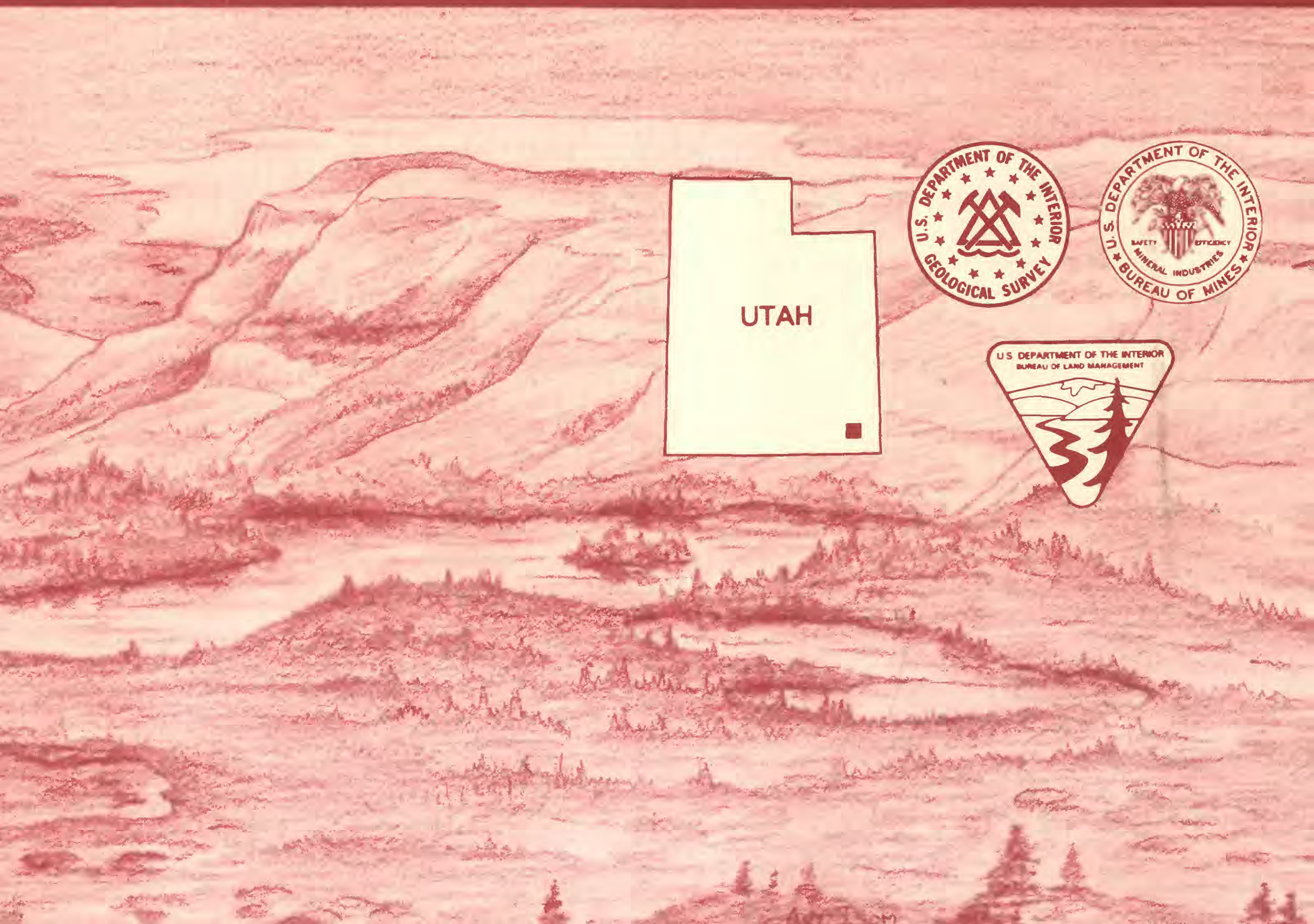
Mineral Resources of the Fish Creek Canyon, Road Canyon, and Mule Canyon Wilderness Study Areas, San Juan County, Utah

U.S. GEOLOGICAL SURVEY BULLETIN 1755–B



Chapter B

Mineral Resources of the Fish Creek Canyon, Road Canyon, and Mule Canyon Wilderness Study Areas, San Juan County, Utah

By DANA J. BOVE, DANIEL R. SHAWE, GREG K. LEE, and WILLIAM F. HANNA
U.S. Geological Survey

RODNEY E. JESKE
U.S. Bureau of Mines

U.S. GEOLOGICAL SURVEY BULLETIN 1755

MINERAL RESOURCES OF WILDERNESS STUDY AREAS:
RED HOUSE CLIFFS REGION, UTAH

DEPARTMENT OF THE INTERIOR
MANUEL LUJAN, JR., Secretary

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

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STUDIES RELATED TO WILDERNESS

Bureau of Land Management Wilderness Study Areas

The Federal Land Policy and Management Act (Public Law 94–579, October 21, 1976) requires the U.S. Geological Survey and the U.S. Bureau of Mines to conduct mineral surveys on certain areas to determine the mineral values, if any, that may be present. Results must be made available to the public and be submitted to the President and the Congress. This report presents the results of a mineral survey of the Fish Creek Canyon (UT–060–204), Road Canyon (UT–060–201), and Mule Canyon (UT–060–205B) Wilderness Study Areas, San Juan County, Utah.

