# Mineral Resources of the Fifty Mile Mountain Wilderness Study Area, Kane County, Utah

U.S. GEOLOGICAL SURVEY BULLETIN 1747–A

Chapter A

# Mineral Resources of the Fifty Mile Mountain Wilderness Study Area, Kane County, Utah

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

DEPARTMENT OF THE INTERIOR
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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 Fifty Mile Mountain (UT–040–080) Wilderness Study Area, Kane County, Utah.

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## PLATE

[Plate is in pocket]



## FIGURES

# Mineral Resources of the Fifty Mile Mountain Wilderness Study Area, Kane County, Utah

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## ABSTRACT

The Fifty Mile Mountain Wilderness Study Area (UT–040–080) is in south-central Utah in Kane County near the border with Arizona. No economic or marginally economic resources were identified in the study area. There are, however, inferred subeconomic resources of sandstone and sand and gravel. All or part of four lode and one placer claim blocks have been staked within the study area. All are located for either uranium or titanium. The mineral resource potential for undiscovered coal and titanium resources is high, except in the southwesternmost part of the study area, which has no potential for either commodity. The mineral resource potential for undiscovered uranium is high in the north-central part and southeastern tip of the study area and moderate elsewhere. The potential for undiscovered geothermal, oil, gas, gypsum, and carbon dioxide resources is moderate. The potential for undiscovered metals, excluding uranium and titanium, is low.

## SUMMARY

The U.S. Geological Survey and the U.S. Bureau of Mines, at the request of the U.S. Bureau of Land Management, investigated the Fifty Mile Mountain Wilderness Study Area (UT–040–080), which covers 92,441 acres in Kane County, Utah, near the Utah-Arizona boundary (fig. 1). This investigation was completed in September 1987. The area is west of the Glen Canyon National Recreation Area and about midway between the towns of Escalante, Utah, and Page, Ariz. Paved access to the area is by U.S. Highway 89 through Glen Canyon City and Utah State Highway 12 through Escalante; numerous unpaved roads provide closer access to the area by use of four-wheel-drive vehicles. These include the Fiftymile Bench road and the Croton Canyon road, main access roads from which numerous jeep trails diverge. Foot access to the area is gained by use of stock trails.

Fifty Mile Mountain Wilderness Study Area is underlain primarily by sedimentary rock units that are continuous and very gently warped into broad north-south-trending folds (Hackman and Wyant, 1973). Paleozoic (see geologic time chart in Appendix) rocks in this area are dominantly marine shelf sediments, and the Mesozoic sequences are primarily continental sediments of fluvial, eolian, and alluvial origin. All of the units are covered, in places, by younger, relatively thin, surficial talus, terrace, and pediment deposits. Bedrock units exposed in the Fifty Mile Mountain Wilderness Study Area are, from oldest to youngest, the Navajo Sandstone, the Carmel Formation, the Romana and Entrada Sandstones, the Morrison Formation, the Dakota Sandstone, the Tropic Shale, and the Straight Cliffs Formation.

The results reported herein are generally consistent with previously published interpretations of the area's geology and resource potential, and no new evidence of important mineral resources has been found.

No economic or marginally economic resources were identified in the study area. The only known resources in the study area are inferred subeconomic resources of sand and gravel and sandstone; these are common in the study area,

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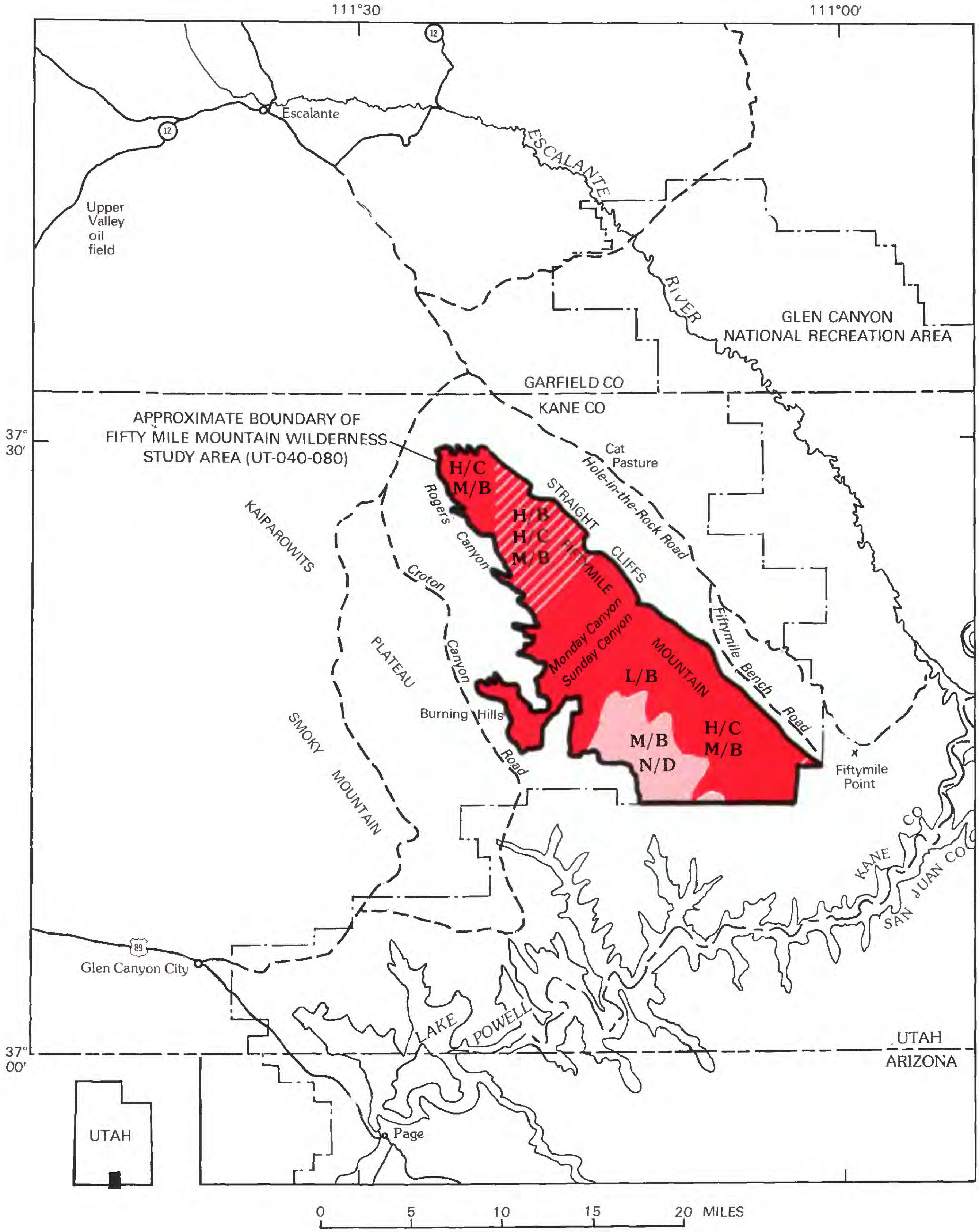


**Figure 1.** Mineral resource potential and location of the Fifty Mile Mountain Wilderness Study Area, Kane County, Utah.

EXPLANATION

| | |
|---|---|
| H/C | Geologic terrane having high mineral resource potential for coal beds less than 5 feet thick, and for titanium, with certainty level C—Applies to all but southwesternmost (pink) part of study area |
| H/B | Geologic terrane having high mineral resource potential for uranium in the subsurface, with certainty level B |
| M/B | Geologic terrane having moderate mineral and energy resource potential for oil, gas, carbon dioxide, and geothermal sources in the subsurface and for uranium and thin beds of gypsum in the surface and subsurface, with certainty level B—Applies to the entire study area for all listed commodities except uranium, which has moderate potential only outside the areas of high potential described above |
| L/B | Geologic terrane having low mineral resource potential for metals other than titanium and uranium, with certainty level B—Applies to entire study area |
| N/D | Geologic terrane having no mineral resource potential for coal or titanium, with certainty level D—Applies only to southwesternmost (pink) part of study area |

——— Paved road

— — — Unpaved road

Levels of certainty:

| | |
|---|---|
| B | Data indicate geologic environment and suggest the level of mineral resource potential |
| C | Data indicate geologic environment and give a good indication of the level of mineral resource potential |
| D | Data clearly define geologic environment and level of mineral resource potential |

but currently cannot be economically produced owing to inaccessibility and distance to potential markets. Ample supplies of sandstone, sand, and gravel are available elsewhere in the region. There are no mines or prospects in the study area, although all or part of four lode and one placer mining claim blocks are located in the study area. One federal coal lease extends a short distance into the study area. Major coal lease holdings on the Kaiparowits Plateau are to the west of the study area. The Straight Cliffs Formation and Dakota Sandstone, which contain large reserves of coal elsewhere on the Kaiparowits Plateau, are largely barren in the study area, having coal beds that either lens out or become very thin. Analyses of heat value, ash, and sulfur content from coal beds in the study area compare unfavorably with those of Kaiparowits Plateau coal. The presence of vast resources of higher quality coal in the main Kaiparowits coal field minimizes the economic value of coal occurrences in the study area.

The Salt Wash Member of the Morrison Formation, which underlies the study area, has been the object of uranium exploration in the region. Previous investigations by government and industry indicated uranium in the Fiftymile Mountain vicinity, but during this investigation the Bureau of Mines found no indication of uranium in the study area. Titanium-bearing sandstone units in the John Henry Member of the Straight Cliffs Formation are in the study area, but the known occurrences are small, low-grade, and isolated. Titanium deposits of higher grade and tonnage exist at more accessible sites elsewhere in southern Utah.

As part of this study, rock and stream-sediment samples and heavy-mineral panned concentrates of stream sediments were collected for geochemical analysis. The results of these analyses indicate no significant geochemical anomalies within the Fifty Mile Mountain Wilderness Study Area.

Results of geophysical studies provide new information on the configuration, depth, and lithology of the basement rocks underlying this part of the Kaiparowits Plateau. These data provide a framework for understanding the relations between basement and surface geology and aid in assessing oil, gas, and carbon dioxide resources and in determining geothermal sources.

The Fifty Mile Mountain Wilderness Study Area adjoins the Kaiparowits coal field, the largest coal resource in Utah. Coal-bearing units are present in the study area, but the coal is lenticular, isolated, and of limited extent. The energy resource potential for undiscovered coal beds in the study area less than 5 ft thick is high except in the southwest part of the study area, which has no potential for coal because the coal-bearing rocks are absent.

The Morrison and Chinle Formations contain uranium deposits elsewhere in the Colorado Plateau, and both of these units underlie the study area. The north-central part and southeastern tip of the study area have geologic conditions favorable for the occurrence of uranium in the Morrison Formation and have a high resource potential for undiscovered uranium; the rest of the study area has moderate resource potential for uranium.

