Mineral Resources of the Scorpion Wilderness Study Area, Garfield and Kane Counties, Utah

U.S. GEOLOGICAL SURVEY BULLETIN 1747–C

Chapter C

Mineral Resources of the Scorpion Wilderness Study Area, Garfield and Kane Counties, Utah

By SUSAN BARTSCH-WINKLER, JANET L. JONES, JAMES E. KILBURN, JOHN W. CADY, JOSEPH S. DUVAL, and KENNETH L. COOK
U.S. Geological Survey

MICHAEL E. LANE and PATRICIA A. CORBETTA
U.S. Bureau of Mines

U.S. GEOLOGICAL SURVEY BULLETIN 1747

MINERAL RESOURCES OF WILDERNESS STUDY AREAS—
ESCALANTE CANYON REGION, UTAH

DEPARTMENT OF THE INTERIOR
MANUEL LUJAN, JR., Secretary

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

UNITED STATES GOVERNMENT PRINTING OFFICE: 1989

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

Library of Congress Cataloging-in-Publication Data

Mineral resources of the Scorpion Wilderness study area, Garfield and Kane Counties, Utah / by Susan Bartsch-Winkler ... [et al.].
p. cm. — (Mineral resources of wilderness study areas—Escalante Canyon region, Utah : ch. C) (U.S. Geological Survey bulletin ; 1747–C)
Bibliography: p.
Supt. of Docs. no.: I 19.3:1747–C
1. Mines and mineral resources—Utah—Scorpion Wilderness. 2. Scorpion Wilderness (Utah) I. Bartsch-Winkler, S. II. Series. III. Series: U.S. Geological Survey bulletin ; 1747–C.
QE75.B9 no. 1747–C
[TN24.U8]
557.3 s—dc20
[553'.09792'51] 89–600159
CIP

STUDIES RELATED TO WILDERNESS

Bureau of Land Management Wilderness Study Areas

The Federal Land Policy and Management Act (Public Law 94–579, October 21, 1976) requires the U.S. Geological Survey and the U.S. Bureau of Mines to conduct mineral surveys on certain areas to determine the mineral values, if any, that may be present. Results must be made available to the public and be submitted to the President and the Congress. This report presents the results of a mineral survey of the Scorpion Wilderness Study Area (UT–040–082), Garfield and Kane Counties, Utah.

CONTENTS

PLATE

[Plate is in pocket]

FIGURES

TABLE

Mineral Resources of the Scorpion Wilderness Study Area, Garfield and Kane Counties, Utah

By Susan Bartsch-Winkler, Janet L. Jones, James E. Kilburn, John W. Cady, Joseph S. Duval, *and* Kenneth L. Cook[1]
U.S. Geological Survey

Michael E. Lane *and* Patricia A. Corbetta
U.S. Bureau of Mines

ABSTRACT

The Scorpion Wilderness Study Area is in south-central Utah in Garfield and Kane Counties west of Glen Canyon National Recreation Area and Capitol Reef National Park. No mining claims or oil and gas leases or lease applications extend inside the study-area boundary. Demonstrated subeconomic resources of less than 30,000 short tons of gypsum are estimated to occur in the study area. The Navajo Sandstone could have industrial uses, but it is not considered an economic resource within the study area due to the distance from markets. Sand deposits in the study area are not unique, and similar deposits are closer to existing markets. The mineral resource potential for undiscovered gypsum in the Carmel Formation and the energy resource potential for geothermal resources is low. The mineral resource potential for uranium is low. The mineral resource potential for metals other than uranium is low. The energy resource potential for oil, gas, and carbon dioxide is moderate.

Manuscript approved for publication May 15, 1989.

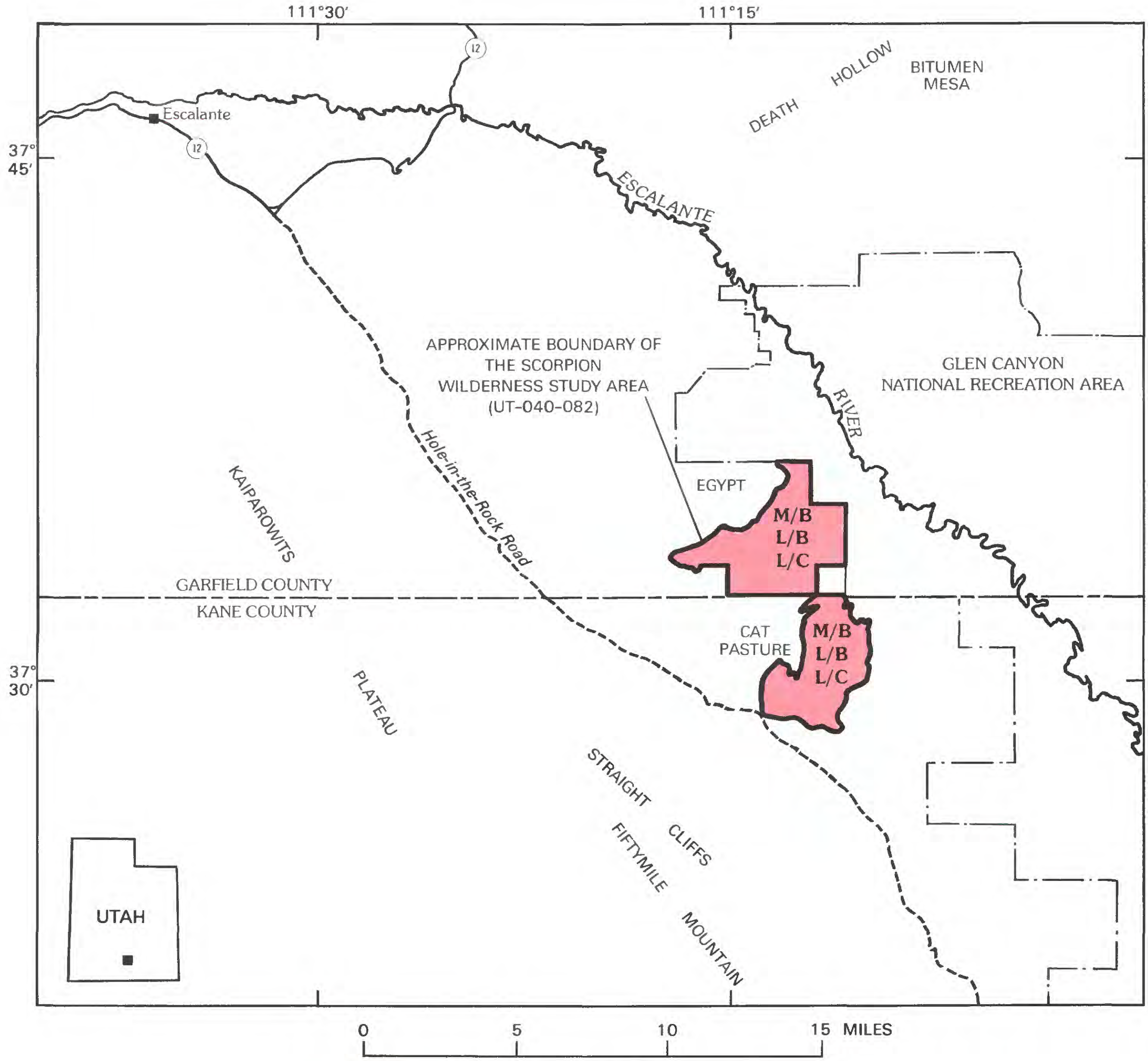
[1]University of Utah.

SUMMARY

Character and Setting

The U.S. Geological Survey and the U.S. Bureau of Mines, at the request of the U.S. Bureau of Land Management, studied 14,978 acres of the Scorpion Wilderness Study Area (fig. 1) in 1988. In this report, the Scorpion Wilderness Study Area is called the "wilderness study area" or simply the "study area." The study area is in an arid region of south-central Utah, near the Circle Cliffs and Kaiparowits Plateau; it lies west of the Glen Canyon National Recreation Area and south and east of Dixie National Forest (fig. 1). Paved access to the area is via U.S. Highway 12 through Escalante, the population center in the region. The study area lies about 7 mi east of the Straight Cliffs (locally called Fiftymile Mountain). The study area is in the Colorado Plateau province of south-central Utah (Thornbury, 1965) and within the Escalante Bench and Canyonlands physiographic province of Doelling (1975, fig. 3). Many unpaved roads provide access to the study area by two- and four-wheel-drive vehicles. The two most important roads are the road that follows the Mormon pioneer route from Escalante to Hole-In-The-Rock and the road to the region known as Egypt.

