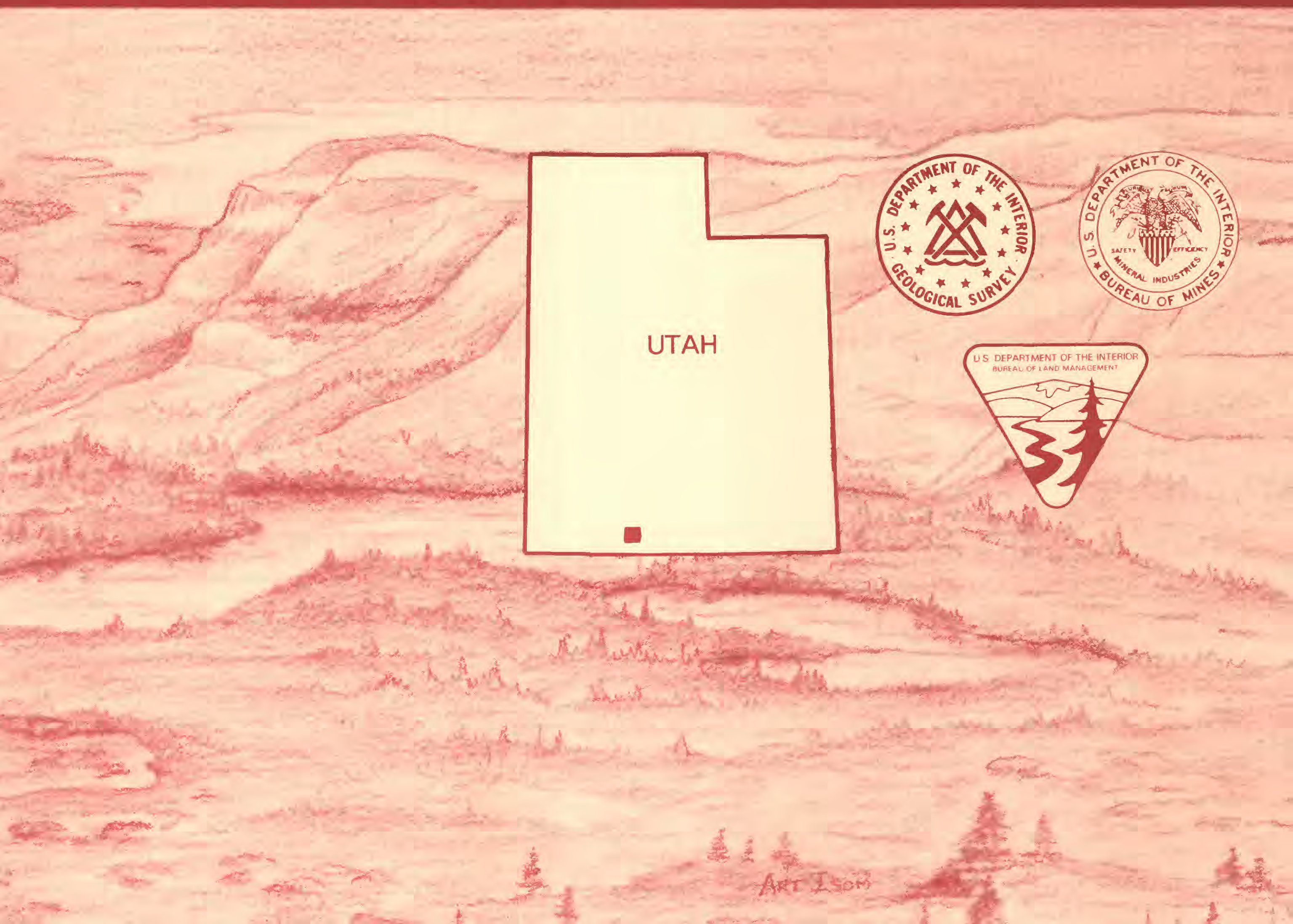
Mineral Resources of the Cockscomb and Wahweap Wilderness Study Areas, Kane County, Utah

U.S. GEOLOGICAL SURVEY BULLETIN 1748–A



Chapter A

Mineral Resources of the Cockscomb and Wahweap Wilderness Study Areas, Kane County, Utah

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U.S. GEOLOGICAL SURVEY BULLETIN 1748

MINERAL RESOURCES OF WILDERNESS STUDY AREAS: THE COCKSCOMB REGION, UTAH

DEPARTMENT OF THE INTERIOR

MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

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STUDIES RELATED TO WILDERNESS

Bureau of Land Management Wilderness Study Areas

The Federal Land Policy and Management Act (Public Law 94–579, October 21, 1976) requires the U.S. Geological Survey and the U.S. Bureau of Mines to conduct mineral surveys on certain areas to determine the mineral values, if any, that may be present. Results must be made available to the public and be submitted to the President and the Congress. This report presents the results of a mineral survey of the Cockscomb (UT–040–275) and Wahweap (UT–040–248) Wilderness Study Areas, Kane County, Utah.

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PLATE

[Plate is in pocket]

FIGURES

Mineral Resources of the Cockscomb and Wahweap Wilderness Study Areas, Kane County, Utah

By Henry Bell III, James E. Kilburn, *and* John W. Cady
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Abstract

The Cockscomb (UT–040–275) and Wahweap (UT–040–248) Wilderness Study Areas are in Kane County, Utah, west of the Kaiparowits Plateau. These study areas are underlain by gently folded sedimentary rocks: the east-dipping East Kaibab monocline in the western part of the Cockscomb study area, and relatively horizontal beds to the east and in the Wahweap study area. No identified resources of metals or nonmetallic minerals occur, but about 1.8 million tons of identified subbituminous coal resources are estimated for the Cockscomb study area, and about 350,000 tons for the Wahweap area. The mineral resource potential for all metals, including gold and uranium, is low in both study areas. Gravel deposits have been mined nearby, and the mineral resource potential is high for additional deposits of sand and gravel in the southern end of the Wahweap Wilderness Study Area. A moderate energy resource potential exists for coal in the Dakota Formation in both study areas, and for coal in the Straight Cliffs Formation in the Wahweap Study Area. The resource potential in both study areas is moderate for oil and gas, and low for geothermal energy.

SUMMARY

At the request of the U.S. Bureau of Land Management, two wilderness study areas in southern Utah (fig. 1) were studied in order to appraise their identified mineral resources and assess their potential mineral resources. The areas studied are the Cockscomb (UT–040–275) Wilderness Study Area, 5,100 acres (8 square miles), and the Wahweap (UT–040–248) Wilderness Study Area, 70,380 acres (110 square miles), both in Kane County, Utah. In this report the areas studied are called "wilderness study areas," simply "study areas," or "Cockscomb area" or "Wahweap area," as appropriate. The Cockscomb area (fig. 1) lies along the steeply east-dipping East Kaibab monocline, and the Wahweap area, farther to the east, consists of flat-lying but gently folded rocks. These areas adjoin the Paria-Hackberry Wilderness Study Area (UT–040–247) to the west.

Manuscript approved for publication February 6, 1990.

Character and Geologic Setting

The wilderness study areas are in the Colorado Plateaus physiographic province, west of the Kaiparowits Plateau, on the Kaibab uplift. The areas are in the part of the Colorado Plateaus called the High Plateaus of Utah, an area of narrow, deep canyons with bordering cliffs separated from nearby mesas by broad, undulating benches that rise like steps from an elevation of about 4,000 feet to 6,000 feet. In this arid region, the Paria River, Wahweap Creek, and streams in several other major canyons are dry much of the time. The seasonally dry beds of the Paria River and Wahweap Creek are passable for vehicles and supplement access from unpaved county roads and from U.S. Highway 89, which passes close to the southern boundary of the study areas.

West of the East Kaibab monocline, near the Cockscomb study area (fig. 1), the oldest exposed rocks are Permian in age (see geologic time chart in appendix), are mostly limestones, and are included in the Toroweap Formation and the Kaibab Limestone. These are exposed in stratigraphic windows eroded through soft reddish sandstone and shale of the Triassic Moenkopi Formation. Unconformably above the Moenkopi Formation are variegated clayey sandstone, shale, and local