Favorable rock units for oil and gas are in the subsurface of the study area, and structures in the study area are also favorable for oil and gas accumulations. However, numerous test wells have been drilled in and near the study area, and none have had any shows of oil or gas. Northeast of the study area, shows of oil were reported. The energy resource potential for undiscovered oil and gas is moderate.

A carbon dioxide reservoir is present 15 mi north of the study area in rocks beneath the Escalante anticline, a structure similar to those in the Fifty Mile Mountain study area. Geophysical evidence suggests the possibility of plutonic activity at depth in the vicinity of the study area, which could have created carbon dioxide gas in the overlying carbonate rocks. However, recent drilling has shown no evidence of carbon dioxide gas. The energy resource potential for undiscovered carbon dioxide gas is moderate.

Concentrations of the titanium minerals ilmenite and leucoxene have been found elsewhere in the Kaiparowits region, in beach deposits of the John Henry Member of the Straight Cliffs Formation. This member covers most of the study area. The mineral resource potential for undiscovered titanium is considered high except in the southwesternmost part of the study area, which has no potential for titanium because the John Henry Member is absent.

The Carmel Formation, which is exposed in the southern part of the study area, contains thin to thick beds of gypsum elsewhere in the region, but only thin beds of gypsum are found near the study area, just outside the southeast boundary of the area. The study area has a moderate mineral resource potential for undiscovered thin beds of gypsum at the surface and in the subsurface.

Although anomalous concentrations of other metals are associated with uranium and titanium deposits elsewhere on the Colorado Plateau, no metallic minerals other than those bearing titanium were found in this study. No geochemical anomalies were present. Therefore, there is low mineral resource potential for all metals other than uranium and titanium.

Geothermal resources are generally lacking within the Colorado Plateau except along the edge, where volcanic rocks are found. No thermal springs were observed in the study area; however, given the possibility of plutonic activity at depth and the excellent water reservoir rocks present, such occurrences cannot be ruled out. Therefore, the study area has moderate potential for undiscovered geothermal resources.

## INTRODUCTION

The U.S. Geological Survey (USGS) and the U.S. Bureau of Mines (USBM) studied 92,441 acres of the Fifty Mile Mountain (UT-040-080) Wilderness Study Area at the request of the U.S. Bureau of Land Management (BLM). In this report, the studied area is called the "wilderness study area" or, simply, the "study area."

This report presents an evaluation of the mineral endowment (identified resources and mineral resource potential) of the study area and is the product of several separate studies by the USBM and the USGS. Identified resources 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 (coal, oil, and gas). Mineral and energy resources (except coal) were classified according to the system of Goudarzi (1984) (see also Appendix); coal resources, where adequate data exist, were classified according to the system of the USGS, as elaborated in Wood and others (1983). Undiscovered resources are studied by the USGS.

The Fifty Mile Mountain Wilderness Study Area consists of 92,441 acres of dissected plateaus and canyons which are rugged, semiarid, and remote. The wilderness study area is within the Colorado Plateaus physiographic province (Thornbury, 1965) and also within the Kaiparowits Plateau of south-central Utah, a warped surface lying west of the Escalante bench and the Canyonlands province of Doelling (1975). The wilderness study area is midway between Page, Ariz., and Escalante, Utah, and east of Reese Canyon and the Burning Hills; the Straight Cliffs form the eastern boundary of the study area (fig. 1, pl. 1). The major geomorphic feature is the Fiftymile Mountain erosional escarpment, which has about 2,300 ft (feet) in topographic relief. Most of the western border of the wilderness study area is along Rogers Canyon, and the southern border is the Glen Canyon National Recreation Area boundary. This section of the Kaiparowits Plateau is dissected by intermittent streams that flow southerly from the Fiftymile Mountain escarpment to the Lake Powell reservoir on the Colorado River.

### Investigations by the U.S. Bureau of Mines

In October and November 1984, May 1985, and May 1987, the Bureau of Mines conducted a mineral investigation of the Fifty Mile Mountain Wilderness Study Area. The field investigation was preceded by a survey of relevant literature regarding the geology, mineral resources, and land status of the Kaiparowits Plateau/Fiftymile Mountain region. Information about land and mineral ownership, oil and gas and coal leases, mining claims, and prospecting activity was researched from records of the Bureau of Land Management.

Field investigations consisted of examining, mapping, and sampling coal outcrops in and near the study area, conducting scintillometer surveys to detect any anomalous radioactivity at sample sites and along foot and vehicle traverses, and collecting stream-sediment samples to determine the extent of any mineralized areas. Altogether, 17 coal samples and 100 stream-sediment samples were taken.

For coal samples taken in 1984 and 1985, proximate and ultimate analyses were performed by Hazen Research, Inc., of Golden, Colo. Stream-sediment samples taken during this period were analyzed by semi-quantitative optical emission spectrographic methods for 40 elements and for elemental uranium by fluorometry at the USBM's Reno Research Center, Reno, Nev. For coal samples taken in 1987, proximate and ultimate analyses were performed by Core Laboratories, Inc., of Aurora, Colo. Sediment samples from 1987 underwent semi-quantitative inductively coupled plasma analysis for 30 elements by Chemex Labs, Inc., of Sparks, Nev. Results of the analyses are found in Martin (1986).

### Investigations by the U.S. Geological Survey

From 1984 through 1986, personnel from the U.S. Geological Survey conducted independent field investigations using four-wheel-drive vehicles for access to the area; a helicopter facilitated geochemical sampling. Foot traverses were undertaken to accomplish most of the field work. Geologic, geophysical, and geochemical information from these investigations and from all available previously published geologic reports and maps as of June 1987 was compiled at 1:50,000 scale.

The geologic information provided in this report was compiled from cited sources and field-checked by Susan Bartsch-Winkler in August 1986. Stream-sediment samples for geochemical analysis were collected during May and June 1986 by Harlan N. Barton, who also interpreted the laboratory analyses of these samples. Geophysical information is provided by John W. Cady, who conducted field investigations during May 1986 and interpreted the aeromagnetic and gravity data, and by Joseph S. Duval, who interpreted the aeroradiometric data. Additional gravity data were provided by Professor K.L. Cook and students at the University of Utah, Salt Lake City.

## APPRAISAL OF IDENTIFIED RESOURCES


## By Clay M. Martin
## U.S. Bureau of Mines


### Mining and Leasing Activity

No mineral production is recorded from the study area. Commodities produced or prospected for near the study area include uranium, coal, and titanium. As of December 1987, all or parts of four lode and one placer claim blocks are inside the study area boundary (fig. 2). Additional lode and placer claim blocks have been staked outside the study area boundaries, principally to the north and northwest. Lode claims in the vicinity of and within the study area were located for uranium and titanium.

The Salt Wash Member of the Morrison Formation has been the focus of extensive uranium exploration in the Fiftymile Mountain vicinity, but early work revealed few indications of any significant uranium occurrence. An Atomic Energy Commission airborne radiometric survey in 1953 indicated no areas of anomalous radioactivity in the study area and vicinity. Preliminary work by the National Uranium Resource Evaluation (NURE) program concluded that geologic conditions favorable for the formation of large uranium deposits in the Chinle and Morrison Formations elsewhere probably never existed in the Fiftymile Mountain area (Dubyk and Young, 1978). NURE stream-sediment-sample analyses indicated anomalous uranium concentrations on the central Kaiparowits Plateau, but not in the study area and vicinity (Heffner, 1980).

More intensive work in later stages of the NURE program produced positive indications of uranium occurrences in the Fiftymile Mountain area. A NURE airborne radiometric survey of the Escalante $1° \times 2°$ quadrangle (Geo-Life, Inc., 1980) showed coinciding uranium and uranium/thorium anomalies in Salt Wash Member outcrops in the Cat Pasture area northeast of the study area. Peterson and others (1982) studied exposures of the Morrison Formation, including the Salt Wash Member, along the Fiftymile Bench below the Straight Cliffs on the study area's northeastern boundary. Their investigation, which included a ground radiometric survey and field observations of structure, stratigraphy, and sedimentology, sought to identify areas in the Morrison Formation with a potential for uranium deposits of at least 100 tons of uranium oxide at a minimum average grade of 0.01 percent. Two areas with such potential, both in the Salt Wash Member, were delineated in the study area vicinity: Cat Pasture and the Fiftymile Point area near the southeastern corner (Peterson and others, 1982). Outcrops exhibiting favorable characteristics are located a mile or more outside the study area; both areas were postulated by Peterson and others (1982) to extend southwestward in the subsurface into the study area.

Interest in uranium in the Fiftymile Mountain vicinity increased in the 1970's with the increase in uranium prices. Although little exploration occurred in the study area, hundreds of claims were staked, principally by Exxon Minerals Company and Gulf Minerals Company, in the Cat Pasture, Fiftymile Bench, and Rogers Canyon vicinities in and near the northwestern part of the study area. Exxon also did some preliminary uranium exploration drilling in this area. Drilling results were inconclusive; they showed orebody-margin conditions near the northwestern boundary of the study area but provided no proof of a significant uranium ore occurrence (R.W. Simms, Exxon Company U.S.A., Denver, Colo., oral commun., 1986). Both corporations submitted plans to BLM for development of their claims, but after demand for uranium declined sharply in the early 1980's, both plans were withdrawn.[2] In the years since, Exxon's claims have been abandoned and, according to BLM records, Gulf has allowed its claims to lapse without assessment.

About 0.5 square miles of federal lands within the study area have been leased for coal (fig. 2). Most of the leases on the Kaiparowits Plateau, where massive coal resources were the subject of considerable interest by industry in the 1960's and 1970's, are west of the study

[2]Unpublished document, "Site specific analysis, Fifty Mile Mountain Wilderness Study Area (UT-040-080), Escalante Resource Area," in the files of the U.S. Bureau of Land Management, District Office, Cedar City, Utah.