The Scorpion Wilderness Study Area is in a region of broad homoclinal folds that formed in Mesozoic (see



EXPLANATION

M/B	Geologic terrane having moderate energy resource potential for oil, gas, and carbon dioxide, with certainty level B, in the subsurface—Applies to entire study area
L/B	Geologic terrane having low mineral resource potential for uranium in the Chinle Formation, with certainty level B—Applies to entire study area
L/C	Geologic terrane having low mineral resource potential for metals other than uranium, gypsum in the Carmel Formation, and geothermal energy, with certainty level C—Applies to entire study area
	Levels of certainty
B	Data indicate geologic environment and suggest the level of energy resource potential
C	Data indicate geologic environment and give a good indication of the level of mineral resource potential

Figure 1. Mineral resource potential and location map of the Scorpion Wilderness Study Area, Garfield and Kane Counties, Utah.

geologic time chart in Appendix) rock sequences. The study area is on a plateau south and west of the Circle Cliffs upwarp and east of the Kaiparowits Plateau coal basin. The study area contains gently dipping to flat lying sedimentary rocks ranging in age from Triassic to Jurassic that are undisturbed by faulting. Throughout the region, these rock units have been folded into gentle anticlinal and synclinal structures with generally northerly and northwesterly directed axes. The study area is composed of sedimentary rock units that consist of predominantly marine shelf and continental sediments of fluvial, eolian, and alluvial origin. All units are covered, in places, by younger, relatively thin talus, terrace, and pediment deposits. From oldest to youngest, the rocks are the Upper Triassic Wingate Sandstone, the Triassic(?) Kayenta Formation; the Triassic(?) and Jurassic Navajo Sandstone; and the Middle Jurassic Page Sandstone, Carmel Formation, and Entrada Sandstone.

Identified Resources

Demonstrated subeconomic resources of less than 30,000 short tons of gypsum are estimated to occur within the study area. The Navajo Sandstone is suitable for some industrial uses other than glass manufacture, but it is too distant from potential markets to be considered a resource. Eolian sand deposits are found in the study area; however, these deposits are not unique, and similar deposits can be found closer to existing markets. Significant uranium mineralized rock is in the Chinle Formation approximately 9 mi northeast of the study area, near the Circle Cliffs; however, the Chinle Formation does not crop out in the study area.

Mineral Resource Potential

Concentrates of stream sediment and rock samples were useful in locating anomalous elements throughout the area. However, geochemical evidence for near-surface mineral occurrences or any mineralized system of consequence is notably absent in the study area. This evaluation is based on the limited number of geochemical anomalies and conspicuous lack of mineralized and altered outcrop within the wilderness study area.

Geophysical evidence shows that the study area is within roughly congruent, ring-shaped belts of gravity and magnetic highs that are interpreted to indicate a zone of subsurface plutons, either in the basement of Precambrian age or intruding the Phanerozoic sedimentary section. The inferred plutons may be analogous to Tertiary plutons that cause gravity and magnetic highs in the Henry Mountains to the east.

Uranium-bearing deposits are known to occur in the region in the Chinle Formation which underlies the study area. Because the Chinle Formation does not crop out within the study area, a low mineral resource potential is assigned for uranium.

No metallic mineral deposits occur in the study area, and geochemical evidence for near-surface deposits or any mineralized system is notably absent. The study area is assigned a low mineral resource potential for metals other than uranium.

Permian and Lower Triassic carbonate reservoir and source rocks that contain hydrocarbon resources elsewhere are present beneath the study area. However, no drilling or oil and gas exploration has been conducted, and no oil and gas resources were identified. Because the study area is underlain by known oil-bearing geologic units in the vicinity of Circle Cliffs, and there are structural similarities to the nearby Upper Valley field about 10 mi southwest of Escalante on the western edge of the Kaiparowits Plateau, a moderate resource potential is assigned for oil, gas, and carbon dioxide resources within the study area.

Geologic units that might contain gypsum deposits crop out in the study area along the western border, but no widespread exposures of gypsum exist. Potential for undiscovered gypsum resources is low.

Geophysical evidence suggests the possibility of plutons at depth adjacent to the study area, although the plutons would be too old to be a source of heat necessary to produce geothermal resources. No volcanic rocks are in the vicinity of the study area. No thermal springs were observed in the study area. Therefore, the energy resource potential for geothermal resources is rated as low.

INTRODUCTION

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

The study area is in a region consisting of rugged mesa and canyon topography dissected by rivers that flow south and southeast from the highlands of the Henry Mountains about 45 mi east of Boulder Town, and Boulder Mountain about 15 mi north of Boulder Town, all north of the wilderness study area, and from the Straight Cliffs west of the study area (Davidson, 1967) (fig. 1). Deeply incised canyons cut by tributaries of the Escalante River, including Twentyfive Mile Wash and

Table 1. Results of whole-rock analyses of Navajo Sandstone from the northern part of the Scorpion Wilderness Study Area, Garfield County, Utah

[Analyses by inductively coupled plasma-atomic emission spectrometry (ICP) by the U.S. Bureau of Mines; ppm, parts per million; *, near detection limit. Values are reported as percentages unless otherwise noted]

Sample No.	SiO_2	Fe_2O_3	Al_2O_3	K_2O	MgO	CaO (ppm)	MnO (ppm)	Na_2O (ppm)	TiO_2 (ppm)	P_2O_5 (ppm)
1	94.9	0.56	2.7	1.00	0.12	580	100	480	820	350
2	97.0	.39	2.1	.71	.10	450	68	320	350	130*

Coyote Gulch ephemeral drainages, dissect the eastern part of the study area. The western and southern parts of the study area consist of more gently inclined surfaces and less developed canyons.

Investigations by the U.S. Bureau of Mines

USBM personnel gathered information from published and unpublished sources and from field examination of the Scorpion Wilderness Study Area. Mining-claim, oil- and gas-lease, and lease-application information was obtained from the U.S. Bureau of Land Management State Office, Salt Lake City, Utah.

Two USBM geologists conducted a 10-day field examination of the study area by four-wheel-drive vehicle along outlying dirt roads and by foot traverses through the study area.

Investigations by the U.S. Geological Survey

In 1985–86 and 1988, USGS personnel conducted field investigations mostly on foot using four-wheel-drive vehicles for access. Geologic information, which includes new geophysical and geochemical data together with all available and previously published geologic reports and maps as of June, 1987, was compiled at 1:50,000 scale. This information was compiled from cited sources and was field checked by Susan Bartsch-Winkler in August 1986. Stream-sediment and bedrock samples for geochemical analysis were collected by J.L. Jones and J.E. Kilburn during July and August 1986 and May 1988, and interpretations of laboratory data were made by them. Geophysical information was provided by J.W. Cady, who conducted a gravity survey during May 1986 and interpreted the aeromagnetic and gravity data, and by J.S. Duval, who interpreted the aeroradiometric data. Additional gravity data were provided by K.L. Cook and students at the University of Utah, Salt Lake City.

APPRAISAL OF IDENTIFIED RESOURCES

By Michael E. Lane and Patricia A. Corbetta U.S. Bureau of Mines

Demonstrated subeconomic resources of less than 30,000 short tons of gypsum are estimated to occur in the study area. The gypsum is of commercial grade, but the limited tonnage, remoteness of the area, and distance from markets make development unlikely.

Three samples of Navajo Sandstone were collected for whole-rock analysis (table 1). Although the sandstone contains 94–97 weight-percent silica, it is substandard for glass production because the iron oxide content exceeds the industrial standard of 0.06 percent. It is suitable as a foundry, fracturing, and filtering sand and for use as an abrasive (Bates, 1960, p. 99–103). Similar and more accessible sandstone deposits occur throughout the Colorado Plateau nearer to possible markets.

Abundant eolian sand deposits occur in the study area; minor amounts of gravel can be found in drainages. These deposits are not unique, and similar deposits can be found closer to existing markets. The deposits are considered to be subeconomic.

Uranium occurrences were not found in the study area. The Chinle Formation, the only rock unit underlying the study area known to contain significant uranium deposits on the Colorado Plateau, lies at depths exceeding 1,000 ft. The nearest mineralized area is approximately 9 mi northeast in the Circle Cliffs area (Lane, 1981). Dubyk and Young (1978, p. 15) indicated that the favorability for uranium deposits and recovery in the Kaiparowits Plateau region is low.

No oil and gas leases are in the study area (fig. 2). Leases to the west are along the Collet anticline and Harris Wash syncline. Drill holes along the east flank of the Collet anticline and along the Willow Tank anticline were dry and abandoned, but penetrated the Lower Triassic Timpoweap Member of the Moenkopi Formation and the Lower Permian Kaibab Limestone, which were productive horizons in the Upper Valley oil field (Doelling, 1975, p. 91).

