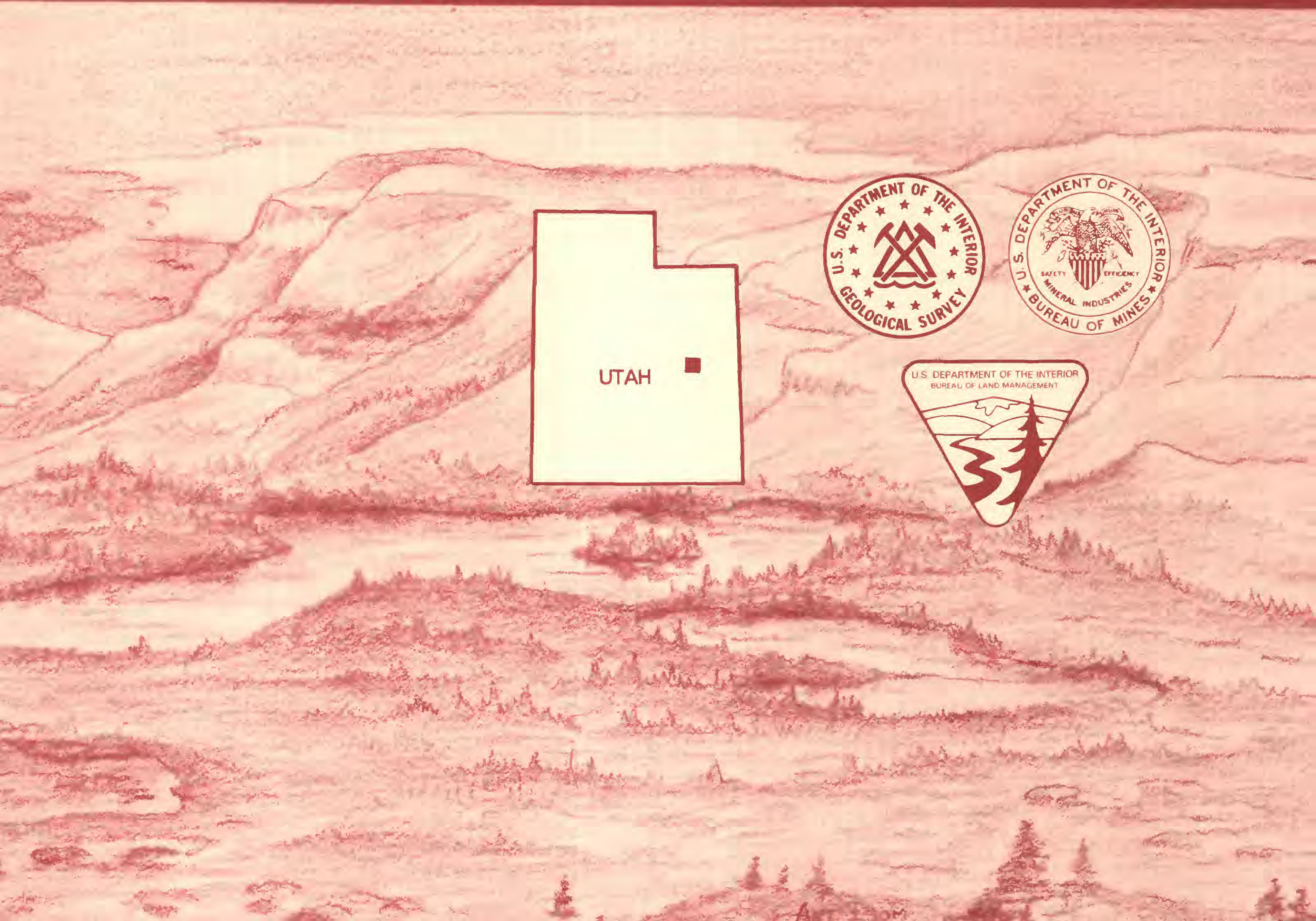
Mineral Resources of the Desolation Canyon, Turtle Canyon, and Floy Canyon Wilderness Study Areas, Carbon, Emery, and Grand Counties, Utah

U.S. GEOLOGICAL SURVEY BULLETIN 1753–B



Chapter B

Mineral Resources of the Desolation Canyon, Turtle Canyon, and Floy Canyon Wilderness Study Areas, Carbon, Emery, and Grand Counties, Utah

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U.S. GEOLOGICAL SURVEY BULLETIN 1753

MINERAL RESOURCES OF WILDERNESS STUDY AREAS:
CENTRAL GREEN RIVER REGION, UTAH

DEPARTMENT OF THE INTERIOR

MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

UNITED STATES GOVERNMENT PRINTING OFFICE: 1990

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

Library of Congress Cataloging-in-Publication Data

Mineral resources of the Desolation Canyon, Turtle Canyon, and Floy Canyon wilderness study areas, Carbon, Emery, and Grand counties, Utah / by William B. Cashion ... [et al.].

p. cm. — (Mineral resources of wilderness study areas—Central Green River Region, Utah ; ch. B) (U.S. Geological Survey bulletin ; 1753-B)
Includes bibliographical references.
Supt. of Docs. no.: I 19.3:1753-B
1. Mines and mineral resources—Utah—Desolation Canyon Wilderness. 2. Mines and mineral resources—Utah—Turtle Canyon Wilderness. 3. Mines and mineral resources—Utah—Floy Canyon Wilderness. 4. Desolation Canyon Wilderness (Utah) 5. Turtle Canyon Wilderness (Utah) 6. Floy Canyon Wilderness (Utah) I. Cashion, W. B. (William Bryan), 1923- . II. Series. III. Series: U.S. Geological Survey bulletin ; 1753-B.
QE75.B9 no. 1753-B
[TN24.U8]
557.3 s—dc20 90-3705
[553'.09792'566] CIP

STUDIES RELATED TO WILDERNESS

Bureau of Land Management Wilderness Study Areas

The Federal Land Policy and Management Act (Public Law 94–579, October 21, 1976) requires the U.S. Geological Survey and the U.S. Bureau of Mines to conduct mineral surveys on certain areas to determine the mineral values, if any, that may be present. Results must be made available to the public and be submitted to the President and the Congress. This report presents the results of a mineral survey of the Desolation Canyon (UT–060–068A), Turtle Canyon (UT–060–067), and Floy Canyon (UT–060–068B) Wilderness Study Areas, Carbon, Emery and Grand Counties, Utah.

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Mineral Resources of the Desolation Canyon, Turtle Canyon, and Floy Canyon Wilderness Study Areas, Carbon, Emery, and Grand Counties, Utah

By William B. Cashion, James E. Kilburn, Harlan N. Barton, Karen D. Kelley, *and* Dolores M. Kulik
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ABSTRACT

In 1985, 1986, and 1988, the U.S. Bureau of Mines and the U.S. Geological Survey studied the Desolation Canyon (UT–060–068A), Turtle Canyon (UT–060–067), and Floy Canyon (UT–060–068B) Wilderness Study Areas, which are contiguous and located in Carbon, Emery, and Grand Counties in eastern Utah. The study areas include 242,000 acres, 33,690 acres, and 23,140 acres respectively.

Coal deposits underlie the Desolation Canyon, Turtle Canyon, and Floy Canyon study areas. Coal zones of Late Cretaceous age occur in the Blackhawk Formation (west of the Green River) and Neslen Formation (east of the Green River). Identified bituminous coal resources in beds 3.5 ft (feet) or more thick and under 2,000 ft or less of overburden are estimated to be 22 million short tons in the Desolation Canyon study area, 6.3 million short tons in the Turtle Canyon study area, and about 45 million short tons in the Floy Canyon study area. In-place inferred oil-shale resources are estimated to contain 60 million barrels of subeconomic shale oil in the Green River Formation underlying the northern part of the Desolation Canyon Wilderness Study Area. Minor occurrences of uranium have been found in the basal part of the Wasatch Formation in the southeastern part of the Desolation Canyon study area and in the western part of the Floy Canyon study area. Mineral resource potential for the study areas is estimated to be (1) for coal, high for all areas, (2) for oil and gas, high for the northern tract of the Desolation Canyon Wilderness Study Area and moderate for all other tracts, (3) for bituminous sandstone, high for the northern part of the Desolation Canyon Wilderness Study Area, and low for all other tracts, (4) for oil shale, low in all areas, (5) for uranium, moderate for the Floy Canyon study area and the southeastern part of the Desolation Canyon study area and low for the remainder of the areas, (6) for metals other than uranium, bentonite, zeolites, and geothermal energy, low in all areas, and (7) for coal bed methane, unknown in all three areas.

Manuscript approved for publication May 29, 1990.

SUMMARY

Character and Setting

The Desolation, Turtle, and Floy Canyon Wilderness Study Areas are contiguous and respectively comprise 242,000; 33,690; and 23,140 acres in Carbon, Emery, and Grand Counties, Utah (fig. 1). In 1985, 1986, and 1988 the U.S. Bureau of Mines and the U.S. Geological Survey conducted investigations of the wilderness study areas as requested by the U.S. Bureau of Land Management and authorized by the Federal Land Policy and Management Act of 1976 (Public Law 94–579). In this report the areas studied are called the wilderness study areas, or simply the study areas. Both investigating agencies reviewed the literature pertaining to the geology, mineral resources, and exploration and mining activity of the region and the study areas. The U.S. Bureau of Mines conducted a field examination of mines, prospects, and mineral occurrences inside and proximate to the study areas. The U.S. Geological Survey conducted field investigations involving geochemical and geophysical surveys and stratigraphic studies.

The study areas are located on the southwestern flank of the Uinta Basin in the northernmost section of the Colorado Plateaus physiographic province. Narrow deeply incised canyons characterize the topography and the most outstanding feature, by far, is Desolation Canyon, which was formed by the Green River and displays approximately 1 mile (mi) of topographic relief.

The surface rocks are of sedimentary origin, range in age from Late Cretaceous to Eocene (see geologic time chart in Appendix), and are principally sandstone, siltstone, shale, and limestone. The rock sequence contains beds of coal, bituminous sandstone, oil shale, and some occurrences of uranium. Oil and gas are produced from these rocks in nearby fields, and coal is mined from them immediately west of the study areas.

In general, the exposed rocks dip gently northeastward toward the axis of the Uinta Basin; faulting has not significantly displaced these strata. The distribution and (or) lithology of rocks deep beneath the surface of the study areas were influenced by intermittent periods of movement along major zones of faulting. The Uncompahgre uplift, which trends northwest across the study areas (pl. 1) is bounded by major fault zones that greatly affected the deposition and (or) erosion of rocks ranging in age from Precambrian to Triassic (Stone, 1977).

Identified Resources

The Bureau of Mines identified coal resources in all three study areas (fig. 2). For the Turtle Canyon study area, identified coal (high-volatile A or B bituminous, metallurgical) resources of possible economic interest are estimated to be 6.3 million tons in the Sunnyside coal zone of the Upper Cretaceous Blackhawk Formation. If coals within the study area were mined in conjunction with coals of the nearby Geneva and Sunnyside Mines (fig. 3), development costs would be minimal. Therefore, these coal resources are considered to be economically developable.

In the southwestern part of the Desolation Canyon study area, also in the Sunnyside coal zone, the estimated reserve base is 4.6 million tons, and identified coal (more sulfur and ash and lower quality than at Turtle Canyon) resources of possible economic interest are 22 million short tons. This coal is rated subeconomic to marginally economic for commercial development.

East of the Green River, in descending order, the Chesterfield, Ballard, and Palisade coal zones of the Upper Cretaceous Neslen Formation underlie the Desolation Canyon and Floy Canyon Wilderness Study Areas; the coal is high-volatile C bituminous, impure with shaly partings. No identified coal resources are assigned to the east-of-the-river part of the Desolation Canyon Wilderness Study Area. For the Floy Canyon study area, drill hole and surface data are lacking, but by projection 45 million short tons of indicated and inferred coal resources are estimated for the area; they are considered to be subeconomic and are not likely to be developed in the near future.

Oil and gas deposits are known along the northern end of the Desolation Canyon study area and as near as 5 mi southeast of the Floy Canyon area. The deposits, as well as two gas discoveries within 0.5 mi of the areas, are related to structural and stratigraphic features that can be projected beneath all three study areas, but insufficient data are available to evaluate the viability for commercial development. Oil-shale deposits occur within the northern part of the Desolation Canyon study area. About 2,220 acres are estimated to contain shale that is 15–45 ft thick with a potential oil yield averaging 15 gallons per short ton (gal/st), suggesting in-place inferred resources of 60 million barrels of shale oil. Available information suggests that an oil-shale sequence to be considered developable needs to have an average oil yield of 25 gal/st and a thickness of at least 25 ft. No shale beneath the study area meets this cutoff, and current (1989) economics preclude the commercial development of oil shale in the United States.

Bituminous sandstone deposits crop out 3–20 mi west of the northwestern boundary of the Desolation Canyon study area and bituminous beds extend beneath the area to depths of about 1,000 ft. The eastward extent of the deposits into the study area is undetermined and subsurface data are lacking. Currently (1989) no bituminous sandstone deposits are being developed to produce energy in the United States.

Uranium occurrences are found in the Desolation and Floy Canyons study areas. Ninety-two pounds of U3O8 (uranium concentrate) were produced from within the southeastern part of the Desolation Canyon study area and prospecting for uranium has taken place in the Floy Canyon area. Uranium minerals are localized in irregularly scattered carbonaceous material and are not disseminated into the host sandstone, which precludes a quantitative appraisal. Available evidence suggests that any future uranium discoveries in the study areas would be small or deeply buried.

Building stone and sand and gravel are found throughout all three study areas. The materials, however, have no unique qualities and economic and logistic constraints restrict the use to local markets. Nearby communities are small and a sufficient supply of similar material is present outside of the areas to satisfy this demand.

Mineral Resource Potential

Each of the study areas is estimated to have a high potential for additional undiscovered coal resources, based on core data and geophysical logs from drill holes within or near the study areas and regional stratigraphic trends. Coal beds of resource thickness (14 inches or more) are likely to occur in the Sunnyside coal zone of the Blackhawk Formation in the Turtle Canyon study area and part of the Desolation Canyon study area west of the Green River and in the Chesterfield, Ballard, and Palisade coal zones of the Neslen Formation in the Floy Canyon study area and part of the Desolation Canyon study area east of the Green River. These resources are buried beneath 3,500 ft or less of overburden in the Turtle Canyon and Floy Canyon study areas and in the Desolation Canyon study area east of the

Green River and 6,000 ft or less in the Desolation Canyon study area west of the Green River.

Coal beneath some tracts in the three study areas may attain a rank and thickness that is favorable for the production of methane. Owing to lack of information, however, the energy potential for coal-bed methane cannot be currently assessed. Therefore, the resource potential for coal-bed methane is unknown for all three study areas.

Oil and gas discoveries and several producing wells are located from less than 1 mi to about 8 mi west of the north end of the Desolation Canyon study area (fig. 4) and 5–10 mi southeast of the Floy Canyon study area. Two drill holes (holes 23 and 29, pl. 1), one less than 1 mi north of the southwestern part of the Desolation Canyon area, and the other less than 0.5 mi from, and between the northern boundary of the Floy Canyon area and southeastern part of the Desolation Canyon area, showed deposits of natural gas at depths between 4,500 and 7,100 ft. The described wells produce from rocks that range in age from Jurassic to Eocene. Helium is produced from rocks of Permian age in the Woodside reserve, about 4 mi west of the Desolation Canyon study area.

The mineral resource potential for oil and gas is estimated to be high for the northern part of the Desolation Canyon study area and moderate for the Turtle Canyon, Floy Canyon, and southern part of the Desolation Canyon study areas (fig. 2 and pl. 1).

Oil-shale beds are found in the Eocene Green River Formation that underlies small areas in the northern and eastern parts of the Desolation Canyon study area. The Bureau's study estimates a possible oil yield of 15 gallons per ton for a sequence 15–45 ft thick in the northernmost part of the Desolation Canyon Wilderness Study Area. The energy resource potential for additional oil-shale resources is estimated to be low in each of the three areas.

Bituminous sandstone has been quarried about 10 mi west of the northern end of the Desolation Canyon study area for use as paving material (fig. 5). The bituminous deposits occur in the Eocene Green River Formation and the Paleocene and Eocene Colton Formation (Wasatch Formation of some reports) and equivalent strata are found less than 1,000 ft beneath the study area. The extent of the beds is not known, but some bitumen-bearing beds probably extend beneath the study area. The mineral resource potential for bituminous sandstone is high in the northern tract of the Desolation Canyon study area and low in all other tracts.

Ninety-two pounds of U_3O_8 (uranium concentrate) were produced from a deposit in the southeastern part of the Desolation Canyon study area, and uranium has been prospected in the Floy Canyon study area (fig. 5). The uranium mineralization is localized in carbonized material that is irregularly distributed within paleochannels near the base of the Paleocene and Eocene Wasatch Formation. Results of the Bureau's study of workings and prospects indicate that the mineralization was not disseminated into the host sandstone, and no quantitiative resource estimate was possible. The potential for additional uranium in the basal conglomeratic unit of the Wasatch Formation, which underlies most of the Floy Canyon study area and the southeastern part of the Desolation Canyon study area, is assessed as moderate due to the unpredictable distribution and limited amount of carbonized plant material in the unit. The potential for uranium in the Morrison Formation in all the study areas is assessed as low due to excessive burial depth and unpredictable distribution of any uranium that may occur in the formation. These two formations are the known uranium hosts in or near the study areas.