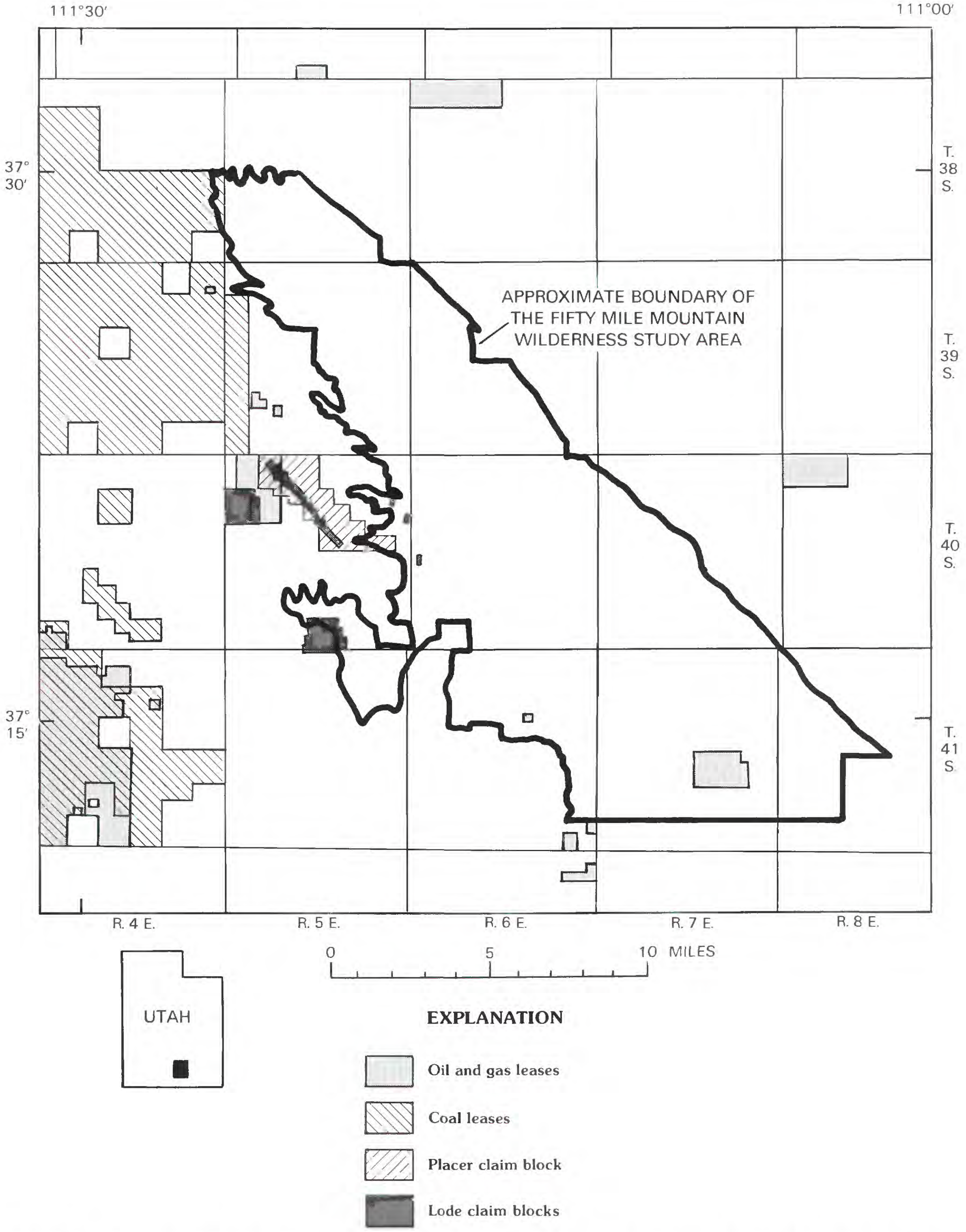


**Figure 2.** Leases and claim blocks in and near the Fifty Mile Mountain Wilderness Study Area, Kane County, Utah.

area. Due to economic and environmental factors, coal mining in the region never developed beyond intermittent production intended for local use. Less than 25,000 short tons of coal was produced before 1965, mostly from small mining operations, to meet local demand in the Escalante vicinity (Grose, 1965). Despite considerable exploration and leasing activity in the late 1960's and early 1970's, almost no coal has been produced from the field in the last 20 years.

Oil and gas leases cover about 1,280 acres of the study area (fig. 2). One test hole was drilled in the area, and several others were drilled to the west and north (Martin, 1986, and unpublished data). No significant shows of oil were detected in any of these holes; the nearest production occurs at the Upper Valley field, 30 mi (miles) northwest of the study area. Production at the Upper Valley field is from the Kaibab Limestone and the Moenkopi Formation, which underlie the study area.

## Appraisal of Sites Examined

### Coal

The study area lies along the extreme eastern edge of the Kaiparowits coal field. The field, which includes more than 1,600 square miles, constitutes the largest coal resource in Utah, estimated at more than 15 billion short tons (Doelling and Smith, 1982). Economic factors, environmental concerns, and the extreme remoteness of the region have prevented any large-scale mining development of Kaiparowits coal.

The central part of the Kaiparowits coal field, which contains the thickest sequences of coal, lies 10 to 20 mi west of the study area. Most of the coal in the field occurs in the John Henry Member of the Straight Cliffs Formation; lesser amounts are found in the Dakota Sandstone and the Tropic Shale. Coal rank in the field ranges from subbituminous B (9,500 to 10,500 Btu/lb) to high-volatile bituminous C (8,300 to 9,500 Btu/lb), which makes it usable only for power generation (Doelling and Smith, 1982). The major minable coal beds are at depths that would require underground mining techniques if the field were developed on a large scale.

The eastern margin of the Kaiparowits coal field is not sharply defined and may overlap the western edge of the study area near Rogers Canyon (Doelling and Graham, 1972). This is an area of geological transition from lagunal and marginal marine coal-bearing strata to predominantly marine, non-coal-bearing sedimentary rocks (Hansen, 1978a). Doelling and Graham (1972) characterize coal zones in this part of the plateau as "barren, sandy, and shaly with the [coal] seams lensing out or becoming very thin."

Subsurface coal occurrences in the study area are poorly known, but the few coal beds exposed in the northwestern and southern reaches of the study area are of low quality, thin rapidly to the east, and are nearly absent 5 mi to the east. Of the exposed coal zones, those in the John Henry Member of the Straight Cliffs are largely barren, and coal in the Dakota Sandstone, which crops out at Fiftymile Bench, is thin and of low quality.

During the USBM investigation of the study area, 17 coal samples from outcrops in or near the study area were analyzed for rank and quality determination. All samples are from outcrops, and analyses reflect the effects of surface weathering. Subsurface samples would give a more accurate indication of coal rank and quality, but none are available.

Sample analyses of both Straight Cliffs Formation and Dakota Sandstone coal beds in the study area were of lower quality than Kaiparowits Plateau averages. Heating values, on an as-received, moist, mineral-matter-free basis, average 8,706 Btu/lb for Straight Cliffs Formation coal samples and 10,036 Btu/lb for Dakota coal samples. The apparent rank of coal samples from both formations ranges from subbituminous A to subbituminous C. Average ash content of Straight Cliffs coal samples (dry basis) average 34.5 percent; Dakota coal samples (dry basis) average 32.4 percent. According to USGS coal classification guidelines (Wood and others, 1983), the ash content of three of the five Dakota Sandstone samples taken is higher than the allowable maximum (33 percent) for inclusion in resource and reserve calculations; six of the twelve Straight Cliffs Formation samples also exceed that level. Straight Cliffs coal samples contain an average 2.08 percent sulfur, compared with 0.73 percent for the Dakota.

Results of the USBM field investigation were consistent with those of previous studies (Peterson, 1975, 1980; Peterson and Barnum, 1973a, b). The average bed thickness for Straight Cliffs Formation samples was 2.3 ft, compared to 1.5 ft for samples from the Dakota Sandstone. All sampled coal beds were badly split and discontinuous; none could be traced for more than 100 ft laterally due to either talus coverage or thinning out of the bed.

Coal in the Fifty Mile Mountain study area is of low value as an energy resource, and falls in the inferred subeconomic resource category of Wood and others (1983). The coal is of low quality and occurs in thin, discontinuous, lenticular beds. The presence of vast resources of higher quality coal in the main Kaiparowits coal field further minimizes the resource value of coal in the study area.

### Uranium

The Chinle and Morrison Formations, which together host most of the uranium deposits in the Colorado Plateaus physiographic province, underlie the study area at varying depths. The important uranium districts of the region are farther east in Utah and in New Mexico and Colorado; production from the formations in the

Kaiparowits Plateau vicinity is small. The Chinle Formation underlies the study area at depths of 2,500–6,000 ft, which is an economically prohibitive depth for uranium exploration or mining. The Morrison Formation crops out in the southern part of the study area, but generally lies at depths of 600–1,000 ft.

Bureau of Mines investigation of the study area, which was limited to field reconnaissance, surface scintillometer traverses, and limited stream-sediment sampling, found no indication of near-surface uranium occurrences within the study area. Uranium was detected in 52 of the 100 sediment samples taken; the average uranium content was 1.44 parts per million, which is a normal abundance for unmineralized rock. No anomalous radioactivity was detected during scintillometer traverses in the study area.

### Titanium

Dow and Batty (1961) report outcrops of titanium-bearing sandstone beds in the Straight Cliffs Formation on the Kaiparowits Plateau, including several in the study area in the vicinity of Rogers, Sunday, and Monday Canyons. The units occur in largely inaccessible cliffs and cap rocks along canyon rims. Location descriptions given by Dow and Batty are generalized; their listed occurrences were not located during the present investigation and are not shown on the map.

Of the accessible titanium-bearing units sampled by Dow and Batty, a composite assay of 13.5 percent titanium oxide was obtained. This is slightly above the lower cutoff limit for economic deposits of titanium as indicated by Lynd and Lefond (1983, p. 1317). The extent and volume of titanium present are unknown and would require exploration to establish, but Dow and Batty's observations indicate that the occurrences are comparatively small and separated from each other by large volumes of barren sandstone. A minable resource of titanium ore has not been identified in the study area.

### Other Commodities

Inferred subeconomic resources of sand and gravel exist in canyon bottoms in the study area, particularly in the larger drainages where primary and secondary alluvial terraces are well developed. These resources are not easily accessible and are far from potential markets. Ample resources of sand and gravel are available elsewhere in the region at locations closer to markets.

Inferred subeconomic resources of sandstone with a wide range of textures, colors, cementations, and bedding thicknesses occur in the study area. Many of the sandstone units would be suitable for use as dimension stone, flagstone, or concrete aggregate, but vast quantities of sandstone of equal or higher quality are available throughout southern Utah and northern Arizona.

# ASSESSMENT OF POTENTIAL FOR UNDISCOVERED RESOURCES

**By Susan Bartsch-Winkler, Harlan N. Barton, John W. Cady, and Kenneth L. Cook[3]**
**U.S. Geological Survey**

## Previous Work

The Fifty Mile Mountain Wilderness Study Area includes areas studied previously for the occurrence of and the resource potential for coal, uranium, and oil and gas. The first detailed geologic investigation of the Kaiparowits Plateau, by Gregory and Moore (1931), was followed by more detailed examinations of particular formations containing minerals of economic interest that crop out in the region (Craig and others, 1955; Kunkel, 1965; Peterson, 1969a, 1975, 1980; Doelling and Graham, 1972; Stewart and others, 1972; Peterson and Barnum, 1973a, b; U.S. Bureau of Land Management, 1976; Hansen, 1978a, b; Dubyk and Young, 1978; Thamm and others, 1981; Peterson and others, 1982; Sargent and Hansen, 1980, 1982; Lidke and Sargent, 1983; Williams, 1985). More recently published are assessments of the petroleum potential of wilderness lands (Miller, 1983) and, more specifically, of those in Utah (Molenaar and Sandberg, 1983). Information on the geology of Garfield County reported by Doelling (1975) is applicable to the geology of Kane County as well and is cited frequently in this report.

