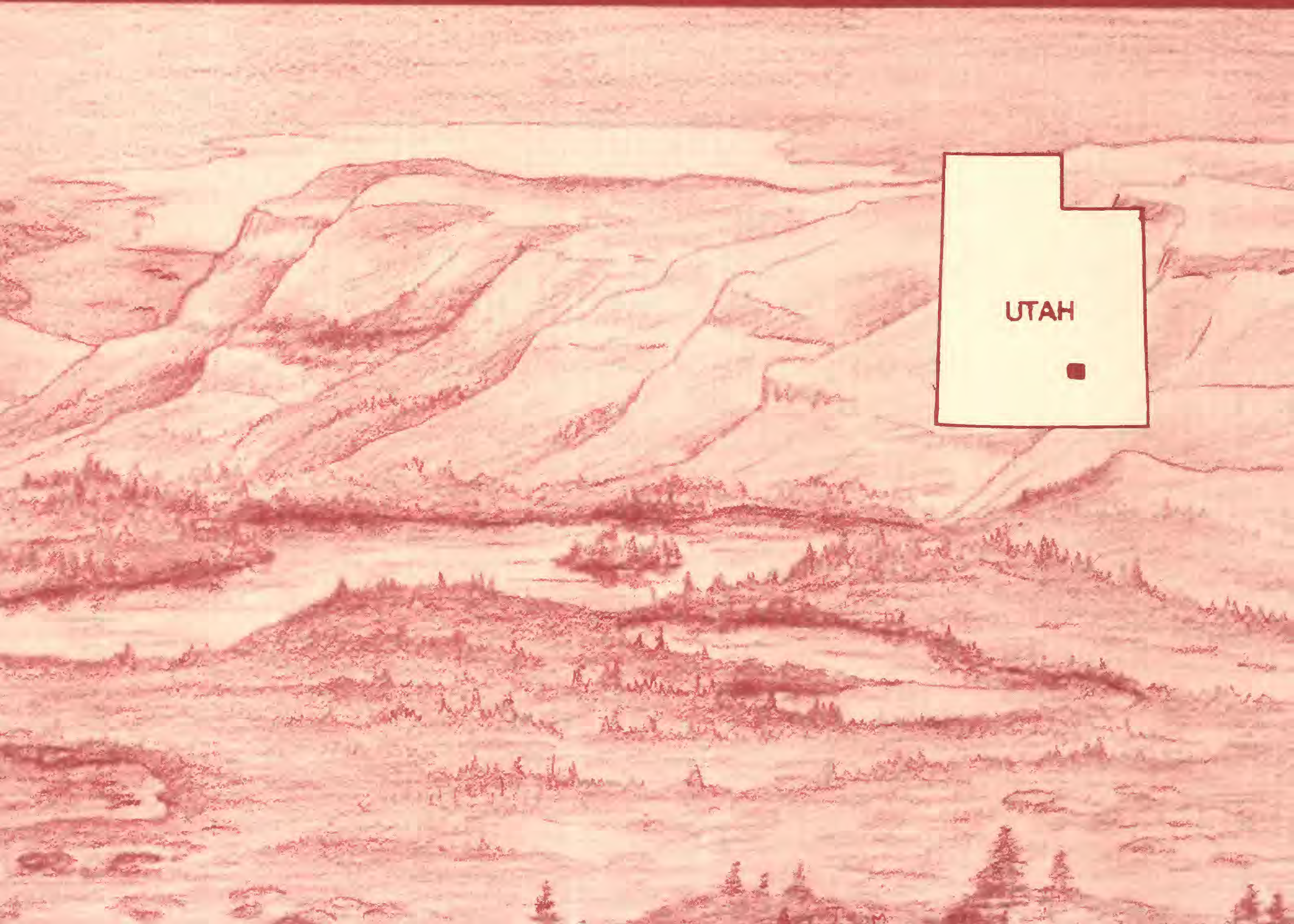
Mineral Resources of the Mount Pennell Wilderness Study Area, Garfield County, Utah

U.S. GEOLOGICAL SURVEY BULLETIN 1751–D



Chapter D

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By RUSSELL F. DUBIEL, CALVIN S. BROMFIELD,
STANLEY E. CHURCH, WILLIAM M. KEMP,
MARK J. LARSON, FRED PETERSON,
and CHARLES T. PIERSON
U.S. Geological Survey

DIANN D. GESE
U.S. Bureau of Mines

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

DEPARTMENT OF THE INTERIOR

MANUEL LUJAN, JR., Secretary

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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 a part of the Mount Pennell (UT–050–248) Wilderness Study Area, Garfield County, Utah.

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Mineral Resources of the Mount Pennell Wilderness Study Area, Garfield County, Utah

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

Diann D. Gese
U.S. Bureau of Mines

ABSTRACT

The Mount Pennell (UT-050-248) Wilderness Study Area comprises 25,800 acres in the Henry Mountains in Garfield County, Utah. Field and laboratory investigations were conducted by the U.S. Geological Survey from 1981 to 1984 and by the U.S. Bureau of Mines in 1988. The investigations indicate that subeconomic measured coal resources of approximately 1.3 million tons occur in the Emery Sandstone Member of the Mancos Shale within the western boundary of the study area. Several mines and prospects for base and precious metals are within the study area, and placer workings for precious metals are just outside the study area boundary; however, no resources are associated with any of these workings. The central portion of the study area underlain by igneous rocks has a moderate mineral resource potential for base (copper, lead, tin, molybdenum, and zinc) and precious (silver and gold) metals; the remainder of the study area has a low mineral resource potential for these metals. The central part of the study area has a low mineral resource potential for uranium and vanadium. The remainder of the study area has a moderate mineral resource potential for uranium and vanadium. The central part of the study area underlain by igneous rocks has a low mineral resource potential for coal; all of the study area outside of this central part has a moderate resource potential for coal in the Ferron Sandstone Member of the Mancos, and the extreme western part of the study area additionally has a high resource potential for coal in the Emery Sandstone Member of the Mancos. The entire study area has a low resource potential for oil and gas and for geothermal energy.

Manuscript approved for publication May 2, 1990.

SUMMARY

Character and Setting

At the request of the U.S. Bureau of Land Management, the U.S. Geological Survey (USGS) and the U.S. Bureau of Mines (USBM) studied the Mount Pennell Wilderness Study Area (UT-050-248) to determine both the identified (known) resources and the mineral resource potential (undiscovered resources) of the area (fig. 1). The Mount Pennell Wilderness Study Area encompasses 25,800 acres surrounding Mount Pennell in the Henry Mountains, Garfield County, Utah (fig. 2). Field and laboratory investigations were conducted by the USGS from 1981 to 1984 and by the USBM in 1988. In this report, the studied area is called the "wilderness study area" or simply the "study area."

The Henry Mountains consist of numerous intrusive igneous rocks and related satellite igneous bodies of Tertiary age. (See geologic time chart in Appendix.) The satellite bodies were injected radially from the central intrusions into the adjacent sedimentary strata. Each of these intrusive igneous bodies was intruded into and domed the overlying sedimentary strata. Subsequent erosion by the Colorado River and its tributaries has exposed the central intrusives and their subsidiary satellite bodies as five mountains and associated major and minor topographic features. Mount Pennell is one of these five mountains. The study area includes the Mount Pennell intrusive center, several satellite