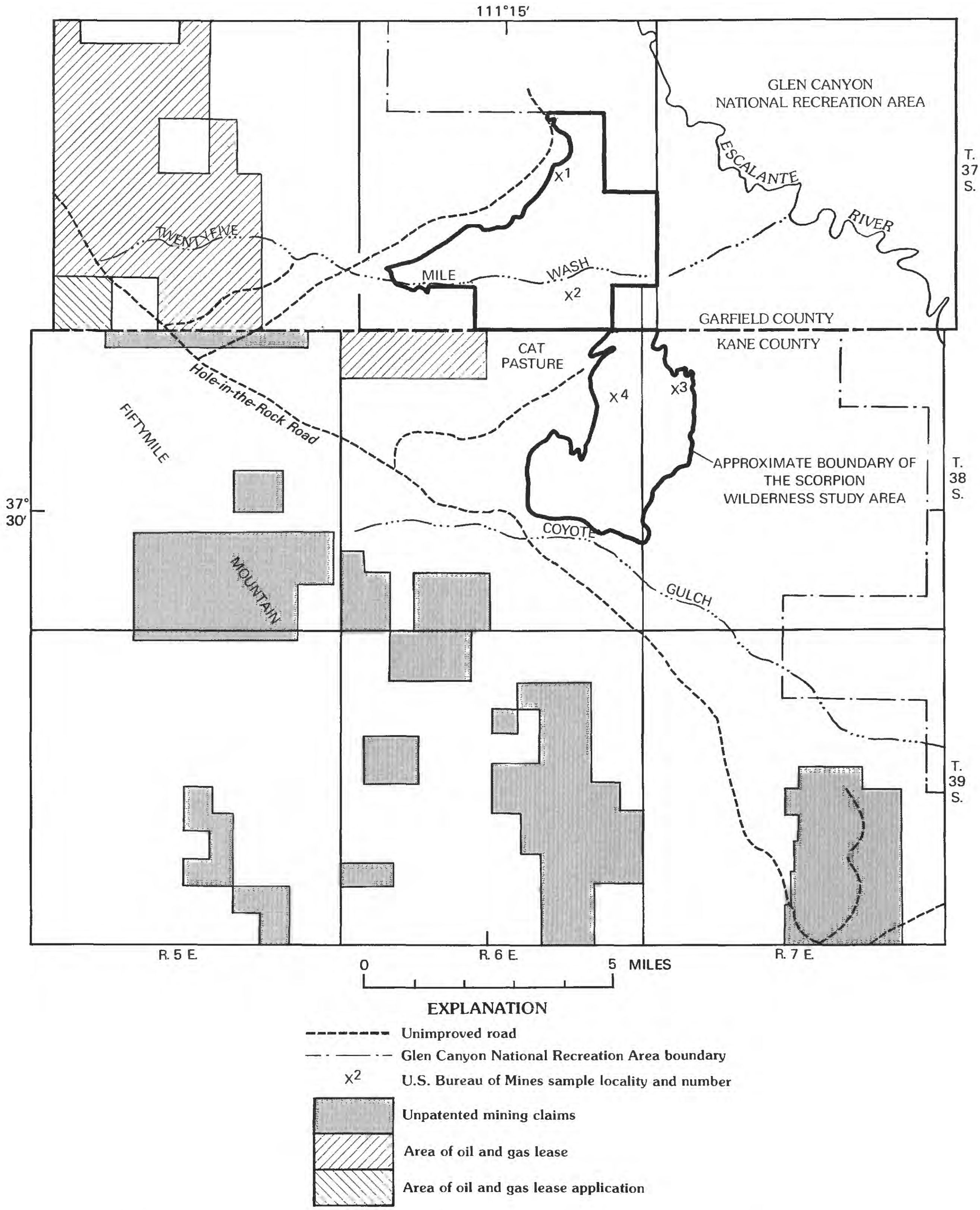


Figure 2. Map showing sample localities, mining claims, and oil and gas leases and lease applications, Scorpion Wilderness Study Area, Garfield and Kane Counties, Utah.

ASSESSMENT OF POTENTIAL FOR UNDISCOVERED RESOURCES

By Susan Bartsch-Winkler, Janet L. Jones, James E. Kilburn, John W. Cady, Joseph S. Duval, and Kenneth L. Cook[2]
U.S. Geological Survey

Geology

Geologic Setting

The earliest reports on the geology of the Circle Cliffs were made in 1872 by M.E. Thompson and his party, as noted in the results of the Powell Survey and Gilbert (1874, 1875), a member of the Wheeler Survey. The geology and stratigraphy of the Aquarius Plateau, Waterpocket fold, and Henry Mountains were studied by Howell (1875) and Gilbert (1877). The Kaiparowits Plateau region was examined in 1915–27 by Gregory and Moore (1931), who completed a detailed map of the Circle Cliffs area. In 1935, the Henry Mountains area, including parts of the Circle Cliffs, was remapped by Hunt and others (1953). Numerous reports detailing the stratigraphy of the region have been published (see Davidson, 1967). In 1954, several promising uranium prospects in the Circle Cliffs area were mapped (Davidson, 1954) to determine the uranium potential of the region. His report concluded that the uranium deposits are small and that the chances for discovery of a large deposit are poor. In the same year, a report on the stratigraphy of the area was published that resulted from unsuccessful exploratory drilling for gas and oil at Wagon Box Mesa 30 mi northeast of the study area (Steed, 1954). Since 1960, no extensive mining or oil and gas drilling, except that associated with exploration, has taken place in the region. The stratigraphic descriptions synthesized in this report are from the recent work by Davidson (1967), Doelling (1975), Sargent and Hansen (1982), and Lidke and Sargent (1983).

The western flank of the Circle Cliffs uplift to the northeast of the study area extends south-southwest into the Escalante River region with little disruption (Doelling, 1975). The structure dips less than about 6° west but contains numerous high-angle normal faults with displacements of less than 50 ft (feet). The region consists of gently dipping, north-trending structural anticlines and synclines.

[2]University of Utah.

Description of Rock Units

In and around the Scorpion Wilderness Study Area, the rocks consist of the Upper Triassic Wingate Sandstone, the Upper Triassic(?) Kayenta Formation, the Triassic(?) and Jurassic Navajo Sandstone and minor exposures of Middle Jurassic Page Sandstone, Carmel Formation, and Entrada Sandstone (Sargent and Hansen, 1982; Hackman, 1955; Hackman and Wyant, 1973). The south-plunging part of the Harris Wash syncline lies directly west of the Scorpion Wilderness Study Area. No structural faults offset rocks in the study area, and the rocks dip gently to the west.

As determined by exploratory drilling in the region, the subsurface sequence includes the Lower and Upper Mississippian Redwall Limestone, the Lower Pennsylvanian Molas and Middle and Upper Pennsylvanian Hermosa Formations, the Lower Permian Cutler Formation and, west of where the Cutler occurs, the Lower Permian Toroweap Formation and Kaibab Limestone, the Lower and Middle(?) Triassic Moenkopi Formation, and the Upper Triassic Chinle Formation (Lidke and Sargent, 1983).

The Upper Triassic Wingate Sandstone is homogeneous, reddish brown, cliff forming, and commonly stained deep purple or black by desert varnish and pockmarked by erosion of noncemented sand. The unit was derived from eolian deposition. Total thickness is as much as 400 ft.

The Upper Triassic(?) Kayenta Formation is fine- to coarse-grained sandstone interbedded with minor siltstone, shale, and conglomerate. The unit is thin to thick bedded, lenticular, and partly crossbedded. Both calcite and silica cement are present in the sandstones. The Kayenta Formation is distinguished from the Wingate and Navajo Sandstones by its grayish-brown color and its common ledge-forming occurrence. The Kayenta was deposited mostly by fluvial systems and is about 200 ft thick.

The Triassic(?) and Jurassic Navajo Sandstone is very fine to medium grained, white to buff, and strikingly crossbedded and massive. The unit is predominantly a wind-blown deposit, but rare thin beds of shaly, dolomitic, and limy beds are present that originated in a lake; no interbeds are thicker than 10 ft, and most are less than 3 ft thick. The unit also contains iron and manganese nodules. The unit, due to strong jointing, is characterized by an elephant-hide pattern of erosion. The Navajo Sandstone forms sheer cliffs and domes, generally lacks vegetation, and forms many long, narrow box canyons. The unit thickens to the west, where, at Escalante, it is as much as 1,400 ft thick. It is an excellent aquifer.

The Page Sandstone is an eolian deposit that closely resembles the Navajo Sandstone and is separated from the Navajo Sandstone at the J-2 unconformity of

Pipiringos and O'Sullivan (1975); in this report we did not map the unconformity, and the Middle Jurassic Page Sandstone was mapped with the Navajo Sandstone, from which it is indistinguishable. The Middle Jurassic Carmel Formation makes a red or brown cap on the Page Sandstone. The Carmel Formation is a ledge-forming unit, commonly mottled and streaked, and composed of sandstone, siltstone, mudstone, limestone, and gypsum. Mudstone and siltstone are variegated in shades of red, orange, gray, white, brown, light tan, and light green. Limestone beds, more common in the lower parts of the formation, are yellowish gray to greenish or orange pink. Gypsum is in nonresistant contorted and broken thick beds, veinlets, fracture fillings, and nodules, and as cement. The Carmel Formation was deposited in a desert lake or marginal marine environment and is about 200 ft thick.

