Mineral Resources of the Tabeguache Creek Wilderness Study Area, Montrose County, Colorado

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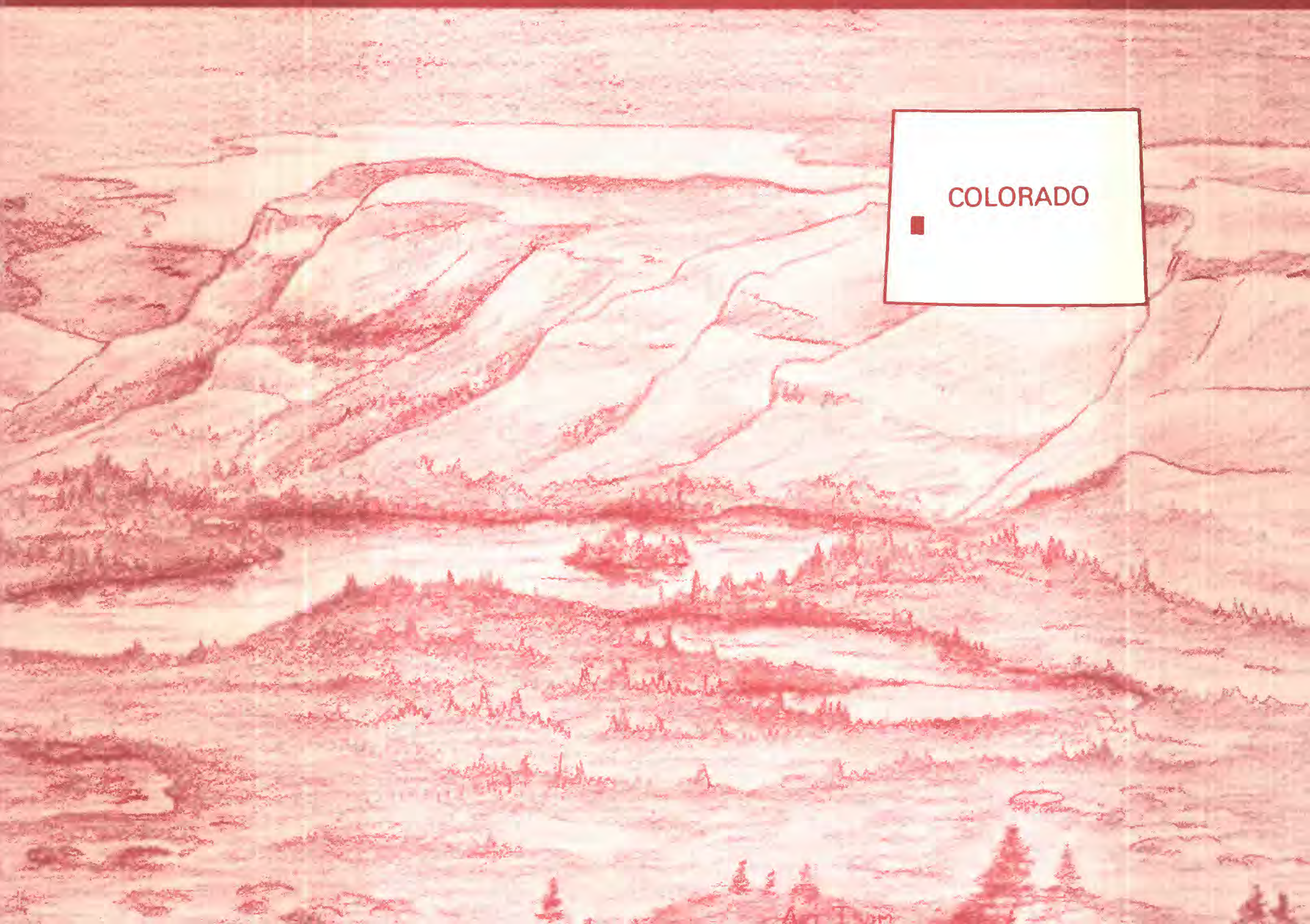

Chapter E

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By ROBERT P. DICKERSON, HARLAN N. BARTON,
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U.S. Geological Survey

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U.S. GEOLOGICAL SURVEY BULLETIN 1715

MINERAL RESOURCES OF WILDERNESS STUDY AREAS—SOUTHWESTERN COLORADO

DEPARTMENT OF THE INTERIOR
MANUEL LUJAN, JR., Secretary

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

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STUDIES RELATED TO WILDERNESS

The 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 to Congress. This report presents the results of a mineral survey of the Tabeguache Creek Wilderness Study Area (CO–030–300), Montrose County, Colorado.

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PLATE

[Plate is in pocket]

FIGURES

Mineral Resources of the Tabeguache Creek Wilderness Study Area, Montrose County, Colorado

By Robert P. Dickerson, Harlan N. Barton, *and* H. Richard Blank, Jr.
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ABSTRACT

The Tabeguache Creek (CO–30–300) Wilderness Study Area is located in Montrose County, Colorado, 3.5 mi (miles) north of Nucla. The study area comprises 7,908 acres of canyon and mesa country on the southwestern flank of the Uncompahgre Plateau. In 1988, the U.S. Bureau of Mines and the U.S. Geological Survey conducted studies to appraise the identified mineral resources (known) and assess the mineral resource potential (unknown) of the study area. The study area contains no known mineral resources. There is a moderate resource potential for undiscovered deposits of oil, gas, and carbon dioxide. There is a low resource potential for undiscovered deposits of uranium and vanadium in the Morrison and Chinle Formations, for gold, copper, and all other metals, and for geothermal energy. There is no resource potential for coal.

Summary

The Tabeguache Creek (CO–30–300) Wilderness Study Area comprises 7,908 acres and is located on the southwestern flank of the Uncompahgre Plateau, 3.5 mi north of the town of Nucla, in Montrose County, Colorado (fig. 1). Tabeguache Creek has eroded a deep canyon into the gently inclined sedimentary rocks of the Uncompahgre Plateau. The canyon floor abounds with cottonwoods and willows, whereas juniper, pinyon, and sage persist on the slopes and surrounding mesas. The study area lies between 5,680 and 7,340 ft (feet) elevation. Access is gained from a maintained dirt road west and north of the study area, from several unmaintained dirt roads to the north, west, and south, and from a foot trail that descends Forty-seven Creek.

Gently southwest-dipping Mesozoic age (see geologic time chart in Appendix) sandstones and shales of the Chinle Formation, Wingate Sandstone, Kayenta Formation, Entrada Sandstone, Wanakah Formation, and Salt Wash Member of the Morrison Formation crop out in the canyon of Tabeguache Creek. The Brushy Basin Member of the Morrison Formation, the Burro Canyon Formation, and the Dakota Sandstone (which crops out west and south of the study area) comprise the surrounding mesas. Several north-, northeast-, and northwest-trending normal faults exist in the eastern part of the study area and in part controlled the course of Tabeguache Creek. Periodic uplift and erosion of the ancestral Uncompahgre Highland and present-day Uncompahgre Plateau through geologic time has influenced the surface and subsurface geology and the mineral endowment of the study area.

Identified Resources

Several million tons of uranium and vanadium ore have been produced from the Morrison Formation in the Uravan mineral belt 6 mi west of the study area (fig. 1). Coal is currently mined from the Dakota Sandstone 1.5 mi south of the study area, near Nucla. Oil and gas have been produced in the Paradox basin from three fields within 20 mi of the study area.