Geochemical analysis of stream sediments and rock samples from the study areas showed no metal concentrations that are considered significant. Unfavorable geologic environment, absence of mines and prospects, and lack of significant geochemical anomalies indicated that the resource potential for metals is low. The resource potential for bentonite and zeolites is low due to the thinness and impurity of the beds containing these minerals. No geothermal sources are known within the study areas and the energy resource potential for undiscovered geothermal energy is estimated to be low.

INTRODUCTION

At the request of the U.S. Bureau of Land Management (BLM), the U.S. Bureau of Mines (USBM), in cooperation with the U.S. Geological Survey (USGS), conducted a mineral investigation of the Desolation Canyon, Turtle Canyon, and Floy Canyon Wilderness Study Areas, in Carbon, Emery, and Grand Counties, Utah. The wilderness study areas respectively comprise 242,000; 33,690; and 23,140 acres of public land managed by the Bureau of Land Management Moab District Office. The study areas are located in rugged terrain north of Green River, Utah, and are accessible only by unimproved dirt roads (fig. 1).

This report presents an evaluation of the mineral endowment (identified resources and mineral resource potential) of the study area and is the product of several separate studies by the U.S. Bureau of Mines and the U.S. Geological Survey. Identified resources are classified according to the system of the U.S. Bureau of Mines and U.S. Geological Survey (1980), which is shown in the Appendix of this report. Identified resources are studied by the USBM, which surveyed and studied mines, prospects, and mineral occurrences. Mineral resource potential is the likelihood of occurrence of undiscovered metals and nonmetals, industrial rocks and minerals, and of undiscovered energy sources (coal, coal-bed methane, oil, gas, oil shale, bituminous sandstone, and geothermal sources) (fig. 2). Mineral resource potential is classified according to the system of Goudarzi (1984), and the classification system is shown in the Appendix. Undiscovered resources are studied by the USGS, based on regional geological, geochemical, and geophysical surveys.

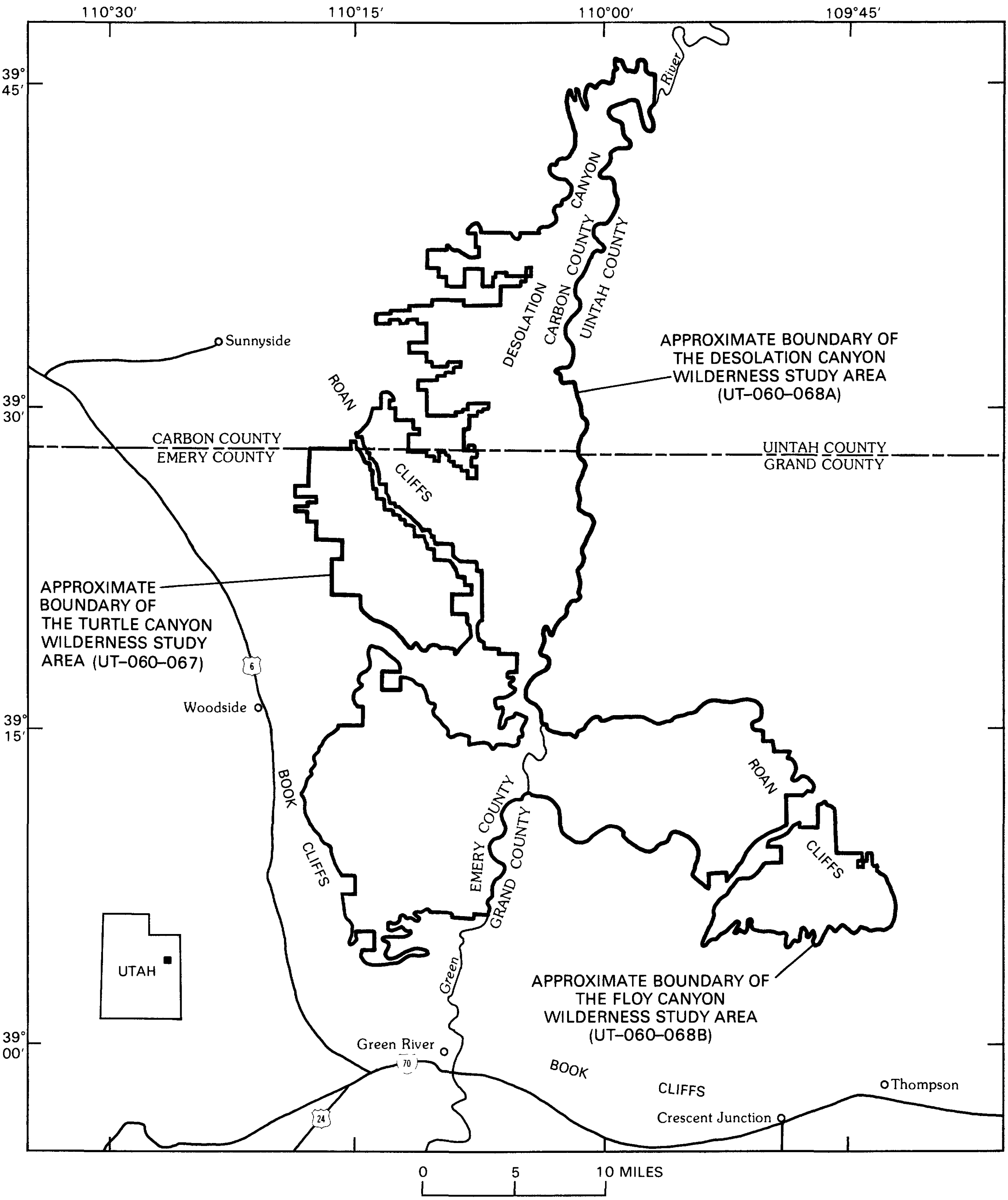

Figure 1. Index map showing location of the Desolation Canyon, Turtle Canyon, and Floy Canyon Wilderness Study Areas, Carbon, Emery, and Grand Counties, Utah.

Previous Investigations

The region that includes the three study areas has been the subject of many studies because of the abundant occurrences of energy minerals and excellent exposures of Cretaceous and Tertiary rocks. Comprehensive discussions of the geology and coal resources in the area, published by Clark (1928), Fisher (1936), and Fisher and others (1960), incorporated much of the previously published work. Young (1955) studied the Upper Cretaceous rocks of the Book Cliffs. Doelling's (1972a, b) description of the Book Cliffs and Sego Coal Fields summarized and updated the geology and coal information reported in previous publications. A mineral appraisal by Cohenour (1963) covered lands in the Roan Plateau between the Book Cliffs and the Green River in T. 14, 15, 16, and 17 S., R. 14, 15, and 16 E. Maberry (1971) focused on the sedimentary features of the Blackhawk Formation, and Osterwald and Maberry (1974) mapped the geology and completed engineering studies in the Woodside quadrangle. USGS open-file reports by AAA Engineering and Drafting, Inc. (1979a-d), and Albee (1979) discussed the coal resources and presented geophysical and lithological logs for 13 holes drilled in the Woodside and Range Creek quadrangles. A correlation chart of Upper Cretaceous and lower Tertiary rock units by Fouch and others (1982) presented preliminary interpretations of correlations between major rock units in and near the study areas.

Studies addressing the petroleum possibilities of the Uinta Basin and the region including the study areas were published by the Utah Geological and Mineralogical Survey (Crawford, 1963; Ritzma and Seeley, 1969; and Campbell and Ritzma, 1979), U.S. Geological Survey (Cashion, 1967; Molenaar and Sandberg, 1983), U.S. Bureau of Mines (Ball Associates, Ltd., 1965), and Intermountain Association of Petroleum Geologists (Preston, 1961; Sabatka, 1964), and Utah Geological Association (Picard, 1985).

Investigations by the U.S. Bureau of Mines

The Bureau's investigation included a review of literature related to the mineral resources and mining activity in and near the study areas. Mining claim information and land status records were obtained from the BLM State Office in Salt Lake City, Utah. Minerals information and production data were assembled from USBM files and other sources.

Two USBM geologists spent 20 field days examining mines, prospects, and mineral occurrences inside and near the study areas. The examination included reconnaissance by helicopter, four-wheel-drive vehicle, and foot traverses of the areas. Mining claim locations and mineral occurrences were examined, and prospects within the study area were surveyed by tape-and-compass method, mapped, and sampled. Twenty-eight samples were collected by Bureau personnel from workings and mineralized areas. Bondar-Clegg, Inc., Lakewood, Colorado, analyzed 19 samples for uranium by fluorometry and for 33 elements by emission spectroscopy to identify any unsuspected element concentrations. Proximate and ultimate analyses, and heat value determination of nine coal samples were made by Hazen Research, Inc., Golden, Colorado. Coal rank is based on the classification system of the USGS (Wood and others, 1983) and the American Society for Testing Materials (1982). See coal resource chart in Appendix for explanation of terms. Sample data were evaluated by McDonnell (1988); complete sample data are available for public inspection at the Bureau of Mines, Intermountain Field Operations Center, Building 20, Denver Federal Center, Denver, Colorado.

Acknowledgments

Appreciation is extended to Kaiser Coal Company representatives for providing company information concerning the Sunnyside coal zone, and special thanks are expressed to W.B. Cashion of the USGS for assistance concerning drill hole data and petroleum resource information.

Investigations by the U.S. Geological Survey

In 1986 and 1988 the U.S. Geological Survey conducted investigations to assess the potential for undiscovered mineral and energy resources of the study areas. The investigations included field studies and a literature review of published and unpublished geologic data pertaining to the study areas and the surrounding region. Field investigations were conducted by James Kilburn, Harlan Barton, and Karen Kelley who collected stream-sediment and rock samples for geochemical analysis and searched for mineralized areas. A geophysical survey of the study areas was conducted by Dolores Kulik. An aerial and ground survey of the southern parts of the Desolation Canyon and Floy Canyon study areas was made by Karen Franczyk and Janet Pitman to determine the stratigraphic relations and ages of some Upper Cretaceous and lower Tertiary rocks.

Acknowledgments

We thank the Utah Geological and Mineral Survey for providing information on mineral resources from their files and John R. McDonnell, Jr., of the U.S. Bureau of Mines for assistance concerning base map materials and coal resource information.

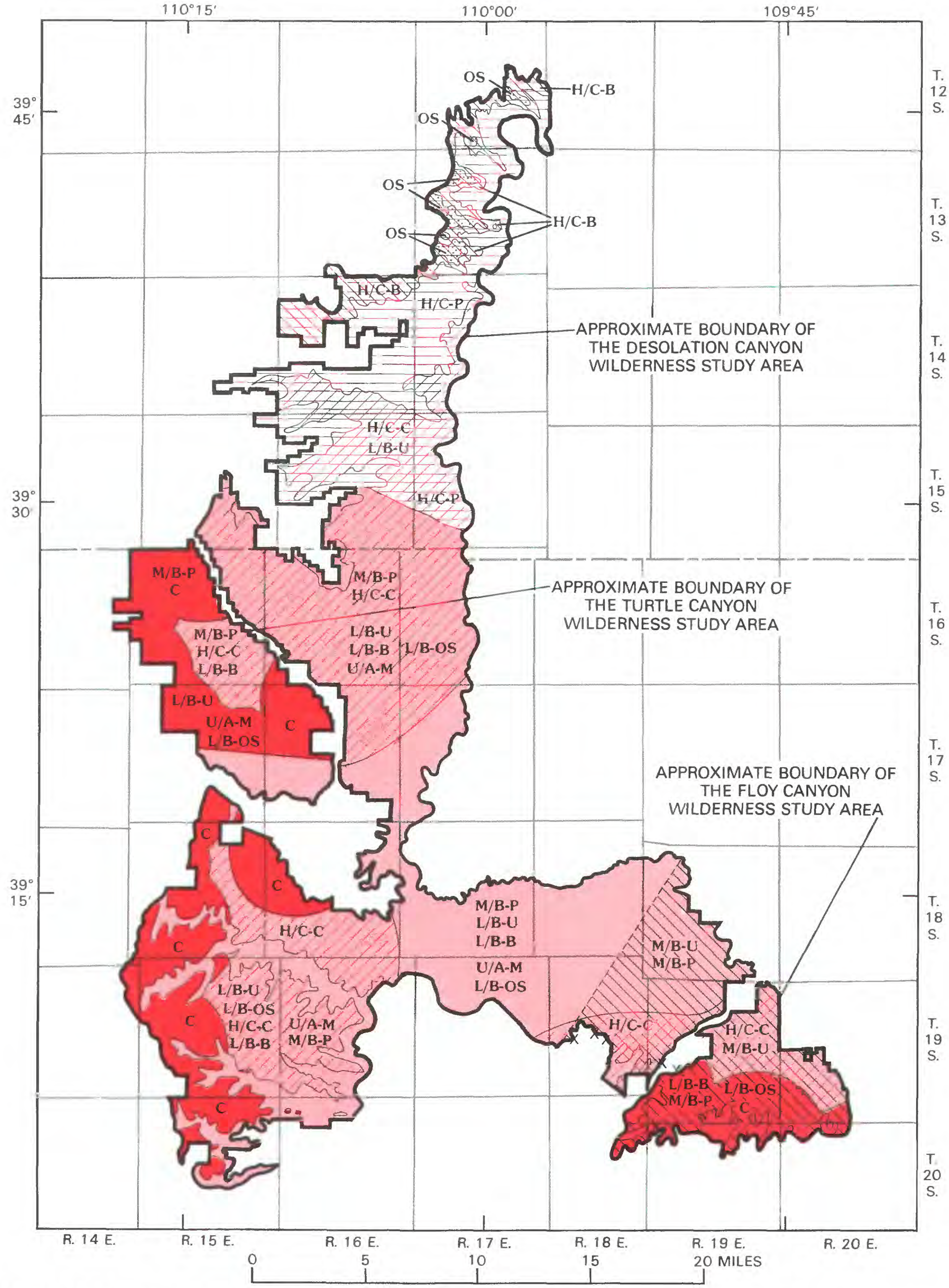

Figure 2 (above and facing page). Summary map showing identified resources and mineral and energy resource potential of the Desolation Canyon, Turtle Canyon, and Floy Canyon Wilderness Study Areas, Carbon, Emery, and Grand Counties, Utah.

EXPLANATION OF MINERAL AND ENERGY RESOURCES POTENTIAL

[Entire study areas have low mineral resource potential for metals besides uranium, bentonite, zeolite, and geothermal energy, with certainty level B. Overlapping patterns indicate areas having potential for more than one resource]

Symbol	Explanation
C	**Geologic terrane underlain by identified coal resources**—Resources west of the Green River are in the Sunnyside coal zone of the Blackhawk Formation and resources east of the Green River are in the Chesterfield, Ballard, and Palisade coal zones of the Neslen Formation
OS	**Geologic terrane underlain by subeconomic oil shale (shale 15 or more ft thick yielding an average of 15 gallons of oil per ton)**—In the Green River Formation
L/B–OS	**Geologic terrane having low mineral resource potential for oil shale, with certainty level B**
M/B–U	**Geologic terrane having moderate mineral resource potential for uranium, with certainty level B**—Associated with carbonized plant remains in conglomeratic beds in the basal part of the Wasatch Formation
L/B–U	**Geologic terrane having low mineral resource potential for uranium, with certainty level B**
H/C–C	**Geologic terrane having high mineral resource potential for coal, with certainty level C**—In the Blackhawk Formation west of the Green River and in the Neslen Formation east of the Green River
H/C–P	**Geologic terrane having high mineral resource potential for oil and gas, with certainty level C**—In rocks of Mesozoic and Tertiary age
M/B–P	**Geologic terrane having moderate mineral resource potential for oil and gas, with certainty level B**—In rocks of Mesozoic age
H/C–B	**Geologic terrane having high mineral resource potential for bituminous sandstone, with certainty level C**—In upper part of Colton Formation and lower part of Green River Formation
L/B–B	**Geologic terrane having low mineral resource potential for bituminous sandstone, with certainty level B**
U/A–M	**Geologic terrane having unknown mineral resource potential for coal-bed methane, with certainty level A**—Applies to all three study areas
X	**Approximate location of uranium mine adit or prospect**

Letter symbols shown, other than those indicating mineral resource potential or certainty level:

C	Coal
OS	Oil shale
U	Uranium
P	Petroleum
B	Bituminous sandstone
M	Coal-bed methane

APPRAISAL OF IDENTIFIED RESOURCES

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U.S. Bureau of Mines

Mining and Mineral-Exploration Activity

Coal

The Turtle Canyon Wilderness Study Area and part of the Desolation Canyon Wilderness Study Area are in the Book Cliffs Coal Field, and parts of the Desolation Canyon and Floy Canyon study areas are in the Sego Coal Field (fig. 3). The Book Cliffs Coal Field and the Sego Coal Field, as defined by Doelling (1972a, b) lie west and east of the Green River, respectively. Part of the Turtle Canyon study area is in the Book Cliffs Known Recoverable Coal Resource Area (KRCRA) and the Floy Canyon study area is near the Thompson Canyon KRCRA (fig. 3).

Development and Production

Mining in the Book Cliffs field began in the late 1880's. Production came from several different coal zones within the Blackhawk Formation, but in the vicinity of the study areas, the Sunnyside coal zone contains the only coal of commercial and resource interest. Evaluation of the Beckwith coal zone, which occurs in the upper part of the Blackhawk Formation, was precluded from commercial and resource interest due to isolated outcrops and lenticular beds.