The Middle Jurassic Entrada Sandstone is composed of unfossiliferous sandstone, siltstone, and mudstone that are banded in places in tints of red, orange, brown, gray, and white. In areas of nonresistant beds, the slopes on the Entrada are earthy and typically covered with sandy soil and vegetation; in places of resistant sandstone, slickrock areas and elephant-hide-jointed cliffs form that are grooved on the bedding planes and typically form so-called "goblins", "stone-babies", posts, turrets, and isolated buttes. The sandstone is of continental or marine origin and is as thick as 900 ft in the region, though considerably thinner (less than 100 ft thick) in the study area.

Geochemistry

In June 1986 and 1988, reconnaissance geochemical surveys were conducted in the Scorpion Wilderness Study Area to aid in the evaluation of the mineral resource potential. Sample media included stream sediments, rock samples collected near the stream-sediment-sample sites, and heavy-mineral-concentrate samples derived from stream sediments (herein referred to as concentrates). These sample media were chosen because they best reflect the geochemistry of rock material eroded from the drainage basin upstream from the sample site as well as from the site itself. Concentrates may contain both the minerals that result from ore-forming processes and accessory heavy minerals common to the rock type. This selective concentration of heavy minerals permits determination of some elements that are not easily detected in bulk stream-sediment samples. Stream-sediment and rock samples provide information that helps identify areas that contain unusually high concentrations of elements related to mineralization. They also help identify rock lithology upstream. Stream-sediment and concentrate samples were collected from active alluvium in first-order unbranched and second-order (below the junction of the first order) streams, as shown on 1:24,000-scale topographic maps of the study area. Rock samples were taken from unaltered outcrop to provide background information on geochemical concentrations. Sample localities are shown on plate 1.

Stream-sediment samples were collected at 55 sites, concentrate samples were collected at 53 sites, and rock samples were collected at 6 sites. Detailed sampling procedures, sample preparation, and analytical techniques were conducted as described by David Detra and others (U.S. Geological Survey, unpub. data, 1988).

Anomalous concentrations of elements were found only in the concentrate samples. Elemental anomalies consisted solely of widespread, generally coincidental occurrences of strontium and barium. Possibly these anomalies are chemical manifestations of celestite, a common strontium sulfate mineral that was identified optically in the samples and later verified by X-ray diffraction. Laser microprobe analyses detected considerable barium within the celestite; apparently barium replaced strontium in a solid-solution series. This strontium-barium enrichment is not considered significant with respect to the mineral resource assessment, however, and probably represents little more than minor celestite occurrence associated with local gypsiferous units as an outgrowth of the secondary hydration of anhydrite.

Titanium was also notably high in the concentrates from the east-flowing ephemeral drainages called Coyote Gulch and Twentyfivemile Wash. Rutile, confirmed by microscope inspection and X-ray diffraction, was abundant in all samples that had anomalous titanium values and is assumed to be the major source of this element. The rounded and frosted nature of the grains of rutile suggests that they were transported a considerable distance prior to deposition. Titanium-bearing fossil placers are known in the Upper Cretaceous Straight Cliffs Formation of the Kaiparowits Plateau region west of the study area, where they occur in beach deposits along Cretaceous shorelines (Adams, 1964; Bartsch-Winkler and others, 1988); this may be the origin of these occurrences in the Scorpion Wilderness Study Area.

Geophysics

Reconnaissance geophysical data typically are not used for the detection of mineral deposits, but such information aids in providing a three-dimensional geologic framework that serves to guide exploration. Geophysical data for the Scorpion Wilderness Study Area came from reconnaissance aeroradiometric surveys, aeromagnetic surveys, and regional gravity surveys.

Aeroradiometric Survey

Aerial gamma-ray spectroscopy is used to determine the near-surface concentrations of potassium, uranium, and thorium. Because uranium and thorium measurements utilize radioactive daughter nuclei that are chemically distinct from the parent nuclei, the uranium and thorium data are described as equivalent concentrations. For a typical aerial survey, each measurement reflects average concentrations for a surface area of about 646,000 square feet to an average depth of about 1 ft. From 1975 to 1983, the U.S. Department of Energy contracted for aerial gamma-ray surveys that covered Utah, with flight-line spacing commonly of 3 mi (miles). Because of the wide flight-line spacing, the survey is only suitable for producing a regional-scale map. Data for Utah were compiled and processed to produce a series of 1:1,000,000-scale maps, including the composite-color maps described by Duval (1983). These maps were examined to estimate the concentrations of potassium (in percent) and uranium and thorium (in parts per million or ppm) for the wilderness study area. To be anomalous, element concentration and its ratios to the other two elements must be high values within the context of the map area. For the Scorpion Wilderness Study Area, the overall radioactivity is low with concentrations of 1.0–1.4 weight percent potassium, 0.5–1.5 ppm equivalent uranium, and 1–4 ppm equivalent thorium. No gamma-ray anomalies are within or near the study area.

Gravity and Aeromagnetic Surveys

Neither the gravity nor the aeromagnetic surveys were designed specifically for either mineral resource or oil and gas investigations, though the results are useful for interpreting the possibilities of mineral and oil and gas resources. Interpretations were based upon a comparison of the geologic map of Hackman and Wyant (1973) with unpublished 1:250,000-scale gravity and magnetic maps. Figures 3 and 4 are small parts of these maps.

A Bouguer gravity anomaly map was first calculated using the standard regional Bouguer reduction density of 2.67 g/cm^3 (grams per cubic centimeter). This map showed southeast-trending gravity lows correlative with the high topography of Fiftymile Mountain, 5–10 mi southwest of the Scorpion Wilderness Study Area. This inverse correlation of Bouguer anomalies with topography indicated that the actual density of the near-surface rocks is less than the reduction density used. Therefore, a series of maps was calculated using reduction densities of less than 2.67 g/cm^3. The correlation of Bouguer anomalies with local topography was nearly eliminated by using a reduction density of 2.30 g/cm^3, the density used in creating figure 3.

An aeromagnetic map (fig. 4) was made from total-intensity aeromagnetic data obtained from a digital tape (National Uranium Resources Evaluation, 1980) and recontoured. Short-wavelength data, originally available along survey flight lines, were lost in the gridding and contouring process, and small features cannot be resolved. However, magnetic profiles (National Uranium Resource Evaluation, 1983) were inspected for short-wavelength anomalies indicating near-surface magnetic rocks. Near-surface magnetic rocks do not appear to be present in the study area, although short-wavelength magnetic anomalies, caused by clinker, occur in the Kaiparowits coal field in the southwestern corner of the area of figure 4 (Bartsch-Winkler and others, 1988).

The major gravity and magnetic anomalies (figs. 3 and 4) have long wavelengths that are best explained by sources 1 to 2 mi or more deep. Determining what caused the anomalies is difficult, but they may be due to relief of meta-igneous basement rocks that underlie the sedimentary strata, variations in composition of these ancient rocks, or intrusive rocks of younger age that cut the meta-igneous basement and possibly the overlying sedimentary section.

Twenty miles west of the map area, magnetic and gravity anomalies clearly reflect basement relief along linear geologic structures like the Kaibab monocline 50 mi west of the study area. Throughout most of the area shown in figures 3 and 4, however, linear geophysical anomalies are subdued, and there is little correlation of geology to these anomalies. An exception is in the vicinity of the northern part of the Waterpocket monocline, where geology coincides with linear gravity and magnetic gradients.

About 25 miles northeast of the Scorpion Wilderness Study Area, magnetic and gravity highs are related to Tertiary intrusive rocks of the Henry Mountains. A belt of gravity highs extends southwest from the Henry Mountains towards the eastern side of the area of figure 3, although it is partly interrupted by the Waterpocket monocline. A belt of magnetic highs extends southwest from the Henry Mountains, but it is south of the area of figure 4.

Within the areas of figures 3 and 4, gravity and magnetic anomalies correlate imperfectly. Where magnetic and gravity highs correlate, the source of the highs is interpreted to be both dense and magnetic—that is, igneous or metamorphic rocks that are denser and more magnetic than adjacent rocks, either in the Precambrian basement or the overlying Phanerozoic sedimentary section. Offsets between approximately correlative gravity and magnetic highs are probably explained by differences in the mathematics of magnetic and gravity fields, lack of closely spaced magnetic and gravity observations, and complexities in the geology not included in the simple igneous-intrusion model.