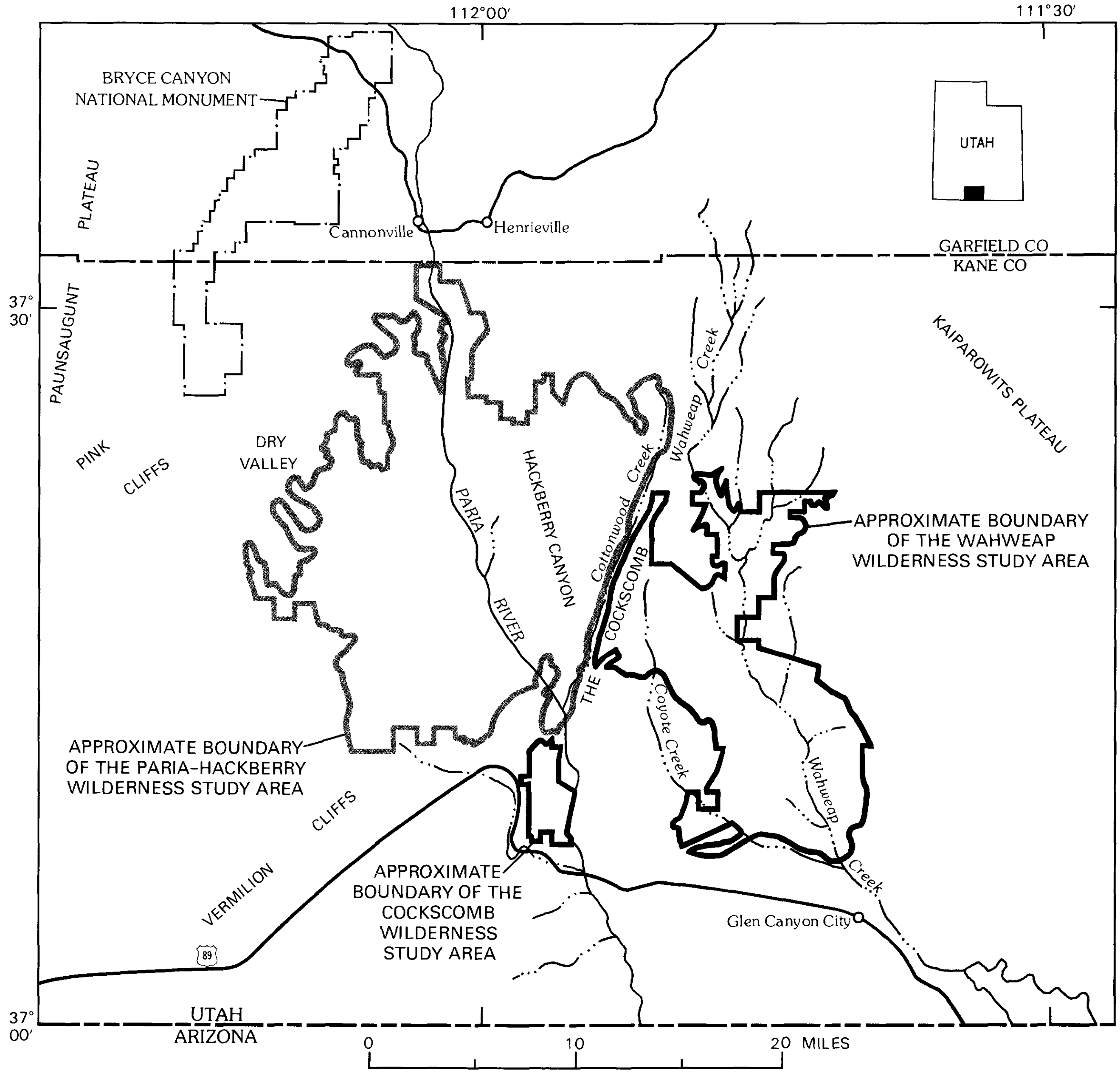


Figure 1. Location of the Cockscomb and Wahweap Wilderness Study Areas, Kane County, Utah. Paria-Hackberry Wilderness Study, not discussed in this report, is shown for location only.

lenticular coarse sandstone of the Triassic Chinle Formation. Above the Chinle Formation are generally light-colored or white, crossbedded sandstones which are, following the usage of Peterson and Pipiringos (1979), the Jurassic Moenave Formation, Kayenta Formation, and Navajo Sandstone. These form cliffs ranging from 600 to 1,000 feet in height. Numerous narrow canyons, including the canyon of the Paria River and Hackberry Canyon, have been cut into these formations. Above the Navajo Sandstone lie mudstone, slabby sandstone and limestone with gypsum beds, and soft, fine-grained, light-colored sandstone forming rounded cliffs in the interfingering Jurassic Carmel Formation and Entrada Sandstone. The Entrada is overlain here by the coal-bearing, Cretaceous Dakota Formation. A widespread unconformity at the base of the Dakota has cut out Summerville-equivalent rocks and the Morrison Formation, which underlie the Dakota just east of the area of plate 1. The rocks plunge northward along the East Kaibab monocline so that older rocks can be seen covered successively by younger rocks, which lie uneroded on both sides of the monocline, preserving the steeply dipping structure. Along the monocline the softer mudstone and shale have been eroded, leaving the more resistant sandstones as hogbacks and cockscomb-like ridges. East of the monocline, the Cretaceous coal-bearing Dakota Formation and the soft, easily eroded Tropic Shale form a wide bench; the overlying Cretaceous Straight Cliffs Formation (a coal-producing formation in the Kaiparowits Plateau) makes sheer cliffs 1,000 feet high. Shaly sandstone grading upward into sandstone in the overlying Cretaceous Wahweap Formation adds as much as 800 feet of additional south-facing cliffs in the Wahweap study area. The uppermost rocks, in the Cretaceous Kaiparowits Formation, are friable silty sandstones with sparse interbedded mudstone and limestone. In the bottom of the larger canyons and at the base of cliffs are alluvium and talus deposits of Quaternary age. On the wide benches, particularly east of the Paria River and near Wahweap Creek, are gravel-bearing terraces and windblown deposits of sand and silt.

Steeply east-dipping rocks in the East Kaibab monocline separate nearly flat-lying strata on the west from nearly flat-lying strata on the east that are as much as 7,000 feet stratigraphically higher. Faults and fractures are abundant along the monocline; many closely spaced faults trend generally north-northeast, along the strike of the beds, and some trend to the northeast, fragmenting and offsetting the steeply dipping beds. Other faults trend northwest, such as those along the Paria River and Hackberry Canyon and the many short segments that cut the monocline along the northwest border of the Wahweap study area. Associated with many of these faults and fractures are iron-oxide-stained rocks and carbonate-cemented rocks, particularly in the Cockscomb area, where prospecting for copper minerals has occurred. The nearly flat-lying rocks east and west of the East Kaibab monocline are gently folded and have north-northeast trending, sinuous fold axes; some of the folds have been tested for oil and gas. Widespread unconformities truncating the folded rocks also have been folded, creating possible sites of hydrocarbon accumulation along the unconformities in the study areas.

Mineral Occurrences and Identified Resources

No identified resources of metallic minerals occur in the study areas. Gold mining was attempted along the Paria River in the adjoining Paria-Hackberry Wilderness Study Area to the west, and there is evidence of prospecting for copper, lead, manganese, titanium, and uranium in and near the study areas. Southeast of the Wahweap study area gravel deposits were mined for aggregate during construction of the Glen Canyon Dam and similar deposits remain. There are no other occurrences of noteworthy industrial rocks or nonmetallic minerals. Coal has been produced nearby from rocks in the Dakota Formation, which crops out in both study areas. Subbituminous coal in the Dakota Formation is the only identified resource; the resource is estimated to consist of about 1.8 million tons in the Cockscomb study area and about 350,000 tons in the Wahweap study area (fig. 2).

Mineral and Energy Resource Potential

Uranium deposits in the predominantly clay-rich Chinle Formation occur in sandstones and conglomerates, especially in those which form stream-channel deposits rich in carbonaceous plant remains. The Chinle crops out within the Cockscomb study area, but the sandstone-shale ratio there is not characteristic of ore-bearing Chinle elsewhere. In addition, no high values for uranium were found in geochemical samples collected in the vicinity; the resource potential for undiscovered uranium deposits is low, at certainty level C in the Cockscomb study area and at certainty level B in the Wahweap study area.

Gold occurs in the Chinle Formation as very fine-grained particles (Lawson, 1913; Gregory, 1948), but it was not detected by chemical analyses of rock or stream-sediment samples in the study areas. The resource potential for gold deposits in the Chinle Formation is judged to be low, at certainty level C in the Cockscomb study area and at certainty level B in the Wahweap study area. The resource potential for gold deposits in all other formations is also low in both study areas.

A few other metallic elements—such as barium, lanthanum, lead, silver, strontium, and thorium—occur in a few samples from widely scattered areas in anomalously high concentrations. The values, however, are too low and the samples generally too scattered to suggest anything more than low mineral resource potential at a certainty level of C for undiscovered deposits of these metals in both study areas.

Analyses of iron-oxide-stained rocks and carbonate-cemented rocks collected adjacent to fractures show a few low, but nevertheless anomalous, values for one or more of the elements arsenic, copper, manganese, and molybdenum. The geologic environment in the vicinity of the study areas is characterized by gypsum beds, impure limestones, and red sandstone with traces of copper minerals, through which fluids have moved on fractures. Although this environment is suitable for the formation of metal-bearing vein deposits, only a low mineral resource potential is indicated because of the relatively low values in the samples collected.

Deposits of gravel and eolian sand are widespread northeast of Coyote Creek, where many lie on the wide bench underlain by the Dakota Formation and the Tropic Shale. Because they are similar to deposits from which

