Mineral Resources of the Indian Creek, Bridger Jack Mesa, and Butler Wash Wilderness Study Areas, San Juan County, Utah

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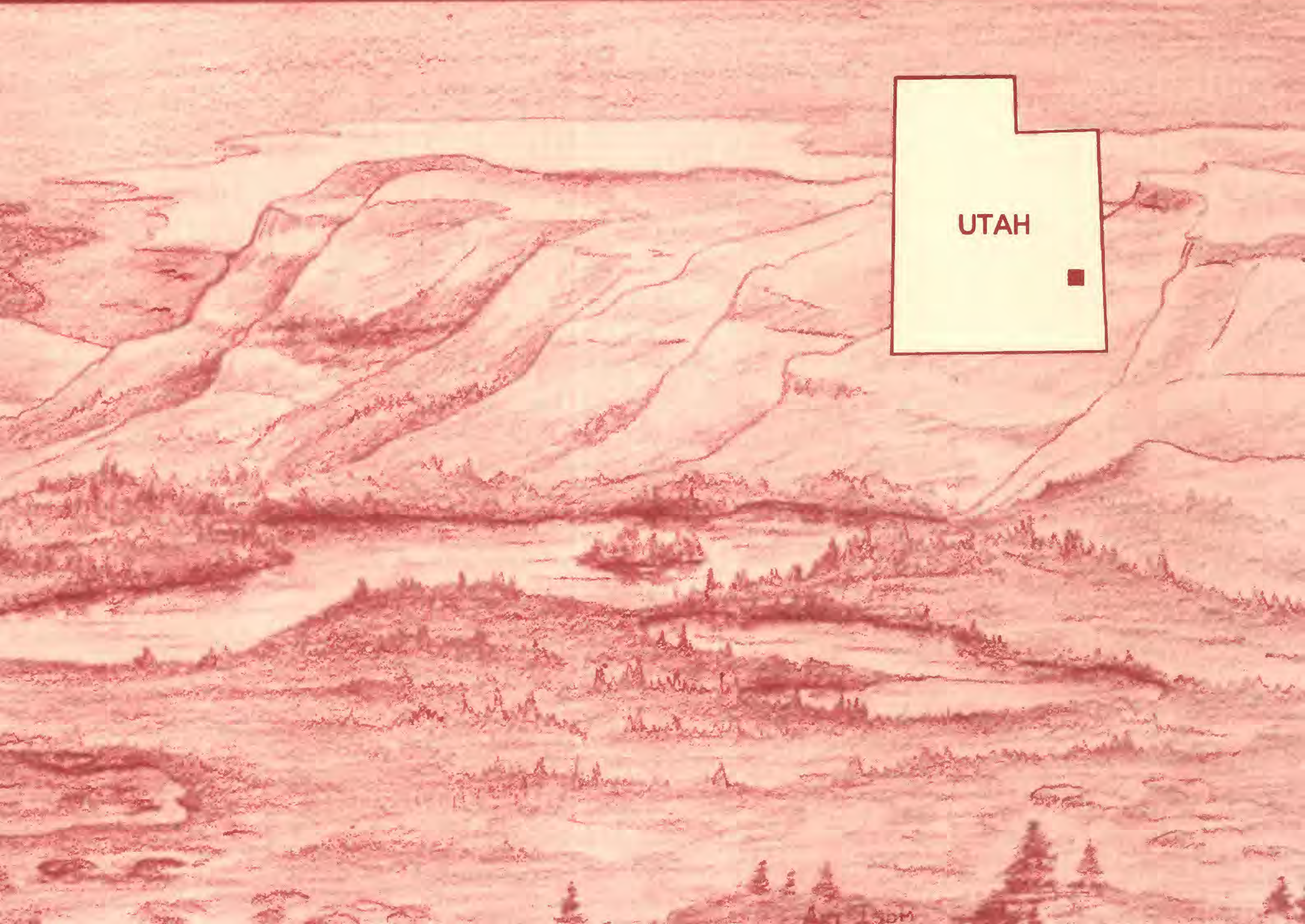

Chapter A

Mineral Resources of the Indian Creek, Bridger Jack Mesa, and Butler Wash Wilderness Study Areas, San Juan County, Utah

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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

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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 Indian Creek (UT-060-164), Bridger Jack Mesa (UT-060-167), and Butler Wash (UT-060-169) Wilderness Study Areas, San Juan County, Utah.

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PLATE

[Plate is in pocket]

1. Map showing mineral resource potential, geology, and mines and prospects of the Indian Creek, Bridger Jack Mesa, and Butler Wash Wilderness Study Areas

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1. Uranium mines and prospects near the Indian Creek, Bridger Jack Mesa, and Butler Wash Wilderness Study Areas **A8**

Mineral Resources of the Indian Creek, Bridger Jack Mesa, and Butler Wash Wilderness Study Areas, San Juan County, Utah

By Charles G. Patterson, Margo I. Toth, James E. Case, Harlan N. Barton, *and* Gregory N. Green
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ABSTRACT

The Indian Creek (UT–060–164), Bridger Jack Mesa (UT–060–167), and Butler Wash (UT–060–169) Wilderness Study Areas are located in San Juan County, southeastern Utah. Inferred subeconomic resources of sandstone and sand and gravel exist within all three wilderness study areas, but because of their abundance throughout the region, their distance from current markets, and their lack of unique properties, these materials have no current likelihood for development. Inferred subeconomic resources of potash and halite are present beneath the Indian Creek Wilderness Study Area, but the likelihood for their development is low. The potential for undiscovered resources of uranium and byproducts vanadium and copper is high for the north quarter of Bridger Jack Mesa Wilderness Study Area and is low for the Butler Wash, Indian Creek, and remaining parts of the Bridger Jack Mesa Wilderness Study Areas. The resource potential for undiscovered oil and gas is moderate in all three wilderness study areas. The resource potential for undiscovered placer gold and silver is low in all three wilderness study areas. The resource potential for undiscovered potash and halite is low for the Butler Wash and Bridger Jack Mesa Wilderness Study Areas. The resource potential is low in all three wilderness study areas for undiscovered geothermal energy, coal, and metals other than uranium, vanadium, and copper. The mineral resource potential for the rare-earth mineral braitschite is unknown in all three wilderness study areas.

SUMMARY

The Indian Creek (UT–060–164), Bridger Jack Mesa (UT–060–167), and Butler Wash (UT–060–169) Wilderness Study Areas consist of 6,870, 5,290, and 24,190 acres, respectively, in San Juan County, southeastern Utah. Monticello, about 25 mi southeast, and Moab, about 25 mi northeast, are the nearest towns. The study areas abut or lie near the north, west, and south perimeters of Canyonlands National Park (fig. 1).

Access to the wilderness study areas from U.S. Highway 191 is via graded dirt roads leading north from State Highway 211 to the Indian Creek Wilderness Study Area, and south past Dugout Ranch to the Bridger Jack Mesa and Butler Wash Wilderness Study Areas. Unimproved dirt roads also lead to the wilderness study areas from Monticello, Blanding, and Moab.

The wilderness study areas are in the Canyonlands section of the Colorado Plateau physiographic province. Indian Creek Wilderness Study Area is in the Paradox fold-and-fault belt, and Bridger Jack Mesa and Butler Wash Wilderness Study Areas are near the southwest margin of the belt. This fold-and-fault belt is an area of structural deformation resulting from flowage of thick, subsurface salt beds to form a series of northwest-trending salt anticlines. Salt-related structures near or within the wilderness study areas include the following: the Grabens, which are an arcuate zone of down-dropped blocks on the east side of the Colorado River near the Butler Wash Wilderness Study Area; the Gibson and Rustler domes, which are nondiapiric (non-piercing) salt swells in and near the Indian Creek Wilderness Study Area; the Meander anticline, which lies along the Colorado River, also near the Indian Creek Wilderness Study Area; and the Bridger graben, an east-northeast-trending downdropped block that intersects the south end of the Bridger Jack Mesa Wilderness Study Area. The region is crossed by several northeast-trending fault zones that parallel this graben.

Sedimentary strata are generally flat or dip gently throughout the region. Rocks exposed in and near the wilderness study areas consist of strata of the Lower Permian

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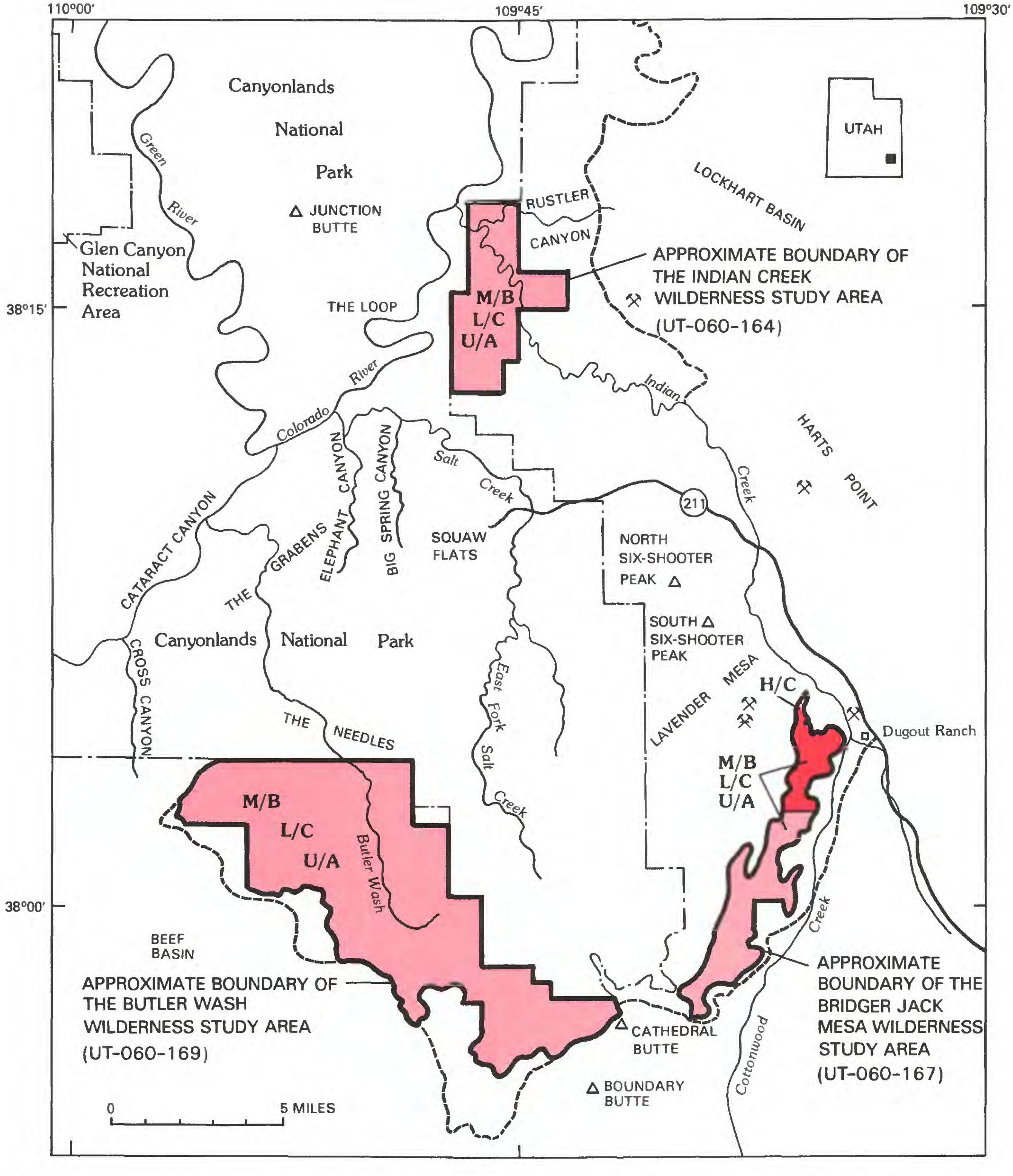

Figure 1 (above and facing page). Mineral resource potential and location of the Indian Creek, Bridger Jack Mesa, and Butler Wash Wilderness Study Areas.