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PLATE

[Plate is in pocket]

FIGURES

Mineral Resources of the Fish Creek Canyon, Road Canyon, and Mule Canyon Wilderness Study Areas, San Juan County, Utah

By Dana J. Bove, Daniel R. Shawe, Greg K. Lee, *and* William F. Hanna
U.S. Geological Survey

Rodney E. Jeske
U.S. Bureau of Mines

Abstract

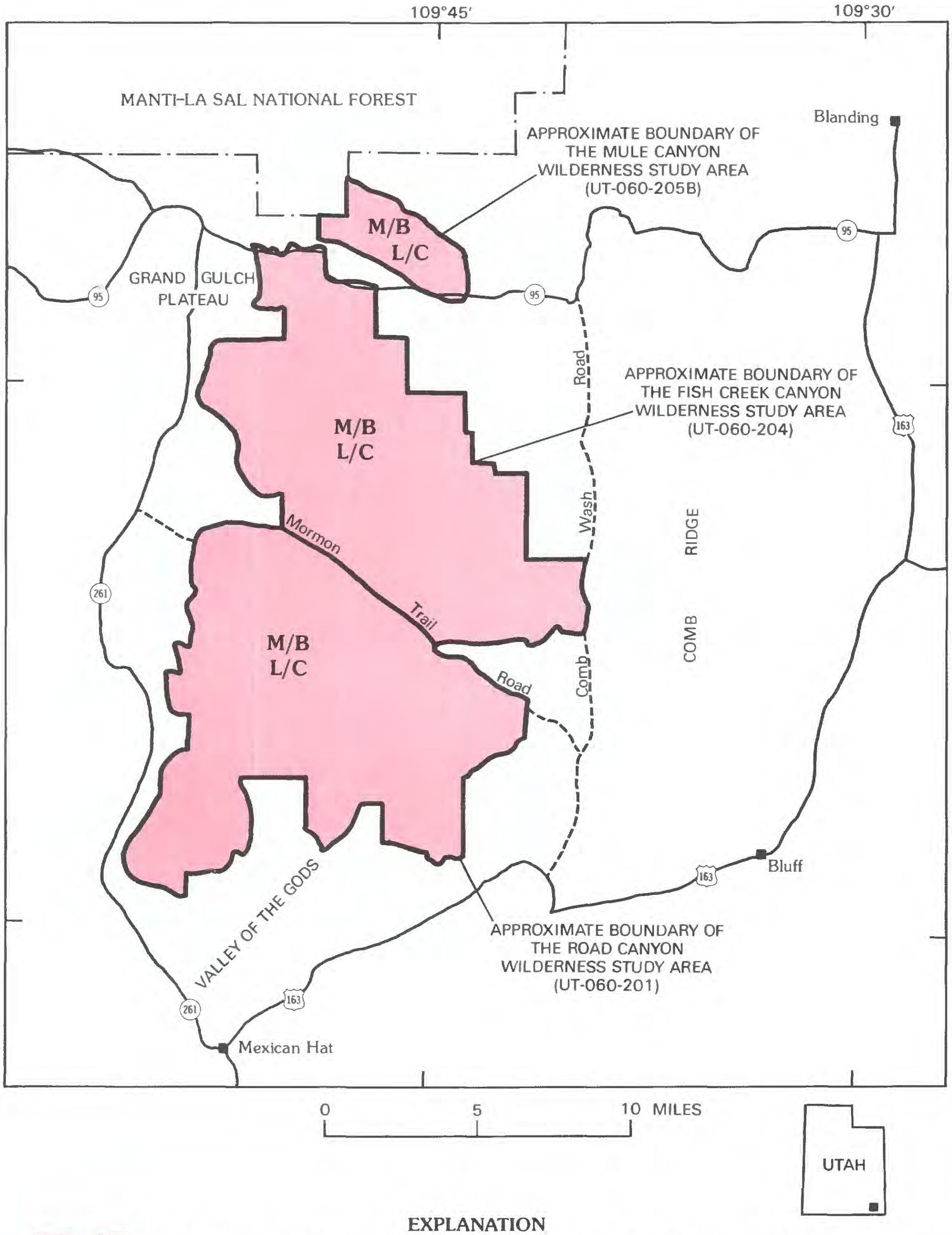
At the request of the U.S. Bureau of Land Management the Fish Creek Canyon (UT–060–204), Road Canyon (UT–060–201), and Mule Canyon (UT–060–205B) Wilderness Study Areas, which comprise 40,160 acres, 52,420 acres, and 5,990 acres, respectively, were studied for their mineral endowment. A search of Federal, State, and county records showed no current or previous mining claim activity, and with the exception of common-variety sand and gravel, no mineral resources were identified during field examination of the study areas. Sandstone and sand and gravel have no unique qualities, but could have limited local use for road metal or other construction purposes. However, similar materials are abundant outside the study areas. The three study areas have moderate resource potential for undiscovered oil and gas and low resource potential for undiscovered metals, including uranium and thorium, coal, and geothermal energy.

SUMMARY

Character and Setting

The Fish Creek Canyon (UT–060–204), Road Canyon (UT–060–201), and Mule Canyon (UT–060–205B) Wilderness Study Areas, which comprise 40,160, 52,420, and 5,990 acres, respectively, are located in south-central San Juan County, about 10–15 mi southwest of Blanding, Utah (fig. 1). Both the Fish Creek Canyon and Mule Canyon Wilderness Study Areas lie on the Grand Gulch Plateau, which is deeply dissected by several major canyons including Fish Creek, Owl Creek, Mule, Road, and Dry Wash canyons (pl. 1). The plateau is flat to gently rolling and is moderately vegetated with pinyon-juniper mixed with sagebrush and desert brush. Road Canyon, which is the southernmost wilderness study area, is relatively low lying and sparsely vegetated, and includes the northern portion of the Valley of the Gods (fig. 1). Elevations in the study areas range from about 4,800 ft in the Valley of the Gods to about 7,200 ft in the northernmost part of the Mule Canyon Wilderness Study Area. Due to the proximity of these three study areas, they will be referred to as the "wilderness study areas" or simply the "study areas;" these areas will be referred to individually if a more specific geographic notation is required.

The study areas are situated in the central part of the Monument upwarp, which is one of the major structural features of the Colorado Plateau. The Monument upwarp is a broad, low arch, about 30–40 mi wide, that trends north for nearly 100 mi from Monument Valley, Arizona. The east flank of the Monument upwarp is bounded by the steeply dipping Comb Ridge monocline, which also makes up the approximate eastern boundary of the wilderness study areas (fig. 1, pl. 1). All rocks exposed in the study



EXPLANATION

M/B Geologic terrane having moderate mineral resource potential, with a certainty level of B, for undiscovered oil and gas. Applies to all three study areas

L/C Geologic terrane having low mineral resource potential, with a certainty level of C, for all undiscovered metals, including uranium and thorium, and coal and geothermal energy. Applies to all three study areas

Levels of certainty

B Available information only suggests the level of resource potential

C Available information gives a good indication of the level of mineral resource potential

Figure 1. Location and mineral resource potential of the Fish Creek Canyon, Road Canyon, and Mule Canyon Wilderness Study Areas, Utah.

areas are sedimentary and range in age from Pennsylvanian to Triassic (see geologic time chart in appendix). Depositional environments of these rocks ranged from marine and marginal marine to continental.