The Sunnyside coal zone was discovered in 1898 in the vicinity of the Sunnyside Mine, 7–10 miles (mi) west to northwest of the Turtle and Desolation Canyons study areas (fig. 3). The mine is still active today (1989), and at one time it had the largest single coke plant in operation in the United States. The Sunnyside zone is in the Blackhawk Formation, and the coal rank is high-volatile A or B bituminous. Coal zones are as thick as 18 feet (ft), but most of the mined zones are 10–16 ft thick (normally includes two beds, each as thick as 8 ft). Current production is for domestic and Japanese use in steam (electrical) generation, steel manufacturing, and as a source or component of some chemical products. Total past production from the Sunnyside coal zone is estimated to be about 120 million tons. (Information and data from Maberry, 1971; Doelling, 1972a; Doelling, Smith, and Davis, 1979; Doelling, Smith, Davis, and Hayhurst, 1979; BLM files; and Ronald Hughes and others, Kaiser Coal Company, oral commun., 1986.)

At present (1989), Kaiser Steel Corporation owns the Sunnyside Mine and holds a majority of the coal leases in the vicinity (fig. 3). In 1986, company representatives indicated that the Sunnyside Mine had recoverable coal reserves of about 60 million tons, and had delineated an additional 100–120 million tons of in-place reserves (recoverable coal is about 60 percent of in-place coal) on their south lease property. The south lease, which covers extensions of coal in the Geneva and Book Cliffs Mines, is adjacent to and extends into the western part of the Turtle Canyon Wilderness Study Area (fig. 3). (Data from Ronald Hughes and others, Kaiser Coal Co., oral commun., 1986.)

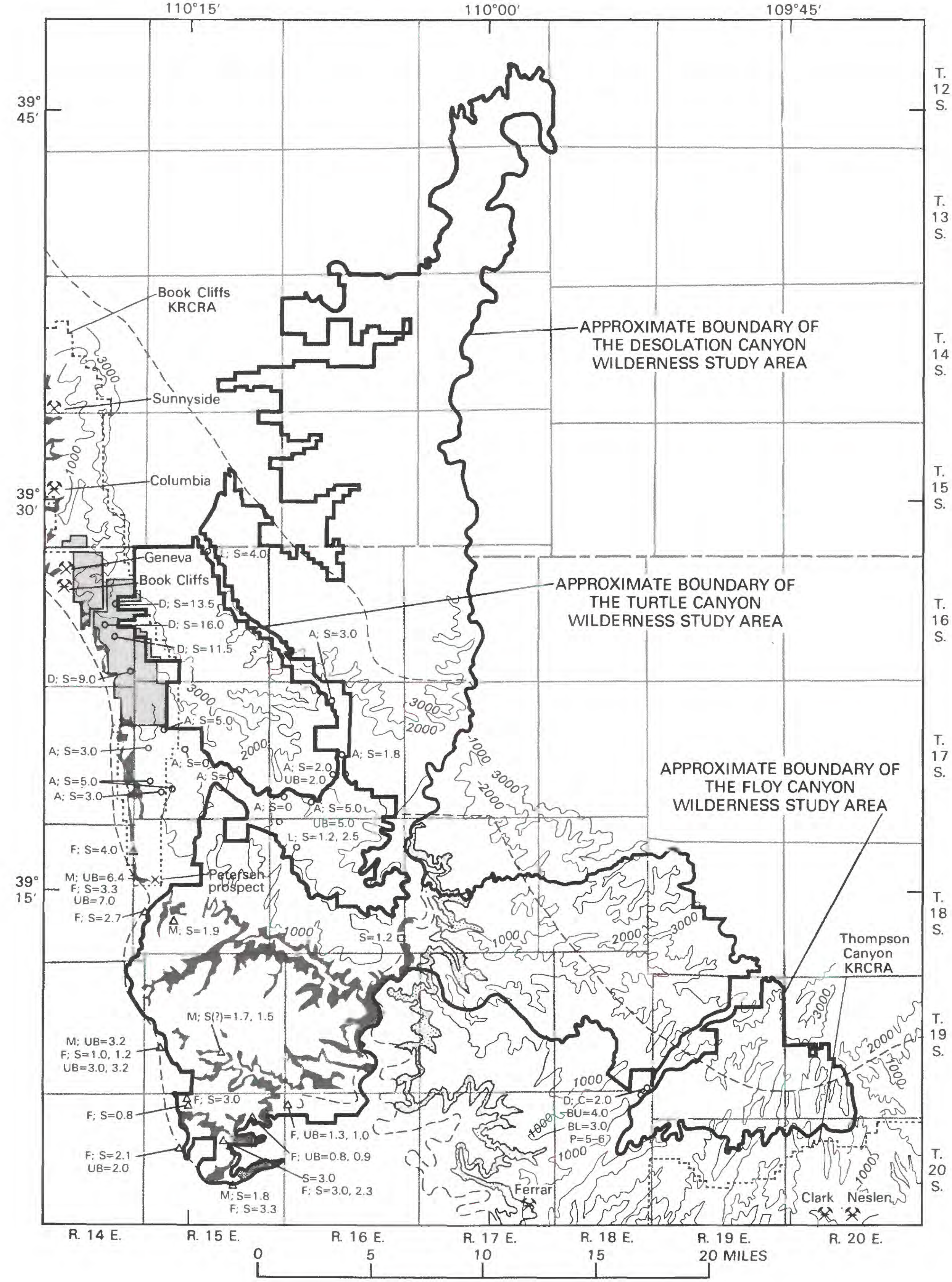

Figure 3 Coal exploration and development activity in and near the Desolation Canyon, Turtle Canyon, and Floy Canyon Wilderness Study Areas, Utah.

EXPLANATION

- - - - - - Approximate boundary of the Book Cliffs coal field (west of the Green River) and Sego coal field (east of the Green River)

-------------- Book Cliffs and Thompson Canyon Known Recoverable Coal Resource Areas (KRCRA)

Coal leases—Showing the Kaiser Coal Company South Lease property

Exposed Blackhawk Formation (only shown west of the Green River)

Exposed Neslen Formation (only shown east of the Green River)

—1000— Overburden thickness in feet; to the Sunnyside coal zone west of the Green River, and to the top of the Neslen Formation east of the Green River

⚒ Coal mine, operating

⚒ Coal mine, not currently operating

× Coal prospect

o Drill hole locality

Coal data locality, showing data source; coal zone, and thickness in feet. S, Sunnyside; UB, Upper Blackhawk; C, Chesterfield; B, Ballard (U, upper; L, lower); and P, Palisade

oL Drill hole, data from individual well log

oA Drill hole, data from Albee, 1979

oD Drill hole, data from Doelling, 1972a, b

×M Prospect, data from McDonnell, 1988

ΔF Outcrop, data from Fisher, 1936

ΔM Outcrop, data from McDonnell, 1988

□S=1.2 Thickness reported by Mutschler, 1969

Mining in the Sego Coal Field was first recorded in 1900 in Sego Canyon 3–5 mi south of the southeastern end of the Floy Canyon study area (fig. 3). The coal was used mainly by the railroad but was also transported for use in the midwestern and northwestern parts of the United States. Over the years more mines opened in the field, but production was small and mostly supplied local needs. Commercial coal occurs in four zones within the Neslen Formation: the Carbonera (which does not occur in the study areas), Chesterfield, Ballard, and Palisade. The coal rank is high-volatile C bituminous, and it is rarely found in beds that are thicker than 5 ft. Doelling (1972b, p. 207) estimated total production from the Sego Coal Field at less than 2.7 million tons of coal. Estimated in-place reserves for the field range widely from 264 million to 691 million tons in beds 4 ft or more in thickness. Most of the reserves occur east and southeast of the Floy Canyon study area. Doelling (1972b, p. 207) reported that all the mines were shut down in 1972, but during the Bureau's field reconnaissance in 1986, one mine in Thompson Canyon appeared to be active intermittently and on a small scale. (See Doelling, Smith, and Davis, 1979; and BLM file data.)

Uranium

BLM file data indicate that, as of 1975, 92 pounds (lb) of U3O8 (uranium concentrate) were produced from the Joker claims within the Desolation Canyon study area in sec. 15, T. 19 S., R. 18 E. (fig. 5; pl. 1). The uranium minerals formed in carbonized plant material in paleochannels in the basal part of the Wasatch Formation. Prospecting for uranium in the Wasatch Formation also took place on the Pine Tree and Ute claims in sec. 20, T. 19 S., R. 19 E. and sec. 6, T. 20 S., R. 19 E. respectively, in the Floy Canyon study area (fig. 5; pl. 1), but the size of the workings indicate that little or no material was produced. As of January 22, 1987, none of these previously claimed areas was covered by mining claims on file with the BLM.

Uranium deposits have been intermittently prospected or mined for many years in areas west and south of the Desolation Canyon study area. The principal source of the uranium was the Salt Wash Member of the Upper Jurassic Morrison Formation. The deposits are generally at depths less than 1,000 ft and formed in paleochannels containing carbonized or silicified vegetal debris. In the study areas little is known of the character of this formation, and it lies at least 5,000 ft below the surface.

Oil and Gas

There are no producing oil or gas wells within the boundaries of the study areas. Sporadic drilling for oil and natural gas in the vicinity of the study areas began in the 1890's. In 1925, gas discoveries were made in the Cisco Dome, about 10 mi southeast of the Floy Canyon study area, in lenticular sands in the Upper Cretaceous Dakota Sandstone, Upper Jurassic Morrison Formation, and Lower and Upper(?) Cretaceous Cedar Mountain Formation. Exploration for oil and gas in the Peters Point area along the northern end of the Desolation Canyon study area (fig. 4; pl. 1) began about 1951. Natural gas was discovered in 1953 in the Colton (Wasatch of some reports) and Green River Formations; thus, the Peters Point Known Geologic Structure (KGS) was established. In 1982 there were eight producing gas wells and one producing oil well in the Peters Point KGS from less than 1 mi to about 8 mi west of the northern end of the Desolation Canyon study area (fig. 4). In 1981, Tenneco

Oil discovered gas in the Dakota Sandstone, in T. 19 S., R. 19 E. (hole 29, pl. 1) and the Rattlesnake Canyon KGS (fig. 4) was delineated. The KGS overlaps onto the Floy Canyon Study area and is adjacent to the eastern part of the Desolation Canyon study area. In 1983 Gulf Oil Co. completed a well (owned in 1989 by Chevron Oil Co.) in T. 18 S., R. 16 E. (hole 23, pl. 1) between the Desolation Canyon and Turtle Canyon study areas, which yielded gas from the Cedar Mountain Formation. (See Burchell, 1964; Young, 1983; and BLM file data.)

The Woodside Helium Reserve (fig. 4) is 4–7 mi west of the southwestern part of the Desolation Canyon study area. The reserve covers the Woodside Dome, which is a north-south elongate asymmetrical anticline that has trapped helium-bearing natural gas reportedly in the Lower Permian Coconino Sandstone or the Kaibab Limestone but most likely occurs in the Lower Permian Cedar Mesa Sandstone Member of the Cutler Formation (Witkind, 1988). The reserve was set aside by the U.S. Government in 1924 because, at that time, helium was considered important to national security due to its nonflammable qualities for use in lighter-than-air craft. The well was plugged when the land was set aside; there is no record of any helium production. (See Osmond, 1956; Seeley, 1961.)

Oil Shale

The Green River Formation contains oil-shale deposits of commercial interest in northeastern Utah, southwestern Wyoming, and northwestern Colorado. The high-grade deposits occur in beds of the Mahogany zone in the Parachute Creek Member of the Green River Formation (the upper member of the Green River Formation in the study areas is equivalent to part of the Parachute Creek Member). The richest deposits in Utah are located in a part of the Uinta Basin that lies northeast of the study areas. In situ shale-oil extraction experiments conducted in the northeastern part of the basin have given some encouraging results. In one large scale operation on federal lands, private industry did a significant amount of construction and developmental mining in preparation for underground mining and surface retorting before closing due to decreasing oil prices. Currently (1989) no attempt is being made in Utah to commercially produce oil from shale. Cashion (1967, p. 30) estimated that oil shale in and adjacent to the Mahogany zone in the Uinta Basin that yields an average of 15 gallons of oil per short ton (gal/st) from a continuous sequence 15 ft or more in thickness contains 321 billion barrels (barrel = bbl) of oil (1 bbl = 42 U.S. gallons). The Desolation Canyon study area extends into the edge of the area of Cashion's estimate, but it is 30–40 mi southwest of the most favorable area for future oil shale development. (See Quigley and Price, 1963; Cashion, 1967.)

Bituminous Sandstone

Since 1980, exposed bituminous sandstone beds and an area underlain by potentially commercial deposits have been included in the Sunnyside and vicinity Designated Tar Sands Area (DTSA); the DTSA also includes a small part of the northwestern side of the Desolation Canyon study area (fig. 5). The bitumen is in sandstones of the Colton and Green River Formations. Bituminous sandstone was quarried intermittently about 10 mi west of the northern third of the Desolation Canyon study area near Sunnyside from 1892 to 1956. Total production was at least 750,000 tons for use as paving material in several western States. In the 1960's, the Shell and Signal oil companies experimented with using steam for in situ oil extraction. In the late 1970's, exploratory drilling was increased throughout the vicinity to evaluate the extent of the bituminous beds and their potential as an oil source. In late 1982, four companies had expressed interest to the BLM for Combined Hydrocarbon Leasing Tracts within the DTSA. (See Holmes and Page, 1956; Ball Associates, Ltd., 1965; Campbell and Ritzma, 1979; and BLM file data.)

RESOURCE APPRAISAL

Coal

Sunnyside and Beckwith Coal Zones

The Sunnyside coal zone crops out 1–4 mi west of the Turtle Canyon study area and along the southwestern boundary of the Desolation Canyon study area, and underlies both (fig. 3). The coal beds are locally continuous, thicken and thin within the coal-bearing zone, and are splits of a single bed that occurs farther to the northwest. Beds are thickest northwest of the Turtle Canyon study area; to the south and east, the split progressively becomes larger, as much as 75 ft, and the beds become thinner. An aerial reconnaissance of the exposed coal beds indicated that they thin rapidly away from the face of the Book Cliffs; they are virtually nonexistent along the Green River. Thicknesses of some measured sections of Sunnyside coal in outcrops and drill holes are shown in figure 3. Samples from the southwestern part of the Desolation Canyon study area exhibit two characteristics of oxidized (weathered) coal: lower heat values and volatile matter, as compared to fresh coal. The apparent rank of oxidized coal samples is subbituminous B to high-volatile C bituminous, which suggests that fresh coal at the sampled localities might rank high-volatile A to C bituminous (McDonnell, 1988).

Coal from the Sunnyside Mine is blended with low- to medium-volatile coals (coals containing higher amounts of fixed carbon and lower amounts of volatile matter) to achieve metallurgical quality. This coal is mainly used in blast furnaces and for making steam in electrical generation plants. Metallurgical-quality coal is determined, among other things, by a low sulfur and ash content. Coal samples collected by the Bureau generally show high sulfur and ash content (McDonnell, 1988). Some of the elevated ash content may be due to clay particles along fractures in the coal due to oxidation. The high sulfur and ash content suggest that the quality of coal in the southwestern part of the Desolation Canyon study area is lower than that to the north, and that it may not be suitable for metallurgical use. However, coal that is not suitable for metallurgical use can be used for making steam, or burned for heating and cooking (Sherman and MacMurphy, 1955, p. 9).

Data for coal resource estimates are from exploratory work by the Kaiser Coal Company, and from Fisher (1936), Cohenour (1963), Doelling (1972a, b), Albee (1979), AAA Engineering (1979a-d), McDonnell (1988), and from individual well logs. Coal resources were estimated following guidelines presented in the USGS Coal Resource Classification System (Wood and others, 1983) and are limited in the following discussions to include only coal beds classified as reserve base[1] or what would be considered minable by underground methods at the Sunnyside Mine. In 1987, the Sunnyside Mine was using underground methods; minable coal beds had an average thickness of 4.0 ft and were under less than 2,500 ft of overburden. For the convenience of using the available resource estimates, the following appraisals of coal resources use a cut-off of 3.5 ft in thickness and less than 2,000 ft of overburden for coal beds of possible economic interest.

Coal resources, some of which may be of commercial value, occur at depth in the Sunnyside coal zone in the Turtle Canyon study area, but no coal beds are exposed and none are near enough to the surface to be considered a reserve base. However, total measured, indicated, and inferred coal resources in beds meeting basic criteria (an average thickness greater than 3.5 ft and under less than 2,000 ft of overburden) are estimated to be 6.3 million short tons. Table 1 shows a detailed breakdown of the estimated resources, and figure 3 shows the area covered by less than 2,000 ft of overburden.

In the southwestern part of the Desolation Canyon study area, a reserve base of about 4.6 million short tons of coal is estimated for the Sunnyside coal zone (table 2). The zone is generally shallower and thinner than that to the north (fig. 3); some coal-bed thicknesses are greater than 3.0 ft, but most are less than 2.3 ft. The beds in the southernmost part of the study area are cut by erosion leaving the coal as discontinuous layers in several mesas that vary in surface area from a few hundred square feet to about 2 mi^2 (square miles). The coal lies mostly in a ¾-mi-wide strip of land that begins just south of the Price River and extends about 13 mi along the Book Cliffs to the southern end of the study area (fig. 3; pl. 1). Total measured, indicated, and inferred coal resources, including only beds that meet or exceed basic criteria are estimated to be about 22 million short tons of coal. Table 2 shows a detailed breakdown of the estimated resources by category and thickness.

Coal beds in the upper part of the Blackhawk Formation (Beckwith zone) also crop out along the cliff face in the southernmost part of the Desolation Canyon study area. The beds are as thick as 3.2 ft, but they have been badly dissected by erosion and are in small, isolated mesas. The coal is lenticular and contains numerous shaly partings. The discontinuous and isolated nature of the coal beds precluded a resource estimation.