There are no mines, oil or gas wells, or known mineral resources within the study area. There are no patented or unpatented mining claims, but most of the study area is under oil and gas lease or lease application. Geochemical surveys conducted within the study area revealed no geo-

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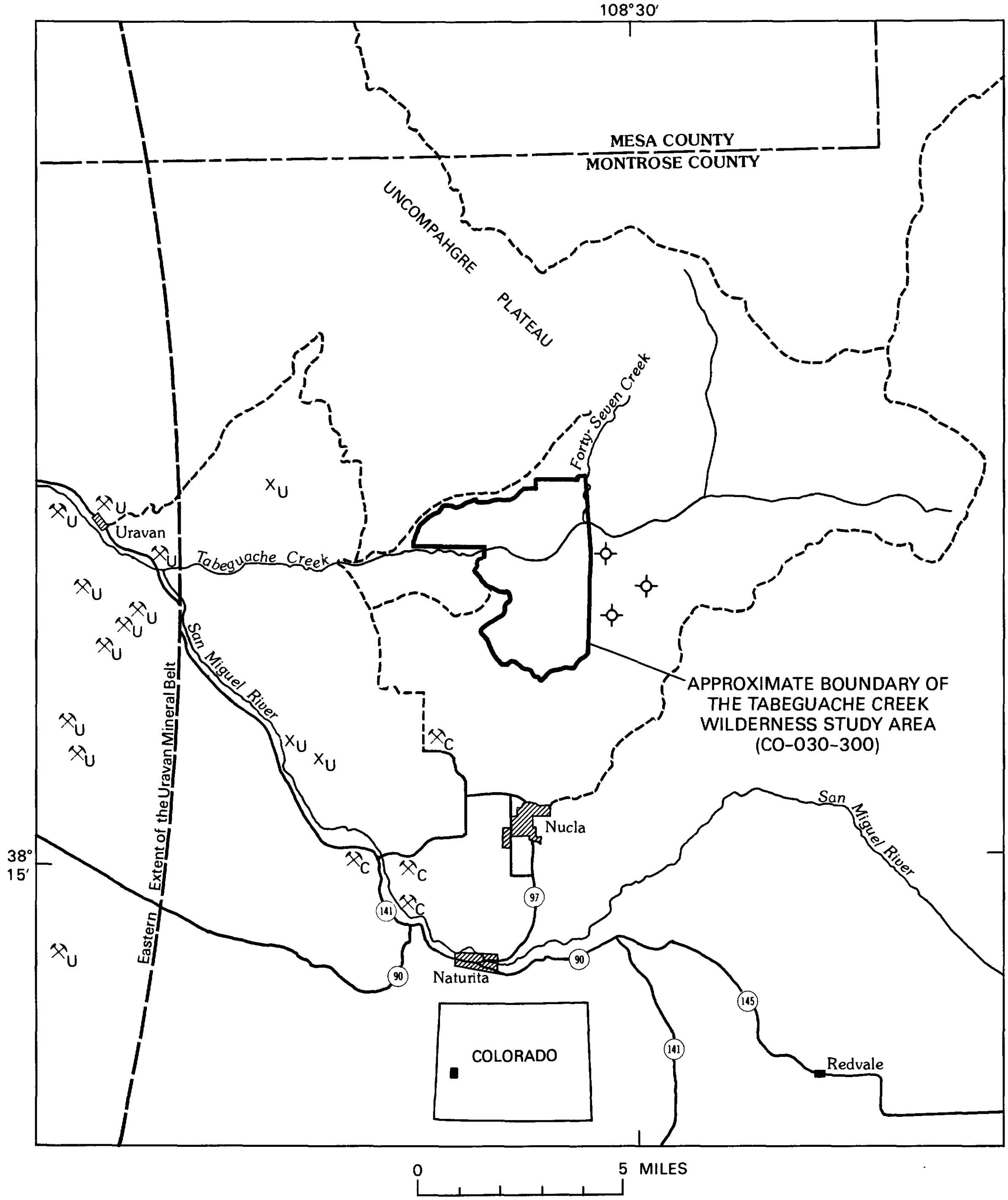

EXPLANATION

- Drill hole
- Mine
- X Prospect
- U, C Commodity mined. U, uranium; C, coal
- -------- Unpaved road

Figure 1. Index map showing location of the Tabeguache Creek Wilderness Study Area, Montrose County, Colorado.

chemical anomalies that would suggest the presence of undiscovered mineral deposits.

Mineral Resource Potential

Seismic and drill-hole data have shown that the southwest flank of the Uncompahgre Plateau has been thrust westward over possible hydrocarbon-bearing Paleozoic sedimentary rocks in the subsurface. The study area, therefore, has a moderate potential for undiscovered oil, gas, and carbon dioxide resources in Paleozoic sedimentary rocks beneath thrust-faulted Precambrian rock (fig. 2).

The study area is near the Uravan mineral belt and 6 mi east of the Uravan mining district, where uranium has been produced. The dominant ore-bearing unit in the belt and district is the Salt Wash Member of the Morrison Formation. The Salt Wash Member crops out or is near the surface throughout most of the study area. However, the Salt Wash Member in the study area lacks the features associated with mineralization elsewhere in the Uravan belt. No radiometric anomalies were detected in the study area, and no geochemical anomalies that would indicate uranium or vanadium enrichment were noted in the stream-sediment samples. The study area is, therefore, assigned a low resource potential for undiscovered uranium-vanadium deposits in the Morrison Formation.

The Chinle Formation contains significant uranium and vanadium deposits in a belt that extends from Slick Rock in southwestern Colorado to the San Rafael Swell in south-central Utah. The deposits are similar to those in the Morrison Formation. The nearest uranium deposit in a Chinle Formation-equivalent unit is 38 mi southwest of the study area. The uranium-bearing units of the Chinle Formation pinch out well to the southwest of the study area. Also, the features commonly associated with mineralization in the Chinle are absent from the study area. The study area therefore has low potential for uranium and vanadium in the Chinle Formation.

No mineralized rocks of any type were observed along faults in or near the study area. Although gold and copper deposits occur elsewhere in the region, stream-sediment geochemical surveys conducted within the study area did not indicate that any deposits were likely to be present. Minor geochemical anomalies detected in the stream-sediment samples were not indicative of any mineralized rock. The study area, therefore, has a low potential for gold, copper, and all other metals.

The Colorado Plateau has low overall heat flow, but young volcanic features of the plateau are promising areas of geothermal exploration. However, there are no recent volcanic features near the study area and no known thermal springs. The study area has a low resource potential for geothermal energy.

Coal has been produced within 1.5 mi of the study area from several mines in the adjacent Nucla-Naturita coal field from the Dakota Sandstone. However, erosion has removed the Dakota from the study area. No other coal-bearing units are present in the study area, which is underlain by crystalline rocks. There is, therefore, no potential for coal resources in the study area.

INTRODUCTION

At the request of the U.S. Bureau of Land Management (USBLM), the U.S. Geological Survey (USGS) and the U.S. Bureau of Mines (USBM) studied the 7,908 acre Tabeguache Creek Wilderness Study Area. The study area is bordered on the east side by the Uncompahgre National Forest, and on the north, south, and west by maintained and unimproved dirt roads. In this report the area studied is referred to as "the study area."