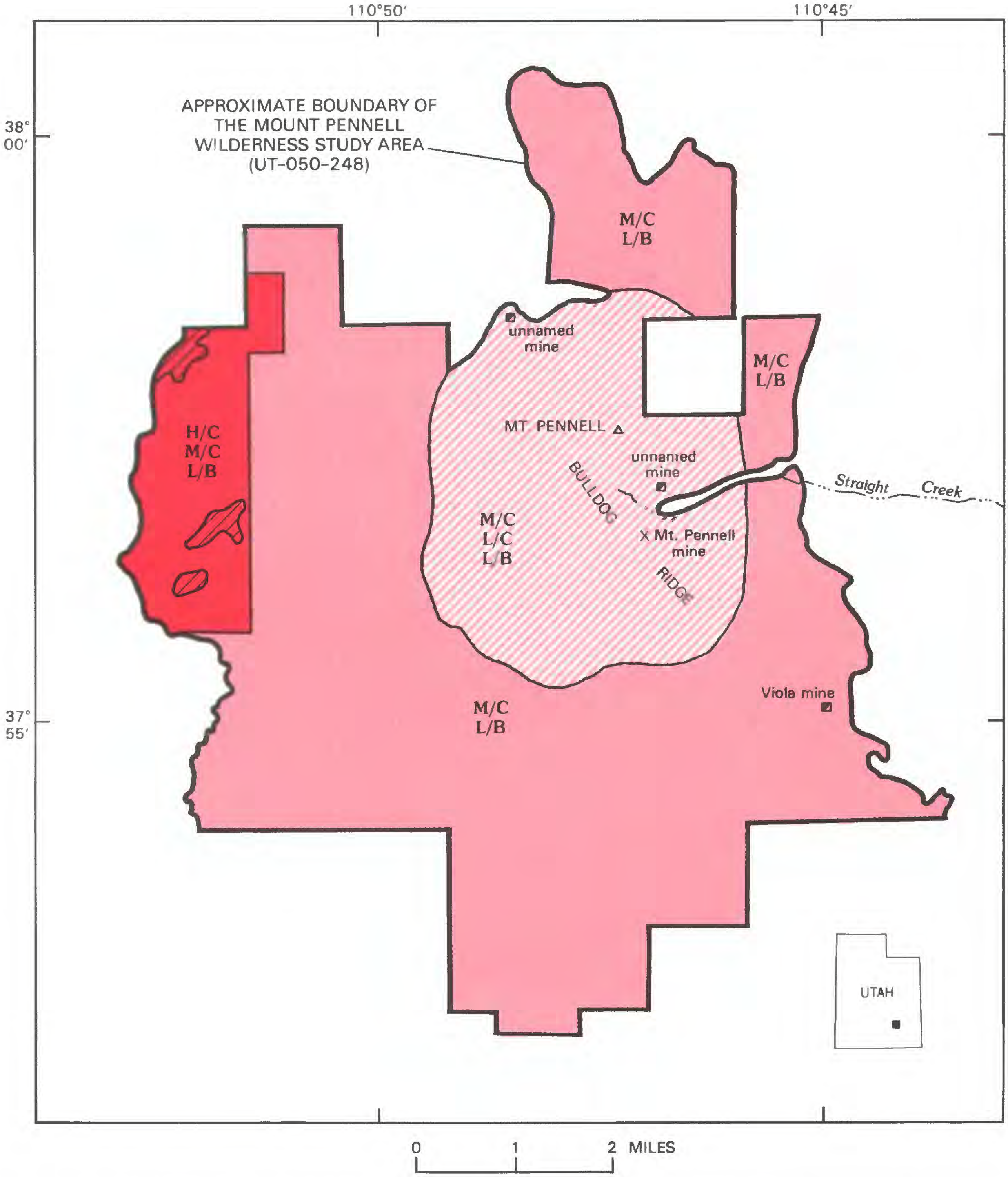

Figure 1. Subeconomic coal resources and mineral resource potential of the Mount Pennell Wilderness Study Area, Garfield County, Utah.

igneous bodies, and numerous sedimentary units that have been deformed by the igneous intrusions. Sedimentary rocks ranging in age from Triassic to Cretaceous were eroded to form a highly dissected topography with narrow, deep canyons and broad, gravel-mantled pediments. Mountain slopes are steep and rugged. Straight Creek drains the east side of Mount Pennell and is the only perennial stream in the study area. There are perennial springs at Mud Spring, Airplane Spring, and Box Spring just outside the study area boundary and at Gibbons Spring just within the study area boundary (pl. 1). Vegetation is sparse and precipitation is low.

EXPLANATION

Geologic terrane having subeconomic coal resources in the Emery Sandstone Member of the Mancos Shale

H/C M/C L/B — Geologic terrane having (1) high mineral resource potential for coal in the Emery Sandstone Member, with certainty level C, (2) moderate mineral resource potential for coal in the Ferron Sandstone Member of the Mancos Shale and for uranium and vanadium, with certainty level C, and (3) low mineral resource potential for base (copper, lead, zinc, molybdenum, and tin) and precious (silver and gold) metals, for oil and gas, and for geothermal resources, with certainty level B

M/C L/B — Geologic terrane having (1) moderate mineral resource potential for coal in the Ferron Sandstone Member of the Mancos Shale and for uranium and vanadium, with certainty level C, and (2) low mineral resource potential for base (copper, lead, zinc, molybdenum, and tin) and precious (silver and gold) metals, for oil and gas, and for geothermal resources, with certainty level B

M/C L/C L/B — Geologic terrane having (1) moderate mineral resource potential for base (copper, lead, zinc, molybdenum, and tin) and precious (silver and gold) metals, with certainty level C, (2) low mineral resource potential for coal, with certainty level C, and (3) low mineral resource potential for uranium and vanadium, for oil and gas, and for geothermal resources, with 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

Identified Resources

Copper, silver, and gold occur in the study area at the Mount Pennell mine on the south side of Mount Pennell, at an unnamed mine between the summit of Mount Pennell and Bulldog Ridge, and at the Viola V mine located about 3 mi (miles) southeast of the summit of Mount Pennell. Resources were not identified in the study area because the mine workings are inaccessible, the ore-bearing veins are poorly exposed, and the concentrations of copper, silver, and gold in samples collected for this study are low and/or inconsistent. Subeconomic measured coal resources of approximately 1.3 million tons occur within the Emery Sandstone Member of the Mancos Shale along the western boundary of the study area (fig. 1, pl. 1). The quality of the coal in the weathered outcrops ranges in rank from subbituminous C to high-volatile C bituminous. The coal is covered by less than 20 ft (feet) of overburden and could be strip-mined; however, the small size of the deposit, the long distances to markets, and the inaccessibility of the coal deposit make it subeconomic at the present time. At present, no oil and gas leases or lease applications include any part of the study area.

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 the central intrusion and the satellite bodies within the Mount Pennell Wilderness Study Area indicate that virtually all of the samples containing anomalous concentrations of metals were from the central intrusion; very few were from the satellite bodies. Several base-metal (copper, lead, zinc, molybdenum, and tin) and precious-metal (silver and gold) anomalies occur in and around the Mount Pennell intrusion. Similar geochemical anomalies were found in samples collected from tributary streams of the study area. These stream-sediment anomalies probably reflect material eroded from the mineralized parts of the igneous intrusions. The central part of the study area underlain by the intrusive igneous center has a moderate mineral resource potential for base (copper, lead, zinc, molybdenum, and tin) and precious (silver and gold) metals. The mineral resource potential in the remaining portion 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 Upper Triassic Chinle Formation. The Salt Wash Member is present in the subsurface of the study area; however, carbonaceous lacustrine mudstones, one of the criteria that indicate a favorable environment for uranium-vanadium deposits in the Salt Wash, are present only in a north-south-trending belt east of the study area. The Chinle Formation is known to contain uranium and vanadium in the White Canyon area about 25 mi southeast of the study area, near Fiddler Butte about 25 mi northeast of the study area, and in the vicinity of Capitol Reef National Park about 20 mi northwest of the study area. Moreover, recent drilling has identified a subeconomic resource of uranium in the Chinle about 20 mi southeast of the study area near Mount Ellsworth. The uranium deposits of the Chinle Formation in those areas are restricted to fluvial sandstones of the Shinarump and Monitor Butte Members. Sedimentologic study of trends of these Chinle fluvial systems on nearby outcrops indicates that they may not underlie the study area. In the central part of the study area, sedimentary rocks probably do not occur because the intrusive igneous rocks were emplaced from below. The central part of the study area, underlain by the intrusive center, has a low mineral resource potential for uranium and vanadium. The part of the study area not underlain by the igneous intrusive center is assigned a moderate mineral resource potential for uranium and vanadium on the basis of (1) the occurrence of uranium and vanadium deposits in the Morrison and Chinle Formations in areas adjacent to the study area, (2) the presence of these units in the study area, (3) the likelihood that the black mudstones associated with Salt Wash ore deposits elsewhere in the Henry basin do not extend beneath the study area and (4) the uncertainty in the location of fluvial paleochannels within the Chinle Formation underlying the study area.