Chesterfield, Ballard, and Palisade Coal Zones

The Chesterfield, Ballard, and Palisade coal zones within the Neslen Formation crop out 3–5 mi south of the Floy Canyon study area and underlie the Floy Canyon study area and a small part of southeastern Desolation Canyon study area. No coal beds are exposed in those areas. Individual coal beds are lenticular, generally less than 5 ft thick, and degraded by partings and splits of shale. Beds are thickest east of the study areas, thin westward, and eventually pinch out near the Green River. (See Doelling, 1972b; and Fouch and others, 1982). Doelling (1972b, p. 229) reported the following coal thicknesses for a drill hole in the southeast corner of sec. 36, T. 19 S., R. 18 E.: Chesterfield zone, 2 ft; Ballard zone, upper bed 4.0 ft, lower bed 3.0 ft; and Palisade zone, 5–6 ft. Drill-log data for two holes drilled to the northeast by Tenneco (secs. 2 and 16, T. 19 S., R. 19 E., holes 29 and 30 on plate 1) show that only trace to minor coal was intercepted.

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[1]Reserve base—identified, in-place, demonstrated (measured plus indicated) coal resources that include bituminous coal beds 2.3 ft or more in thickness, at depths to 1,000 ft (see Wood and others, 1983).

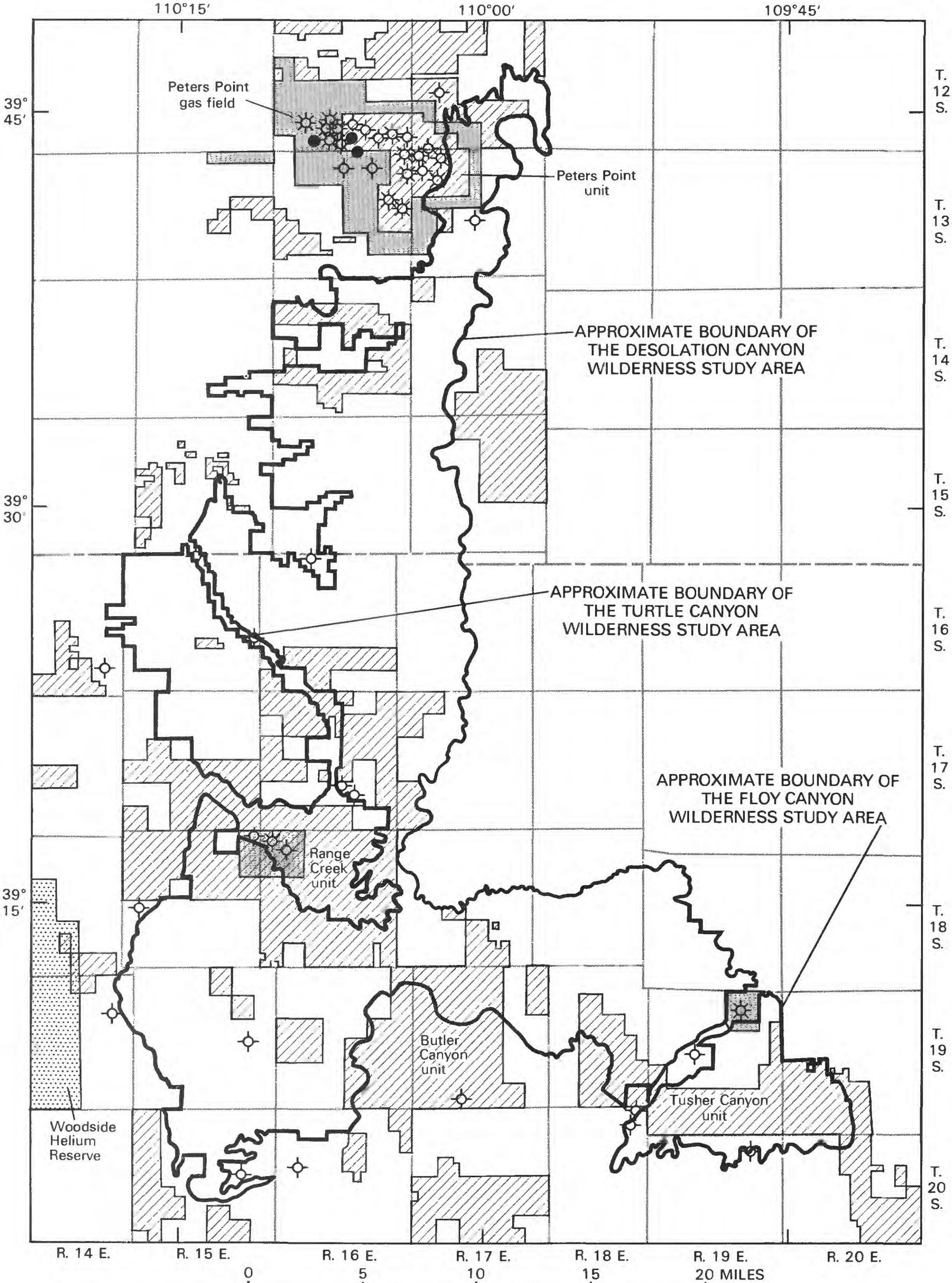

Figure 4 (above and facing page). Wells, dry holes, Known Geologic Structures, oil and gas leases and unit lease agreements, and Woodside Helium Reserve in and near the Desolation Canyon, Turtle Canyon, and Floy Canyon Wilderness Study Areas, Utah.

EXPLANATION

Known Geologic Structure (BLM files, May 1987)

Helium reserve (BLM files, May 1987)

Oil and gas leases and unit lease agreements (BLM files, May 1987)

Oil and gas wells—Localities from BLM files and individual well records

Gas well

Oil well

Shut in gas well

Dry hole

Coal from the Neslen Formation in the Sego field (fig. 3) is generally of high-volatile C bituminous rank and has a high heat value, but much of it is impure. Neslen coal that has been mined from near the Floy Canyon study area was used by the railroads and locally for heating and cooking.

Coal resources in the Floy Canyon study area were estimated by using an average thickness for each of the coal zones and data from Doelling (1972b) and individual well logs (table 3). The estimates include about 50 percent indicated and inferred resources, and about 50 percent hypothetical resources. No coal beneath the study area can be considered as reserve base or measured resources because the beds are too deeply buried, too thin, or too far from a point of measurement. The Ballard coal zone is the only one that meets basic criteria and would be considered to have coal of possible economic interest, about 45 million short tons of indicated and inferred resources. Figure 3 shows the area of resource estimate covered by less than 2,000 ft of overburden. No estimate of coal resources was made for the southeastern part of the Desolation Canyon study area because of a lack of subsurface data. Outcrops west of the Floy Canyon study area and drill holes between the Desolation Canyon and Floy Canyon area boundaries indicate that the coal zones extend beneath the Desolation Canyon area. Data are not available northwest of the drill sites to allow linear extrapolation or thickness estimates within the study area.

Economic Feasibility

The identified coal resources of the study areas are in-place tonnages and include coal that would not be extracted during mining. By applying the Sunnyside Mine recovery rate and production costs (long-wall mining methods and average recovery rate of about 60 percent according to Rob Wiley, Kaiser Coal Co., oral commun., 1987) a gross profitability range can be determined for the coal resources in the study areas. Table 4 presents this data and attempts to show the gross profitability that might be expected for the identified coal resources considered to be of possible economic interest. Using the Sunnyside Mine production rate (about 1.5 million short tons of coal a year) mine-life and yearly gross profitability is estimated to be as follows: Turtle Canyon—2.5 years, $0 to $18.2 million/year; SW. Desolation Canyon—(reserve base) 1.9 years, $0 to $17.7 million/year, (resources) 8.8 years, $0 to $18 million/year; Floy Canyon—18 years, $0 to $18 million/year.

Coal resources within the Turtle Canyon study area have a gross profitability of as much as $45 million, but a short mine life. The coal, however, is an extension of well-defined reserves in the Kaiser Coal Co. south lease, which are an extension of coals that were mined at the Geneva Mine. Proximity to existing facilities at the nearby Geneva Mine and the Sunnyside Mine could permit relatively low start-up costs, and so the coal resources beneath the Turtle Canyon study area are considered to be economically developable.

In the southwestern part of the Desolation Canyon study area, the estimated gross profitability for the coal reserve base is as much as $33.6 million and for the coal resources is as much as $158.4 million, but total start-up costs make the reserve-base coal subeconomic. If future exploration were to expand the reserve base to include some of the estimated resources in the area, the coal could be rated marginally economic.

Coal resources in the Floy Canyon study area have an estimated gross profitability of as much as $324 million and an 18-year mine-life, but because of location and lack of facilities the coal is considered subeconomic and not likely to be developed in the near future.

Oil and Gas

Oil and gas discoveries have been reported in strata and structures that can be projected into the study areas. Gas wells and dry holes in or very near the study areas are listed in table 5 and shown on plate 1, and wells, leases, and Known Geologic Structures are shown in figure 4. The southeast projection of the Jack Canyon anticline in the Peters Point field trends beneath the northern part of the Desolation Canyon study area, and the Uncompahgre uplift extends beneath all three study areas (pl. 1). Anticlinal folds associated with the uplift caused entrapment of oil and gas in the fields east of the Floy Canyon study area. Individual deposits within the nearby oil and gas fields are small to moderate in size, generally containing less than 50,000 bbl of oil and 1,000 million cubic feet (MMcf) of gas (BLM file data). Clem (1985) reported that cumulative production to December 1981 from the Peters Point field was 131,434

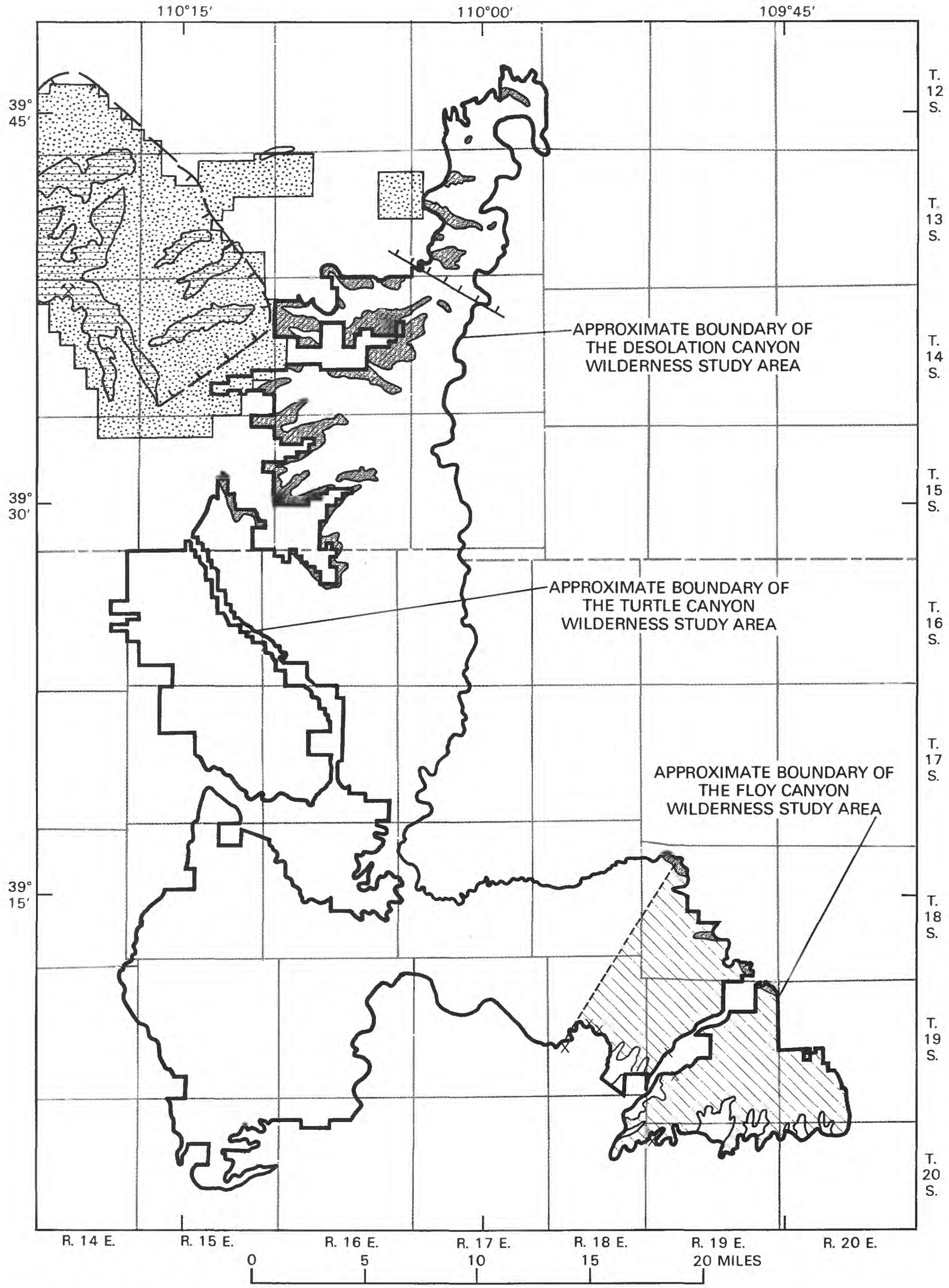

Figure 5 (above and facing page). Bituminous sandstone, oil shale, and uranium in and near the Desolation Canyon, Turtle Canyon, and Floy Canyon Wilderness Study Areas, Utah.

EXPLANATION

Known outcrop of bituminous sandstone or area where bituminous sandstone can be reliably projected based on data from outcrops and drill holes (from Campbell and Ritzma, 1979)

Approximate boundary of area probably completely underlain by bituminous sandstone (Ritzma, 1979)

Sunnyside and vicinity Designated Tar Sand Area (DTSA)

Area underlain by oil shale in the Mahogany zone of the upper member of the Green River Formation

Approximate southwest limit of oil shale in the Mahogany zone that has an average oil yield of 15 gallons per ton and is at least 15 ft thick

Area underlain by basal conglomerate of the Wasatch Formation

X Uranium prospect or mine adit in the basal part of the Wasatch Formation

Bituminous sandstone quarry in the middle member of the Green River Formation

bbl of oil and 2,426 MMcf of gas. Preston (1961) estimated that the entire Peters Point field had an original reserve of 40,000 MMcf of gas. The Tenneco Rattlesnake Canyon 2–12 (hole 29, pl. 1) was estimated to have a gas reserve of 1,600 MMcf; estimates of reserves for the Chevron Range Creek Federal 1 were not available (BLM file data).

Oil Shale

Oil shale in the Mahogany zone of the upper member of the Green River Formation underlies about 13,150 acres within the northern and southeastern parts of the Desolation Canyon Wilderness Study Area (fig. 5; pl. 1). Extrapolation from data outside the study areas indicates that most of the acreage (10,930) is underlain by shale beds that are less than the cut-off used to determine which lands are withdrawn from oil-shale leasing (an average oil yield of 15 or more gal/st and 15 ft or more in thickness).

Precise oil-shale resource estimates cannot be made because of a lack of drilling data points in the study areas; however, core drilling information from outside the study area can be used to indicate trends in the increases or decreases in thickness and grade of the Mahogany zone within the study areas. The USBM and USGS authors (McDonnell and Cashion) concur that based on data from Cashion (1959, 1967, 1981) and Stanfield and others (1964), the remaining 2,220 acres, which are at the northern end of the Desolation Canyon study area, are estimated to contain shale that is 15–45 ft thick with a potential oil yield averaging 15 gal/st, and by averaging the thicknesses and yields, and converting to barrel per acre foot using factors discussed by Cashion (1967, p. 25), in-place inferred resources within the Desolation Canyon study area are estimated to be about 60 million bbl of shale oil. Ranney (1979, p. 13) estimated that about 50 percent of in-place shale oil would be recoverable by underground and surface mining making recoverable resources of 30 million bbl of oil.

Available information suggests that for an oil shale sequence to be considered developable it needs to have an average oil yield of 25 gal/st and a thickness of at least 25 ft (Cashion, 1967, p. 24; Ranney, 1979, p. 6). None of the oil shale beneath the study area is estimated to meet these criteria and currently (1989), there are no commercial shale oil producers in the United States. Interest in the commercial development of oil shale generally has coincided with periods of national emergency or large increases in the price of oil. To date, no technology has been developed to recover oil from shale at a price that is competitive with the world price of crude oil. However, future economic changes or advancements in recovery technology could make shale oil a commercially viable product.

Bituminous Sandstone

The Sunnyside bituminous sandstone (tar sand) deposits occur in interfingering strata of the upper part of the Colton and the lower part of the Green River Formations (pl. 1; fig. 5). Surface exposures extend about 9 mi along the steep slopes of the Roan Cliffs, 3–20 mi west of the northwest boundary of the Desolation Canyon study area. The strata dip 3–10 degrees to the northeast and underlie the study area to about 1,000 ft. Bituminous zones tend to be limited in lateral extent and can have numerous individual beds that range from 10 to 350 ft in thickness, with an entire zone being as thick as 860 ft and containing as much as 680 net feet of bituminous sand. Campbell and Ritzma (1979, p. 15) reported that thicknesses can be expected to vary considerably, and the vertical extent of the bituminous section may decrease by 75 percent within about 1.5 mi east of the outcrop (see section on resource potential for bituminous sandstone). Reported oil content for the Sunnyside DTSA ranges from 0.3 to 32 gal/st, with a mean value of about 14 gal/st, and reserve estimations range from 728 million to 5 billion bbl of oil, depending on cut-off grade used. Using known mining and processing technology, Ranney (1979, p. 28) estimated a net recovery of 500 million bbl of oil for the Sunnyside deposit, beginning with 5 billion bbl of oil as in-place reserves. (See Holmes and Page, 1956; Ball Associates, Ltd., 1965; Campbell and Ritzma, 1979; Ranney, 1979; and BLM file data).