Stream-sediment samples were collected in and adjacent to the study areas and analyzed by the U.S. Geological Survey. Inspection of the statistical distributions of the analytical data and consideration of average crustal abundances of the elements in comparable lithologic terranes suggest that the study areas, for the most part, are lacking in mineral enrichment. Gravity and magnetic studies are largely of a reconnaissance nature and are adequate only to define regional features with respect to the subsurface distribution of rock masses and the structural framework of the area.

Identified Resources

In addition to field examination, the U.S. Bureau of Mines conducted a literature search for geologic information and locations of patented and unpatented mining claims, mineral leases, and oil and gas leases in and near the study areas. A search of Federal, State, and county records showed no current or previous mining-claim activity, and no mineral resources were identified during field examination. Sandstone and sand and gravel could be used for road metal if no better rock is available; however, these materials have no unique qualities and there are ample sources outside the study areas. With the exception of secs. 30 and 31, T. 38 S., R. 20 E., all three study areas are under lease for oil and gas.

Mineral Resource Potential

The mineral resource potential for all undiscovered metals, including uranium and thorium, in the wilderness study areas is low (fig. 1). The geologic environment is unfavorable; mineralized rock was not identified at the surface during field studies or by remote-sensing surveys; and there were no significant anomalous values in the geochemical data.

Oil and gas have been produced in the adjacent Paradox basin to the northeast mostly from Paleozoic rocks that range in age from Devonian through Permian, and these same strata are known to occur in the subsurface in the study areas. Many dry holes have been drilled in and near the study areas. The study areas have moderate resource potential for undiscovered oil and gas on the basis of the regional geology and occurrence of strata that could contain hydrocarbons.

There are no indications and no reports of geothermal resources in or near the study areas. No known coal-bearing formations are present at the surface or in the subsurface of the study areas. Therefore, there is low resource potential for undiscovered geothermal resources and coal in the study areas.

INTRODUCTION

At the request of the U.S. Bureau of Land Management (BLM) the Fish Creek Canyon (UT–060–204), Road Canyon (UT–060–201), and Mule Canyon (UT–060–205B) Wilderness Study Areas, which comprise 40,160 acres, 52,420 acres, and 5,990 acres, respectively, were studied for their mineral endowment. The study areas are located in south-central San Juan County, about 10–15 mi southwest of Blanding, Utah (fig. 1). Fish Creek Canyon and Mule Canyon, which are the two northernmost study areas, lie on the Grand Gulch Plateau, which is deeply dissected by several major canyons including Fish Creek, Owl Creek, Mule, Road, and Dry Wash canyons (pl. 1). The plateau is flat to gently rolling and is moderately vegetated with pinyon-juniper mixed with sagebrush and desert brush. Road Canyon, which is the southernmost of the three study areas, is relatively low lying and sparsely vegetated, and includes the northern portion of the Valley of the Gods (fig. 1). Elevations in the study areas range from about 4,800 ft in the Valley of the Gods to about 7,200 ft in the northern portion of the Mule Canyon Wilderness Study Area. Several maintained dirt roads, which include the Comb Wash and Mormon Trail roads, originate from U.S. Highway 163 and Utah State Highways 95 and 261. These roads extend around and provide access to the study areas. Although numerous dirt roads cross the study areas, heavy rains generally make these routes impassable until repairs can be made.

This report presents an evaluation of the mineral endowment (identified resources and mineral resource potential) of the study areas and is the product of several separate studies by the U.S. Bureau of Mines (USBM) and the U.S. Geological Survey (USGS). Identified resources are classified according to the system of the U.S. Bureau of Mines and the U.S. Geological Survey (1980), which is shown in the appendix of the report. Identified resources are studied by the USBM. Mineral resource potential is the likelihood of occurrence of undiscovered concentrations of metals and nonmetals, industrial rocks and minerals, and of undiscovered energy sources (coal, uranium, oil, gas, oil shale, and geothermal resources). It is classified according to the system of Goudarzi (1984) and is shown in the appendix. Undiscovered resources are studied by the USGS.