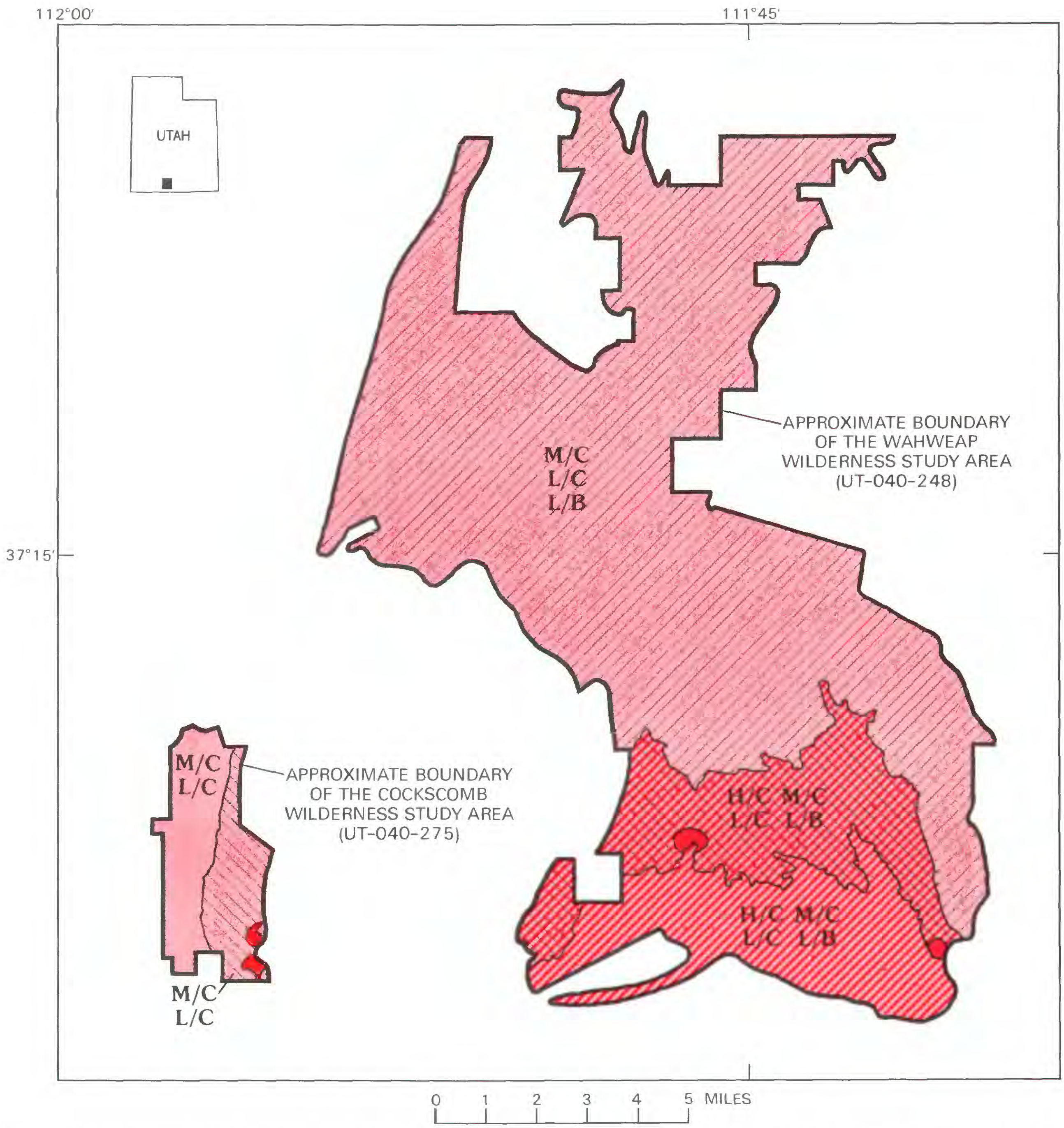


Figure 2 (above and facing page). Mineral and energy resource potential in the Cockscomb and Wahweap Wilderness Study Areas, Kane County, Utah.

aggregate was mined during construction of Glen Canyon Dam, the mineral resource potential for sand and gravel deposits is high at certainty level C in the southern part of the Wahweap study area.

An energy resource potential for coal occurs in the Dakota Formation outside the areas of identified coal resources in both study areas, and it is rated as moderate at certainty level C. In the Wahweap study area, north of the Dakota outcrop belt (pl. 1), the Dakota is deeply buried below the Straight Cliffs Formation.

Undiscovered coal resources also may occur in the Straight Cliffs Formation in the Wahweap study area, and this resource potential also is classed as moderate at certainty level C. The Straight Cliffs Formation contains coal in the Kaiparowits Plateau to the east, but in the Wahweap area the beds are deeply buried and no coal

EXPLANATION

Identified subeconomic resource of coal in the Dakota Formation

H/C Geologic terrane having high mineral resource potential for sand and gravel, at certainty level C

M/C Geologic terrane having moderate mineral resource potential for coal in the Dakota and Straight Cliffs Formations, at certainty level C

M/C Geologic terrane having moderate mineral resource potential for coal in the Dakota Formation only, at certainty level C

M/C Geologic terrane having moderate mineral resource potential for oil and gas at certainty level C—Applies to all parts of both study areas

L/C Geologic terrane having low mineral resource potential at certainty level C, for geothermal resources and for all metals—Applies specifically to arsenic, gold, copper, manganese, molybdenum, and uranium in the Cockscomb area; does not apply to uranium and gold in the Wahweap area

L/B Geologic terrane having low mineral resource potential for uranium and gold, at certainty level B

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

crops out. However, a drill hole close to the eastern boundary of the study area cut about 4 feet of coal (Hansen, 1978), which may indicate that other deeply buried coal deposits occur farther to the west.

The energy resource potential for oil and gas is judged to be moderate at certainty level C, because productive oil and gas formations in the Upper Valley field to the northeast also underlie the study areas. Although the study areas contain structures that are similar to those in the productive areas, the few test holes that have been drilled are dry and have been abandoned.

No hot springs or thermal anomalies are known in the study areas. Although the occurrence of iron oxide stain and carbonate cement adjacent to fractures suggests fluid flow in fractures, no evidence of high temperatures has been found. Geophysical data give no evidence of volcanic rocks or igneous intrusions that might provide a source of geothermal energy at shallow levels below the study areas. There is, therefore, a low resource potential for geothermal energy at a certainty level of C.

INTRODUCTION

At the request of the U.S. Bureau of Land Management, two wilderness study areas in southern Utah (fig. 1) were studied in order to appraise their identified mineral resources and assess their potential mineral resources. The areas studied are the Cockscomb (UT–040–275) Wilderness Study Area, 5,100 acres (8 square miles), and the Wahweap (UT–040–248) Wilderness Study Area, 70,380 acres (110 square miles), both in Kane County, Utah. The following text refers to these as "wilderness study areas," simply "study areas," or "Cockscomb area" or "Wahweap area," as appropriate. These areas are contiguous with the Paria-Hackberry Wilderness Study Area (UT–040–247) to the west.

This report presents an evaluation of the mineral endowment (identified resources and mineral resource potential) of the study areas and is the product of separate studies by the U.S. Bureau of Mines (USBM) and the U.S. Geological Survey (USGS). Identified resources are classified according to the system of the 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 resources (coal, oil, gas, oil shale, and geothermal sources). It is classified according to the system of Goudarzi (1984), which is also shown in the appendix. Undiscovered resources are studied by the USGS.

Location and Geographic Setting

The wilderness study areas are within the Colorado Plateaus physiographic province west of the Kaiparowits Plateau (fig. 1). Kanab, the county seat, is about 25 miles to the west and Henrieville, in Garfield County, is about 5 miles northwest of the Wahweap area. U.S. Highway 89 passes near the southern boundaries of the study areas and connects with unpaved county roads that provide access to the study areas. From an unpaved county road along Cottonwood Creek, several jeep trails lead into the Wahweap area. The beds of the Paria River and Wahweap Creek are usable by vehicles as roads during parts of the year, providing access to otherwise inaccessible areas. Narrow, deep canyons with bordering cliffs separated from mesas of sandstone by terraced benches, typical of canyonlands topography, characterize the study areas. The benches rise like steps from an elevation of about 4,000 feet to 6,000 feet. Water supply is low, seasonal, and erratic, the principal sources being the Paria River, temporary streams in various canyons, and numerous springs.

Investigations by the U.S. Bureau of Mines

Bureau of Mines personnel reviewed literature concerning mining and geology of the region, and also reviewed Bureau of Land Management records for mining claim information and oil and gas applications. Figure 3 shows oil and gas leases, placer claims, and unpatented mining claims in and near the study areas.

Two geologists spent 25 days completing the field examination inside the study areas and within a mile outside the boundaries. Surface workings and accessible mines were surveyed by compass and tape method, mapped, and sampled. Coal beds were measured and sampled.

During the field investigations, 57 samples were collected: 50 from the Cockscomb study area, 4 from the Wahweap study area, and 3 from outside the study areas. Chip samples were taken across geologic structures or at outcrops. All chip samples were analyzed by Bondar-Clegg, Inc., Denver, Colo., for 26 elements, including gold and silver, by neutron activation; selected samples were analyzed for copper by atomic absorption analysis. Proximate, ultimate, and heat value determinations were made for all coal samples by Core Laboratories, Denver, Colo. (Lane, 1987). Complete analytical data for all samples are available for public inspection at the Bureau of Mines, Intermountain Field Operations Center, Building 20, Denver Federal Center, Denver, CO 80225.

Investigations by the U.S. Geological Survey

Investigations by the U.S. Geological Survey included geologic reconnaissance and inspection of all mines and prospects in the study areas and surrounding regions. Rocks and stream sediments were sampled in 1986 and 1987 to provide geochemical data for mineral resource assessment. Alfred L. Bush, John Jackson, and David E. Detra assisted the authors in the field and with samples and maps in the office. The expert assistance in the preparation and editing of this report by A.L. Bush is particularly appreciated.

Several wide-ranging studies on coal, oil, uranium, and other metallic and nonmetallic mineral resources have included parts of the study areas. These have provided descriptions of the various rock units and structure. The U.S. Geological Survey carried out an extensive series of studies on land resources, coal, chemical quality of ground and surface water, and other subjects relating to the Kaiparowits coal basin; these were published by various authors in U.S. Geological Survey Miscellaneous Investigations Series maps (1977–1985) numbered I–1033–A through I–1033–L. This report has relied for much detail on the data in those maps. Other principal sources of data include geologic mapping and studies of stratigraphy and structure by Gregory and Moore (1931), Gregory (1948), Hintze (1963), and Hintze and Stokes (1964). Valuable data has also been provided by the geologic map of Kane County, Utah (Doelling and Davis, 1989), which is used as the geologic base for plate 1. Additional data comes from a geologic map showing structural features and uranium deposits by Hackman and Wyant (1973). Data on the petroleum potential of the study areas has come from Molenaar and Sandberg (1983) and other sources.

APPRAISAL OF IDENTIFIED RESOURCES

By Michael E. Lane
U.S. Bureau of Mines

Mining History

Records of the Bureau of Land Management indicate 10 unpatented claims and no patented claims in the study areas (fig. 3); 5 are placer claims. No workings were found on the known claims in the study areas. Four adits and four prospects were found in the Cockscomb area. Within 1 mile of the south boundary, bulldozer cuts have been made, probably for uranium exploration. Coal has been mined within 1 mile of the east boundary, but the small size of the workings makes it doubtful that they yielded any appreciable production.

No mine workings or prospects were found in the Wahweap study area. Aggregate for the construction of Glen Canyon Dam, about 15 miles southeast, was mined from gravel deposits southeast of the Wahweap study area, where large deposits of similar material remain.

Energy Resources

Oil and gas leases and lease applications cover parts of the study areas (fig. 3). No holes for oil or gas exploration have been drilled in either area, but one dry hole was drilled about 1 mile east of the Wahweap study area (Doelling and others, 1986, p. 6). A test hole was drilled near Hackberry Canyon, west of the Wahweap study area (Brown and Hannigan, 1986). Cuttings from the hole showed oil traces, but it was abandoned and no further drilling was done. Both areas, however, are in a sparsely explored part of the Colorado Plateau. Oil-bearing rocks to the northeast are Permian carbonates, which are found at the surface along the East Kaibab monocline and near the study areas (Molenaar and Sandberg, 1983, p. K11).