(see geologic time chart in the Appendix) Cutler Formation, which comprises almost all of Indian Creek and Butler Wash Wilderness Study Areas, and the Lower and Middle(?) Triassic Moenkopi Formation, Upper Triassic Chinle Formation, and the Lower Jurassic Glen Canyon Group, which comprise all of Bridger Jack Mesa Wilderness Study Area. The Middle

EXPLANATION

[The entire Indian Creek Wilderness Study Area has inferred subeconomic resources of potash and halite in the subsurface]

H/C	Geologic terrane having high mineral resource potential for uranium, and byproducts vanadium and copper (north quarter of Bridger Jack Mesa Wilderness Study Area) with certainty level C
M/B	Geologic terrane having moderate mineral resource potential for oil and gas with certainty level B—Applies to entire area of each of the three wilderness study areas
L/C	Geologic terrane having low resource potential for uranium and associated byproducts vanadium and copper, potash and halite (in the subsurface), gold, silver, and all other metals, and coal and geothermal energy, with certainty level C—Applies to entire area of each of the three wilderness study areas except for uranium, vanadium, and copper in the north quarter of Bridger Jack Mesa Wilderness Study Area
U/A	Geologic terrane having unknown resource potential for rare-earth elements, with certainty level A—Applies to entire area of each of the three wilderness study areas

Level of certainty

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

⚒	Mines and prospects
------	Unpaved road

Pennsylvanian Hermosa Formation underlies all three study areas and contains the salt-bearing Paradox Member, which is present only beneath the Indian Creek Wilderness Study Area.

Topography in the wilderness study areas consists of (1) deep, narrow, winding canyons, as in the Indian Creek Wilderness Study Area; (2) narrow to wide canyons, spires, cliffs and domes, as in the Butler Wash Wilderness Study Area; and (3) spectacular vertical orange-red cliffs bounding a tableland as in the Bridger Jack Mesa Wilderness Study Area. No permanent streams or springs are found within the wilderness study areas. Vegetation is sparse at lower altitudes owing to lack of precipitation, but stands of pinyon pine and juniper are found atop the Bridger Jack Mesa Wilderness Study Area and on slopes within the Butler Wash Wilderness Study Area.

There has been no mining activity within the wilderness study areas, although some prospect pits are present on the eastern boundary of the Indian Creek Wilderness Study Area, and uranium mining has occurred near the north, east, and west boundaries of the Bridger Jack Mesa Wilderness Study Area. Uranium occurs in the Cutler Formation near the Indian Creek Wilderness Study Area and in paleochannels in the Chinle Formation near the Bridger Jack Mesa Wilderness Study Area. Drilling, done in 1978, indicates that a mineralized paleochannel extends into the northern part of the Bridger Jack Mesa Wilderness Study Area.

All three study areas are in the Paradox basin, which is a known producer of potash and halite. The saline facies of the Hermosa Formation contains potash and halite and underlies the Indian Creek Wilderness Study Area, but does not extend under the Butler Wash or Bridger Jack Mesa Wilderness Study Areas. About 7,000 mi^2 (square miles) of the Paradox basin is underlain by potash and halite at depths ranging from 1,700 to 14,000 ft. In 1965, estimated resources of bedded potash in the Paradox basin were as follows: known reserves, 254 million tons K_2O; inferred reserves, 161 million tons K_2O. The Gibson dome in Indian Creek Wilderness Study Area was considered as a viable area for underground mining of potash because source beds are close to the surface. Potash and halite are classified as an inferred subeconomic resource in the study area.

As part of the regional geochemical survey, rock samples from the study areas and stream-sediment samples were collected for analysis, but only one sample had anomalous concentrations of any elements. One panned-concentrate sample from the southern boundary of the Butler Wash Wilderness Study Area contained anomalous concentrations of gold and silver. The source of these metals is not known, but may be the Chinle Formation, a paleoplacer, or some unknown source.

The regional gravity data reveal a series of oval highs that are related to density contrasts in deeply buried Precambrian basement rocks or to thickening and thinning of the lower density salts. In general, Bouguer gravity values indicate a steep north- and northeast-sloping gradient caused by a deepening of the Precambrian basement below the Paradox basin, or thickening of salt, or both. Aeromagnetic data provide little or no information about the sedimentary rocks covering the Precambrian basement. Remote sensing studies utilizing satellite imagery disclosed no anomalies indicative of metal deposits and none indicative of oil and gas accumulations.

The resource potential for undiscovered uranium and byproducts vanadium and copper in the Chinle Formation is high in the north quarter of the Bridger Jack Mesa Wilderness Study Area. This assessment is based upon the presence of mineralized rock and a geologic environment favorable for uranium deposition. The resource potential for undiscovered uranium and byproducts vanadium and copper in the Chinle Formation is low in the south part of the Bridger Jack Mesa Wilderness Study Area based on the absence of any indications of mineralization. A small outcrop of the Chinle

Formation is at the southeast end of the Butler Wash Wilderness Study Area, but had no indication of uranium mineralization. The Chinle is absent from the Indian Creek Wilderness Study Area. The resource potential for undiscovered uranium and byproducts vanadium and copper in the Chinle Formation is therefore low for the Butler Wash and Indian Creek Wilderness Study Areas.

The resource potential for undiscovered uranium and byproducts vanadium and copper in the Cutler Formation is low in all three study areas. Although the Butler Wash and Indian Creek Wilderness Study Areas are underlain by the Cutler Formation and are in the favorable zone for uranium deposition, no evidence of near-surface mineralization was noted.

The resource potential for undiscovered oil and gas is moderate in all three study areas. Hydrocarbon-bearing formations and structural traps exist at depth, but drilling in adjacent areas has not resulted in any production.

The resource potential for undiscovered potash and halite is low beneath the Butler Wash and Bridger Jack Mesa Wilderness Study Areas. The thick sequence of bedded salts, which are classed as an inferred subeconomic resource of potash and halite under the Indian Creek Wilderness Study Area, pinch out to the south and do not extend under the Butler Wash and Bridger Jack Wilderness Study Areas.

The rare-earth mineral braitschite is present elsewhere in the Hermosa Formation associated with a thin layer of the saline facies of the Paradox Member. Whether this mineral occurs beneath the study areas is unknown, and the resource potential for braitschite beneath the three study areas is unknown.

The isolated geochemically anomalous sample that had 50 ppm (parts per million) gold and 20 ppm silver was found in the Butler Wash Wilderness Study Area; its probable source is a paleoplacer or rocks of the Chinle Formation. However, because of the lack of any other anomalous samples, and the lack of any mineralized rock in the region, the resource potential for undiscovered gold and silver in the Butler Wash study area is considered to be low. The resource potential for undiscovered gold and silver in the Indian Creek and Bridger Jack Mesa study areas is also considered to be low. Although a series of lineaments that traverse the three study areas are mineralized elsewhere in the region, there is no surface evidence of their being mineralized within the study area. The resource potential for metals other than uranium, vanadium, and copper is considered to be low.

No indications of geothermal activity were seen or have been reported. No coal-bearing formations are present in the study areas. The resource potential for undiscovered geothermal energy and coal is therefore low in all three study areas.

INTRODUCTION

The Indian Creek, Bridger Jack Mesa, and Butler Wash Wilderness Study Areas consist of 6,870, 5,290, and 24,190 acres, respectively, in San Juan County, southeastern Utah. In this report, the Indian Creek, Bridger Jack Mesa, and Butler Wash Wilderness Study Areas may be referred to as the wilderness study areas(s) or just study area(s). They occupy parts of the rugged and isolated canyon and mesa country bordering Canyonlands National Park on the northeast, east, and south (fig. 1). The Indian Creek Wilderness Study Area consists of a system of narrow, winding canyons leading down to the Colorado River. The Butler Wash Wilderness Study Area has high mesas and open valleys near the Abajo Mountains, through Butler Wash down to the Needles and Grabens districts of Canyonlands National Park. The Bridger Jack Mesa Wilderness Study Area consists of a long narrow mesa. Elevations in the study areas range from 3,980 ft, near the Colorado River on Indian Creek, to 7,450 ft atop Bridger Jack Mesa.

There are no perennial streams or springs in the study areas. Indian Creek Wilderness Study Area is drained by Indian Creek and its tributaries, which flow into the Colorado River. Butler Wash Wilderness Study Area is drained by Butler Wash and its tributaries, and includes a small part of the headwaters of West Fork Salt Creek, which drains into Canyonlands National Park. Bridger Jack Mesa Wilderness Study Area supports no perennial drainages, but runoff enters Cottonwood Wash, Dry Fork, and Lavender Creek.

Access to the study areas is limited by the rough and impassable nature of the terrain they occupy. State Highway 211 extends west from U.S. Highway 191 north of Monticello and ends just inside Canyonlands National Park. Graded and unimproved roads lead north from this route to the Indian Creek Wilderness Study Area, and south past Dugout Ranch to Bridger Jack Mesa and Butler Wash Wilderness Study Areas. Foot travel within the study areas is difficult because of sheer cliffs and rough terrain.

This report presents an evaluation of the mineral endowment (identified resources and mineral resource potential) of the wilderness study areas and is the product of 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 USBM and USGS (1980) which is shown in the Appendix. 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 undiscovered energy sources (coal, oil, gas, oil shale, and geothermal sources). It is classified according to the system of Goudarzi (1984) and is shown in the Appendix. Undiscovered resources are studied by the USGS.

Investigations by the U.S. Bureau of Mines

The Bridger Jack Mesa, Butler Wash, and Indian Creek Wilderness Study Areas were examined by the

U.S. Bureau of Mines in 1986 (Schreiner, 1987; Thompson, 1988). Prior to the field investigations, published and unpublished literature relating to the study areas was reviewed to obtain pertinent information concerning mineral occurrences and mining activity. Mining claim locations and land status plats were acquired from the Bureau of Land Management State Office, Salt Lake City, Utah (fig. 2).

Twenty employee-days in the Bridger Jack Mesa and Butler Wash Wilderness Study Areas and nine employee-days in the Indian Creek Wilderness Study Area were spent mapping and sampling prospects and mineralized areas. Forty-five chip samples and two grab samples were taken in mines and prospects within a mile of the Bridger Jack Mesa and Butler Wash Wilderness Study Areas. Five chip samples were taken from prospects along the boundary of the Indian Creek Wilderness Study Area.

Analytical determinations were made by U.S. Bureau of Mines, Reno Research Center, Reno, Nev., and Bondar–Clegg, Inc., Lakewood, Colo. All samples were analyzed by fluorimetry for uranium and by inductively coupled plasma-atomic emission spectroscopy for vanadium. In addition, all samples from the Bridger Jack Mesa and Butler Wash Wilderness Study Areas were analyzed by fire assay for gold and silver, and by inductively coupled plasma-atomic emission spectroscopy for an additional 31 elements. At least one sample from each prospect near the Bridger Jack Mesa and Butler Wash Wilderness Study Areas was analyzed for 40 elements by semiquantitative optical emission spectroscopy to determine the presence of any unsuspected elements. The results are available for public inspection at 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 areas by the U.S. Geological Survey in 1986 and 1987 consisted of rock and stream-sediment sampling, a survey using a hand-held radiometer, stratigraphic and sedimentologic analysis, and remote sensing, gravity, and magnetic studies. The geophysical studies were done in the decade preceding 1976 and were revised and updated for this report. No new geologic mapping was done in this investigation; current mapping was modified for this report.

Acknowledgments.—We gratefully acknowledge the cooperation and assistance of the personnel of the U.S. Bureau of Land Management, Grand and San Juan Resource Districts; of local resident Bill Head, manager of Dugout Ranch; and of the staff of Canyonlands National Park. A.M. Leibold, A.M. Wilson, D.J. Maloney, G.S. Desborough, R.B. Vaughn, and J.M. Nishi of the U.S. Geological Survey provided valuable assistance in the field and in the office.

APPRAISAL OF IDENTIFIED RESOURCES

By R.A. Schreiner and J.R. Thompson U.S. Bureau of Mines

Mining History

The Indian Creek Wilderness Study Area and the northern part of the Bridger Jack Mesa Wilderness Study Areas lie within the Indian Creek area of the Monticello uranium district; the southern parts of the Bridger Jack Mesa and Butler Wash Wilderness Study Areas lie adjacent to the northern part of the Elk Ridge area of the White Canyon uranium district (Doelling, 1969). Uranium was discovered in the region in the 1950's and was mined intermittently until the early 1980's, when all operations were suspended due to low uranium prices.

Uranium has been mined from the Chinle Formation at the Moki (Nighthawk) and Royal (Jean no. 1) mines located within a mile of the northeast boundary of the Bridger Jack Mesa Wilderness Study Area (pl. 1). Production from 1955 to 1973 from the Moki and Royal mines totalled 115,830 and 138,568 lbs (pounds) of uranium oxide (U_3O_8), respectively (unpublished U.S. Geological Survey Mineral Resources Data System (MRDS) data files, originally provided by the Utah Geological and Mineralogical Survey, Salt Lake City, Utah, 1986). The Moki mine produced an additional 18,220 lbs U_3O_8 from 1978 to 1980 (Lymon Shumway, past owner, Kanab, Utah, oral commun., 1986). The Royal mine had produced an additional 6,000 lbs U_3O_8 from 1976 to 1980 (James Andrus, Energy Fuels Nuclear, Inc., current owner, Kanab, Utah, oral commun., 1986). The mines have had a total production of 278,618 lbs U_3O_8. The grades of ore produced averaged from 0.08 to 0.33 percent U_3O_8.