Currently (1989) there are no bituminous sandstone deposits in the United States being developed to produce energy.

Table 1. Estimated coal resources within the Sunnyside coal zone in the Turtle Canyon Wilderness Study Area, Utah (x 1,000 short tons)

[No coal beds thicker than 1.2 ft were estimated to have less than 1,000 ft of overburden]

Classification of coal resource	Coal thickness, in feet			
	1.2-2.3	2.3-3.5	3.5-7.0	7.0-14.0
1,000-2,000 ft of overburden				
Measured	0	0	100	0
Indicated	500	1,100	800	0
Inferred	5,000	10,900	2,400	3,000
Subtotal identified	5,500	12,000	3,300	3,000
Hypothetical	0	0	0	0
2,000-3,000 ft of overburden				
Measured	0	0	0	500
Indicated	0	100	0	2,800
Inferred	4,000	18,200	12,000	19,100
Subtotal identified	4,000	18,300	12,000	22,400
Hypothetical	0	6,000	1,600	0
Greater than 3,000 ft of overburden				
Measured	0	0	0	0
Indicated	0	0	2,500	200
Inferred	0	11,700	49,600	44,500
Subtotal identified	0	11,700	52,100	44,700
Hypothetical	0	12,300	21,600	0

Uranium

Mining and prospecting for uranium have taken place in the southeastern part of the Desolation Canyon Wilderness Study Area and in the western part of the Floy Canyon Wilderness Study Area (fig. 5; pl. 1). The occurrences consist of carbonized vegetal remnants that have been mineralized with uranium in paleochannels in a conglomeratic interval at the base of the Wasatch Formation. The conglomeratic interval underlies most of the Floy Canyon study area and a small part of the southeastern part of the Desolation Canyon study area (fig. 5). Although commercial deposits of uranium are found in the Wasatch Formation in Wyoming, this formation is not known locally for significant uranium deposits.

USBM personnel took 19 samples in the mine workings and prospects across sandstone/carbonaceous zones and areas where gamma-ray scintillometer readings were judged to be high (background readings were less than 50 counts per second (cps); high was considered to be 200 cps or more, as readings of 50–150 cps were common anywhere near the workings). Chip samples contained 4–220 parts per million (ppm) uranium, with a weighted average of 62 ppm, and a select sample, which was taken across the exposed end of a carbonized log that had a scintillometer reading of greater than 10,000 cps, contained more than 2,000 ppm uranium. Commercial grade at large mines currently (1989) is about 0.5 percent (5,000 ppm) U3O8. The uranium occurrences are localized, irregularly scattered, and not disseminated into the host sandstone, which precluded quantitative resource estimations. (See McDonnell, 1988.)

Building Stone and Sand and Gravel

Building stone and sand and gravel are found throughout all three of the study areas. The materials, however, have no unique qualities and are of limited use. Material derived from sedimentary rocks is generally limited to use for building and road construction. It has high transportation costs and a low unit value, which restricts the use to local markets. Communities in the

Table 2. Estimated coal resources, showing reserve base, within the Sunnyside coal zone in the southwestern part of the Desolation Canyon Wilderness Study Area, Utah (x 1,000 short tons)

Classification of coal resource	Coal thickness, in feet			
	1.2-2.3	2.3-3.5	3.5-7.0	7.0-14.0
Less than 1,000 ft of overburden				
Measured---------------	600	800*	400*	0*
Indicated--------------	6,500	3,400*	0*	0*
Inferred---------------	47,500	19,000	500	0
Subtotal identified--	54,600	23,200	900	0
Hypothetical-----------	62,500	1,800	400	0
1,000-2,000 ft of overburden				
Measured---------------	0	0	0	0
Indicated--------------	0	0	0	0
Inferred---------------	1,900	15,700	21,100	0
Subtotal identified--	1,900	15,700	21,100	0
Hypothetical-----------	13,600	2,800	600	0
2,000-3,000 ft of overburden				
Measured---------------	0	0	0	0
Indicated--------------	0	0	0	0
Inferred---------------	0	800	2,100	0
Subtotal identified--	0	800	2,100	0
Hypothetical-----------	0	0	0	0

*Reserve base

vicinity are small and a sufficient supply of similar material exists outside the study areas to satisfy this limited demand.

ASSESSMENT OF POTENTIAL FOR UNDISCOVERED RESOURCES

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Geology

Regional Setting

The study areas are located on the southwestern flank of the Uinta Basin, which is the northernmost section of the Colorado Plateaus physiographic province. The terrain is characterized by deeply incised canyons with walls formed by successions of cliffs in stairlike appearance. The dominant topographic feature in the region is Desolation Canyon, formed by the Green River and local tributaries. The Green River flows from north to south across the entire rock sequence exposed in the study areas. Altitudes range from approximately 4,100 ft along the Green River in the southern part of the Desolation Canyon Wilderness Study Area to approximately 9,600 ft at the top of the Roan Cliffs in the west-central part of the Desolation Canyon Wilderness Study Area.

Geologic Structure

Direction of regional dip in the study areas is northeast toward the axis of the Uinta Basin, and the strata are inclined at angles ranging from approximately 3° to 14°. The regional dip is interrupted in some areas by northwest-trending anticlines (pl. 1). Surface faults in the study areas are not structurally significant,

Table 3. Estimated coal resources in the Floy Canyon Wilderness Study Area, Utah

[>, greater than; no beds have less than 500 ft of overburden]

Average thickness (ft)	Overburden thickness (ft)	Area (acres)	Tonnage (x 10^6 short tons)
Chesterfield coal zone			
2.0	500-1,000	640	2.3
2.0	1,000-2,000	11,885	42.7
2.0	2,000-3,000	8,540	30.7
2.0	>3,000	2,075	7.5
Ballard coal zone[1]			
4.0	500-1,000	640	4.6
4.0	1,000-2,000	11,885	85.6
4.0	2,000-3,000	8,540	61.5
4.0	>3,000	2,075	14.9
Palisade coal zone			
3.0	500-1,000	640	3.5
3.0	1,000-2,000	11,885	64.2
3.0	2,000-3,000	8,540	46.1
3.0	>3,000	2,075	11.2

[1]Meets basic criteria of 3.5 ft thickness, less than 2,000 ft below surface.

generally having displacements of less than 100 ft. Deep-seated faults with major displacements trend northwest across the study areas.

The Uncompahgre uplift, a buried northwest-plunging tectonic feature bounded on the northeast and southwest by major fault zones extends across the study areas (pl. 1). There are no definitive surface manifestations of the anticlinal axis or bounding faults of the Uncompahgre uplift in the study areas and the character and magnitude of those features are interpreted by means of deep drilling and geophysical data. The Uncompahgre fault has been interpreted as a normal fault (Case, 1966) and a reverse fault (Stone, 1977; Frahme and Vaughn, 1983). Several periods of movement on the southwest bounding fault zone have displaced strata perhaps as much as 20,000 ft and produced rock sequences that differ greatly from one side of the fault zone to the other (Stone, 1977). On the crest of the Uncompahgre uplift, strata of Triassic age rest unconformably on Precambrian basement rocks; while the stratigraphic sequence immediately southwest of the uplifted block includes a very thick column of Paleozoic beds between rocks of Precambrian and Triassic age. Above the Triassic rocks, the stratigraphic sequence is virtually complete and unbroken by major faulting, but uplift and renewed movement on basement faults has produced folds near the study areas where gas has accumulated in strata of Mesozoic age (Stone, 1977).

Description of Rock Units

Rocks exposed in the study areas are of sedimentary origin and are Late Cretaceous to middle Eocene in age. Owing to facies changes and different geologic perspectives, and on the basis of observations in widely separated areas, more than one stratigraphic nomenclature has been assigned to rocks in the study areas. In this report, stratigraphic nomenclature applied to the rock sequence west of the Green River is different from that applied to the sequence east of the Green River (pl. 1). Upper Cretaceous strata west of the Green River comprise, from oldest to youngest, the upper part of the Mancos Shale, Blackhawk Formation, Castlegate Sandstone, mudstone member of the Price River Formation, Bluecastle Tongue of the Castlegate Sandstone, and the Price River Formation. Upper Cretaceous strata east of the Green River comprise, from oldest to youngest, the upper part of the Mancos Shale, Blackhawk Formation, Castlegate Sandstone, Buck Tongue of the Mancos Shale, Sego Sandstone, Neslen Formation, Farrer Formation, and Tuscher Formation.

The upper part of the Mancos Shale exposed in the study areas, exclusive of the Buck Tongue, is approximately 500 ft thick and consists of shale and some shaly siltstone. The Blackhawk Formation is 150–700 ft thick and principally composed of sandstone, siltstone, and shale with some coal beds. The Sunnyside coal zone lies in the upper part of the Blackhawk Formation and yields coal from mines west of the Turtle Canyon Wilderness Study Area. The overlying Castlegate Sandstone, exclusive of the Bluecastle Tongue, is 100–200 ft thick. The mudstone member of the Price River Formation has a maximum thickness of 400 ft and is composed of mudstone, siltstone, and sandstone. The lateral equivalent of part of the mudstone member is the Buck Tongue of the Mancos Shale, as much as 200 ft thick, consisting of shale with some sandy and silty beds. The overlying Sego Sandstone, recognized east of the Green River only, is 60–150 ft thick. The Bluecastle Tongue recognized west of the river is composed of sandstone and ranges in thickness from 80 to 200 ft. East of the river sandstones in the upper part of the Neslen are equivalent to part of the Bluecastle Tongue of the Castlegate Sandstone. The Neslen Formation, 300–450 ft thick, consists mostly of sandstone and shale and contains, in ascending order, the Palisade, Ballard, and Chesterfield coal zones. Mines a few miles south of the Floy Canyon study area have produced coal from the Neslen Formation. The Price River Formation consists of sandstone with some beds of conglomerate and

Table 4. Estimated gross profitability of coal resources in Desolation Canyon, Turtle Canyon, and Floy Canyon Wilderness Study Areas, Utah

[st, short ton; na, not applicable; selling price and production costs as of September 1987, according to Rob Wiley, Kaiser Coal Co.]

Area and classification	In-place coal (x million st)	Recoverable coal (x million st)	Selling price $25/st (x million U.S. dollars)	Selling price $30/st	Production cost $18/st	Production cost $25/st	Gross profitability range
Turtle Canyon							
Reserve base------	0	0	na	na	na	na	na
Resources---------	6.3	3.8	95	114	68.4	95	0 to 45.6
SW Desolation Canyon							
Reserve base------	4.6	2.8	70	84	50.4	70	0 to 33.6
Resources---------	22.0	13.2	330	396	237.6	330	0 to 158.4
Floy Canyon							
Reserve base------	0	0	na	na	na	na	na
Resources---------	45.0	27.0	675	810	486	675	0 to 324

mudstone. It ranges in thickness from 50 to 700 ft. The Farrer and Tuscher Formations, in ascending order, overlie the Neslen Formation and are composed principally of sandstone and shale. The combined thickness of the two units is as much as 1,600 ft.

The Upper Cretaceous rocks are unconformably overlain by Tertiary rocks. Tertiary rocks west of the Green River comprise, from oldest to youngest, the North Horn Formation, Flagstaff Member of the Green River Formation, Colton Formation, middle member of the Green River Formation, and upper member of the Green River Formation. Tertiary rocks east of the Green River have been assigned to, from oldest to youngest, the Wasatch Formation (with the beds at Dark Canyon at the base), middle member of the Green River Formation and the upper member of the Green River Formation. The North Horn Formation is composed of sandstone, siltstone, and mudstone, and the Flagstaff Member is composed of limestone, mudstone, and siltstone. Because of their intertonguing relationship these two units are mapped as one. The combined units have a maximum thickness of approximately 800 ft, thin eastward, and pinch out a short distance east of the Green River. Within the study areas the Wasatch Formation and the Colton Formation are largely temporal and lithologic equivalents. The Colton Formation (west of the Green River) consists of sandstone, siltstone, and shale and has a maximum thickness of approximately 3,500 ft. The Wasatch Formation (east of the Green River) includes a basal conglomeratic sequence, called "the beds at Dark Canyon," which underlies much of the area south and southeast of the head of Rattlesnake Canyon, located in the southeastern part of the Desolation Canyon study area (pl. 1). This Paleocene sequence is bounded at top and bottom by unconformities that converge in a northwestward direction to form the pinchout of the conglomeratic unit in the area between the head of Left Hand Tusher Canyon and the head of Rattlesnake Canyon (Karen Franczyk, oral commun., 1989). The middle member of the Green River Formation, overlying and interfingering with the Colton or Wasatch Formation, consists of sandstone, shale, and limestone and ranges in thickness from 300 to 800 ft. The Mahogany ledge, a rich oil-shale sequence at the base of the upper member of the Green River Formation overlies the middle member. That part of the upper member above the Mahogany ledge is composed of marlstone, siltstone, sandstone, and a few thin beds of oil shale. Approximately 900 ft of the upper member is exposed in the study areas and forms the highest ridges and benches.

Geochemistry

Reconnaissance geochemical surveys were conducted in the Desolation Canyon, Turtle Canyon, and Floy Canyon Wilderness Study Areas during 1986 to aid in their mineral resource assessment. Stream sediments and heavy-mineral concentrates derived from stream sediments (referred to simply as concentrates) were selected as the primary sample media. In addition, rock samples were collected in the Floy Canyon study area.

All samples were analyzed by a six-step semiquantitative emission spectrographic method for 31 elements. In addition, stream-sediment samples gathered in Desolation Canyon and Turtle Canyon study areas were analyzed by more sensitive and precise techniques for arsenic, antimony, bismuth, cadmium, gold, uranium, and zinc. Stream-sediment and rock samples collected in the Floy Canyon study area were analyzed for uranium. A complete listing of analytical results together with a description of the sampling methods, analytical

Table 5. Gas wells and dry holes in or near the Desolation Canyon, Turtle Canyon, and Floy Canyon Wilderness Study Areas

[IPF = initial production flow; MCFGPD = 1,000 cubic feet of gas per day; D and A = dry and abandoned]

Map number (plate 1)	Lease name and well number	Operator	Total depth (ft) and oldest rocks penetrated	Results, producing unit, and month of completion	
1	Peters Point 2	El Paso Natural Gas Co.	4,984, Wasatch Fm.	IPF 2120 MCFGPD from Wasatch Fm.	June 1953
2	Peters Point 36-9	Getty Oil Co.	3,430, Wasatch Fm.	D and A	Aug. 1981
3	Gulickson Federal 1	El Paso Natural Gas Co.	5,136, Wasatch Fm.	D and A	Aug. 1954
4	Peters Point 9	Kimbark Operating Co.	4,754, Wasatch Fm.	IPF 1612 MCFGPD from Wasatch Fm.	Sept. 1974
5	Peters Point 13	Reserve Oil and Gas Co.	3,750, Wasatch Fm.	IPF 435 MCFGPD from Green River Fm.	June 1977
6	Peters Point 14-9	Getty Oil Co.	3,201, Wasatch Fm.	IPF 1162 MCFGPD from Green River Fm.	Nov. 1981
7	Peters Point 4	El Paso Natural Gas Co.	5,140, Wasatch Fm.	IPF 1500 MCFGPD from Wasatch Fm.	March 1954
8	Peters Point 10	Kimbark Operating Co.	4,840, Wasatch Fm.	D and A	Sept. 1974
9	Peters Point CS-1	Reserve Oil and Gas Co.	8,309, Mesaverde Fm.	IPF 2823 MCFGPD from Wasatch Fm.	Aug. 1976
10	Peters Point 5-14	Getty Oil Co.	3,300, Wasatch Fm.	IPF 725 MCFGPD from Wasatch Fm.	Dec. 1981
11	Peters Point 14	Reserve Oil and Gas Co.	1,678, Wasatch Fm.	D and A	Aug. 1977
12	Peters Point 3	El Paso Natural Gas Co.	4,833, Wasatch Fm.	IPF 648 MCFGPD from Wasatch Fm.	Nov. 1953
13	Peters Point 7	El Paso Natural Gas Co.	5,147, Wasatch Fm.	D and A	Sept. 1955
14	Peters Point 5	El Paso Natural Gas Co.	3,200, Wasatch Fm.	D and A	June 1954
15	Arnold 25-1	Forest Oil Co.	12,602, Madison Ls.	D and A	Oct. 1959
16	Nelson 1	Chevron USA	8,752, Morrison Fm.	D and A	Oct. 1975
17	Trail Canyon 1-24	Bow Valley Petroleum Co.	12,706, Cambrian rocks	D and A	Oct. 1981
18	Lighthouse 1-4	Bow Valley Petroleum Co.	12,704, Morrison Fm.	D and A	Sept. 1985
19	Range Creek 2	Pacific Natural Gas Co.	735, Mesaverde Fm.	D and A	Aug. 1963
20	Range Creek 1-27	Pacific Natural Gas Co.	8,480, Precambrian rocks	D and A	Nov. 1962
21	Range Creek Federal 2	Chevron Oil Co.	6,650, Cedar Mountain Fm.	D and A	Aug. 1984
22	Witter Federal 1	Shamrock Oil and Gas Co.	9,394, Desert Creek Ls.	D and A	Aug. 1966
23	Range Creek Federal 1	Chevron Oil Co.	14,150, Mississippian rocks	IPF 1054MCFGPD from Cedar Mountain Fm.	March 1983
24	Norris Federal 1	Chevron Oil Co.	13,463, Mississippian rocks	D and A	June 1974
25	Barrier Bank 1	Calif-Time Petroleum Co.	8,794, Pennsylvanian rocks	D and A	July 1968
26	USA-Thomas Walsh Federal 1	Clinton Oil Co.	10,818, Permian rocks	D and A	March 1975
27	Butler Canyon USA 33-12	Tenneco Oil Co.	5,730, Entrada Sandstone	D and A	Nov. 1982
28	Tuscher Creek 1	Shamrock Oil and Gas Co.	6,468, Entrada Sandstone	D and A	Aug. 1961
29	Rattlesnake Canyon 2-12	Tenneco Oil Co.	8,174, Morrison Fm.	IPF 298 MCFGPD from Dakota Fm.	Dec. 1981
30	Rattlesnake Canyon 16-4	Tenneco Oil Co.	7,570, Entrada Sandstone	D and A	Sept. 1981
31	USA 1	R.R. Schnier and Assoc.	3,000, Morrison Fm.	D and A	Dec. 1982
32	State GRN 1	Kewanee Oil Co.	3,550, Entrada Sandstone	D and A	Aug. 1974
33	Tusher Canyon USA 1-6	Tenneco Oil Co.	5,984, Entrada Sandstone(?)	D and A	Oct. 1981
34	Tusher Canyon State	Tenneco Oil Co.	125, Tuscher Fm.	D and A	June 1982

procedures, and sample locality maps are found in Detra and others (1989), Bullock and others (1989), and Hopkins and others (1989). Day and Barton (1987) reported the results of analyzing concentrates from the Turtle Canyon study area.

