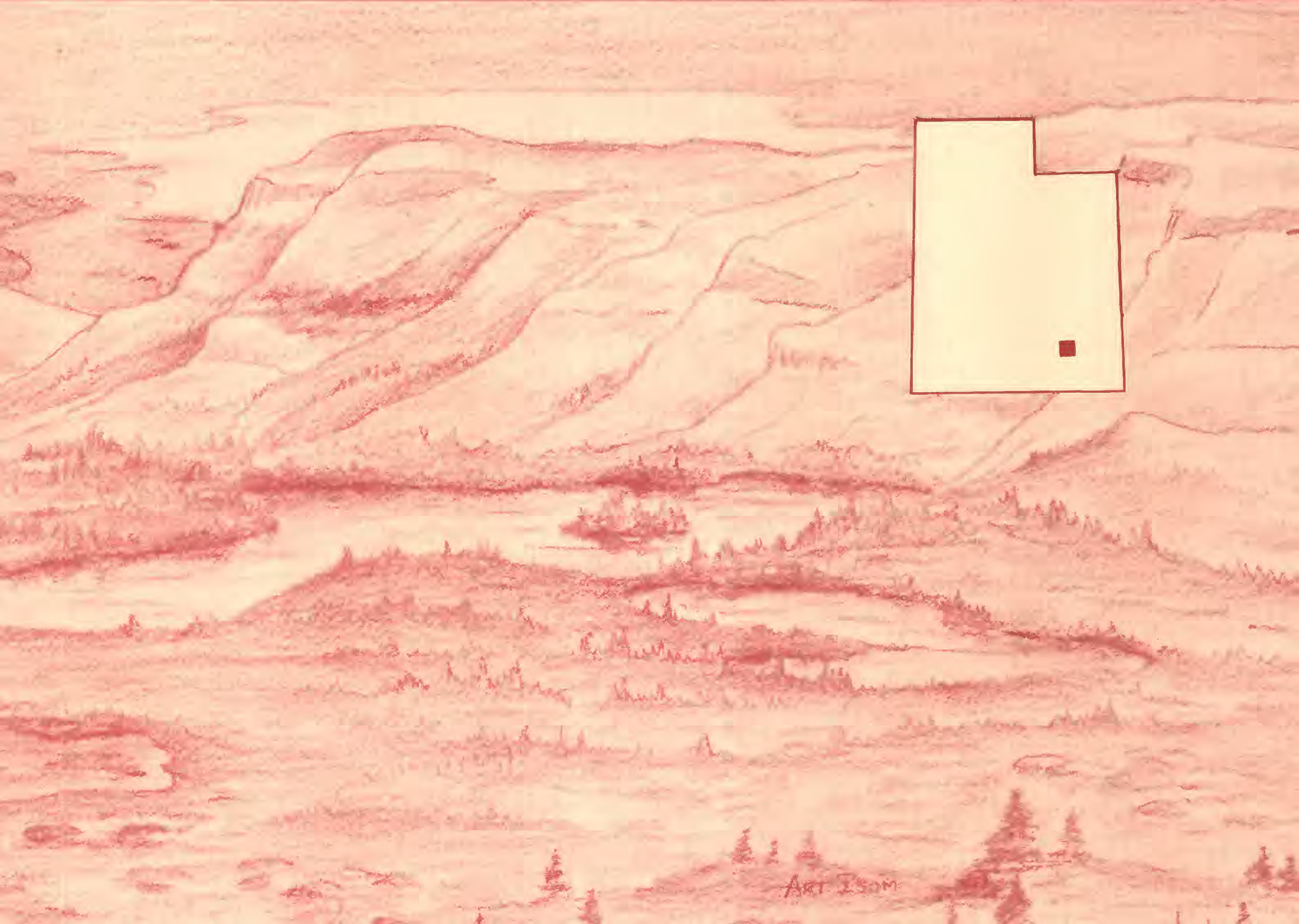
Mineral Resources of the Mt. Hillers Wilderness Study Area, Garfield County, Utah

U.S. GEOLOGICAL SURVEY BULLETIN 1751–C



Chapter C

Mineral Resources of the Mt. Hillers Wilderness Study Area, Garfield County, Utah

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U.S. GEOLOGICAL SURVEY BULLETIN 1751

MINERAL RESOURCES OF WILDERNESS STUDY AREAS—
HENRY MOUNTAINS REGION, UTAH

DEPARTMENT OF THE INTERIOR
DONALD PAUL HODEL, Secretary

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

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STUDIES RELATED TO WILDERNESS

Bureau of Land Management Wilderness Study Areas

The Federal Land Policy and Management Act (Public Law 94-579, October 21, 1976) requires the U.S. Geological Survey and the U.S. Bureau of Mines to conduct mineral surveys on certain areas to determine the mineral values, if any, that may be present. Results must be made available to the public and be submitted to the President and the Congress. This report presents the results of a mineral survey of the Mt. Hillers (UT-050-249) Wilderness Study Area, Garfield County, Utah.

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PLATE

[Plate is in pocket]

FIGURES

Mineral Resources of the Mt. Hillers Wilderness Study Area, Garfield County, Utah

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SUMMARY

Abstract

The Mt. Hillers Wilderness Study Area (UT–050–249) comprises 20,000 acres in the Henry Mountains, Garfield County, Utah. Field and laboratory investigations were conducted by the U.S. Geological Survey (USGS) from 1981 to 1984 and by the U.S. Bureau of Mines (USBM) in 1986. The area was studied for identified (known) resources as well as for mineral resource potential (undiscovered resources). These investigations indicate that small occurrences of uranium and vanadium are present near the northeastern and southern boundaries of the study area (fig. 1), and that copper, gold, lead, and zinc occur in the study area, but no identified resources of these commodities are present. Inferred subeconomic resources of the common variety materials, sand and gravel and stone, in the study area have no unique qualities and are not likely to be developed. The eastern part of the study area has a high mineral resource potential for uranium and vanadium and a low mineral resource potential for all other metals, and coal (fig. 1). The central part of the study area has a moderate mineral resource potential for base (copper, lead, and zinc) and precious (gold) metals, and a low mineral resource potential for uranium and vanadium, and coal. The western part of the study area has a moderate mineral resource potential for coal and uranium and vanadium, and a low mineral resource potential for all other metals. The entire Mt. Hillers Wilderness Study Area has a low mineral resource potential for oil and gas and for geothermal energy.

Character and Setting

The Henry Mountains consist of numerous igneous stocks and related satellite igneous bodies of Tertiary age (a geologic time chart is available in the Appendix). The satellite bodies were injected radially from the stocks into the adjacent sedimentary strata. Each of these igneous bodies was intruded into and domed the overlying sedimentary strata. Subsequent erosion by the Colorado River and its tributaries has exposed the intrusive stocks and their subsidiary satellite bodies as five mountains and associated major and minor topographic features. The Mt. Hillers Wilderness Study Area surrounds Mt. Hillers, one of the igneous stocks of the Henry Mountains. The area includes several satellite bodies as well as several sedimentary units that have been deformed by the igneous intrusions. Sedimentary rocks ranging in age from Permian to Cretaceous were eroded to form a highly dissected topography with narrow and deep canyons and broad, gravel-mantled pediments (benches). Mountain slopes are steep and rugged. There are no perennial streams in the study area; however, there are perennial springs at Indian Spring, Squaw Spring, Woodruff Spring, Star Spring, and the head of Maidenwater Creek, all located just outside the study area boundary. Vegetation is sparse and precipitation is low.

Identified Resources

There are inferred subeconomic resources of sand, gravel, and stone in the study area. Hydrocarbon leases cover approximately one-third of the Mt. Hillers Wilderness Study Area, but no drilling has been done for hydrocarbons.

