Mineral Survey Bulletin 119, 162 p.

Crock, J.G., Briggs, P.H., Jackson, L.L., and Lichte, F.E., 1987, Analytical methods for the analysis of stream sediments and rocks from wilderness study areas: U.S. Geological Survey Open-File Report 87–84, 35 p.

Fassett, J.E., ed., 1975, Canyonlands country: Four Corners Geological Society, 8th Field Conference, Guidebook, 281 p.

Fenneman, N.M., 1931, Physiography of Western United States: New York, McGraw-Hill, 534 p.

Fischer, R.P., 1937, Sedimentary deposits of copper, vanadium, uranium, and silver in the southwestern United States: Economic Geology, v. 32, p. 571–599.

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., plus supplement, 9 p.

Grimes, D.J., and Marranzino, A.P., 1968, Direct-current arc and alternating-current spark emission spectrographic field methods for the semiquantitative analysis of geologic materials: U.S. Geological Survey Circular 591, 6 p.

Hildenbrand, T.G., and Kucks, R.P., 1983, Regional magnetic and gravity features of the Gibson dome area and surrounding region, Paradox Basin, Utah—A preliminary report: U.S. Geological Survey Open-File Report 83–359, 34 p.

Hite, R.J., 1960, Stratigraphy of the saline facies of the Paradox Member of the Hermosa Formation of southeastern Utah and southwestern Colorado: Four Corners Geological Society, 3rd Field Conference, Guidebook, p. 86–89.

______ 1961, Potash-bearing evaporite cycles in the salt anticlines of the Paradox Basin, Colorado and Utah: U.S. Geological Survey Professional Paper 424–D, p. D135–D138.

______ 1975, An unusual northeast-trending fracture zone and its relations to basement wrench faulting in northern Paradox Basin, Utah and Colorado, *in* Fassett, J.E., ed., Canyonlands country: Four Corners Geological Society, 8th Field Conference, Guidebook, p. 217–223.

______ 1976, A potential target for potash solution mining in cycle 13, Paradox Member, near Moab, Utah: U.S. Geological Survey Open-File Report 76–755, 21 p.

______ 1978, The geology of the Lisbon Valley potash deposits, San Juan County, Utah: U.S. Geological Survey Open-File Report 78–148, 21 p.

______ 1982, Potash deposits in the Gibson Dome area, southeast Utah: U.S. Geological Survey Open-File Report 82–1067, 9 p., 1 pl.

Hite, R.J., and Lohman, S.W., 1973, Geological appraisal of Paradox Basin salt deposits for waste emplacement: U.S. Geological Survey Open-File Report 73–114, 75 p.

Hunt, C.B., 1958, Structural and igneous geology of the LaSal Mountains, Utah: U.S. Geological Survey Professional Paper 294–I, p. 305–364.

Huntoon, P.W., Billingsley, G.H., Jr., and Breed, W.J., 1982, Geologic map of the Canyonlands National Park and vicinity, Utah: Moab, Utah, Canyonlands Natural History Association, scale 1:62,500.

Huntoon, P.W., and Richter, H.R., 1979, Breccia pipes in the vicinity of Lockhart Basin, Canyonlands area, Utah, *in* Baars, D.L., ed., Permian lands: Four Corners Geological Society, 9th Field Conference, Guidebook, p. 41–56.

Joesting, H.R., Case, J.E., and Plouff, Donald, 1966, Regional geophysical investigations of the Moab-Needles area, Utah: U.S. Geological Survey Professional Paper 516–C, p. C1–C21.

Johnson, H.S., Jr., and Thordarson, William, 1966, Uranium deposits of the Moab, Monticello, White Canyon, and Monument Valley districts, Utah and Arizona: U.S. Geological Survey Bulletin 1222–H, p. H1–H53.

Johnson, V.C., 1983, Preliminary aeromagnetic interpretation of the Uncompahgre uplift and Paradox Basin, west-central Colorado and east-central Utah, *in* Averett, W.R., ed., Northern Paradox Basin-Uncompahgre uplift: Grand Junction, Colo., Grand Junction Geological Society, p. 67–70.