Small deposits of uranium occur in the upper members of the Cutler Formation. The main area of production was about 3 mi north of the Indian Creek Wilderness Study Area, where 37,100 tons at an average grade of 0.26 percent U_3O_8 was produced from the Cutler Formation. The mines in this region have been inactive for many years (Chenoweth, 1975, p. 258).

According to records on file with the BLM as of July 1986, claims staked for uranium by various companies and individuals cover most of the Chinle Formation outcrop in and near the Bridger Jack Mesa and Butler Wash Wilderness Study Areas (pl. 1). The

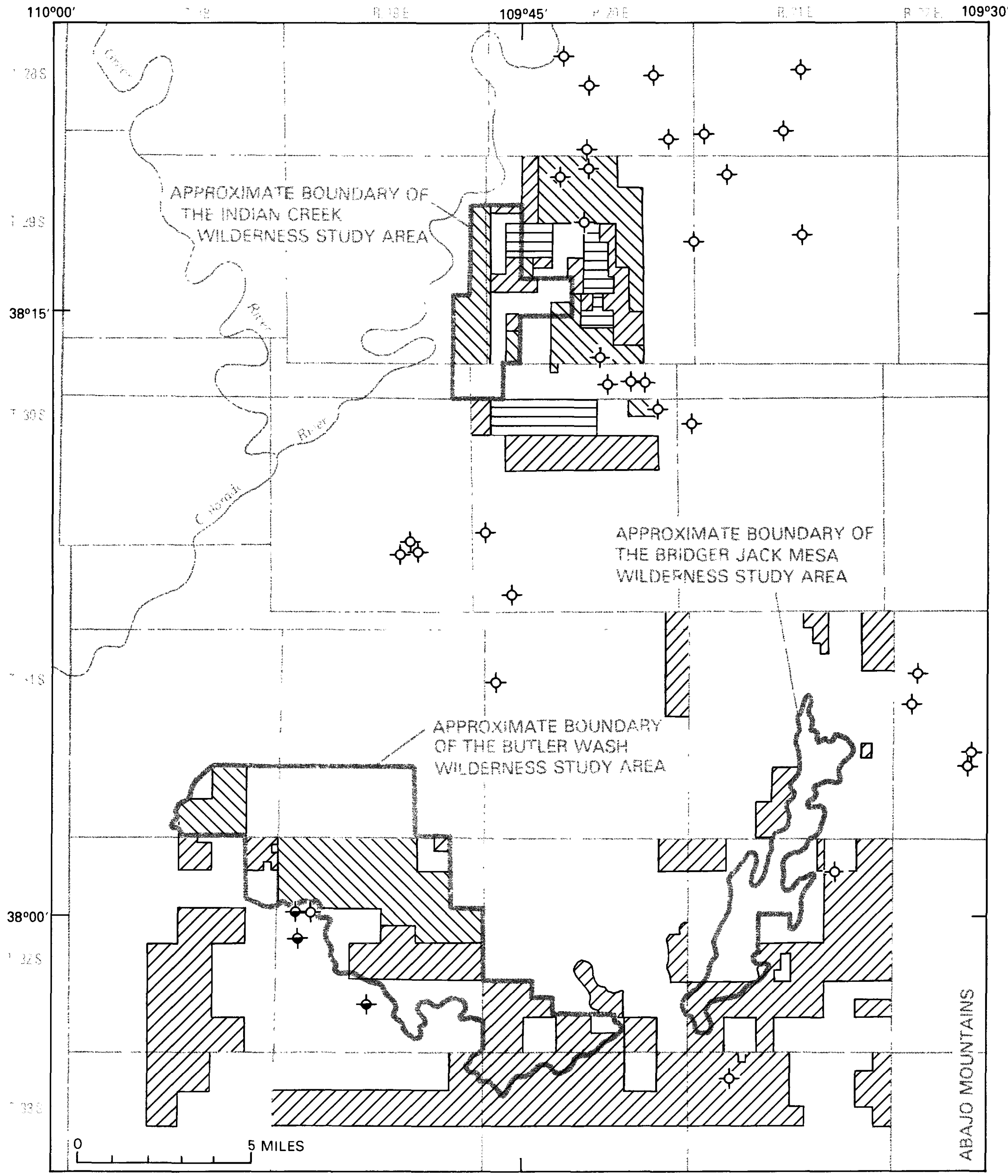

Figure 2 (above and facing page). Oil and gas drill holes, leases, and applications, and unpatented mining claims in the vicinity of Indian Creek, Bridger Jack Mesa, and Butler Wash Wilderness Study Areas. Oil and gas lease information from the Bureau of Land Management; current as of June 1985. Drill hole information from Petroleum Information card files, Petroleum Information Corporation, Denver, Colorado.

Indian Creek Wilderness Study Area contains one block of mining claims staked for uranium on the Cutler Formation; three additional claim blocks are located outside the study area (pl. 1).

EXPLANATION

Oil and gas leases

Oil and gas applications

Unpatented mining claims

Oil and gas drill hole

Oil and gas drill hole with show of oil and gas

Oil and gas leases and lease applications cover about 3,720 acres of the Indian Creek Wilderness Study Area, 7,000 acres of the Butler Wash Wilderness Study Area, and 800 acres of the Bridger Jack Mesa Wilderness Study Area. Two dry holes have been drilled about 2 mi north of the Indian Creek study area, and two dry holes were drilled within 1½ mi of the Bridger Jack Mesa study area. Four holes, three containing oil and gas shows in Pennsylvanian and Mississippian rocks, have been drilled within 1 mi of the Butler Wash study area. There are no potash leases in the study areas.

Mineral Appraisal

Uranium

No uranium resources were identified at the surface in the wilderness study areas. However, uranium occurs near the boundary of the Indian Creek Wilderness Study Area, and uranium deposits are located within 1 mi of the Bridger Jack Mesa and Butler Wash Wilderness Study Areas. Uranium occurs in the Chinle Formation near the Bridger Jack Mesa and Butler Wash Wilderness Study Areas and in the Cutler Formation near the Indian Creek Wilderness Study Area.

Uranium in the Chinle Formation

The Chinle Formation, the principal uranium-bearing unit in the Elk Ridge and southern part of the Indian Creek uranium areas, contains mines and prospects within 1 mi of the Bridger Jack Mesa and Butler Wash Wilderness Study Areas. Summary and specific data for individual mines and prospects are given in table 1. Uranium occurs in sandstones of the Moss Back Member of the Chinle Formation in paleochannels cut into the underlying Moenkopi Formation and is associated with carbonized logs, branches, and debris. The Chinle Formation underlies the Bridger Jack Mesa Wilderness Study Area, is absent in most of the the Butler Wash Wilderness Study Area (occurring only just inside the southeastern boundary), and is absent from the Indian Creek Wilderness Study Area.

Moki and Royal mines.—The Moki (Schreiner, 1987, pl. 1 and figs. 3 and 4) and Royal (Schreiner, 1987, fig. 5) mines are on a west- to southwest-trending, 10- to 15-ft-thick paleochannel that contains uranium concentrated in a series of irregular lenses of higher grade (0.08–0.33 percent U_3O_8) material intermixed with low-grade and barren rock. At the accessible workings, most of the lenses appear to have been mined out, but samples (weighted average of 0.25 percent, U_3O_8, table 1) indicate that an additional lens, at least 80 ft long and 2 ft thick, is present in part of the Moki mine (Schreiner, 1987, fig. 4). Because of the irregular shape of the lenses, additional sample data from drilling would be required to estimate tonnage. The mineralized part of the paleochannel appears to be about 150 ft wide and ½ mi long, based on the extent of the workings. The western end of the Royal mine workings extends to within ¼ mi of Bridger Jack Mesa Wilderness Study Area, and the paleochannel trends toward the study area. Drilling to the west of the Royal mine by Energy Fuels Nuclear, Inc., in the late 1970's and early 1980's penetrated no additional uranium; however, the drilling project was not completed due to low uranium prices (James Andrus, Energy Fuels Nuclear, Inc., Kanab, Utah, oral commun., 1986). This paleochannel extends into the Bridger Jack Mesa Wilderness Study Area.

Bee Gee claims.—The adit on the Bee Gee claims (pl. 1), about ¼ mi from the northwest boundary of the Bridger Jack Mesa Wilderness Study Area, is on a northeast-trending, 130-ft-wide, 10-ft-thick paleochannel. Uranium is erratically distributed, but samples containing as much as 0.87 percent U_3O_8 and scintillometer readings greater than 10,000 cps (counts per second) indicate that concentrations increase in or near the back of the last 100 ft of the adit (Schreiner, 1987, fig. 6). Drilling by Plateau Resources in 1978 indicated that the paleochannel extends 3,500 ft north-northeast from the adit on the Bee Gee claims under the Wingate Sandstone rim, about 500 ft into the study area. About 25 percent of the paleochannel is mineralized several feet above the contact with the Moenkopi Formation; grade is estimated at 0.15 percent U_3O_8 (Jack C. Hamm, Plateau Resources, Ticaboo, Utah, oral commun., 1986). Additional uranium deposits may occur in the extension of this paleochannel in the Bridger Jack Mesa Wilderness Study Area. The paleochannel exposed at the Bee Gee workings could be a continuation of the paleochannel at the Moki and Royal mines, 2 mi northeast.

Other prospects.—At the four southernmost unnamed prospects (pl. 1), where only minor local concentrations of uranium occur, a thin mudstone unit lies between the sandstones of the Moss Back Member

Table 1. Uranium mines and prospects near the Indian Creek, Bridger Jack Mesa, and Butler Wash Wilderness Study Areas

[Sample numbers are those from Schreiner (1987) and Thompson (1988) and are used here for the reader's convenience]

Summary	Sample data
Samples 1-14 from the Moki mine (Nighthawk); see plate 1, present report	
Workings consist of an adit, flooded at 115 ft; a 110-ft-long open cut; four adits and a shaft that interconnect over a distance of 250 ft, most of which is flooded; and an 80-ft-long adit, a flooded adit and pit. Uranium occurs in west- to southwest-trending paleochannel consisting of conglomeratic sandstone with siltstone and mudstone lenses of the Moss Back Member of the Upper Triassic Chinle Formation, cut into the underlying Lower and Middle(?) Triassic Moenkopi Formation. Uranium is erratically distributed; irregular lenses of high-grade material are intermixed with low-grade and barren rock in reduced gray conglomeratic sandstone that contains carbonized logs, branches, and trash. Hinrichs and Krummel (1957, p. 104) reported that the ore at the Moki and Royal mines consisted chiefly of uraninite, pyrite, and sparse sphalerite, and galena (cobaltite, bieberite, and ilsemannite were also identified); spectrographic analysis indicated that a zone of anomalously high barium and cobalt occurs within 10-40 ft of one of the larger high-grade lenses. Scintillometer readings in the workings ranged from 100 to 8,000 counts per second; in an 80-ft adit, readings ranged from 800 to 8,000 counts per second. The area around these workings has been extensively drilled.	Chip samples contained from 0.0008 to 1.0554 percent U_3O_8 and 0.0086 to 0.1196 percent V_2O_5. A random grab sample and a select grab sample from the dump of the 115-ft-long flooded adit contained 0.0401 and 6.6037 percent U_3O_8, respectively. In the 80-ft-long adit, a high-grade lens at least 80 ft long and 2 ft thick had a weighted average of 0.2529 percent U_3O_8 and 0.0135 percent V_2O_5.
Samples 7-11; property name JBTM; see plate 1, present report	
Workings consist of a bulldozer trench--50 ft x 8 ft x 4 ft in depth, cut into Cutler Formation sandstone with jasper and red and green banding (scintillometer readings of 950-3,500 counts per second) in the sandstone.	Five samples taken at the trench contained as much as 0.021% U_3O_8 and 0.115% U_2O_5.
Samples 15-23 from the Royal mine (Jean no. 1 mine); see plate 1, present report	
Workings consist of two adits and six shafts that interconnect over a distance of 500 ft, most of which is flooded. Uranium occurs as described for the Moki mine, and it appears to be an extension of the same deposit (a series of irregular lenses of high-grade material) that has been breached by Indian Creek. The paleochannel is about 15 ft thick. Scintillometer readings in the workings ranged from 100 to 9,000 counts per second. The area around these workings has been extensively drilled.	Chip samples contained from 0.0019 to 0.7665 percent U_3O_8, and 0.0068 to 0.0250 percent V_2O_5.
Samples 24-32 from the Bee Gee claims; see plate 1, present report	
Workings consist of a 295-ft-long adit. Uranium occurs in a southwest trending paleochannel, as described for the Moki and Royal mines, about 10 ft thick and 130 ft wide. Scintillometer readings in the adit ranged from 100 to greater than 10,000 counts per second; in last 100 ft of adit, readings were 1,000 to greater than 10,000 counts per second in or near the back. The area around the adit has been extensively drilled.	Chip samples contained from 0.0008 to 0.8785 percent U_3O_8, and 0.0079 to 0.0196 percent V_2O_5.