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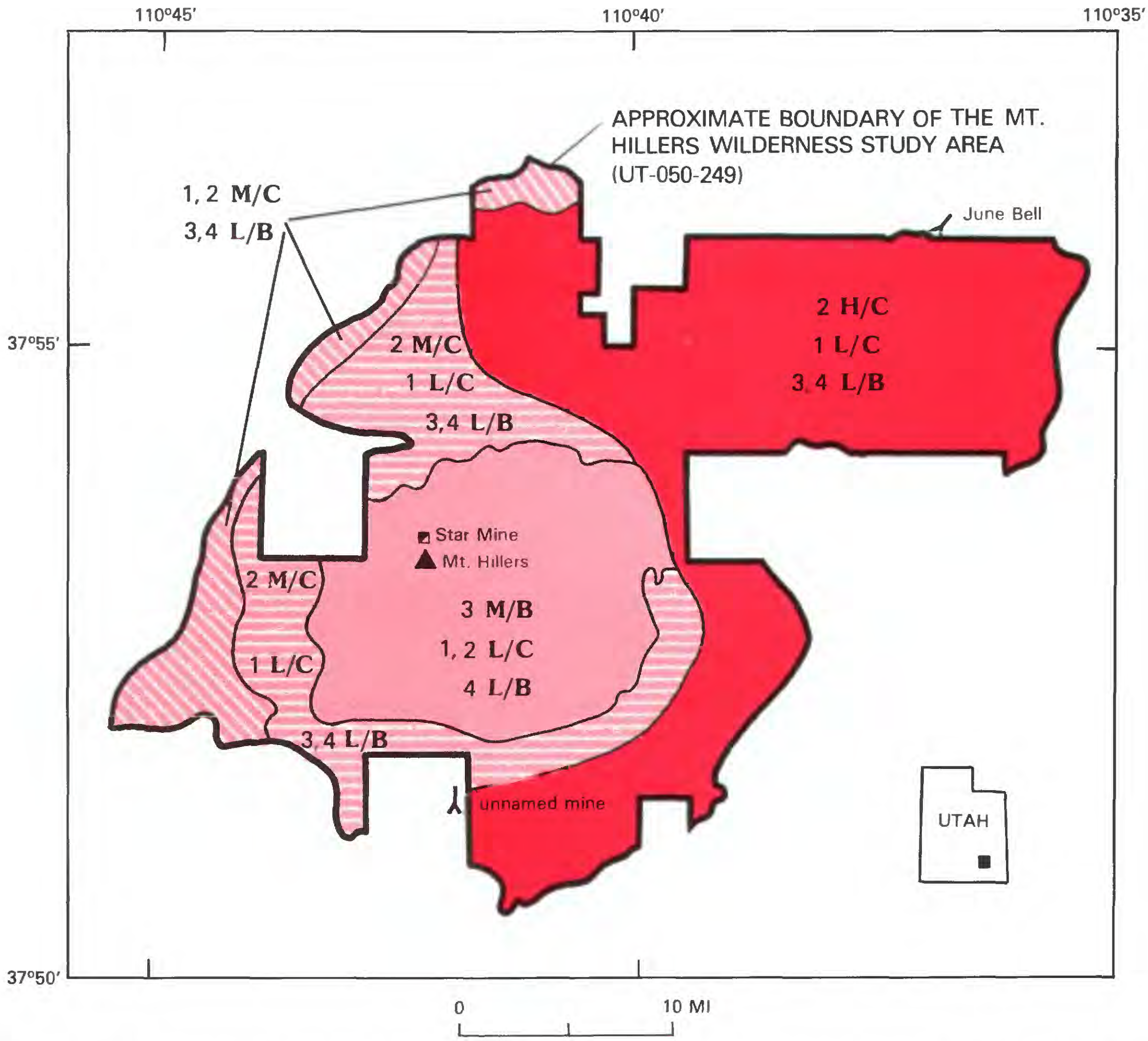

Figure 1. Summary map showing mineral resource potential of the Mt. Hillers Wilderness Study Area, Garfield County, Utah.

Mineral Resource Potential

Stream-sediment and rock samples were collected by the USGS from the Henry Mountains region for geochemical analysis as part of the appraisal of the mineral resource potential of several wilderness study areas. Analyses of igneous rock samples from both stocks and satellite bodies within the Mt. Hillers Wilderness Study Area indicate that virtually all of the samples that contain anomalous values of metals occur in the igneous stocks, and only rarely do they occur in the satellite bodies. Several base-metal (copper, lead, and zinc) anomalies occur around the Mt. Hillers stock. Similar geochemical anomalies were found in tributary streams south of the Mt. Hillers study area on Cow Flat and in Mud Creek. These anomalies are probably related to mineralization associated with the igneous stocks. The central part of the study area underlain by the intrusive center has a moderate mineral resource potential for base (copper, lead, and zinc) and precious (gold) metals. The mineral resource potential in the rest of the study area is low for all metals other than uranium and vanadium.

Known uranium and vanadium occurrences in the region are restricted to fluvial sandstones of the Salt Wash Member of the Upper Jurassic Morrison Formation and to fluvial sandstones of the Chinle Formation. The Salt Wash Member is present in the study area, and carbonaceous lacustrine mudstones that indicate a favorable environment for uranium-vanadium deposits in the Salt Wash are present in the eastern part of the Mt. Hillers Wilderness Study Area, exclusive of the area underlain by the Mt. Hillers stock. The Chinle Formation is known to contain uranium and vanadium in the White Canyon area about 20 mi southeast of the study area, near Fiddler Butte about 20 mi northeast of the study area, and in the vicinity of Capitol Reef National Park about 25 mi northwest of the study area. Recent drilling has identified a subeconomic resource of uranium in the Chinle about 8 mi southeast of the study area near Mt. Ellsworth. The uranium deposits of the Chinle Formation in those areas

EXPLANATION OF MINERAL RESOURCE POTENTIAL

2 H/C, 3, 4 L/B, 1 L/C — Geologic terrane having high mineral resource potential for commodity 2, with certainty level C; geologic terrane having low mineral resource potential for commodities 3 and 4, with certainty level B; geologic terrane having low mineral resource potential for commodity 1, with certainty level C

3 M/B, 4 L/B, 1, 2 L/C — Geologic terrane having moderate mineral resource potential for commodity 3, with certainty level B; geologic terrane having low mineral resource potential for commodity 4, with certainty level B; geologic terrane having low mineral resource potential for commodities 1 and 2 with certainty level C

2 M/C, 3,4 L/B, 1 L/C — Geologic terrane having moderate mineral resource potential for commodity 2, with certainty level C; geologic terrane having low mineral resource potential for commodities 3 and 4, with certainty level B; geologic terrane having low mineral resource potential for commodity 1, with certainty level C

1, 2 M/C, 3, 4 L/B — Geologic terrane having moderate mineral resource potential for commodities 1 and 2, with certainty level C; geologic terrane having low mineral resource potential for commodities 3 and 4, with certainty level B

Commodities

1. Coal
2. Uranium and vanadium
3. Base (copper, lead, zinc) and precious (gold) metals
4. Oil and gas and geothermal energy

Levels of certainty

- A Available information not adequate
- B Available information suggests level of resource potential
- C Available information clearly defines the level of resource potential
- D Available information clearly defines the level of resource potential

are restricted to fluvial sandstones of the Shinarump and Monitor Butte Members. Sedimentologic study of these Chinle fluvial systems indicates that they may not underlie the study area. The occurrence of fluvial sandstones of the Salt Wash Member of the Morrison Formation and black mudstones commonly associated with ore deposits elsewhere indicate that the eastern part of the study area has a high mineral resource potential for uranium and vanadium. The occurrence of fluvial sandstones of the Chinle Formation and uncertainty in the location of the paleochannels indicates that the western portion of the study area has a moderate mineral resource potential for uranium and vanadium. The central part of the study area underlain by the igneous rocks has a low mineral resource potential for uranium and vanadium.