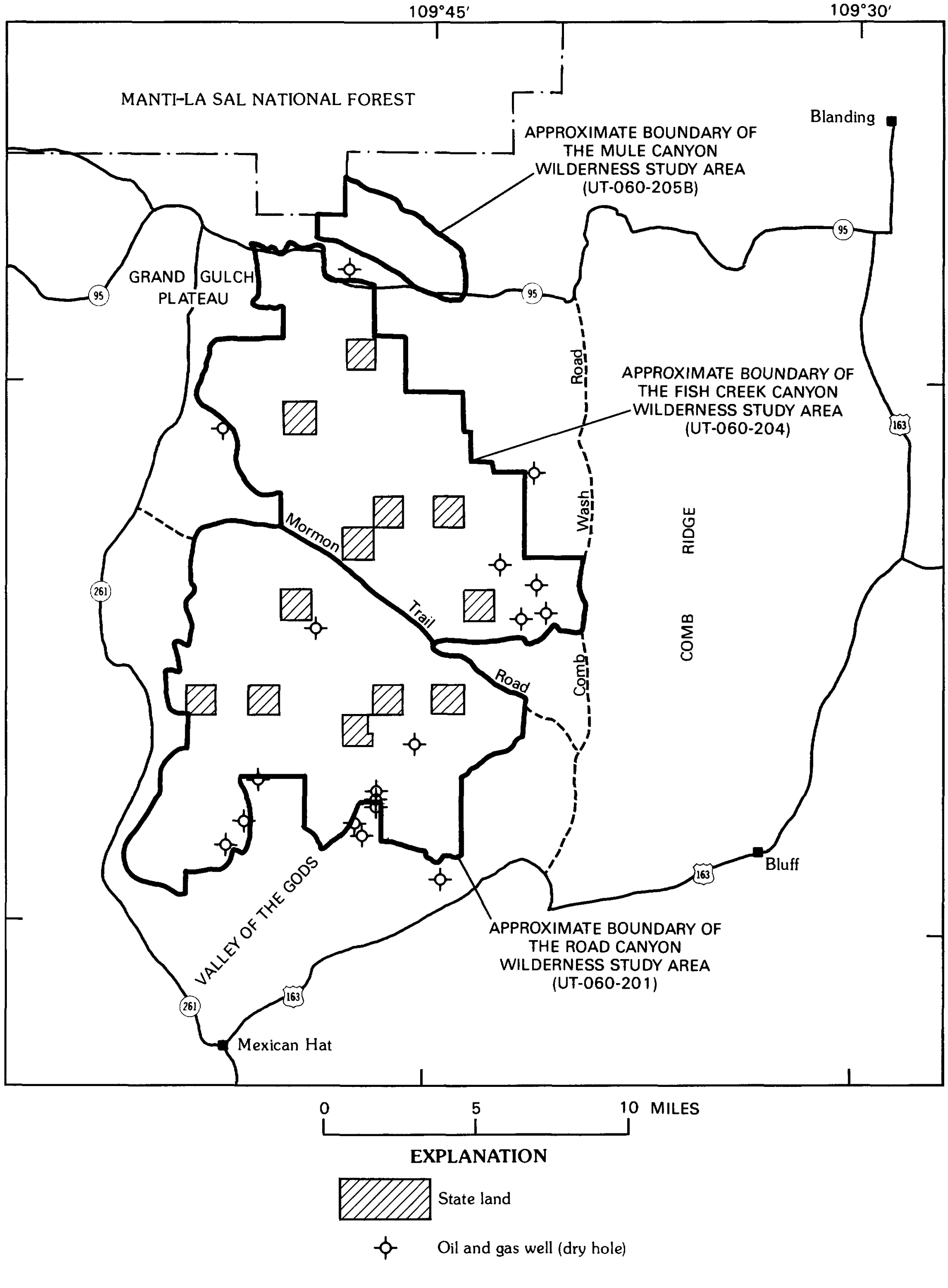


Figure 2. Oil and gas wells (dry holes) drilled in and near the Fish Creek Canyon, Road Canyon, and Mule Canyon Wilderness Study Areas, Utah.

Previous Work

Numerous geologic studies have covered all or part of the study areas and surrounding region. Early studies of the regional geology and stratigraphy were made by Baker (1933) and Baker and Reeside (1929). Between 1955 and 1956, four 1:24,000-scale photogeologic maps, all mostly within the study areas, were compiled (Orkild, 1955a, b; Platt, 1955; Marshall, 1956). Lewis and Campbell (1965) reported on the geology and uranium deposits of Elk Ridge and vicinity; that report described the geology and stratigraphy and included a 1:62,500-scale geologic map of the northern part of the study areas. In 1972, Haynes and others published a map of the geology, structure, and uranium deposits of the Cortez 1°×2° quadrangle, which includes the study areas. Uranium resource potential of the Cortez 1°×2° quadrangle was evaluated by Campbell and others (1980) under contract to the U.S. Department of Energy for the National Uranium Resource Evaluation (NURE) program. The petroleum potential of the study areas was evaluated by Molenaar and Sandberg (1983) in a report on petroleum potential of Utah wilderness lands.

Investigations by the U.S. Bureau of Mines

The USBM examined BLM records of mining claims and oil and gas leases in and near the study areas. Field studies were conducted during the summers of 1987 and 1988 to examine, map, and sample all known mines, prospects, and mineralized zones in and near the study areas to inventory past production, proven and unproven reserves, and subeconomic resources. Results of these studies are presented in Jeske (1988).

Investigations by the U.S. Geological Survey

From 1987 to 1988 the USGS conducted field and laboratory studies to evaluate the mineral resource potential of the Fish Creek Canyon, Road Canyon, and Mule Canyon Wilderness Study Areas. The USGS field-checked previous mapping (Orkild, 1955a, b; Platt, 1955; Marshall, 1956; Lewis and Campbell, 1965) and made necessary revisions in interpretation; conducted field mapping in previously unmapped sections of the study areas; examined and sampled rock units within potentially mineralized areas; collected stream-sediment samples for geochemical analysis; conducted aeromagnetic and gravimetric studies; and searched for previously published and unpublished data on the geology and mineral resources in and near the study areas.

Acknowledgments.—We would like to thank Gayle Coller for her cheerful help in setting aerial photograph models on the PG-2 plotter.

APPRAISAL OF IDENTIFIED RESOURCES

By Rodney E. Jeske
U.S. Bureau of Mines

Mining and Exploration History, and Identified Resources

There has been no known mineral production from the study areas, and there are no mines, prospects, or mineral claims in or near the study areas. With the exception of secs. 30 and 31, T. 38 S., R. 20 E., in the Fish Creek Canyon Wilderness Study Area, the study areas are covered by oil and gas leases. About 55 wells have been drilled in and near the study areas from 1908 to the 1980's, to depths of about 7,000 ft (Jeske, 1988, pl. 1). All wells were dry and abandoned, although shows of oil and (or) gas were encountered in about one-half of the holes. Eighteen of the wells were drilled in or very close to the study areas (fig. 2).

Identified resources were not located in the study area. Sandstone and sand and gravel have no unique qualities, but they may have limited local use for road metal or other construction purposes. The sandstone is friable and contains carbonate cement and iron-oxide stains that make its quality unsuitable for most industrial purposes. Similar sandstone and sand and gravel are abundant outside the study areas.