Samples 33-39; property name unknown; see plate 1, present report	
Workings consist of two 150-ft-long adits connected by two 20-ft-long crosscuts. Adits were cut in conglomeratic sandstone of the Moss Back Member and the mudstone unit of Upper Triassic Chinle Formation. The mudstone unit is in contact with the underlying Lower and Middle(?) Triassic Moenkopi Formation. Scintillomter readings in the adits ranged from 70 to 620 counts per second; highest counts were in mudstone. A few drill holes were noted in the area.	Chip samples contained from 0.0012 to 0.0778 percen U_3O_8, and less than 0.0008 to 0.0196 percent V_2O_5
Samples 40-42; property name unknown; see plate 1, present report	
Workings consist of a 60-ft-long adit cut in sandstone and conglomeratic sandstone of the Moss Back Member and the mudstone unit of the Upper Triassic Chinle Formation. The mudstone unit is in contact with the underlying Lower and Middle(?) Triassic Moenkopi Formation. Uranium is concentrated in a 20-ft-wide area at the portal (scintillometer readings of 200 to 2,500 counts per second) in reduced gray conglomeratic sandstone with carbonized and silicified logs, branches, and trash.	Two chip samples at the portal and one chip sample at the face contained from 0.2948, 0.0637, and 0.0070 percent U_3O_8, and less than 0.0008, 0.0159 and 0.0250 percent V_2O_5, respectively.
Samples 43-44; property name unknown; see plate 1, present report	
Workings consist of a 32-ft-long adit cut in conglomeratic sandstone of the Moss Back Member and the mudstone unit of the Upper Triassic Chinle Formation. The mudstone unit is in contact with the underlying Lower and Middle(?) Triassic Moenkopi Formation. Uranium is concentrated in a 15-ft-wide area at the portal (scintillometer readings of 200 to 2,000 counts per second) in mudstone with thin fine sandstone lenses and carbonaceous material.	Chip samples taken at the portal and at the face face contained 0.0118 and 0.0024 percent U_3O_8, and 0.0116 and 0.0152 percent V_2O_5, respectively.
Samples 45-47; property name unknown; see plate 1, present report	
Workings consist of a 45- and 14-ft-long adit. The adits are cut in conglomeratic sandstone of the Moss Back Member and the mudstone unit of the Upper Triassic Chinle Formation. The mudstone unit is in contact with the underlying Lower and Middle(?) Triassic Moenkopi Formation. Uranium is concentrated in a 25-ft-wide area at the portal (scintillometer readings of 200 to 5,000 counts per second) in reduced gray conglomeratic sandstone with carbonized logs, branches, and trash.	Two chip samples taken at the portal and one taken near the face of the 45-ft-long adit contained 0.1179, 0.0142, and 0.0047 percent U_3O_8, and 0.0086, 0.0116, and 0.0137 percent V_2O_5, respectively.

and the underlying Moenkopi Formation (Schreiner, 1987, figs. 7–10). At the Moki, Royal, and Bee Gee workings, where large uranium concentrations (resources) are present, paleochannel sandstones are in direct contact with the Moenkopi Formation. Lewis and Campbell (1963, p. B43) reported that, in the Elk Ridge area, only paleochannel sandstones that lie in direct contact with the Moenkopi Formation contain ore-grade material. The mudstone unit, which may be absent locally, apparently pinches out between these unnamed prospects and the Moki, Royal, and Bee Gee workings.

Analytical data.—Chip samples from prospects and mines outside but within a mile of the three wilderness study areas contained as much as 1.1 percent U_3O_8 and 0.12 percent vanadium oxide (V_2O_5). A select grab sample contained 6.6 percent U_3O_8. Trace-element concentrations as high as 0.06 oz (ounces) gold/short ton, 1.3 oz silver/short ton, 0.18 percent zinc, 0.17 percent barium, 0.12 percent lead, 860 ppm cobalt, 670 ppm nickel, 530 ppm molybdenum, 520 ppm copper, 500 ppm arsenic, and 420 ppm chromium were present in individual samples (this report, table 1; Schreiner, 1987, appendix). These elements are commonly associated with uranium deposits in the region.

Uranium in the Cutler Formation

The Cutler Formation contains a few small uranium deposits and occurrences in the northern part of the Indian Creek uranium area. Uranium occurs in sandstones of the Cutler Formation, and is associated with bleached zones 50–200 ft long and wide, and 5–10 ft thick (Chenoweth, 1975, p. 258). Uranium minerals in these zones are sparse and their distribution is spotty.

The Cutler Formation in the Indian Creek Wilderness Study Area is composed of several undivided sandstone members that intertongue. At the highest point in the north part of the Indian Creek Wilderness Study Area, a small uranium-bearing sandstone bed crops out just outside the boundary of the study area. This bed in the Cutler Formation has been eroded from the study area. The undivided Cutler Formation and the Cedar Mesa Sandstone Member of the Cutler, which underlie the study area, are not known to be uranium-bearing in the Indian Creek Wilderness Study Area. The Cutler Formation occurs at depth in the Bridger Jack Mesa Wilderness Study Area and is exposed in the Butler Wash Wilderness Study Area, but no outcropping uranium deposits or occurrences were noted.

The JBTM claims in the northeast part of the Indian Creek Wilderness Study Area are staked on the upper member of the Cutler Formation. Just outside the eastern boundary, a prospect site on the claims contains several pits dug into sandstone and siltstone that contain abundant jasper. Scintillometer readings ranged from a background of 55 cps to a high of 3,500 cps. Sandstone, siltstone, and jasper that have high radiation levels were analyzed for uranium and vanadium. Uranium content ranged from 4 ppm to 180 ppm, and vanadium ranged from 17 ppm to 645 ppm (Thompson, 1988). The high concentrations are equivalent to 0.02 percent U_3O_8 and 0.12 percent V_2O_5. Currently, estimated uranium grades for economic mining have to be higher than 0.2 percent U_3O_8 (Schreiner, 1987).

Mineral Economics

At the 1987 price of $17.00/lb U_3O_8 (American Metal Market, v. 95, no. 184, July 13, 1987), and at grades ranging from 0.1 to 0.3 percent U_3O_8 (grades previously produced from the Moki and Royal mines), the gross value of a ton of material in place would be about $34.00-$102.00. Assuming a small-lease miner's costs of about $30.00 per ton for underground mining, $8.00 per ton for transportation to the nearest mill, 55 mi away at Blanding, Utah, and $55.00-$60.00 per ton for milling (John Maruyama, Energy Fuels Nuclear, Inc., Denver, Colo., oral commun., 1987), the sampled sandstone-type uranium deposits in and near the study areas are not currently economic.

Potash and Halite

Salt deposits, including potash and halite in the Paradox basin, occur in the "saline facies" of the Paradox Member of the Hermosa Formation. The areal extent of the "saline facies" in the Paradox basin is about 11,000 mi^2, nearly two-thirds of which is underlain by potash at depths ranging from 1,700 to 14,000 ft below the surface. (See Hite, 1961, p. D135.)

Salt resources of the Paradox basin have been extensively explored, both by core drilling and by oil-well drilling. Much of the exploration drilling results for potash is proprietary information. Although the broad outlines of the potash basin include the Indian Creek Wilderness Study Area, detailed figures on thickness of beds, K_2O content, and reserves of ore generally are not available (Ritzma and Doelling, 1969).

Lewis (1965) estimated reserves of bedded potash in the Paradox basin, including the Indian Creek Wilderness Study Area, as follows: known reserves, 254 million tons K_2O; inferred reserves, 161 million tons K_2O. His estimate was based on a minimum bed thickness of 4 ft, a minimum equivalent K_2O content of 14 percent, and a cutoff depth of 4,000 ft. If solution mining of the deeper deposits is considered, the reserve figure for the Paradox basin would be much larger (Ritzma and Doelling, 1969).

The Cane Creek Mine, operated by Texasgulf, Inc., is on the northeast flank of the Cane Creek anticline, about 25 mi north of the Indian Creek Wilderness Study

Area. The mine was started by sinking a 3,000-ft-deep shaft in 1964 and began production in 1965. In 1971, because of methane gas, high temperature, and a distorted, undulating potash bed, the mine was converted from conventional room-and-pillar underground mining to solution mining and solar evaporation (Phillips, 1975, p. 261). The estimated annual capacity from the facility is 110,000 metric tons of K_2O equivalent (Searls, 1985, p. 619).

Unlike the flat-lying salt deposits of New Mexico and Saskatchewan, the Paradox basin beds have been extensively folded and contorted. These structural complexities are a formidable barrier to underground mining. Also, 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. One area that does meet the preceding conditions is the Gibson dome (Ritzma and Doelling, 1969, p. 32), which is in the Indian Creek Wilderness Study Area. Potash and halite in the subsurface of the Indian Creek Wilderness Study Area are classified as an inferred subeconomic resource.

Because solution mining of potash is currently (1988) being used 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 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). To accurately determine the amount of potash buried under the study areas, drilling would be required to prove thickness and depth of beds.

Common Industrial Materials

Large quantities of inferred subeconomic resources of sandstone exist in all three study areas, and small amounts of inferred subeconomic resources of sand and gravel are present in the Butler Wash and Indian Creek Wilderness Study Areas. Because of the abundance of these materials in the region, the distance from markets, and their lack of unique properties, they have no current likelihood for development.

Conclusions

No uranium resources were identified at the surface in the wilderness study areas; however, uranium was mined nearby. Uranium occurs in a paleochannel of the Chinle Formation that has been mined at the Moki and Royal mines a quarter mile east of the Bridger Jack Mesa study area. The channel extends toward the study area. A similar paleochannel has been mined at the Bee Gee claims west of the study area. Past drilling indicated that the mineralized paleochannel is 3,500 ft long and about 500 ft of this channel is in the study area. Additional uranium may exist at depth in extensions of these possibly related paleochannels in the Bridger Jack Mesa Wilderness Study Area. At the 1987 uranium price of $17.00/lb, these sandstone-type deposits are not economic to mine by underground methods. Price increases to late 1970's levels of $30.00-$40.00/lb would be required to encourage exploration and development of this type of uranium deposit.

The inferred subeconomic resources of potash in the Indian Creek study area could be developed at the Gibson dome depending on the price for potash and operating costs. The Gibson dome is one of the most likely sites for development in the Paradox basin because of the nearness of the source beds to the surface. As an example, the Cane Creek potash mine, near Moab, is economically operated as a solution mining operation, and this would be a viable way of mining potash at the Gibson dome. Problems in development would be the remoteness of the area, the current relatively low price of potash, and the lack of surface water and unknown amount of underground water.

Inferred subeconomic resources of sandstone and sand and gravel in the wilderness study areas have no current likelihood of development.

ASSESSMENT OF POTENTIAL FOR UNDISCOVERED RESOURCES

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Geology

Previous Work

The Canyonlands section of the Colorado Plateau (Fenneman, 1931) has been the subject of many classic geologic studies, beginning with the work of Powell (1875), and including work by Cross (1907), Baker (1933), Kelley (1955), and Hunt (1956). Exploration for oil and gas, uranium, and potash has stimulated the modern era of geologic studies.

Current studies and compilations of geology include, but are not limited to, Fassett and Wengerd (1975), Lohman (1974, 1975), and Wiegand (1981).

Regional geologic map compilations include Williams (1964), Haynes and others (1972), and Huntoon and others (1982). Useful compilations of stratigraphy are Wengerd and Matheny (1958), Baars (1975), O'Sullivan and MacLachlan (1975), and Molenaar (1981).

Geologic Setting

The wilderness study areas lie within the Paradox basin subdivision of the Canyonlands section of the Colorado Plateau physiographic province (Fenneman, 1931; Kelley, 1955). Older sedimentary rocks in the subsurface include, in ascending order, the Cambrian Tapeats Sandstone, Bright Angel Shale, Muav Limestone, and some thin units that may be equivalent to the Lynch Dolomite; the Upper Devonian Elbert Formation and Ouray Limestone; the Lower Mississippian Leadville Limestone; the Lower Pennsylvanian Molas Formation; and the Middle to Upper Pennsylvanian Hermosa Formation, which is partly exposed in the Colorado River canyon west of the study areas.