## Geologic Setting and Description of Rock Units

The sedimentary rock sequences that crop out in the region of the Fifty Mile Mountain Wilderness Study Area are laterally continuous and gently warped into a series of broad, asymmetric anticlines and synclines (pl. 1). The structures are oriented generally north to northwest and have dip angles less than 10 degrees. The rocks are generally undeformed by faulting.

The sedimentary sequence exposed in and near the study area (pl. 1) comprises rocks of the Triassic(?) and Jurassic Navajo Sandstone; the Jurassic Carmel

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Formation, Romana Sandstone, Entrada Sandstone, and Morrison Formation; and the Upper Cretaceous Dakota Sandstone, Tropic Shale, and upper and lower members of the Straight Cliffs Formation (Peterson and Barnum, 1973b; Peterson, 1980; Sargent and Hansen, 1982). As determined by exploratory drilling near the study area, the subsurface sequence includes the Cambrian Tapeats Sandstone, Bright Angel Shale, and Muav Limestone; the Devonian Ouray Limestone; the Mississippian Redwall Limestone; the Pennsylvanian Molas and Hermosa Formations; the Permian Cutler Formation and Kaibab Limestone; and the Triassic Moenkopi Formation, Chinle Formation, Moenave Sandstone, Wingate Sandstone, and Kayenta Formation (Lidke and Sargent, 1983). The exposed sedimentary sequence is broken by unconformities at the Triassic-Jurassic boundary between the Navajo Sandstone and the Carmel Formation, at the upper and lower contacts of the Romana Sandstone, at the Jurassic-Cretaceous boundary between the Morrison Formation and the Dakota Sandstone, and within the Cretaceous sequence between the lower and upper members of the Straight Cliffs Formation (Sargent and Hansen, 1982; Peterson, 1980).

The main mass of the Navajo Sandstone is probably Late Triassic(?) based on a paucity of fossil evidence (Lewis and others, 1961, p. 1439). However, in some places the Thousand Pockets Tongue of the Navajo Sandstone (Phoenix, 1963) intertongues with the Carmel Formation, which is Jurassic in age (Wright and Dickey, 1963). The Navajo is a very fine- to medium-grained, white to buff-colored sandstone unit (with scattered pebbles interspersed) that is dominantly eolian and strikingly crossbedded to massive. Rare lacustrine (lake-deposited) interbeds of shale, dolomite, and limestone also occur in this unit, but none exceed 10 ft in thickness; most are less than 3 ft thick (Doelling, 1975). Near Escalante, the Navajo Sandstone contains a few interbeds of red, flat-bedded sandstone and silty sandstone (in some places slumped and contorted, both in the surface and subsurface) that are tentatively correlated by Wright and Dickey (1963) with the Thousand Pockets Tongue of the Navajo Sandstone as described by Phoenix (1963). The Navajo Sandstone, due to strong jointing, is characterized by a "checkerboard" or "elephant-hide" pattern of erosion. It typically forms sheer cliffs and domes, is mostly without vegetation, and creates numerous box canyons of great length and minimal width. The unit thickens to the west where, at Escalante, it is as much as 1,400 ft thick (Doelling, 1975). Manganese and iron nodules are found in some places in the Navajo Sandstone.

The Carmel Formation makes a reddish or brownish cap on the Navajo Sandstone. The Carmel Formation is a ledge-forming unit, commonly mottled and streaked, composed of sandstone, siltstone, mudstone, limestone, and gypsum. Mudstone and siltstone are variegated white, light green, greenish gray, red, and brown. Limestone beds, more common in the lower parts of the formation, are yellowish-gray to greenish- or orangish-pink. Gypsum is found in nonresistant thick beds, veinlets, fracture fillings, and nodules and as cement. Where gypsum is present, the beds are brecciated or contorted.

The Romana and Entrada Sandstones of Middle Jurassic age are undifferentiated on the geologic map (pl. 1). The Romana is a cliff-forming sandstone unit containing small conglomerate lenses. The unit represents nearshore marine, beach, and eolian depositional environments. The unit is cut by the unconformity at the base of the Morrison Formation to the east and pinches out to the northwest, near the northern end of the study area (Sargent and Hansen, 1982). The Entrada Sandstone contains three intergrading informal units that total 1,100 ft in thickness in the Escalante area (Doelling, 1975) and thin to 400 ft or less to the south and east: (1) The upper unit is a pale-gray, yellowish-gray, and reddish-brown, fine- to coarse-grained, eolian, cliff-forming sandstone that is as much as 300 ft thick. (2) The middle unit consists of alternating reddish-brown mudstone and dusky red siltstone, with minor dark-reddish-brown siltstone and grayish-purple bentonite. This unit forms slopes, is 70–310 ft thick, and is probably of shallow marine, sabkha (salt flat), and eolian (wind-blown) origin. (3) The lower unit is a reddish-brown to pale-gray, very fine grained, thinly to thickly crossbedded sandstone of eolian and sabkha origin that ranges from 380 to 650 ft in thickness.

The Jurassic Morrison Formation, divided into three members, is composed of lenticular beds of sandstone, conglomerate, mudstone, and claystone and minor beds of limestone and gypsum, which represent alluvial-plain, lacustrine (lake), flood-plain, sabkha, and fluvial (stream) deposits. The lower member forms slopes and contains beds of sandstone, mudstone, and minor limestone. In general, the Salt Wash Member, the sandstone-rich middle unit of the Morrison Formation, is the cliff-forming unit. The upper member is a mudstone-rich, slope-forming unit. The Salt Wash Member is the predominant unit of the Morrison Formation in the Fifty Mile Mountain Wilderness Study Area; it is mainly of fluvial deposition and is highly variable in thickness. The conglomeratic clasts in the Salt Wash Member are composed of quartzite, chert, siliceous limestone, and clay or shale in a sandstone matrix; some of the clasts contain Late Paleozoic-age crinoid stems and bryozoan hash. The Salt Wash Member is the most important exposed uraniferous host rock within the Fifty Mile Mountain Wilderness Study Area.

The Cretaceous Dakota Sandstone is a transgressional littoral sequence that includes fluvial, marsh, tidal, and nearshore marine sediments; it has interbeds of carbonaceous and sandy shale, shaly sandstone, claystone, mudstone, coal, and minor siltstone and limestone (Doelling, 1975). Conglomeratic layers are interspersed throughout the unit and locally include such fossils as *Gryphaea*, *Exogyra*, and *Inoceramus*. Coal beds are thin; bentonite and refractory clays are found throughout the unit (Doelling, 1975).

The Cretaceous Tropic Shale, a drab, fossiliferous, slope-forming gray mudstone and shale unit, is marine in origin. The thinly laminated beds are bentonitic at the top and base; the unit is typified by its lack of vegetation and by a badlands topography. Near the wilderness study area, the unit is about 700–800 ft thick and contains minor discontinuous beds of coal (Doelling, 1975).

The Straight Cliffs Formation is a clastic sequence of conglomeratic sandstone, sandstone, siltstone, and mudstone that is, in part, carbonaceous and coaly. The formation includes marine, nearshore marine, and nonmarine sequences and has been subdivided into a lower unit and an upper unit, each consisting of two members. The members are, in ascending order, the Tibbet Canyon and Smoky Hollow Members, which make up the lower unit, and the John Henry and Drip Tank Members, composing the upper unit. The total formation thickness is more than 1,800 ft. The John Henry Member is coal-bearing and is one of the most important sources of coal in the State, though in the study area, coal in the John Henry Member is of low grade and is not found in significant quantities (Peterson, 1980; this report). Titaniferous sand is also found in this member in Garfield County (Doelling, 1975) and in parts of the study area (this report, "Appraisal of identified resources").

## Geochemistry

### Analytical Methods

In the reconnaissance geochemical study of the Fifty Mile Mountain Wilderness Study Area, minus-80-mesh stream-sediment samples and heavy-mineral panned concentrates derived from stream-sediment samples were selected as the primary sample media. Stream-sediment samples represent a composite of rock and soil exposed in the drainage basin upstream from the sample site. Their analysis provides information that helps to identify those basins containing unusually high concentrations of elements that may be related to mineral occurrences.

Both types of samples (bulk stream-sediment and heavy-mineral concentrate) were collected from alluvium in stream channels at 81 sites on first- and second-order streams. Rock samples were collected from six sites in the study area. Samples that appeared unaltered were collected to provide information on geochemical background values. Altered and mineralized samples were collected to determine suites of elements associated with the observed alteration or mineralization. A gamma radiation detector was used to determine radiation levels at all sampling sites as an indication of possible uranium or thorium mineralization.

Dry stream-sediment samples were sieved through 80-mesh stainless steel sieves and the portion passing through the sieve was saved for analysis. To produce the heavy-mineral concentrates, bulk stream sediment was first sieved through a 10-mesh screen. Approximately 10 pounds of the portion passing through the sieve was panned to remove most of the quartz, feldspar, organic materials, and clay-sized material. The panned concentrate was separated into light and heavy fractions using heavy liquid (bromoform) with a specific gravity of 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 used in the analyses.

Stream-sediment, heavy-mineral-concentrate, and rock samples were each analyzed for 31 elements using the semiquantitative emission spectrographic method (Grimes and Marranzino, 1968). In addition, stream-sediment samples were analyzed for arsenic, antimony, bismuth, cadmium, gold, uranium, and zinc by specific chemical methods (Crock and others, 1987). Analytical data, sample sites, and a detailed description of the sampling and analytical techniques are given in Bullock and Barton (1988).

### Results of Analyses

Only one sample site near the Fifty Mile Mountain Wilderness Study Area gave an anomalous value of 500 parts per million lead in the heavy-mineral concentrate. The site is outside the study area, approximately 1.4 mi northeast of the northernmost point of the area boundary. It is approximately 130 yards downstream (northeast) from a nonworking mine, and its anomalous lead value probably represents either material from the tailings or some contaminant resulting from mining operations.

Analytical data for uranium and thorium in stream-sediment samples show no anomalous values. These samples reflect the surface geology of the study area. However, rocks of the Jurassic Morrison Formation underlie portions of the study area in the northeast and south, and its Salt Wash Member is known to be a favorable host for uranium mineralization in the region.

## Geophysical Studies

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

### Aeroradiometric Survey

Aerial gamma-ray spectroscopy is utilized to determine the near-surface concentrations of potassium, uranium, and thorium; because uranium and thorium measurements detect 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 on the order of 15 acres 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 most of the U.S., including Utah. Most of the surveys in Utah used a flight-line spacing of 3 mi. Because of the wide flight-line spacing, the survey data are only suitable for producing a regional-scale map. As part of the state mapping project of Utah, data 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, uranium, and thorium for each wilderness area in the State. Anomalies were defined wherever one of these elements had both a high concentration, compared to regional background levels, and high ratios to the other two elements. For the Fifty Mile Mountain Wilderness Study Area, the overall radioactivity is low, implying concentrations of 0.4–1.2 percent potassium, 0.5–2.5 parts per million equivalent uranium, and 2–8 parts per million equivalent thorium. There are no gamma-ray anomalies within or adjacent to the study area.