ASSESSMENT OF POTENTIAL FOR UNDISCOVERED RESOURCES

By Dana J. Bove, Daniel R. Shawe,
Greg K. Lee, and William F. Hanna
U.S. Geological Survey

Geology

The Fish Creek Canyon, Road Canyon, and Mule Canyon Wilderness Study Areas are situated in the central part of the Monument upwarp, which is one of the major structural features of the Colorado Plateau (Haynes and others, 1972). The Monument upwarp is a broad, low arch, about 30–40 mi wide, that trends north for nearly 100 mi from Monument Valley, Ariz. The east flank of the Monument upwarp is bounded by the steeply dipping Comb Ridge monocline, which also makes up the approximate eastern boundary of the study areas (fig. 1). The Comb Ridge monocline trends approximately north near the study areas and locally dips to the east as much as 30°. The west flank of the Monument upwarp is broader and more gently dipping than the east flank. Several minor folds, including the Elk Ridge anticline, the Cedar Mesa anticline, and the Mexican Hat syncline, occur along the broad crest of the Monument upwarp and generally trend north, northeast, and southeast, respectively.

The Monument upwarp was active as early as Late Permian time (Lewis and Campbell, 1965; Baars, 1962). Uplift also occurred during the Late Jurassic when it was probably accompanied by monoclinal flexing of the Comb Ridge monocline, but the major activity commenced during the late Paleocene (Peterson, 1986). The symmetrical association of the Comb Ridge monocline with the Monument upwarp suggests that these two structural features are genetically related and formed contemporaneously (Lewis and Campbell, 1965).

All rocks exposed in the study areas are sedimentary and range in age from Pennsylvanian to Triassic. Depositional environments of these rocks ranged from marine and marginal marine to continental. The Middle Pennsylvanian to Lower Permian Rico Formation, which consists chiefly of thin to thick beds of greenish-gray to reddish-brown, fossiliferous, cherty marine limestone, is exposed only in the Road Canyon study area. The Lower Permian Halgaito Tongue of the Cutler Formation is best exposed in the Road Canyon study area where it overlies the Rico Formation. The Halgaito Tongue is conspicuously reddish brown and composed predominantly of thin-bedded shaly siltstone and some very fine grained sandy siltstone.

The Lower Permian Cedar Mesa Sandstone Member of the Cutler Formation, which caps the broad plateaus and forms most of the steep-walled canyons, rests upon the Halgaito Tongue of the Cutler Formation in the Road Canyon study area and conformably overlies the Rico Formation in the northern half of the Fish Creek Canyon study area and in the entire Mule Canyon study area. The Cedar Mesa is composed mostly of fine-grained quartzose sandstone, within which tabular-planar and wedge-planar crossbedding is common (Stanesco and Campbell, 1989). Studies by Stanesco and Campbell (1989) suggest that the Cedar Mesa Sandstone Member formed in an eolian depositional environment that consisted of dunes, dry and wet interdunes, and sandsheets. An easily distinguishable lithologic break occurs near the base of the Cedar Mesa Sandstone Member. The lower unit, which is characterized by thin-bedded, gray to green, silty sandstone to mudstone, typically is separated from overlying, more massive crossbedded sandstone by a thin, laterally persistent, dark-brown to black, nonfossiliferous limestone. In this study we have mapped this interval—the sandstone and mudstone and the limestone—as a discrete unit, which is referred to as the lower part of Cedar Mesa Sandstone Member. The Rico Formation may be mapped locally with the lower part of the Cedar Mesa in the Fish Creek and Road Canyon study areas. In the southeastern corner of the Road Canyon study area, the Cedar Mesa interfingers with a relatively thick sequence of gypsum, siltstone and limestone (Stanesco and Campbell, 1989).

The Lower Permian Organ Rock Tongue of the Cutler Formation, which conformably overlies the Cedar Mesa Sandstone Member, crops out along the eastern margin of the study areas, just west of the Comb Ridge monocline (pl. 1). This unit is composed almost entirely of red sandy siltstone, red sandy shale, and thin lenses of red silty sandstone. The Organ Rock Tongue is overlain conformably by the Triassic Moenkopi Formation, which is the youngest formation in the study areas. The Moenkopi Formation consists of brown and reddish-brown silty sandstone and thin beds of sandstone.

Quaternary units in the study areas are confined to locations in and near present streams and consist of alluvial sand and gravel, slope wash or colluvial deposits, debris fans, and stream-terrace deposits.

Geochemistry

Reconnaissance geochemical surveys were conducted in the study areas in 1987. Forty stream-sediment and 37 heavy-mineral panned-concentrate samples were collected and analyzed.

Sample Media

Silt and clay (fine fraction) in stream sediments serve as nuclei for the adsorption and precipitation of dissolved metals contained in the stream water. Analysis of stream-sediment samples provides information about the chemical composition of rock material eroded from the drainage basin upstream from each sample site. Such information is useful in identifying those basins which contain concentrations of elements that may be related to mineral deposits.

Analysis of heavy-mineral panned-concentrate samples also provides information about the abundances of certain minerals in rock material eroded from the drainage basin upstream from each sample site. The selective concentration of minerals, many of which may be ore related, permits determination of some elements that are not easily detected in stream-sediment samples.

Geochemical Sampling Methods

Stream-sediment samples were collected from most active stream drainages in the study areas. At each sample site a composite of fine material from several localities within the stream was taken and later air dried for sieving and analysis.

Panned concentrates of stream sediments were collected from streams that were large enough to deposit gravel-sized and coarser sediment. These samples were generally taken in the proximity of the stream-sediment sample sites but were derived from coarser material that represents a relatively high energy depositional environment in the stream. Heavy-mineral concentrates were obtained by panning, after which the concentrate samples were submitted to the laboratory for drying and analysis.

Sample Preparation and Analysis

Stream-sediment samples were dried and sieved through an 80-mesh screen, and the fraction finer than 80 mesh was analyzed. Panned concentrates were dried, and a small split of each sample was separated for spectrographic analysis. The entire remainder of each concentrate was weighed and chemically analyzed for gold content.