Most of the rocks exposed in the study areas consist of, in ascending order, the Upper and Middle Pennsylvanian and Upper Permian Rico Formation, the Lower Permian Cutler Formation, the Lower and Middle(?) Triassic Moenkopi Formation, the Upper Triassic Chinle Formation, and the Lower Jurassic Glen Canyon Group, consisting of the Wingate Sandstone, Kayenta Formation, and Navajo Sandstone. The Bridger Jack Mesa Wilderness Study Area is underlain mainly by the Moenkopi and Chinle Formations and the Glen Canyon Group, whereas the Butler Wash and Indian Creek Wilderness Study Areas are underlain by the upper members of the Cutler Formation and Rico Formation (fig. 3).

Younger rocks, present in the close vicinity but eroded from the study areas, include the Middle Jurassic Entrada Sandstone and Upper Jurassic Morrison Formation, Lower Cretaceous Burro Canyon Formation, Upper Cretaceous Dakota Sandstone, and the Upper Cretaceous Mancos Shale. Laccolithic intrusions of intermediate porphyry of Miocene age occur southeast of the study areas in the Abajo Mountains (Witkind, 1964) and northeast in the La Sal Mountains (Hunt, 1958).

Geologic structures in and near the study areas are dominated by the flow of the underlying bedded salts of the Paradox Member. The Paradox fold-and-fault belt is defined by the presence of salt-related structures and occupies the northeast and deepest part of the 12,000 mi^2 Paradox basin, a depositional basin of Middle-to-Late Pennsylvanian age (Kelley, 1955; Hite and Lohman, 1973). The original total thickness of the salt is difficult to assess, due to subsequent flowage, but may have been several thousand feet in the northeast part of the basin. Maximum salt thickness under the study areas is from 700 to 1,000 ft under Butler Wash and Bridger Jack Mesa Wilderness Study Areas and more than 2,000 ft under the Indian Creek Wilderness Study Area. The salt is at depths between 2,000 and 3,000 ft (Clem and Brown, 1984) in the Butler Wash and Bridger Jack Mesa Wilderness Study Areas, and is at shallower depths in the Indian Creek Wilderness Study Area due to the formation of the Gibson dome. One proposed site for the disposal of high-level radioactive waste for the U.S. Atomic Energy Commission (now U.S. Department of Energy) was just north of the Bridger Jack Mesa Wilderness Study Area in bedded salts 1,000 ft below the surface.

Flowage of the salt began some time during the Permian Period and has continued episodically through the present. Other evidence of salt flowage through succeeding periods consists of facies changes and thinning or absence of overlying units, presumably because of diversion by salt bulges during deposition of these units. Salt domes or anticlines in the region of the study areas include Rustler dome, Gibson dome, Shafer dome, Cane Creek anticline, and Elk Ridge anticline (fig. 3). In these structures, salt has bulged close to the surface but has not pierced overlying sedimentary formations. Other salt-related structures in the region of the study areas include the following: the Meander anticline, a salt-related structure along the course of the Colorado River; breccia pipes of Lockhart basin, hydrologic(?) features related to upward movement of brines that have been mineralized in other areas including the Grand Canyon region (Huntoon and Richter, 1979); the Grabens fault zone, an arcuate band of down-dropped blocks apparently caused by salt flowage towards the Colorado River; and Salt Creek, Shay, and Bridger grabens—east-northeast-trending collapse structures that cross the southern end of the Butler Wash and Bridger Jack Mesa Wilderness Study Areas (Sugiura and Kitcho, 1981; Kitcho, 1981).

Hite (1975) described a series of subparallel, regional northeast-trending fractures, a few of which are shown on figure 3. These fractures are a part of the Colorado lineament described by Warner (1978). The course of the Colorado River may, in part, be determined by these fractures. In some areas near Moab, and on the east flank of the La Sal Mountains, northeast-trending fractures have contained copper-barite-silver deposits (Hite, 1975; Fisher, 1937).

Description of Rock Units

Middle and Upper Pennsylvanian Hermosa Formation (unit ₽h)—Only the upper part of the Hermosa Formation (known to some workers as the Honaker Trail Formation of the Hermosa Group (Wengerd and Matheny, 1958)) is exposed along the Colorado River canyon west of the study areas (fig. 3).

There it consists of dark-gray to gray, medium- to thick-bedded limestones, some of which contain chert, and a few thin beds of reddish to blue-gray shale and sandstone. The thickness of this unit may be as much as 1,500 ft (Huntoon and others, 1982; Hite, 1960). The Middle Pennsylvanian Paradox Member, which consists of several thousand feet of interbedded salts, dark siltstones, sandstones, and organic-rich shales, is below the upper part of the Hermosa.

Middle and Upper Pennsylvanian and Lower Permian Rico Formation (unit PℙPr)—The Rico Formation consists of interbedded limestones, siltstones, sandstones, and conglomerates. The top of the Rico is exposed in Indian Creek and Butler Wash Wilderness Study Areas, where it is defined as the oldest regionally extensive fossiliferous limestone. This unit commonly forms an impassable cliff, or "jump," along canyons. Springs or seeps are commonly found at the top of this unit. The thickness of the Rico may be more than 1,000 ft. The Rico represents a transition between older marine sedimentary rocks and younger clastic sedimentary rocks of terrestrial origin of the Cutler Formation (O'Sullivan, 1965). The Rico, in part, is equivalent to the Elephant Canyon Formation of Baars (1975).

Lower Permian Cutler Formation undivided (unit Pcu)—The Cutler Formation is not divisible into members northeast of the center of Indian Creek Wilderness Study Area. There it is red, arkosic conglomerates, reddish-yellow sandstones and siltstones, and red to purple shales. Fluvial origin is indicated by irregular lenticular bedding. Cut-and-fill crossbeds indicate transport direction from an easterly source, the ancestral Uncompahgre highland. The Cutler weathers to form ledgy, indented slopes or cliffs. The formation is divisible into several distinctive members west and southwest of the Indian Creek Wilderness Study Area. In ascending order, the members are the Halgaito Tongue (equivalent to the upper part of the Rico), the Cedar Mesa Sandstone Member, the Organ Rock Tongue, and the White Rim Sandstone Member. The total thickness of this unit may be as much as 2,000 ft.

Lower Permian Halgaito Tongue of the Cutler Formation (unit Pch)—The Halgaito Tongue consists of reddish-brown to purple arkosic siltstones, sandstones, and conglomerates interbedded with thin, gray limestones. The Halgaito forms ledgy slopes, and attains a thickness of more than 400 ft (O'Sullivan, 1965).

Lower Permian Cedar Mesa Sandstone Member of the Cutler Formation (unit Pcc)—The Cedar Mesa is a white to pale-reddish-brown, fine-grained, calcareous sandstone. Tabular cross-stratification indicates sediment transport from the northwest; the unit is probably of eolian origin. The Cedar Mesa weathers to form sheer cliffs and domes; it also forms spires where it is heavily jointed as in the Needles district in the Butler Wash Wilderness Study Area. The Cedar Mesa commonly has conspicuous black stains of desert varnish. Thickness is about 1,000 ft.

Lower Permian Cedar Mesa Sandstone Member transition to Cutler Formation undivided (unit Pccu)—These rocks are pale-yellow to pale-reddish-brown, fine to medium grained, calcareous sandstones and siltstones. The conspicuous reddish and yellowish horizontal layering seen in the Needles district is the transition zone of the interfingering between the fluvial part of the Cutler Formation from the east and the eolian Cedar Mesa Sandstone from the northwest. This zone may be as thick as 1,000 ft.

Lower Permian Organ Rock Tongue of the Cutler Formation (unit Pco)—The Organ Rock Tongue consists of reddish-brown siltstones and sandy shales. The unit forms a ledgy slope; its thickness is 250–400 ft.

Lower Permian Organ Rock Tongue transition to Cutler Formation undivided (unit Pcou)—These are reddish-brown silty shales, siltstones, and sandstones towards the east. This unit crops out along the Colorado River northeast of the confluence of the Colorado and Green Rivers and may be as much as 400 ft thick.

Lower Permian White Rim Sandstone Member of the Cutler Formation (unit Pcw)—The White Rim is a light-gray to yellowish-gray, fine-grained, calcareous, cross-bedded sandstone. The White Rim forms vertical to overhanging cliffs and creates an extensive benchland to the west of the Colorado River. The White Rim pinches out to the northwest at the Colorado River. The thickness of the White River is from 0–250 ft.

Lower and Middle(?) Triassic Moenkopi Formation (unit ₸m)—The Moenkopi consists of reddish-brown siltstones and shales and some thin sandstone layers. Bedding in the Moenkopi is even over long distances; bedding surfaces have mud cracks, ripple marks, sole marks, and rare load casts, all of which indicate deposition in a transitional marine environment. The Moenkopi forms a ledgy slope. The thickness of the Moenkopi is about 250 ft.

Upper Triassic Chinle Formation (unit ₸c)—The Chinle Formation consists of red, purple, gray, and green variegated, locally bentonitic mudstones and siltstones interbedded with thin, nodular limestone and sandstone. The Chinle forms a slope with some cliff bands at the base of the overlying Wingate cliff. Members of the Chinle include the Shinarump, Monitor Butte, Moss Back, Petrified Forest, Owl Rock, and Church Rock. At the base of the slope is a discontinuous 80- to 100-ft-thick ledge of light-grayish-yellow quartz and chert conglomerate, and fine- to medium-grained sandstone that has cut-and-fill trough crossbedding and rare fragments

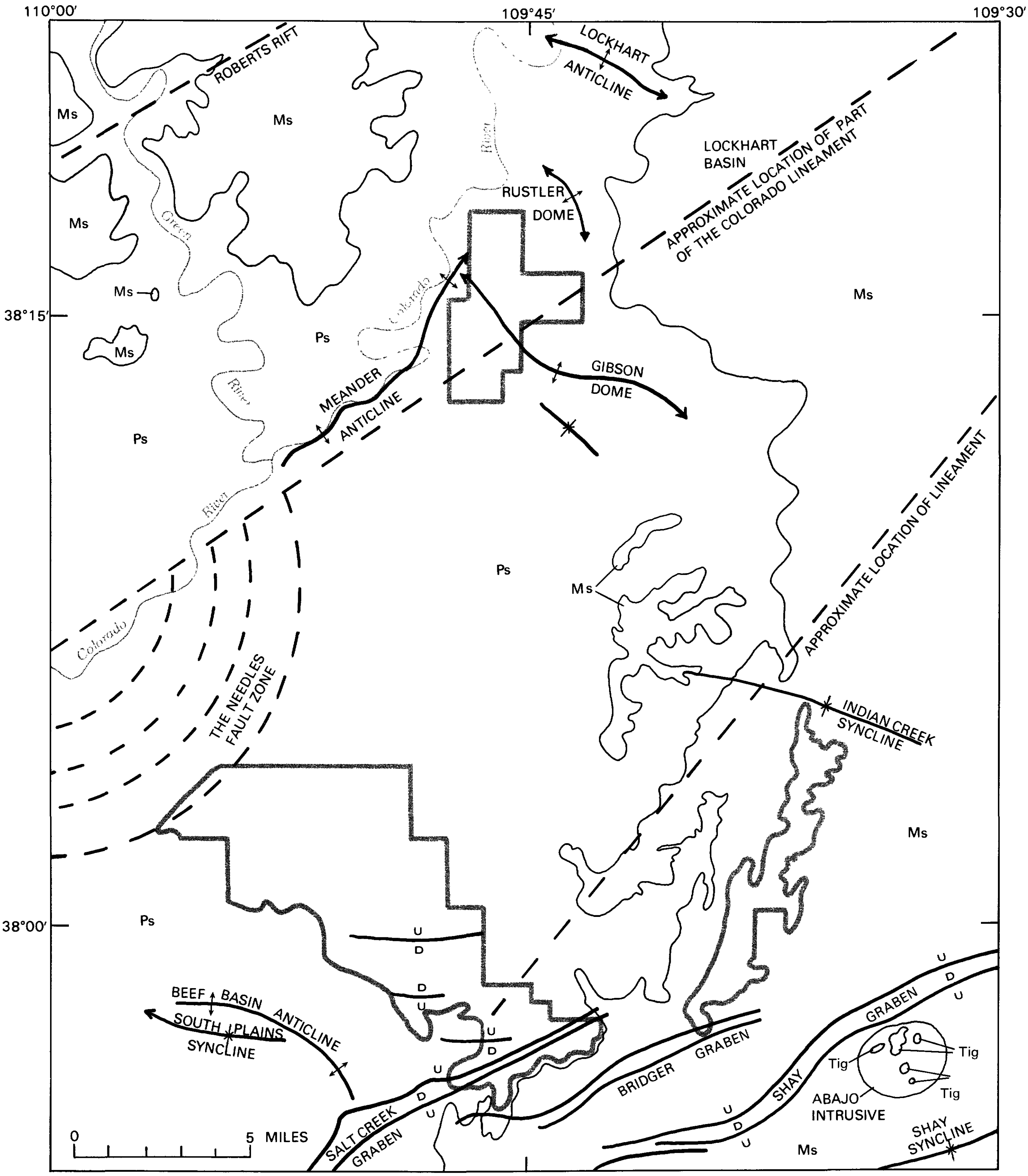

Figure 3 (above and facing page). Generalized geology and structure of the Indian Creek, Bridger Jack Mesa, and Butler Wash Wilderness Study Areas, from Williams (1964) and Haynes and others (1972).

of silicified and carbonized wood. This lowest sandstone near the study areas is the Moss Back Member, which represents ancient stream channels primarily from sources to southeast and east (Lewis and Campbell,

EXPLANATION

Tig	**Tertiary igneous rocks of the Abajo Mountains**
Ms	**Mesozoic sedimentary rocks**
Ps	**Paleozoic sedimentary rocks**

U/D **Fault**—Dashed where inferred. D, down; U, up

Anticline—Showing trace of axial plane and plunge

Syncline—Showing trace of axial plane and plunge

1965; Stewart and others, 1972; Malan, 1968). The total thickness of the Chinle ranges from 330 to 660 ft.