In figures 3 and 4, gravity and magnetic highs that correlate are labeled GH1 through GH4 and MH1 through MH4, respectively. Gravity and magnetic lows that correlate are GL1 and GL2 and ML1 and ML2. Gravity and magnetic highs that correlate poorly are GHa through GHc and MHa through MHh. Gravity and magnetic lows that do not correlate are labeled GLa and MLa through MLf.

Gravity highs GH1 through GH4 and GHa through GHc encircle gravity low GL1. Of these gravity anomalies, only high GHc correlates with a mapped geologic feature, the Circle Cliffs anticline. Northeast of high GHc, gravity low GL2 is centered over a syncline, the Henry Mountains structural basin. Between the high and the low is a gravity gradient associated with the Waterpocket monocline. Although gravity high GHc coincides with the structural high west of the Circle Cliffs, the gravity high is not an artifact of the Bouguer reduction density because it persists in maps made using reduction densities ranging from 2.30 to 2.67 g/cm³. High GHc, as well as the other gravity highs shown on figure 4, are probably caused in part by higher average densities in the Permian through Lower Jurassic section (limestone, shale, and sandstone) west of the Waterpocket monocline. An Upper Jurassic through Upper Cretaceous sequence of sandstone and shale that has lower average density occurs east of the Waterpocket monocline in the northeastern part of the area of figures 3 and 4.

The circular configuration of gravity highs GH1 through GH4 and GHa through GHc surrounding low GL1 (fig. 4) cannot be explained by structures in the sedimentary section. The structure contour map of Hackman and Wyant (1973) shows no evidence for circular structures. The magnetic highs form a circular belt that coincides roughly with the circle of gravity highs shown on figure 3. Although the correlation of magnetic and gravity highs is imperfect, they are probably all caused by fairly dense magnetic rocks, probably plutons, either in the basement or intruding the sedimentary section. Even granitic plutons could be more dense than adjacent sedimentary rocks. Gravity low GL1 (fig. 3) and magnetic low ML1 (fig. 4) coincide, indicating an area in the center of the anomaly ring belt in which subsurface plutons appear to be missing. Although gravity low GLa and magnetic low MLd do not exactly coincide, together they also indicate a region lacking subsurface plutons.

The approximate depth to the top of the inferred plutons is equal to the width of the zone of steepest gradients bounding the magnetic highs, or about 1–2 mi (fig. 4). Gravity high GH1 is wider than magnetic high MH1. A second magnetic high (MH1') coincides with the southern part of GH1, and magnetic low MLc separates MH1 and MH1'. The two coincident magnetic anomalies may be caused by a multiphase pluton with a nonmagnetic center and a magnetic rim. Magnetic highs MHa through MHh coincide with the belt of gravity highs that extends from GH3 through GHa through GHc to GH1, although individual magnetic and gravity anomalies fail to correlate, probably because of variations in the magnetic properties of the inferred plutons.

Gravity highs GHc and GH1 terminate at the Waterpocket monocline, suggesting a relationship between the monocline and the inferred plutons. However, magnetic high MHg crosses the monocline. The relationship between the Waterpocket monocline and the buried sources of the geophysical anomalies remains largely an unsolved problem. The uplift west of the Waterpocket monocline could be caused in part by the Tertiary(?) intrusions inferred from the gravity and magnetic highs.

In conclusion, the encircling belt of gravity and magnetic highs (figs. 3 and 4) is interpreted to be caused by a ring-shaped subsurface plutonic complex. The Scorpion Wilderness Study Area lies within and overlies the southern side of this inferred plutonic complex. The inferred plutons are denser than the rocks, either Precambrian basement or Phanerozoic sedimentary rocks, that they intrude. The plutons are generally magnetic, but nonmagnetic phases are present. The plutons may be analogous to exposed plutons in the Henry Mountains that cause magnetic and gravity highs.

Mineral and Energy Resources

Uranium

Sandstone-hosted uranium deposits are associated with generally flat bedded feldspathic or tuffaceous sandstone of Devonian or younger age in a stable platform or foreland interior basin setting (Turner-Peterson and Hodges, 1986). According to Turner-Peterson and Hodges (1986), the microcrystalline uranium oxides and silicate ores are deposited during postdepositional alteration of fine- to medium-grained permeable sandstone beds within shale and mudstone sequences, and are later redistributed by ground water; uranium is concentrated at an oxidation-reduction boundary. Further, the interbedded mudstone or shale is the source of ore-bearing fluids; carbonaceous material typically reacts with the ore fluid to precipitate the uranium. Fluvial channels, braided-stream deposits, continental basin margins, and stable coastal plains are the most characteristic settings for sediment-hosted uranium deposits. In some tabular uranium-bearing sandstone sequences, humic-acid mineralizing fluids

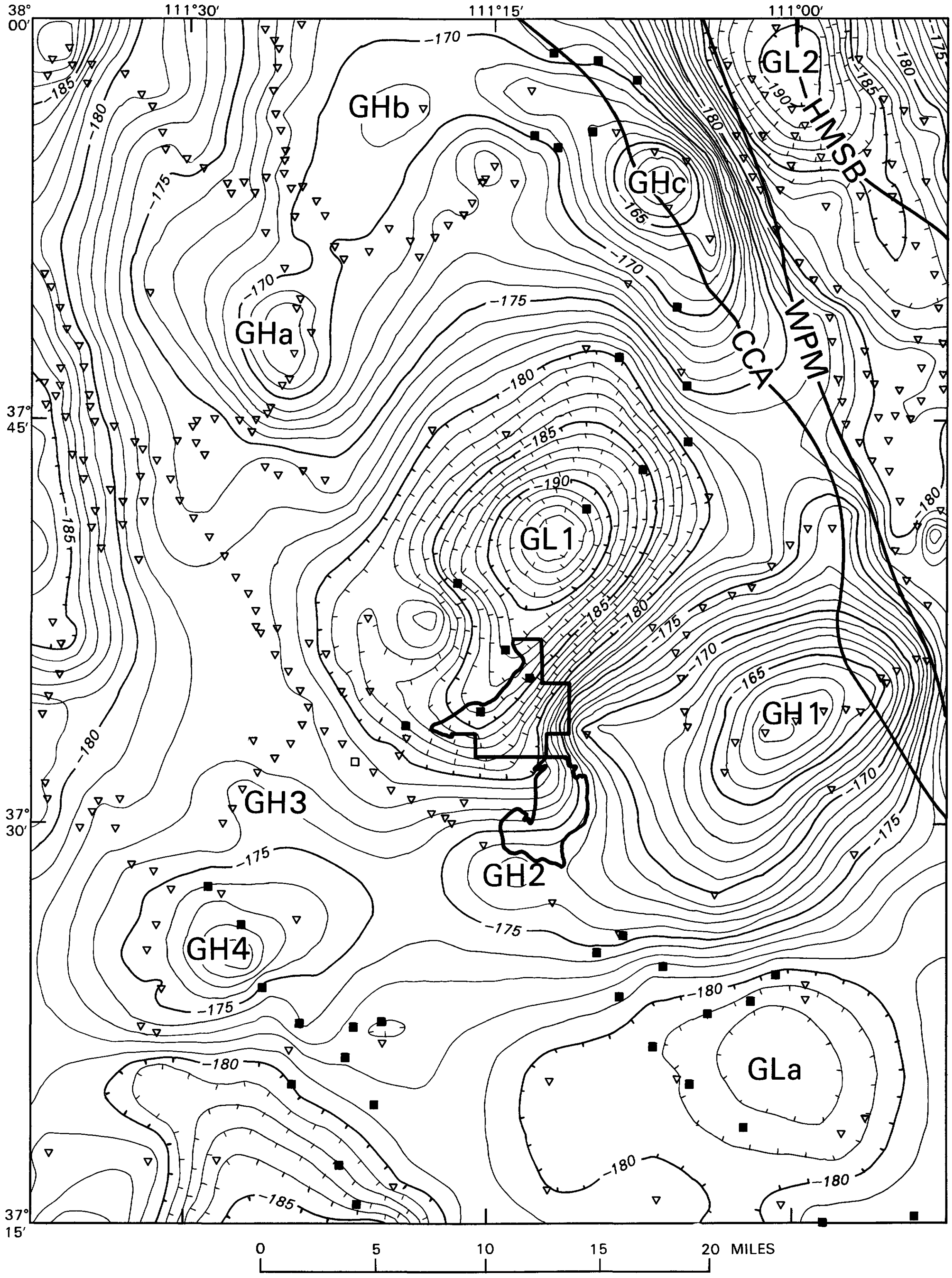


Figure 3 (above and facing page). Complete Bouguer gravity anomaly map of an area that includes the Scorpion Wilderness Study Area, Utah. Bouguer reduction density 2.30 g/cm³. WPM, Waterpocket monocline; CCA, Circle Cliffs anticline; HMSB, Henry Mountains structural basin. Symbols explained in text.