Stream sediments and corresponding concentrates were collected from active alluvium in stream drainages with catchment basins ranging from fractions of a square mile area to several square miles. Stream sediments provide a representative chemical and lithologic composite of rocks exposed in the upstream drainage basin. Minor constituents found in the sediment load, such as elements possibly associated with mineral deposits, may be detected in the sediment analysis, but the influence is often small. For this reason, a second sample, the concentrate, is gathered in conjunction with the stream sediment. The intent of this medium is to concentrate the transported heavy-mineral components, which may include minerals that result from ore-forming processes. With most of the rock-forming silicates, clays, and organic material removed, elemental anomalies may be enhanced to the extent that the probability of recognizing anomalous samples is greatly improved.

Rock samples collected from unaltered and altered outcrops were analyzed to determine background levels and suites of elements associated with bedrock alteration and mineralization.

The study areas are underlain by a thick sequence of Upper Cretaceous to middle Eocene sedimentary rocks, and their expected barren nature relative to metallic mineralization is borne out by the geochemical study. Concentrate anomalies include only widespread barium, localized accumulations of strontium and zinc, and some scattered lead and tin occurrences. Stream-sediment anomalies were limited to localized arsenic, barium, copper, and zinc as well as sporadic traces of silver. Aside from their anomalous qualities, however, these elemental enrichments are not considered significant, and geochemical evidence for near-surface ore deposits or for any mineralized system of consequence is notably absent.

Barium

The study areas are characterized by abundant and widely distributed barium in the concentrate medium (greater than 10,000 ppm in all samples). With this in mind, it is of some interest that associated concentrate strontium and stream-sediment barium anomalies are for the most part confined to the Upper Cretaceous rocks that crop out in much of the Turtle Canyon study area and the southern part of Desolation Canyon study area. This collective barium-strontium enrichment is largely a chemical manifestation of the common sulfate mineral, barite. Barite was identified optically in the concentrates and subsequently confirmed by X-ray diffraction. Laser microprobe studies uncovered considerable strontium in randomly selected barite grains, allusive evidence of strontium replacing barium in a solid-solution series. The source of the barite, however, is problematic. The pervasive or ubiquitous nature of the barium and related barite would in some measure appear indicative of a regional cementation phenomena associated with authigenic processes. In any case, the barite is probably of sedimentary origin, and as such is of much too low a concentration in the stream sediments to represent a barite potential.

Barium in red-stained conglomeratic sandstone rock samples from the Floy Canyon study area ranges from 2,000 ppm to >5,000 ppm. Clean, well-sorted sandstone samples from the same area contain only 20 ppm barium. These data suggest that conglomeratic sandstone units probably contain barite as a principal cementing agent.

Uranium

As small amounts of uranium were mined from the conglomeratic unit at the base of the Tertiary Wasatch Formation within the Floy Canyon Wilderness Study Area, and in a tributary of Left Hand Tusher Canyon just to the north (pl. 1), special attention was given during the geochemical sampling to collect rock samples of this unit where it is exposed in the central and northeastern portions of the Floy Canyon study area. These samples, however, contain only moderate enrichments compared to overall background values.

Background levels for uranium in rock samples collected from the Floy Canyon area are 2.80 ppm in shale, 0.52 ppm in well-sorted buff-colored sandstone, and 2.63 ppm in red, iron-rich sandstone. Coal-rich layers in sandstone contain the highest uranium concentrations. For example, one coal-rich sample collected from near the mouth of Thompson Canyon contains 12.5 ppm uranium (as well as enrichments in several other elements). The elevated concentration of uranium may be attributed to the strong affinity of organic carbon for the adsorption of uranium and is not significant with respect to economic concentrations of uranium.

Uranium concentrations in stream-sediment samples were only slightly higher in the Floy Canyon study area, ranging from 2 to 5 ppm, in comparison to 1–2 ppm for the Desolation Canyon and Turtle Canyon study areas.

Other Metals

A small number of zinc and tin anomalies are present in concentrates gathered from the southern part of the Desolation Canyon Wilderness Study Area. Most of the anomalous zinc shows up in samples collected in and around the Beckwith Plateau (pl. 1), particularly in Long Canyon. The zinc is related to minor occurrences of sphalerite, a zinc sulfide mineral that was identified by optical and X-ray diffraction techniques in concentrate samples. Likely hosts for minor disseminations of sphalerite are the carbonaceous shales and coal seams of the Upper Cretaceous Blackhawk Formation that is extensively exposed in drainages of the Beckwith Plateau. The source of the anomalous tin is unknown.

The basis of the localized arsenic and scattered silver anomalies noted in stream sediments in the Desolation Canyon study area is conjectural. Although chemical analysis detected small amounts of arsenic in sediments gathered from throughout the study area, the region north of Cedar Ridge Canyon near the northern confines of the study area (pl. 1) is relatively enriched in this element. Despite being a pathfinder for numerous types of ore deposits, the arsenic anomalies are not considered significant with respect to near-surface or concealed mineral occurrences but may indicate comparatively high background levels of arsenic in rock units that crop out locally (possibly earmarking the carbonaceous shales and (or) tuff beds of the Eocene Green River Formation which underlies much of the region north of Cedar Ridge Canyon). The anomalous silver generally occurs as traces scattered about the study area with no apparent areal or geologically oriented pattern or elemental associations. These circumstances preclude a definitive interpretation, although a connection with mineralized rock is not apparent. Perhaps the silver is linked in some manner or fashion to coal and lignitic fragments present in the sedimentary rocks, or to oxide nodules or impregnations noted in the sandstone units. Iron oxide nodules (mostly a mixture of goethite and hematite) from the nearby Flume Canyon Wilderness Study Area have proven to contain minor concentrations of silver (Jerry Gaccetta, oral commun., 1988).

Only a few trace element anomalies in stream-sediment, concentrate, or rock samples from the Floy Canyon Wilderness Study Area may be attributed to mineralizing processes. Localized elevated concentrations of silver, copper, nickel, and zinc are characteristic of iron- and coal-rich sandstone or of iron-manganese nodules within the sandstone units.

Related anomalies in heavy-mineral-concentrate samples include tin, lead, and zinc. Samples containing anomalous concentrations of tin are scattered over a broad area in the eastern and northern portions of the study areas. Other anomalies include a single sample from Thompson Canyon with anomalous lead, and one from the western portion of the area containing anomalous zinc. Mineral phases rich in these elements were not observed in the concentrate samples, although sphalerite (ZnS) was identified in several concentrate samples from the Desolation Canyon study area to the north. The localized and high-level anomalies for lead, zinc, and possibly tin from the Floy Canyon area are interpreted to be most likely the result of contamination. There are numerous jeep trails and dirt roads throughout the area, and many small coal and (or) uranium prospects and mines in the area. Mining equipment, automobile parts, trash, and other contaminants were observed in specific areas. Although care was taken to collect the samples away from or upstream from such visible contamination, it could not always be avoided.

Geophysics

Magnetic, gravity, and radiometric studies were undertaken as part of the mineral resource evaluation of the Desolation Canyon, Turtle Canyon, and Floy Canyon Wilderness Study Areas to provide information on the subsurface distribution of rock masses and the structural framework. The magnetic and gravity data are largely of a reconnaissance nature and are adequate only to define regional structural features.

Residual intensity aeromagnetic data from four surveys are shown in figure 6 as a composite map. Contours have been joined arbitrarily at survey boundaries and are shown as dashed lines in those areas. A flight line map is shown in figure 7. Data south of 39 °N. latitude and east of 110 °W. longitude are from U.S. Department of Energy GJM–406 (1983a), north of 39 °N. latitude and east of 110 °W. longitude are from U.S. Department of Energy GJM–100 (1983b), north of 39 °N. latitude and west of 110 °W. longitude are from U.S. Dept. of Energy GJM–414 (1983c), south of 39 °N. latitude and west of 110 °W longitude are from U.S. Dept. of Energy GJM–415 (1983d). All surveys were flown with east-west flight lines at 2–5 mi intervals and at 400 ft mean elevation above the ground surface.

For this study, 113 gravity stations were measured by Kulik in and adjacent to the study areas in 1986 and 1988; additional data are from the files of the Defense Mapping Agency of the Department of Defense. Stations measured for this study were established using Worden gravimeter W–177. The data were tied to the International Gravity Standardization Net 1971 (U.S. Defense Mapping Agency, Aerospace Center, 1974) at base station ACIC 2187–1 at Grand Junction, Colorado. Station elevations were obtained from benchmarks, spot elevations, and estimates from topographic maps at 1:24,000 and 1:62,500 scales, and are accurate to ±20 and ±40 ft, respectively. The error in the Bouguer anomaly is less than 2.5 milligals (mGal) for errors in elevation control. Bouguer anomaly values were computed using the 1967 gravity formula (International Association of Geodesy, 1967) and a reduction density of 2.67 grams per cubic centimeter (g/cm^3). Mathematical formulas are given in Cordell and others (1982). Terrain corrections were made by computer for a distance of 167 km from the station using the method of Plouff (1977). The data are shown in figure 8 as a complete Bouguer anomaly map with a contour interval of 5 mGal. A station location map with index contours only is shown in figure 9.

Trends and anomaly configurations in both magnetic and gravity data are of a variety of orientations, and in many cases, merge or change direction due to a complex history of deposition and deformation in the area. East-west trends reflect the juxtaposition of Precambrian basement rocks of different lithologies during the original development and accretion of continental crust and (or) structural offset and subsequent leveling by erosion. Northwest trends are related to tectonic movements mainly during Pennsylvanian and Laramide deformation, and northeast trends are related to cross structures developed during deformation. Both northeast- and northwest-trending structures may have been controlled or localized by fault systems or weaknesses developed in the basement rocks prior to Pennsylvanian time. Subtle north-south trends are also present in the geophysical data and may be related to thrust belt development to the west of the area during Jurassic to Tertiary deformation.

The aeromagnetic signature in the northeastern two-thirds of the map (fig. 6) is characterized by generally linear, largely east-west-trending, high anomalies separated by low anomalies of smaller magnitude. Similar alternating high and low anomalies

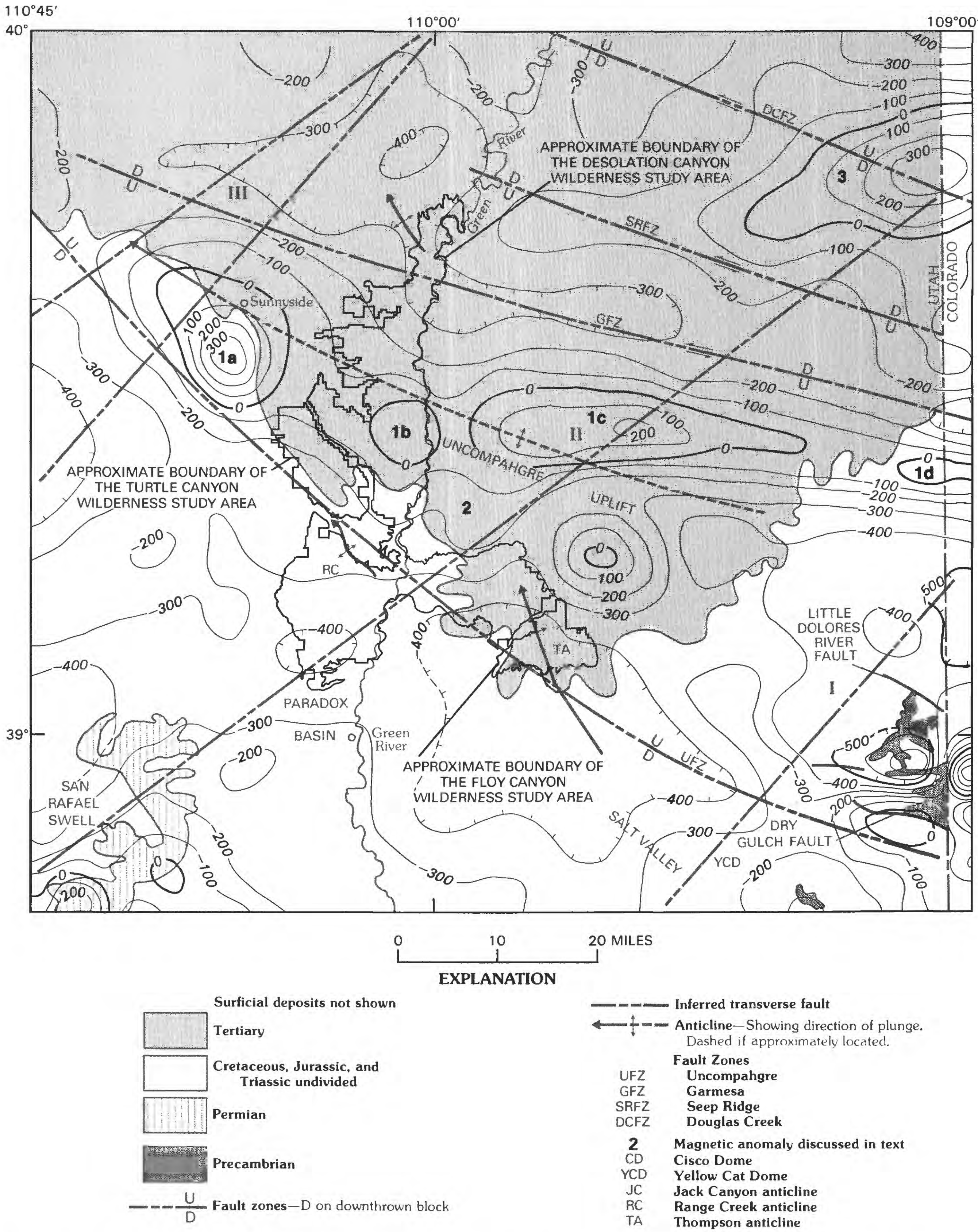
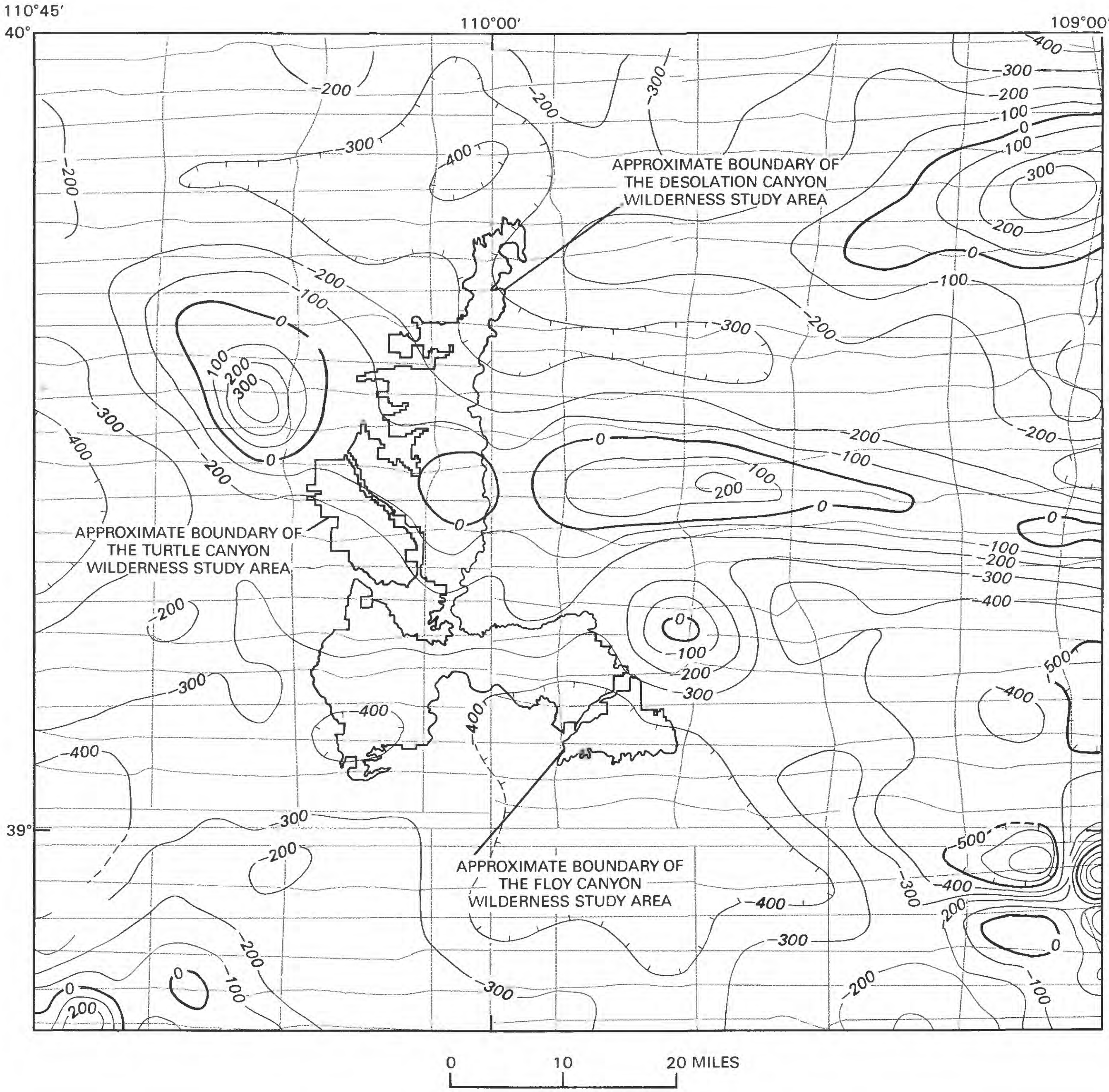
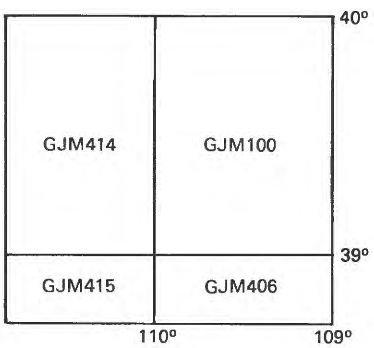