Kelley, V.C., 1955, Regional tectonics of the Colorado Plateau and relationships to the origin and distribution of uranium: Albuquerque, University of New Mexico Press, 120 p.

Kitcho, C.A., 1981, Characteristics of surface faults in the Paradox Basin, *in* Wiegand, D.L., ed., Geology of the Paradox Basin: Rocky Mountain Association of Geologists, 1981 Field Conference, Guidebook, p. 1–21.

Lee, Keenan, 1988, Remote sensing study in support of mineral resource appraisal of wilderness study areas near Moab, Utah—Dolores River Canyon Wilderness Study Area, Montrose and San Juan Counties, Colorado; Lost Spring Canyon Wilderness Study Area, Grand County, Utah; Behind the Rocks Wilderness Study Area, Grand and San Juan Counties, Utah; Indian Creek Wilderness Study Area, San Juan County, Utah; and Butler Wash Wilderness Study Area, San Juan County, Utah: U.S. Geological Survey Open-File Report 88–219, 17 p.

Lewis, R.W., 1965, Potassium, *in* Mineral facts and problems: U.S. Bureau of Mines Bulletin 630, p. 721–731.

Litwin, R.J., 1986, The palynostratigraphy and age of Chinle and Moenave Formations, southwestern U.S.A.: College Park, Pennsylvania State University, Ph.D. thesis, 204 p.

Lohman, S.W., 1974, The geologic story of Canyonlands National Park: U.S. Geological Survey Bulletin 1327, 126 p.

______ 1975, The geologic story of Arches National Park: U.S. Geological Survey Bulletin 1393, 113 p.

Mattox, R.B., 1975, Upheaval dome, a possible salt dome in the Paradox Basin, Utah, *in* Fassett, J.E., ed., Canyonlands country: Four Corners Geological Society, 8th Field Conference, Guidebook, p. 225–234.

Millard, H.T., Jr., 1976, Determination of uranium and thorium in USGS standard rocks by the delayed neutron technique, *in* Flanagan, F.J., compiler and editor, Descriptions and analyses of eight new USGS rock standards: U.S. Geological Survey Professional Paper 840, p. 61–66.

Molenaar, C.M., and Sandberg, C.A., 1983, Petroleum potential of wilderness lands in Utah, *in* Miller, B.M., ed., Petroleum potential of wilderness lands in the western United States: U.S. Geological Survey Circular 902–K, p. K1–K14.

National Oceanic and Atmospheric Administration, 1980, [compiled from data provided by the Utah Geological and Mineralogical Survey], Geothermal resources of

Utah: U.S. Department of Energy, Division of Geothermal Energy, scale 1:1,000,000.

Parker, J.M., 1981, Lisbon Field, San Juan County, Utah, *in* Wiegand, D.L., ed., Geology of the Paradox Basin: Rocky Mountain Association of Geologists, 1981 Field Conference, Guidebook, p. 89–100.

Phillips, Margie, 1975, Cane Creek Mine solution mining project, Moab potash operations, Texasgulf Inc., *in* Fassett, J.E., ed., Canyonlands country: Four Corners Geological Society, 8th Field Conference, Guidebook, p. 261.

Pipiringos, G.N., and O'Sullivan, R.B., 1978, Principal unconformities in Triassic and Jurassic rocks, Western Interior United States—A preliminary survey: U.S. Geological Survey Professional Paper 1035–A, p. A1–A26.

Powell, J.W., 1875, Exploration of the Colorado River of the West and its tributaries: Washington, D.C., Smithsonian Institution Annual Report, 291 p.

Raup, O.B., Gude, A.J., III, and Groves, H.L., Jr., 1967, Rare-earth mineral occurrence in marine evaporites, Paradox Basin, Utah: U.S. Geological Survey Professional Paper 575–C, p. C38–C41.

Richmond, G.M., 1962, Quaternary stratigraphy of the LaSal Mountains, Utah: U.S. Geological Survey Professional Paper 324, 135 p.