The Mount Pennell Wilderness Study Area lies within the Henry Mountains coal field, except for the small part of the study area underlain by the intrusive igneous rocks. The Emery and Ferron Sandstone Members of the Upper Cretaceous Mancos Shale are important coal-bearing strata

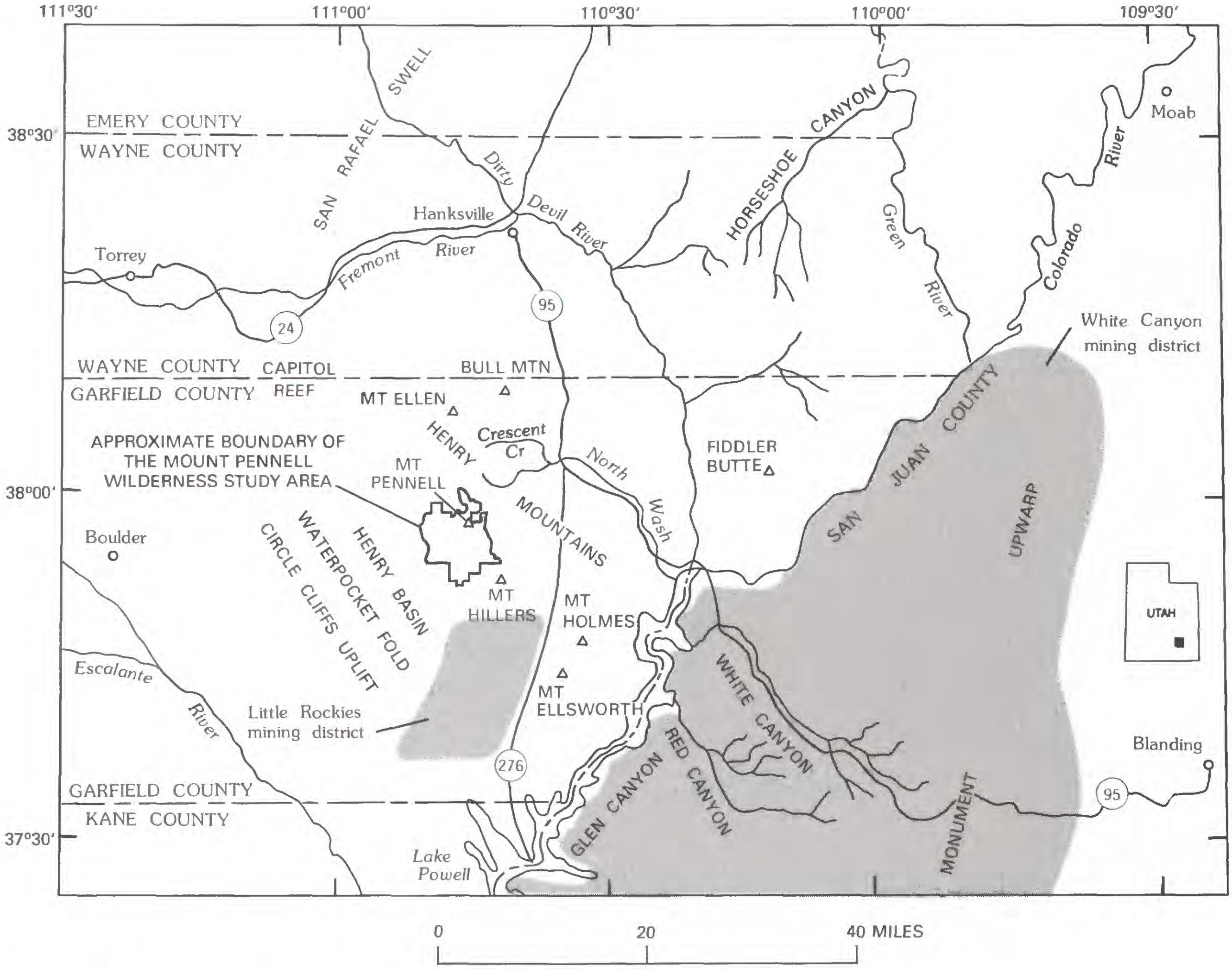

Figure 2. Location of the Mount Pennell Wilderness Study Area, Garfield County, Utah.

within the coal field. The Emery contains coal only in its upper sandstone beds, which have been removed by erosion from all but the westernmost part of the study area. The Ferron contains thin lenticular coal beds; it crops out locally in the study area and underlies most of it. The Upper Cretaceous Dakota Sandstone also contains thin, discontinuous coal seams that are less than 1 foot thick. The Dakota crops out in the northeastern part of the study area and occurs in the subsurface of the southern and western parts of the study area. The area underlain by the intrusive igneous center has a low mineral resource potential for coal. The western part of the study area that contains the upper, coal-bearing beds of the Emery has a high mineral resource potential for coal. The remaining part of the study area has a moderate mineral resource potential for coal in the Ferron.

Oil and gas have been produced from Pennsylvanian, Permian, and Triassic rocks in basins adjacent to the Henry basin, and these rocks are known to occur in the subsurface of the Henry basin. However, these rocks are mostly untested in the Henry basin; their subsurface distribution and hydrocarbon content are poorly known. 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 Mount Pennell (UT–050–248) Wilderness Study Area comprises about 25,800 acres encompassing Mount Pennell 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 6,000 ft along pediment benches east and west of the study area to 11,371 ft on the summit of Mount Pennell. The study area is about 25 mi south of Hanksville and about 20 mi northwest of Lake Powell. Maintained dirt roads originating at Utah State Highway 276 extend around and provide access to the study area.

This report presents an evaluation of the mineral endowment (identified resources and mineral resource potential) of the study area and is the product of 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), which is also shown in the 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). Recent studies have documented the geology of the Mount Pennell igneous stock (G. Hunt, 1988) and the mechanisms of emplacement of the igneous centers and associated satellite intrusions (Pollard and Johnson, 1973; Jackson, 1987; Jackson and Pollard, 1988a). The debate concerning the origin of the central igneous complexes of the Henry Mountains as intrusive stocks or large intrusive laccoliths remains lively (C.B. Hunt, 1988; Jackson and Pollard, 1988b).

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 U.S. Department of Energy) in the 1940's and 1950's. These reports are available through the U.S. Geological Survey, Books and Open-File Reports Section, Federal Center, Box 25425, Denver, CO 80225. 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 1988, the USBM evaluated the identified resources of the Mount Pennell Wilderness Study Area. Mineral, geothermal, and oil and gas lease information was gathered from interviews with persons having knowledge of mineral occurrences and mining activity in the region, published and unpublished literature, USBM files, and oil and gas lease and mining-claim records at the U.S. Bureau of Land Management Office in Salt Lake City, Utah. Field studies during August 1988 included the collection of samples for geochemical analysis, an evaluation of coal resources, and a search for mines, prospects, and mineralized areas in and near the study area.

The USBM collected 23 rock-chip samples, 4 channel samples, and 2 placer samples. The rock-chip samples were analyzed by inductively coupled plasma–atomic absorption spectroscopy; five of these samples were fire assayed for an ore grade analysis for copper by Chemex Labs, Inc., Sparks, Nev. For each placer sample, a measured volume of gravel (1 cubic foot) was screened to one-half-inch size. This material was sent to the USBM placer lab in Spokane, Wash., where the visible gold particles were handpicked from the concentrate and weighed. The remaining material was amalgamated, the gold picked up by the amalgam was weighed, and the two gold weights were added to determine the total gold content for each sample. Proximate, ultimate, and heat-value analyses of coal samples were performed by Core Labs, Casper, Wyo. (Gese, 1989, tables 1–3).