EXPLANATION

—170— Gravity contour showing complete Bouguer gravity anomaly—Contour interval 1 milligal. Hachures show closed areas of lower gravity values

Gravity measurement stations

▿ From digital data set compiled for Bouguer gravity anomaly map of Utah

■ Obtained specifically for this study (McCafferty and Cady, 1987)

—— Approximate boundary of the Scorpion Wilderness Study Area

leach iron from detrital magnetite and ilmenite minerals and leave relict titanium minerals (Turner-Peterson and Hodges, 1986). According to Wood and Grundy (1956), ore in the Chinle Formation is commonly associated with (1) bottoms and sides of fluvial channels, (2) poorly sorted argillaceous, arkosic sandstone or conglomerate interbedded with mudstone and clay lenses, (3) irregular channels with steep, narrow cross sections, (4) carbonaceous material and clay lenses, (5) a thickened bleached zone in the underlying Moenkopi Formation, and (6) nearby copper sulfides, sulfates, and carbonates; iron sulfides, sulfates, and hydrous oxides; and cobalt arsenate.

Uranium, a commodity produced from the Colorado Plateau, is found in the Upper Triassic Chinle Formation and the Upper Jurassic Morrison Formation of northern New Mexico, southwestern Colorado, and southeastern Utah (Doelling, 1975; Dubyk and Young, 1978). Significant uranium and copper mineralized rock and associated cobalt, molybdenum, and silver, occur in the lower ledge-forming members of the Chinle Formation (Doelling, 1975, p. 31). The Morrison Formation has been eroded from the study area, but the Chinle occurs at depth beneath the study area. The unit crops out approximately 9 mi northeast of the study area near the Circle Cliffs. Sandstone-type uranium occurrences could be present in the Chinle Formation at depth beneath the study area. The Chinle Formation in the subsurface beneath the study area has been rated as unfavorable for uranium deposits by R.D. Lupe, U.S. Geological Survey (*in* Peterson and others, 1982), and Dubyk and Young (1978) concluded that the Chinle Formation in the Kaiparowits Plateau region is unfavorable for uranium deposits and recovery. This conclusion is based, in part, on: (1) only 3 of 34 test-hole logs in the Kaiparowits Plateau area showed gamma-ray readings greater than two times background; (2) the absence of carbonaceous matter that is associated with uranium deposits; and (3) the great depth to the Chinle Formation. The mineral resource potential for uranium in concealed rocks of the Chinle Formation of the Scorpion Wilderness Study Area is low with certainty level B.

Other Metals

The Scorpion Wilderness Study Area does not contain any metallic mineral resources. Geochemical data indicate no anomalous concentrations of metals in stream-sediment samples collected from drainages. However, anomalous concentrations of titanium were found in concentrate samples from along east-flowing ephemeral drainages of the study area. Microscopic examination of rutile grains (and also staurolite) showed them to be highly rounded and probably transported considerable distances; they may have come from the Straight Cliffs region to the west of the study area. Evidence for near-surface mineral deposits or any mineralized system of consequence is notably absent, based on a limited number of anomalies and a conspicuous lack of mineralized and altered outcrop. The Scorpion Wilderness Study Area has a low mineral resource potential for metals other than uranium, with certainty level C.

Oil and Gas

The formations targeted as most favorable for oil and gas exploration in south-central Utah are the Honaker Trail Formation and the Paradox Formation (Pennsylvanian) (Oakes and others, 1981), the Redwall Limestone (Mississippian) (Kunkel, 1965; Oakes and others, 1981), the Cedar Mesa Sandstone Member of the Cutler Formation (Permian), the Kaibab Limestone (Lower Permian) (Kunkel, 1965; Oakes and others, 1981), and the upper part of the Moenkopi Formation and the lowermost Chinle Formation (Triassic) (Doelling, 1975, p. 91–96; Oakes and others, 1981; Campbell and Ritzma, 1982). The Upper Valley oil field lies about 10 mi southwest of Escalante and is structurally similar to the study area. In the Circle Cliffs area east of the study area, a low-grade deposit of oil-impregnated rock occurs in the sandstone and siltstone of the middle part of the Moenkopi Formation and lowermost Chinle Formation (Campbell and Ritzma, 1982). According to Lidke and Sargent (1983), the Mississippian through Triassic section is present beneath the Scorpion Wilderness Study Area.

Oil and gas resources in Utah were appraised by Molenaar and Sandberg (1983), and the Scorpion Wilderness Study Area was designated as having moderate potential. In the nearby Upper Valley oil field, about 10 mi southwest of Escalante on the western edge of the Kaiparowits Plateau, production is primarily from the Kaibab Limestone (Campbell, 1969; Molenaar and Sandberg, 1983). The oil and gas occur in a southeasterly plunging anticline in which a hydrodynamic gradient has produced an inclined oil-water contact (Sharp, 1978; Molenaar and Sandberg, 1983). At one tract on the western flank of the Upper Valley structural anticline in the Upper Valley oil field, 21 million barrels of oil have been produced (Sharp, 1976). Some exploration has been done on similar structural anticlines in south-central Utah, including those near the Scorpion Wilderness Study Area, since production began from the Upper Valley field, but no commercial oil and gas has been identified. Campbell and Ritzma (1982) discussed oil-impregnated sandstone and siltstone beds of the Moenkopi Formation and lowermost Chinle Formation on the anticlinal uplift east of the Circle Cliffs. Beneath the Circle Cliffs, the western flank of the anticline contains as much as 310 ft of bituminous rock, which ranges from rock containing traces of petroleum to black rocks oozing viscous petroleum; the deposit is of moderate oil saturation (Campbell and Ritzma, 1982, p. 38), and the rocks extend beneath the Scorpion Wilderness Study Area.

No oil and gas leases or lease applications exist in the wilderness study area (fig. 2). Leases to the west are along the Collet anticline and Harris Wash syncline. Holes drilled into the Collet and Willow Tank anticlines were dry and abandoned but penetrated the Timpoweap Member of the Moenkopi Formation and the Kaibab Limestone, which are the productive horizons in the Upper Valley field (Doelling, 1975, p. 91), as well as the Moenkopi and Chinle Formations, which contain oil-impregnated rocks in the Circle Cliffs area (Campbell and Ritzma, 1982). The Scorpion Wilderness Study Area is assigned a moderate energy resource potential for oil and gas with certainty level B.

Carbon Dioxide

Carbon dioxide is used in oil-recovery enhancement techniques, such as those being used in west Texas oil fields. Because carbon dioxide is miscible with oil, it acts as a solvent and displaces enough water to mobilize oil in water-invaded reservoirs that would otherwise be unrecoverable. The largest carbon dioxide gas reservoirs in the region are the McElmo Dome and Doe Canyon fields near the Four Corners area of southwestern Colorado, about 100 mi southeast of the study area. The source rock is the Leadville Limestone of Early Mississippian age. Carbon dioxide gas was created when the water-filled Leadville was altered by high pressure and temperature during deep-seated volcanism.

In the early 1960's, during exploration for oil and gas in the Death Hollow area about 8 mi northeast of Escalante, a carbon dioxide reservoir was discovered in rocks beneath the Escalante anticline (Oil and Gas Journal, 1984), a structure similar to those near the Scorpion Wilderness Study Area. The anticline is overlain on its north half by igneous volcanic rocks (Oil and Gas Journal, 1984). Drilling confirmed a field of high-purity carbon dioxide in the Upper Triassic Chinle Formation and the Lower Permian Kaibab Limestone, Cedar Mesa Sandstone Member, and Toroweap Formation (Tooker and others, 1984). Mid-Continent Oil and Gas Reserves Inc. confirmed a carbon dioxide gas reservoir with a gauged open-flow of 124,347,000 cu ft (cubic feet) daily at one well; the gas occurs in an interval from 1,354 to 3,443 ft depth (The Denver Post, Nov. 20, 1983). This deposit is estimated to contain several trillion cubic feet of the gas (Leed Petroleum Corporation, written commun., 1984).

