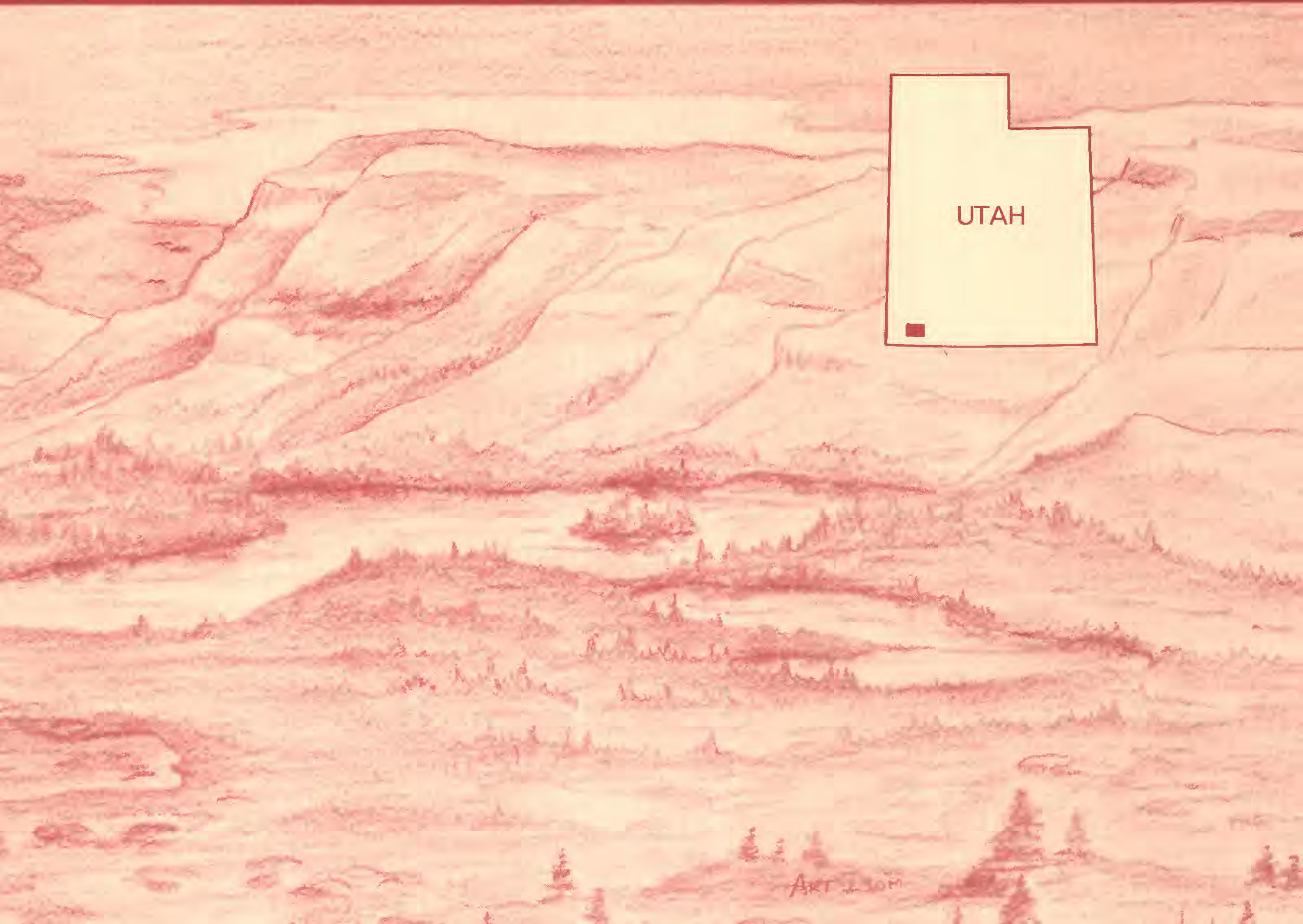
Mineral Resources of the Cottonwood Canyon Wilderness Study Area, Washington County, Utah

U.S. GEOLOGICAL SURVEY BULLETIN 1746–C



Chapter C

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U.S. GEOLOGICAL SURVEY BULLETIN 1746

MINERAL RESOURCES OF WILDERNESS STUDY AREAS—SOUTHWESTERN UTAH

DEPARTMENT OF THE INTERIOR
DONALD PAUL HODEL, Secretary

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Dallas L. Peck, Director

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STUDIES RELATED TO WILDERNESS

Bureau of Land Management Wilderness Study Areas

The Federal Land Policy and Management Act (Public Law 94–579, October 21, 1976) requires the U.S. Geological Survey and the U.S. Bureau of Mines to conduct mineral surveys on certain areas to determine the mineral values, if any, that may be present. Results must be made available to the public and be submitted to the President and the Congress. This report presents the results of a mineral survey of part of the Cottonwood Canyon Wilderness Study Area (UT–040–046), Washington County, Utah.

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PLATE

[Plate is in pocket]

FIGURES

Mineral Resources of the Cottonwood Canyon Wilderness Study Area, Washington County, Utah

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ABSTRACT

The U.S. Bureau of Mines and the U.S. Geological Survey studied 9,853 acres of the Cottonwood Canyon Wilderness Study Area (UT–040–046) in Washington County, Utah, during spring 1986. There are no mines, prospects, or mineralized areas; however, there are inferred subeconomic resources of building stone, silica sand, and limestone at the surface. There is moderate mineral resource potential for silver, copper, gold, uranium, and vanadium beneath the study area (fig. 1). The resource potential for all other metallic minerals and for oil and gas is low. The energy resource potential for low-temperature geothermal sources is high. There is no energy resource potential for coal.

SUMMARY

Character and Setting

The Cottonwood Canyon Wilderness Study Area (UT–040–046) is in southwestern Utah, about 8 mi (miles) northeast of St. George (fig. 2). Access is chiefly by graded roads from Interstate Highway 15, which passes within ½ mi of the eastern edge of the study area. The study area is 7.5 mi long (east-west direction) and 3 mi wide. Maximum topographic relief is about 1,860 ft (feet). The study area is characterized by deep canyons, such as Cottonwood Canyon, cut by southeast-flowing intermittent streams. These canyons are cut into the 2,000-ft-thick Navajo Sandstone of Triassic(?) and Jurassic age (see geologic time chart in Appendix), which underlies most of the study area. Other rocks exposed in the study area are mudstone, sandstone, and limestone of Mesozoic age, and late Cenozoic basaltic andesite flows. The study area is on the northwest limb of the northeast-trending Virgin anticline (fig. 2), so the rocks dip to the northwest and the ages of the exposed Mesozoic rocks progress from oldest on the southeast to youngest on the northwest. The basaltic andesite flows cap mesas at the western edge of the study area. The Washington fault is the only major structure identified in the study area other than the northwest limb of the Virgin anticline.

Analysis of geophysical data indicates that the study area overlies an east-west-trending regional gravity gradient. The gradient generally decreases in field values from south to north, and has been inferred to be a result of large-scale emplacement of silicic intrusive rock beneath the Great Basin to the north, and (or) a northward deepening of the surface of dense Paleozoic carbonate rocks and the underlying Precambrian crystalline basement. The study area also overlies a regional aeromagnetic gradient that is interpreted as a reflection of the northward deepening of the basement surface. No aeromagnetic anomalies occur over either the Hurricane fault or the Virgin anticline, suggesting that the