Tonnages for three coal deposits in the western part of the study area were calculated by multiplying the area of the deposit (in square feet) by the deposit thickness (in feet), and dividing the resulting volume by a tonnage factor of 24.6 (cubic feet per ton). The area of the coal deposit was estimated using a planimeter; its thickness was measured in the field, and the tonnage factor was determined using the specific gravity of 1.3 for subbituminous coal. Areas and thicknesses used to calculate the coal resources in this report are given in Gese (1989, table 4). A complete data set for these samples can be found in Gese (1989) and is also available for public inspection at the USBM, Intermountain Field Operations Center, Building 20, Denver Federal Center, Denver, Colo.

Investigations by the U.S. Geological Survey

From 1981 to 1986, the USGS assessed the potential for undiscovered mineral resources of the Mount Pennell 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 regional stream-sediment sampling for geochemical analysis (Detra and others, 1984); and a search of previously published studies on the geology (Hunt and others, 1953; Peterson, 1977, 1980a; G. Hunt, 1988; Jackson and Pollard, 1988a) and mineral deposits of the study area (Butler, 1920; Johnson, 1959; Doelling, 1967, 1975, 1980; Peterson, 1977, 1980a, 1980b; Chenoweth, 1980). Models developed for the occurrence of uranium (Peterson, 1980b; Dubiel, 1983b) and base and precious 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. Potassium-argon determinations were provided by R.W. Tabor. We also thank all of the USGS personnel who assisted in the field on all aspects of this interdisciplinary study in the Henry Mountains: 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 Diann D. Gese
U.S. Bureau of Mines

Mining Districts, Mineralized Areas, and Identified Resources

Base and Precious Metals

The Mount Pennell Wilderness Study Area is in the Henry Mountains mining district. The district was initially prospected after placer gold was discovered along the Colorado River in 1883 near Hite, Utah, a former settlement 8 mi east of Mount Holmes, now inundated by Lake Powell. The Henry Mountains were believed to be the most likely source of the gold. Gold, silver, and copper were produced in the 1890's from fissure veins in the diorite porphyry stock of Mount Ellen, 3.5 mi north of the Mount Pennell Wilderness Study Area in Bromide Basin (Hunt and others, 1953; Doelling, 1975, 1980; Gese, 1984). The deposits in Bromide Basin were discovered in 1889 or 1890 (Doelling, 1975). The ore minerals occur in quartz-breccia veins within the diorite stock surrounding Mount Ellen. Approximately 700 oz (ounces) of gold, 3,000 oz of silver, and 9 tons of copper have been produced from the Bromide Basin area since 1889 (Doelling, 1972; Gese, 1984).

Similar precious metal deposits were found on Mount Pennell at about the same time. In 1913, Butler (1920) found prospects from the peak of Mount Pennell southward into the Straight Creek basin and along Bulldog Ridge. An arrastre had been built on Straight Creek to treat ore from the Baby Ruth (Rico) claim. Records show a production of 17 tons of ore yielding 12.8 oz of gold and 1 oz of silver from this claim in 1925 and 1927 (Doelling, 1975). The exact location of the Baby Ruth claim is uncertain, but the ore was most likely from the Mount Pennell vein.

By the late 1960's and early 1970's, the Mount Pennell vein was being developed by an adit about 70 ft long and by bulldozer cuts. The recorded value of ore produced was $263, mostly in gold (Doelling, 1980, p. 291). At the same time, the Viola V mine at the southern end of Bulldog Ridge was also being developed by a 150-ft-long adit and a 72-ft-deep shaft. There is no known production from the Viola V mine; a sample collected by Doelling (1975, p. 127) from the face of the adit contained only traces of silver and gold.

The south side of Mount Pennell, including the Mount Pennell vein, Bulldog Ridge, Viola V mine, and Straight Creek, has been prospected for copper, silver, and gold. All underground workings in the study area were inaccessible at the time of the field investigation. Prospects on the south side of Mount Pennell (pl. 1) contain copper, silver, and a trace of gold.

The Mount Pennell vein is a northwest-trending fissure vein that cuts both the monzonite and diorite porphyries that make up the Mount Pennell intrusive center. The vein is exposed in an opencut in the SE¼ sec. 10, T. 33 S., R. 10 E. The vein is as much as 15.5 ft wide and can be traced along strike for about 100 ft. The opencut appears to be the site of the Mount Pennell mine, which was about 60 ft long when Doelling (1975, p. 129) mapped it in 1966. The vein is composed of silicified monzonite and diorite porphyry that contains pyrite, chalcopyrite, bornite, malachite, and iron oxides.

Samples of the vein material contain as much as 1.67 percent copper, 0.5 ounces silver per short ton (17 ppm), and 960 ppb (parts per billion) gold (Gese, 1989, table 2, samples 9–15). The limited exposure of the vein and the low and inconsistent copper and silver concentrations preclude the identification of a copper, silver, or gold resource along the Mount Pennell vein.

Outcrops of the silicified monzonite porphyry were sampled along the strike of the Mount Pennell vein for a distance of about ¼ mi and were found to contain as much as 8,660 ppm (parts per million) (0.87 percent) copper, 4 ppm silver, and 475 ppb gold. Thus, this material was not as mineralized as the samples from the mine site (Gese, 1989, table 2, samples 2–7).

Six prospect pits located either on quartz-filled fissure veins or along the contact of the diorite porphyry and the shattered sedimentary rocks were examined and sampled along Bulldog Ridge in secs. 14 and 15, T. 33 S., R. 10 E. The workings were old and showed no evidence of any recent mineral-related activity. Mineralization along this part of Bulldog Ridge was not extensive, and it resulted in precipitation of primarily iron oxides and pyrite. Most samples collected contained copper, silver, and gold, but the concentrations were low: maximum values were 291 ppm copper, 0.8 ppm silver, and 225 ppb gold.

The Viola V mine consists of a caved adit and shaft in the SE¼ sec. 24, T. 33 S., R. 10 E. The adit was driven along the contact of the diorite porphyry and a metamorphosed shale. Mineralized rock samples observed on the ore pile apparently came from fractures in the diorite porphyry and consist of malachite, pyrite, chalcopyrite, and iron oxides. A high-grade sample from the ore bin contained 1.25 percent copper, 0.3 oz silver per short ton (10 ppm), and 310 ppb gold (Gese, 1989, table 1, sample 25).

Placer gold has been reported from several creeks outside the study area in the Henry Mountains; however, only the area along Crescent Creek has had reported gold production. The value of gold contained in samples collected from various creeks in the Henry Mountains ranged from $0.77 to $6.59 per cubic yard of sediment (based on $70.00/oz gold; Doelling, 1980). Current value of these placer deposits, based on $400.00/oz gold, is $4.40 to $37.66 per cubic yard. The gold occurs as fine flakes at the base of the surface gravels and in the fanglomerates. Placer claims cover Straight Creek in the east-central part of the study area, and "unverified reports" of placer gold along the creek have been mentioned by Doelling (1980). Two placer samples were collected from the gravels along Straight Creek. Both samples contained gold, but it was very fine grained, and its value in the two samples would be only $0.02 and $0.025 per cubic yard of sediment (Gese, 1989, table 1). One sample contained two particles of gold and the other contained one particle; all three particles are very angular in shape, indicating little transport of the gold from its source. Fissure veins along the south side of Mount Pennell and Bulldog Ridge are the most likely sources of the placer gold.

At the time of this investigation, most of the precious-minerals activity in the study area was along Straight Creek and on the south side of Mount Pennell. Placer and lode claims cover most of this part of the study area. A claimant had been drilling in this vicinity, but the extent and results of that exploration are unknown at the present time.

Uranium and Vanadium

The Mount Pennell 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, where they drilled and identified a subsurface uranium deposit (Dubiel and others, 1987). No part of the White Canyon mining district is within the Mount Pennell Wilderness Study Area.