The entire Mt. Hillers Wilderness Study Area lies within the Henry Mountains coal field. The Ferron and Emery Sandstone Members of the Upper Cretaceous Mancos Shale are important coal-bearing strata within the coal field. The Emery Sandstone Member has been eroded from the study area, but the Ferron Sandstone Member crops out locally on the northern and western margin of the study area. The underlying Upper Cretaceous Dakota Sandstone contains thin, discontinuous coal seams less than 1-ft thick. This coal is not classified as an identified resource. The thickness and discontinuous nature of coal seams in the Ferron Sandstone Member adjacent to the study area indicate that the western margin of the study area has a moderate potential for coal resources where this sedimentary unit occurs; the rest of the study area has low resource potential for coal.

Oil and gas have been produced from Pennsylvanian, Permian, and Triassic rocks in basins adjacent to the Henry basin, and these same strata are known to occur in the subsurface of the Henry basin, but they remain mostly untested. Investigations of the regional geology and occurrence of possible hydrocarbon-bearing units within the study area are coupled with less knowledge on the exact subsurface distribution of these rocks and their hydrocarbon content. The present information indicates that the entire study area has a low mineral resource potential for oil and gas.

There is no evidence, such as heated waters or associated mineral deposits, to suggest any shallow occurrence of geothermal sources, and the study area is considered to have a low resource potential for geothermal energy.

INTRODUCTION

The Mt. Hillers Wilderness Study Area (UT–050–249) comprises about 20,000 acres encompassing Mt. Hillers in the central Henry Mountains in Garfield County, southeastern Utah (fig. 2; pl. 1). High, rugged mountains, surrounded by pediment gravel surfaces, rise from intricately dissected, sparsely vegetated plateaus. Elevations in the region range from about 4,400 ft along Trachyte Creek and near Woodruff Hole east of the study area to 10,723 ft on Mt. Hillers. The Mt. Hillers Wilderness Study Area is located about 30 mi south of Hanksville, and about 10 mi northwest of Lake Powell. Maintained dirt roads originating at Utah State Highway 276 extend around and provide access to the Mt. Hillers Wilderness Study Area.

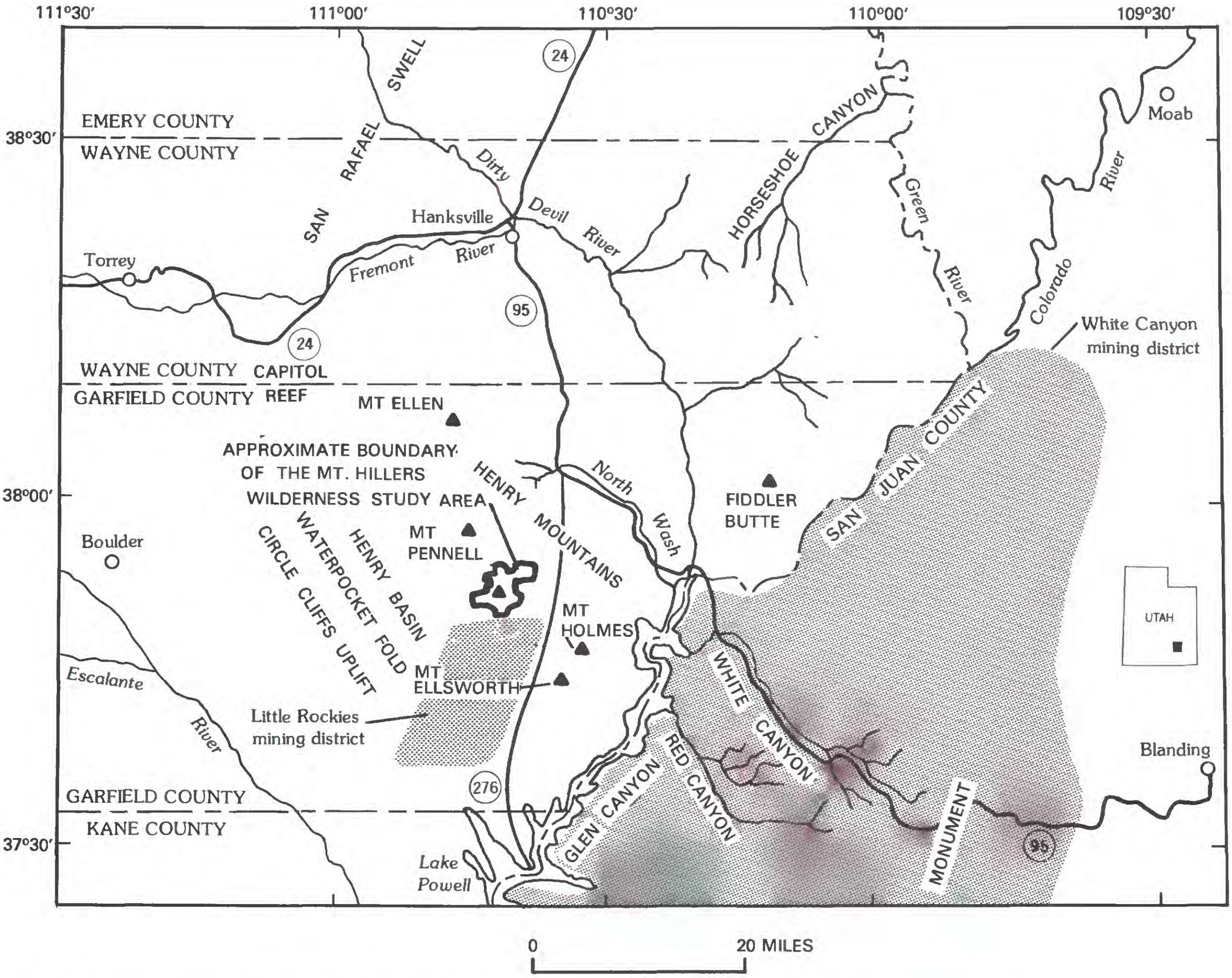

Figure 2. Index map showing location of the Mt. Hillers Wilderness Study Area, Garfield County, Utah.

This report presents an evaluation of the mineral endowment (identified resources and mineral resource potential) of the study area 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 the U.S. Geological Survey (1980), which is shown in the Appendix of this report. Identified resources were studied by the USBM. Mineral resource potential is the likelihood of occurrence of undiscovered concentrations of metals and nonmetals, industrial rocks and minerals, and of undiscovered energy sources (coal, uranium, oil, gas, oil shale, and geothermal sources). Mineral resource potential and the level of certainty of the resource assessment were classified according to the system of Goudarzi (1984; see Appendix). The potential for undiscovered resources was studied by the USGS.

Previous Work

G. K. Gilbert (1877) was the first geologist to examine, describe, and interpret the laccoliths and processes of igneous intrusion in the Henry Mountains. Between 1935 and 1939, C. B. Hunt and his associates reinterpreted the geology of the Henry Mountains and later published a detailed report (Hunt and others, 1953). Doelling (1972) mapped several 7½ minute quadrangles as part of a study of the Henry Mountains coal field. Uranium has been the only mineral commodity of any importance in this region, and many investigations were conducted by, or done under contract to, the Atomic Energy Commission (now the Nuclear Regulatory Commission) in the 1940's and 1950's. These reports are available through the Grand Junction, Colo., Office of the Nuclear Regulatory Commission. Butler

(1920) was the first to describe the mineral resources of the Henry Mountains region. Reports published on the uranium deposits of the Henry Mountains include Johnson (1959), Doelling (1967, 1975), Peterson (1977, 1980a, 1980b), and Chenoweth (1980). Doelling (1980) described the various metal deposits of the region.

Investigations by the U.S. Bureau of Mines

In 1986, the USBM evaluated the identified mineral resources of the Mt. Hillers Wilderness Study Area. Minerals and oil and gas information was gathered from published and unpublished literature, USBM files, and oil and gas lease and mining-claim records of Garfield County, Utah, and the U.S. Bureau of Land Management Office in Salt Lake City, Utah (Neubert, 1987). Field studies during July of 1986 included a search for mines, prospects, and mineralized areas in and within ½ mi of the study area boundary; several adits and prospects were found (Neubert, 1987). The USBM collected 37 samples, determined assay values, and investigated past exploration activity in the study area.