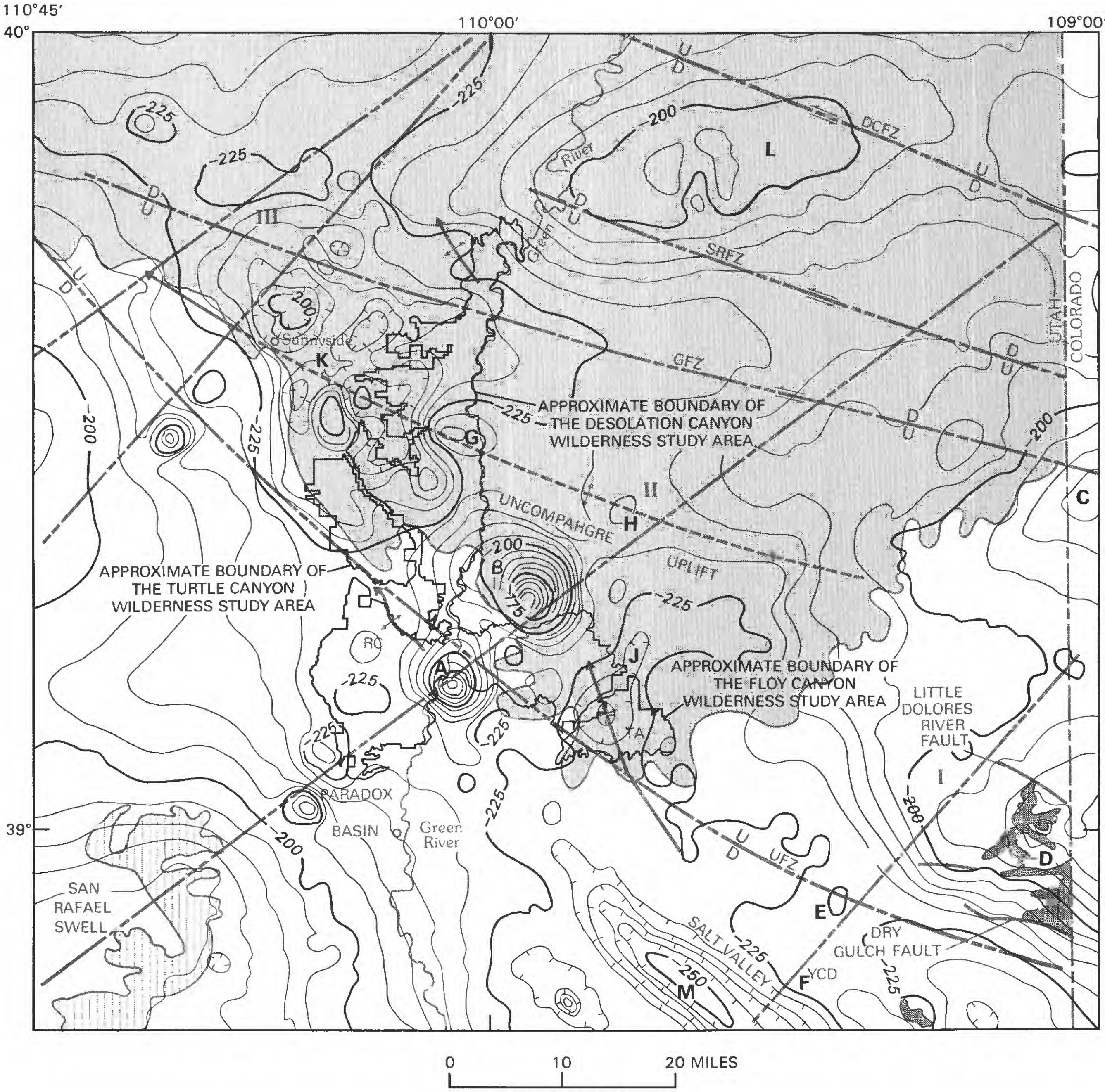
Figure 6. Residual intensity aeromagnetic anomaly and generalized geologic map of the Desolation Canyon, Turtle Canyon, and Floy Canyon Wilderness Study Areas, Utah.





Index map showing parts of four U.S. Department of Energy Residual Intensity Magnetic Anomaly contour maps from which data were taken for this study. Areas are identified by map numbers (U.S. Dept. of Energy 1983 a, b, c, d).

Figure 7. Flight line map of the Desolation Canyon, Turtle Canyon, and Floy Canyon Wilderness Study Areas, Utah. Contour interval 100 nanoTeslas.



EXPLANATION

Surficial deposits not shown

- Tertiary
- Cretaceous, Jurassic, and Triassic undivided
- Permian
- Precambrian
- Fault zones—D on downthrown block (U/D)
- Inferred transverse fault
- Anticline—Showing direction of plunge. Dashed if approximately located.

Fault Zones

UFZ	Uncompahgre
GFZ	Garmesa
SRFZ	Seep Ridge
DCFZ	Douglas Creek
A	Gravity anomaly discussed in text
CD	Cisco Dome
YCD	Yellow Cat Dome
JC	Jack Canyon anticline
RC	Range Creek anticline
TA	Thompson anticline

Figure 8. Complete Bouguer gravity anomaly and generalized geologic map of the Desolation Canyon, Turtle Canyon, and Floy Canyon Wilderness Study Areas, Utah.

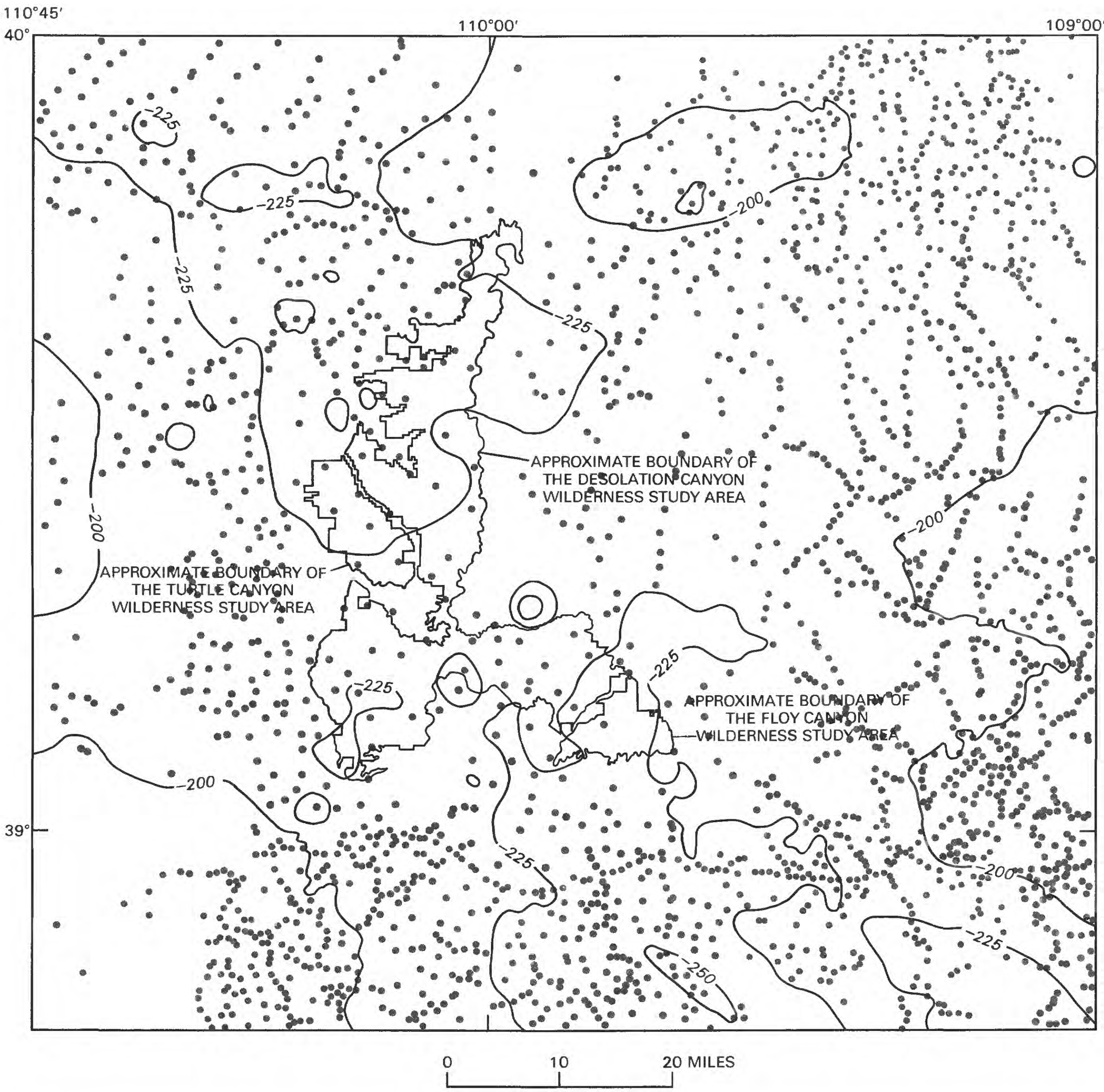


Figure 9. Gravity station location map of the Desolation Canyon, Turtle Canyon, and Floy Canyon Wilderness Study Areas, Utah. Contour interval 25 mgal.

are present on the magnetic anomaly map of the U.S. (Bond and Zietz, 1987) west of the Rocky Mountains and extending across northwestern Colorado, northern Utah, and southern Wyoming. The alternating pattern may be caused by zones of juxtaposition of different lithologies within the basement or by structural offset of different basement lithologies that were leveled by erosion prior to Phanerozoic deposition. The aeromagnetic pattern in the southwestern third of the map is characterized by broader, less linear anomalies of lesser magnitude in the Paradox basin. Part of the difference in character between the two areas is related to structural relief on the Uncompahgre fault zone. In the southeastern corner of the map, the Precambrian core of the Uncompahgre uplift is exposed at the surface. The uplift plunges northwestward from this point and is partly buried beneath sedimentary rocks of the Uinta Basin. The basement rocks of the Uncompahgre uplift are highly variable in lithology, density, and effective magnetic susceptibility (Shoemaker, 1956; Joesting and Case, 1962; Case, 1966). Case (1966) stressed that most anomalies within the Uncompahgre uplift are caused by variations in density and magnetic susceptibility rather than by basement relief. The short-wavelength anomalies in the southeastern corner of the map where basement rocks crop out may be caused by such variation or local faulting within the upper plate of the Uncompahgre fault.

Although the range of densities and susceptibilities reported by Case (1966) is wide indeed, his cross sections (p. 1426) and gravity and magnetic models assume a contact between the basement and sedimentary rocks of the basin that dips approximately 45° southwest and has a vertical offset on the Uncompahgre fault. Seismic and well data (Frahme and Vaughn, 1983) indicate that the frontal Uncompahgre fault actually dips northeast, probably at angles less than 45° requiring a re-evaluation of Case's models. On the basis of well data, seismic lines, and interpretation of aeromagnetic differences, Stone (1977) identified the buried Uncompahgre fault, which separates the Uncompahgre uplift (figs. 6 and 8) from the Paradox basin, and placed the first recognizable tectonic activity along the fault in late Precambrian time. Baars and Stevenson (1981) interpreted the Uncompahgre fault as one of a northwest-trending swarm of faults within a major shear system that was activated about 1,700 million years (m.y.) ago. Case (1966) interpreted the Dry Gulch and Little Dolores River fault zones in the southeast corner of the maps in figures 6 and 8 to be rejuvenated ancient fault zones because they have sheared, brecciated, and granulated zones tens of meters wide in Precambrian rocks, and only single faults or narrow zones of slip in Mesozoic rocks. The steep and relatively continuous magnetic and gravity gradients along the inferred subsurface Uncompahgre fault zone also suggest that the fault zone is controlled by a fundamental boundary within the basement.

The strong gravity gradient that trends northwest along the Uncompahgre fault zone marks the transition from the Uncompahgre uplift on the northeast to the Paradox basin on the southwest (fig. 8). The gradient becomes diffuse north of Cisco Dome where the exposed core of the uplift plunges beneath sedimentary rocks of the Uinta Basin. The gradient is represented by a saddle between gravity highs A and B (discussed later) and extends to the northwest corner of the map, defining the trace of the subsurface extension of the Uncompahgre fault zone as inferred by Stone (1977). A high gravity anomaly is associated with the uplift where it extends southeast of the mapped area, and continues into the eastern boundary of the map where it separates into two noses that culminate in anomalies C and D (fig. 8). A linear composite magnetic high (Ia-Ie, fig. 6) is associated with the buried northwest nose of the Uncompahgre uplift; the gradient bounding the north flank of the anomaly extends along the northern border of the uplift defined by the Garmesa fault zone (GFZ). Aeromagnetic anomaly peaks Ic, Id, and Ie coincide with the northern high Bouguer gravity anomaly (C) and its westward-extending nose. Less continuous high magnetic values follow the southern edge of the uplift to the area of the southern gravity anomaly (D) and the group of short-wavelength high and low anomalies mentioned earlier. Gravity and magnetic lows occur between the high gravity anomalies (C and D) suggesting that the uplift has a composite crest here. Alternatively, the variations in magnetic and gravity values may be caused by density and susceptibility contrasts within the Precambrian core of the uplift.

Three zones of transverse faults (I, II, and III, figs. 6 and 8) that cross the Uncompahgre fault zone are suggested by the gravity and magnetic data. Zone I extends southwest along the northeast-trending gravity gradient of anomaly D (fig. 8) through the structural uplifts and associated low and high anomalies respectively at Cisco Dome (E) and Yellow Cat Dome (F) and the gravity saddle southeast of the low point of anomaly M. Zone II extends southwest along the northeast-trending gravity gradient of anomaly C; through the high anomalies A and B, which are flanked to the south by a line of local high anomalies; and continues through local high and low anomalies southwest of the Uncompahgre fault zone and along the northeast-trending anomaly associated with the San Rafael Swell. The crest of the San Rafael Swell is located along the inferred fault zone. The Tertiary rocks north of the Uncompahgre fault zone thicken rapidly to the northwest across this inferred transverse zone (Bruhn and others, 1983; Dickinson and others, 1986), and indicate a rapid plunge of the uplift to the northwest or possible down-to-the-northwest faulting of this end of the uplift. Zone III encompasses two short subparallel trends. The one to the northwest extends along the northeast-trending gradient of anomalies L and K and dies out in a series of small deviations in the north-northwest-trending gradient at the west edge of the map. The one to the southeast begins along the gradient of anomaly L and traverses a line of local high and low anomalies that occur within composite anomaly K and which extend southwest of the Uncompahgre fault zone.

All three inferred zones of transverse faulting are characterized in the gravity data by a northeast-trending gradient that marks the northwest termination of a regional west-trending high anomaly (fig. 8). (In zones I and II, the zones continue to the northeast along a gradient that marks the southeast boundary of a closed high within the regional anomaly. The gravity data do not extend far enough to determine if this is also the case for zone III). In all three zones a line of local high and low anomalies extends southwestward as the inferred transverse zone crosses the Uncompahgre fault. All three inferred zones are characterized in the magnetic data by termination of anomalies, deviations in linear anomaly trends, and by small isolated anomalies along the inferred fault trends (fig. 6).