Access and Setting

The study area is located on the southwestern flank of the Uncompahgre Plateau, 3.5 mi north of the town of Nucla, Colorado. The study area encompasses part of the canyon of Tabeguache Creek, one of the major drainages on the southwestern flank of the Uncompahgre Plateau. Access is gained from one maintained and several unimproved dirt roads on the north and west side of the study area and from a foot trail that descends Forty-seven Creek in the northern part.

The Uncompahgre Plateau is a high alpine plateau that rises above the desert and canyons to the west. Tabeguache Creek has eroded into the gently inclined and faulted sedimentary rocks of the Uncompahgre Plateau, creating a deep canyon surrounded by mesas that rise to the northeast. Elevations within the study area range from 5,680 ft in the bottom of Tabeguache Creek to 7,340 ft in the northern part of the study area. Pinyon and juniper forests and sagebrush flats cover most of the study area, whereas cottonwood and dense willow groves thrive on the canyon bottom. Few manmade trails exist within the wilderness study area, and wildlife abounds.

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 USGS. Identified resources are classified according to the system of the USBM and USGS (1980), which is shown in the Appendix of the present 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 undiscovered energy resources (coal, oil, gas, oil shale, tar sand, and geothermal sources). It is classified according to the system of Goudarzi (1984) and is shown in the Appendix of the present report. The potential for undiscovered resources is studied by the USGS.

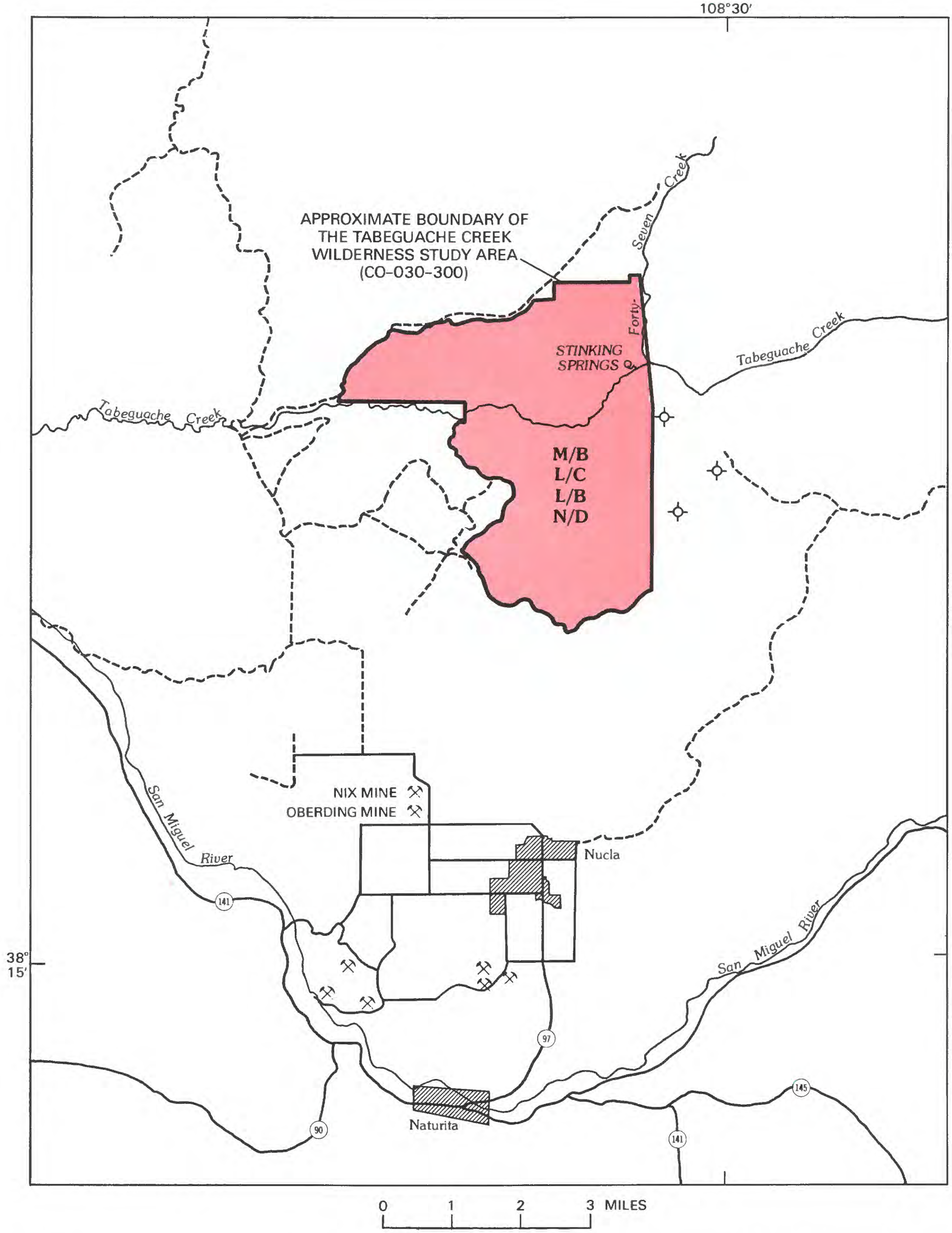

Figure 2 (above and facing page). Summary map showing mineral resource potential of the Tabeguache Creek Wilderness Study Area, Montrose County, Colorado.

EXPLANATION OF MINERAL RESOURCE POTENTIAL

M/B — Geologic terrane having moderate mineral resource potential for oil, gas, and carbon dioxide, with certainty level B—Applies to entire study area

L/C — Geologic terrane having low mineral resource potential for uranium and vanadium in the Chinle Formation, for gold, copper, and all other metals, and for geothermal energy, with certainty level C—Applies to entire study area

L/B — Geologic terrane having low mineral resource potential for uranium and vanadium in the Morrison Formation, with certainty level B—Applies to entire study area

N/D — Geologic terrane having no mineral resource potential for coal, with certainty level D—Applies to entire study area

Levels of certainty:

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 resources

——— Paved roads and maintained dirt roads

- - - - Unmaintained dirt roads

⚒ Mine

Spring

Drill hole

Investigations by the U.S. Bureau of Mines

A review of pertinent literature on geology, mineralization, and mining activity was completed prior to the field examination. Two USBM geologists spent 3 days conducting a field investigation utilizing vehicles around the area and foot traverses through the study area. The results of the study are published in Scott (1989). Information on coal resources 1–5 mi south of the study area has been previously reported (U.S. Bureau of Mines, 1976).

Investigations by the U.S. Geological Survey

A review of the literature on the geology of the region was completed prior to field work. A geologic map (pl. 1) of the Tabeguache Creek Wilderness Study Area was prepared by R.P. Dickerson from mapping done in October 1988, guided by a regional geologic map (Williams, 1964). Measured stratigraphic sections and scintillometer surveys were made of the Salt Wash Member of the Morrison Formation. Sampling for a stream-sediment geochemical survey was conducted in September 1988; H.N. Barton collected and analyzed the geochemical samples and interpreted the data. The interpretations of aeromagnetic and Bouguer gravity data were originally published on the region, including the study area, by Joesting and Byerly (1958) and Case and Joesting (1972). These and other geophysical data have been interpreted for the present study by H.R. Blank, Jr.