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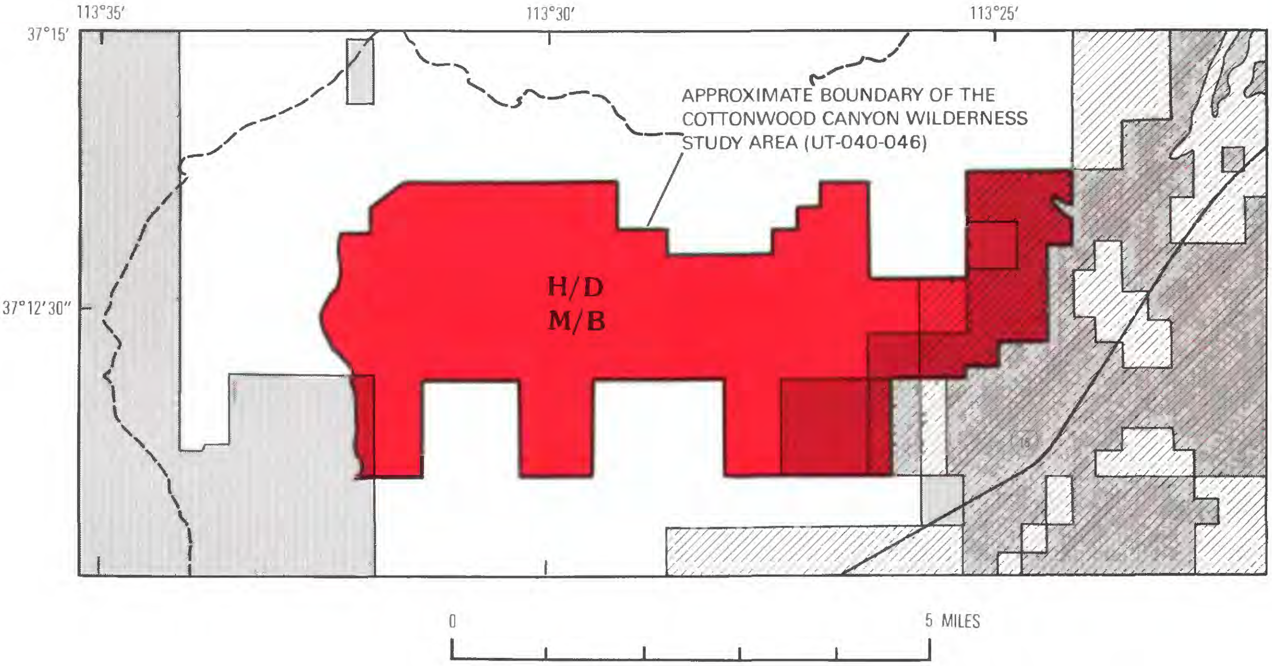


EXPLANATION OF MINERAL AND ENERGY RESOURCE POTENTIAL

[Entire study area has low resource potential for (1) oil and gas, with certainty level B, and (2) all metallic minerals other than silver, copper, gold, uranium, and vanadium, with certainty level C. Entire study area has no energy resource potential for coal, with certainty level D]

H/D M/B — **Geologic terrane having (1) high energy resource potential for low-temperature geothermal sources, with certainty level D, and (2) moderate mineral resource potential for silver, copper, uranium, vanadium, and gold, with certainty level B**

Certainty levels

B — **Data indicate geologic environment and suggest level of resource potential**

C — **Data indicate geologic environment and resource potential, but do not establish activity of resource-forming processes**

D — **Data clearly define geologic environment and level of resource potential, and indicate activity of resource-forming processes in all or part of study area**

Unpatented mining claims

Oil and gas leases—Information from the U.S. Bureau of Land Management as of August 1985

– – – – – **Graded road**

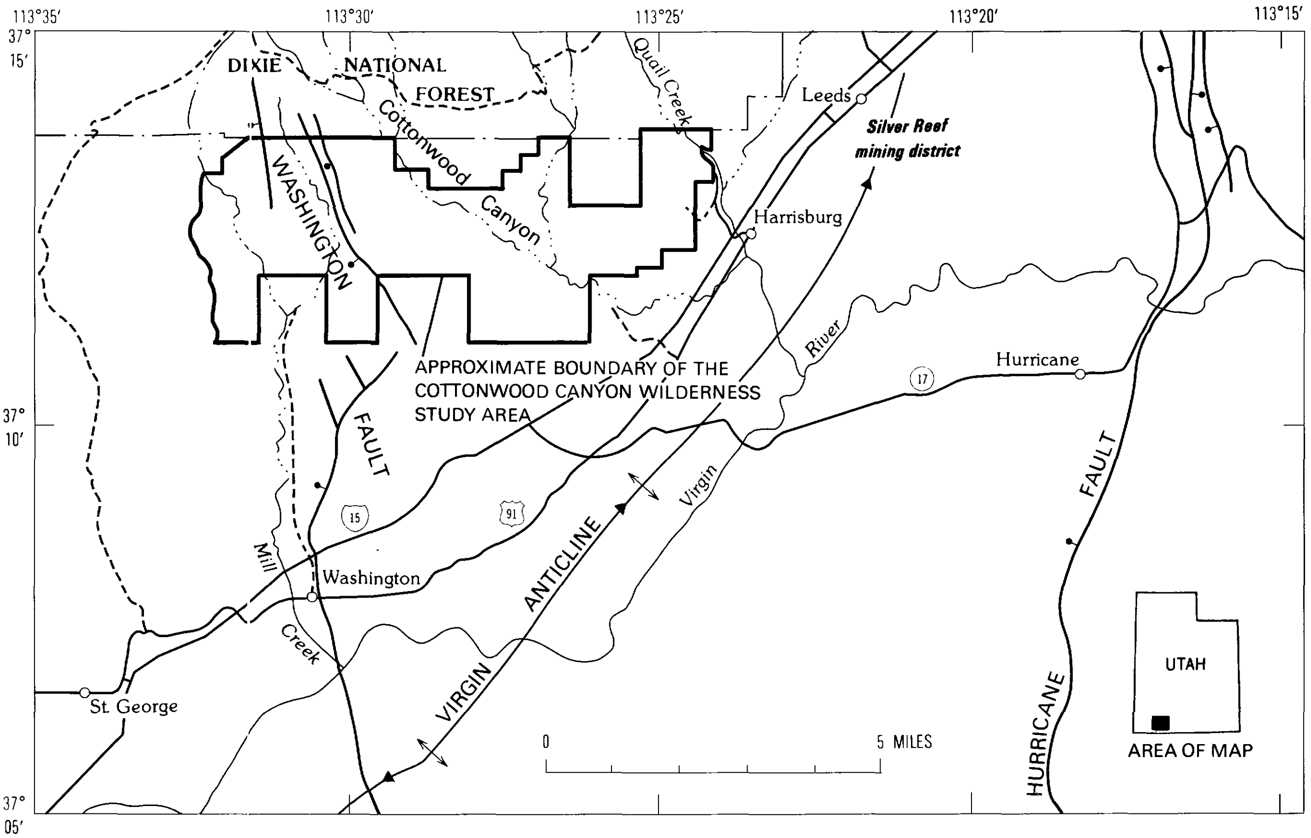
Figure 1. Summary map showing mineral and energy resource potential, mining claims, and oil and gas leases in the Cottonwood Canyon Wilderness Study Area and vicinity, Washington County, Utah.

Hurricane fault, a high-angle structure at the surface, may flatten at depth and that the Virgin anticline may be detached from the basement.

Identified Resources and Resource Potential

Although the eastern part of the study area is within the 144-mi^2 Silver Reef mining district, no mining has been done within the area and no prospects were found. A large block of unpatented mining claims overlaps the eastern side of the study area, and as of August 1985, approximately 2,120 acres of the study area were under lease for oil and gas. No evidence of present or past drilling or other petroleum exploration activity was seen during field reconnaissance. Inferred subeconomic resources of building stone, silica sand, and limestone are present in the study area; however, the low unit values of these commodities require a local market to be economically viable.

No occurrences of mineralized rock were seen in the study area. The geochemical survey of the study area indicated that barium is the only metallic element present in



EXPLANATION

Fault—Bar and ball on downthrown side

Anticline—Showing direction of plunge

-------- Graded road

Figure 2. Index map of the Cottonwood Canyon Wilderness Study Area, Washington County, Utah. Structural data modified from Cook (1960).

significantly anomalous amounts. Further, there are no radioactivity anomalies within or near the study area, which suggests that there are no uranium mineral deposits near the surface. However, the Springdale Sandstone Member of the Moenave Formation (host rock of the sandstone-silver deposits at Silver Reef) extends beneath the entire study area at depths ranging from about 175 ft at the eastern side to more than 3,000 ft over most of the rest of the study area. Analysis of the geologic setting suggests that the Springdale Sandstone Member could host silver resources beneath the study area. Thus, the entire study area has (1) moderate mineral resource potential for silver, copper, gold, uranium, and vanadium in undiscovered sandstone-hosted silver deposits, and (2) low mineral resource potential for other metals.

