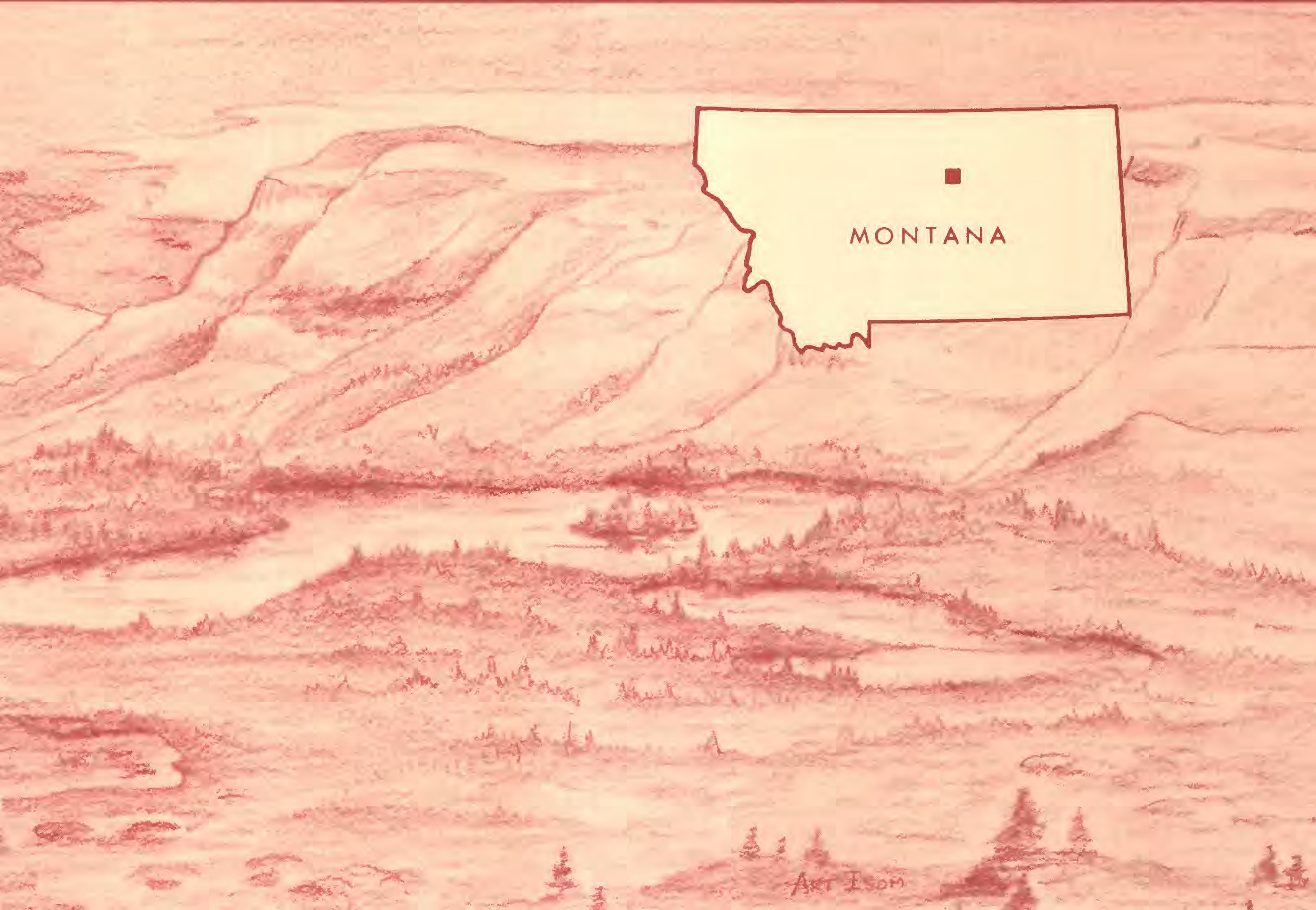
Mineral Resources of the Cow Creek and Antelope Creek Wilderness Study Areas, Blaine and Phillips Counties, Montana

U.S. GEOLOGICAL SURVEY BULLETIN 1722–C



Chapter C

Mineral Resources of the Cow Creek and Antelope Creek Wilderness Study Areas, Blaine and Phillips Counties, Montana

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U.S. GEOLOGICAL SURVEY BULLETIN 1722