APPRAISAL OF IDENTIFIED RESOURCES

By David C. Scott
U.S. Bureau of Mines

History of Mining and Oil and Gas Exploration

As of September 1988, there were no patented or unpatented mining claims nor coal leases or lease applications within the study area. The entire area was under oil and gas lease or application for lease as of September 1988. No evidence of any type of mining activity was found during the field investigation, nor is the study area part of any mining district. However, the Uravan (San Miguel River) district is about 6 mi west of the western edge of the study area (Fischer and others, 1946). The Uravan district is synonymous with the area known as the Uravan mineral belt. Uranium deposits in the Salt Wash Member of the Morrison Formation in the Moab 1°×2° quadrangle have yielded a little more than 9,100,000 metric tons of uranium and vanadium ore worth more than $600 million; more than 80 percent of this ore came from the Uravan mineral belt (Butler and Fisher, 1978).

Coal is being produced from the middle part of the Dakota Sandstone about 1.5 mi south of the study area. Peabody Coal Company's multiple-bench Nucla strip mine is producing about 500 tons per day for use in the Colorado-Ute Electric Association's stoker-fired Nucla power plant (U.S. Bureau of Mines, 1976). The coal is of low quality, usually high-volatile B or C bituminous rank, and contains many impurities such as shale partings, bony coal, and sand. The Dakota Sandstone is not present in the study area, and, therefore, no coal beds are present.

The study area is in the Paradox oil and gas province, where production is from Pennsylvanian and Mississippian carbonate reservoirs and Permian and Cretaceous sandstones. Although no holes have been drilled in the study area, oil and gas leases and lease applications cover the entire area (as of September 1988). Three holes have been drilled within 1 mi of the eastern boundary of the study area. In 1968, Miami Oil Producers, Inc., drilled a 7,988-ft hole in the SE¼NW¼ sec. 10, T. 47 N., R. 15 W. The hole bottomed in granite at 7,988 ft and was plugged and abandoned as a dry hole that same year. In 1970, Texas Pacific Oil Co., Inc. drilled an 8,430-ft hole in the SE¼SE¼ sec. 3, T. 47 N., R. 15 W. This hole penetrated Mississippian strata at 8,080 ft and was plugged and abandoned as a dry hole that year. The most recent hole was drilled by McMoran Exploration Company in 1974 in the SW¼NW¼ sec. 3, T. 47 N., R. 15 W. This hole bottomed in the Devonian Elbert Formation at 5,935 ft and was plugged and abandoned as a dry hole in 1975 (USGS Conservation Division, Individual Well Records, available at the Montrose USBLM District Office, Montrose, Colorado).

Results of Investigation

No mines or prospects are present in the study area; however, geologic conditions similar to those in the Uravan mineral belt exist in the study area. A gamma-ray spectrometer was used to test outcrops of the Salt Wash Member for uranium, but no significant readings above background were noted.

No surface or near-surface mineralized rock was noted within the study area. Although geologic conditions in the study area are similar to those in the nearby Uravan mineral belt, no uranium deposits are known to be present in the study area. The Dakota Sandstone hosts coal beds 1.5 mi south of the study area, but the Dakota is not present in the study area.

ASSESSMENT OF POTENTIAL FOR UNDISCOVERED RESOURCES

By Robert P. Dickerson, Harlan N. Barton, and H. Richard Blank, Jr.
U.S. Geological Survey

Geology

Geologic Setting

The Tabeguache Creek Wilderness Study Area is on the southwest flank of the Uncompahgre Plateau and contains gently inclined sedimentary rocks of Mesozoic age. The sedimentary rocks have been subtly warped and locally displaced along normal faults that probably originated in the Precambrian basement. The Mesozoic-age rocks of the study area include the Chinle Formation of Triassic age, the Wingate Sandstone, the Kayenta Formation, the Entrada Sandstone, the Wanakah and Morrison Formations of Jurassic age, and the Burro Canyon Formation. The Dakota Sandstone of Cretaceous age crops out just beyond the study area boundary. Although the Wingate Sandstone and Kayenta Formation of the Glen Canyon Group have been assigned to the Late Triassic by several authors (Cater and others, 1955; Williams, 1964; Cater, 1970), the present report follows the more recent work of Pipiringos and O'Sullivan (1978), Peterson and Pipiringos (1979), Litwin (1986), and Padian (1989) in assigning the Glen Canyon Group to the Early Jurassic. Previous workers (Cater and others, 1955; Williams, 1964; Cater, 1970) labeled the formation overlying the Entrada Sandstone as the Summerville Formation. However, O'Sullivan (1980, 1981) showed that the Summerville Formation of the San Rafael Swell pinches out west of the Colorado State line, whereas O'Sullivan (1984) and Steele (1985) showed these rocks to be the Wanakah Formation in southwestern Colorado. The Mesozoic rocks are nearly flat strata lying nonconformably on top of crystalline rocks of the Precambrian basement. Basement rocks are exposed in the canyon of Tabeguache Creek east of the study area. Precambrian rocks are believed to be thrust-faulted over younger Paleozoic sedimentary rocks in the subsurface (Stone, 1977; Frahme and Vaughn, 1983; Gries, 1983).

Structure

The Uncompahgre Plateau is a regional fault block that has been uplifted thousands of feet. The plateau is bounded at the surface on the northeast and southwest by northwest-trending normal faults, high-angle reverse faults, monoclines, and homoclines. These faults parallel other major structures in the region and may be controlled by crustal weaknesses dating from the Precambrian (Stone, 1977; Baars and Steven, 1981). In the subsurface on the southwest side of the Uncompahgre Plateau, Precambrian crystalline rocks have been thrust southwestward over Paleozoic sedimentary rocks (Stone, 1977; Frahme and Vaughn, 1983; Gries, 1983). Such foreland thrust plates are more common in the central Rocky Mountains than once thought, and drilling has revealed that a number of these thrust sheets conceal structures favorable for oil and gas (Berg, 1962; Gries, 1981; 1983).

Within and just east of the study area there are a number of north- and northwest-trending normal faults. Several subsidiary northeast-trending faults splay off the main fault system. Several of the major faults influenced the course of Tabeguache Creek. Most faults in and near the study area are down to the west, northwest, or southwest and have juxtaposed the Triassic Chinle Formation against the Jurassic Entrada Sandstone in part of the canyon of Tabeguache Creek. East of the main fault, a small northeast-trending graben parallels the northeastern bend in the main fault. This graben appears to be a down-dropped keystone block created by right-lateral movement along the main fault. The fault system within the study area is part of a larger, northwest-trending regional fault system that has locally faulted Precambrian crystalline rocks against the Cretaceous Burro Canyon Formation. In general, unfaulted sedimentary rocks in the study area dip 4°–5° to the southwest. Strata north of the graben and the northeast bend in the main fault dip southeast towards the fault at 9°–15°.