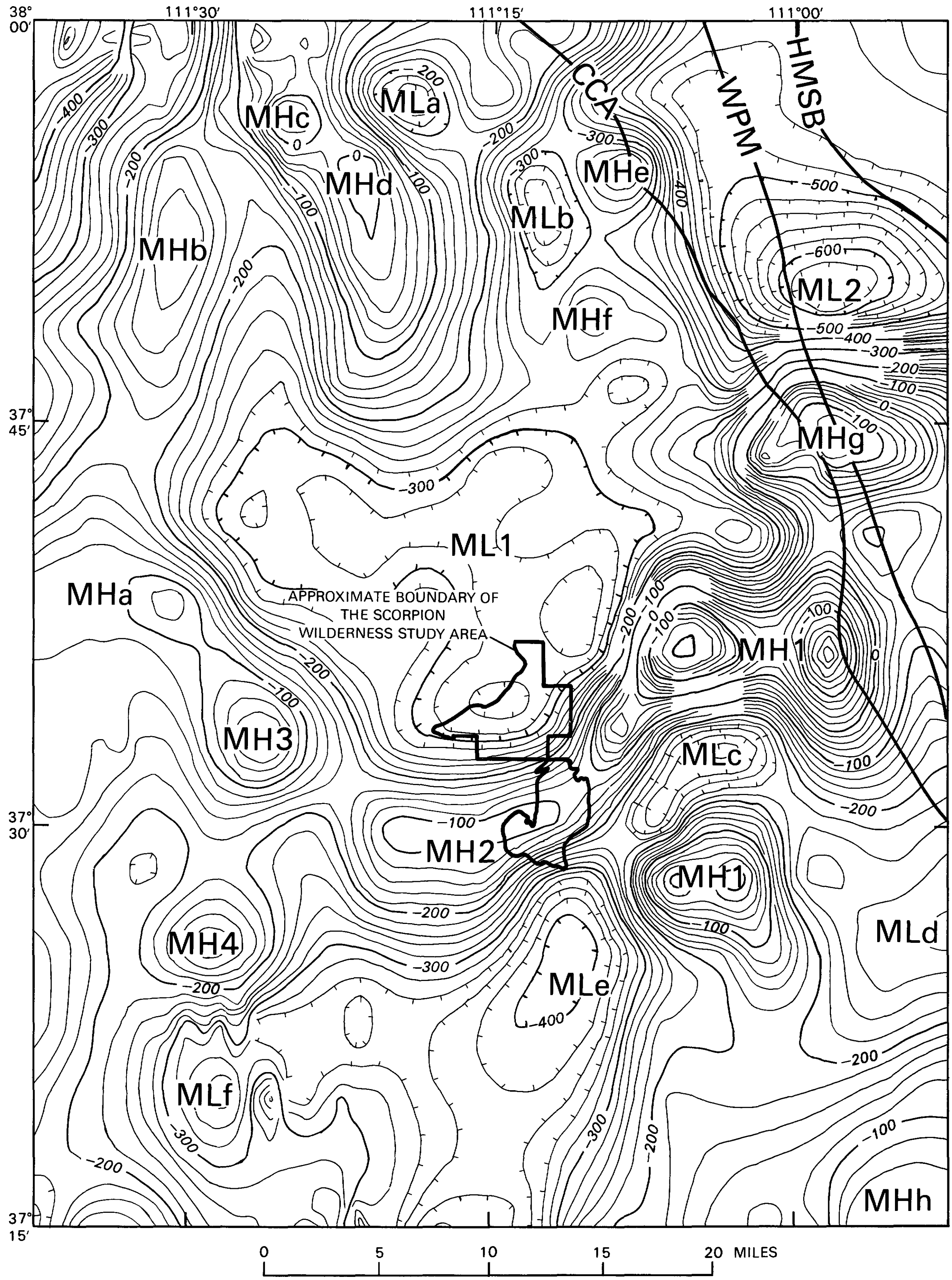
Geophysical evidence suggests the possibility of plutonic activity of unknown age at depth in the vicinity of the study area (see the section on "Geophysics," this report). If the plutonic activity took place at a propitious time interval, the heat and pressure generated by such activity might enable carbon dioxide to generate in the overlying carbonate rocks. There are no volcanic rocks in the vicinity of the study area such as those overlying the Escalante anticline that might produce the necessary heat and pressure to form carbon dioxide gas in the underlying limestone strata. Although recent drilling has shown no evidence of carbon dioxide gas in the study area, because the Escalante anticline is similar to the structures in the study area and because of its proximity to the study area, the energy resource potential for carbon dioxide gas in the wilderness study area is rated as moderate with certainty level B.

Gypsum

Gypsum, a chemical precipitate, commonly originates in inland sabkhas (salt flats) and desert lakes in basins where rainfall is limited and evaporation is rapid (Reineck and Singh, 1975). Gypsum typically occurs in evaporite deposits or in extensive beds interstratified with limestone, shale, and clay.

Near the Scorpion Wilderness Study Area, a 125-ft section of the upper and middle parts of the Carmel Formation contains alternating beds of gypsum and siltstone (Doelling, 1975, p. 148). The lower part of the Carmel crops out along the western border of the wilderness study area, but gypsum is not widely exposed (occurring in beds less than 4 ft thick). Gypsum resources of less than 30,000 short tons exist in the study area. Additional gypsum resources are assigned a low potential with certainty level C.

Figure 4 (facing page). Total-field aeromagnetic map of an area that includes the Scorpion Wilderness Study Area, Utah. Survey was flown 400 ft (nominal) above ground along east-west flight lines 3 mi apart. Magnetic contour interval 20 gammas; hachures show closed areas of lower magnetic intensity. Magnetic declination approximately 15° east. WPM, Waterpocket monocline; CCA, Circle Cliffs anticline; HMSB, Henry Mountains structural basin. Symbols explained in text.



38° 00′
111°30′
111°15′
111°00′
37° 45′
37° 30′
37° 15′
MHa
MHb
MHc
MHd
MHe
MHf
MHg
MHh
MLa
MLb
MLc
MLd
MLe
MLf
ML1
ML2
MH1
MH2
MH3
MH4
CCA
WPM
HMSB
APPROXIMATE BOUNDARY OF THE SCORPION WILDERNESS STUDY AREA
0 5 10 15 20 MILES

Geothermal Resources

Geothermal resources are lacking within the Colorado Plateau except along the edges where volcanic rocks are present. No thermal springs were observed in the study area. Igneous rocks that crop out on the Colorado Plateau are generally between 17 and 65 million years old (Luedke and Smith, 1978); according to some investigators, these rocks are too old to be a viable source of heat necessary to produce geothermal activity. In addition, stream incision has caused lowering of the ground-water table in the study area. However, because of the possibility of plutonic activity at depth and the excellent aquifers present, geothermal activity cannot be ruled out. The Scorpion Wilderness Study Area has low resource potential for geothermal energy with a certainty level of C.

REFERENCES CITED

Adams, J.W., 1964, Titanium, *in* Mineral and water resources of Utah: Utah Geological and Mineralogical Survey Bulletin 73, p. 119–120.

Bartsch-Winkler, Susan, Barton, H.N., Cady, J.W., Cook, K.L., and Martin, C.M., 1988, Mineral resources of the Fifty Mile Mountain Wilderness Study Area, Kane County, Utah: U.S. Geological Survey Bulletin 1747–A, p. A1–A20.

Bates, R.L., 1960, Geology of the industrial rocks and minerals: New York, Dover Publications, Inc., 459 p.

Campbell, J.A., 1969, Upper Valley oil field, Garfield County, Utah, *in* Geology and natural history of the Grand Canyon region: Four Corners Geological Society, 5th field conference, 1969, guidebook, p. 195–200.

Campbell, J.A., and Ritzma, H.R., 1982, Geology and petroleum resources of the major oil-impregnated sandstone deposits of Utah: Utah Geological and Mineralogical Survey Special Study 50, 24 p.

Corbetta, P.A., 1986, Mineral investigation of a part of the Scorpion Wilderness Study Area (UT–040–082), Garfield County, Utah, and North Escalante Canyon (V) Instant Study Area, Kane County, Utah: U.S. Bureau of Mines Open-file Report MLA 59–86.

Davidson, E.S., 1954, Circle Cliffs area, Utah, *in* Geologic investigations of radioactive deposits, semiannual progress report, June 1 to November 30, 1954: U.S. Geological Survey TEI–490, issued by the U.S. Atomic Energy Commission, Technical Information Service, Oak Ridge, Tenn., p. 36–38.

——— 1967, Geology of the Circle Cliffs area, Garfield and Kane Counties, Utah: U.S. Geological Survey Bulletin 1229, 140 p., 3 pl., scale 1:48,000.

Doelling, H.H., 1975, Geology and mineral resources of Garfield County, Utah: Utah Geological and Mineral Survey Bulletin 107, 175 p.

Dubyk, W.S., and Young, Patty, 1978, Preliminary evaluation of the uranium favorability in the Kaiparowits Plateau region, Garfield and Kane Counties, Utah: U.S. Department of Energy report GJBX–64(78), 28 p. Available from U.S. Geological Survey, Books and Open-file Reports Section, Box 25425, Federal Center, Denver, CO 80225.

Duval, J.S., 1983, Composite color images of aerial gamma-ray spectrometric data: Geophysics, v. 48, p. 722–735.

Gilbert, G.K., 1874, Preliminary geological report, expedition of 1872: U.S. Geographical and Geological Survey West of the 100th Meridian (Wheeler), Progress Report, p. 48–52.