Oil and gas have been produced from upper Paleozoic and Lower Triassic rocks at two fields about 15 mi east and northeast of the study area, east of the Hurricane fault. These rocks are probably present beneath the study area, but no favorable structural or stratigraphic traps have been identified in the study area, and no definite shows of oil have been reported from test wells drilled west of the Hurricane fault. Aeromagnetic data, which suggest that the Hurricane fault flattens at depth and that the Virgin anticline is detached from the basement, imply that structural and stratigraphic sequences at depth may be different from those present in the upper few thousand feet of the crust in and around the study area. Because currently available data are inadequate to evaluate this implication, a low energy resource potential for oil and gas is assigned to the study area.

The study area is in a region having terrestrial heat flow between 1.5 and 2.5 heat flow units (1.0 heat flow unit yields a geothermal gradient of about 15 °F per 1,000 ft). Thus, the energy resource potential for low-temperature geothermal sources (less than 194 °F at depths generally less than 0.6 mi) is high.

Coal, ranging in rank from lignitic to bituminous, is present in Upper Cretaceous rocks north and east of the study area. There is only one small outcrop of Upper Cretaceous rocks within the study area, however, and it contains no coal. Mesozoic and Paleozoic rocks beneath the study area are not known to contain coal in the region. Thus, the study area has no energy resource potential for coal.

INTRODUCTION

The USBM (U.S. Bureau of Mines) and the USGS (U.S. Geological Survey) studied 9,853 acres of the Cottonwood Canyon Wilderness Study Area (UT–040–046) in Washington County, Utah (fig. 2), as requested by the BLM (U.S. Bureau of Land Management). In this report the area studied is referred to as the "wilderness study area" or simply the "study area." The Cottonwood Canyon Wilderness Study Area is in southwestern Utah, about 8 mi northeast of St. George and 45 mi southwest of Cedar City. The smaller communities of Leeds and Washington are 2 mi to the east and 4 mi to the south, respectively (fig. 2).

The study area is bounded on the north by Dixie National Forest. Interstate Highway 15 passes within ½ mi of the eastern edge of the study area. Access to much of the area is from the northern Leeds interchange of the interstate highway or from the eastern St. George interchange via a graded road that loops around the northern boundary of the study area. Access to the northeastern part of the study area is provided from the southern Leeds interchange via a paved road to the Red Cliffs BLM recreation area. The southern part of the study area can be reached via a graded road in Mill Creek valley and via unimproved roads that branch off old U.S. Highway 91.

The study area is 7.5 mi long (east-west direction) and 3 mi wide. It ranges in altitude from about 3,160 ft near Quail Creek on the east to 5,018 ft at the northwestern corner. The study area is characterized by deep canyons, which have been cut into the underlying Navajo Sandstone of Triassic(?) and Jurassic age by southeast-flowing intermittent streams. The canyons are typically 500 ft deep and locally are as deep as 1,200 ft.

This report presents an evaluation of the mineral endowment (identified resources and mineral resource potential) of the study area and is the product of several separate studies by the USBM and the USGS. Identified resources are classified according to the system of the USBM and USGS (1980), which is shown in the Appendix of this report. Identified resources are studied by the USBM. Mineral resource potential is the likelihood of occurrence of undiscovered metals and nonmetals, industrial rocks and minerals, and of undiscovered energy sources (coal, oil, gas, oil shale, and geothermal sources). It is classified according to the system of Goudarzi (1984) and is shown in the Appendix. The potential for undiscovered resources is studied by the USGS.

Investigations by the U.S. Bureau of Mines

USBM personnel reviewed various sources of minerals information including published and unpublished literature. Mining claim and oil and gas lease information was obtained from the BLM state office in Salt Lake City, Utah. USBM field studies in April and May 1986 included searching for mines and prospects both inside and as far as 1 mi outside the study area. Rock-chip samples were taken in mineralized areas. Sandstone and limestone beds were sampled to determine their suitability for specific industrial uses. Detailed descriptions of analytical procedures and results are in Wood (1987). Additional information is available from the USBM, Intermountain Field Operations Center, Building 20, Denver Federal Center, Denver, CO 80225.

Investigations by the U.S. Geological Survey

The study area lies within the area mapped by photogeology and in reconnaissance at scale 1:125,000 for the geologic map of Washington County (Cook, 1960). More detailed geologic mapping of the region at scale 1:62,500 has been done by W. Kenneth Hamblin of Brigham Young University (St. George and Hurricane 15-minute quadrangles, unpub. data). Geologic mapping for this mineral resource assessment of the study area was done by B.B. Houser at scale 1:24,000 during April and May 1986. Exposures were examined for signs of mineralized rock, and rock samples were collected for chemical analysis and petrographic study. The geochemical study was done in 1986 by J.L. Jones and J.E. Kilburn; stream-sediment samples and heavy-mineral concentrates of stream sediments were collected at 37 sites, and rock samples were collected at 26 sites (Detra and others, 1988). Collection of new gravity data and interpretation of gravity and aeromagnetic data were by H.R. Blank, Jr., and interpretation of available radiometric data was by J.S. Duval.

APPRAISAL OF IDENTIFIED RESOURCES

By Robert H. Wood II
U.S. Bureau of Mines

The only record of mining or prospecting in the Cottonwood Canyon Wilderness Study Area is a large block of unpatented mining claims that overlaps the eastern side of the study area (fig. 1). These mining claims and the eastern part of the study area are within the 144-mi^2 Silver Reef mining district. This district is noted primarily for silver production from the Springdale Sandstone Member of the Moenave Formation, but gold, copper, and uranium also were recovered. Most of the production came from a 2-mi^2 area centered near Leeds, Utah. Silver production from the district, between 1875 and 1910, was estimated to be about 8 million oz (troy ounces), or nearly $8 million ($60 million at the 1987 price of $7.50 per oz). Sporadic production between 1949 and 1968 amounted to about 30 oz of gold, 166,000 oz of silver, 60 st (short tons) of copper, and at least 2,500 lbs (pounds) of uranium oxide (uranium production records in 1958 and 1959 are confidential and are not included in this total). Cerargyrite, malachite, and carnotite are the principal ore minerals found in the district. (See Proctor, 1953, p. 68–78; Cook, 1960, p. 107–109; and U.S. Bureau of Mines, 1949–1968.)

Oil, Gas, and Geothermal Sources

As of August 1985, approximately 2,120 acres of the study area were under lease for oil and gas (fig. 1). No evidence of drilling or past exploration activity was seen during the USBM's field reconnaissance. Oil and gas is not an identified resource in the study area.

The nearest oil and gas fields, the Anderson Junction and Virgin fields, are approximately 15 mi northeast and 15 mi east, respectively, of the study area. The Anderson Junction field has been abandoned since 1971. Oil production from the Pennsylvanian Callville Limestone in the Anderson Junction field was associated with a fault and fold intersection. Oil shows in this field were reported in the Permian Kaibab Limestone, Toroweap Formation, and Coconino Sandstone and in the Mississippian Redwall Limestone. Oil production in the Virgin field is along the nose of an anticline in the basal member of the Moenkopi Formation of Triassic age. Oil shows also were reported in the Coconino Sandstone and the Callville Limestone. (See Oakes and others, 1981, p. 13–18, 54–56.)

The nearest KGRA's (Known Geothermal Resource Areas) are about 30 mi north of the study area at Newcastle and Navajo Lake, Utah. Neither are identified resources for the study area. Hot springs within 1 mi of the study area have temperatures of less than 187 °F. (See Oakes and others, 1981, p. 21, 57, 58.)