The Little Rockies mining district lies about 5 mi south of the Mount Pennell Wilderness Study Area. 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.

About 5 mi east of the study area, the Salt Wash Member of the Upper Jurassic Morrison Formation hosts economic uranium and vanadium deposits in a region known as the Henry Mountains mineral belt (Peterson, 1977). The mineral belt is divided into three areas: North Wash, Trachyte Ranch, and Little Rockies (fig. 3). Carnotite-bearing outcrops were discovered in 1913 at Trachyte Ranch. Since that time, the deposits have been mined for radium from 1914 to 1924, for vanadium from 1936 to 1978, and for uranium from 1948 to 1978 (Chenoweth, 1980). More recently, Plateau Resources discovered a uranium orebody containing at least 6 million pounds U_3O_8 at the Shootering Canyon mine (Kreidler, 1984, p. 6). The Salt Wash Member of the Morrison Formation does not crop out within the study area but is present in the subsurface.

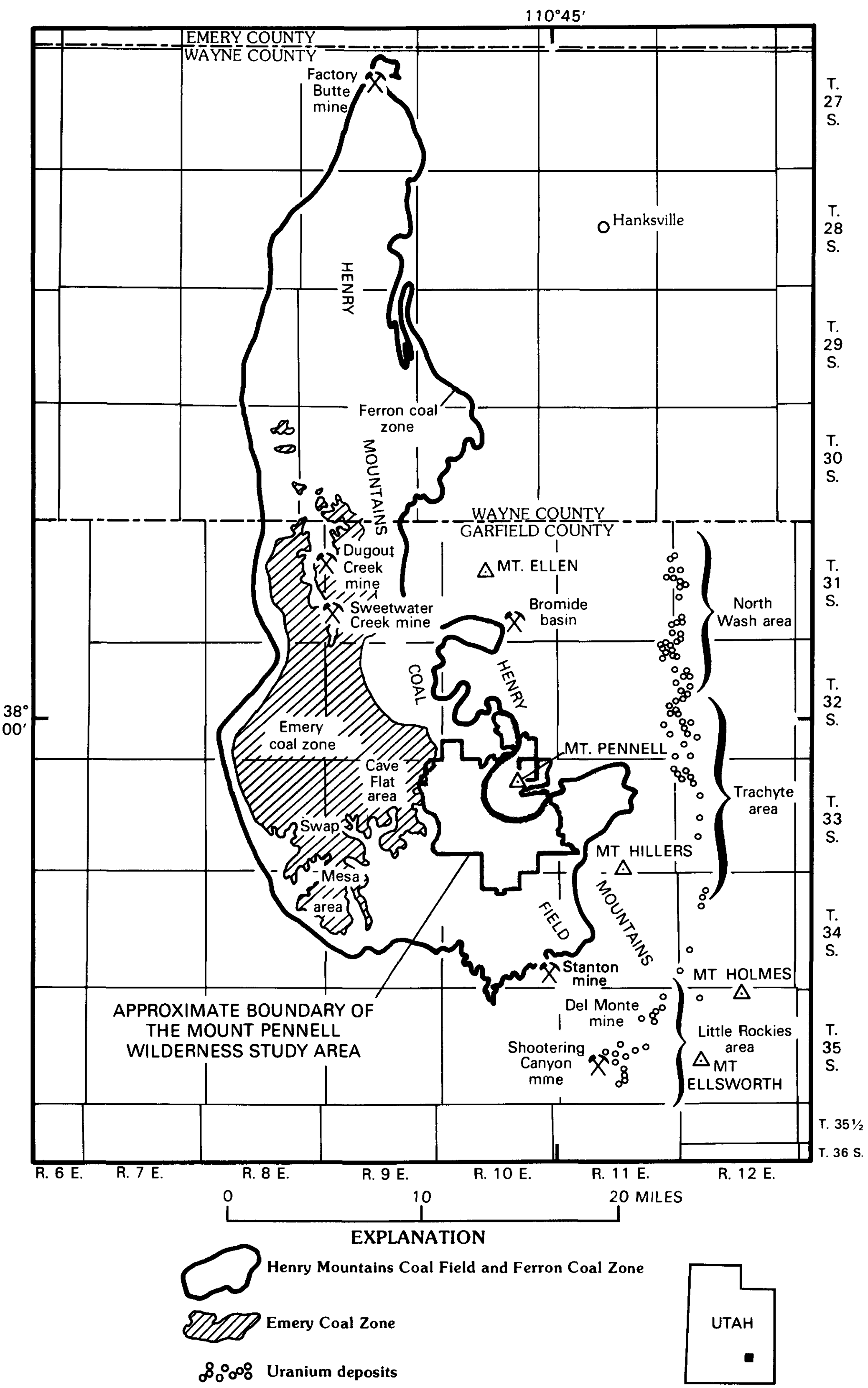

Figure 3. Location of the Henry Mountains coal field and mineralized areas in and near the Mount Pennell Wilderness Study Area. Map modified from Doelling (1972); uranium deposits from Chenoweth (1980).

Coal

Most of the Mount Pennell Wilderness Study Area is in the Henry Mountains coal field (fig. 3). This coal field is 48 mi long and 18 mi wide and contains minable reserves (measured, estimated, and inferred) of 230 million tons of coal primarily in the Emery and Ferron coal zones (Doelling, 1972). Coal was first mined in the area at the Stanton mine (fig. 3), about 5 mi south of the study area, around 1890. The Factory Butte mine in the northern part of the Henry Mountains coal field opened in 1908 and operated intermittently until about 1945. Two mines west of Mount Ellen operated in the late 1940's and supplied coal for local use. Total production from all mines in the coal field was about 9,000 tons (Doelling, 1972).

The Mount Pennell Wilderness Study Area is partly in the Cave Flat area of the Henry Mountains coal field (fig. 3). Doelling (1972) estimated that the Cave Flat area was 3,186 acres in size and contained about 36 million short tons of coal with 100 ft or less of overburden. The coal is in the Emery Sandstone Member of the Mancos Shale, is a low-sulfur, medium-ash coal, and is high-volatile C bituminous in rank (Doelling, 1972).

Coal beds in the Emery Sandstone Member crop out along the western boundary of the study area. Drill logs for seven holes less than 1 mi west of the study area show these coal beds to be as much as 8.7 ft thick at a depth of about 98 ft. The shallowest minable coal (>4 ft thick) is at a depth of 44 ft. Coal beds in the Cave Flat area are persistent but are very lenticular; where the coal thickens, it generally splits into two or more coal beds.

A subeconomic measured coal resource of approximately 1.3 million tons was calculated using criteria from Wood and others (1983, p. 6–7) for three deposits in the Mount Pennell Wilderness Study Area (Gese, 1989, table 4). The coal ranged in rank from subbituminous C to high-volatile C bituminous, but the samples collected from the outcrop for this study were of weathered coal beds and may not accurately indicate the true quality of the coal in this region (Gese, 1989, table 3). Fresh, unoxidized coal would be expected to be of higher quality.

The Emery coal in the study area could be strip-mined because the overburden is less than 20 ft. Compared to other Utah coal deposits in the Book Cliffs, Wasatch Plateau, Emery, and Kaiparowits Plateau coal fields, the coal-bearing zone in the study area is smaller, farther from market, and less accessible. For these reasons, the coal in the Mount Pennell Wilderness Study Area is considered subeconomic at the present time.

Oil and Gas

The Mount Pennell 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). Within the Paradox basin, oil and gas production 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 Mount Pennell Wilderness Study Area, but remain untested. There are no oil and gas leases or lease applications in the study area.

Sand, Gravel, and Stone

Materials that could be used for construction purposes are present in the Mount Pennell Wilderness Study Area. Sand and gravel are present in terrace deposits along stream courses, and most of the Jurassic and older rocks could be sources of building stone. Development of these materials is unlikely due to the lack of unique qualities or local markets.