Coal beds occur in the Dakota Formation in both study areas, ranging in thickness from a few inches to several feet. Gregory and Moore (1931) state that coal beds in the Dakota Formation and the Tropic Shale are thin and poor in quality and have little commercial value. No coal was seen in the Tropic Shale during the investigation. In the Cockscomb study area, coal is found only

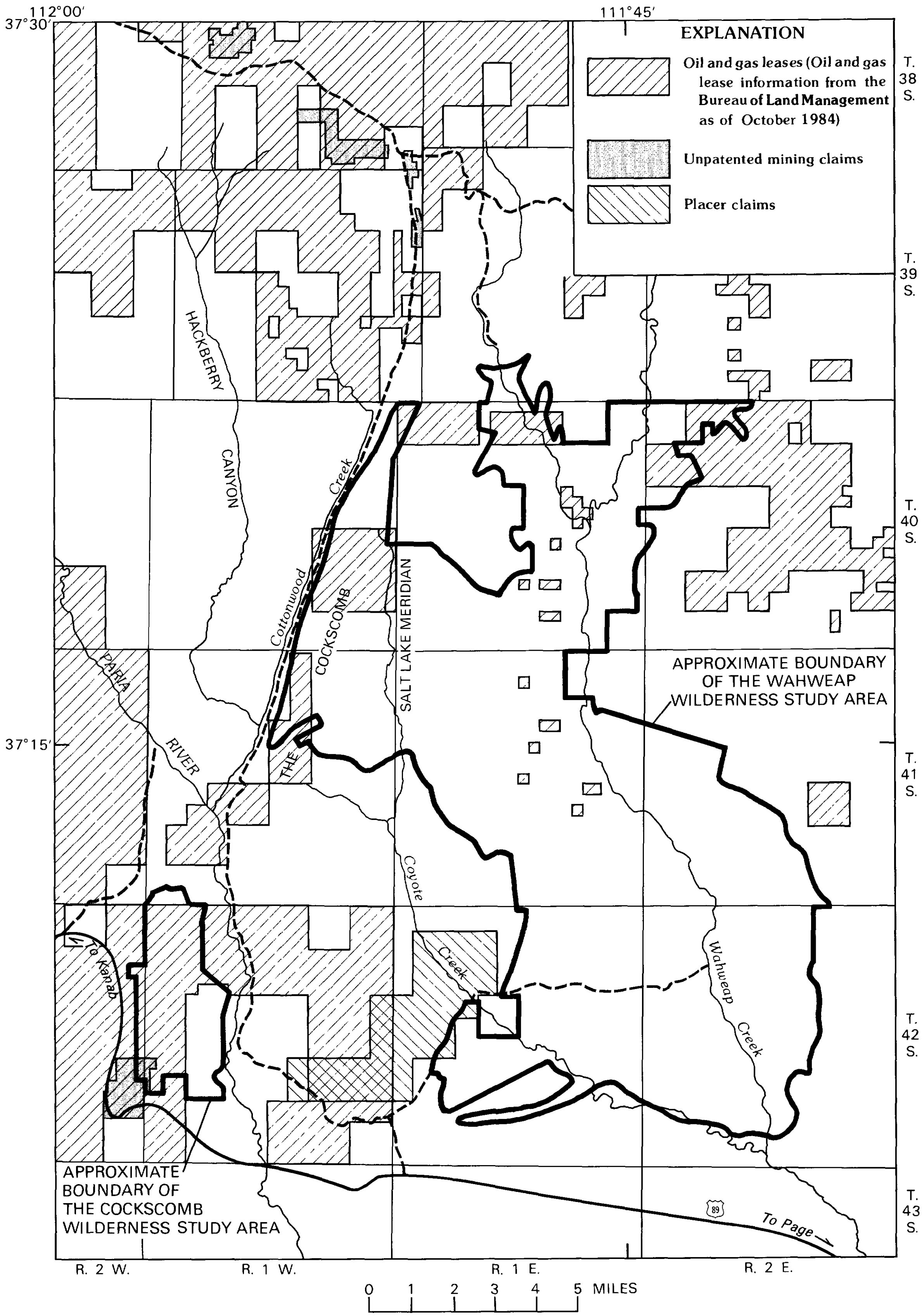


Figure 3. Oil and gas leases, placer claims, and unpatented mining claims in the Cockscomb and Wahweap Wilderness Study Areas and vicinity, Kane County, Utah (from Brown and Hannigan, 1986, and Lane, 1987).

in discontinuous, lenticular beds in the Dakota Formation in the eastern part of the area. Resource calculations are hampered by limited exposures and the localized, lenticular nature of the coal beds. In the southern part of the Wahweap study area, coal in the Dakota Formation crops out. The Straight Cliffs Formation, which is exposed widely in the Wahweap area is host to thick commercial coal beds east and northeast of the study areas. Doelling and others (1986) state that, in the Smoky Mountain area, 5 to 10 miles east of the study area, the coals are of higher quality than those of the Dakota Formation; however, the field investigation found no outcrops of coal in the Straight Cliffs Formation in the study area.

Appraisal of Examined Sites

Four adits and four prospects in the Cockscomb study area were examined, and 50 rock samples were collected. Two samples contained minor amounts of silver, 13 and 11 parts per million (ppm); very minor amounts of gold were found in two samples, 9 and 6 parts per billion. Copper was found in all samples; the range was from trace amounts (7 ppm) to 6.3 percent found in a grab sample of Navajo Sandstone showing the copper minerals malachite, chrysocolla, and possibly chalcocite. Only three samples contained copper in excess of 1 percent. The majority of the samples contained uranium but the grades were low; the highest from both study areas was 56.9 ppm (Lane, 1987). No identified mineral resources are indicated.

The Hattie Green Mine is the largest working in the study areas. Part of the mine follows a northwest-trending fault that hosts small occurrences of copper minerals. The highest copper content found in the mine is 6,850 ppm (0.69 percent) from a select sample, and the lowest is 7 ppm; seven samples indicated copper in excess of 200 ppm. No identified copper mineral resource is indicated.

Three hundred twenty-five tons of material averaging 0.48 percent copper was estimated at an adit east of the Hattie Green Mine, where a grab sample showing 3.5 percent copper was the highest value found (Lane, 1987, fig. 4). Because of the small tonnage and low grade of the material, no identified mineral resource is indicated.

Coal outcrops in the Dakota Formation were sampled in both study areas; eight samples were taken and proximate, ultimate, and heat value analyses were done. The samples were of weathered coal beds and may not be good indicators of the true quality of the coal in the area. Fresh coal probably would be higher quality.

In the Cockscomb study area, Dakota coal is lenticular, pinching and thickening locally. Beds range in thickness from 8 to 59 inches, and overburden locally exceeds 100 feet. According to the system of Wood and others (1983), coal in the Cockscomb area ranges from lignite A to subbituminous A in rank and contains low to moderate sulfur (0–3 percent) and ash (0–14 percent) (Lane, 1987). Assuming the coal beds extend ¼ mile from the sampled locality and are uniform in thickness, about 1.8 million tons of subeconomic coal resources exists in the Cockscomb study area.

In the Wahweap study area Dakota coal exposures are very sparse; two samples were taken from 12- and 17-inch-thick beds. Overburden is very thick in many areas where the rocks dip under cliffs formed by the Straight Cliffs and Wahweap Formations. The coal in the study area has a rank of subbituminous B and C and has medium (1.1–3.0 percent) sulfur and medium to high (9–14 percent) ash content (Lane, 1987). Assuming the same parameters as for the Cockscomb study area, about 350,000 tons of subeconomic coal resources exist in the Wahweap study area. Drilling is needed to accurately define the coal boundaries and thicknesses.

Conclusions

Coal in the Dakota Formation is the only resource identified in the Cockscomb and Wahweap study areas. Coal in the Cockscomb study area is lenticular and limited in exposure. Coal in the Wahweap study area is exposed in only a few areas, and information on the size and shape of the coal beds is sparse. It is estimated, however, that about 1.8 million tons of coal exists in the Cockscomb study area and about 350,000 tons exists in the Wahweap study area. Given present field data, lack of bed continuity, and sparse dimensional information, the coal resources are subeconomic.

The Cockscomb study area contains occurrences of copper and uranium minerals but not in amounts sufficient to be considered an identified resource.

ASSESSMENT OF POTENTIAL FOR UNDISCOVERED RESOURCES

By Henry Bell III, James E. Kilburn, and John W. Cady
U.S. Geological Survey

Geologic Setting

Plate 1 shows a geologic map of the study areas, modified from the geologic map of Kane County, Utah (Doelling and Davis, 1989). The Wahweap Wilderness Study Area is underlain by gently folded but generally flat-lying sedimentary strata. These eastern strata are separated from other generally flat-lying rocks to the