Silver

The Cottonwood Canyon study area is between the Silver Reef and Santa Clara mining districts. Silver has been mined from the Springdale Sandstone Member of the Moenave Formation in these two districts (Hess, 1933, p. 454). The Springdale Sandstone Member is not exposed in the study area but is close to the surface beneath the southeastern part of the area. The Springdale Member is covered by as much as 1,200 ft of Kayenta Formation and 2,000 ft of Navajo Sandstone throughout most of the rest of the study area.

A rock sample (no. 29, pl. 1) was taken above a 35-ft-deep inclined shaft about ¼ mile outside of the eastern boundary of the study area (Wood, 1987, fig. 2). This shaft was driven along the bedding in the upper part of the Moenave Formation, which dips toward the study area (48° NW.) at the shaft. The metal concentrations in this sample are insignificant (Wood, 1987, table 1).

Industrial Rocks and Minerals

Inferred subeconomic resources of common varieties of building stone, silica sand, and limestone occur in the study area. Navajo Sandstone has been quarried for building stone about ½ mi north of the study area (Wood, 1987, fig. 2), and similar Navajo Sandstone occurs in the study area.

According to Cook (1960, p. 112), "Silica sand has been produced intermittently from a deposit between St. George and Veyo." This deposit was not found during the USBM's field study, but is most likely in the Navajo Sandstone or in dunes derived from weathered Navajo Sandstone. Rock samples taken by the USBM in and near the study area show that the silica content in the Navajo Sandstone ranges from 90.95 to 94.70 percent (Wood, 1987, table 2, sample nos. 20, 21, 26). These percentages are below the minimum specification of 95.00 percent suggested for the manufacture of glass (Buie and Robinson, 1958, table 1), and therefore suggest that the Navajo Sandstone within the study area is not suitable for glass manufacture; however, it is suitable as foundry sand and for common construction uses, such as a subbase under paving and as fill where good drainage is important. Near the contact of the Navajo with the overlying Carmel Formation just north of the study area (pl. 1), the Navajo Sandstone is cemented with silica and, thus, may contain more than 95.00 percent silica. Occurrences of silica-cemented Navajo Sandstone are apt to be thin and local however.

The Carmel Formation contains gypsum and limestone beds about ½ mi north of the study area, but no gypsum beds were seen in Carmel Formation exposures within the study area. The USBM's sampling of an 8-ft-thick limestone bed in the northwestern part of the study area (Wood, 1987, table 2, sample no. 18) contained 50.82 percent CaO (equivalent to 90.7 percent $CaCO_3$). The limestone sample tested is pure enough only for agricultural uses (O'Neill, 1964, table 2.1).

All of the industrial rocks present in the study area have low unit value and require local markets to be economically viable; demand for these resources from the study area is unlikely.

ASSESSMENT OF POTENTIAL FOR UNDISCOVERED RESOURCES

By B.B. Houser, Janet L. Jones, James E. Kilburn, and H.R. Blank, Jr. U.S. Geological Survey

K.L. Cook University of Utah

Geology

Geologic Setting

The Cottonwood Canyon Wilderness Study Area is underlain by chiefly clastic sedimentary rocks of Mesozoic age and by late Cenozoic basaltic andesite flows (pl. 1). The area is on the northwest limb of the northeast-trending Virgin anticline (fig. 2), so the ages of exposed Mesozoic rocks progress from oldest on the southeast to youngest on the northwest. The massive cliff-forming Navajo Sandstone of Triassic(?) and Jurassic age forms the surface of nearly all of the study area. The basaltic andesite flows cap mesas at the western edge of the study area.

Stratigraphy

The Upper Triassic Petrified Forest Member of the Chinle Formation (Wilson and Stewart, 1967) and the Dinosaur Canyon and Springdale Sandstone (Silver Reef Sandstone of Proctor, 1953) Members of the Upper Triassic(?) Moenave Formation (Harshbarger and others, 1957) are exposed just outside the eastern boundary of the study area. The overlying Kayenta Formation of Late Triassic(?) age (Averitt and others, 1955) is exposed along the eastern boundary of the study area and is the oldest unit present in the study area. These units (Chinle, Moenave, and Kayenta) form a sedimentary sequence of mudstone and sandstone that is in large part fluvial. Most of the Springdale Sandstone Member is composed of crossbedded channel sandstone lenses that vary considerably in number and thickness along strike. Minor interbeds of greenish-gray to pale-red claystone and clay-pebble conglomerate in the Springdale locally contain abundant detrital carbonaceous material. Petrified wood is common. Contacts between the Chinle, Moenave, and Kayenta are disconformities or minor erosional unconformities marked by fluvial channels and clay-pebble conglomerate lenses. The contact of the Kayenta with the overlying Navajo Sandstone is gradational and intertonguing over a vertical interval of about 50–75 ft, and records a change from deposition on coastal salt flats (upper part of the Kayenta) to deposition of eolian sand dunes (Navajo).

Except for strips less than a mile wide at the eastern and western ends, all of the study area is underlain by the Triassic(?) and Jurassic Navajo Sandstone. The Navajo Sandstone is about 2,000 ft thick in southwestern Utah, and is characterized by large-scale eolian crossbedding, strong jointing, a tendency to develop smoothly sculptured vertical cliffs, and vividly contrasting reddish-orange and white color.

The Middle Jurassic Carmel Formation and Upper(?) Cretaceous Iron Springs Formation are exposed in the northwestern corner of the study area and extensively northward. The contact of the Carmel with the underlying Navajo Sandstone is an erosional unconformity marked by 1–15 ft of relief and by reworking of sand from the Navajo into the basal beds of the Carmel. The surface of the Navajo at the unconformity locally is cemented with chalcedony. Broken fragments of this lithology have a vitreous appearance. The Carmel consists of gypsum, limestone, and reddish-brown mudstone and sandstone, and represents shallow-marine and continental deposition. The chiefly clastic lower part of the sequence included in the Carmel in this report probably corresponds to the Temple Cap Sandstone (Gregory, 1950a, b; Peterson and Pipiringos, 1979).

The Carmel Formation is separated from the overlying Upper(?) Cretaceous Iron Springs Formation by an erosional unconformity—a hiatus that probably represents all of Late Jurassic and Early Cretaceous time. The Upper Cretaceous Dakota Conglomerate, commonly present throughout the region between the Carmel and Iron Springs Formations, is absent in the vicinity of the study area. The Iron Springs consists of mudstone and sandstone that may represent shallow-marine and fluvial-deltaic deposition.

Mesa-capping basaltic andesite (53.4 percent SiO_2, 5.16 percent Na_2O+K_2O; sample 437SGNE86, pl. 1) at the western edge of the study area is probably late Pliocene or Pleistocene in age. A basalt flow (43.5 percent SiO_2, 3.14 percent Na_2O+K_2O; sample 417HUNW86, pl. 1) that flowed southward down a stream valley from a volcanic vent just south of the area has been dated at 1.7±0.1 Ma (million years ago) (Best and others, 1980). Deposits of terrace alluvium commonly overlie relatively nonresistant rock outside the study area, but apparently either were not deposited or not preserved on the Navajo Sandstone in the study area.

Much of the Navajo is covered by a blanket of residual sand ranging from a few inches to as much as several tens of feet thick.

Structure

The study area lies in the eastern part of the 25-mi-wide transition zone that separates relatively undeformed rocks of the Colorado Plateau on the east from the block-faulted terrane of the Basin and Range physiographic province on the west. Two structures affect the geology within the study area—the Virgin anticline and the Washington fault. The northeast-trending Virgin anticline (axis about 1 mi southeast of the study area, fig. 2) imparts a northwesterly dip to all the units in the study area. Small thrust faults in the Moenave Formation and Petrified Forest Member of the Chinle Formation (only one fault is shown on pl. 1) probably reflect minor adjustments by units of different lithologies to the stress field imposed by the anticlinal folding (Proctor, 1986). Most of the production of the Silver Reef mining district came from ore bodies located on noses and flanks of small folds and faults superimposed on the Virgin anticline just northeast of the study area. Cook (1960, p. 65) regarded the Virgin anticline as a Laramide structure (Late Cretaceous through Paleocene).