ASSESSMENT OF POTENTIAL FOR UNDISCOVERED RESOURCES

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

Geology

The Mount Pennell 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 this asymmetric basin is formed by the steeply eastward dipping rocks of the Waterpocket Fold, a monocline that separates the Henry basin from the adjacent Circle Cliffs uplift to the west. Strata of the gently dipping east flank of the basin gradually rise eastward toward the crest of the Monument upwarp. The five intrusive complexes 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: Mount Ellsworth, Mount Holmes, Mount Hillers, Mount Pennell, and Mount Ellen extend in a north-northwest line for about 35 mi. The core of each igneous complex is a separate diorite porphyry intrusion that is discordant to the surrounding sedimentary rocks. The study area includes several laccoliths as well as sedimentary units that have been deformed by the igneous bodies. The sedimentary rocks have been eroded to form a highly dissected topography with narrow, deep canyons and broad, gravel-mantled pediment benches. Mountain slopes are steep and rugged. Straight Creek on the east side of Mount Pennell is the only perennial stream in the study area. There are perennial springs at Mud Spring, Airplane Spring, and Box Spring just outside the study area and at Gibbons Spring just inside the study area boundary (pl. 1). Vegetation is sparse and precipitation is low.

Mount Pennell consists of a central complex of intruded igneous rocks around which sedimentary rocks are turned upward at about 45° in a nearly circular dome (pl. 1; Hunt and others, 1953; Larson and others, 1985). Hunt and others (1953) and G. Hunt (1988) characterize the central igneous intrusion as a stock from which the satellite igneous bodies were radially injected into sedimentary rocks. Recent studies (Jackson, 1987; Jackson and Pollard, 1988a,b) have suggested that the central igneous intrusions are themselves laccoliths that have intruded the sedimentary strata. The debate over the merits of these hypotheses continues at present (C.B. Hunt, 1988; Jackson and Pollard, 1988b). Sedimentary rocks surrounding the peak are intruded by laccoliths, dikes, and sills injected from the central igneous intrusion. Brecciation around the Mount Pennell central intrusion is not as widespread as on Mount Ellen or Mount Hillers but is present in a zone forming Bulldog Ridge southeast of the stock and in a small area west of the stock (Tps on pl. 1; Hunt and others, 1953; Larson and others, 1985).

The central intrusive complex of Mount Pennell covers approximately 1,280 acres (pl. 1) and, in contrast to the intrusive centers on Mount Hillers and Mount Ellen, exhibits a more complex history of multiple igneous intrusions. The central complex is composed chiefly of diorite porphyry that has been intruded by a smaller body of monzonite porphyry and locally by aplitic dikes. Laccoliths and minor satellite bodies of diorite porphyry extend north and northeast from the central complex. All of the laccoliths except the biotite-bearing Horn laccolith 3 mi north of Mount Pennell are composed of diorite porphyry, but the sills and dikes are composed of either diorite or monzonite porphyry.

As at the other intrusive centers in the Henry Mountains, alteration and metamorphism associated with the Mount Pennell igneous complex are neither pervasive nor widespread. Epidote and chlorite are locally conspicuous along joint surfaces and as replacement minerals in the porphyries. Argillic alteration was noted locally along small fractures in the central part of the intrusive complex. Locally, iron staining resulted from the oxidation of pyrite; it is particularly apparent in and near the Mount Pennell central intrusion. Hunt and others (1953) also noted minor pyrite in some of the satellite laccoliths. Metamorphic effects of the intrusions on the invaded sedimentary rocks generally resulted in the induration, or "baking," of the rocks along with minor discoloration. These effects, however, are restricted to a zone within a few feet of the intrusive contacts.

Surrounding the Mount Pennell intrusive center are several thousand feet of exposed sedimentary rocks, ranging in age from Jurassic to Late Cretaceous (pl. 1). Around the intrusive center of Mount Hillers, about 3 mi to the southeast of the study area, Triassic and younger sedimentary rocks are tilted upward, and Permian rocks are exposed in the shattered zone surrounding the igneous complex (Hunt and others, 1953; Jackson and Pollard, 1988b). Mount Pennell contains no well-developed shattered zone like that at Mount Hillers (Hunt and others, 1953; Dubiel and others, 1988), and the porphyry is in direct contact with the steeply dipping sedimentary rocks. East of the central igneous complex, the strata are vertical and locally are overturned, but a short distance from the contact with the igneous center the dips are much less steep. Sedimentary rocks also dip much less steeply on the south and west sides of Mount Pennell.

Several laccoliths and smaller satellite igneous bodies were injected radially from the central igneous intrusion into the adjacent sedimentary strata. The Horn, Coyote Creek, and Dark Canyon laccoliths intruded sedimentary rocks on the north and northeast side of Mount Pennell. Bulldog Ridge and Browns Knoll, on the southeast side of the peak, are smaller intrusions injected from the igneous center. Many sills, dikes, and other small igneous intrusions surround Mount Pennell.

The sedimentary rocks that surround the igneous complex at Mount Pennell were deposited in depositional environments that range from marine, through marginal marine, to continental. Permian rocks and the Lower and Middle(?) Triassic Moenkopi Formation are recognized only in the shattered zone surrounding Mount Hillers, 3 mi southeast of the study area (Hunt and others, 1953). Descriptions, thicknesses, and interpretations of sedimentary rocks in the study area are given on plate 1.

The ages of the igneous intrusions are not known with certainty. The youngest sedimentary rock that is intruded by the igneous rocks in the Henry Mountains is Late Cretaceous in age. Potassium-argon (K-Ar) ages of 44 and 48 million years (Armstrong, 1969) were determined for hornblende from the diorite porphyry of the Bull Mountain bysmalith (a laccolith with faulted

Table 1. Potassium-argon ages from hornblende separates from the Henry Mountains

[Dashes (--) indicate data not available. Decay constants: ^{40}K $\lambda_{\epsilon} = 0.581 \times 10^{-10}$/yr; $\lambda_{\beta} = 4.962 \times 10^{-10}$/yr; $^{40}K/K = 1.167 \times 10^{-4}$ mol/mol]

Intrusive center	K_2O (pct)	Radiogenic ^{40}Ar Moles/gram ($\times 10^{-10}$)	Radiogenic ^{40}Ar Percent of total ^{40}Ar	Age[1]
Mt. Pennell	1.117	0.6647	33.3	40.9±3.3
Mt. Hillers[2]	1.230	0.4814	21.6	24.8±4.0
Mt. Ellen[2]	0.930	0.5522	22.8	40.8±4.5
Bull Mtn.[3]	--	--	--	46 ±3

[1]Millions of years before present.
[2]Averages of three replicate determinations.
[3]Age from Armstrong (1969).

margins), about 10 mi northeast 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 mid-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).

Hornblende separates from three samples from igneous intrusions in the Henry Mountains were dated by K-Ar methods during the present study (table 1). The samples were not very radiogenic, and hence they give ages having rather large deviations. The data indicate ages for the intrusions that are somewhat younger than those presented by Armstrong (1969) and, moreover, suggest that the intrusion at Mount Hillers is much younger than those exposed at Mount Pennell, Mount Ellen, and Bull Mountain. This younger date for Mount Hillers supports the data reported by Sullivan (1987).

Geochemistry

A reconnaissance geochemical survey of the Mount Pennell Wilderness Study Area was conducted during the summers of 1982 and 1984 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 Henry Mountains region. A total of 153 stream-sediment samples, 147 heavy-mineral panned-concentrate samples, and 181 rock samples collected in and near the Mount Pennell Wilderness Study Area were analyzed by semiquantitative emission spectrography (Grimes and Marranzino, 1968). Minerals in the heavy-mineral panned concentrates were visually identified. A sample locality map and a list of the data are in Detra and others (1984).