MINERAL RESOURCES OF WILDERNESS STUDY AREAS—EASTERN MONTANA

DEPARTMENT OF THE INTERIOR
DONALD PAUL HODEL, Secretary

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

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON: 1988

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

Library of Congress Cataloging-in-Publication Data

Mineral resources of the Cow Creek and Antelope Creek Wilderness
Study Areas, Blaine and Phillips counties, Montana
(Mineral resources of wilderness study areas—eastern Montana ; ch.
C) (U.S. Geological Survey bulletin ; 1722–C)
Bibliography: p.
Supt. of Docs. No.: I 19.3:1722–C
1. Mines and mineral resources—Montana—Cow Creek Wilderness.
2. Mines and mineral resources—Montana—Antelope Creek
Wilderness. 3. Cow Creek Wilderness (Mont.) 4. Antelope Creek
Wilderness (Mont.) I. Mytton, James W. II. Series. III. Series: U.S.
Geological Survey bulletin ; 1722–C.
QE75.B9 no. 1722–C 557.3 s [553'.09786'15] 87–600377
[TN24.M9]

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 parts of the Cow Creek (MT–066–256) and Antelope Creek (MT–065–266) Wilderness Study Areas, Blaine and Phillips Counties, Montana.

CONTENTS

PLATE

[Plate is in pocket]

FIGURES

Mineral Resources of the Cow Creek and Antelope Creek Wilderness Study Areas, Blaine and Phillips Counties, Montana

By James W. Mytton, Viki Bankey, M. Dean Kleinkopf, John W. M'Gonigle, *and* Edward E. McGregor
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SUMMARY

At the request of the U.S. Bureau of Land Management, 21,590 acres of the 34,050-acre Cow Creek (MT–066–256) Wilderness Study Area and 9,600 acres of the 12,350-acre Antelope Creek (MT–065–266) Wilderness Study Area were studied from 1984 to 1986 in order to appraise the identified mineral resources and assess the mineral resource potential. In this report the studied areas are called the "wilderness study areas" or simply the "study areas." Mineral occurrences in the Cow Creek and Antelope Creek study areas currently considered noneconomic include clay, zeolites, gold, silver, and platinum-group elements. Coal in the Cow Creek study area is subeconomic and in the Antelope Creek study area is marginally economic. The study areas have a low mineral resource potential for undiscovered coal and all metallic minerals, bentonite, and zeolites, with a certainty level of C. Parts of the Cow Creek study area have moderate mineral resource potential for diamonds, with certainty level B. The remaining parts of the Cow Creek study area and all of the Antelope Creek study area have low mineral resource potential for diamonds, with certainty level C. The study areas have a low mineral resource potential for undiscovered oil, with a certainty level of B, and a high mineral resource potential for undiscovered gas, with a certainty level of B (fig. 1).

The study areas are in the Northern Great Plains physiographic province, Blaine and Phillips Counties, north-central Montana. They are on the north side of the Missouri River, between the Bearpaw Mountains on the northwest, the Little Rocky Mountains on the northeast, and the Judith Mountains on the south (fig. 2). The study areas are typified by rugged badland topography, known as the "Missouri Breaks." Regional topography is characterized by flat-top ridges and plateaus and by winding coulees, many of which are precipitously steep and narrow, although some have broad flood plains. The areas are accessible mainly by unpaved roads connecting with Montana State Highway 66 and U.S. Highway 191 to the east. Within the study areas, access is by unpaved roads and jeep trails that may be impassable during wet weather.

The study areas are underlain by marine and nonmarine Upper Cretaceous rocks (see geologic time chart in appendix) whose regional dip, 1° or 2° eastward from the Bearpaw Mountains uplift, is disrupted by low- to high-angle reverse faults and normal faults related to gravity sliding of Upper Cretaceous strata at shallow depths. These rocks are intruded by dikes and pipes (diatremes) of ultramafic material derived from deep-seated sources. Quaternary alluvium and colluvium cover much of the bedrock. The salient structural feature of the study areas is a series of northeast-trending, parallel, arcuate belts of faulted and folded Upper Cretaceous rocks that bound the southeastern part of the Bearpaw Mountains uplift and are related to plainsward gravity sliding of blocks of Upper Cretaceous strata off the flanks of the uplift during various stages of doming associated with igneous intrusion and volcanism. A prominent northwest-trending fault in the Cow Creek area forms a boundary between two groups of gravity-slide blocks and may reflect movement at depth along basement zones of weakness.

The region of gravity-slide blocks, or belts of disturbed Upper Cretaceous rocks, on the south flank of the Bearpaw Mountains is within an area where natural gas is produced from Cretaceous strata and where oil is contained primarily in Jurassic rocks (Perry and others, 1983). No exploratory holes have been drilled in the