——— 1875, Report on the geology of portions of Nevada, Utah, California, and Arizona: U.S. Geographical and Geological Survey West of the 100th Meridian (Wheeler), v. 3, p. 17–187.

——— 1877, Report on the geology of the Henry Mountains [Utah]: U.S. Geographical and Geological Survey of the Rocky Mountain Region (Powell), 160 p.

Goudarzi, G.H., 1984, Guide to preparation of mineral survey reports on public lands: U.S. Geological Survey Open-File Report 84–787, 51 p.

Gregory, H.E., and Moore, R.C., 1931, The Kaiparowits region—A geographic and geologic reconnaissance of part of Utah and Arizona: U.S. Geological Survey Professional Paper 164, 161 p.

Hackman, R.J., 1955, Photogeologic map of the Circle Cliffs-14 quadrangle, Garfield and Kane Counties, Utah: U.S. Geological Survey Miscellaneous Geologic Investigations Map I–29, scale 1:24,000.

Hackman, R.J., and Wyant, D.G., 1973, Geology, structure, and uranium deposits of the Escalante quadrangle, Utah and Arizona: U.S. Geological Survey Miscellaneous Geologic Investigations Series Map I–744, scale 1:250,000.

Howell, E.E., 1875, Report of the geology of portions of Utah, Nevada, Arizona, and New Mexico: U.S. Geographical and Geological Survey West of the 100th Meridian (Wheeler), v. 3, p. 227–301.

Hunt, C.B., Averitt, Paul, and Miller, R.L., 1953, Geology and geography of the Henry Mountains region, Utah: U.S. Geological Survey Professional Paper 228, 234 p.

Kunkel, R.P., 1965, History of exploration for oil and natural gas in the Kaiparowits region, Utah, *in* Geology and resources of south-central Utah—Resources for power: Utah Geological Society Guidebook 19, p. 93–111.

Lane, M.E., 1981, Mines and prospects map of the Escalante Canyon Instant Study Area, Garfield County, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF–1313–B, scale 1:48,000.

Lidke, D.J., and Sargent, K.A., 1983, Geologic cross sections of the Kaiparowits coal-basin area, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I–1033–J, scale 1:125,000.

Luedke, R.G., and Smith, R.C., 1978, Map showing distribution, composition, and age of late Cenozoic volcanic centers in Colorado, Utah, and southwestern Wyoming: U.S. Geological Survey Miscellaneous Investigations Series Map I–1091–B, scale 1:1,000,000.

McCafferty, A.E., and Cady, J.W., 1987, Gravity survey data of seven wilderness study areas in southwest Utah, Kane and Garfield Counties, Utah: U.S. Geological Survey Open-File Report 87–200, 9 p.

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

National Uranium Resources Evaluation, 1980, Aerial radiometric and magnetic survey, Escalante national topographic map, Arizona/Utah: Geo-Life, Inc., 183 p., 106 fiches, PR–80–13, 2/6/80.

——— 1983, Residual intensity magnetic anomaly profile map, Escalante national topographic map, Arizona/Utah: U.S. Department of Energy Open-File Map GJM–416.

Oakes, Ed., Wedow, Helmuth, Poling, Robert, and Voelker, Al, 1981, Energy resource evaluation of wilderness study areas administered by the Bureau of Land Management—Cedar City District, Utah: U.S. Department of Energy, Leasing Policy Development Office, Oak Ridge, Tenn., 317 p.

Oil and Gas Journal, 1984, Utah CO_2 reservoir scheduled for delineation: Oil and Gas Journal, April 23, 1984, p. 53.

Peterson, Fred, Campbell, J.A., Franczyk, K.J., and Lupe, R.D., 1982, National uranium resource evaluation, Escalante quadrangle, Utah: U.S. Department of Energy Report PGJ/F–049(82) (prepared by U.S. Geological Survey), 73 p. Available from U.S. Geological Survey, Books and Open-file Reports Section, Box 25425, Federal Center, Denver, CO 80225.

Pipiringos, G.N., and O'Sullivan, R.B., 1975, Chert-pebble unconformity at the top of the Navajo Sandstone in southeastern Utah, *in* Canyonlands country: Four Corners Geological Society, 8th Field Conference, guidebook, p. 149–156.

Reineck, H.E., and Singh, I.B., 1975, Depositional sedimentary environments: New York, Springer-Verlag, 439 p.

Sargent, K.A., and Hansen, D.E., compilers, 1982, Bedrock geologic map of the Kaiparowits coal-basin area, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I–1033–I, scale 1:125,000.

Sharp, G.C., 1976, Reservoir variations of Upper Valley field: Rocky Mountain Association of Geologists Cordilleran-Hingeline Guidebook, p. 325–344.

——— 1978, Upper Valley, *in* Oil and gas fields of the Four Corners area: Four Corners Geological Society, v. 2, p. 709–711.

Steed, R.H., 1954, Geology of Circle Cliffs anticline [Utah], *in* Geology of portions of the high plateaus and adjacent canyon lands, central and south-central Utah: Intermountain Association of Petroleum Geologists, 5th Annual Field Conference, 1954, guidebook, p. 99–102.

Thornbury, W.D., 1965, Regional geomorphology of the United States: New York, John Wiley, 609 p.

Tooker, E.W., Wong, George, and Morris, H.T., 1984, The status of mineral and energy resource evaluations of wilderness and roadless areas, Utah: U.S. Geological Survey Open-File Report 84–221, 6 p.

Turner-Peterson, C.E., and Hodges, C.A., 1986, Descriptive model of sandstone U, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 209–210.

U.S. Bureau of Mines and U.S. Geological Survey, 1980, Principles of a resource/reserve classification for minerals: U.S. Geological Survey Circular 831, 5 p.

Wood, H.B., and Grundy, W.D., 1956, Techniques and guides in exploration for uranium in Shinarump channels on the Colorado Plateau, *in* Page, L.R., Stocking, H.E., and Smith, H.B., compilers, Contributions to the geology of uranium and thorium by the United States Geological Survey and Atomic Energy Commission for the United Nations International Conference on Peaceful Uses of Atomic Energy, Geneva, Switzerland, 1955: U.S. Geological Survey Professional Paper 300, p. 651–657.

APPENDIX

DEFINITION OF LEVELS OF MINERAL RESOURCE POTENTIAL AND CERTAINTY OF ASSESSMENT

Definitions of Mineral Resource Potential

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

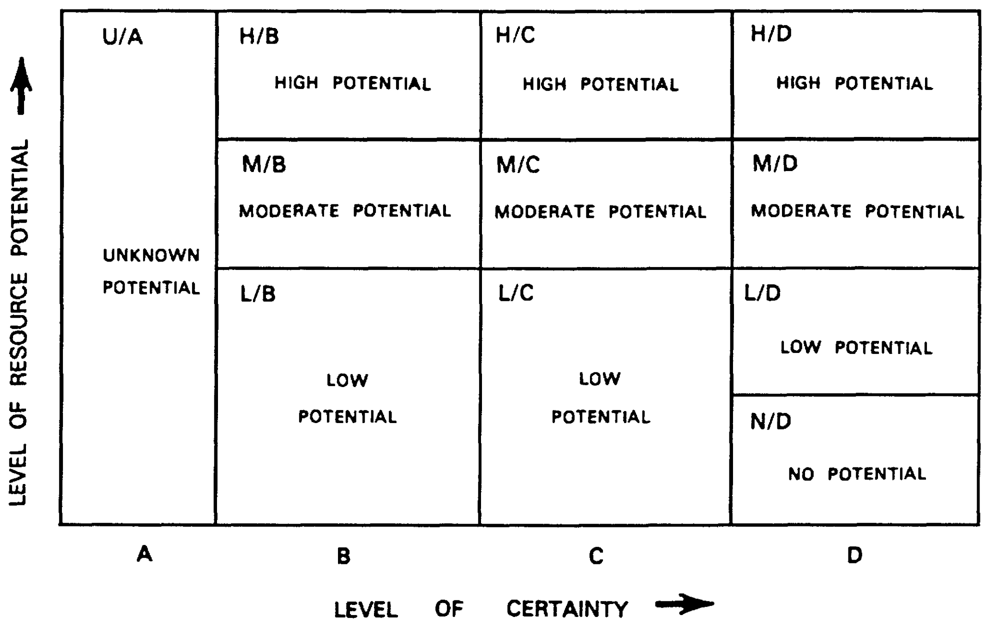
MODERATE mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence, where interpretations of data indicate a reasonable likelihood of resource accumulation, and (or) where an application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

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

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

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

Levels of Certainty



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

Abstracted with minor modifications from:

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

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

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

RESOURCE/RESERVE CLASSIFICATION

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

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

GEOLOGIC TIME CHART

Terms and boundary ages used in this report

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

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

[2] Informal time term without specific rank.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1989-673-047/86113