Neutron activation analyses for gold and 25 other elements were done by Bondar-Clegg, Inc., Denver, Colo. Uranium content was determined by fluorometric analysis. A complete data set for these samples can be found in Neubert (1987) and is also available for public inspection at the USBM, Intermountain Field Operations Center, Building 20, Denver Federal Center, Denver, Colo., 80225.

Investigations by the U.S. Geological Survey

From 1981 to 1985, the USGS assessed the potential for undiscovered mineral resources of the Mt. Hillers Wilderness Study Area. The studies consisted of geologic mapping (Larson and others, 1985); a search for mines, prospects, and mineralized areas; sedimentologic studies (Dubiel, 1982, 1983a, 1983b); rock and stream-sediment sampling for geochemical analysis (Detra and others, 1984); and a search of previously published studies on the geology (Peterson, 1977, 1980a) and mineral resources of the study area. Models developed for the occurrence of uranium (Peterson, 1980b; Dubiel, 1983b) and metals (Cox and Singer, 1986) were applied to the evaluation of mineral resource potential in the study area.

Acknowledgments.—Our assessment of the mineral resource potential of the area was aided by the expertise and contributions of many people. The USGS acknowledges the assistance of our helicopter pilots, Leonard Smith and the late Jaxon Ruby, whose skill as pilots made many of the field tasks in remote areas considerably easier. We would also like to thank all of the USGS personnel who assisted in the field on all aspects of this interdisciplinary study: Brad Esslinger, James Faulds, Joseph Fontaine, Darlene Francis, David Hammond, Carl Harris, Paul Milde, Denise Mruk, Charles Patterson, Richard Reeves, Michael Rendina, David Scott, William Thoen, Ann Tirrell, Bruce van Brundt, Shawn Yasataki, and Christine Yee.

APPRAISAL OF IDENTIFIED RESOURCES

By John T. Neubert
U.S. Bureau of Mines

Mining Districts, Mineralized Areas, and Identified Resources

Most of the mineral production from the Henry Mountains has been from Bromide Basin about 15 miles north of the Mt. Hillers Wilderness Study Area. Gold, silver, and copper were produced in the 1890's from quartz breccia veins in the diorite porphyry stock of Mt. Ellen (Hunt and others, 1953; Doelling, 1975, 1980; Gese, 1984a). Approximately 700 ounces of gold, 3,000 ounces of silver, and 9 tons of copper have been produced from the Bromide Basin area since 1889 (Doelling, 1972; Gese, 1984a).

Current (1986) mining claims are present in and near the Mt. Hillers Wilderness Study Area (Neubert, 1987). Most of the claims are for uranium, with the exception of unpatented gold placer claims along Straight Creek about 2½ mi north of the study area.

The Star mine on the north slope of Mt. Hillers (pl. 1) was probably worked about 1895 (Doelling, 1975). Copper and precious metals were the targets; however, no production was recorded despite extensive prospecting. Fissures and quartz veins on the north side of Mt. Hillers near the Star mine are iron stained and locally contain sulfides, including chalcopyrite, galena, sphalerite, and pyrite. A propylitic alteration zone in the Mt. Hillers area is characterized by epidote and chlorite along joint faces and by chloritization in the diorite porphyry. Local iron staining results from the oxidation of pyrite.

Copper occurs within the Mt. Hillers Wilderness Study Area in the shattered zone and in the igneous stock near the summit of Mt. Hillers. The copper is present in quartz veins as bornite, malachite, chalcopyrite, and chalcocite. The workings are shallow prospect pits with the exception of the Star mine, which is a 30-ft shaft. A select sample from the dump of the Star mine assayed 2.07 percent copper and 653 parts per billion (ppb) (0.02 ounces/ton) gold. Other samples from this area contained less than 1 percent copper and 400 ppb gold (Neubert, 1987).

Very fine grained pyrite is disseminated in the diorite on the southeastern ridge of Mt. Hillers within the study area. Three shallow prospect pits excavated in the limonite-stained outcrops were sampled for this study. The samples contained a maximum of 65 ppb gold. Concentrations of all other metals were correspondingly low (Neubert, 1987).

The presence of gold and copper in the quartz veins at the Star mine indicates that base- (copper, lead, zinc) and precious- (gold) metal mineralization has occurred in the Mt. Hillers igneous stock. Analyses of rock samples and stream-sediment samples do not define near-surface identified resources of base or precious metals in the Mt. Hillers Wilderness Study Area.

The Mt. Hillers Wilderness Study Area is near two uranium mining districts: the White Canyon district and the Little Rockies district (fig. 2). The White Canyon mining district is about 15 mi southeast of the study area, across Lake Powell in San Juan County, Utah. In 1950, uranium was discovered in this area in paleochannels of the Shinarump Member of the Upper Triassic Chinle Formation. In the 1970's, Texasgulf Minerals Exploration Co. projected Shinarump paleochannel trends westward into the area east of the Little Rockies and drilled and identified a subsurface uranium deposit within the Little Rockies Wilderness Study Area (Dubiel and others, 1987). No part of the White Canyon mining district is within the Mt. Hillers Wilderness Study Area.

The Little Rockies mining district lies about 5 mi south of the Mt. Hillers Wilderness Study Area on the west side of Utah State Highway 276. Uranium in the district occurs in paleochannels of the Salt Wash Member of the Upper Jurassic Morrison Formation. Two examples of this type of deposit are the Shootering Canyon mine and the Del Monte mine, both located south of the study area and west of Utah State Highway 276. No part of the Little Rockies mining district is within the study area.

The Salt Wash Member of the Morrison Formation has been prospected for uranium and vanadium in and near the Mt. Hillers Wilderness Study Area (Doelling, 1967). Several prospects are present within the northeastern part of the study area, and underground and surface workings exist at the June Bell prospect 500 ft northeast of the study area boundary (pl. 1; Neubert, 1987). An unnamed adit lies 300 ft outside of the southern boundary of the study area. Underground workings for uranium in the Salt Wash Member of the Morrison Formation lie outside the study area 1.5 mi to the east at Woodruff Springs, 2.5 mi to the northeast at Trachyte Ranch, and about 15 mi to the south at Shootering Canyon. About 13,000 pounds (lbs) of U_3O_8 and 37,000 lbs of V_2O_5 have been produced at Trachyte Ranch (Doelling, 1967).

Samples from prospects within the northeastern part of the study area were analyzed for uranium and vanadium. The highest concentrations from these prospects were 34 parts per million (ppm) uranium and 1,245 ppm vanadium. Underground and surface workings from the June Bell prospect, 500 ft outside the northeast boundary of the study area, yielded isolated samples with up to 8 percent uranium and 4.5 percent vanadium (Neubert, 1987). Most other samples from this area contained less than 1 percent uranium and 3 percent vanadium. Most of these samples were collected from narrow, discontinuous seams with visible carnotite or from areas with associated high scintillometer readings. A sample from an unnamed adit near the southern boundary of the study area contained 1,920 ppm uranium; uranium concentrations in other samples were considerably less. The highest vanadium concentration in samples from this area was 860 ppm. A sample of carbonaceous material collected from the underground workings near Woodruff Springs 2 mi east of the study area contained 4.2 percent uranium and 9.5 percent vanadium (Neubert, 1987).

Background scintillometer readings established for the Morrison Formation in the Mt. Hillers Wilderness Study Area are 25–40 counts per second. Recorded readings in the vicinity of prospects and surface workings were 20–120 times the recorded background. Scintillometer traverses over the Morrison Formation within the study area did not yield readings above the recorded background measurements.

The uranium-vanadium occurrences near the Mt. Hillers Wilderness Study Area contain high-grade pockets but are discontinuous and could not be traced into the study area. The known uranium-vanadium occurrences within the study area are low grade and discontinuous and are not considered to be an identified resource.