Analyses of stream-sediment samples represent the geochemistry of the material eroded from the drainage basin upstream from the sample site. In addition, the silt fraction of the sediment provides potential nuclei for the adsorption of dissolved metals that may be contained in the stream water. These samples are utilized to identify which drainage basins, if any, contain concentrations of elements that may be related to mineral deposits. Analyses of heavy-mineral panned-concentrate samples provide information about the chemistry of certain ore and ore-related minerals in eroded and transported rock material derived from the contributing drainage basins. The selective concentration of panned minerals permits the determination of some elements that are not easily detected in stream-sediment samples. Analyses of altered or mineralized rock samples, where present, may provide useful geochemical information about the major- and trace-element assemblages associated with a mineralizing system. Rock samples were collected from throughout the study area, but sampling was concentrated within the igneous rocks of the intrusive center, the satellite laccoliths, and the smaller igneous bodies because of the known mineralization in those areas. Stream-sediment samples were collected from active stream drainages in and around the study area (Detra and others, 1984, pl. 1). Heavy-mineral panned-concentrate samples of stream sediments were collected from drainages that were large enough to transport coarse sand and gravel.

Analyses of rock samples from both the central igneous complex and the satellite laccoliths within and near the Mount Pennell Wilderness Study Area indicate that virtually all of the samples containing anomalous concentrations of metals were from the central igneous complex; very few were from the laccoliths (Detra and others, 1984). Of 11 samples collected in the monzonite porphyry of the Mount Pennell central intrusion, all were anomalous in copper, lead, or both (greater than 100 ppm Cu or Pb). Of 27 samples collected in the diorite of the Mount Pennell central intrusion, 52 percent were anomalous in copper and/or lead. Sample suites collected in the Mount Hillers Wilderness Study Area (51 samples) had smaller percentages of copper and lead anomalies than those from Mount Pennell (Detra and others, 1984).

Additional geochemical anomalies were found in stream-sediment samples from tributary streams south of Mount Pennell and west of Mount 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 probably represent material eroded and transported from mineralized areas of the intrusive igneous complexes.

Mineral and Energy Resources

The evaluation of the mineral resource potential of the Mount Pennell Wilderness Study Area is based on the following criteria: (1) geologic investigations (pl. 1; Larson and others, 1985), (2) geochemical investigations (Detra and others, 1984), (3) mineral 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; G. Hunt, 1988).

Base and Precious Metals

Deposits of base metals (copper, lead, zinc, tin, molybdenum, and related metals) and precious metals (silver and gold) in the North American Cordillera

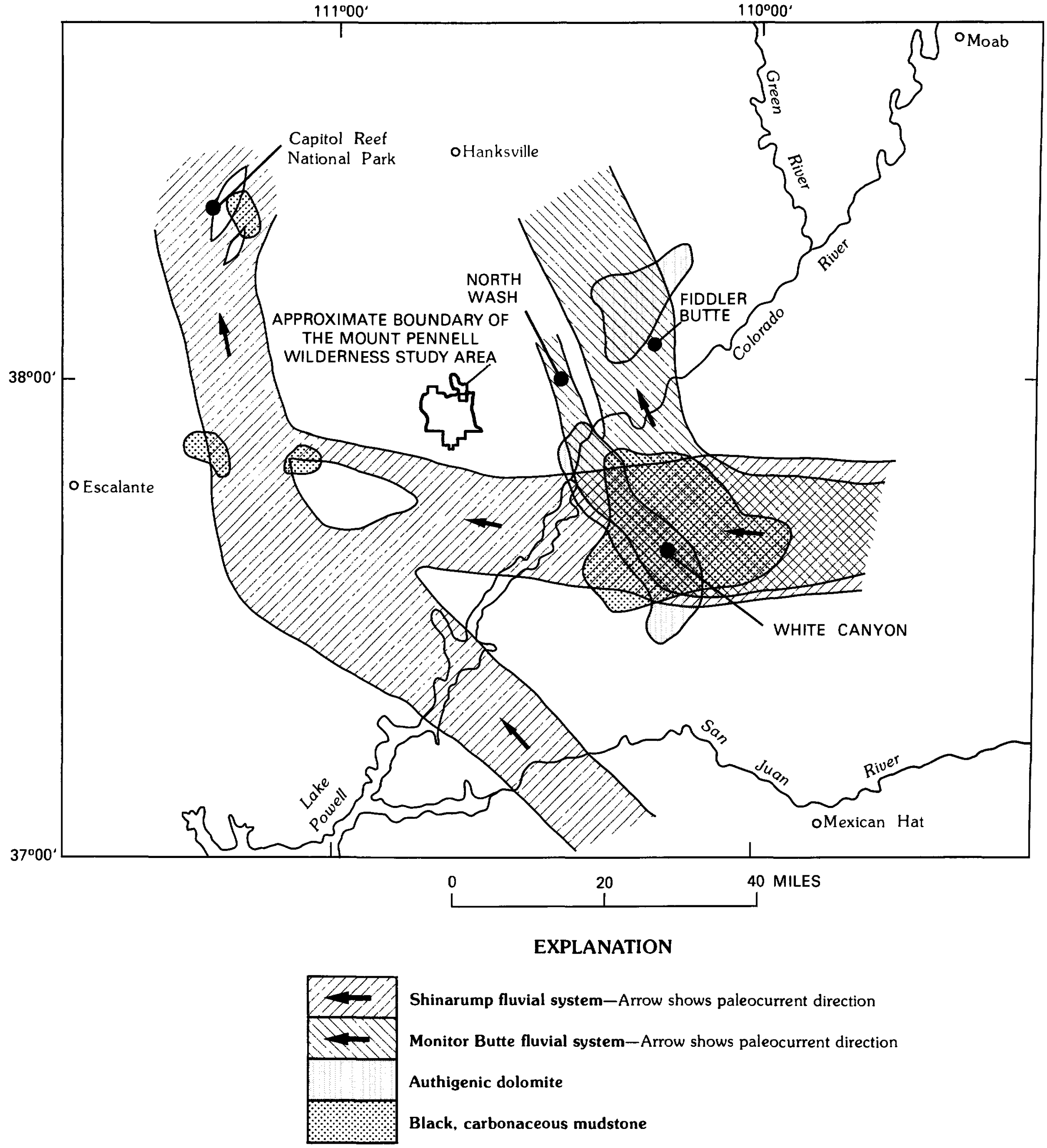

Figure 4. Distribution of the fluvial systems of the Shinarump and Monitor Butte Members of the Chinle Formation, authigenic dolomite, and black, carbonaceous mudstone used to evaluate uranium potential in the Mount Pennell Wilderness Study Area and vicinity. Modified from Dubiel and others (1985).

commonly are associated with plutons (Cox, 1986a,b,c). The sparse metallic mineralization in the Henry Mountains is almost entirely restricted to the central igneous intrusions and the complex shattered zones that border them. For reasons not well understood, igneous rocks associated with the laccolith-bearing igneous complexes within the Colorado Plateau, including those complexes in the Henry Mountains, generally have not been found to host important resources of copper, lead, silver, or gold. In the Henry Mountains, though, igneous intrusive centers that are surrounded by laccoliths nevertheless include sparse areas of mineralized rock. As noted by Hunt and others (1953, p. 165), the intrusions of the Henry Mountains were nearly devoid of volatiles, and temperatures at the time of emplacement were low. As a result, contact metamorphism and rock alteration were slight; sedimentary rocks adjacent to the central and laccolithic igneous intrusions exhibit only slight induration and baking within a few inches, or at most a few feet, of the intrusions. In addition, channelways available for mineralizing solutions were neither large nor numerous.

Small amounts of copper, silver, and gold occur in veins at and near the summit of Mount Pennell and south of the summit along Bulldog Ridge. Chemical analyses indicate trace amounts of copper, silver, and gold in the limonite-stained diorite porphyry of the central intrusion (Detra and others, 1984; Gese, 1989). Geologic and geochemical evidence suggest that mineralization was localized (1) within veins, (2) near the contact of the diorite porphyry intrusion with the younger monzonite porphyry, and (3) in the adjacent shattered sedimentary strata.