The Washington fault trends generally north-northwest and passes through the western half of the study area (fig. 2, pl. 1). This high-angle normal fault, with down-to-the-west relative movement, causes the Carmel and Iron Springs Formations to be exposed in the northwest corner of the study area. The Washington fault has only about 200 ft of displacement at the northern boundary of the study area, but the amount of displacement apparently increases southward. Dobbin (1939, p. 136) estimated 2,500 ft of displacement on the fault at the Arizona line. The Washington fault is a Basin and Range structure (Miocene through Holocene).

Geochemistry

Methods

The geochemical survey of the study area included the collection of stream-sediment samples, the collection of rock samples near most of the stream-sediment sample sites, and the derivation of heavy-mineral concentrates (hereafter referred to as concentrates) from the stream-sediment samples. Stream sediments and concentrates were collected from active alluvium in first-order streams (unbranched) and second-order streams (below the junction of the first-order streams as determined from 1:24,000-scale maps). Rock samples were taken from unaltered outcrops to provide background information for geochemical values.

These sample media were chosen because they best reflect the chemistry of rock material eroded from the drainage basin upstream from the sample site, as well as from the site itself. Concentrates may contain minerals that result from ore-forming processes in addition to detrital heavy minerals common to sedimentary rocks. The selective concentration of heavy minerals permits determination of some elements that are not easily detected in bulk stream-sediment samples. Stream-sediment and rock samples provide information that helps identify areas that contain unusually high concentrations of elements that may have been derived from mineral deposits. These samples also help to identify rock lithology upstream.

Stream sediments and concentrates were collected at 37 sites, and rocks were collected at 26 sites. These sample sites are located both within and outside of the study area (pl. 1). Stream sediments were sieved to minus-80 mesh and then pulverized to fine powder for analysis. To obtain concentrates, bulk stream-sediment samples were sieved to minus-10 mesh and then panned to eliminate most of the quartz, feldspar, clays, and organic material. The remaining lightweight minerals were removed by heavy-liquid separation (bromoform, specific gravity 2.8) and discarded. The heavy minerals were separated magnetically into three fractions—magnetic, slightly magnetic, and nonmagnetic. The nonmagnetic fraction was ground to a fine powder before analysis. The rock samples were crushed and then pulverized to a fine powder for analysis. Splits of the pulverized samples were analyzed for 31 elements by six-step, optical emission, semiquantitative spectrography (Grimes and Marranzino, 1968). Detailed sampling procedures and sample preparation and analytical techniques can be found in Detra and others (1988).

Anomalous elemental concentrations obtained from analysis of the three sample types were used to delineate possible mineralization. Values were determined to be anomalous by comparison with background values of the area and with crustal abundance (Rose and others, 1979). Background values were developed by calculating the mean of each element within the study area and then applying two standard deviations to the mean to yield a minimum threshold value. This value was then compared with the average crustal abundance of each element and with data given in the literature for similar material. From this procedure, tentative anomalous values were determined.

Results

Concentrates, stream sediments, and rocks were all useful in locating anomalous concentrations of elements in the study area on a reconnaissance basis. Anomalous elemental values, however, were found only in the analyses of the nonmagnetic fraction of the concentrates. The nonmagnetic fraction of the concentrates indicates that anomalous values of barium (greater than 10,000 ppm (parts per million)) are scattered throughout the study area. Barite, as confirmed by optical inspection and X-ray diffraction, is the source of the barium. Molybdenum also was noted to be anomalous (70 ppm), but only at a single site in the north-central part of the study area. Because this element was an isolated occurrence with no other anomalous elements present, it must be considered nonsignificant. Optical identification of specific minerals in the concentrates was not feasible because most individual grains are well rounded and highly frosted, thus masking crystal characteristics necessary for identification.

Four rock samples were collected from the Springdale Sandstone Member outside the study area and analyzed to investigate variation in mineralization of the sandstone along strike. Sample 439HUNW86, taken near the southern limit of mining activity in the Silver Reef mining district about a mile north of Quail Creek (pl. 1), contained 30 ppm silver. In contrast, samples 419HUNW86, 420HUNW86, and 422HUNW86, taken from the Springdale Sandstone Member just east of the study area (pl. 1), contained only 1.5, 0.5, and 0.0 ppm silver, respectively. These values suggest that the amount of mineralized rock present in outcrops of the Springdale decreases abruptly southwest of Quail Creek, but the presence of silver probably is significant still.

Geophysics

Regional Bouguer gravity and aeromagnetic anomaly data in the Cottonwood Canyon Wilderness Study Area and vicinity and limited aeroradiometric data provide insight and constraints on structural and lithologic interpretations that may affect the assessment of mineral resource potential. The gravity anomalies chiefly reflect regional structural and compositional trends and do not provide evidence for any mineral deposits or occurrences in the study area. Interpretations of aeromagnetic anomalies, which suggest that the Hurricane fault flattens at depth and that the Virgin anticline is detached from the basement, may have important implications for future asssessment of oil and gas resource potential as more data become available.

Gravity Data

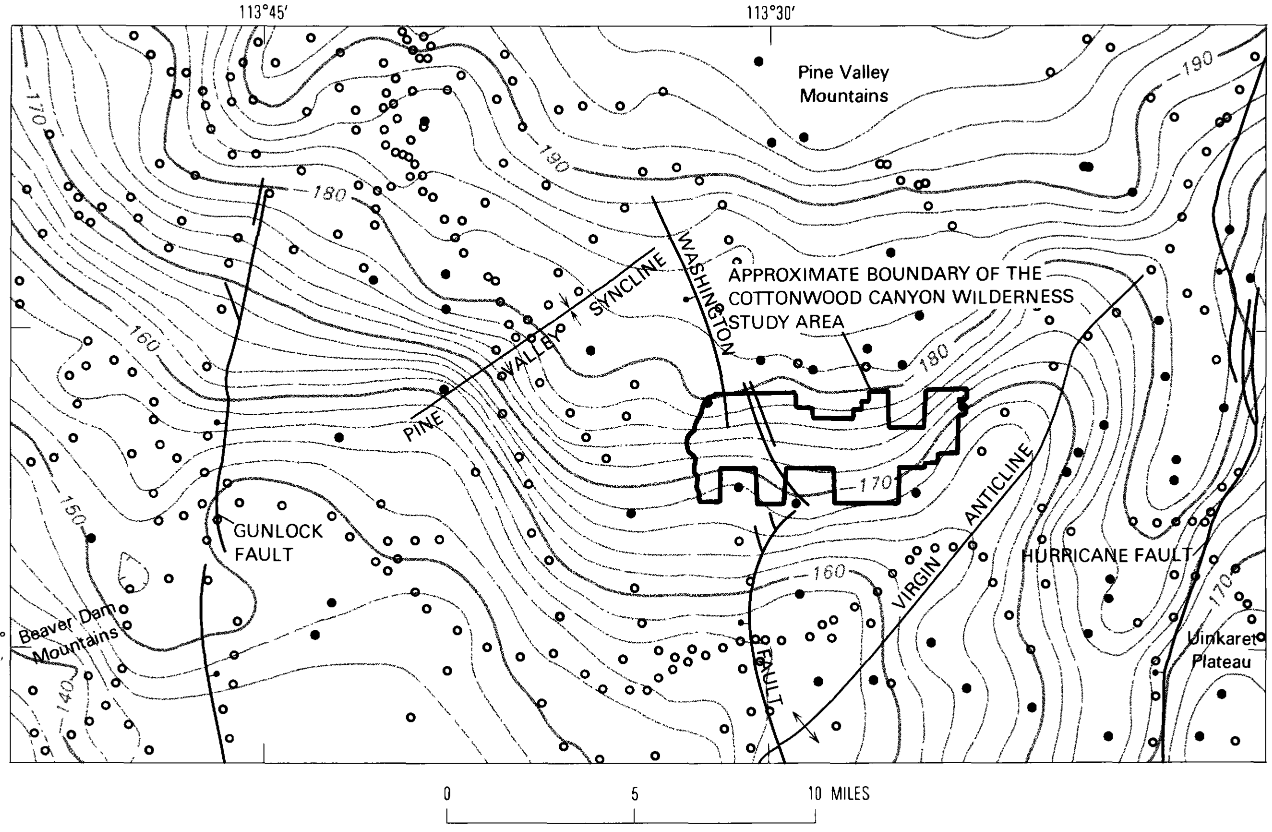
The Bouguer gravity anomaly map (fig. 3) was prepared from gravity observations at 48 stations established in conjunction with this study and at more than 300 stations established previously. Principal facts for the older stations are available from the National Center for Geophysical and Solar-Terrestrial Data (Boulder, CO 80301), and from K.L. Cook (Department of Geology and Geophysics, University of Utah, Salt Lake City, UT 84112). All readings were reduced to complete Bouguer anomaly values at a standard density of 2.67 g/cm^3 (grams per cubic centimeter) following routine procedures (see Cordell and others, 1982, for equations used). Terrain corrections were made from digital topography out to a distance of 100 mi from each station; no corrections were made manually.