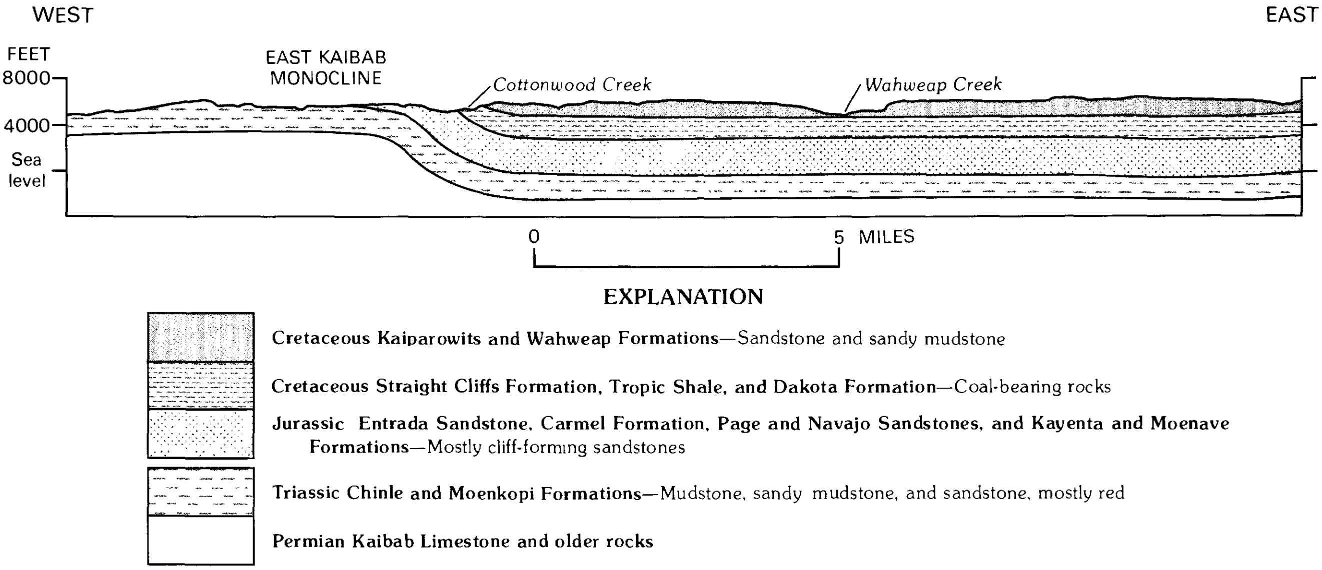


Figure 4. Diagrammatic east-west geologic section across the Wahweap Wilderness Study Area showing the East Kaibab monocline, Kane County, Utah.

west by steeply east-dipping rocks along the East Kaibab monocline. The Cockscomb Wilderness Study Area is along these steeply dipping rocks. Older formations, ranging from the Permian Kaibab Limestone to the Jurassic Carmel Formation, crop out mostly to the west of the monocline. Younger formations, ranging from the Jurassic Entrada Sandstone to the Cretaceous Kaiparowits Formation, occur mainly to the east of the monocline. Figure 4 is a geologic cross section across the East Kaibab monocline, showing the steeply dipping strata with nearly flat-lying strata at the surface to the east and west. Windblown sand, alluvial sand and gravel, and talus deposits are widespread on benches, along the river and canyon floors, and along the base of cliffs. These surficial deposits are Quaternary in age.

Summary Description of Rock Units

The geologic map of the study areas and environs (pl. 1) shows the distribution of units ranging from the Permian Toroweap Formation and Kaibab Limestone to unconsolidated rocks of Quaternary age. This geologic map is adopted with minor modifications from Doelling and Davis (1989); their formation names and ages are also adopted with minor modifications for this report. The general nature of these units is summarized here; more detailed lithologic and petrographic descriptions can be found in the references cited.

Mudstone and sandstone of the Triassic Moenkopi Formation are the oldest and stratigraphically lowest outcropping rocks within the study areas. West of the Cockscomb study area, they underlie a wide bench where windows eroded through the Moenkopi expose limestone of the underlying Permian Kaibab Limestone and, in the deepest canyon, the Permian Toroweap Formation. Variegated clay-rich rocks of the Triassic Chinle Formation unconformably overlie the Moenkopi. In places, lenticular sandstone and conglomerate beds, commonly in the form of stream-channel deposits, are present near the base of the formation. In some parts of Colorado and Utah, these paleostream deposits are incised into the underlying strata. Some channel deposits, particularly those rich in carbonaceous plant remains, contain uranium-, copper-, and vanadium-bearing minerals in numerous ore deposits in southeastern Utah and adjacent parts of Colorado. On the geologic map the Chinle Formation is shown as divided into a lower part, the Shinarump Member, and an upper part, the Petrified Forest Member (pl. 1). Along the Paria River and in the Cockscomb area these members have a high sandstone-to-mudstone ratio, a characteristic considered unfavorable for uranium deposits (Dubyk and Young, 1978). Researchers have been known for many years (Lawson, 1913; Phoenix, 1963) that very fine flakes of probably detrital gold are widely distributed and disseminated in mudstones and sandstones in the Petrified Forest Member of the Chinle Formation, which formerly were included by Lawson (1913) in the "Shinarump clay."

Above the Chinle Formation are massive cliff-forming sandstones of the reddish Moenave and Kayenta Formations and the clean white Navajo Sandstone. These rocks are probably Triassic or Jurassic in age and are shown on plate 1 as Jurassic following Peterson and

Pipiringos (1979). They are the rocks in which the Paria River canyon, Hackberry Canyon, and numerous other canyons west of the study areas have been cut, forming cliffs of 600–1,000 feet that expose the entire thickness of the formations. These formations are conspicuous in the Cockscomb area.

Along the East Kaibab monocline, the outcropping rocks range from the Jurassic Carmel Formation to the Cretaceous Dakota Formation and overlying Tropic Shale; all these rocks dip steeply to the east and are greatly fractured and deformed by faulting. The sandstones form narrow hogbacks and cockscomb-like outcrops, characteristic of the Cockscomb study area, separated by more easily eroded mudstones and soft sandstones. The Carmel Formation is a red marine unit that includes sandstone, limestone, and gypsum beds. Some of the sandstones are cliff-forming and particularly conspicuous in the northern part of the Cockscomb study area and along Cottonwood Creek. To the north and west of the Wahweap area, however, slope-forming beds of mudstone, siltstone, slabby limestone, and gypsum are locally as much as 11 feet thick. Gregory (1951, p. 57) reported the occurrence of copper minerals in trace amounts in the upper part of sandstone beds in this formation. The red, marine, cliff-forming sandstones of the Carmel, and similar rocks in the overlying Entrada Sandstone, were partly eroded during the Jurassic Period, and the Cretaceous Dakota Formation was deposited on a widespread unconformity which underlies the Wahweap study area and probably the Cockscomb study area also.

East of the Kaibab monocline and south of the Wahweap study area, the nearly flat-lying Dakota Formation contains beds of coal. In that area the coal is locally more than 7 feet thick (Hansen, 1978), which is sufficient for mining, but the coal in the Dakota is discontinuous and of low quality, ranging in rank from lignite to subbituminous. The Cretaceous Tropic Shale, overlying the Dakota, is a formation of thick, soft, gray rocks locally containing thin beds of bentonite derived from volcanic ash. It has been widely eroded, with the result that an undulating bench has been formed on the underlying Dakota. North of the bench, cliffs in the Cretaceous Straight Cliffs Formation rise about 1,000 feet above the Tropic Shale and are surmounted by at least 800 feet of additional cliffs in the Cretaceous Wahweap Formation.

The Straight Cliffs and Wahweap Formations are the principal exposed rocks in the Wahweap study area. The cliff-forming sandstones and mudstones and the interlayered carbonaceous shales and coal in the Straight Cliffs Formation have been divided into three members: in ascending order, the lower member, the John Henry Member, and the Drip Tank Member (pl. 1). The principal coal resources of the Kaiparowits Plateau are in the middle part of the John Henry Member (Sargent and Hansen, 1982), where the coal occurs in several zones more than 7 feet thick. These zones are the lower, Henderson, Christensen, Rees, and Alvey, with the Christensen and Alvey being the major zones. Extensions of some of these coal zones may underlie much of the Wahweap study area, although the zones are probably thinner there. Projections would extend the coal-bearing zones to the cliffs in the southern part of the Wahweap area and along Cottonwood Creek (pl. 1), although no coal has been found in the Straight Cliffs Formation there. Some fine-grained sandstones near the top of the Straight Cliffs Formation may be beach or lacustrine deposits in which heavy minerals, winnowed by waves along a shore, accumulated as fossil placer deposits. The most abundant heavy mineral in these sandstones is ilmenite, but minor amounts of zircon, monazite, and hematite have also been identified (Dow and Batty, 1961). The Straight Cliffs Formation is overlain by the Wahweap Formation, which is composed of mudstone with lenses of fine to silty sandstone at its base and grades upward into massive cliff-forming ledges of sandstone.

Locally, remnants of the Cretaceous Kaiparowits Formation are preserved above the Wahweap Formation. In much of the Wahweap study area, therefore, the coal-bearing zones in the Straight Cliffs Formation are covered by more than 1,000 feet of rocks. The Kaiparowits Formation is predominantly friable, fine and silty sandstone with sparse interbeds of mudstone, and rare thin limestone beds. It contains fossils such as dinosaur bones, turtles, mollusks, and plant remains indicative of nearshore continental environments. At the highest elevations in the study area small areas of this formation are preserved, and farther to the north and east the formation underlies large areas of the Kaiparowits Plateau.

The youngest deposits in the study areas are Quaternary in age. They are unconsolidated alluvial sands and sandy clays along canyon and river bottoms. Low terraces along the Paria River, underlain by thick alluvium, are the sites for now abandoned farming villages. Along the floor of some canyons in the Wahweap area, the alluvium includes cobbles and boulders of quartzite and volcanic rocks, derived from sources to the north. Similar gravel forms deposits on terraces along the Paria River, to the northeast of Coyote Creek, and along the broad lower reaches of Wahweap Creek, where thick deposits were mined for aggregate during construction of the Glen Canyon Dam. Thick deposits of windblown sand also occur locally and may locally obscure deposits of gravel. Fallen blocks of sandstone and other rocks are common and widespread near cliffs, as are landslide deposits.

Structure

The Paunsaugunt fault and the East Kaibab monocline are major north-trending structures in southern Utah. To the northwest the Paunsaugunt fault bounds the Paunsaugunt Plateau on the east and lies east of Bryce Canyon National Monument, well outside the study areas. The fault extends southward, however, into Dry Valley, about 15 miles northwest of the study areas, where it is associated with an extensive zone of faults and fractures that may extend into the study areas. The East Kaibab monocline (fig. 4) is a conspicuous structural feature in the study areas. It separates strata on the west from strata as much as 7,000 feet stratigraphically higher on the east. Within the study areas, rocks ranging in age from Permian to Late Cretaceous have been folded along the monocline. The belt of steeply dipping rocks between outcrops of the Kaibab Limestone on the west and the Dakota Formation on the east is only about 2 miles wide within the Cockscomb Wilderness Study Area (pl. 1). To the north, however, the belt is wider and the dip is lower. Along the East Kaibab monocline in Cottonwood Creek canyon and south of the Paria River, many closely spaced faults trend north, along the strike of beds, and others trend to the northeast and northwest, fragmenting and offsetting the steeply dipping rocks. Some northwest-trending faults extend along the Paria River and near Hackberry Canyon. These may be splays of the Paunsaugunt fault or may be related to a zone of faulting west of the study areas. The displacement of strata appears to be minor. Nevertheless, some of the faults and fractures have served as conduits for fluids. Local iron oxide staining, calcite cement in rocks adjacent to fractures, and silica-cemented sandstone dikes (Sargent and Philpott, 1985) indicate that fluids of various compositions have been present.