Lower Jurassic Wingate Sandstone of the Glen Canyon Group[1] (unit Jw)—The Wingate is a reddish-brown to reddish-orange fine-grained sandstone. It has large-scale crossbedding, which indicates eolian transport from the northwest (Poole, 1962). The Wingate forms prominent, vertically jointed cliffs, which are in places stained black by desert varnish. The thickness of the Wingate is about 350 ft.

Lower Jurassic Kayenta Formation of the Glen Canyon Group (unit Jk)—The Kayenta is a reddish-brown, fine- to coarse-grained sandstone with some shale. Lenticular bedding that has small-scale trough crossbedding indicates a fluvial origin of the Kayenta and a source to the east. The Kayenta weathers to form a ledgy cliff or slope. The unit acts as a protective cap rock for the underlying Wingate Sandstone. The thickness of the Kayenta is about 275–300 ft.

Lower Jurassic Navajo Sandstone of the Glen Canyon Group (unit Jn)—The Navajo is a yellowish-gray fine-grained sandstone. It has prominent large-scale tabular crossbeds that indicate eolian transport from the northwest. Rare, thin but laterally widespread beds of cherty limestone act as cap rocks for the conspicuous rounded domes formed by the Navajo as it weathers and erodes. The thickness of the Navajo is about 300 ft, although the top is eroded away or covered near the study areas.

Middle Jurassic Entrada Sandstone (unit Je)—The Entrada is a salmon-red to pale-orange, fine- to medium-grained, crossbedded sandstone. It forms smooth rounded cliffs, and only a small remnant is preserved in the vicinity of the study areas.

[1]The series assignment of the Glen Canyon Group (Wingate, Navajo, and Kayenta Formations) has been revised according to work by the U.S. Geological Survey (Pipiringos and O'Sullivan, 1978; Litwin, 1986). The formations are now thought by some workers to be Early Jurassic in age, based on studies of the equivalent Moenave Formation in northeastern Arizona.

Quaternary surficial deposits (unit Qu)—These are surficial deposits, mainly of sandy, gravelly stream alluvium along canyon bottoms, but also including windblown sand and slope deposits of coarse, angular, blocky talus and landslide debris. Thickness ranges from 0 to 10(?) ft.

Geochemistry

Introduction and Methods

A reconnaissance geochemical survey was conducted in Indian Creek, Bridger Jack Mesa, and Butler Wash Wilderness Study Areas during the summer of 1986.

Minus-80-mesh stream sediments and heavy-mineral, panned concentrates derived from stream sediments were collected for chemical analysis. Stream-sediment samples represent a composite of rock and soil exposed in the drainage basin upstream. Their analysis provides information to help identify those basins that contain unusually high concentrations of elements that may be related to mineral occurrences.

Chemical analysis of heavy minerals concentrated from stream sediments provides information about the chemistry of certain high-density, resistant minerals eroded from the drainage basin upstream. The removal of most of the rock-forming silicates, clays, and organic material permits the determination of elements in the concentrate that are not generally detectable in anomalously high amounts in bulk stream sediments by the analytical methods available. Some of these elements can be constituents of minerals related to ore-forming processes rather than rock-forming ones.

Both types of sample, bulk stream sediment and heavy-mineral concentrate, were collected from active alluvium of 53 first- or second-order stream sites to give an average sampling density of one site per 1.4 mi^2.

Rock samples were collected from four sites in the study areas. 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 observed alteration or mineralization.

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

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, and zinc by inductively coupled argon plasma-atomic absorption spectroscopy. Gold and silver were analyzed by atomic absorption (Crock and others, 1987). Analytical data, sampling sites, and a detailed description of the sampling and analytical techniques are from unpublished data by J.H. Bullock, Jr., and H.N. Barton (USGS, Box 25046, DFC, MS–973, Denver, CO 80225).

Results

Anomalous concentrations, defined as those above the upper limit of normal background values, were determined for each element by inspection of the analytical data rather than by statistical techniques. A relatively small number of samples (53 each of stream-sediment and heavy-mineral concentrate) were taken, and many elements were detected in only a few samples.

No anomalous concentrations were determined with the exception of one heavy-mineral concentrate sample that contained 20 ppm silver and 50 ppm gold, without other anomalous values. The sampling site is in the Butler Wash Wilderness Study Area in a west tributary to Salt Creek, 600 yards north of the Bright Angel Trail. This occurrence may represent sediments derived from a paleoplacer deposit or from the Chinle Formation.

Geophysics

Interpretation of Magnetic Data

East-west magnetic traverses were flown over most of the regions surrounding the study areas at about 8,500 ft above sea level at a spacing of about 1 mi. Surveys of the Abajo Mountains area in the southwest corner of the surveyed region were flown at 11,500 ft. The contour interval is 10 gammas. The magnetic data subsequently were continued upward mathematically to an elevation of 12,500 ft by Hildenbrand and Kucks (1983; fig. 4).

Because the sedimentary rocks are regarded as nonmagnetic, most magnetic variation of the region results from contrasts in magnetization of the Precambrian basement or from variations in depth of the basement. Magnetic heterogeneity of the Precambrian rocks of the region has been demonstrated by studies of exposed rocks on the Uncompahgre Uplift (Case, 1966).

Within the region, elongate zones of steepened magnetic gradient suggest faults or other fairly straight contacts between Precambrian units of contrasting magnetization. Oval anomalies suggest plutons whose magnetization contrasts with that of surrounding rocks (fig. 4).

One of the most prominent anomalies in the Butler Wash and Bridger Jack Mesa Wilderness Study Areas is a zone of steepened gradient that trends easterly across both areas. Magnetic values are lower to the south, indicating that the basement rocks in the south are less magnetic or deeper. However, a magnetic low near the southeast end of the Butler Wash Wilderness Study Area coincides approximately with a gravity high (fig. 5), so that a moderately dense but weakly magnetic rock, such as gneissic granodiorite, is a possible cause of the anomaly (see Case, 1966). Magnetic relief across the gradient is about 100–150 gammas. At the northwest end of the Butler Wash Wilderness Study Area, a prominent magnetic low represents a polarization low associated with a highly magnetic body farther southwest that produces a magnetic high of more than 300 gammas.

North of Bridger Jack Mesa, two oval magnetic highs (A and B on fig. 4) align trending approximately north of west, and a third magnetic high within this alignment is east of the area shown on figure 4. These highs, whose amplitudes are 50–150 gammas, may represent small, moderately magnetic plutons. Hildenbrand and Kucks (1983, p. 30) stated: "The circular patterns of these highs suggest that they reflect intermediate to mafic intrusions, similar to those lying northwest and northeast of Lockhart basin. The highs are less intense and they may have deeper sources than those near Lockhart basin. The linearity of the zone of highs (A, B, and one east of the area of fig. 4) may indicate the presence of a deep-seated northwest-trending fault that provided a channelway for ascending magma or the presence of a zone of weakness which localized intrusive activity. Alternative interpretations of the three magnetic highs are also possible. For example, the depth of magnetic basement may shallow beneath the highs, or rocks with higher susceptibilities unrelated to intrusive activity may produce the magnetic highs."

North of the three highs, a curvilinear zone of steepened magnetic gradient trends approximately east-west. The magnetic values decrease northward across the zone by 100–150 gammas. A magnetic low trends westerly across the Indian Creek Wilderness Study Area, and may, in part, represent a polarization low related to the three highs to the south (A, B, and one east of the area of fig. 4). Weakly magnetic rocks, such as metasedimentary gneisses, probably underlie the low.

North of the Indian Creek Wilderness Study Area just outside figure 4, three oval magnetic highs are inferred to be caused by mafic or intermediate plutons

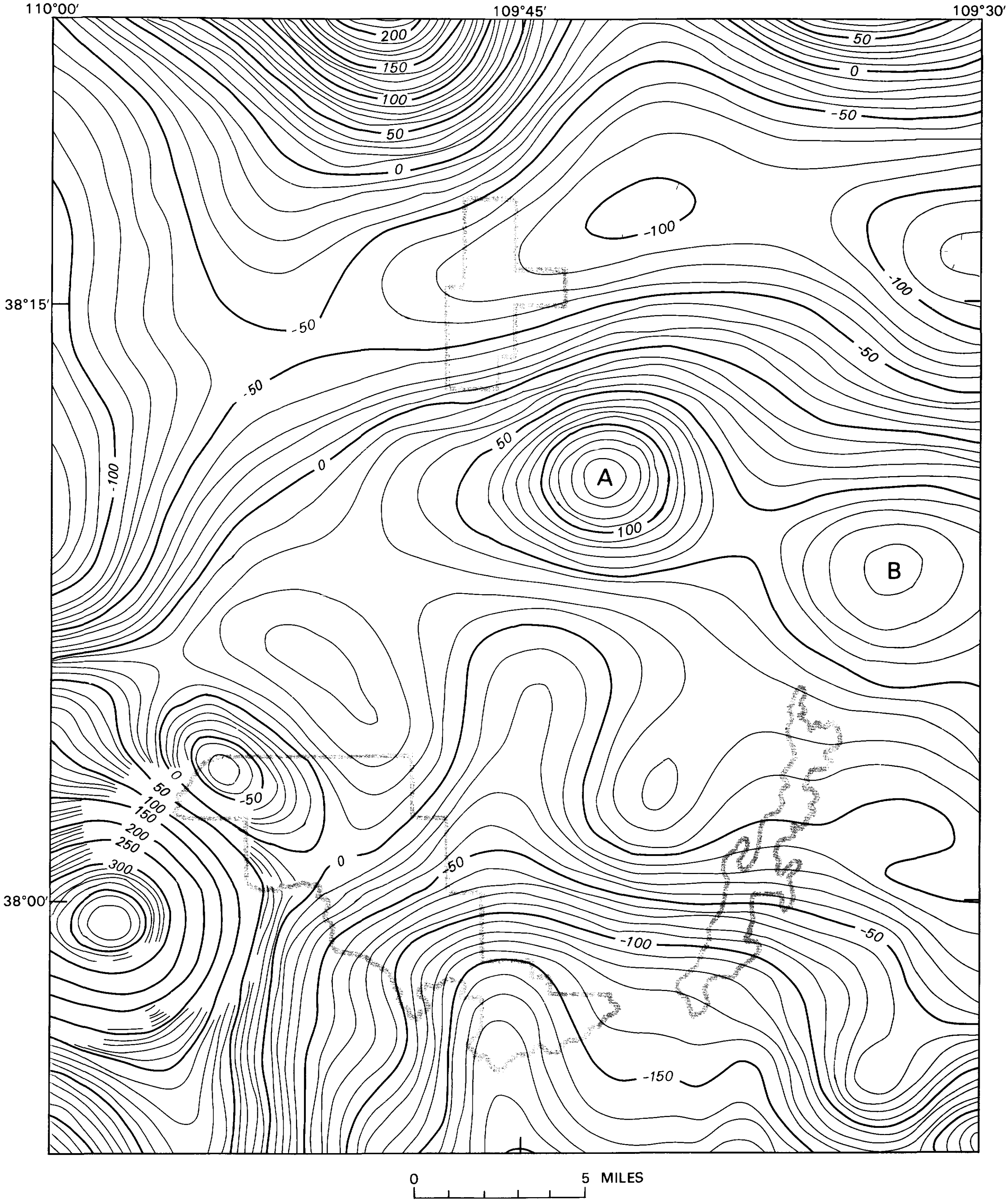

Figure 4. Residual total-intensity aeromagnetic map of the Butler Wash, Bridger Jack Mesa, and Indian Creek study areas; from Hildenbrand and Kucks (1983). Contour interval, 10 gammas. Original magnetic data continued upward to 12,500 ft. A, B, gravity highs.