The gravity relief is approximately 60–65 mGals (milligals), mostly expressed as a general decrease in field values from south to north, with contours trending more or less east-west across the map area in a broad arcuate pattern (fig. 3). The Cottonwood Canyon Wilderness Study Area lies directly astride the steepest part of this gradient. The same gradient extends west to the Sierra Nevada and east into the Colorado Plateau. Locally it is strongly perturbed and almost everywhere it is non-uniform, consisting of two or more parallel "steps" in the field level. Eaton and others (1978) have pointed out that the gradient coincides with the southern limit of voluminous silicic volcanism as well as with a sharp change in regional elevation. Analysis of transverse profiles in the Basin and Range province of Nevada led them to interpret the gradient as the signature of a density discontinuity largely involving crustal rocks, rather than mantle rocks, and they speculated that the gradient results from large-scale emplacement of silicic intrusive rock beneath the Great Basin. In southwestern Utah the gradient also coincides with a northward deepening of the surface of dense Paleozoic carbonate rocks and the underlying Precambrian crystalline basement. Large volumes of silicic rock have intruded Mesozoic and younger strata in the region of low Bouguer anomaly values north of the study area.

The lowest Bouguer gravity values occur in the Pine Valley Mountains north of the study area (fig. 3), where the regional gradient appears to flatten. These mountains are composed chiefly of quartz monzonite porphyry of the 3,000-ft-thick Pine Valley sill and consanguineous extrusive rocks. The form of the intrusion, which should be denser than the surrounding rocks, is not depicted by the gravity contours, perhaps because of its limited depth and the relatively wide station spacing.

Aeromagnetic Data

The aeromagnetic map (fig. 4) was produced from total-intensity data obtained from a survey carried out by Scintrex Mineral Surveys, Inc., under the direction of the USGS, and subsequently published as part of the aeromagnetic map of Utah (Zietz and others, 1976). Flight



EXPLANATION

Gravity contour—Contour interval 2 milligals. Hachures indicate closed low. Reduction density 2.67 grams per cubic centimeter

Gravity station

- ● **From this study**
- ○ **From previous studies**

Fault—Bar and ball on downthrown side

Anticline

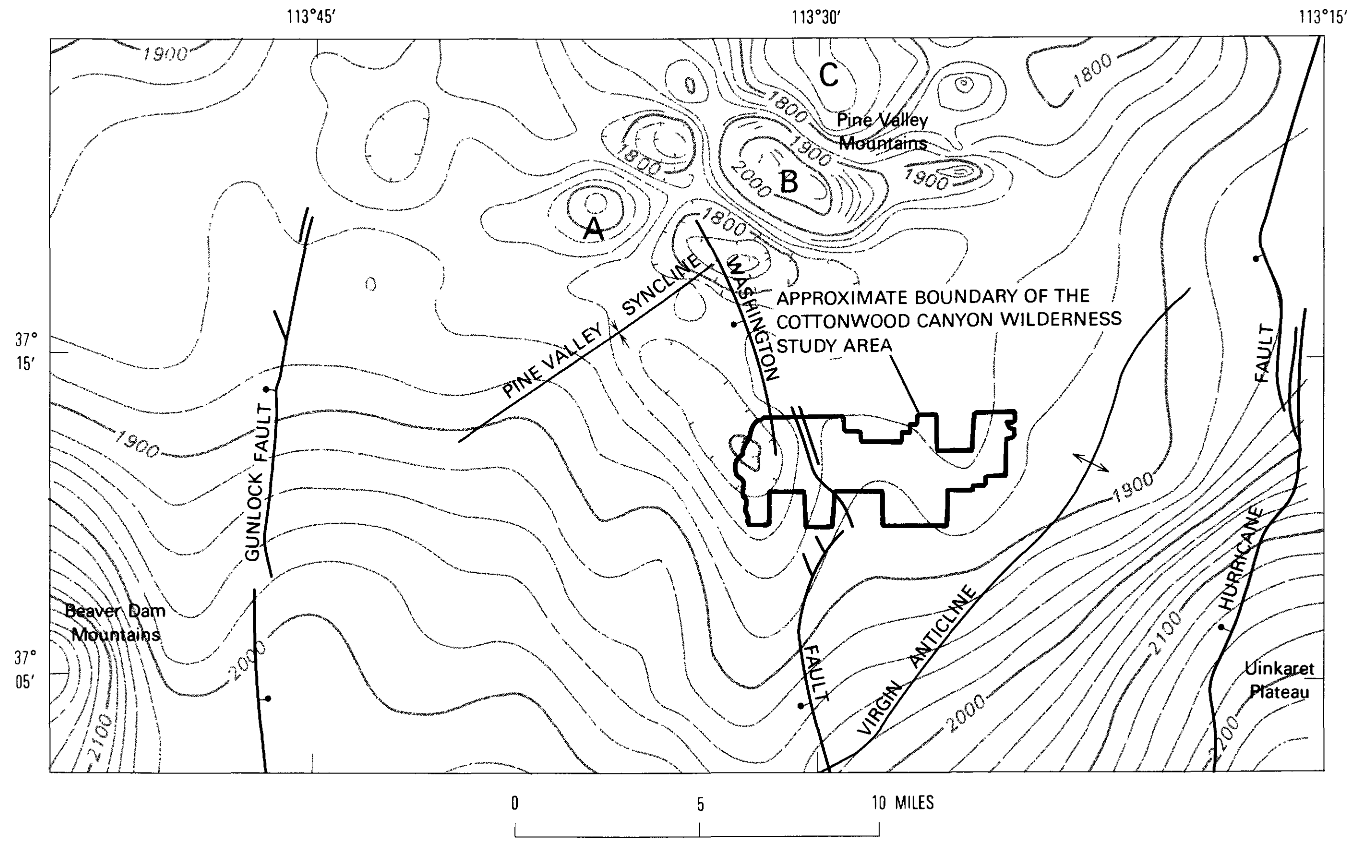
Syncline

Figure 3. Complete Bouguer gravity anomaly contours of the Cottonwood Canyon Wilderness Study Area and vicinity, Washington County, Utah. Structural data modified from Cook (1960).

traverses were oriented north-south and spaced 2 mi apart at a barometric elevation of 9,000 ft above sea level. The main field of the Earth was removed prior to contouring.

The aeromagnetic map shows some features in common with those of the gravity map but in other respects differs significantly. Sedimentary rocks of the Colorado Plateau and transition zone successions are effectively transparent to the magnetic probe, which "sees" through them at this flight elevation to the much more strongly magnetized crystalline basement. Besides the basement rocks, the only other sources of aeromagnetic anomalies are igneous rocks of Cenozoic age.