Geologic History

The geologic history of the Uncompahgre Plateau is one of periodic uplift and erosion, followed by deposition of marine and terrestrial sediments. This pattern of erosion and deposition has dictated what mineral resources can occur on the plateau. The Ancestral Uncompahgre Highland was uplifted during Pennsylvanian time, and the detritus eroded was shed westward into the Paradox basin. All potential Paleozoic petroleum source rocks were eroded from the highland. During this uplift, the Precambrian crystalline core of the uplift was slowly being thrust southwestward over Mississippian and older strata (Stone, 1977). The Ancestral Uncompahgre Highland was eventually worn down to a low-lying peneplane of Precambrian rock. This surface was buried during Late Triassic time by the encroaching sediments of the Chinle Formation. The Chinle Formation is much thicker west of the Uncompahgre Plateau, where the Chinle contains uranium deposits in channel sandstones in the lower parts (Finch, 1959). During Early and Middle Jurassic time, eolian, fluvial, and marine sediments of the Wingate, Kayenta, Entrada, and Wanakah Formations were deposited. Although these formations are adequate reservoir rocks for oil and gas in many parts of the Colorado Plateau, they do not contain petroleum on the Uncompahgre Plateau because they are exposed at the surface by erosion, are incised by canyons, and are far from source rocks. During Late Jurassic and Cretaceous time, the Morrison and Burro Canyon Formations, and the Dakota Sandstone to the west and southwest of the study area were deposited in a low-lying terrestrial environment; volcanic activity supplied material from the west (Craig and others, 1955). This volcanic material was probably the source of the uranium concentrated in channel sandstones in the lower part of the Morrison Formation (Finch, 1967; Thamm and others, 1981). Coal formed in coastal swamps during deposition of the Dakota Sandstone, but erosion has removed the Dakota and younger formations from the study area. During the Laramide orogeny, 70–35 m.y. (million years) ago, dip-slip and reverse movement recurred on the major boundary faults of the Uncompahgre Plateau (Stearns and Jamison, 1977; Heymen, 1983). This movement folded and faulted Mesozoic age sedimentary rocks. Continued uplift and erosion of the Uncompahgre Plateau produced the topography seen in the study area today.

Description of Rock Units

All unit symbols mentioned here follow usage on plate 1.

Upper Triassic Chinle Formation (unit ₸c).—This slope-forming unit consists of red siltstone and mudstone and thin layers of fine-grained sandstone, but may contain basal, conglomeratic channel sandstones. Within the study area this formation is about 200 ft thick.

Lower Jurassic Wingate Sandstone (unit Jw).—This unit is a buff, massively crossbedded, well-sorted eolian sandstone that forms prominent cliffs in the study area. It unconformably overlies the Chinle Formation and is about 200–250 ft thick.

Lower Jurassic Kayenta Formation (unit Jk).—Conformably overlying the Wingate Sandstone, the Kayenta Formation consists of a buff, coarse-grained, cross-bedded fluvial sandstone about 70–100 ft thick. It forms ledgy slopes and overhangs above the Wingate Sandstone.

Middle Jurassic Entrada Sandstone (unit Je).—This unit is a salmon to white, fine-grained, crossbedded eolian sandstone with horizontal bedding near the top. It forms a rounded cliff in the study area. It varies widely in thickness but is about 50–100 ft thick in the study area. It unconformably overlies the underlying Kayenta Formation.

Middle Jurassic Wanakah Formation (unit Jwa).—This slope-forming unit consists of red, buff, and yellow, fine-grained, thinly bedded sandstone, siltstone, and shale. Widely variable in thickness, it ranges from about 30 to 80 ft thick in the study area. It conformably overlies the Entrada Sandstone.

Upper Jurassic Tidwell and Salt Wash Members of the Morrison Formation (unit Jmst).—The lowest part of the Morrison Formation is the fine-grained, thin-bedded sandstone, mudstone, and nodular limestone of the Tidwell Member. Above this zone, the Salt Wash Member is a series of buff, poorly sorted, crossbedded fluvial sandstones and variegated tan, red, gray, and green mudstones. The fluvial sandstones are more continuous near the bottom than at the top and may contain sparse carbonaceous matter. These members are 350–370 ft thick and form a series of cliffs, steep slopes, and benches. The Morrison Formation unconformably overlies the Wanakah Formation.

Upper Jurassic Brushy Basin Member of the Morrison Formation (unit Jmb).—The Salt Wash Member grades upward into the Brushy Basin Member, a slope-forming, gray, green, red, and purple bentonitic mudstone that in places contains thin, discontinuous channel sandstones. In this report, the contact with the underlying Salt Wash Member is put at the top of the youngest, widely persistent sandstone. The Brushy Basin Member is about 200–300 ft thick.

Lower Cretaceous Burro Canyon Formation and Upper Cretaceous Dakota Sandstone, undivided (unit Kdb).—The Burro Canyon Formation is white to gray, thickly bedded to massive sandstone interbedded with green siltstone and mudstone. This formation unconformably overlies the Morrison Formation and is unconformably overlain by the Dakota Sandstone. The Dakota Sandstone consists of buff to gray, poorly sorted sandstone interbedded with gray to black carbonaceous shale and contains thin to thick, discontinuous coal seams. This unit forms a prominent cliff and caps mesas within the study area. Within the study area, this unit appears to consist solely of the Burro Canyon Formation, but the Dakota Sandstone does crop out just west and south of the study area.

Quaternary surficial deposits (units Qac, Qrf).—These units include rock falls (Qrf) and alluvium and colluvium (Qac) of Holocene age.

Geochemistry

Methods

A reconnaissance geochemical survey was conducted in the Tabeguache Creek Wilderness Study Area during September 1988 to aid in the mineral resource assessment. The study area and adjacent areas outside its boundaries were sampled as part of the present report.

Stream sediments and heavy-mineral panned concentrates derived from stream sediments were collected from active alluvium from 16 first- or second-order ephemeral streams whose drainage basins occupy from 0.1 to 5.0 square miles. Sample sites were located on Tabeguache Creek where it enters the study area, on tributary drainages to Tabeguache Creek, in Doby Canyon, and on tributary drainages to Coal Canyon. Analysis of stream sediments and heavy-mineral panned concentrates helps identify those drainage basins that contain unusually high concentrations of elements that may be related to mineral deposits. Rock samples were collected to provide geochemical background values and to detect possible mineralized bedrock. No visibly altered or mineralized rocks were found.

Stream sediments, heavy-mineral panned concentrates, and rock samples were analyzed for 35 elements that are routinely looked for using a semiquantitative emission spectrographic method. In addition, stream sediments and rock samples were analyzed for arsenic, antimony, bismuth, cadmium, gold, uranium, thorium, and zinc by specific chemical and instrumental methods. Analytical data, sample sites, and a detailed description of the sampling and analytical techniques with references are available from J.H. Bullock, Jr., U.S. Geological Survey, MS 973, Box 25046, Denver Federal Center, Denver, CO 80225.

Results

Anomalous values, defined as those values above the upper limit of normal background values, were determined by inspection of the analytical data rather than by statistical techniques because the number of samples collected did not readily lend itself to statistical analysis. For some elements (silver, gold, tungsten, molybdenum, and tin), any occurrence above the detection limit would be anomalous.

Samples from three sites (pl. 1), all near where Tabeguache Creek enters the study area, were very slightly anomalous for some elements. Sample site TB002 on Tabeguache Creek receives sediment from the adjacent Uncompahgre National Forest to the east and likely does not represent geochemical values for rocks within the study area. The stream-sediment sample collected at site TB002 contained 14 ppm (parts per million) arsenic, 0.3 ppm cadmium, 9.2 ppm thorium, and 3.4 ppm uranium. Sample site TB001, on Forty-seven Creek near its confluence with Tabeguache Creek, contained 6 ppm arsenic in the stream-sediment sample and 2 ppm silver in the heavy-mineral concentrate. Much of the Forty-seven Creek drainage lies outside the study area boundary, and the source of the silver in sample TB001 may well represent a source outside the study area. The values determined for arsenic at these two sites as well as for cadmium, thorium, and uranium at site TB002 are about the same as median crustal abundance values for shale (Rose and others, 1979) and probably are not significant. Sample site TB003 is on a minor drainage to Tabeguache Creek, about 0.3 mi west of the other two sites, in the area of Stinking Springs. A stream-sediment sample from this site contained 19 ppm arsenic. Sulfur was found coating rock surfaces at Stinking Springs and as a surface scum on standing water at the springs. Arsenic is commonly found in such cold or warm springs environments. The values reported for the three sample sites are at or slightly above published median crustal abundance values for shale and sandstone (Rose and others, 1979) and probably do not indicate the presence of mineral deposits.