The presence of both pyrite and an argillic alteration zone characterized by epidote and chlorite along joint faces and by chloritization in the diorite porphyry suggests that an incipient zone of mineralization may be exposed at the surface of the central igneous complex at Mount Pennell. According to mineral deposit models (Cox, 1986a,b,c; Cox and Singer, 1986), such evidence may indicate a porphyry deposit at depth. Geologic mapping (Hunt and others, 1953; Larson and others, 1985) indicates that the Mount Pennell intrusive center had an igneous history that was more complex than that of the other intrusive centers in the Henry Mountains but not as complex as the histories at other intrusive and laccolithic centers on the Colorado Plateau, such as the La Sal and La Plata Mountains (Eckel, 1949; Hunt and others, 1953; Hunt, 1958; Larson and others, 1985). Unlike the other Henry Mountain intrusive centers, the Mount Pennell diorite porphyry stock is intruded by a small monzonite porphyry stock and younger aplite dikes (pl. 1). The Mount Pennell intrusive center has a propylitic alteration zone and disseminated chalcopyrite along fracture zones and in brecciated rock. Intrusive rock types that host porphyry copper deposits in the western United States are typically granodiorite or quartz monzonite porphyries rather than diorite or monzonite, the types found in the Henry Mountains, and alteration around deposits is generally more pervasive and intense than that in the Henry Mountains (Cox, 1986a,b,c). Nevertheless, more intense sampling at depth in the central intrusive igneous complex may indicate that the alteration zones and the minerals observed at the surface are the expression of more intensely mineralized rock in the subsurface.

Geologic and geochemical evidence and comparison to mineral deposit models (Cox, 1986a,b,c; Cox and Singer, 1986) indicate that the Mount Pennell Wilderness Study Area has a moderate mineral resource potential for disseminated, porphyry-hosted base metals (copper, lead, tin, molybdenum, and zinc) in the central intrusive igneous complex and the associated shattered zones (fig. 1; pl. 1), and for narrow, precious-metal (silver and gold) fissure veins near the summit of Mount Pennell. The moderate mineral resource potential is assigned a certainty level of C 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, which contains predominantly sedimentary rocks, 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 following section.

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 and east of the study area in a north-trending zone known as the Henry Mountains mineral belt (Peterson, 1977, 1980a). Both the Shootering Canyon mine and the Del Monte mine (fig. 3), about 10 mi south of Mount Hillers, are in this belt. Detailed sedimentologic studies of the Salt Wash Member indicate that, in the Henry basin, uranium-vanadium deposits occur where carbonaceous lacustrine mudstone strata are interbedded with the sandstones (Peterson, 1980a,b). These carbonaceous lacustrine mudstone beds occur in a north-south-trending belt that lies several miles east of the study area boundary. Because the igneous rocks intruded from below, it is not likely that the Salt Wash Member and the carbonaceous lacustrine mudstones underlie the mapped area of the central igneous intrusion or the associated shattered zone. The Salt Wash Member crops out north and northeast of the study area, and the Salt Wash may underlie those parts of the study area not intruded by the igneous rocks, but the belt of carbonaceous mudstone associated with ore-bearing Salt Wash sandstones does not appear to underlie the study area.

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 Mount Ellsworth in the southern Henry Mountains. The Chinle Formation underlies the Morrison and younger Triassic rocks throughout the Henry basin, but in the vicinity of the study area it is exposed only locally as the innermost, upturned sedimentary strata around the southern margins of the Mount Hillers central igneous complex and shattered zone, about 3 mi southeast of the study area. The Chinle probably does not underlie the intrusive center of Mount Pennell because of the mechanism of intrusion from below but does underlie the remainder of the study area. 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 Mount Ellsworth in the southern Henry Mountains has discovered uranium in subsurface paleochannels of the Chinle (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, 1987a,b) 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 Mount Pennell Wilderness Study Area (fig. 4) (Dubiel, 1983b, 1987a,b). However, some uncertainty exists in predicting the exact trend of the paleochannel systems, and that uncertainty increases as distance from the outcrop and the study area increases.

Studies by Northrup (1982) of uranium ore deposits in the Morrison Formation of the Henry basin suggest that authigenic dolomite occurs in fluvial sandstone beds that contain uranium and vanadium ore 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 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, 1987a,b), 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 Formation paleochannels indicate that the mineral resource potential for uranium and vanadium in fluvial channel sandstones of the Shinarump and Monitor Butte Members of the Chinle Formation beneath the study area is moderate with certainty level C. The part of the study area underlain by the central igneous complex and shattered zone is considered to have a low mineral resource potential for uranium and vanadium with certainty level B, because the Chinle and Morrison Formations probably do not underlie the igneous center. The certainty levels of B and C are assigned 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 uncertain projection of trends favorable for the formation of uranium deposits into the study area on the basis of models developed for this study. Copper and other metals such as cobalt and nickel may be associated with the areas of uranium potential because these metals are known to occur in uranium deposits in the Shinarump Member in other places on the Colorado Plateau (Shoemaker and others, 1959), although the present data do not indicate their presence.

Coal

Except for the area underlain by the central igneous intrusion, the entire Mount Pennell Wilderness Study Area is within the Henry Mountains coal field (Doelling, 1972; Gese, 1989). The Emery and Ferron Sandstone Members of the Cretaceous Mancos Shale are important coal-bearing strata that occur within the coal field. The Cretaceous Dakota Sandstone also contains black, carbonaceous mudstone and some coal seams, but these are laterally discontinuous and are generally less than 1 ft thick. The Emery and Ferron Sandstone Members occur in the study area where sedimentary rocks crop out around the central igneous complex. These sandstone beds are thickest west and south of the study area along the axis of the Henry basin. The Emery crops out in the study area but has been eroded from the area north of the igneous complex and, because of the nature of the igneous intrusion from below, does not occur in the area of the central igneous intrusion. The Emery contains laterally extensive coal beds as much as 10 ft thick (Doelling, 1972), but the coal-bearing zone is restricted to the upper part of the member (Law, 1980). The erosion of sedimentary strata around the igneous complex has removed the upper coal-bearing zone of the Emery from all but the extreme western portion of the study area (pl. 1).

The Ferron Sandstone Member locally crops out in the study area but does not occur in the area of the central igneous intrusion (pl. 1; Larson and others, 1985). The Ferron is known to contain coal in the Henry Mountains coal field, but little is known about coal in the Ferron within the study area (Doelling, 1972).

The extreme western part of the study area, where the upper coal-bearing part of the Emery Sandstone Member is known to be present, has a high mineral resource potential for coal in the Emery. Because of the nature of intrusion of the igneous complex from below, the central part of the study area underlain by the igneous complex has a low mineral resource potential for coal. 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 remaining part of the study area has a moderate mineral resource potential for coal in the Ferron. The designations of high, 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 intrusions, which have uplifted, deformed, and only slightly heated the adjacent sedimentary rocks (Hunt and others, 1953; Molenaar and Sandberg, 1983). The Mount Pennell 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, the occurrence of possible hydrocarbon-bearing units within the study area, and a lack of knowledge of 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 occurrence of geothermal sources in the study area. Hence, the Mount Pennell 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

LEVEL OF RESOURCE POTENTIAL →

<table>
<tr><td rowspan="4">U/A
UNKNOWN POTENTIAL</td><td>H/B
HIGH POTENTIAL</td><td>H/C
HIGH POTENTIAL</td><td>H/D
HIGH POTENTIAL</td></tr>
<tr><td>M/B
MODERATE POTENTIAL</td><td>M/C
MODERATE POTENTIAL</td><td>M/D
MODERATE POTENTIAL</td></tr>
<tr><td rowspan="2">L/B
LOW POTENTIAL</td><td rowspan="2">L/C
LOW POTENTIAL</td><td>L/D
LOW POTENTIAL</td></tr>
<tr><td>N/D
NO POTENTIAL</td></tr>
<tr><td>A</td><td>B</td><td>C</td><td>D</td></tr>
</table>

LEVEL 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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MANUEL LUJAN, JR., Secretary

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

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[Letters designate the chapters]