Ritzma, H.R., and Doelling, H.H., 1969, Mineral resources, San Juan County, Utah, and adjacent areas, Part I—petroleum, potash, groundwater, and miscellaneous minerals: Utah Geological and Mineralogical Survey Special Studies 24, 125 p.

Searls, J.P., 1985, Potash, *in* Mineral facts and problems: U.S. Bureau of Mines Bulletin 675, p. 617–633.

Spencer, C.W., 1975, Petroleum geology of east-central Utah and suggested approaches to exploration, *in* Fassett, J.E., ed., Canyonlands country: Four Corners Geological Society, 8th Field Conference, Guidebook, p. 263–276.

Stewart, J.H., Poole, F.G., and Wilson, R.F., 1972, Stratigraphy and origin of the Chinle Formation and related upper Triassic strata in the Colorado Plateau region: U.S. Geological Survey Professional Paper 690, 336 p.

Sugiura, Roy, and Kitcho, C.A., 1981, Collapse structures in the Paradox basin, *in* Wiegand, D.L., ed., Geology of the Paradox Basin: Rocky Mountain Association of Geologists, Field Conference, Guidebook, p. 33–46.

Thompson, J.R., 1988, Mineral investigation of the Behind the Rocks and Indian Creek Wilderness Study Areas, Grand and San Juan Counties, Utah: U.S. Bureau of Mines Open File Report MLA 2–88, 25 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.

Warner, L.A., 1978, The Colorado lineament—a middle Precambrian wrench fault system: Geological Society of America Bulletin, v. 89, p. 161–171.

Weir, G.W., Kennedy, V.C., Puffett, W.P., and Dodson, C.L., 1961, Preliminary geologic map and section of the Mount Peale 2 NW quadrangle, San Juan County, Utah: U.S. Geological Survey Mineral Investigations Field Studies Map MF–152, scale 1:24,000, 1 sheet.

Wenrich-Verbeek, K.J., 1977, Uranium and coexisting element behavior in surface waters and associated sediments with varied sampling techniques used for uranium exploration: Journal of Geochemical Exploration, v. 8, p. 337–355.

Wiegand, D.L., ed., 1981, Geology of the Paradox Basin: Rocky Mountain Association of Geologists, 1981 Field Conference, Guidebook, 285 p.

Williams, P.L., compiler, 1964, Geology, structure, and uranium deposits of the Moab quadrangle, Colorado and Utah: U.S. Geological Survey Miscellaneous Geologic Investigations Map I–360, scale 1:250,000.

Witkind, I.J., 1975, The Abajo Mountains—an example of the laccolithic groups on the Colorado Plateau, *in* Fassett, J.E., ed., Canyonlands country: Four Corners Geological Society, 8th Field Conference, Guidebook, p. 245–252.

Wood, H.B., 1968, Geology and exploitation of uranium deposits in the Lisbon Valley area, Utah, *in* Ridge, J.D., ed., Ore deposits of the United States, 1933–1966: American Institute of Mining and Metallurgical Engineers, p. 771–776.

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

LEVEL OF RESOURCE POTENTIAL ↑

<table>
<tr><td rowspan="4">U/A
UNKNOWN POTENTIAL</td><td>H/B
HIGH POTENTIAL</td><td>H/C
HIGH POTENTIAL</td><td>H/D
HIGH POTENTIAL</td></tr>
<tr><td>M/B
MODERATE POTENTIAL</td><td>M/C
MODERATE POTENTIAL</td><td>M/D
MODERATE POTENTIAL</td></tr>
<tr><td rowspan="2">L/B
LOW POTENTIAL</td><td rowspan="2">L/C
LOW POTENTIAL</td><td>L/D
LOW POTENTIAL</td></tr>
<tr><td>N/D
NO POTENTIAL</td></tr>
<tr><td>A</td><td>B</td><td>C</td><td>D</td></tr>
</table>

LEVEL 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: 1988—673-047/86,017 REGION NO. 8