Between the East Kaibab monocline and the Paunsaugunt fault is a broad anticline plunging north at a low angle. Both to the east and the west of the East Kaibab monocline, sinuous north- or northeast-trending shallow folds occur. Northeast of the Wahweap area, oil-bearing rocks have been penetrated by drilling in the Upper Valley anticline, one of these folds. Other similar structures in the vicinity of the study areas, such as the Butler Valley and Tommy Canyon anticlines (pl. 1), also have been tested by drilling, but only traces of hydrocarbons have been found.

Several widespread unconformities, developed at various times during Permian to Cretaceous deformation, truncate the folded rocks. The Dakota Formation was deposited on one such unconformity with the result that some rock units beneath the Dakota, such as the Summerville Formation and stratigraphic equivalents, are thin or missing west of the monocline.

Geochemical Studies

A reconnaissance geochemical survey was conducted in the wilderness study areas to aid in their mineral-resource assessment. Stream sediments and heavy-mineral concentrates derived from stream sediments were selected as appropriate sample media and were analyzed chemically to help target or identify those stream basins with high concentrations of elements worthy of further attention for possible mineral deposits. All samples were analyzed by a six-step semiquantitative emission spectrographic method for 31 elements (Grimes and Marranzino, 1968). In addition, some sediment samples were analyzed by more sensitive and precise techniques for arsenic, bismuth, cadmium, antimony, zinc, and gold (Crock and others, 1987). Analyses for uranium were by a delayed neutron activation technique (McKown and Millard, 1987). A complete listing of the analytical results and a concise description of the sampling methods, analytical techniques, and sample localities are given in Detra and others (1988).

Samples of stream sediment were collected and heavy-mineral concentrates were made from active alluvium in small streams generally below the junction of two streams. Catchment basins of the sampled streams range from fractions of a square mile to several square miles. Stream sediments provide a representative chemical and lithologic composite sample of rocks exposed in each upstream drainage basin. Elements associated with mineral deposits may be detected in these samples by chemical analysis. In heavy-mineral concentrates, analysts look for enhanced chemical values which may indicate ore-forming processes. With most of the rock-forming silicate minerals, clays, and organic material removed, the contained heavy minerals are concentrated, unusually high chemical values are easily recognized, and ore and ore-related minerals can be identified. Samples of iron-oxide-stained rock and calcite-cemented rock were also collected near fractures and faults in the study areas, particularly near mineral prospects, to test for metal values.

The results of chemical analyses indicate that in the study areas element anomalies are largely restricted to the heavy-mineral concentrates. These include widely separated samples with anomalously high strontium values, a single sample with an anomalously high lead value of 700 ppm, and some widely scattered anomalously high concentrations of lanthanum and thorium. Stream-sediment anomalies are limited to samples with high concentrations of either silver or lanthanum. Plate 1 shows the localities of widely scattered anomalous samples and also shows areas having tightly clustered anomalous samples. The high lead value is considered insignificant because of its isolated occurrence in one sample, the lack of associated elements, and the proximity of the sample site to the road and manmade contaminants. East of the East Kaibab monocline the high values for barium and the localized high values for strontium, which occur in both stream-sediment samples and heavy-mineral concentrates, result from the common sulfate minerals barite ($BaSO_4$) and celestite ($SrSO_4$), which were identified optically in the samples and later verified by X-ray diffraction. Both minerals are enriched in the heavy-mineral concentrates because of their high specific gravity. The origin of the barium and/or barite is uncertain. It may be indicative either of a regional original cement in sedimentary rocks or a later event, such as a widespread aqueous infiltration of the sedimentary units. Barium and strontium anomalies occur along Wahweap Creek, extending southward from Ty Hatch Bench to near the confluence of Wahweap and Nipple Creeks, close to the southeastern margin of the study areas (pl. 1). In this area many stream-sediment samples contain 1,500 to 2,000 ppm barium, and some have 300 ppm strontium. Heavy-mineral concentrates all contain more than (>) 10,000 ppm barium and some have >10,000 ppm strontium. The strontium is probably derived from local gypsiferous units as a result of secondary hydration of anhydrite. The barium and strontium enrichments in the Wahweap study area are not considered significant.

A small number of lanthanum anomalies in both sample media, together with a few thorium anomalies in concentrates, are found on the east side of Jack Riggs Bench and near the southeastern periphery of the Wahweap study area (pl. 1). Values range from 150 to >2,000 ppm lanthanum; thorium values are 200 ppm or less. Titanium and thorium minerals, particularly ilmenite and monazite, deposited as small placers now incorporated in sandstone beds which are part of the Straight Cliffs Formation, crop out east of the study areas (Dow and Batty, 1961). The anomalously high lanthanum and thorium values are not regarded as noteworthy for these reasons: (1) sporadic and isolated occurrence indicating only small areas of anomalous values, (2) relatively moderate titanium values in the stream sediments, suggesting no large fossil placers nearby, and (3) a lack of abundant monazite, a mineral containing thorium, rare-earth elements, and phosphorus. Monazite is a major source of thorium and lanthanum in fossil placer deposits.

A number of stream-sediment samples from the Wahweap study area contain anomalous amounts of silver (pl. 1). Three are in the vicinity of Jack Riggs Bench, and a fourth is located near the head of Tommy Smith Canyon. The absence of silver anomalies in heavy-mineral concentrates from the same sites suggests that Fe-Mn oxides contain traces of silver, or possibly that even some coal or lignite fragments in the sediments are the source of the silver values.

Samples of iron-oxide-stained rocks and calcite-cemented rock collected near fractures have yielded traces of arsenic, copper, manganese, molybdenum, and zinc. No high values were discovered, however, and no combination of unusually high metal values was found to suggest concealed metal-bearing veins.

Geophysics

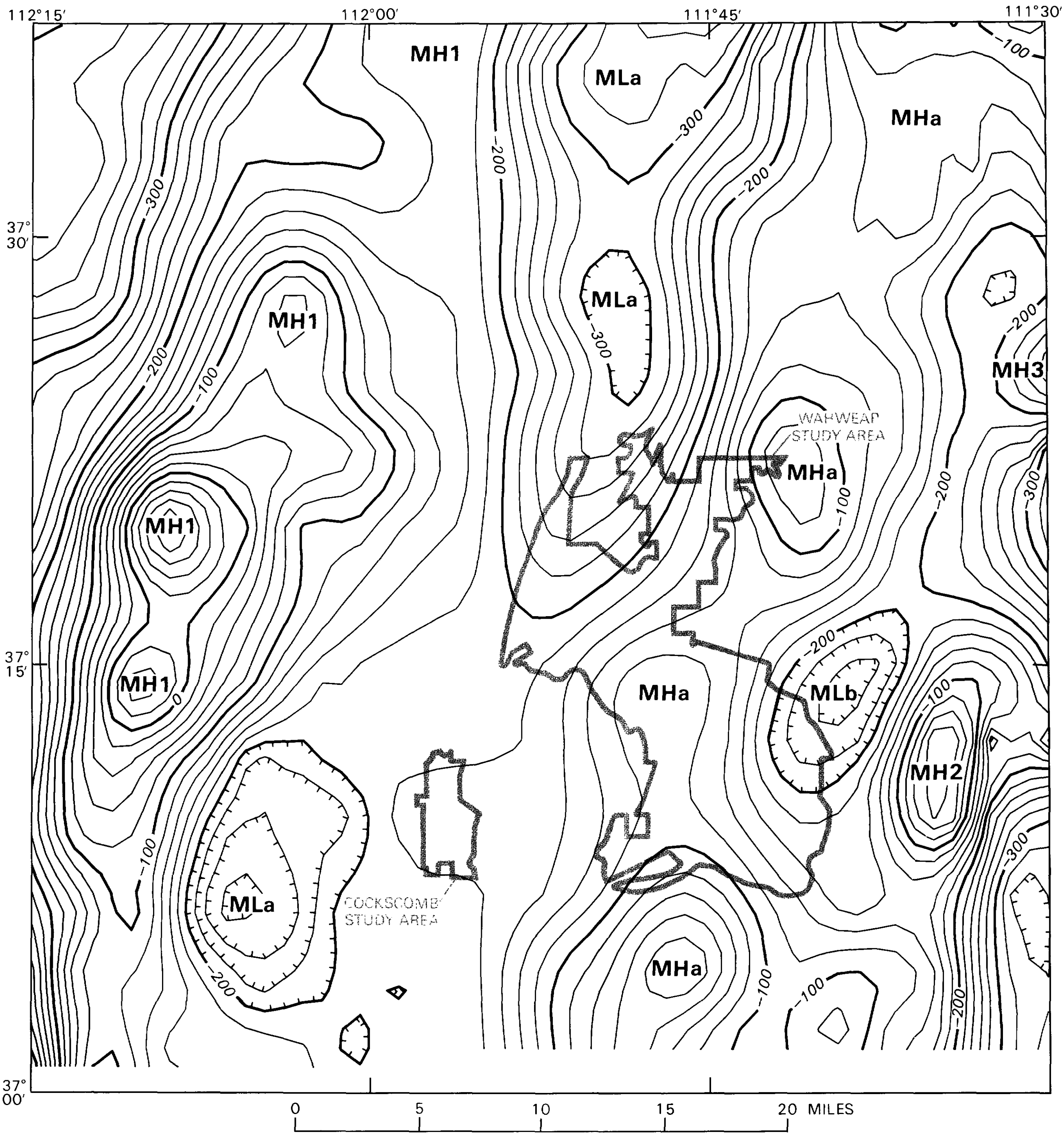
Gravity, aeromagnetic, and radiometric geophysical data were obtained for additional information about the geology of the study areas. Gravity and aeromagnetic data provide information about rock units in the upper crust that have contrasting densities and magnetic properties. Magnetic properties are mainly controlled by the presence or absence of magnetite. Radioactivity data provide information about the chemical characteristics of near-surface rocks based upon the radioactivity produced by various minerals.