Six-step semiquantitive emission spectrographic analyses were made of all samples by R.T. Hopkins, Jr., using the method of Grimes and Marranzino (1968). Each spectrographic analysis included determinations of 35 elements for the stream-sediment samples and 37 elements for the panned-concentrate samples. Atomic-absorption spectrophotometric analysis for gold was performed on every panned-concentrate sample by P.L. Hageman using the method described by Thompson and others (1968). Inductively coupled plasma atomic-emission spectrometric determinations of antimony, arsenic, bismuth, cadmium, and zinc were made on the stream-sediment samples by P.H. Briggs and A.H. Love using the method described by Crock and others (1987). All stream-sediment samples were also analyzed for uranium by T.A. Roemer using a modification of the fluorometric method described by Centanni and others (1956).

The analytical results of the geochemical studies of the Fish Creek Canyon, Road Canyon, and Mule Canyon Wilderness Study Areas are listed in Hopkins and Lee (1989).

Summary of Results

Inspection of the analytical data and consideration of average crustal abundances of the elements in comparable lithologic terranes (Rose and others, 1979) suggest that the study areas generally are lacking in mineral enrichment.

Possible exceptions in the Fish Creek Canyon Wilderness Study Area are indicated by samples collected at sites 10 (South Fork Fish Creek) and 12 (west tributary of Fish Creek which enters about ½ mi south of South Fork) (Hopkins and Lee, 1989). A heavy-mineral panned-concentrate sample from site 10 contained detectable gold (0.2 ppm), and a stream-sediment sample from site 12 contained 3 ppm silver. In addition, a panned-concentrate sample from site 12 (mouth of Barton Range Canyon) in the Road Canyon Wilderness Study Area contained 1.15 ppm gold. These three minor geochemical anomalies are apparently isolated mineral occurrences and probably do not reflect the presence of any significant mineralization in any of the three study areas.

Geophysics

The study areas are covered by gravity and magnetic surveys that have sufficient resolution to define anomalies of a square mile or more in areal extent. Gravity data are in the form of a terrain-corrected Bouguer gravity anomaly map (fig. 3) that has a 2.67-gram per cubic centimeter reduction density, referred to here as the average density. This map was produced for this study by using available station values (Defense Mapping Agency Aerospace Center, 1974, 1975), most of which were acquired or compiled by Case and Joesting (1972). The gravity data were gridded by means of a minimum-curvature algorithm (Briggs, 1974; Webring, 1981) and contoured by using an algorithm for splining under tension (Cline, 1974; Evenden, 1975; Godson and Webring, 1982). The gravity contours are based on 18 stations in the study areas and more than 100 stations near the study areas. Most of the stations are spaced 1–4 mi apart. Similarly, magnetic data are in the form of an aeromagnetic anomaly map (fig. 4) based on total-field measurements made by the USGS along 32 east-west traverses, 22 of which cross the three study areas. The traverses are spaced about 1 mi apart at an average elevation of 8,500 ft. Because the coverage of the aeromagnetic data is more uniform, the magnetic anomaly data define contours more precisely than the gravity anomaly data. Correlations of gravity to magnetic anomalies noted later in this discussion take into account this difference of precision. General knowledge of rock density and magnetization is based on data published by Case and Joesting (1972) and Joesting and Byerly (1958).