The regional northward-sloping aeromagnetic gradient in the southern part of the map area (fig. 4) is interpreted as a reflection of the northward deepening of the basement surface. The strong aeromagnetic high in the southwestern corner is associated with a granitic intrusion exposed in the Precambrian core of the Beaver Dam Mountains. The high in the southeastern corner of the map area (Uinkaret Plateau) is considered to be the expression of a concealed basement uplift. There is no indication that the source of the Uinkaret Plateau anomaly is offset by the Hurricane fault, as the aeromagnetic contours pass through the map trace of the fault without apparent disturbance. This relation



EXPLANATION

—1700— **Aromagnetic contour**—Contour interval 200 nanoTeslas. Hachures indicate closed low. International Geomagnetic Reference Field removed

A **Aeromagnetic anomaly**—Referred to in text

Fault—Bar and ball on downthrown side

Anticline

Syncline

Figure 4. Residual total-intensity aeromagnetic contours of the Cottonwood Canyon Wilderness Study Area and vicinity, Washington County, Utah. Structural data modified from Cook (1960).

suggests that the Hurricane fault, a high-angle structure at the surface, flattens with depth. Similarly, no aeromagnetic anomaly occurs over the Virgin anticline, suggesting that the anticline does not have a core of magnetic rock and may be detached from the basement.

The anomaly field in the northern half of the map area is a broad depression, locally perturbed by large thicknesses of basalt, as at A, and of quartz monzonite, as at B (fig. 4). An aeromagnetic low (C) occurs where the thickness of the Pine Valley quartz monzonite sill has been greatly reduced by erosion (Cook, 1960).

Aeroradiometric Data

Limited aeroradiometric data are available for the study area as a result of the NURE (National Uranium Resource Evaluation) program. In southwestern Utah these data were collected along east-west traverses spaced 3 mi apart at a nominal elevation of 400 ft above terrain. The data have been examined by J.S. Duval (USGS, written commun., 1987), who reports that the Cottonwood Canyon Wilderness Study Area has overall low radioactivity with concentrations of 0.2–1.2 percent K (potassium), 0.1–1.0 ppm eU (equivalent uranium), and 1–4 ppm eTh (equivalent thorium). No radioactivity anomalies were found within or adjacent to the wilderness study area at the flight spacing of 3 mi.

Mineral and Energy Resource Potential

Metals

No mines, prospects, evidence of mineralized rock, or significant geochemical anomalies were found in the wilderness study area. The eastern part of the study area is included in the Silver Reef mining district, however, and there are many small prospects just east of the study area along the outcrop belt of the Springdale Sandstone Member of the Moenave Formation, the host rock of the silver-rich ore bodies. The Springdale crops out within 300 ft of the study area (pl. 1) and is estimated to be present beneath the area at a depth as shallow as 175 ft.

The ore zones of the Silver Reef district are tabular bodies that occur chiefly within the lenses of fluvial sandstone that form the 30- to 100-ft-thick Springdale Member. Cerargyrite is the principal ore mineral, along with minor malachite and carnotite. The richest ore bodies were located on the faulted nose and adjacent flanks of the northeast-trending Virgin anticline (fig. 2) (Proctor, 1953). The amount of mineralized rock present in outcrops of the Springdale decreases abruptly southwest of Quail Creek, but probably is significant still. Rock sample 439HUNW86, taken near the southern limit of mining activity about a mile north of Quail Creek (pl. 1), contained 30 ppm silver. In contrast, rock samples 419HUNW86 and 420HUNW86, taken from the Springdale just east of the study area (pl. 1), contained only 1.5 and 0.5 ppm silver, respectively; rock sample 422HUNW86 contained no silver.

Deposit model

Heyl (1978) noted that Proctor's (1953) detailed description of the mineralogy and occurrence of the silver, copper, and uranium-vanadium ore of the Silver Reef district has many characteristics in common with the ore-deposit model for tabular sandstone-uranium deposits (as later outlined by Finch, 1982). The syngenetic model suggested by Proctor (1953, 1986) for the genesis of the ore is somewhat similar to the sandstone-uranium model, although sandstone-uranium deposits generally are not considered to be syngenetic.

The specific sandstone-uranium ore-deposit model that best matches the characteristics of the Silver Reef silver-copper-uranium ore is as follows. Widely dispersed elements, derived chiefly from volcanic ash beds interbedded with continental sedimentary rocks (probably from the Petrified Forest Member of the Chinle Formation), were dissolved by ground water and transported laterally or downward to a favorable host rock (Springdale Sandstone Member). Favorable host rocks are light-gray to white, fluvial sandstones that contain detrital carbonaceous material. As ground water flowed through the sandstone host rock, the dissolved metal ions it carried were precipitated as sulfide compounds in the reducing conditions present in the immediate vicinity of the carbonaceous material. Subsequent lowering of the water table caused oxidation of the primary mineral deposits and resulted in the formation of secondary ores composed (in the case of Silver Reef) chiefly of cerargyrite (silver chloride mineral) and minor malachite and carnotite. Some additional concentration may have accompanied formation of the secondary ore.

Two aspects of the sandstone-uranium model have particular bearing on assessing the mineral resource potential for silver, copper, or uranium deposits beneath the wilderness study area: (1) the model predicts that unoxidized primary ore bodies will occur below the water table, and (2) the means by which metal ions are transported from a source rock to the host rock.

First, the model implies that unoxidized sulfide ore bodies should be present in the Springdale Sandstone Member below the water table (Heyl, 1978) and, thus, may extend down dip within the Springdale beneath the study area. The relatively low silver content of samples immediately east of the study area may be a result of leaching rather than enrichment following lowering of the water table and may have no bearing on the silver content of the postulated primary ore bodies below the water table. Because the mines of the Silver Reef district are abandoned and flooded, evidence for the presence of unoxidized ore below the water table comes for the most part from the accounts of early miners (Proctor, 1953) and of later visitors to some of the abandoned mines (A.V. Heyl, oral commun., 1986).

James and Newman (1986) expressed doubt that unoxidized ore exists below the water table and suggested another ore-deposit model to account for what they considered to be the occurrence of primary silver chloride ore in the Silver Reef district. In their model, hydrocarbons and associated low-sulfur chloride brine migrated upward into the Virgin anticline. The brine was enriched in silver by contact with regional silver-rich rocks or igneous systems. Silver chloride, which was carried in solution as chloride complexes, was precipitated where the brine encountered ground water. Ore minerals were concentrated locally by detrital carbonaceous material, and along faults and joints. The hydrocarbons were degraded by contact with ground water and bacteria, or migrated out of the anticlinal structure following the erosion which led to supergene metal enrichment.

Using this model, James and Newman (1986) considered that the base of the ore zone may be somewhat irregular, but that the ore bodies are confined to the crest of the Virgin anticline, and that the Springdale Sandstone Member in general is not strongly mineralized at any great distance away from the crest. Thus, this model is not favorable for the occurrence of significant concentrations of silver, copper, or uranium minerals beneath the study area.

The second aspect of the sandstone-uranium ore-deposit model to be considered in assessing the mineral resource potential for silver, copper, or uranium deposits beneath the study area is the mechanism by which the metal ions were transported from the Petrified Forest Member of the Chinle (the proposed favorable source rock (Proctor, 1986, p. 176, table 6)) to the Springdale Sandstone Member. Ordinarily in this model, metal ions are envisioned as being transported downward and (or) laterally by ground water until a suitable host rock is intercepted. The Petrified Forest Member is stratigraphically lower than the Springdale Member, however, being separated from it by the 300- to 370-ft-thick Dinosaur Canyon Member of the Moenave Formation. Thus, in the absence of structural deformation, metal ions could not be carried from the source rock to the host rock by lateral or downward flow of ground water.

Proctor (1953, 1986) recognized the problem and suggested that, during Springdale time, the Chinle was exposed to erosion some distance to the southeast of the mining district, and that the metals were carried by streams as mineral fragments and (or) in solution to the site of deposition of the fluvial sandstone bodies of the Springdale. Based on this source model, the primary ore bodies should occur chiefly in channel sandstone lenses, and should be elongate to the northwest (the direction of flow of the paleostreams). This model suggests a moderate potential for the occurrence of silver, copper, or uranium ore bodies beneath the study area. However, the lenses of channel sandstone in the Springdale are thinner, less numerous, and less continuous south of Quail Creek than in the active part of the mining district, and may have been deposited near the edge of the main channel of the postulated paleostream(s) that carried the metals into the region. This possibility may account for the low silver content in samples from the Springdale immediately east of the study area, but chiefly it serves to point out that using Proctor's source model, the size and grade of any primary ore bodies present beneath the study area may depend on the specific fluvial depositional environment of the Springdale. Specific depositional environments of the Springdale may be less of a factor in the source model described in the following paragraph.