J.S. Duval (written commun., 1987) reports that both the Cockscomb and Wahweap study areas show low overall radioactivity, indicating the following elemental concentrations: potassium, 0.5–2.0 percent in the Cockscomb area and 0.6–1.6 percent in the Wahweap area; equivalent uranium, 0.5–2.0 ppm in the Cockscomb area and 0.5–2.5 ppm in the Wahweap area; and equivalent thorium, 1–6 ppm in the Cockscomb area and 1–8 ppm eTh in the Wahweap area.

Neither the gravity nor the aeromagnetic surveys were designed primarily for mineral resource or hydrocarbon investigations. The aeromagnetic survey was flown along flight lines 3 miles apart, and gravity information originally available from closely spaced gravity stations was lost in the gridding and contouring process. Hence the data cannot resolve small features.

Figure 5 is an aeromagnetic map prepared from data obtained from digital tapes (Geodata International, Inc., 1980; Geo-Life, Inc., 1980). The gridding and contouring process preserved only the long-wavelength components. Therefore, magnetic profiles recorded along flight lines (Bendix Field Engineering Corporation, 1983a,b) were inspected for short-wavelength anomalies indicating buried volcanic rocks, near-surface intrusions, or clinker. None were found in the wilderness study areas. However, some short-wavelength magnetic anomalies caused by clinker do occur outside the study areas in the Kaiparowits coal field (southeast corner of figure 5) (Bartsch-Winkler and others, 1988, fig. 4). These are not shown on the contour map.

The aeromagnetic map is traversed by a north-northeast-trending band of magnetic highs and lows. In the west, the depth to the magnetic sources, estimated



EXPLANATION

Approximate boundaries of wilderness study areas

—— -100 —— Aeromagnetic contour showing residual magnetic intensity in nanoteslas—Hachures point toward closed areas of lower magnetic intensity

Figure 5. Residual total field aeromagnetic map of the Cockscomb and Wahweap Wilderness Study Areas and vicinity, Kane County, Utah. Flight lines are east-west, 400 feet (nominal) above ground, and about 3 miles apart. Magnetic highs MH1–MH3 correlate with gravity highs GH1-GH3 on figure 6. Magnetic high MHa and lows MLa and MLb do not correlate with gravity anomalies.

from the width of the zones of steepest gradient bounding the highs, is 4–6 miles. To the east of low anomaly MLa (fig. 5) are shorter wavelength magnetic highs and lows that indicate magnetic sources as shallow as 2 miles.

Figure 6 is a complete Bouguer gravity anomaly map calculated using standard USGS data reduction methods (McCafferty and Cady, 1987). Bouguer and terrain corrections were made using a reduction density of 2.30 g/cm^3 (grams per cubic centimeter), which minimized the correlation between local negative gravity anomalies and high topography that occurred on maps made using the standard Bouguer reduction density of 2.67 g/cm^3.

The gravity map is dominated by anomaly GH1, a broad north-northeast trending high that has Bouguer anomaly values 10 to 20 milligals higher than the broad gravity low, anomalies GLa-GLd. Gravity stations are too sparse to allow the depth to the source of anomaly GH1 to be calculated, but it is probably as deep as the sources of magnetic high anomaly MH1, 4 to 6 miles. Several shorter wavelength gravity highs, with amplitudes of 5 to 10 milligals, are scattered over the eastern part of the map and are probably caused by shallower sources.

The magnetic and gravity maps have important features in common: anomalies trend north-northeast; long-wavelength, correlative highs occur in the west (MH1 and GH1); long-wavelength, correlative lows occur in the center (MLa and GLa–GLd); short-wavelength, poorly correlative highs and lows occur in the east and overlap the center on the gravity map. The Cockscomb study area lies in the central area on both maps; the Wahweap study area overlaps both the central and eastern areas of the maps.

The sources of the magnetic highs must be in the crystalline basement, for the Phanerozoic sedimentary cover is nonmagnetic. Similarly, the dense sources of most of the gravity highs are probably in the basement as well. In the western part of the map area (figs. 5 and 6), magnetic and gravity high anomalies MH1 and GH1 correlate with a broad anticline in the surface rocks (Hackman and Wyant, 1973). The magnetic and gravity highs are probably caused by an uplifted block of dense, magnetic basement bounded by the Paunsaugunt fault on the west and the East Kaibab monocline on the east. Thick sedimentary rocks east of the monocline cause magnetic low anomaly MLa and gravity low anomalies GLa–GLd. In the eastern part of the map area, where there is little correlation between mapped geology (Hackman and Wyant, 1973) and geophysical anomalies, the anomalies are probably caused by lithologic variations within a relatively shallow basement block.

A cluster of relatively short-wavelength gravity high anomalies (GHa-GHd) probably delineates a belt of dense, relatively nonmagnetic rock in the shallow subsurface beneath both the Cockscomb and Wahweap study areas. Gravity high anomaly GHc is diminished slightly when a Bouguer reduction density of 2.67 g/cm^3 is used. A possible interpretation is that some of the anomalous mass, with a density greater than 2.3 g/cm^3, makes up part of the topography of Jack Riggs Bench, which underlies the anomaly. In view of the absence of associated magnetic anomalies, there is no reason to suspect that gravity high anomalies Gha-Ghd are caused by volcanic rocks or shallow intrusions.

In conclusion, the gravity and magnetic data mainly reflect lithology and relief in the Precambrian basement, providing a framework for understanding the structure and surface geology in the study areas.

Mineral Resource Potential

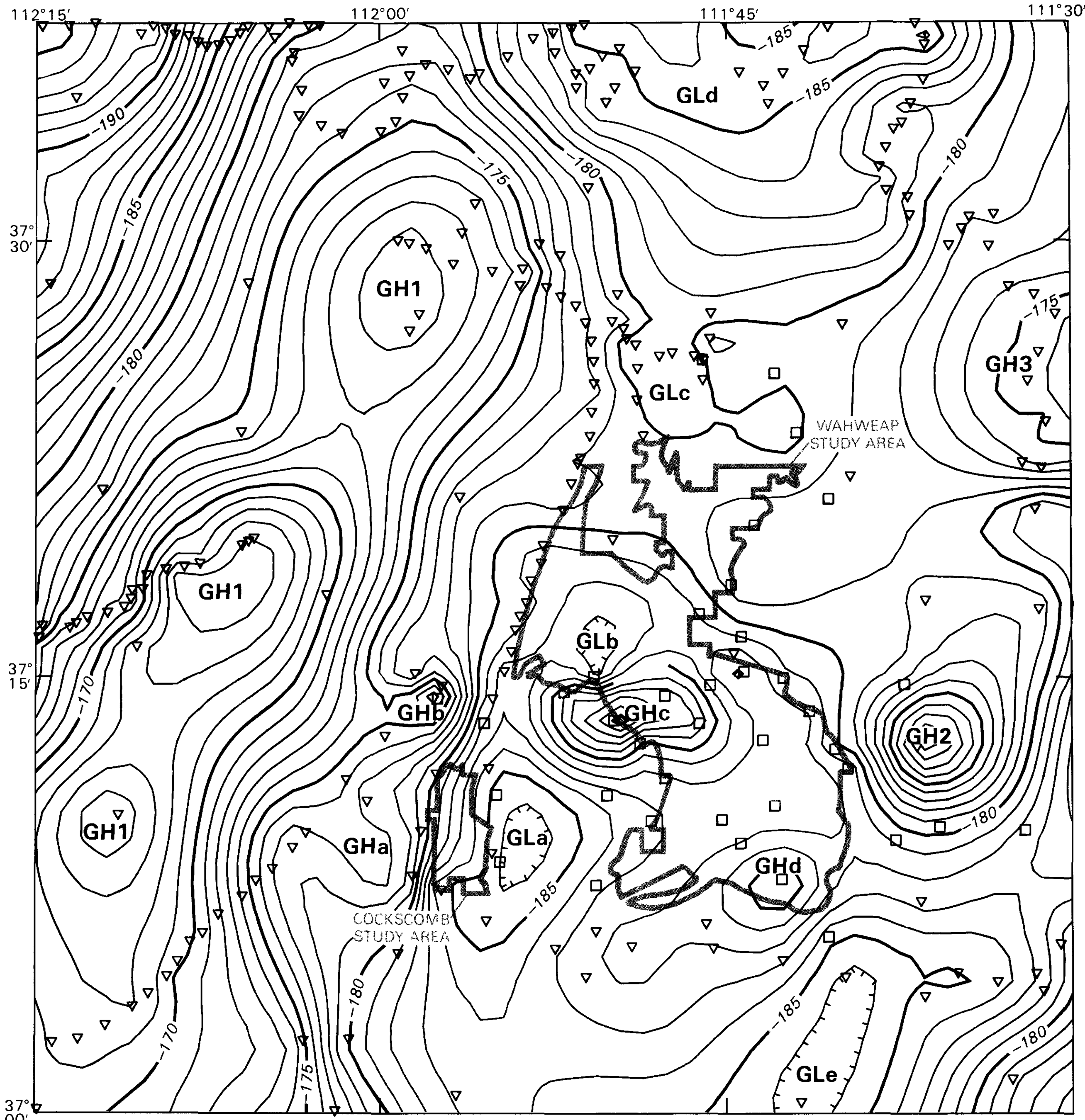
Gold mining has been attempted near the study areas, and there is evidence of prospecting for copper, lead, manganese, and uranium minerals within them. Close to the Wahweap study area, aggregate has been produced from deposits of gravel. Mining claims for deposits of titanium-bearing minerals have been located nearby.