Geophysics

Regional geophysical data for the Tabeguache Wilderness Study Area and vicinity supplement the geologic mapping and help establish the geologic framework for evaluating the mineral resource potential. In general, the Precambrian crystalline basement rocks may be expected to have greater densities and magnetizations than the overlying predominantly clastic sedimentary strata. The principal problem in interpretation lies in distinguishing the effects of structural relief on the surface of the basement from the effects of intrabasement lithologic heterogeneities. Paleotopographic relief on the Precambrian surface in this region is probably only a few tens of feet or less and a negligible source of geophysical anomalies.

The aeromagnetic and Bouguer gravity features of the Uravan area were discussed by Joesting and Byerly (1958) and of the central Colorado Plateau by Case and Joesting (1972). Both these studies, although involving much larger areas than that of the present study, addressed the significance of anomalies on the Uncompahgre front in the vicinity of the study area. Their data do not extend onto the Uncompahgre Plateau, however, and little additional data are available in the public domain.

An aeromagnetic map of the study area and vicinity is shown on figure 3. Previous coverage (2-mi traverse spacing) has been supplemented with additional data from the NURE (National Uranium Resource Evaluation Program) surveys of the Moab 1°×2° quadrangle (GeoMetrics, Inc., 1979). The NURE surveys in this region were flown east-west at a nominal 400 ft above ground and a 3-mi spacing. The two prominent magnetic highs shown on figure 3 (A and B) are part of a string of such highs that trends from northwest to southeast along the front of the Uncompahgre uplift. The magnetic highs are almost certainly due to shallow crystalline basement rock. The northwesterly of the two anomalies shown (A) corresponds well with basement outcrop immediately northeast of the main frontal fault, whose trace veers abruptly to the east at the latitude of the wilderness study area. No crystalline rock is exposed in the vicinity of the southeasterly anomaly (B), but from inspection of the gradient the source of this anomaly is probably within a mile or so of the surface. The two anomalies suggest the existence of two major thrust sheets, each of which involves allochthonous basement.

Figure 4 shows the complete Bouguer gravity anomaly field of the wilderness study area and vicinity, computed from data available from Defense Mapping Agency (DMA) files (through the National Center for Solar-Terrestrial and Geophysical Data, Boulder, Colorado). The raw data were reduced at a density of 2.67 g/cm^3 (grams per cubic centimeter) using standard USGS procedures (see, for example, Cordell and others, 1982) and computer-terrain corrected for Hayford-Bowie zones A–O (0–100 mi) using 15-minute digital topography. Lack of coverage on the Uncompahgre Plateau precludes a direct comparison with the aeromagnetic results, but we note that neither of the two aeromagnetic highs (A, B) just discussed has a strong gravity expression, which again suggests that the anomaly sources are rootless; that is, floored on shallow thrust faults. The pronounced north-directed gravity gradient in the northeast corner of the map area leads to an extensive gravity high produced by dense crystalline basement rock in the core of the Uncompahgre uplift. The north-northeast-directed gradient in the southwest corner of the map area represents the flank of an anomaly associated with evaporites in the Paradox basin, immediately adjacent to the southwest. The diffuse high in the west-central part of the map area reflects an anticlinal structure that has Pennsylvanian carbonate rocks exposed in its core.

Mineral and Energy Resources

Oil, Gas, and Carbon Dioxide

Oil, gas, and carbon dioxide have been produced from the Devonian Ouray Limestone, the Mississippian Leadville Limestone, the Pennsylvanian Paradox and Honaker Trail Formations of the Hermosa Group of some geologists, and the Triassic Chinle Formation in the Paradox basin southwest of the Uncompahgre Plateau (Mahoney and Kunkel, 1963; Krivanek, 1981). Natural gas has been discovered in the Pennsylvanian Hermosa Group and the Permian Rico Formation 10 mi southwest of the study area in the Montrose dome field, 18 mi south at the Andys Mesa field, and 18 mi southeast at the Hamilton Creek field (Scanlon, 1983).

Of the formations that are known to exist within or adjacent to the study area, the Chinle, Wingate, Entrada, Morrison, and Dakota Formations have produced hydrocarbons from wells in the Paradox basin or in regions adjacent to the Uncompahgre Plateau to the north and northwest (Schwochow, 1978). Within the study area, however, these formations have been uplifted, stripped of impermeable cap rocks, and exposed to oxidizing conditions at the surface. These conditions are not favorable for the occurrence of oil and gas in these rocks within the study area.

Studies based on seismic and well data (Stone, 1977; Frahme and Vaughn, 1983; White and Jacobson, 1983; Gries, 1983) show that Precambrian crystalline rocks have been thrust southwestward over younger Paleozoic sedimentary rocks in the subsurface west of the