Another mechanism for the transport of metal ions from the Chinle to the Springdale is lateral or downward transport by ground water after the folding of the Virgin anticline. The Navajo Sandstone (a principal aquifer of the region today) could have supplied abundant water to the underlying rocks through the faults that developed on the nose and flanks of the anticline. The water may have had high concentrations of sulfate or chloride ions derived from the Kayenta Formation or Temple Cap Sandstone. This source model accounts for the location of the ore bodies on the nose and adjacent flanks of the Virgin anticline, and implies that other ore bodies may be present where structures raise the Chinle (the presumed source of the metals) up to or above the level of the Springdale and where fractures allow entry of ground water into the system. This source model favors a moderate potential for the occurrence of silver, copper, uranium, vanadium, and gold mineral deposits in the Springdale Sandstone Member beneath the eastern part of the area and beneath the area on the western (downthrown) side of the Washington fault (fig. 2, pl. 1).

Potential

The analysis of ore-deposit models suggests that there is moderate mineral resource potential for deposits of silver, copper, uranium, vanadium, and gold beneath the Cottonwood Canyon Wilderness Study Area, with certainty level B. The most likely deposit type is tabular sandstone-hosted silver ore containing the other metals in minor amounts. The favorable host rock, the Springdale Sandstone Member of the Moenave Formation, is present beneath the entire study area at depths ranging from 175 ft in the east to about 3,000 ft in most of the rest of the area. The mineral resource potential for deposits containing metals other than silver, copper, uranium, vanadium, and gold beneath the study area is low, with certainty level C.

Oil and Gas

Molenaar and Sandberg (1983) assigned a low resource potential for oil and gas to the part of southwestern Utah, west of the Hurricane fault, that includes the study area. Oil and gas have been produced from upper Paleozoic and Lower Triassic rocks east of the Hurricane fault (fig. 2) at two fields about 15 mi east and northeast of the study area. The geologic map of Washington County (Cook, 1960) indicates that these rocks are probably present beneath the study area, but no favorable structural or stratigraphic traps have been identified within the area. Aeromagnetic data suggest, however, that the Hurricane fault flattens at depth and that the Virgin anticline is detached from the basement. This implies that structural and stratigraphic sequences at depth may be different from those present in the upper few thousand feet of the crust in and around the study area. Currently available data are inadequate to evaluate the importance of this implication to the assessment of the oil and gas resources of the study area.

No conclusive shows of oil have been reported unambiguously from test wells drilled west of the Hurricane fault in Washington County (Cook, 1960, p. 112). Molenaar and Sandberg (1983) suggested the possibility that long-distance eastward petroleum migration may be the cause of the apparent absence of oil and gas in this region of southwestern Utah. In agreement with this assessment, the energy resource potential for oil and gas is rated as low beneath the entire study area, with certainty level B.

Geothermal Sources

The energy resource potential for low-temperature geothermal sources (less than 194 °F at depths less than 0.6 mi) is high beneath the entire study area, with certainty level D. The study area is in a region having terrestrial heat flow between 1.5 and 2.5 HFU (heat flow units) (Sass and Lachenbruch, 1979) and a mean annual temperature of about 60 °F. (1.0 HFU yields a temperature gradient of about 15 °F per 1,000-ft depth.) These parameters indicate that at a depth of 0.6 mi beneath the study area, temperatures on the order of 130–180 °F will be encountered.

Coal

Coal, ranging in rank from lignitic to bituminous, is present in Upper Cretaceous rocks north and east of the study area (Gregory, 1950b; Averitt, 1962). Upper Cretaceous rocks occur in the northwestern corner of the study area, but they contain no coal. Mesozoic and Paleozoic rocks beneath the study area are not known to contain coal in the region. Thus, the study area has no energy resource potential for coal, with certainty level D.

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APPENDIX

DEFINITION OF LEVELS OF MINERAL RESOURCE POTENTIAL AND CERTAINTY OF ASSESSMENT

Definitions of Mineral Resource Potential

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

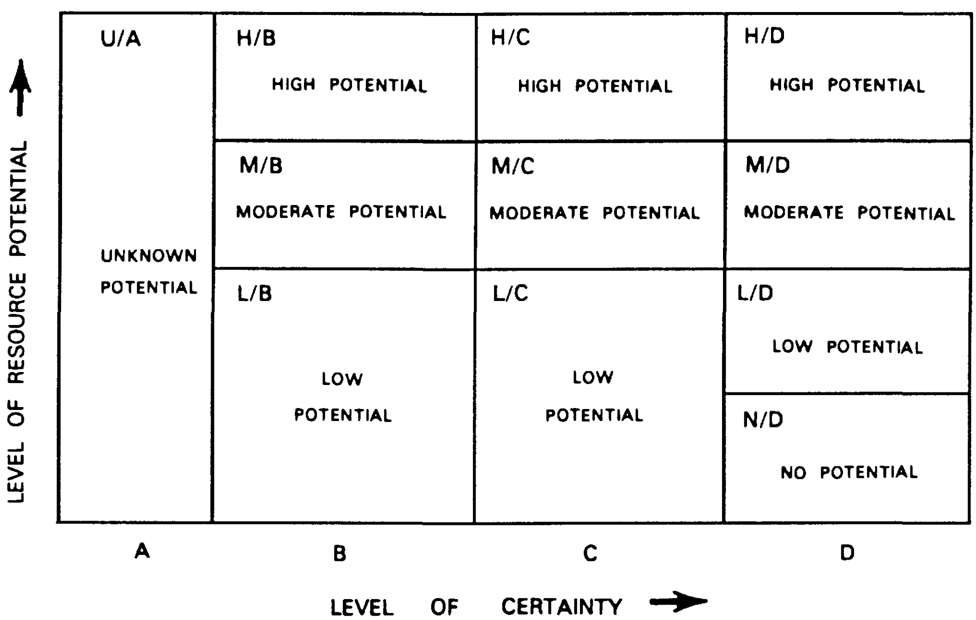
MODERATE mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence, where interpretations of data indicate a reasonable likelihood of resource accumulation, and (or) where an application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

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

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

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

Levels of Certainty



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

Abstracted with minor modifications from:

Taylor, R. B., and Steven, T. A., 1983, Definition of mineral resource potential: Economic Geology, v. 78, no. 6, p. 1268–1270.

Taylor, R. B., Stoneman, R. J., and Marsh, S. P., 1984, An assessment of the mineral resource potential of the San Isabel National Forest, south-central Colorado: U.S. Geological Survey Bulletin 1638, p. 40–42.

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RESOURCE / RESERVE CLASSIFICATION

<table>
<tr><td rowspan="3"></td><td colspan="3">IDENTIFIED RESOURCES</td><td colspan="2">UNDISCOVERED RESOURCES</td></tr>
<tr><td colspan="2">Demonstrated</td><td rowspan="2">Inferred</td><td colspan="2">Probability Range (or)</td></tr>
<tr><td>Measured</td><td>Indicated</td><td>Hypothetical</td><td>Speculative</td></tr>
<tr><td>ECONOMIC</td><td colspan="2">Reserves</td><td>Inferred Reserves</td><td colspan="2" rowspan="3"></td></tr>
<tr><td>MARGINALLY ECONOMIC</td><td colspan="2">Marginal Reserves</td><td>Inferred Marginal Reserves</td></tr>
<tr><td>SUB-ECONOMIC</td><td colspan="2">Demonstrated Subeconomic Resources</td><td>Inferred Subeconomic Resources</td></tr>
</table>

Major elements of mineral resource classification, excluding reserve base and inferred reserve base. Modified from U. S. Bureau of Mines and U. S. Geological Survey, 1980, Principles of a resource/reserve classification for minerals: U. S. Geological Survey Circular 831, p. 5.

GEOLOGIC TIME CHART

Terms and boundary ages used in this report

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

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

[2] Informal time term without specific rank.

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