### Aeromagnetic Survey and Regional Gravity Survey

Figures 3 and 4 are regional gravity and aeromagnetic maps near the Fifty Mile Mountain Wilderness Study Area. Neither the gravity nor the aeromagnetic surveys were designed specifically for either mineral resource or hydrocarbon investigations, but geological interpretations of the results can aid such assessments. Interpretations were based upon a comparison of the gravity and magnetic data with the geologic map of Hackman and Wyant (1973).

Figure 3 is a complete Bouguer gravity anomaly map of the Fiftymile Mountain vicinity. Bouguer anomaly contours were first calculated using the standard regional Bouguer reduction density of 2.67 grams per cubic centimeter. The result showed southeast-trending gravity lows correlative with the high topography of Fiftymile Mountain. Such contours are not useful for delineating deep geologic features: they only indicate that the actual density of the near-surface rocks is less than the reduction density. The contours were recalculated using various lower reduction densities. The correlation of Bouguer gravity anomaly with local topography was nearly eliminated with a reduction density of 2.30 grams per cubic centimeter, the density used in creating figure 3.

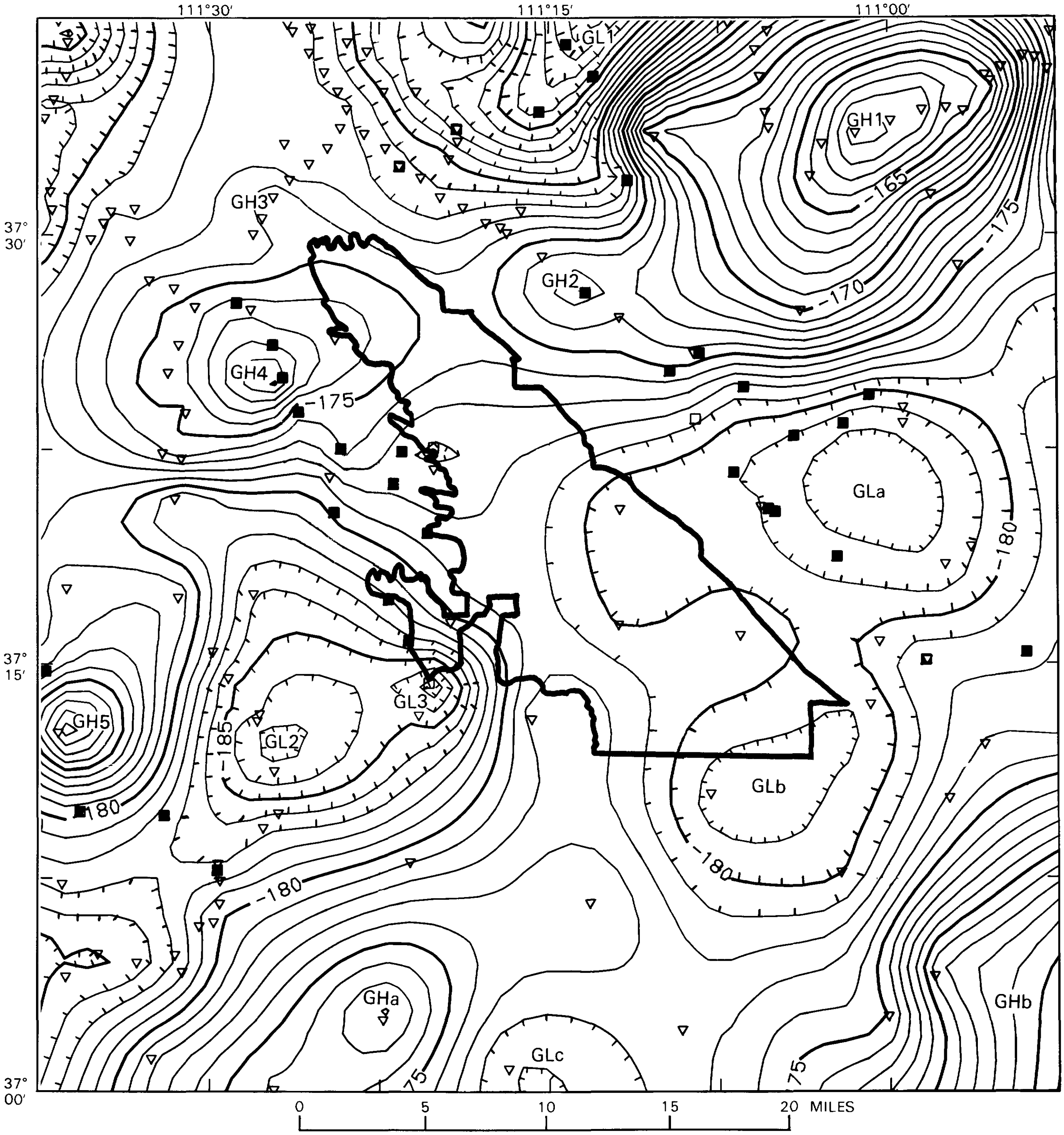
Figure 4 is a map showing total-density aeromagnetic data obtained from a digital tape (Geo-Life, Inc., 1980) and recontoured. Data for the aeromagnetic map were collected along east-west flight lines spaced 3 mi apart and at 400 ft (nominal) above the ground. Short-wavelength information, originally available from closely spaced gravity stations or along magnetic flight lines, was lost in the gridding and contouring process, and small features cannot be resolved.

Magnetic profiles (Bendix Field Engineering Corp., 1983) were inspected for short-wavelength anomalies. One area containing short-wavelength magnetic anomalies of several hundred nanoteslas was found to overlap the Fifty Mile Mountain Wilderness Study Area, and it is shaded in figure 4. Such short-wavelength, high-amplitude magnetic anomalies are characteristic of basalt and of clinker formed in clastic sedimentary rocks near burning coal beds. No basalts were mapped by Hackman and Wyant (1973) within the area of figure 4. The magnetically anomalous area coincides with the Kaiparowits coal field, and burning coal beds and clinker are widespread within the area, giving rise to names such as Smoky Mountain and the Burning Hills. Almost certainly the short-wavelength magnetic anomalies are caused by clinker.

The major gravity and magnetic anomalies shown in figures 3 and 4 have long wavelengths that can be explained by sources a mile or more deep. It is difficult to determine whether they are caused by relief in the depth to basement, variations in basement composition, or younger intrusive rocks cutting the basement and (or) the overlying sedimentary section.

Thirty miles west of the Fifty Mile Mountain Wilderness Study Area, magnetic and gravity anomalies clearly reflect relief in the depth to basement along linear geologic structures, such as the Kaibab monocline (fig. 5). Near the study area, however, linear geophysical anomalies are subdued. The Waterpocket monocline, just east of figures 3 and 4, correlates with a weak geophysical lineament defined by the truncation of some magnetic and gravity anomalies.

About 50 mi northeast of the study area, magnetic and gravity highs are related to Tertiary intrusive rocks of the Henry Mountains. Long wavelength, arcuate




EXPLANATION

Approximate boundary of Fifty Mile Mountain Wilderness Study Area

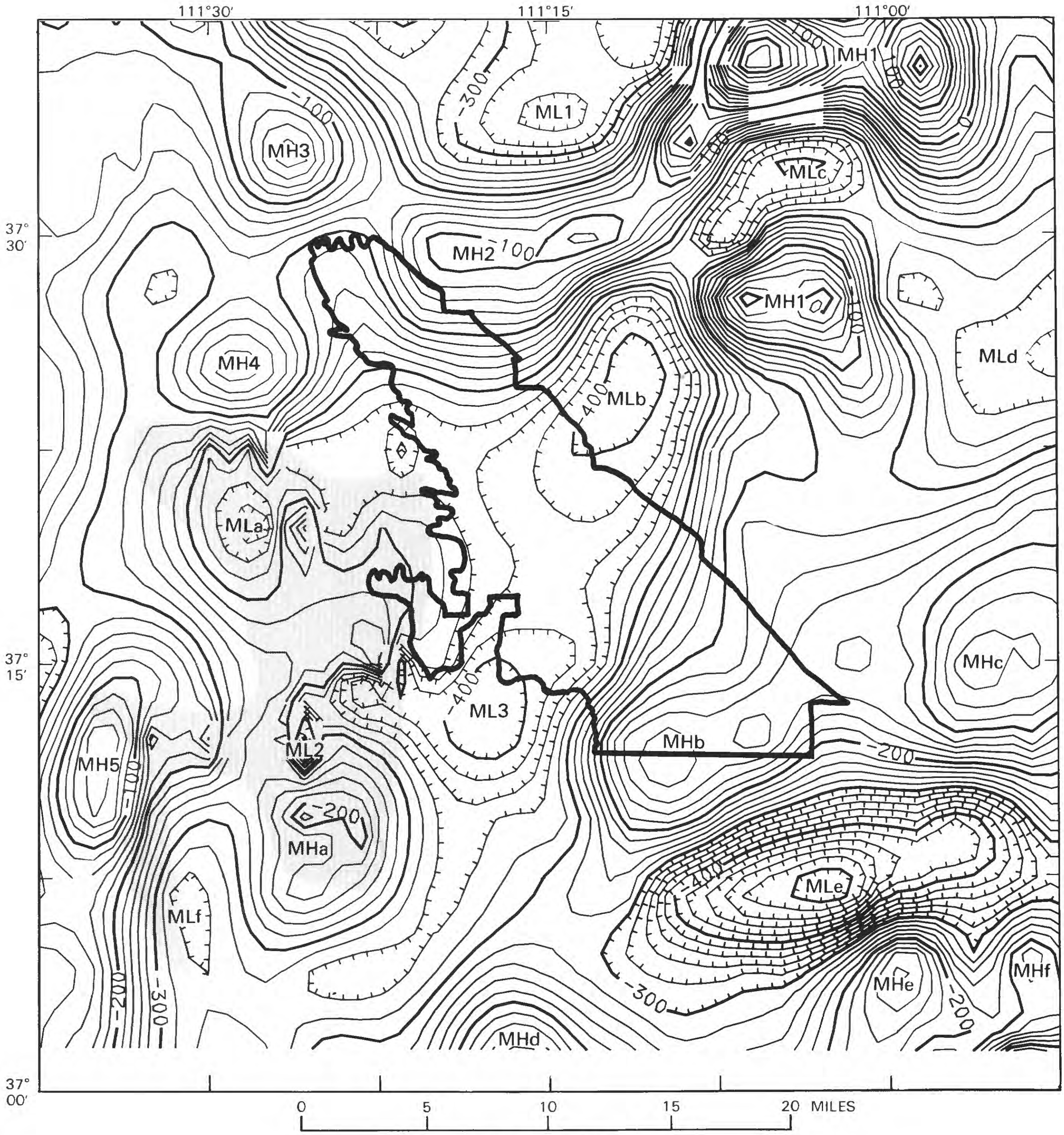
— *-180* — Gravity contour showing complete Bouguer gravity anomaly in milligals—Hachures point toward closed areas of lower gravity

Gravity measurement stations

▽ Compiled for Bouguer gravity anomaly map of Utah—Data from Vickey Bankey (written commun., 1986)

■ Obtained specifically for this study—Data from McCafferty and Cady (1986)

**Figure 3.** Complete Bouguer gravity anomaly map of the Fifty Mile Mountain Wilderness Study Area, Utah. Bouguer reduction density 2.30 grams per cubic centimeter. Gravity anomalies GH1–GH5 and GL1–GL3 correspond to magnetic anomalies MH1–MH5 and ML1–ML3 on figure 4. Anomalies GHa–GHb and GLa–GLc do not correspond to magnetic anomalies.