Oil and Gas

The Mt. Hillers Wilderness Study Area is in the Henry basin, a Laramide (Late Cretaceous to Eocene) structural basin near the northwestern part of the Pennsylvanian Paradox basin. The Henry basin is one of the few Rocky Mountain basins that has not produced oil and gas (Irwin and others, 1980). Oil and gas production within the Paradox basin has been primarily from bioherms and structural traps within carbonate rocks of the Pennsylvanian Hermosa Group, although there has been minor production from Permian and Triassic rocks

(Irwin and others, 1980). These formations underlie the Henry Mountains and the Mt. Hillers Wilderness Study Area but remain untested. Oil and gas leases cover approximately one-third of the Mt. Hillers Wilderness Study Area (fig. 3), but no drilling for hydrocarbons has taken place in the study area.

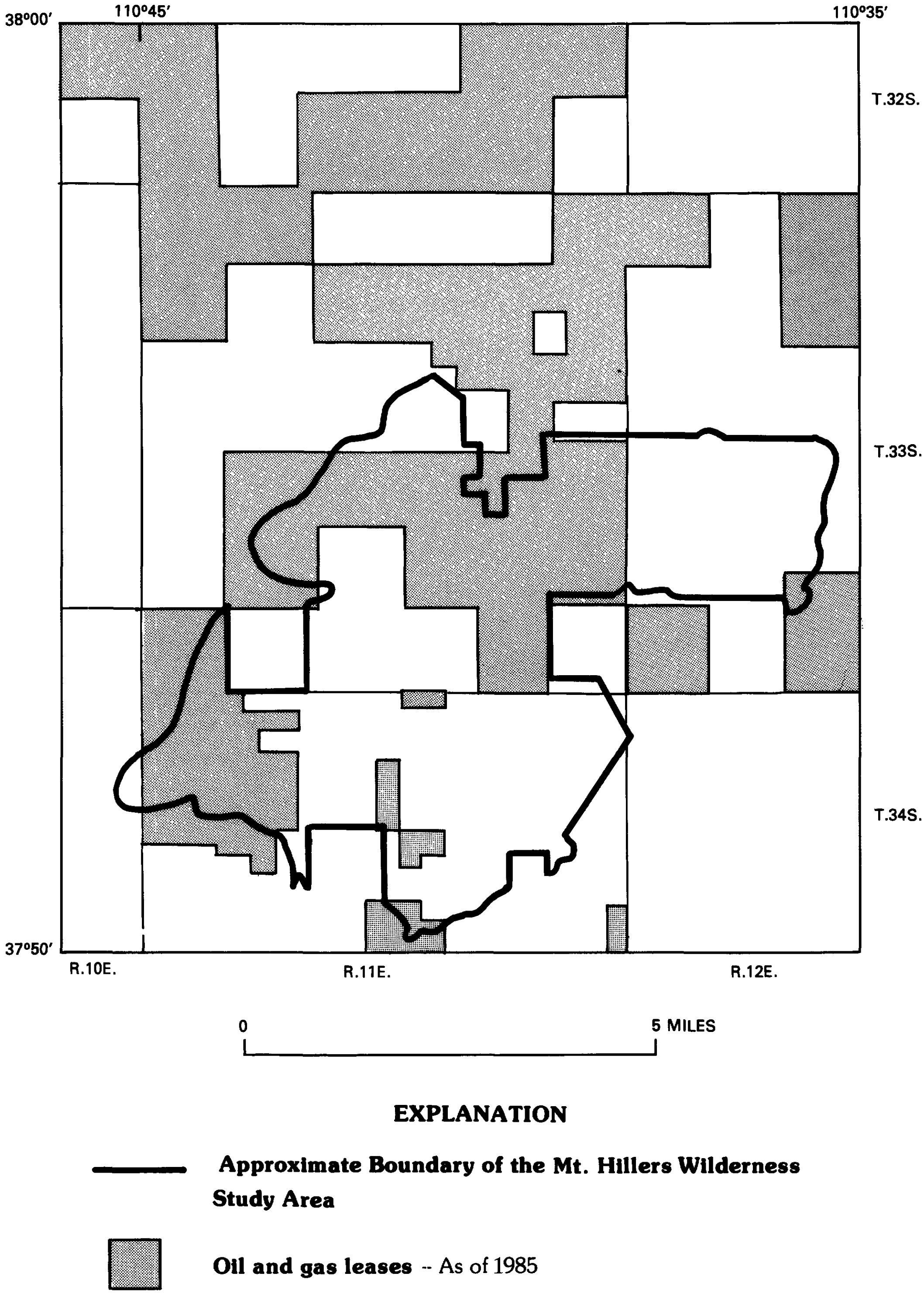

Figure 3. Map showing oil and gas leases in and near the Mt. Hillers Wilderness Study Area, Garfield County, Utah.

Sand, Gravel, and Stone

Materials that could be used for construction purposes are present in the Mt. Hillers Wilderness Study Area. Inferred subeconomic resources of the common variety material sand and gravel is present in terrace deposits along stream courses, and most of the Jurassic and older rocks could be sources of building stone. Development of these identified resources is unlikely due to the lack of unique qualities and the abundance of sand, gravel, and stone closer to possible markets.

ASSESSMENT OF POTENTIAL FOR UNDISCOVERED RESOURCES

By Russell F. Dubiel, Calvin S. Bromfield, Stanley E. Church, William M. Kemp, Mark J. Larson, and Fred Peterson U.S. Geological Survey

Geology

The Mt. Hillers Wilderness Study Area is in the central Henry Mountains (fig. 2), on the northeastern flank of the Henry basin, a north-south trending topographic and structural basin about 100 mi long and 50 mi wide. The western flank of the asymmetric basin is formed by the steeply eastward dipping rocks of the Waterpocket Fold, a monocline that separates the basin from the adjacent Circle Cliffs uplift farther to the west. Strata on the gently dipping east flank of the basin gradually rise eastward toward the crest of the Monument upwarp. The intrusive centers of the Henry Mountains locally interrupt the gradual eastward rise of the sedimentary strata.

The Henry Mountains consist of five distinct intrusive centers that form large structural domes. Mt. Ellsworth, Mt. Holmes, Mt. Hillers, Mt. Pennell, and Mt. Ellen extend in a north-northwest line for about 35 mi. The core of each igneous intrusive center is a separate diorite porphyry stock that is discordant to the surrounding sedimentary rocks. The area includes several laccoliths as well as sedimentary units that have been deformed by the igneous intrusions. Sedimentary rocks have been eroded to form a highly dissected topography with narrow, deep canyons and broad, gravel-mantled pediments (benches). Mountain slopes are steep and rugged. No perennial streams are in the study area; however, Indian Spring, Squaw Spring, Woodruff Spring, Star Spring, and the spring at the head of Maidenwater Creek are perennial springs, all located just outside the study area boundary. Vegetation is sparse and precipitation is low.

The stock of the Mt. Hillers intrusive center (pl. 1) covers approximately 1,600 acres and is surrounded by a zone of shattered sedimentary rock that has been intricately intruded by diorite porphyry. The shattered zone consists of a complex series of dikes, sills, and irregular minor igneous intrusions and severely deformed sedimentary rocks. The intrusive center has domed the overlying sedimentary strata, which are tilted nearly vertical on the south and east flanks of Mt. Hillers. Black Table, Big Ridge, and Cass Creek Peak are laccoliths of diorite porphyry that extend north and northeast from the Mt. Hillers stock. They were injected radially into the adjacent sedimentary strata and deformed the strata by arching.

Surrounding the intrusive centers are several thousand feet of exposed sedimentary rocks, ranging in age from Permian to Late Cretaceous (pl. 1). The shattered zone that surrounds the stock is composed of intricately intruded dikes, sills, and minor igneous masses and deformed sedimentary rocks of varying age (Hunt and others, 1953). For example, south and east of Mt. Hillers, the shattered zone includes the entire Lower and Middle(?) Triassic Moenkopi Formation and a few hundred feet of Permian rocks. The shattered beds dip about 55° away from the stock, but outside the shattered zone Triassic and Jurassic rocks are vertical. Triassic and Jurassic strata in this area are intruded by a less complex system of radial dikes and sills of diorite porphyry (pl. 1). West, north, and northeast of Mt. Hillers the shattered zone includes sedimentary rocks that are Jurassic or older.