Uranium

Sandstone and conglomerate beds within the predominantly clay-rich Chinle Formation contain uranium deposits at many places in Colorado and Utah. Sandstone and conglomerate rich in carbonaceous plant remains occurring in paleo-stream-channel deposits are especially favorable sites for, and guides to, undiscovered uranium deposits. The Chinle Formation crops out in the Paria River canyon and locally along the west-facing slopes of the Cockscomb area (pl. 1). In these areas no samples with high values for uranium were found during these investigations. No areas of anomalously high radioactivity have been recognized by Duval (1983) in data from airborne surveys. In addition, the high ratio of sandstone and conglomerate to mudstone in these areas is not characteristic of ore-bearing rocks in the Chinle Formation elsewhere in Colorado and Utah (Dubyk and Young, 1978). For these reasons the Chinle Formation and its members in the Cockscomb area are considered to have low mineral resource potential for small deposits of uranium-bearing minerals, with a certainty level of C. The Wahweap study area is also underlain by the Chinle Formation that probably has characteristics similar to the outcropping rocks in the Cockscomb study area, but the Chinle Formation does not crop out, has not been sampled, and is overlain by hundreds of feet of younger rocks. Therefore the potential for uranium in the Wahweap study area is considered low, with certainty level B.

Gold

Gold also occurs in the Chinle Formation in nearby parts of Utah and Arizona (Lawson, 1913; Gregory and



EXPLANATION

Approximate boundaries of wilderness study areas

—170— **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 (1987)

Figure 6. Complete Bouguer gravity anomaly map of the Cockscomb and Wahweap Wilderness Study Areas and vicinity, Kane County, Utah. Bouguer reduction density 2.30 grams per cubic centimeter. Gravity highs GH1–GH3 correlate with magnetic highs MH1–MH3 on figure 5. Other gravity highs (GHa–GHd) and lows (GLa–GLe) do not correlate with magnetic anomalies.

Moore, 1931), although the very fine particle size (Phoenix, 1963) and clay-rich matrix make detection and separation difficult. Geochemical analyses of stream-sediment and rock samples did not detect any gold in the study areas. This failure to detect gold-bearing samples and the failure of mining attempts nearby both indicate that the gold deposits associated with the Chinle Formation are probably small and scattered in this area. The likelihood of undiscovered gold deposits in the Chinle Formation is therefore judged to be low in both study areas; this rating of low potential carries certainty level C in the Cockscomb study area, where the Chinle is exposed, and certainty level B in the Wahweap study area, where it is concealed. The potential for gold deposits in all other formations is also low (L/C) in both study areas. None of the samples collected contained detectable gold, and the geologic setting in which the widespread formations of sandstone and shale were deposited is not known to be favorable for the occurrence of large gold deposits.

Other Metals

Geochemical surveys using stream sediments have shown a few widely scattered samples to yield unusual chemical values for one or (less commonly) more of the following elements: barium, lanthanum, lead, silver, strontium, and thorium. Most of the geochemical samples, however, have only values commonly encountered in chemical analyses of similar materials. The few unusual chemical values are too low and too widely spaced to indicate anything more than a low level of mineral resource potential, at certainty level C. In particular, the values found for barium and strontium are those expected from either sedimentary rocks deposited in a marginal marine basin or sedimentary sequences containing coal beds. In both of these settings the rocks commonly have carbonate cement containing traces of barite or other barium minerals, and layers and veins of gypsum with traces of strontium. A low resource potential for large tonnage deposits of barite or celestite, with a certainty level of C, is indicated; the rocks do not have the characteristics of barium- or strontium-bearing rocks deposited in a deep-water marine environment, where large tonnage deposits might be expected.

Throughout most of the study areas, widely scattered samples of stream sediments and concentrates show unusual values for lanthanum, lead, silver, or thorium, but none of these values are really high. The likelihood of deposits enriched in any of these elements is therefore considered to be low (L/C) throughout the study areas.

Metal-bearing vein deposits might be expected where fluids have moved on fractures that penetrate gypsum beds, impure limestones, and red sandstone containing traces of copper minerals, and such conditions do occur near the study areas. However, samples of iron-oxide-stained rock and calcite-cemented rock (showing the effects of circulating fluids) collected near fractures and fault zones along the Paria River, Hackberry Canyon, and The Cockscomb were found to have only slightly elevated values for one or more of the pathfinder elements arsenic, copper, manganese, molybdenum, and zinc. Because no high values were found for any of these elements, the concentrations are not considered unusual or indicative of ore-forming environments. The mineral resource potential for metal-bearing vein deposits in both study areas is low at certainty level C.

Sand and Gravel

Along the floors of some canyons in the Wahweap study area cobbles and boulders of quartzite and volcanic rocks derived from sources to the north occur in alluvium and on terraces. Deposits of gravel and eolian sand are especially widespread northeast of Coyote Creek, where many lie on the wide bench underlain by the Dakota Formation and the Tropic Shale. Southeast of the Wahweap study area, aggregate has been produced from similar deposits for construction purposes during the building of the Glen Canyon Dam. Because similar gravel deposits crop out in the Wahweap study area and others may be obscured by overlying eolian sand deposits, the mineral resource potential for undiscovered sand and gravel deposits is high at certainty level C.

Energy Resource Potential

Coal

The coal in the Dakota Formation occurs in thin, discontinuous lenses. Identified resources are present (see section on identified resources) in the southern parts of both study areas; the energy resource potential of the remainder of the areas is classed as moderate at certainty level C. Throughout most of the Wahweap study area, the Dakota is overlain by several hundred feet of the Straight Cliffs Formation.

The Straight Cliffs Formation underlies most of the Wahweap study area and is known to contain coal beds to the east, but no outcrops of coal have been found within the area. In a large part of the area the Straight Cliffs Formation is overlain by as much as a thousand feet of younger rocks. A drill hole close to the eastern boundary of the study area encountered coal about 4 feet thick within the Straight Cliffs (Hansen, 1978). In addition, rocks identified as part of the coal-bearing members of the formation crop out extensively in cliffs in the southern part of the Wahweap study area and along Cottonwood Creek, although outcrops of coal have not been found there. Because rocks of the coal-bearing members have been identified in outcrop and because coal has been encountered in drill holes nearby, the potential for coal in the Straight Cliffs Formation within much of the Wahweap study area is considered moderate with a certainty level of C.

Oil and Gas

The energy resource potential for oil and gas accumulations within the study areas is moderate with a certainty level of C, because rock units from which oil and gas have been produced underlie the study areas, and structures similar to those of the producing Upper Valley field are present. Although some test holes have been drilled without success, the geologic and structural conditions within the study areas are conducive to oil and gas accumulation. The area immediately to the west of the Cockscomb study area has been appraised as having low potential, and the area to the north and northeast of the Wahweap study area has been rated as having "medium" potential for oil and gas by Molenaar and Sandberg (1983) and by Molenaar and others (1982).

Geothermal Energy

No hot springs or thermal anomalies are known in the study areas. Although the occurrence of iron oxide stain and carbonate cement on rocks adjacent to fractures suggests fluid flow in fractures, no evidence of high temperature has been recognized. Small basalt flows and igneous intrusions of Quaternary age occur to the west of the study areas, but no such bodies, which could be a source for geothermal energy, are indicated by geophysical anomalies in the study areas. A low potential is recognized for geothermal energy in the study areas, at a certainty level of C.

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APPENDIX

DEFINITION OF LEVELS OF MINERAL RESOURCE POTENTIAL AND CERTAINTY OF ASSESSMENT

Definitions of Mineral Resource Potential

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

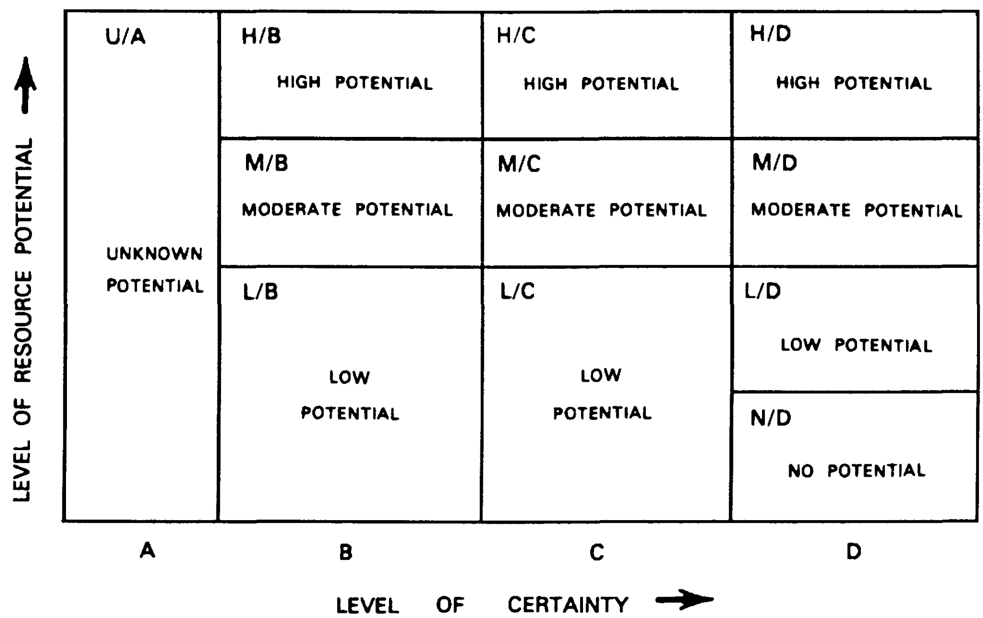
MODERATE mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence, where interpretations of data indicate a reasonable likelihood of resource accumulation, and (or) where an application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

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

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

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

Levels of Certainty



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

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RESOURCE/RESERVE CLASSIFICATION

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

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

GEOLOGIC TIME CHART

Terms and boundary ages used in this report

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

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

[2] Informal time term without specific rank.

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