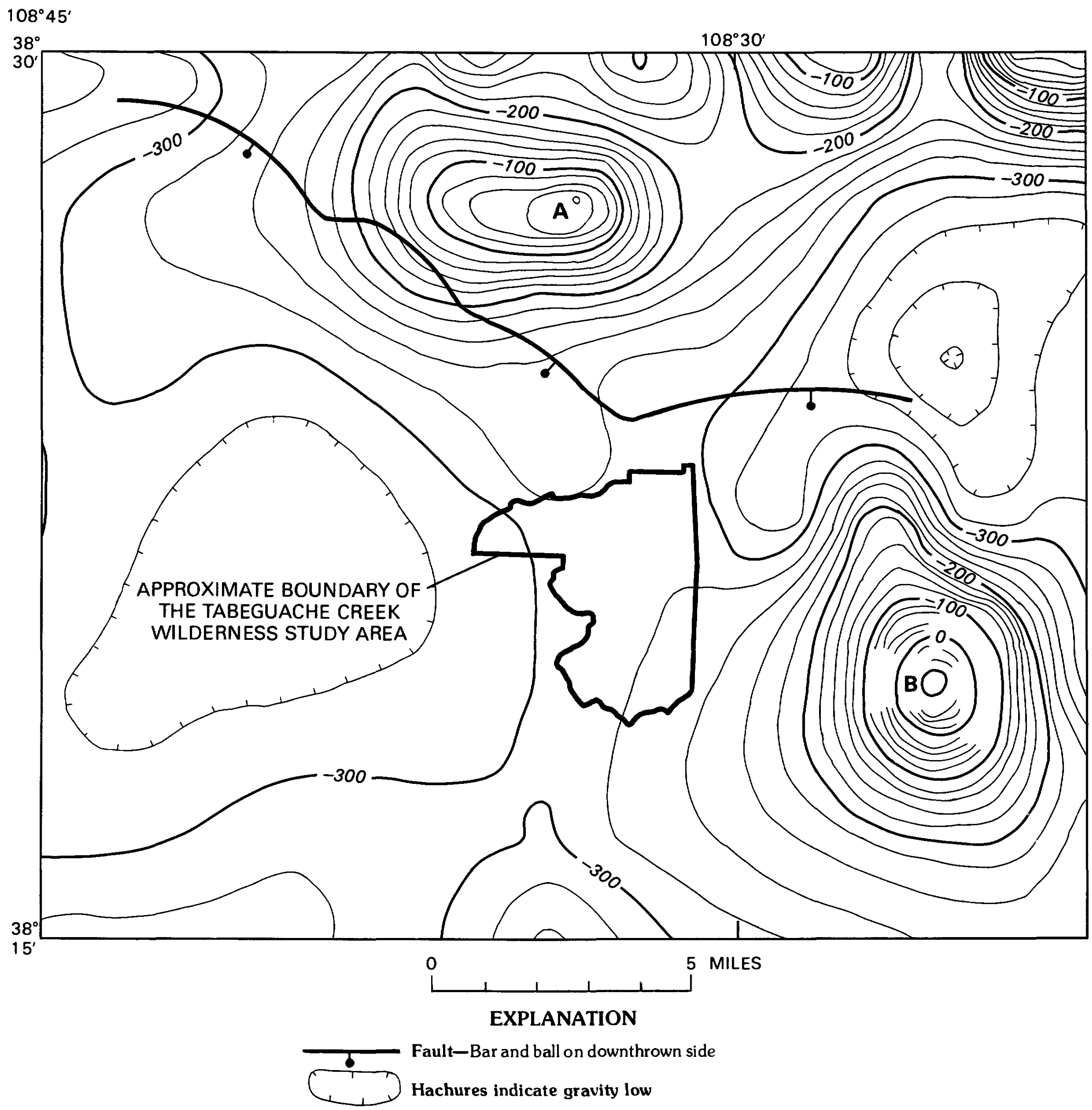

Figure 3. Residual total-intensity aeromagnetic map of the Tabeguache Creek Wilderness Study Area and vicinity, Colorado. Data from National Uranium Resource Evaluation (Moab 1° × 2° quadrangle; GeoMetrics, Inc., 1979) and Case and Joesting (1972). Contour interval is 20 nanoteslas. Scale 1:250,000.

Uncompahgre Plateau. This interpretation is supported by the aeromagnetic data cited earlier in this report. Interpretations vary as to how much crystalline rock has been thrust over Paleozoic sedimentary rocks, because drill-hole data are few. Studies utilizing seismic and drill-hole data of this and other foreland thrust plates in the Rocky Mountains have shown that favorable structures such as anticlines and thrust slivers are common beneath such plates, many of which contain shows of hydrocarbons (Berg, 1962; Gries, 1981; 1983). These thrust faults were active during the Permian uplift of the Ancestral Uncompahgre Highland, and this terrane was subsequently overlain by the Triassic and Jurassic formations of the study area. Published cross sections (White and Jacobson, 1983) and geophysical studies for the present report show such thrust faults in the vicinity of the study area. These structures, as well as the discovery of natural gas in Paleozoic rocks within 10 mi of the study area and of natural gas reservoirs along the strike of these structural features 18 mi to the southeast, indicate that the study area has a moderate potential for oil, gas, and carbon dioxide, with a certainty level of B.

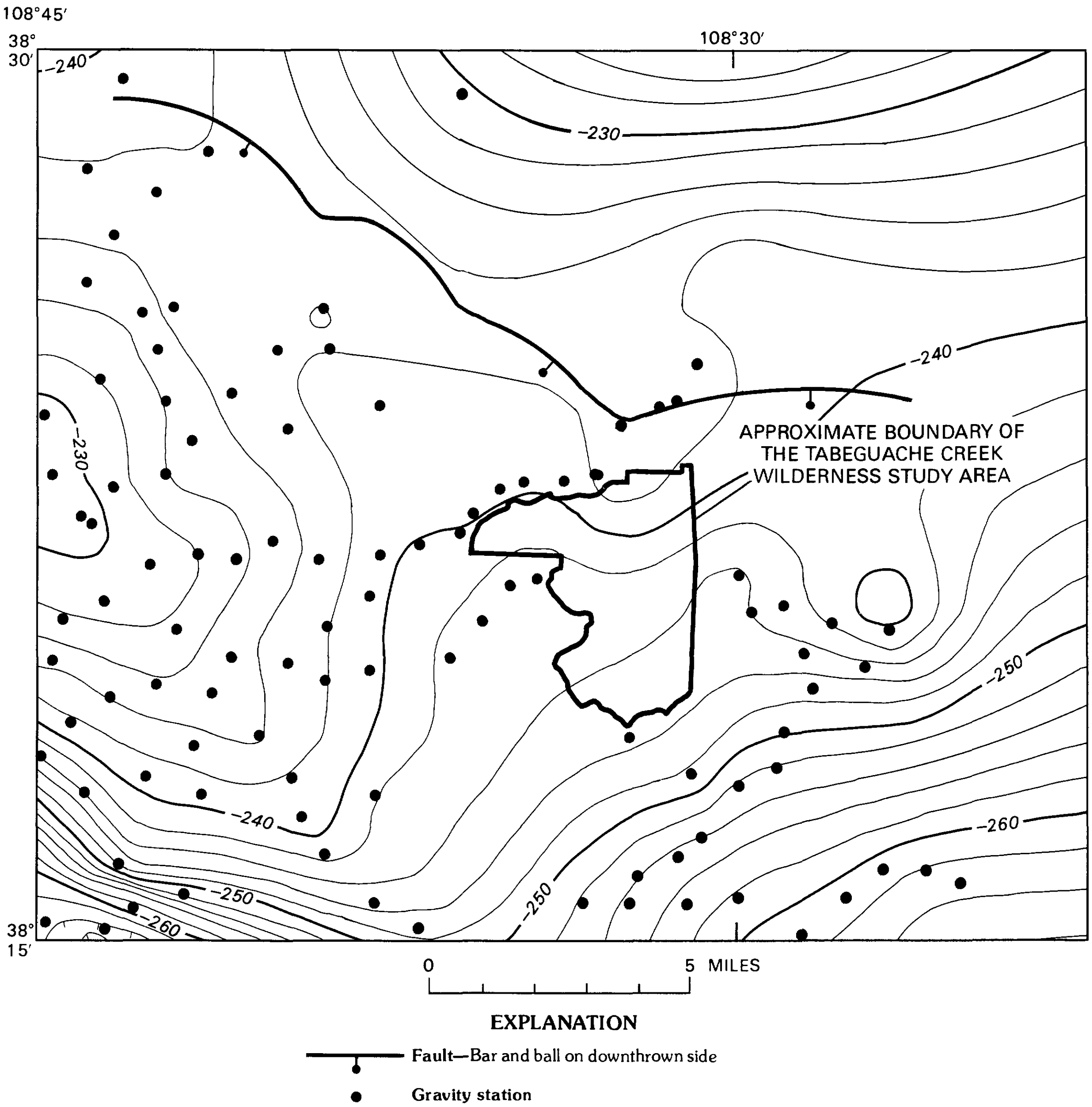

Figure 4. Complete Bouguer gravity anomaly map of the Tabeguache Creek Wilderness Study Area and vicinity, Colorado. Data from Defense Mapping Agency. Map has been computer-terrain-corrected to 100 miles. Contour interval is 2 milligals. Scale 1:250,000.

Uranium and Vanadium

The study area is near the Uravan mineral belt and 6 mi east of the Uravan mining district. Fischer and Hilpert (1952) defined the Uravan mineral belt as "a narrow, elongate area in which the carnotite deposits generally have closer spacing, larger size, and higher grade than those in adjoining areas and the region as a whole." The deposits in the belt are typified by the deposits in the Uravan mining district.