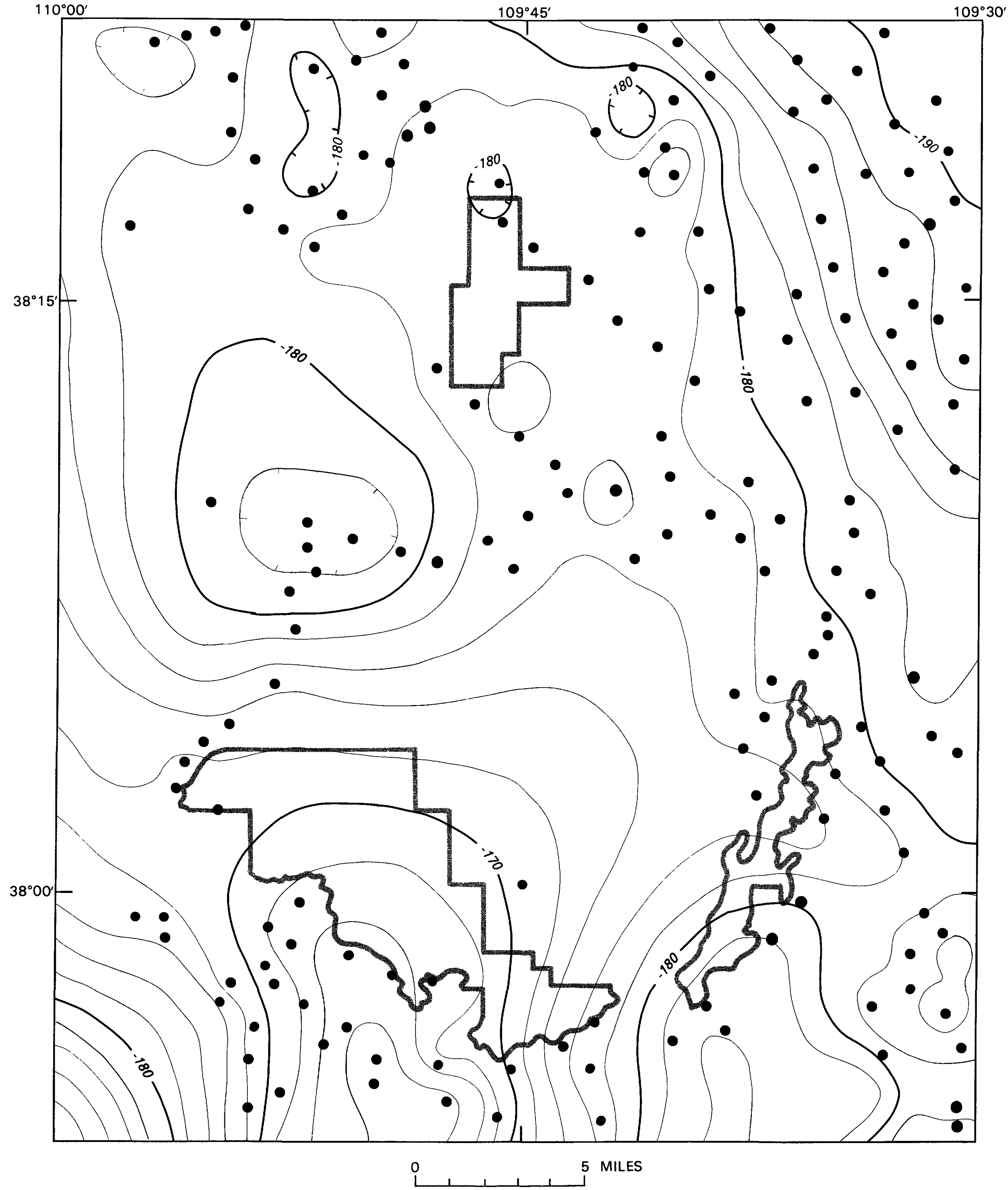

Figure 5. Bouguer gravity anomaly map of the Butler Wash, Bridger Jack Mesa, and Indian Creek Wilderness Study Areas and vicinity, from Hildenbrand and Kucks (1983). Contour interval, 2 milligals. Solid circles are gravity stations; hachures indicate closed gravity low.

that have diameters of 3–5 mi (Case and Joesting, 1972). The southern parts of two highs are located at the extreme north edge of the map area in figure 4. If the three plutons were once colinear, they subsequently were offset left-laterally by about 10 mi. This proposed offset trends northeast, parallel to the basement high inferred from well data, and is located just northwest of the Indian Creek Wilderness Study Area.

The magnetic data provide little or no quantitative information about the thickness of the sedimentary sequence or local structures within the study areas, but they do provide information on structural trends and the possible location of plutons within the Precambrian basement.

Interpretation of Regional Gravity Data

Gravity stations are scant within the three study areas, but data from nearby areas provide control for positions of Bouguer value contours through the study areas (fig. 5). Contoured Bouguer values shown on figure 5 have been reduced using a density of 2.5 g/cm³ (grams per cubic centimeter) and have been extracted from the map of Hildenbrand and Kucks (1983). The contour interval is 2 mGals (milligals), the probable error in the Bouguer anomaly values, when errors in terrain corrections and elevation are considered (Hildenbrand and Kucks, 1983).

Many "regional" gravity features are shown on figure 5. A gravity high of about 6 mGals or more occurs in the south over the northern nose of the Monument uplift. Part of the high is due to structural relief of the uplift, but, as discussed by Case and Joesting (1972), part of the high is due to fairly dense rocks within the Precambrian basement. In the extreme southwest corner of the area, a gravity low of more than 10 mGals occurs even though the elevation of the top of the Precambrian surface is about the same as at the site of the gravity high. The low must be produced in part by a mass of fairly low density within the basement, such as a quartzite or highly silicic granite. East of the high, a steepened eastward-sloping gradient coincides generally with the northern extension of Comb Ridge monocline. Values rise again to a high of about 10 mGals over the Abajo Mountains, at the southeast corner of the map area. Most of the Butler Wash area is on the nose of the main high at the northern end of the Monument uplift. A local east-plunging positive gravity nose of about 4 mGals occurs over the central part of the Bridger Jack Mesa Wilderness Study Area. Whether the high is produced by an intrabasement dense mass or by thickening of salt away from the high is unknown.

An oval gravity low of 4–6 mGals occurs over the northern part of the Needles fault zone (shown on fig. 3) between the Butler Wash and Indian Creek Wilderness Study Areas. This low has been interpreted to be caused by thickened salt, but it may be produced by low-density rocks within the Precambrian basement (Joesting and others, 1966). Thickened salt was the preferred interpretation of Joesting and others, because the Needles faults are commonly regarded as caused by downslope sliding of the rocks above the salt toward the Colorado River. Lewis and Campbell (1965), Stromquist (1976), Huntoon (1979), and Hildenbrand and Kucks (1983) interpreted the anomaly source as low-density, moderately magnetized Precambrian rocks because of small magnetic highs in the area of the low (not shown on fig. 5).

A major zone of steepened gravity gradient trends northwest across the northeast part of the area. This gradient is caused by: (1) a major intrabasement density contrast in which denser basement rocks are to the southwest, (2) increasing depth of the Precambrian basement northeastward, and (3) increasing thickness of the Paradox evaporites toward the northeast. A model showing the features was calculated by Joesting and others (1966) along a profile just north of the area shown on figure 5.

A general gravity high of 2–4 mGals (relative to gravity lows farther west) extends from the Bridger Jack Mesa Wilderness Study Area to the Indian Creek Wilderness Study Area. The high may be due to thinner salt than in adjacent areas, or it may be due to slightly denser Precambrian basement. Small highs and lows of about 2 mGals are superimposed on the broad gravity high. Neither Gibson dome nor Rustler dome appear to have any particular anomaly associated with them at this map scale or gravity-station spacing.

Remote Sensing

Landsat multispectral scanner data were processed digitally to map variations in surface limonite and to map lineaments in an attempt to evaluate the resource potential for metallic minerals, uranium, and oil and gas. These remote-sensing data were interpreted by Lee (1987).

Methods

Landsat multispectral scanner imagery data were acquired and processed to map variations in limonite. The images were used to target hydrothermal alteration associated with mineralization and limonite anomalies associated with either uranium deposits or hydrocarbon seepage.

Landsat images were also used as the basis of a lineament analysis that covered a large area of western Colorado and eastern Utah. Linear features mapped on the images were interpreted to derive longer linear trends of parallel linear features called lineaments.

Lineaments were interpreted for possible basement structures. The methods used are described more fully in Lee (1987).

Results

A major regional northeast-trending lineament passes through the Indian Creek Wilderness Study Area (fig. 3). The lineament probably represents a major fault system in the Precambrian basement, and as such it may have controlled emplacement at depth of igneous rocks, which may have associated hydrothermal mineral deposits.

Reverse limonite anomalies were sought on the Landsat images that might correspond to hydrocarbon seepage or uranium deposits, but no such anomalies were identified. One mapped uranium occurrence in the Cutler Formation (undivided) was visited in Rustler Canyon to investigate possible reduction-oxidation changes, but no anomalous limonite patterns were noted.

The Butler Wash Wilderness Study Area is on a very long lineament that trends northeast approximately parallel to the Colorado lineament, which is about 18 mi away (fig. 3). Where the lineament passes through the wilderness study area, it coincides with the Salt Creek graben.

These results are described more fully in Lee (1987).

Aerial Gamma-Ray Data

Aerial gamma-ray surveys were flown at 3-mi spacing during 1975–1983. This technique provides estimates of near-surface (0–20 inch depth) concentrations of percent potassium (K), parts per million equivalent uranium (ppm eU), and parts per million equivalent thorium (ppm eTh). Data are from Joe Duval (written commun., 1987).

The Indian Creek Wilderness Study Area has generally low radioactivity and concentrations of 1.2–2.5 percent K, 0.5–2.5 ppm eU, and 2–6 ppm eTh. Some of the potassium concentrations along the northern part of the study area are high and are probably associated with the underlying salt in Gibson dome.

The Butler Wash Wilderness Study Area has overall low radioactivity and concentrations of 0.8–1.2 percent K, 0.5–1.5 ppm eU, and 1–4 ppm eTh. There are no anomalies within or near the study area.

The Bridger Jack Mesa Wilderness Study Area has overall low radioactivity and concentrations of 1.0–2.0 percent K, 0.5–2.5 ppm eU, and 2–6 ppm eTh. There are no anomalies within or near the study area.

Mineral and Energy Resources

Uranium and Associated Byproducts Vanadium and Copper

Chinle Formation

Uranium deposits containing small amounts of vanadium and copper occur in the Moss Back Member of the Chinle Formation in the vicinity of the study areas. Uranium deposits near the south part of the Bridger Jack Mesa and Butler Wash Wilderness Study Areas are adjacent to the Elk Ridge area of the White Canyon uranium district. Studies of the White Canyon district by Lewis and Campbell (1965) and Malan (1968) found that deposits were localized in scours of paleochannels of the basal Chinle cut into the underlying Moenkopi Formation. The basal units of the Chinle are the Shinarump and the Monitor Butte south of the Butler Wash and Bridger Jack Mesa Wilderness Study Areas, and the vicinity of the two study areas. The Shinarump and the overlying Monitor Butte Member either were removed from these study areas by erosion or not deposited at all during the Triassic, making the Moss Back the basal unit. Malan (1968) believed that remnants of the Shinarump may be present in the district near the study areas. Thin remnants of Monitor Butte rocks at the base of the Chinle were observed during the present study, but not Shinarump (these are not shown on plate 1 due to their small size).

In the White Canyon district, deposits in the Shinarump tend to be larger and more extensive than deposits in the Moss Back (Chenoweth, 1975; Malan, 1968). Regionally, the largest uranium deposits in the Moss Back Member are in the Lisbon Valley district to the east of the study areas, but these deposits have a strong structural control that is lacking in the White Canyon district.

Uranium deposits in the Shinarump and Moss Back Members in the White Canyon district vary greatly in size and form and are mostly confined to paleochannels. Individual ore bodies may be from a few feet to a few hundred feet long and from 1 to 12 feet thick; they tend to be aligned with paleochannel axes. The deposits contain varied amounts of copper and vanadium. The weighted average for copper is 0.69 percent and for vanadium oxide is 0.23 percent in the White Canyon district (Chenoweth, 1975).

Primary ore minerals are uraninite, copper sulfides, and montroseite (a vanadium mineral). Oxidized parts of deposits contain uranophane, carnotite, autunite, several other uranium minerals, and the copper minerals azurite and malachite (Chenoweth, 1975). The minerals are associated with concentrations of coalified woody material referred to as "carbonaceous trash," which may be the reducing agent responsible for reduction of uranium and precipitation of primary uranium minerals. Basal sandstones of the Chinle containing carbonaceous material are considered to be favorable sites for the occurrence of uranium.