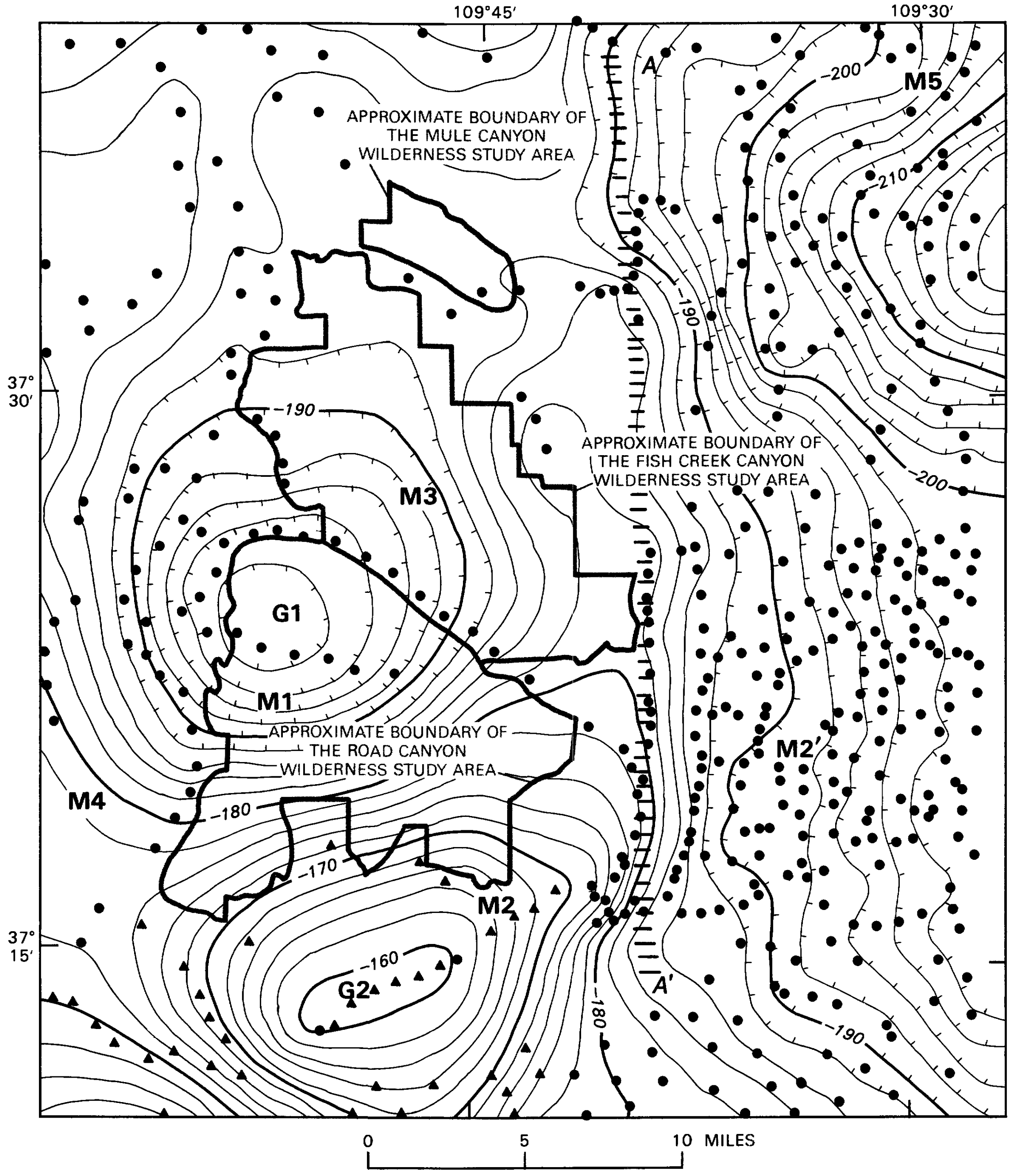


Figure 3. Bouguer gravity anomaly map of the Fish Creek Canyon, Road Canyon, and Mule Canyon Wilderness Study Areas, Utah, showing location of gravity features (G) discussed in text. M = magnetic feature. Contour interval = 2 milligals. Hachures indicate closed areas of low anomaly values. Dots represent gravity stations available for production of map; triangles represent additional stations shown by Case and Joesting (1972). Geophysical data suggest a change in the level of the basement surface along line *A–A′*.

Prominent gravity and magnetic anomalies in and near the study areas mainly reflect compositional and structural trends of basement rocks (Case and Joesting, 1961). These basement rocks lie beneath 8,000–9,000 ft of Paleozoic and Mesozoic rocks in the Blanding basin 10 mi east of the study areas and beneath 2,000–6,000 ft of mainly Paleozoic rocks

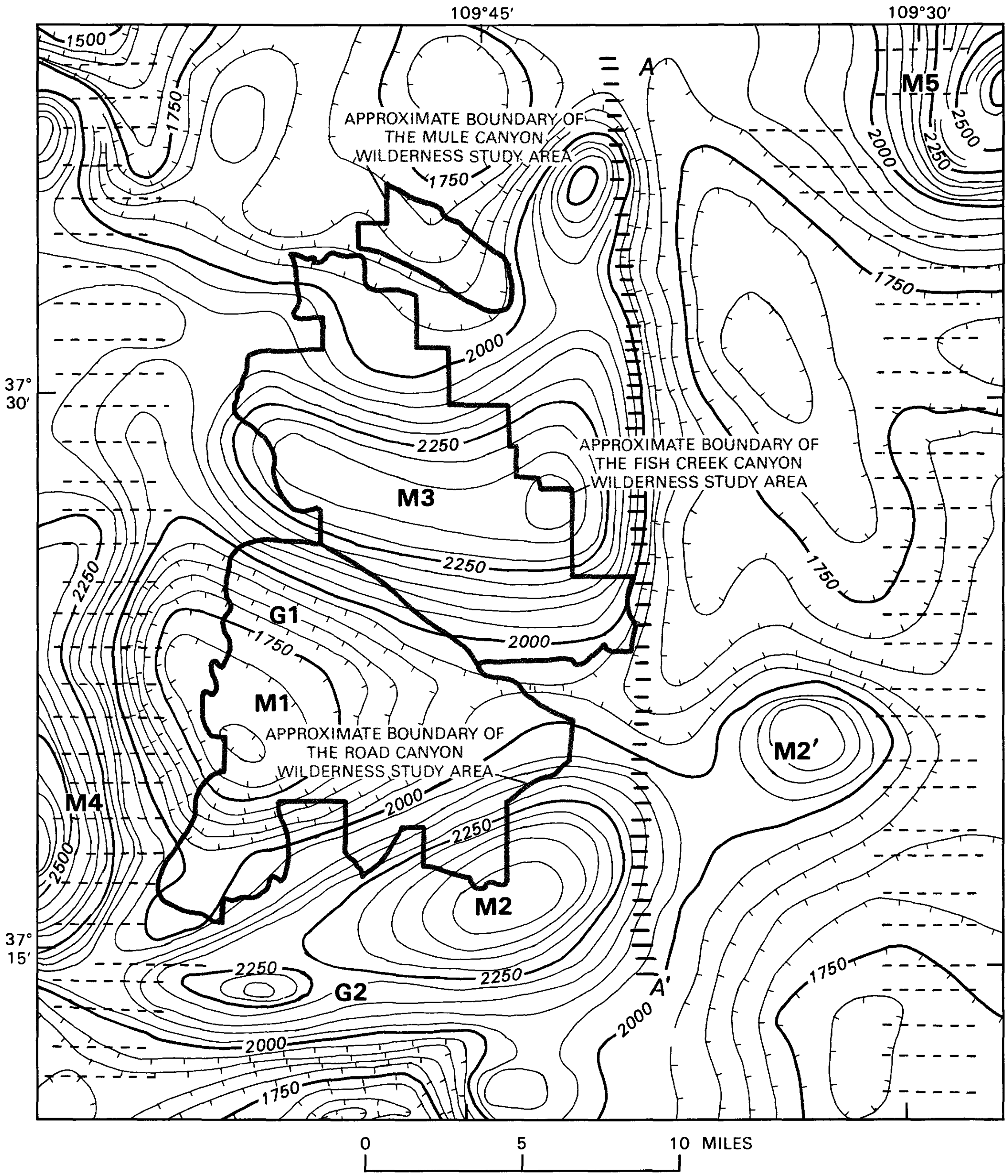


Figure 4. Aeromagnetic anomaly map of the Fish Creek Canyon, Road Canyon, and Mule Canyon Wilderness Study Areas showing location of magnetic features (M) discussed in text. G = gravity feature. Contour interval = 50 nanoteslas. Hachures indicate closed areas of low anomaly values. Flight line traces are shown by dashes near map margin. Geophysical data suggest a change in the level of the basement surface along line *A–A′*.

on the Monument upwarp in the study areas. A change in level of the basement surface, defined by drill-hole data, is shown by the geophysical data to be steepest along line *A–A′* (figs. 3, 4), on the basis of north-trending, straight, closely spaced contours of gravity and magnetic anomalies. These data indicate that the three study areas are underlain by elevated Precambrian basement rocks. The sedimentary rock section above basement is known to be essentially nonmagnetic (Joesting and Byerly, 1958) and average in density, except for low-density salt and associated evaporite deposits of Pennsylvanian age. Basement rocks are inferred to have highly variable magnetization and density, based on measurements of exposures in the central Colorado Plateau outside of the study areas (Case and Joesting, 1972).