**EXPLANATION**

Approximate boundary of Fifty Mile Mountain Wilderness Study Area

—— *-200* —— Aeromagnetic contour showing residual magnetic intensity in gammas—Hachures point toward closed areas of lower magnetic intensity

Area of short-wavelength anomalies caused by clinker

**Figure 4.** Residual total field aeromagnetic map of the Fifty Mile Mountain Wilderness Study Area, Kane County, Utah. Survey flown 400 ft (nominal) above ground along east-west flight lines 3 mi apart. Magnetic anomalies MH1–MH5 and ML1–ML3 correspond to gravity anomalies GH1–GH5 and GL1–GL3 on figure 3. Anomalies MHa–MHf and MLa–MLf do not correspond to gravity anomalies.

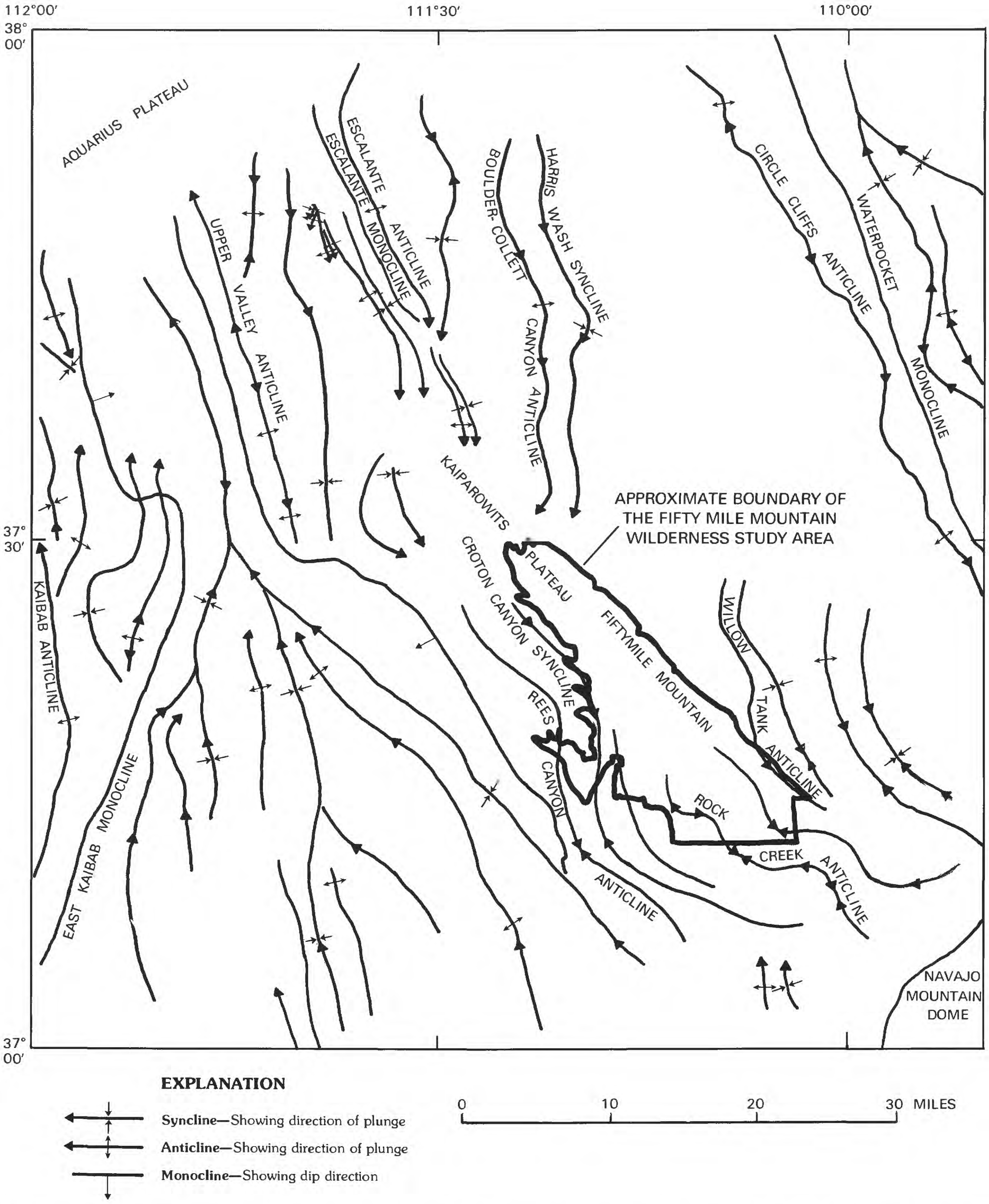



**Figure 5.** Important structural features in and near the Fifty Mile Mountain Wilderness Study Area, Kane County, Utah. Generalized from Hackman and Wyant (1973).

magnetic and gravity highs on trend with the exposed intrusive rocks suggest that hidden plutons underlie a wide region that includes the study area.

Within and near the Fifty Mile Mountain Wilderness Study Area, magnetic anomalies correlate poorly with surface geology and imperfectly with gravity anomalies. Where magnetic and gravity highs correlate, the source is interpreted to be igneous rocks, which are both denser and more magnetic than adjacent rocks, in either the Precambrian basement or the overlying Phanerozoic sedimentary section. Offsets between approximately correlative gravity and magnetic highs are easily explained by differences in the mathematics of the magnetic and gravity fields, by the lack of closely spaced magnetic and gravity observations, and by 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–GH5 and MH1–MH5, respectively; gravity and magnetic lows that correlate are labeled GL1–GL3 and ML1–ML3, respectively. Gravity and magnetic highs that do not correlate are labeled GHa–GHb and MHa–MHf, respectively; gravity and magnetic lows that do not correlate are labeled GLa–GLc and MLa–MLf, respectively.

The simplest anomalies to interpret are correlative gravity highs GH1–GH4 and magnetic highs MH1–MH4, which cross the north end of the Fifty Mile Mountain Wilderness Study Area. They may be caused by plutons that intrude the pre-Paleozoic sedimentary section, inasmuch as Tertiary plutons cause similar gravity and magnetic anomalies in the Henry Mountains. 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. Gravity high GH1 is wider than magnetic high MH1. A second magnetic high labeled MH1′ coincides with the southern part of GH1, and magnetic low MLc separates MH1 and MH1′. The dual magnetic anomalies may be caused by a multiphase pluton with a nonmagnetic center and a magnetic rim.

Magnetic highs MHb and MHc cross the southeastern portion of the study area. They are offset 15 mi from the closest gravity high, GHb, and their cause is not known.

The center of the study area is dominated by correlative areas of low gravity and magnetic relief and intensity, although individual gravity and magnetic lows do not generally correlate. This central region is interpreted to be an area not underlain by buried intrusions.

## Mineral and Energy Resources

### Coal

Major coal resources occur in the central and southern parts of Utah, in a stable platform setting underlain by Cretaceous and Tertiary sedimentary rocks of deltaic or marginal marine origin (Oakes and others, 1981). Coal that is low in ash and sulfur content and that is deposited in thick, laterally continuous seams is generally located in such a setting, and most large coal deposits are interpreted to have been deposited in deltas (McCabe, 1984). The western edge of the Fifty Mile Mountain Wilderness Study Area adjoins the Kaiparowits coal field, the largest coal resource in Utah, on the Kaiparowits Plateau (Doelling and Smith, 1982, p. 20; fig. 1). Within the coal field, the coal beds thin and become more lenticular eastward, decreasing in quality. Within the wilderness study area, the rocks become predominantly marine in origin and relatively non-coal-bearing.

Regionally, coal-bearing units, in order of coal abundance, include the John Henry Member of the Straight Cliffs Formation, the Dakota Sandstone, and the Tropic Shale (Peterson, 1969b, 1980). The Cretaceous sedimentary rocks that make up the Straight Cliffs Formation and the Dakota Sandstone are the most important coal-bearing units within the wilderness study area and commonly contain thin beds of bituminous to subbituminous coal (Peterson, 1980; Oakes and others, 1981; see also "Appraisal of identified resources," above). Within the upper part of the Straight Cliffs Formation are included the Christensen, Rees (Reese), and Alvey coal zones, which are up to 14 ft thick in the Kaiparowits coal field (Doelling and Graham, 1972; Hansen, 1978a; Oakes and others, 1981). The eastern margin of the Kaiparowits coal field is in the vicinity of Rogers Canyon (the western border of the study area) (Doelling and Graham, 1972, p. 116). Here, the rocks are in transition from deltaic coal-bearing strata to predominantly marine, non-coal-bearing strata (Hansen, 1978b); the coal beds lens out to the east, where they are generally less than 5 ft thick in the Fifty Mile Mountain Wilderness Study Area (Hansen, 1978a; Peterson, 1980; and "Appraisal of identified resources," above). Evidence of eastward degradation in coal beds is found at the Fiftymile Mountain escarpment, where coal zones exposed in the John Henry Member of the upper part of the Straight Cliffs Formation are largely barren and the Dakota Sandstone contains only beds of low quality, less than 4 ft thick (Peterson, 1969b). Similarly, the Tropic Shale exposed in the study area contains thin, discontinuous coal beds. Thus, within the wilderness study area, coal deposits are lenticular, isolated, and of limited extent, with an average thickness of 4.4 ft and less than 100 ft of lateral continuity ("Appraisal of identified resources," above). The energy resource potential for undiscovered coal in beds less than 5 ft thick is high with certainty level C (see Appendix for description of certainty levels), except in the southwesternmost part of the study area, where Cretaceous rocks are absent (pl. 1). The southwesternmost part of the study area has no potential for coal, with certainty level D.

### Uranium

In a stable platform or foreland interior basin setting, such as south-central Utah, sandstone-hosted uranium deposits are usually associated with generally flat-bedded feldspathic or tuffaceous sandstone of Devonian or younger age, according to Turner-Peterson and Hodges (1986), whose model is the basis for the following description. 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, which concentrates some uranium oxides at an oxidation-reduction boundary. The interbedded mudstone or shale provides the source for ore-related fluids; humin or carbonaceous material is typically the main concentrator of the uranium. Fluvial channels, braided stream deposits, continental basin margins, and stable coastal plains are the most characteristic settings for uranium deposits. Near some tabular uranium-bearing sandstone sequences, mineralizing fluids containing humic acid leach iron from detrital magnetite and ilmenite minerals and leave relict titanium minerals.