The Bridger Jack Mesa Wilderness Study Area is underlain by the Moss Back Member, which has been mined for uranium on the west, north, east, and northeast flanks of the mesa (pl. 1). Measured paleocurrent directions in the Moss Back are generally to the west or northwest, although the channels at the Moki, Royal, and Bee Gee claims trend to the southwest (Schreiner, 1987). Ore minerals in place at the Bee Gee claims are on a channel that would extend under the study area.

Resource Potential.—The resource potential for uranium with byproduct vanadium and copper in the north quarter of the Bridger Jack Mesa Wilderness Study Area is high, based on the presence of mineralized rock and the presence of a geologic environment favorable for uranium occurrence. The assessment is made with a certainty level of C. Geochemical studies, stratigraphic studies, and hand-held and aerial radiometer surveys revealed no other near-surface uranium along the outcrop of the Chinle. The resource potential for uranium and byproducts copper and vanadium in the Chinle Formation in the south three-quarters of the Bridger Jack Mesa Wilderness Study Area is low, based on the absence of indications of mineralization. The assessment is made with certainty level of C. A very small outcrop of the Moss Back Member at the southeast end of the Butler Wash Wilderness Study Area, near Cathedral Butte in the upper East Fork Salt Creek (pl. 1), was examined carefully and found to have no indication of uranium mineralization; the Moss Back Member is absent from the Indian Creek Wilderness Study Area. Therefore, the resource potential for uranium and byproducts vanadium and copper in the Chinle Formation is low in the Butler Wash and Indian Creek Wilderness Study Areas, with certainty level C.

Cutler Formation

The Cutler Formation crops out in both the Butler Wash and Indian Creek Wilderness Study Areas. The occurrence of uranium, vanadium, and copper in the Cutler Formation has been discussed by Campbell (1981) and Chenoweth (1975) and mapped by Williams (1964) and Haynes and others (1972). Campbell studied depositional systems within the Cutler and identified those that were favorable for the occurrence of uranium deposits. Uranium deposits in the Cutler are found in the zone of intertonguing of marine rocks of the Rico Formation and the distal alluvial fan rocks of the Cutler Formation undivided. Uranium is hosted by coarse-grained arkosic conglomerates and sandstones. Uranium deposits near the Indian Creek Wilderness Study Area are in the Indian Creek area of the Monticello district (Campbell and others, 1980; Chenoweth, 1975; Doelling, 1969).

The Cedar Mesa Sandstone Member of the Cutler Formation is the dominant lithology in the Butler Wash Wilderness Study Area, and potential host rocks for uranium are scarce to absent there. The Indian Creek Wilderness Study Area, however, does have a zone favorable for uranium occurrence in the Cutler Formation. Uranium may be present in arkosic, fluvial, medium- to coarse-grained sandstones near Indian Creek. In this area, just outside the eastern study area boundary, radiometric readings are more than 10 times background, and sandstones that normally are red and purple are bleached white. Azurite and malachite are present, but no uranium minerals have been identified (Campbell, 1981). However, stream-sediment geochemistry, a radiometric survey, and detailed geologic observation within the Indian Creek Wilderness Study Area revealed no further evidence of near-surface uranium-vanadium-copper mineralization.

Resource Potential.—The resource potential for uranium and byproducts vanadium and copper is low in the Indian Creek and Butler Wash Wilderness Study Areas, with a certainty rating of C. The Cutler Formation beneath the Bridger Jack Mesa Wilderness Study Area is not within the favorable zone for uranium deposition, and therefore resource potential for uranium and byproducts vanadium and copper in the Cutler Formation beneath the Bridger Jack Mesa Wilderness Study Area is also low, with a certainty rating of C.

Oil and Gas

The Indian Creek, Bridger Jack Mesa, and Butler Wash Wilderness Study Areas are all underlain by rock units that produce oil and gas elsewhere in the Paradox basin. Reservoir rocks of Pennsylvanian age include the various clastic intervals found within the salt in the Paradox Member. Source rocks are the black, organic-rich shales also found within the Paradox, or marine sedimentary rocks in east-central Utah (Spencer, 1975). Most production in the region is from the porous upper part of the Lower Mississippian Leadville Limestone.

The Lisbon field, to the east of the study areas, is the largest in the area; more than 98 percent of total production is from the Lower Mississippian Leadville, some is from the Middle Pennsylvanian Paradox, and minor amounts are from the Upper Devonian McCracken Sandstone Member of the Elbert Formation. The structure at the Lisbon field consists of a northwest-trending block fault, down to the northeast, that is overlain by impermeable salt beds of the Paradox (Parker, 1981; Hite and Lohman, 1973). The surface expression is the northwest-trending Lisbon Valley collapsed salt anticline. Structures, mainly nondiapiric salt swells, in the vicinity of the wilderness study areas are shown on figure 3. Rustler dome, Gibson dome, Beef basin, and other areas on less obvious structures have been drilled (fig. 2). Thus far, only a few oil and gas shows have been reported (Clem and Brown, 1984). Spencer (1975) proposed that repeated tilting of the Paradox basin caused back and forth migration of hydrocarbons, leaving a telltale residue of oil and gas no longer present in quantity, which accounts for the abundance of oil and gas shows but no production. The nearby Colorado River has cut down to the Paradox Member in the vicinity of the study areas. Whether this cutting has had any effect on reservoir pressures is unknown. Molenaar and Sandberg (1983) rated the study areas as having medium potential. The presence of favorable source beds, reservoir beds, and trapping structures, but no production from more than 20 drill holes (fig. 2), indicates a resource potential rating of moderate for all three study areas for oil and gas with certainty level B.

Potash and Halite

The three wilderness study areas are underlain by a thick sequence of bedded salts, including sodium- and potassium-bearing salts, and minor limestone, dolostone, black shale, and siltstone intervals known as the Paradox Member of the Hermosa Formation. These salt beds have been studied by Hite (1960, 1961), Hite and Lohman (1973), Hite and Buckner (1981), and many others. The following summary and evaluation is taken from their work.

The approximate depocenter of the basin is located immediately adjacent to the southwest flank of the ancestral Uncompahgre uplift, 60–70 mi northwest of the wilderness study areas. The area was uplifted in Late Pennsylvanian or Early Permian time, and the uplift bisected the Middle Pennsylvanian Paradox basin, which spread from southeastern Utah into what is now southwestern Colorado (Szabo and Wengerd, 1975; Baars and Stevenson, 1981). Although mainly halite was deposited, in almost every cycle of evaporite sedimentation conditions became right for the precipitation of potassium minerals, mainly sylvite (potassium chloride) but also carnallite (potassium-magnesium sulfate). Hite (1961) mapped the subsurface distribution of the zones containing potash and identified areas favorable for exploitation of salt deposits by conventional or solution-mining techniques (Hite, 1982). By reference to Hite's work, the Butler Wash and Bridger Jack Mesa Wilderness Study Areas have low resource potential for undiscovered potash and halite (certainty level C) because they are outside the area of deposition of potassium salts in the Paradox basin.

The Indian Creek Wilderness Study Area is on the flank of Gibson dome (fig. 3). Here, a nondiapiric salt swell has raised the Paradox Member potassium-rich bed to within 3,400–4,100 ft of the surface. These deposits are rated as inferred subeconomic resources by the U.S. Bureau of Mines (this report).

Braitschite (A Rare-earth Mineral)

The resource potential for the rare-earth mineral braitschite in potassium-rich beds is unknown in all three study areas. Investigations by Raup and others (1967) in the Paradox basin discovered braitschite, a rare-earth borate, in potassium-rich beds of the Paradox Member of the Hermosa Formation. The extent and origin of the braitschite is unknown. The resource potential for braitschite is therefore unknown, with certainty level A.

Gold and Silver

An isolated geochemically anomalous sample containing 50 ppm gold and 20 ppm silver was discovered near the headwaters of the West Fork of Salt Creek and Butler Wash in the Butler Wash Wilderness Study Area. Further downstream, sampling indicates that the anomaly is limited. Samples of the gold were isolated and examined by scanning electron microscope (SEM). The gold particles are small (less than 100 micrometers), angular (subhedral crystal surfaces), and show no evidence of significant transport. A likely source for this very fine grained gold is the remnant of Chinle Formation that caps the mesa in sections 25 and 26, T. 32 S., R. 19 E. Gold has been reported from the Chinle (Butler and others, 1920; Lawson, 1913) in small quantities, but no large accumulation has been found despite much exploration. Alternative explanations for the gold source include paleoplacers derived from deposits in the Abajo Mountains or from deposits related to the northeast-trending lineaments (fig. 3) just southeast of the gold anomaly. Gold, and possibly silver, leached from wall rocks by rising chloride-rich brines from the salt in the Paradox could have emplaced these metals along the fractures.

The potential for gold and silver resources is considered to be low for all three wilderness study areas, with certainty level C. Although gold and silver were found in one sample in the Butler Wash Wilderness Study Area, it is an isolated occurrence, and there is no indication of additional deposits in the study areas.

Other Metals

Hite (1975) called attention to a parallel series of northeast-trending fractures that traverse the region containing the wilderness study areas (fig. 3). These fractures are part of a larger fracture system known as the Colorado lineament (Warner, 1978). The Colorado River follows this lineament for some distance, and the Colorado mineral belt is localized along the lineament that may also include Salt Creek, Bridger Jack, and Shay grabens. Some copper-silver deposits have been reported by Fisher (1937) along zones of this lineament mainly near Sinbad, Paradox, and Salt Valleys, on the east side of the La Sal Mountains. Copper minerals and barite have been reported by Hite (1975) northwest of Moab. No geochemical anomalies suggestive of mineralization were present along these fractures nor were mineralized areas observed in the study areas. The mineral resource potential for metals other than uranium and byproducts vanadium and copper is rated as low in all three study areas, with certainty level C.

Geothermal Energy and Coal

No evidence of geothermal activity was seen, or has ever been reported (NOAA, 1980). No coal-bearing formations are present in the study areas. Therefore, the resource potential for coal and geothermal energy is low in the wilderness study areas, with certainty level C.

Recommendations for Further Work

Oil and gas potential, especially in Mississippian and Pennsylvanian rocks beneath the salt of the Paradox Member, could be further assessed by drilling; seismic exploration is made difficult by the presence of salt.

Mineral resources related to the system of northeast-trending fractures are little studied. Conceptual models for formation of deposits of copper, silver, barite, and gold have yet to be developed for these structures.

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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.

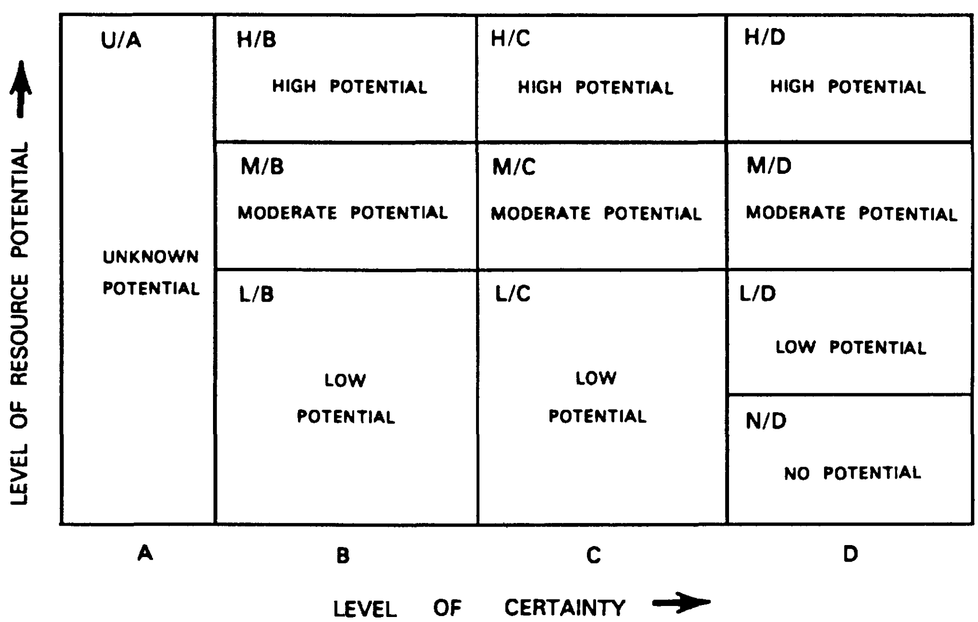
MODERATE mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence, where interpretations of data indicate a reasonable likelihood of resource accumulation, and (or) where an application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

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RESOURCE/RESERVE CLASSIFICATION

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

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

GEOLOGIC TIME CHART
Terms and boundary ages used in this report

EON	ERA	PERIOD		EPOCH	BOUNDARY AGE IN MILLION YEARS
Phanerozoic	Cenozoic	Quaternary		Holocene	0.010
				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.

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