The Salt Wash Member of the Morrison Formation is a sequence of fluvial sandstones interbedded with floodplain-type mudstones in which sandstones predominate. The uranium-vanadium deposits of the Uravan district (and other uranium-vanadium districts in the Uravan mineral belt) are mostly in the upper fluvial sandstones of the Salt Wash Member, although some are in the lower part of the member. Uranium-vanadium deposits are rare in sandstone bodies in the Brushy Basin Member (Nelson-Moore and others, 1978).

These uranium-vanadium deposits generally are irregular, tabular bodies elongate parallel to sedimentary trends, concordant with bedding, and have sharp boundaries between mineralized and unmineralized rock

(Chenowith, 1981). In most areas, deposits are confined to a single stratigraphic horizon (Fischer and Hilpert, 1952). The vanadium to uranium ratio in these deposits ranges from 3:1 to 10:1 but averages 5:1. The following characteristics of these deposits provide useful guides in identifying favorable ground (Fischer and Hilpert, 1952; Weir, 1952): (1) deposits are in the thicker, central part of major sedimentary channels in permeable sandstones greater than 40 ft thick, (2) favorable sandstones have been altered from red to yellow-tan, and the deposits are at or near the oxidation/reduction boundaries associated with these color changes, and (3) ore-bearing sandstones usually contain abundant carbonaceous matter and interbedded gray mudstones.

Sedimentary structures and the distribution of lithologies in the Salt Wash Member suggest that a smaller alluvial fan was superimposed on a large alluvial plain during deposition of the member in the region of the Uravan mineral belt. In this belt, oxidized sandstone of high-energy, midfan facies interfingers with unoxidized sandstone of low-energy, distal-fan facies (Shawe, 1962). Such interfingering of oxidized rocks with unoxidized rocks causes conditions favorable for the oxidized, uranium-bearing solutions to become reduced. Peterson (1980) suggested that such facies changes are environments suitable for the deposition of humate-generating gray mudstones that were important in precipitating uranium. Carbonaceous matter—also an important precipitator of uranium—is abundant in the mineral belt but largely disappears to the east and west. Where carbonaceous matter is locally present west of the mineral belt, ore deposits are also present (Shawe, 1962; Butler and Fisher, 1978). East of the mineral belt, strata of the ore-bearing horizon appear to be thinner, flatter bedded, and less lenticular.

The evidence for undiscovered uranium-vanadium deposits in the Morrison Formation of the study area is equivocal. The nearest mine is 3.5 mi to the northwest, whereas most mines of the Uravan district are more than 6 mi to the west, northwest, and southwest. The Salt Wash Member of the Morrison Formation crops out or is near the surface throughout most of the study area. Within the study area, the sandstone equivalent to the ore-bearing sandstone of the Uravan district is a cross-bedded, fluvial sandstone of similar nature and is greater than 40 ft thick (50 ft thick where measured for this report). Gray mudstones are interbedded between some sandstone bodies but not within any individual sandstones. Oxidized and reduced sandstones do not interfinger, and the rocks are devoid of carbonaceous matter. Shawe (1962) reported that the study area lies east of the favorable facies changes in the Uravan mineral belt. No radiometric anomalies were detected, and no geochemical anomalies that would indicate uranium or vanadium enrichment were noted in stream-sediment samples. The study area is therefore assigned a low resource potential for undiscovered uranium-vanadium deposits in the Morrison Formation, with a certainty level of B.

The Triassic Chinle Formation contains significant uranium deposits in a belt (known as the Moab belt) that extends from Slick Rock in southwestern Colorado to the San Rafael Swell in south-central Utah. Chinle uranium deposits are similar to Morrison Formation uranium deposits because they are tabular, concordant bodies within reduced fluvial sandstones. The Chinle uranium deposits of the Moab belt share certain features that aid in determining favorable ground. Within this belt the deposits are concentrated in the Moss Back Member, although the Shinarump and Monitor Butte Members contain uranium deposits in areas southwest of the Moab belt. The deposits are localized in channels and lenses of conglomeratic fluvial sandstone at or near the bottom of the Moss Back Member and in regions where this member thins or pinches out. The ore-bearing sandstones contain abundant carbonaceous matter and are underlain by a zone of purple and gray altered rock (Finch, 1959).

The nearest uranium deposit in a Chinle Formation equivalent is in the Dolores Formation in the Dolores River canyon 38 mi southwest of the study area (Finch, 1959). The Moss Back, Monitor Butte, and Shinarump Members all pinch out well to the southwest of the study area. Additionally, the red siltstone of the upper part of the Chinle Formation in the study area was deposited in a lower energy environment than the fluvial sandstones of the other ore-bearing members (Stewart and others, 1972). Channel sandstones, carbonaceous matter, and purple and gray altered rock were not observed and probably are not in the study area. The study area is therefore assigned a low mineral resource potential for undiscovered uranium and vanadium deposits in the Chinle Formation, with a certainty level of C.

Gold, Copper, and All Other Metals

Placer gold has been found in gravel deposits along the San Miguel and Dolores Rivers west and southwest of the study area (Vanderwilt, 1947). Because neither river has ever flowed through the study area, gravels deposited by them are not present.

Copper occurs along fractures in Permian, Triassic, and Jurassic red beds 25 mi west of the study area in the La Sal district (Carter and Gualtieri, 1965). An occurrence of conglomeratic boulders mineralized with copper has been reported in upper Tabeguache Creek 5–7 mi east of the study area, but the source of the boulders is not known (Vanderwilt, 1947). Small copper deposits occur in fractures in the Precambrian crystalline rocks of Unaweep Canyon 30 mi north of the study area (Vanderwilt, 1947).

No mineralized rocks of any type were observed along faults in or near the study area. Stream-sediment geochemical surveys conducted within the study area did not detect any geochemical anomalies that would indicate copper or placer gold deposits. The minor geochemical anomalies detected in the stream-sediment samples were not indicative of mineralized rocks and may represent the composition of rocks outside the study area. Precambrian rocks, which host metals in other places, do not crop out within the study area. The study area has a low potential for undiscovered resources of metals, with a certainty level of C.

Geothermal Energy

The Colorado Plateau has a low overall heat flow, but young volcanic features of the plateau are promising areas of geothermal exploration. A known hydrothermal convection system in the Colorado Plateau is located in the San Juan Mountains near Dunton, Colorado (Brooks and others, 1979; Pearl, 1980). There are no recent volcanic features anywhere near the study area and no known thermal springs (Pearl, 1980). There are cold springs that contain sulfur, and possibly arsenic, within the study area at Stinking Springs in the canyon of Tabeguache Creek. The sulfur-tainted cold water of Stinking Springs is not indicative of geothermal potential, and the study area is assigned a low resource potential for geothermal energy, with a certainty level of C.

Coal

Coal has been produced within 1.5 mi of the Tabeguache Creek Wilderness Study Area from several mines in the adjacent Nucla-Naturita coal field. At least three beds are present within a stratigraphic interval of 45 ft within the Dakota Sandstone. The coal beds are usually split by many partings, but a bench of the middle bed is more than 4 ft thick with no partings. This bench is the productive bed at local coal mines (Landis, 1959).

Field mapping done in conjunction with this report revealed that erosion has removed the Dakota Sandstone from the entire study area, although coal-bearing parts of the Dakota Sandstone crop out 2.5 mi west of the study area. No other coal-bearing units are present in the study area, which is underlain by crystalline rock. Accordingly, the entire study area is assigned no potential for undiscovered resources of coal, with a certainty level of 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

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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DEPARTMENT OF THE INTERIOR
MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY
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