Uranium has been produced in other parts of the Colorado Plateau. It is found in the Jurassic Morrison and the Triassic Chinle Formations of northern New Mexico, southwestern Colorado, and southeastern Utah (Doelling, 1975; U.S. Department of Energy, 1979). Production is low in the vicinity of the Kaiparowits Plateau, where the targeted uranium-bearing layers lie at depth. In much of the study area, the Salt Wash Member of the Morrison Formation is at about 700 ft and the Chinle Formation lies from 2,500 to 6,000 ft below the pediment surface. Radioactivity counts of approximately twice background were obtained from the Smoky Hollow Member of the Straight Cliffs Formation and the base of the Dakota Sandstone in the study area (Peterson, 1980), but such occurrences are isolated.

Dubyk and Young (1978, p. 15–16) state that conditions favorable for formation of large uranium deposits in the Chinle and Morrison Formations probably did not exist in the Fiftymile Mountain area, yet Peterson and others (1982) consider two areas that extend into the study area to be favorable for the occurrence of significant uranium deposits; these are the Fiftymile Point and Cat Pasture areas of Peterson and others (1982, p. 41–42). According to Dubyk and Young, both the Chinle Formation and the Salt Wash Member of the Morrison Formation have sand/mud ratios too high to provide a source of ore-bearing fluids, and both generally lack fluvial channeling and accumulations of organic material, which are usually associated with uranium mineralization. Peterson and others (1982), however, cite geologic evidence that the Salt Wash Member may contain gray mudstone beds similar to those that host uranium elsewhere in the Colorado Plateau. These beds reflect relatively low-energy sites of deposition. In addition, in the Cat Pasture area, a significant radioactivity anomaly was detected by ground surveys in a conglomerate, which reflects high-energy deposition (Peterson and others, 1982, p. 42).

The mineral resource potential for undiscovered uranium is designated as high in the parts of the study area that overlap the Fiftymile Point and Cat Pasture areas of Peterson and others (1982) and moderate in the rest of the study area. Both designations have a certainty level of B.

### Oil and Gas

The most favorable formations targeted for oil and gas exploration in south-central Utah are the Honaker Trail and Paradox Formations of the Hermosa Group (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 (Permian) (Kunkel, 1965; Oakes and others, 1981), and the upper part of the Moenkopi Formation (Triassic) (Doelling, 1975, p. 91–96; Oakes and others, 1981). Lidke and Sargent (1983) have projected all of these strata into the subsurface beneath the study area, although they use the name Hermosa Formation for beds called the Honaker Trail and Paradox Formations by Oakes and others (1981).

Oil and gas resources in Utah have been appraised by Molenaar and Sandberg (1983), who assigned moderate potential to the Fifty Mile Mountain Wilderness Study Area. In the nearby Upper Valley field, about 10 mi southwest of Escalante on the western edge of the Kaiparowits Plateau, production is primarily from the Kaibab Limestone (Molenaar and Sandberg, 1983). At one tract on the west flank of the Upper Valley structural anticline (fig. 5) in the Upper Valley field, 21 million barrels of oil have been produced (Sharp, 1977). Some exploration activity has taken place on similar structural anticlines in south-central Utah (fig. 5), including those at Fiftymile Mountain (see below), since production began from the Upper Valley field, but no commercial oil and gas has been identified.

In general, structures in the Fifty Mile Mountain Wilderness Study Area consist of very gentle folds having shallow southwesterly trending axes and few faults with minimal offsets. Numerous test wells have been drilled; the targeted formations have been the Redwall Limestone, the Cedar Mesa Sandstone Member of the Cutler Formation, the Kaibab Limestone, and the upper part of the Moenkopi Formation (Oakes and others, 1981). Some structural features remain untested. Test wells closest to the study area include three wells drilled into the Rees (Reese) Canyon anticline to the west (sec. 31, T. 39 S., R. 5 E.; and secs. 5 and 9, T. 40 S., R. 5 E.), three wells into the Willow Tank anticline (sec. 2, T. 40 S., R. 7 E.; and sec. 34, T. 39 S., R. 7 E.) outside the study area boundary to the east, and one well into the Croton Canyon syncline (sec. 2, T. 39 S., R. 4 E.) outside the study area boundary to the west (Sargent and Hansen, 1982). No oil shows were reported for any of these. The dry wells drilled into the Rees (Reese) Canyon anticline (Picard, 1955; Picard and Wise, 1956; Kunkel, 1965) extend to (1) Cambrian-age Muav Limestone at a depth of 10,045 ft (Peterson, 1975; Oakes and others, 1981), (2) Devonian rocks at unknown depth (Kunkel, 1965), and (3) Mississippian Redwall Limestone at a depth of 9,017 ft (Oakes and others, 1981). Northeast of the study area, the structurally highest part of the south-plunging Collett Canyon anticline reported shows of oil from the Kaibab Limestone, at a depth of 1,540 to 1,545 ft (Campbell and Hebrew, 1957; Kunkel, 1965; Oakes and others, 1981). Oakes and others (1981) concluded that it was unlikely that oil and gas would be found in structurally lower portions of this anticline located nearer to the wilderness study area. The Rock Creek anticline was test-drilled near the crest of the structure at sec. 19, T. 41 S., R. 7 E., in the southern portion of the study area (pl. 1). This well bottomed in the Permian Cutler Formation (Peterson and Barnum, 1973b) and was dry. As 29 dry holes were drilled in the Upper Valley field in the 13 years prior to its discovery (Doelling, 1975, p. 3), discovery of petroleum in the Fifty Mile Mountain Wilderness Study Area is a possibility. The underlying units and structures of the study area are similar to those of the Upper Valley field. Therefore, the energy resource potential for undiscovered oil and gas is assessed as moderate with certainty level B.

### Carbon Dioxide

Carbon dioxide is important in oil recovery enhancement techniques like those used in West Texas oil fields. Since carbon dioxide is miscible with oil, it acts as a solvent, displacing enough water to mobilize oil in water-invaded reservoirs that would otherwise be unrecoverable. The largest carbon dioxide gas reservoirs are the McElmo Dome and Doe Canyon fields in southwestern Colorado, where carbon dioxide is derived from the Leadville Limestone of Mississippian age. Carbon dioxide gas was created when this water-filled carbonate formation was subjected to high pressure and temperature alteration during deep-seated igneous activity.

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 occurring in the Fifty Mile Mountain Wilderness Study Area. The Escalante anticline, located about 15 mi north of the study area, has about 5,000 ft of relief, is about 17 mi long and 8 mi wide, trends north-south, and dips to the west. The north half of the anticline is overlain by volcanic rocks (Oil and Gas Journal, 1984). Subsequent drilling confirms that a field of high-purity carbon dioxide is located in sedimentary rocks of the Triassic Chinle Formation and the Permian Kaibab Limestone, Cedar Mesa Sandstone Member of the Cutler Formation, and Toroweap Formation (Tooker and others, 1984). Mid-Continent Oil and Gas Reserves, Inc., confirmed a carbon dioxide gas reservoir at one well having a gaged open flow of 124,347,000 cubic feet daily; the gas occurs in rocks at 1,354–3,443 ft depth (The Denver Post, Nov. 20, 1983; Oil and Gas Journal, 1984). Estimates are that as much as several trillion cubic feet of the gas occurs in this deposit (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. If the plutonic activity took place during a suitable time interval, the heat and pressure generated by such activity might have created carbon dioxide gas in the overlying carbonate rocks. However, the study area includes no volcanic rocks like those overlying the Escalante anticline, which might have produced sufficient heat and pressure to form carbon dioxide gas in underlying limestone strata. Recent drilling has shown no evidence of carbon dioxide gas occurrence in the study area, but the area is close to the Escalante anticline and contains structures similar to it. Therefore the potential for undiscovered carbon dioxide gas resources in the Fifty Mile Wilderness Study Area is rated as moderate with certainty level B.

### Titanium

The titanium minerals ilmenite and leucoxene have been found in the Straight Cliffs Formation of the Kaiparowits region, where they occur as concentrations in beach deposits along Cretaceous shorelines (Davidson, 1967; Doelling, 1975). Occurrences of titanium-bearing sandstone in the John Henry Member of the

Straight Cliffs Formation within the Kaiparowits Plateau are small and isolated; some are in largely inaccessible cliffs and cap rocks along canyon rims in the vicinity of Rogers, Sunday, and Monday Canyons (pl. 1; Dow and Batty, 1961). However, the outcrop area of the John Henry Member covers much of the study area. Therefore the mineral resource potential for undiscovered titanium minerals is assigned as high with certainty level C, except in the southwesternmost part of the study area, where the John Henry Member is absent (pl. 1). The southwesternmost part of the study area has no potential for titanium, with certainty level D.

### Gypsum

Gypsum, a chemical precipitate, commonly originates in inland sabkha (salt flat) and desert-lake settings in basins where rainfall is low and evaporation is rapid (Reineck and Singh, 1975). Gypsum typically occurs in evaporite deposits or in extensive beds interstratified with limestone, shale, and clay.

One or more thin gypsum beds are present in the upper half of the Carmel Formation in the Big Hollow Wash quadrangle adjacent to the southeast boundary of the Fifty Mile Mountain study area (Peterson, 1980), and thin to thick beds are typical of the Carmel Formation in the region, according to Hackman and Wyant (1973). The Carmel Formation crops out in the southern part of the study area and is less than 1,000 ft beneath the surface in the rest of the study area (Lidke and Sargent, 1983). Because of the favorable geologic setting and the occurrence of gypsum nearby, the resource potential for undiscovered gypsum resources in and beneath the Fifty Mile Mountain Wilderness Study Area is rated as moderate with certainty level B.

### Other Metals

Although anomalous concentrations of other metals are associated with uranium and titanium deposits elsewhere on the Colorado Plateau, no metallic minerals other than those bearing titanium were found in this investigation within the Fifty Mile Mountain Wilderness Study Area. Furthermore, no anomalous metal concentrations were reported for geochemical samples from within the study area. Therefore, the study area has low mineral resource potential for metals other than uranium and titanium, with certainty level B.

### Geothermal Resources

Geothermal resources are lacking within the Colorado Plateau except along the edges, where volcanic rocks are found. No thermal springs were observed in the Fifty Mile Mountain Wilderness Study Area; however, given the possibility of plutonic activity at depth and the excellent water reservoir rocks present, such occurrences cannot be ruled out. Therefore, the study area has moderate potential for geothermal resources with a certainty level of B.