In the study areas, a gravity low (located as G1) correlates with a magnetic low (located as M1) (figs. 3, 4). Unlike most other anomalies in the region, G1 and M1 may reflect a source other than basement rocks. G1 may be caused by buried salt, which was derived from the subsurface Paradox Member of the Hermosa Formation and was thickened by buoyant flow. This member is known to thicken from about 100 ft at Mexican Hat, 10 mi south of the study areas, to 1,500 ft at Monticello, 30 mi northeast of the study areas (Wengerd and Matheny, 1958). Where salt intrusions occur elsewhere in the Paradox basin, density lows similar to or larger in amplitude than G1 are generated. Corollary to this interpretation is the requirement that basement rocks underlying the salt be no more than average in density and that they be either nonmagnetic or, if magnetic, reversely magnetized. An alternative interpretation, which was favored by Case and Joesting (1961, 1972), is that G1 and M1 are caused by a basement block of relatively low density and low or reversed magnetization. Such a basement block could be composed of quartzite, argillite, or granite that is surrounded by, for example, granodiorite gneiss, metagabbro, or amphibolite.

South of G1 and M1, at the southern margin of the Road Canyon Wilderness Study Area, gravity high G2 correlates with magnetic high M2 (figs. 3, 4). Because this is the only location where a gravity high is associated spatially with a magnetic high in or near the study areas, the source of the highs is presumed to be compositionally unique there. This source, which is both dense and magnetic, may be metagabbro or amphibolite. The magnetic source appears to extend northeastward beyond the abrupt ascent of the basement surface, shown by line *A–A'* (figs. 3, 4), to the location labeled M2', where its associated anomaly is less sharply defined because of the greater depth of the source there. The source thus appears to have been emplaced prior to the deformation associated with the displacement of the basement surface.

North of G1 and M1, in the north-central part of the Fish Creek Canyon Wilderness Study Area, magnetic high M3 does not correlate with a specific gravity feature, which suggests that the magnetic source rock is about average in density (figs. 3, 4). Similar magnetic highs at M4, 5 mi west of the study areas, and at M5, 19 mi northeast of the study areas near Blanding (figs. 3, 4), also do not correlate with specific gravity features, which also suggests that their magnetic source rocks have average densities. These magnetic rocks of average density may be intermediate-composition basement rocks, such as quartz monzonite, or rocks similar to the most strongly magnetic basement exposed in the Uncompahgre uplift, 95 mi northeast of the study areas, and described by Joesting (1962, p. 397) as "porphyritic granite" and "mafic quartz diorite." A less likely alternative is that the source rocks are deeply buried Laramide intrusive rocks of intermediate composition, similar to the quartz diorite porphyries or granodiorite porphyries emplaced as stocks and laccoliths in the Abajo Mountains (Witkind, 1964), 20 mi north of the study areas.

The geophysical data delineate structural elements of the Precambrian basement where contours are especially straight and close together or where contours are systematically displaced. Steep, linear gradients suggest that most of the basement is composed of compositionally distinct blocks that are bounded by steep discontinuities, which are presumed to be faults. This polygon geometry of the basement beneath the study areas was inferred by Case and Joesting (1972) to extend throughout much of the central Colorado Plateau.

Mineral and Energy Resources

Metallic Deposits

None of the rocks that occur in the study areas are favorable to contain a specific endowment of uranium or thorium (Campbell and others, 1980). Furthermore, limited ground-based scintillometer surveys and aerial gamma-ray surveys (J.S. Duvall, written commun., 1987) indicate that there are no radiometric anomalies in or near the study area. Based on these and other geological and geochemical data gathered during the course of this study, the mineral resource potential for undiscovered uranium and thorium in the study areas is low, with a certainty level of C.

The geologic environment for other undiscovered metal deposits is unfavorable; mineralized rock was not identified at the surface during field studies or by remote sensing surveys (K. Lee, written commun., 1987); and there are no significant anomalous values in the geochemical data. Therefore the mineral resource potential for all undiscovered metals, including uranium and thorium, in the study areas is low, with a certainty level of C.

Oil and Gas

Oil and gas have been produced in the adjacent Paradox Basin mostly from Paleozoic rocks that range in age from Devonian through Permian (Schneider and others, 1971; Molenaar and Sandberg, 1983), and these same strata are known to occur in the subsurface in the study areas. Many dry holes have been drilled in and near the study areas (fig. 2) (Molenaar and Sandberg, 1983). The study areas have moderate resource potential, with a certainty level of B, for undiscovered oil and gas on the basis of the possible occurrence of hydrocarbon-bearing units underlying the study areas and on the basis of studies by Molenaar and Sandberg (1983). A certainty level of B is assigned due to the lack of knowledge on the exact subsurface distribution of these rocks and their hydrocarbon content.

Coal

The study areas have low resource potential, with a certainty level of C, for undiscovered coal, as there are no coal-bearing formations present in the study areas. The rocks that are present in the study areas are not known to contain coal elsewhere.

Geothermal Energy

There is no evidence, such as heated waters or associated mineral deposits, of any occurrence of geothermal resources in the study areas. Therefore the study areas have low resource potential, with a certainty level of C, for undiscovered geothermal resources.

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APPENDIX

DEFINITION OF LEVELS OF MINERAL RESOURCE POTENTIAL AND CERTAINTY OF ASSESSMENT

Definitions of Mineral Resource Potential

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

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

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

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

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

Levels of Certainty

LEVEL OF RESOURCE POTENTIAL →

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

LEVEL OF CERTAINTY →

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

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RESOURCE/RESERVE CLASSIFICATION

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

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

GEOLOGIC TIME CHART

Terms and boundary ages used in this report

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

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

[2] Informal time term without specific rank.

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[Letters designate the chapters]