The sedimentary rocks that surround the Mt. Hillers igneous complex were deposited in depositional environments that range from marine, through marginal marine, to continental. Permian rocks are recognized only in the shattered zone and were not differentiated by Hunt and others (1953), nor are they differentiated in this report. Detailed descriptions, thicknesses, and interpretations of depositional environments of sedimentary rocks in the study area are on plate 1.

The age of the igneous intrusions is not known with certainty. The youngest sedimentary rock that is intruded by the stocks in the Henry Mountains is Late Cretaceous in age. Potassium-argon ages of 44 and 48 million years (Armstrong, 1969) were determined for hornblende from diorite porphyry of the Bull Mountain bysmalith (a laccolith with faulted margins) about 15 mi north of the study area. These age determinations indicate an Eocene age for the intrusion. However, on the basis of their similarity to other intrusive complexes on the Colorado Plateau, Hunt (1980) suggested that a middle Tertiary age for the intrusions of the Henry Mountains is more likely. This contention is supported by four fission track ages ranging from 21.2 to 29.2 million years from zircon and sphene from diorite and quartz diorite in the Henry Mountains (Sullivan, 1987).

Geochemistry

A reconnaissance geochemical survey of the Mt. Hillers Wilderness Study Area was conducted during the summers of 1982 and 1983 to assist in the assessment of the mineral resource potential. This geochemical survey was part of a larger program designed to examine the geochemistry of several wilderness study areas in the region. A total of 153 stream-sediment samples, 147 panned-concentrate samples, and 181 rock samples collected within and in the vicinity of the Mt. Hillers Wilderness Study Area were analyzed by semiquantitative emission spectrography (Grimes and Marranzino, 1968). Minerals in the heavy-mineral concentrates were identified. A sample location map and a list of the analytical data are in Detra and others (1984).

Analyses of igneous rock samples from both stocks and laccoliths within and in the vicinity of the Mt. Hillers Wilderness Study Area indicate that virtually all of the samples that contain anomalous concentrations of metals occur in the igneous stocks, and only rarely do they occur in the laccoliths. Of 11 samples collected in the monzonite core of the Mt. Pennell stock, all were anomalous in copper or lead, or both (greater than 100 ppm Cu or Pb). Of 27 samples collected in the diorite of the Mt. Pennell stock, 52 percent were anomalous in copper or lead, or both. Sample suites collected in the Mt. Hillers Wilderness Study Area (51 samples) had smaller percentages of copper and lead anomalies than those from Mt. Pennell (Detra and others, 1984).

Several base-metal (copper, lead, and zinc) anomalies occur around the Mt. Hillers stock. Additional geochemical anomalies were found in tributary streams south of Mt. Pennell and Mt. Hillers on Cow Flat (sample HM137 contains Ag, Cu, Pb, Mo, Sn) and in Mud Creek (samples HM148 and HM149 contain Ag and Mo) (Detra and others, 1984). These anomalies are probably related to material eroded and transported from mineralized areas associated with the igneous stocks.

Mineral and Energy Resources

Evaluation of the mineral resource potential of the Mt. Hillers Wilderness Study Area is based on: (1) geologic investigations (pl. 1; Larson and others, 1985); (2) geochemical investigations (Detra and others, 1984); (3) development of and comparison to mineralization occurrence models (fig. 4; Peterson, 1977, 1980b; Dubiel, 1983b; Cox and Singer, 1986); and (4) previously published studies on the geology and mineral occurrences of the study area (Hunt and others, 1953; Doelling, 1972; Molenaar and others, 1983; Molenaar and Sandberg, 1983).

Metals, Other than Uranium and Vanadium

Base- (copper, lead, zinc) and precious- (silver and gold) metal deposits in the North American Cordillera commonly are associated with igneous plutons. The sparse metallic minerals in the Henry Mountains are almost entirely restricted to the igneous stocks and the complex intrusive shattered zones that border them. For reasons not well understood, the igneous rocks associated with the laccolithic centers within the Colorado Plateau, including those of the Henry Mountains, generally have not yet been found to be host to important resources of copper, lead, zinc, silver, or gold. Nevertheless, the sparse areas of metallic mineralization in the Henry Mountains are believed to be related to hydrothermal processes associated with the emplacement of the intrusive stocks, around which the laccoliths are clustered. Occurrences of base and precious metals are almost entirely restricted to the stocks and the complexly intruded contact or shattered zones that border them. The stock associated with the Mt. Hillers intrusive center is coincident with the summit of Mt. Hillers. As noted by Hunt and others (1953, p. 165), the intrusions were nearly devoid of volatiles, temperatures at the time of emplacement were low, and, as a result, contact metamorphism and rock alteration were slight. Sedimentary rocks adjacent to the igneous intrusions exhibit only slight induration and baking within a few inches of the intrusions. In addition, there were neither large nor numerous channelways available for mineralizing solutions.

The presence of gold and copper in the narrow quartz veins at the Star mine, and analyses that indicate trace amounts of gold in the limonite-stained diorite porphyry (Neubert, 1987) suggest that gold and copper mineralization has occurred in the vicinity of the summit of Mt. Hillers. Geologic and geochemical evidence suggest that mineralization was localized near the contact of the porphyry stock and the adjacent shattered zone.

The presence of both pyrite and a propylitic zone characterized by epidote and chlorite along joint faces and by chloritization in the diorite porphyry, and a comparison to mineral-deposit models (Cox and Singer, 1986), suggest there is an alteration zone at the surface of the Mt. Hillers Wilderness Study Area that may indicate a porphyry deposit at depth. Geologic mapping (Hunt and others, 1953; Larson and others, 1985) indicates that the Mt. Hillers intrusive center did not have a complex