Local low and high gravity anomalies (fig. 8) occur over Cisco Dome (E) and Yellow Cat Dome (F), respectively, superimposed on a gravity saddle that crosses the northeast-trending gravity low associated with Sagers Wash syncline, which lies immediately west of Cisco Dome. Relatively high values extend northwest and southeast from Yellow Cat Dome, suggesting that a slice of Precambrian rocks extends southwest of the major uplift block and that the Cisco and Yellow Cat Domes have developed on this imbricate fault wedge. Precambrian rocks were interpreted to lie at shallower depths below the domes than in the area to the west (Joesting and Case, 1962). A similar gravity high extends southwest beyond the gradient associated with the Uncompahgre fault zone south, west, and north of anomaly A. It occurs over the southwest extension of the Desolation Canyon Wilderness Study Area and suggests a similar structural configuration to that at Cisco and Yellow Cat Domes. Local gravity highs similar to that over Yellow Cat Dome occur in this area and extend northeast parallel to the inferred transverse fault. Local highs G and H are similar in size and magnitude, but they appear to be associated with the buried crest of the uplift. The gravity low over Cisco Dome suggests that salt may be present in its core.

A major gravity low (M) is associated with an anticline in Salt Valley. An arcuate low of lesser magnitude (J) extends across the Uncompahgre fault zone suggesting that salt occurs in the subsurface here. If the salt occurs in the lower plate, it indicates that the angle of the fault is certainly less than 45° in this area, as suggested by the seismic and well data of Frahme and Vaughn (1983) mentioned earlier, and deformed sedimentary rocks may underlie the Uncompahgre block in the Floy Canyon study area and the extreme southeastern corner of the Desolation Canyon study area. Alternatively, the salt may occur within the upper plate of the Uncompahgre fault. Well data suggest 1,400 ft of offset of the basement surface between the low anomaly and the outcropping rocks of the Precambrian core of the uplift beneath anomaly D. Salt may have been deposited in a restricted synclinal basin formed by oblique slip on a lateral ramp or tear fault (Dahlstrom, 1970, p. 380). Major gravity highs (A and B) lie near the intersection of the Uncompahgre fault zone and one of the inferred transverse fault zones. Anomaly A occurs at the boundary of two magnetic surveys where the configuration of the contours is in doubt, but the gravity anomaly is well defined by more than a dozen stations. Anomaly B is defined by only one gravity station; thus, its magnitude is in doubt, but the -215 and lower contours are well defined by the data; the anomaly is approximately coincident with a high magnetic nose (feature 2, fig. 6). These anomalies may be caused by intrusive rocks localized by the intersecting fault zones, although no surface faulting, alteration, or hot springs have been reported. No geochemical anomalies were identified in the immediate area, but uranium and barium anomalies were identified nearby (see preceding sections).

A low gravity anomaly (K) in the northwest corner of the map (fig. 8) is the southernmost extension of a major low anomaly associated with the Uinta Basin north of the mapped area. The low is broken by a complex pattern of short-wavelength high and low anomalies with amplitudes as high as 25 mGal. The inferred traces of the Uncompahgre fault zone and the Garmesa fault zone, which bound the Uncompahgre uplift on the south and north, respectively, are approximately defined by gradients southwest and northeast of the low. The major magnetic high (fig. 6) associated with the uplift extends into and culminates in the area of the gravity low (fig. 8). The magnetic anomaly probably is caused by the buried Precambrian core of the uplift while the composite low gravity anomaly is caused by low density Phanerozoic rocks. Bruhn and others (1983) and Dickinson and others (1986) suggested that a large Paleogene delta system with thick deposits of low density sedimentary rocks was built in the area. A northeast-trending structural element across which sedimentary units thicken is apparent in isopachs of rocks as old as Devonian and Mississippian in the area of inferred transverse fault zone II, and the structural element is strongly evident in isopachs of Pennsylvanian and Permian rock thicknesses (Sanborn, 1981), during part of the time that the salt-bearing Hermosa Formation was being deposited in the Paradox basin. Sanborn shows approximately 2,500 ft of Pennsylvanian and Permian rocks in the area of anomaly K. Kulik has previously suggested (Gerlitz and others, 1988), on the basis of the correlation of gravity lows and magnetic highs, that the Paradox basin salt-cored anticlines were controlled by faults that parallel the Uncompahgre uplift and offset the basement rocks. If salt or other low density evaporites are the cause of the broad low anomaly K, these deposits do not seem to have been deformed into the long, narrow anticlines typical of those in the Paradox basin. The occurrence of salt beneath anomalies J and (or) K would be both north and west of any known occurrences associated with the Uncompahgre uplift and the related Paradox basin. The apparent lack of basement fault controls and narrow salt-cored anticlines similar to those interpreted for the Paradox basin to the southeast suggests that evaporites inferred as the source for anomaly K are not developed in the underlying Paradox basin but were deposited on the upper plate of the

Uncompahgre fault where it bends steeply downward to the northwest, possibly across a lateral ramp within the plate. Similar down-to-the-northwest structural relief and Pennsylvanian and Permian rocks including salt beds and associated deformation may be present as well beneath the overriding Uncompahgre fault, but the geophysical expression of those features is masked by the upper plate. The gradients between the local high and low anomalies superposed on anomaly K suggest that the underlying rocks are highly faulted and (or) have high density contrasts, and that the anomalies are caused by a source near the surface. The local high gravity anomalies could be caused by the occurrence of anhydrite within an evaporite sequence, and the gradients suggest further that the sequence is in the upper plate of the Uncompahgre fault.

Both a gravity high (L) and a magnetic high (3) occur in the northeast corner of the map. Both are long-wavelength anomalies and trend east-west; they are probably caused by lithologic contrasts in the basement. In the southwest corner of the map, gravity and magnetic highs are associated with rocks of the San Rafael Swell.

Aerial gamma-ray spectroscopy is a technique that provides estimates of the near-surface (0–50 cm depth) concentrations of potassium (K, in percent), equivalent uranium (eU, in ppm), and equivalent thorium (eTh, in ppm). These data provide a partial geochemical representation of the near-surface materials (J.S. Duval, U.S. Geological Survey, written commun., 1987). From 1975 to 1983, the U.S. Department of Energy contracted for aerial gamma-ray surveys that covered almost all the United States. Because of the wide flight-line spacings, these surveys are, in general, only suitable for producing regional-scale maps (J.S. Duval, written commun, 1987).

Data from the surveys indicate that the three study areas have overall low to moderate radioactivity with estimated concentrations of 0.6–2.4 percent K, 1.0–5.0 ppm eU, and 2–12 ppm eTh and that there is one small tract near the eastern boundary of the Desolation Canyon Wilderness Study Area with anomalous concentrations of uranium and potassium (J.S. Duval, written commun., 1987). The tract is centered at about 110°W longitude and 39.5°N latitude; data suggest that it has a radius of about 3 mi (J.S. Duval, written commun., 1987).

Mineral and Energy Resource Potential

Coal

Each of the study areas has high potential for additional coal resources outside those tracts where identified coal resources occur (fig. 2; pl. 1). Geologic environments and shoreline trends show favorable conditions for the occurrence of coal in those terrains delineated in figure 2 and on plate 1 as having high resource potential. In the southwestern part of the Desolation Canyon Wilderness Study Area the Sunnyside coal zone of the Blackhawk Formation contains hypothetical coal resources under 2,000 ft or less of overburden. Estimates of these resources are shown in table 2.

In the central part of the Desolation Canyon study area, where the stratigraphic interval that may contain the Sunnyside coal zone lies beneath 3,000–6,000 ft of overburden, there are no drill holes to determine the presence or absence of coal, but American Stratigraphic Company logs and geophysical logs from holes a few miles west of the northern part of the study area show thin beds of coal in the Blackhawk Formation at depths greater than 8,000 ft. The coal-bearing interval probably extends southeastward into the Desolation Canyon study area and, based on a structure contour map by Johnson (1986), the interval would be under less than 6,000 ft of overburden in the central sector of the study area. There are not enough data to make an estimate of hypothetical resources in that sector. Assessment of hypothetical coal resources in the southeastern part of the Desolation Canyon study area is based on studies of coal outcrops south of the study area (Fisher, 1936) and interpretation of logs from drill holes immediately east of the study area (Doelling, 1972b). Owing to the scarcity of information, no estimate is made of the hypothetical resources, but there is probably a small area underlain by coal in the Neslen Formation (see fig. 2).

Assessment of hypothetical coal resources in the Turtle Canyon Wilderness Study Area is based on data from core holes outside the study area, and the results are shown in table 1. The hypothetical resource is in the Sunnyside coal zone and beneath overburden less than 6,000 ft thick.

There are no coal outcrops in the Floy Canyon Wilderness Study Area, and the assessment of hypothetical coal resources is based on the same subsurface information used to assess the southeastern part of the Desolation Canyon study area. All of the Floy Canyon study area is probably underlain by coal in the Neslen Formation, but due to the scarcity of data, classification guidelines were modified and estimates of identified and hypothetical coal resources were combined. The estimates are shown in table 3 and discussed in the coal resource appraisal of the Chesterfield, Ballard, and Palisade coal zones. The energy resource potential for coal in each of the three study areas is assessed as high, with a certainty level of C.

Coal-Bed Methane

Coal beneath some tracts in the three study areas may attain a rank and thickness that is favorable for the production of methane, but the energy potential for coal-bed methane cannot be assessed at the present time due to a lack of information. Therefore, the resource potential for coal-bed methane is unknown, with certainty level A.

Oil and Gas

The energy resource potential for oil and gas is estimated to be high for the northern part of the Desolation Canyon Wilderness Study Area and moderate for the Turtle Canyon, Floy Canyon, and southern part of the Desolation Canyon Wilderness Study Areas (fig. 2; pl. 1). This is in agreement with the ratings of Molenaar and Sandberg (1983). Certain stratigraphic units (see below) are positive targets for oil and gas prospecting in the study areas because those units yield oil and (or) gas in nearby areas and their stratigraphic characteristics, lithologies, and thermal histories in the study areas are similar to those in the producing areas.

Sandstone beds in the Green River and Colton Formations produce gas and some oil in the Peters Point field, which is immediately northwest of the of the northern sector of the Desolation Canyon study area (fig. 4; pl. 1). The Peters Point field lies along the Jack Canyon anticline, a northwest-trending structure that extends southeastward a short distance into the study area. Two wells producing gas from the Colton Formation are located less than ½ mi from the study area boundary. Facies changes and pinch-outs in beds of the interfingering Colton and Green River Formations and the minor dip reversal over the Jack Canyon anticline have caused the accumulation and entrapment of liquid hydrocarbons in the Peters Point field, and these same geologic conditions extend a short distance into the study area.

Lenticular sandstones in the Cedar Mountain Formation and Dakota Sandstone contain gas as shown by wells located less than 1 mi from study area boundaries (see holes 23 and 29, pl. 1). The Chevron Oil Company Range Creek Federal 1 (hole 23, pl. 1), a shut-in gas well located on the Range Creek anticline, encountered gas in the Cedar Mountain Formation and the Tenneco Oil Company Rattlesnake Canyon 2–12 (hole 29, pl. 1), a producing gas well located on the east flank of the Thompson anticline, yields gas from the Dakota Sandstone. The Range Creek anticline extends a short distance into the Desolation Canyon study area and the Thompson Canyon anticline extends across all of the Floy Canyon study area and into the easternmost sector of the Desolation Canyon study area (pl. 1). The Cedar Mountain Formation and Dakota Sandstone also produce gas from the Cisco Dome field, which is located about 6 mi southeast of the Floy Canyon study area. Several additional gas-producing fields, east of the study areas, occur on anticlinal structures along the northwest-trending Uncompahgre uplift. The uplift extends across parts of each study area.

Deep, and less favorable, exploration targets may lie in those parts of the study areas immediately south of the Uncompahgre uplift. There, a thick sequence of Paleozoic rocks that abut the uplifted block of the Uncompahgre may contain strata that favor the accumulation of oil or gas. The energy resource potential for petroleum in Mesozoic and Tertiary rocks in the northern tract of the Desolation Canyon study area is assessed as high, with a certainty level of C. The energy resource potential for Mesozoic rocks in all other parts of the study areas is assessed as moderate with a certainty of B.

The potential for helium in all parts of the study areas is assessed as low, with a certainty level of B. Deep holes drilled adjacent to the southwestern part of the Desolation Canyon study area penetrated the Coconino Sandstone and the Kaibab Limestone but did not encounter helium.

Bituminous Sandstone

The northern part of the Desolation Canyon Wilderness Study Area has a high potential for bituminous sandstone deposits (fig. 2; pl. 1). Sandstone strata in the middle member of the Green River Formation and the upper part of the Colton Formation contain bitumen a few miles west of the study area (fig. 5), and this lithologic sequence extends beneath the study area. Regional deposition of these widespread marginal lacustrine and fluvial rocks indicate that this rock interval contains beds in the study area that favor the accumulation of bitumen. There is no drill information to confirm the presence of bitumen-bearing beds in the study area, but logs from drill holes a few miles west describe oil-stained sandstone cuttings. An American Stratigraphic Company log for a hole about 4 mi west of the study area shows several oil-stained sandstones in the middle member of the Green River Formation. One of these sandstones is approximately 90 ft thick; the others are much thinner. The resource potential for bituminous sandstone in the northern part of the Desolation Canyon study area is assessed as high, with a certainty level of C, and all other areas are assessed as low, with a certainty level of B.

Oil Shale

All identified oil-shale resources in the study areas occur in the lower part of the upper member of the Green River Formation; extent and grade of these beds is described in "Appraisal of Identified Resources." A few thin low-grade oil-shale beds occur in the upper part of the upper member of the Green River Formation in the Desolation Canyon Wilderness Study Area. These beds are estimated to have low energy resource potential for oil shale, with a certainty level of C. Although some beds in the Flagstaff Member of the Green River Formation in the Desolation Canyon and Turtle Canyon Wilderness Study Areas contain organic matter, the energy resource potential for oil shale is assessed as low, with a certainty level of B.

Uranium

Uranium occurrences in the basal conglomeratic beds of the Wasatch Formation (fig. 5) are small and randomly located and their areal distribution is not predictable. The Morrison Formation, which has yielded uranium in areas south of the study areas, extends beneath the study areas. If uranium deposits are present in the Morrison beneath the study areas, they are deeply buried, more than 5,000 ft for the most part, and their areal distribution would be difficult to determine by drilling methods.

Geochemical investigations in and near the study areas found that, of the rock and stream-sediment samples collected, coal-rich samples contained the highest concentration of uranium. One sample collected near the mouth of Thompson Canyon contained 12.5 ppm uranium (see "Geochemistry"). A reconnaissance evaluation of the uranium potential of part of the Uinta Basin conducted by Noble and Annes (1957) revealed no uranium prospects in the northern part of the Desolation Canyon Wilderness Study Area, the only sector of the three study areas included in the evaluation. The mineral resource potential for uranium is assessed as moderate in the Floy Canyon Wilderness Study Area and the southeastern part of the Desolation Canyon Wilderness Study Area, with a certainty level of B, and low in the remainder of the areas, with a certainty level of B.

Metallic Minerals

Mineral resource potential for all other metals in all three study areas is low, with a certainty level of B. No minerals have been produced, other than a very small amount of uranium, and geochemical sampling revealed no concentrations indicative of an environment in which mineralization is likely in the study areas.

Bentonite and Zeolites

The mineral resource potential for bentonite and zeolite is assessed as low, with a certainty level of B. Thin impure analcime (zeolite) beds that occur in the Green River Formation have low resource potential. Bentonite beds that occur in the study areas are thin and (or) lenticular, and thus have low resource potential.

Geothermal Energy

There are no known geothermal energy sources in or near the study areas, and no warm springs were noted during this study. The resource potential for geothermal energy is assessed as low, with a certainty level of B.

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APPENDIX

DEFINITION OF LEVELS OF MINERAL RESOURCE POTENTIAL AND CERTAINTY OF ASSESSMENT

LEVELS OF RESOURCE POTENTIAL

H 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.

M 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 reasonable likelihood for resource accumulation, and (or) where an application of mineral-deposit models indicates favorable ground for the specified type(s) of deposits.

L 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 permissive. This broad category embraces areas with dispersed but insignificantly mineralized rock, as well as areas with little or no indication of having been mineralized.

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

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

LEVELS OF CERTAINTY

A Available information is not adequate for determination of the level of mineral resource potential.

B Available information only 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.

LEVEL OF RESOURCE POTENTIAL →

A	B	C	D
U/A UNKNOWN POTENTIAL	H/B HIGH POTENTIAL	H/C HIGH POTENTIAL	H/D HIGH POTENTIAL
	M/B MODERATE POTENTIAL	M/C MODERATE POTENTIAL	M/D MODERATE POTENTIAL
	L/B LOW POTENTIAL	L/C LOW POTENTIAL	L/D LOW POTENTIAL
			N/D NO POTENTIAL

LEVEL OF CERTAINTY →

Abstracted with minor modifications from:

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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 by the U.S. Geological Survey in this report

EON	ERA	PERIOD		EPOCH	AGE ESTIMATES OF BOUNDARIES (Ma[1])
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	~ [2]570
Proterozoic	Late Proterozoic				900
	Middle Proterozoic				1600
	Early Proterozoic				2500
Archean	Late Archean				3000
	Middle Archean				3400
	Early Archean				3800?
pre-Archean[3]					4550

[1]Millions of years prior to A.D. 1950.

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

[3]Informal time term without specific rank.

☆U.S. GOVERNMENT PRINTING OFFICE: 1990-773-047/06076

Mineral Resources of Wilderness Study Areas—Central Green River Region, Utah

This volume was published
as separate chapters A and B

U.S. GEOLOGICAL SURVEY BULLETIN 1753

DEPARTMENT OF THE INTERIOR
MANUEL LUJAN, JR., Secretary

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

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[Letters designate the chapters]