## REFERENCES CITED

Bendix Field Engineering Corporation, 1983, Residual intensity magnetic anomaly profile map, Escalante National Topographic Map, Arizona/Utah: U.S. Department of Energy report GJM–416(83), 1 fiche. Available from U.S. Geological Survey, Books and Open-File Reports Section, Box 25425, DFC, Denver, CO 80225.

Bullock, J.H., Jr., and Barton, H.N., 1988, Analytical results and sample locality map of stream-sediment and heavy-mineral-concentrate samples from the Fifty Mile Mountain Wilderness Study Area, Kane County, Utah: U.S. Geological Survey Open-File Report, in press.

Campbell, G.S., and Hebrew, Quey, 1957, Oil and gas developments in Utah and Nevada in 1956: American Association of Petroleum Geologists Bulletin, v. 41, no. 6, p. 1242–1250.

Craig, L.C., Holmes, C.N., Cadigan, R.A., Freeman, V.L., Mullens, T.E., and Weir, G.W., 1955, Stratigraphy of the Morrison and related formations, Colorado Plateau region, a preliminary report: U.S. Geological Survey Bulletin 1009-E, 168 p.

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

Davidson, E.S., 1967, Geology of the Circle Cliffs area, Garfield and Kane Counties, Utah: U.S. Geological Survey Bulletin 1229, 133 p.

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

Doelling, H.H., and Graham, R.L., 1972, Southwestern Utah coal fields—Alton, Kaiparowits Plateau, and Kolob-Harmony: Utah Geological and Mineralogical Survey Monograph 1, 333 p.

Doelling, H.H., and Smith, M.R., 1982, Overview of Utah coal fields, 1982: Utah Geological and Mineralogical Survey Bulletin 118, 26 p.

Dow, V.T., and Batty, J.V., 1961, Reconnaissance of titaniferous sandstone deposits of Utah, Wyoming, New Mexico, and Colorado: U.S. Bureau of Mines Report of Investigations 5860, 52 p.

Dubyk, W.S., and Young, Patti, 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) (prepared by Bendix Field Engineering Corporation), 28 p. Available from U.S. Geological Survey, Books and Open-File Reports Section, Box 25425, DFC, Denver, CO 80225.

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

Geo-Life, Inc., 1980, Aerial radiometric and magnetic survey, Escalante national topographic map, Arizona/Utah: U.S. Department of Energy Report GJBX–15(80), 183 p., 106 fiche. Available from U.S. Geological Survey, Books and Open-File Reports Section, Box 25425, DFC, Denver, CO 80225; computer-readable magnetic tape available from EROS Data Center, U.S. Geological Survey, Sioux Falls, SD 57198.

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

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

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

Grose, L.T., 1965, Kolob, Kanab, and Kaiparowits coal fields in southwestern Utah, *in* Geology and resources of south-central Utah—Resources for power: Utah Geological Society Guidebook to Geology of Utah, no. 19, p. 121–133.

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.

Hansen, D.E., 1978a, Maps showing amount of overburden on major coal zones in the Kaiparowits coal basin, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I–1033–D, scale 1:125,000.

——— 1978b, Map showing extent and total thickness of coal beds in the Kaiparowits Coal Basin, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I–1033–C, scale 1:125,000.

Heffner, J.D., 1980, Hydrogeochemical and stream sediment reconnaissance, Escalante 1°×2° NTMS area, Utah (abbreviated data report): U.S. Department of Energy Report GJBX—209(80) (prepared by Savannah River Laboratory, E.I. duPont de Nemours and Company), 18 p., 3 fiche. Available from U.S. Geological Survey, Books and Open-File Reports Section, Box 25425, DFC, Denver, CO 80225.

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 to Geology of Utah, no. 19, p. 93–111.

Lewis, G.E., Irwin, J.H., and Wilson, R.F., 1961, Age of the Glen Canyon Group on the Colorado Plateau: Geological Society of America Bulletin, v. 72, no. 9, p. 1437–1440.

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.

Lynd, L.E., and Lefond, S.J., 1983, Titanium minerals, *in* Industrial minerals and rocks, 5th edition: New York, American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., p. 1303–1362.

Martin, C.M., 1986, Mineral investigation of a part of the Fifty Mile Mountain Wilderness Study Area (UT–040–080), Kane County, Utah: U.S. Bureau of Mines Open File Report MLA 58–86, 37 p.

McCabe, P.J., 1984, Depositional environments of coal and coal-bearing strata, *in* Rahmani, R.A., and Flores, R.M., eds., Sedimentology of coal and coal-bearing sequences: International Association of Sedimentologists Special Publication 7, p. 13–42.

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.

Miller, B.M., 1983, Petroleum resource assessments of the wilderness lands in the western United States, *in* Miller, B.M., ed., Petroleum potential of wilderness lands in the western United States: U.S. Geological Survey Circular 902–A, p. A1–A10.

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

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: Prepared for 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, 1969a, Four new members of the Upper Cretaceous Straight Cliffs Formation in the southeastern Kaiparowits region, Kane County, Utah: U.S. Geological Survey Bulletin 1274–J, 28 p.

——— 1969b, Cretaceous sedimentation and tectonism in the southeastern Kaiparowits region, Utah: U.S. Geological Survey open-file report, 259 p.

——— 1975, Geologic map of the Sooner Bench quadrangle, Kane County, Utah: U.S. Geological Survey Miscellaneous Geologic Investigations Series Map I–874, scale 1:24,000.

——— 1980, Geologic map and coal deposits of the Big Hollow Wash quadrangle, Kane County, Utah: U.S. Geological Survey Coal Investigations Map C–84, scale 1:24,000.

Peterson, Fred, and Barnum, B.E., 1973a, Geologic map and coal resources of the northeast quarter of the Cummings Mesa quadrangle, Kane County, Utah: U.S. Geological Survey Coal Investigations Map C–63, scale 1:24,000.

——— 1973b, Geologic map and coal resources of the northwest quarter of the Cummings Mesa quadrangle, Kane County, Utah: U.S. Geological Survey Coal Investigations Map C–64, scale 1:24,000.

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., 7 fiche. Available from U.S. Geological Survey, Books and Open-File Reports Section, Box 25425, DFC, Denver, CO 80225.

Phoenix, D.A., 1963, Geology of the Lees Ferry area, Coconino County, Arizona: U.S. Geological Survey Bulletin 1137, 86 p.

Picard, M.D., 1955, Oil and gas developments in Utah and Nevada in 1954: American Association of Petroleum Geologists Bulletin, v. 39, no. 6, p. 1035–1045.

Picard, M.D., and Wise, Gordon, 1956, Oil and gas developments in Utah and Nevada in 1955: American Association of Petroleum Geologists Bulletin, v. 40, no. 6, p. 1303–1314.

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

Sargent, K.A., and Hansen, D.E., 1980, Landform map of the Kaiparowits coal-basin area, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I–1033–G, scale 1:125,000.

——— 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., 1977, Reservoir variations of Upper Valley field, Garfield County, Utah, *in* Hill, J.G., ed., Geology of the Cordilleran hingeline: Denver, Colo., Rocky Mountain Association of Geologists, p. 325–344.

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

Thamm, J.K., Kovschak, A.A., Jr., and Adams, S.S., 1981, Geology and recognition criteria for sandstone uranium deposits of the Salt Wash type, Colorado Plateau province, final report: U.S. Department of Energy Report GJBX–6(81), 135 p. Available from U.S. Geological Survey, Books and Open-File Reports Section, Box 25425, DFC, Denver, CO 80225.

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 Land Management, 1976, Final environmental impact statement—Proposed Kaiparowits project: U.S. Bureau of Land Management, Report FES 76-12, 3199 p.

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

U.S. Department of Energy, 1979, National uranium resource evaluation, interim report: U.S. Department of Energy Report GJO–111(79), 184 p. Available from U.S. Geological Survey, Books and Open-File Reports Section, Box 25425, DFC, Denver, CO 80225.

Williams, V.S., 1985, Surficial geologic map of the Kaiparowits coal-basin area, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I–1033–L, scale 1:125,000.

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

Wright, J.C., and Dickey, D.D., 1963, Relations of the Navajo and Carmel Formations in southwestern Utah and adjoining Arizona, *in* Geological Survey research 1962: U.S. Geological Survey Professional Paper 450–E, p. E63–E67.

# 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.

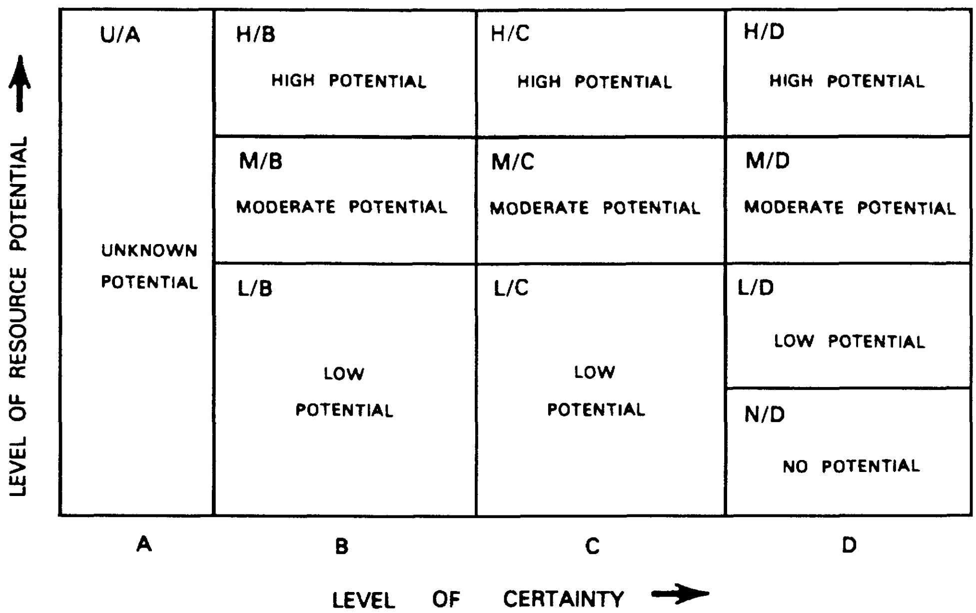
MODERATE mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence, where interpretations of data indicate a reasonable likelihood of resource accumulation, and (or) where an application 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 resourca classification, excluding reserve base and inferred reserve bese. 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 |
|---|---|---|---|---|---|
| Phenerozoic | 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<br>Middle<br>Early | 205 |
| | | Triassic | | Late<br>Middle<br>Early | ~ 240 |
| | Paleozoic | Permian | | Late<br>Early | 290 |
| | | Carboniferous Periods | Pennsylvanian | Late<br>Middle<br>Early | ~ 330 |
| | | | Mississippian | Late<br>Early | 360 |
| | | Devonian | | Late<br>Middle<br>Early | 410 |
| | | Silurian | | Late<br>Middle<br>Early | 435 |
| | | Ordovician | | Late<br>Middle<br>Early | 500 |
| | | Cambrian | | Late<br>Middle<br>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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