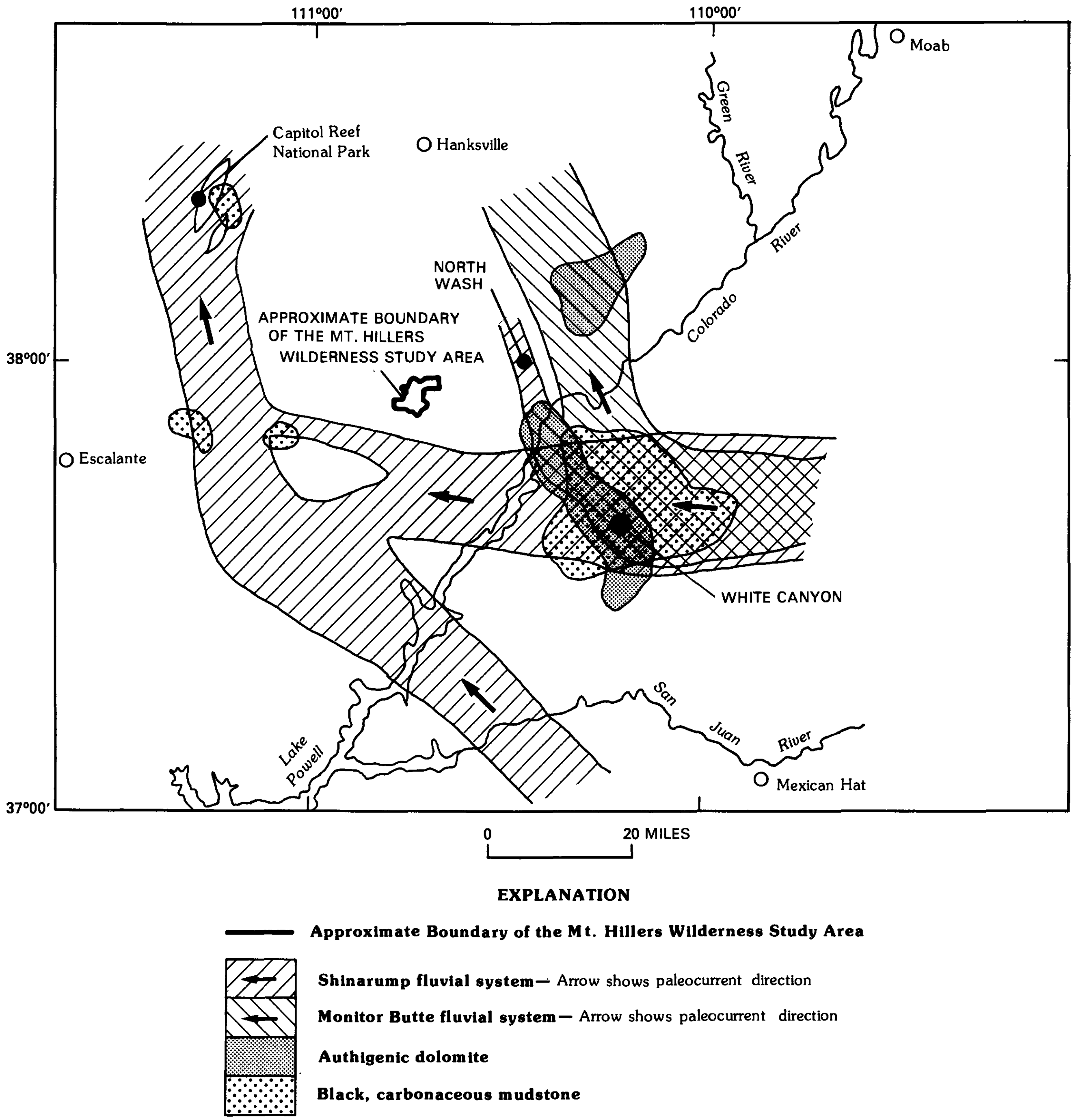

Figure 4. Map showing distribution of the fluvial systems of the Shinarump and Monitor Butte Members of the Chinle Formation, authigenic dolomite, and black carbonaceous mudstone used to evaluate uranium potential in the Mt. Hillers Wilderness Study Area and vicinity. (Modified from Dubiel and others, 1985.)

igneous history. In comparison, the Mt. Pennell intrusive center exhibits a more complex intrusive history since the Mt. Pennell diorite porphyry stock is intruded by a small monzonite porphyry stock and younger aplite dikes (pl. 1). The Mt. Pennell intrusive center has a propylitic alteration zone and disseminated chalcopyrite along fracture zones and in brecciated rock. Intrusive rock types associated with porphyry copper deposits in the Western United States are typically granodiorite or quartz monzonite porphyries rather than diorite or monzonite as in the Henry Mountains, and alteration is generally more pervasive and intense (Cox, 1986a, 1986b, 1986c). Nevertheless, more intense sampling at depth in the intrusive igneous rocks may indicate that the alteration zones and the minerals observed at the surface are the expression of more intense mineralization in the subsurface.

Geologic and geochemical evidence and comparison with mineral deposit models (Cox and Singer, 1986) indicate that the central part of the Mt. Hillers Wilderness Study Area has a moderate mineral resource potential for disseminated, porphyry-related base (copper, lead, zinc) metals in the igneous stock and shattered zone (fig. 1; pl. 1), and for narrow, precious- (gold) and base-metal fissure veins near the summit of Mt. Hillers. The moderate mineral resource potential is assigned a certainty level of B on the basis of the known geologic and geochemical data and the relative uncertainty in the understanding of mineralization processes and models for this intrusive igneous terrane. The remaining portion of the study area has a low mineral resource potential for metals other than uranium and vanadium, with a certainty level of B.

Minor occurrences of metals that are intimately associated with uranium and vanadium are discussed in the subsequent section on uranium and vanadium.

Uranium and Vanadium

Uranium and vanadium occurrences in the Henry basin generally are restricted to fluvial sandstone beds of the Salt Wash Member of the Morrison Formation, and most of these are south of the study area in a north-trending zone known as the Henry Mountains mineral belt (Peterson, 1977). Both the Shootering Canyon mine and the Del Monte mine about 10 mi south of Mt. Hillers are in this belt. Detailed sedimentologic studies of the Salt Wash Member indicate that, in the Henry basin, uranium-vanadium deposits are associated with carbonaceous lacustrine mudstone strata interbedded with the sandstones (Peterson, 1980a, 1980b). These carbonaceous lacustrine mudstone beds occur in a north-south trending belt that overlaps the eastern half of the Mt. Hillers Wilderness Study Area. Because the igneous rocks intruded from below, it is not likely that the Salt Wash Member and the carbonaceous lacustrine mudstones of the Morrison Formation underlie the mapped area of the igneous stock or the associated shattered zone. The northeastern and southeastern parts of the study area, which are not underlain by the stock or the shattered zone do contain Salt Wash sandstones and carbonaceous mudstones at the surface or in the shallow subsurface. Geochemical studies (Lupe and others, 1982) indicate that there are uranium anomalies associated with the Salt Wash Member in these parts of the study area. Sedimentologic and geochemical studies of the Morrison Formation indicate that the mineral resource potential for uranium and vanadium is high in the eastern part of the study area in the Salt Wash Member of the Morrison Formation where the carbonaceous lacustrine mudstones also occur (fig. 1; pl. 1), with certainty level C.

In the past, uranium exploration in the Henry basin was limited to the uranium- and vanadium-bearing Salt Wash Member of the Morrison Formation. More recently, a minor effort has been directed toward exploration of the Upper Triassic Chinle Formation just northeast of Mt. Ellsworth in the southern Henry Mountains. The Chinle Formation underlies the Morrison and younger Triassic rocks throughout the Henry basin, but it is exposed in the study area only locally as the inner, upturned sedimentary strata around the southern margins of the Mt. Hillers stock and shattered zone. The Chinle probably does not underlie the intrusive center because of the mechanism of intrusion from below. The Chinle is known to contain uranium deposits in the White Canyon area 20 mi southeast of the study area, near Fiddler Butte 20 mi northeast of the study area, and near Capitol Reef National Park 25 mi northwest of the study area. In addition, recent drilling northeast of Mt. Ellsworth in the southern Henry Mountains has discovered uranium in subsurface paleochannels of the Upper Triassic Chinle Formation (Dubiel and others, 1987). In these areas, uranium deposits that contain vanadium and copper are restricted to fluvial-channel sandstone and conglomerate beds of the Shinarump Member to the east and west, and of the Monitor Butte Member to the north near Fiddler Butte. Sedimentologic analysis of these fluvial systems based on paleochannel trends extrapolated from nearby outcrops (Dubiel, 1983b) indicates that the fluvial depositional systems of the Shinarump Member trend west from the area of White Canyon and north to northwest through the area of Capitol Reef National Park (fig. 4). The sedimentology study also indicates that the fluvial depositional systems of the Monitor Butte Member trend north in the area of North Wash and Fiddler Butte (fig. 4). These fluvial systems may not underlie the Mt. Hillers Wilderness Study Area (fig. 4) (Dubiel, 1983b). However, some uncertainty exists in predicting the exact trend of the paleochannel systems as distance from the outcrop and the study area is increased.

Studies by Northrup (1982) of uranium deposits in the Morrison Formation of the Henry basin suggest that authigenic dolomite occurs in fluvial sandstone beds that contain uranium and vanadium deposits. Rock samples from the lower part of the Chinle Formation, including the Shinarump and Monitor Butte Members, were collected during this study for dolomite analysis where the Chinle crops out around the Henry basin. X-ray diffraction studies indicate that the areas of greatest concentration of authigenic dolomite coincide with the areas of Shinarump and Monitor Butte paleochannel systems (fig. 4), thus supporting the concept that Shinarump and Monitor Butte fluvial systems may have some potential for containing uranium deposits.

Carbonaceous lacustrine mudstones, similar to those reported to be related to Morrison Formation uranium deposits (Peterson, 1977), are also abundant in the lower part of the Chinle Formation (Dubiel, 1983b) and in the same areas that contain the fluvial systems and the dolomite concentrations (fig. 4). The coincidence of carbonaceous mudstones and authigenic dolomite and the uncertain location of Chinle paleochannels indicate that the mineral resource potential for uranium and vanadium is moderate with certainty level C in the Shinarump and Monitor Butte Members, in the western part of the study area.

The central part of the study area, underlain by the igneous stock and shattered zone, is considered to have a low mineral resource potential with certainty level C, for uranium and vanadium because the Chinle and Morrison Formations probably do not underlie the igneous center. The designations of high, moderate, and low mineral resource potential for uranium and vanadium are assigned a certainty level of C on the basis of the known occurrences of uranium deposits in adjacent areas, the occurrence of similar host rocks within the study area, and the projection of trends favorable for the formation of uranium deposits into the study area on the basis of models developed for this study.

Coal

The entire Mt. Hillers Wilderness Study Area is within the Henry Mountains coal field (Gese, 1984b). The Ferron and Emery Sandstone Members of the Upper Cretaceous Mancos Shale are important coal-bearing strata that occur within the coal field. These beds are thickest west and south of the study area along the axis of the Henry basin. The Upper Cretaceous Dakota Sandstone also contains black, carbonaceous mudstone and thin, laterally discontinuous coal seams generally less than 1-ft thick. The coal-bearing Emery Sandstone Member has been eroded from the study area. However, the coal-bearing Ferron Sandstone Member locally crops out in the western, northern, and southern parts of the study area (pl. 1; Larson and others, 1985). Measured sections within the Ferron Sandstone Member at 14 locations near the study area (Doelling, 1972), show thin, discontinuous coal seams that range in thickness from 7 to 9 ft. Doelling (1972, table 2, p. 117) provides proximate analyses of Ferron coal that indicate 11,575 Btu/lb (British thermal units/pound), 2.75 percent sulfur, and 15.3 percent ash.

The presence of coal seams in the Ferron Sandstone Member near the study area and outcrops of the Ferron Sandstone Member within the study area indicate that the western part of the Mt. Hillers Wilderness Study Area has a moderate mineral resource potential for coal. The remaining part of the study area that contains outcrops of Dakota Sandstone or that is underlain by the intrusive igneous center has a low mineral resource potential for coal. The designations of moderate and low resource potential are assigned a certainty level of C on the basis of the known occurrences of coal in the region, the occurrence of similar host rocks in the study area, geologic studies that indicate the thin but persistent nature of the coal beds in these units, and the lack of significant coal-bearing units in the central part of the study area.

Oil and Gas

Oil and gas have been produced from Pennsylvanian, Permian, and Triassic rocks in basins adjacent to the Henry basin, and these same strata are known to occur in the subsurface of the Henry basin, but they remain mostly untested. Factors detrimental to oil and gas accumulation in the study area are the extensive dissection of the region by the Colorado River and its tributaries, which would have lowered reservoir pressures by exposing reservoir rocks (Irwin and others, 1980), and the emplacement of the Henry Mountain igneous bodies, which have uplifted, deformed, and only slightly heated the adjacent sedimentary rocks (Hunt and others, 1953; Molenaar and Sandberg, 1983). The Mt. Hillers Wilderness Study Area has been assessed as having a low resource potential for oil and gas, on the basis of data from this study and from studies by Molenaar and others (1983) and Molenaar and Sandberg (1983). A certainty level of B is assigned on the basis of the regional geology and occurrence of possible hydrocarbon-bearing units within the study area coupled with a lack of knowledge on the exact subsurface distribution of these rocks and their hydrocarbon content.

Geothermal Energy

There is no evidence, such as heated waters or associated mineral deposits, to suggest any shallow occurrence of geothermal sources in the study area. The Mt. Hillers Wilderness Study Area has a low resource potential for geothermal energy. A certainty level of B is assigned on the basis of the lack of geologic evidence for geothermal sources in the study area.

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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.

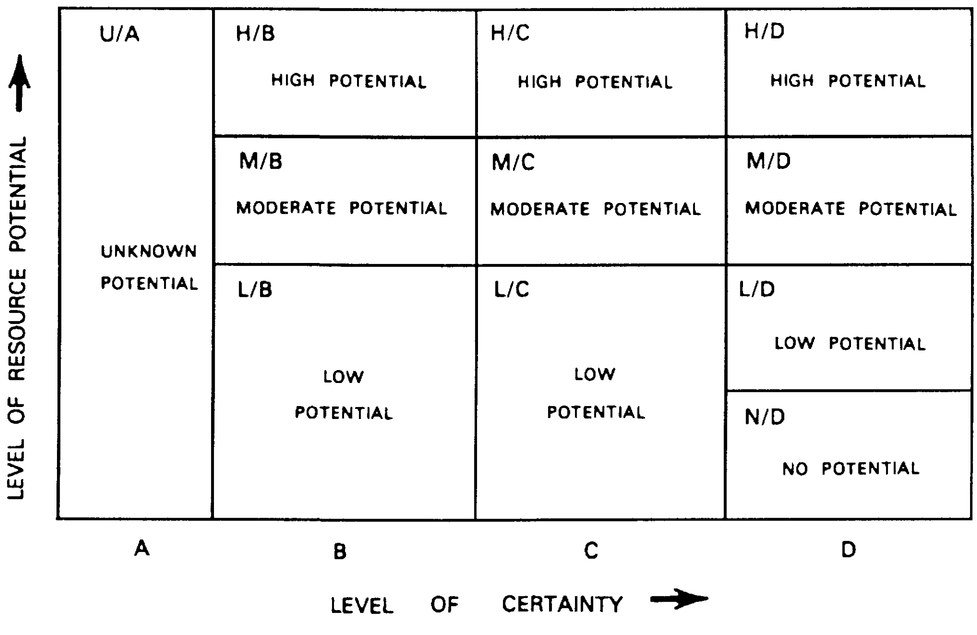
MODERATE mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence, where interpretations of data indicate a reasonable likelihood of resource accumulation, and (or) where an application 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 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
Phanerozoic	Cenozoic	Quaternary		Pleistocene	1.7
Phanerozoic	Cenozoic	Tertiary	Neogene Subperiod	Pliocene	5
Phanerozoic	Cenozoic	Tertiary	Neogene Subperiod	Miocene	24
Phanerozoic	Cenozoic	Tertiary	Paleogene Subperiod	Oligocene	38
Phanerozoic	Cenozoic	Tertiary	Paleogene Subperiod	Eocene	55
Phanerozoic	Cenozoic	Tertiary	Paleogene Subperiod	Paleocene	66
Phanerozoic	Mesozoic	Cretaceous		Late	96
Phanerozoic	Mesozoic	Cretaceous		Early	138
Phanerozoic	Mesozoic	Jurassic		Late Middle Early	205
Phanerozoic	Mesozoic	Triassic		Late Middle Early	~ 240
Phanerozoic	Paleozoic	Permian		Late Early	290
Phanerozoic	Paleozoic	Carboniferous Periods	Pennsylvanian	Late Middle Early	~ 330
Phanerozoic	Paleozoic	Carboniferous Periods	Mississippian	Late Early	360
Phanerozoic	Paleozoic	Devonian		Late Middle Early	410
Phanerozoic	Paleozoic	Silurian		Late Middle Early	435
Phanerozoic	Paleozoic	Ordovician		Late Middle Early	500
Phanerozoic	Paleozoic	Cambrian		Late Middle Early	~ 570[1]
Proterozoic	Late Proterozoic				900
Proterozoic	Middle Proterozoic				1600
Proterozoic	Early Proterozoic				2500
Archean	Late Archean				3000
Archean	Middle Archean				3400
Archean	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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