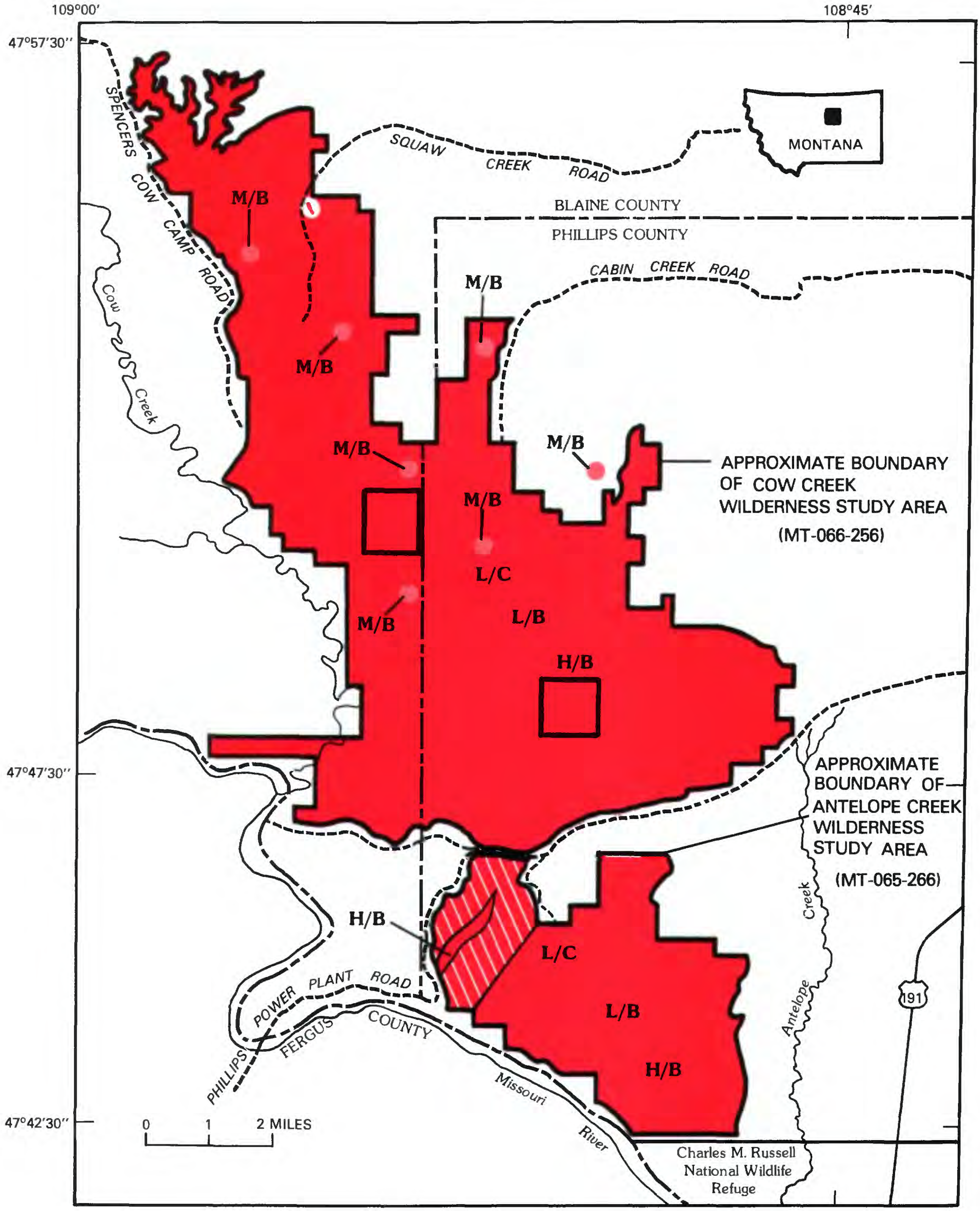

Figure 1 (above and facing page). Summary map showing mineral resource potential of the Cow Creek and Antelope Creek Wilderness Study Areas, Blaine and Phillips Counties, Mont.

EXPLANATION

Areas of identified coal resources—Areas underlain by Judith River Formation (Kjr) and Eagle Sandstone (Ke) also have high mineral resource potential for natural gas, with certainty level B

H/B **Geologic terrane having high mineral resource potential for natural gas, with certainty level B**—Applies to areas underlain by Judith River Formation (Kjr) and Eagle Sandstone (Ke)

M/B **Geologic terrane having moderate mineral resource potential for diamonds in diatremes, with certainty level B**—Applies to areas underlain by intrusive igneous rocks (Ti)

L/C **Geologic terrane having low mineral resource potential for all metallic minerals, diamonds, coal, bentonite, and zeolites, with certainty level C**—With exception of diamonds in diatremes (Ti), applies to all of both study areas

L/B **Geologic terrane having low mineral resource potential for oil, with certainty level B**—Applies to all of both study areas

Levels of certainty

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**

study areas; the resource potential for oil there is considered low, and the resource potential for gas is considered high, with a certainty level of B for both oil and gas. The best prospects for gas reservoir rocks would be the sandstones in the Eagle Sandstone and Judith River Formation.

Coal occurs in nonmarine coastal-plain rocks of the Eagle Sandstone and Judith River Formation, but is generally impure, the highest grade being subbituminous. Small tonnages of coal were recovered, mostly for local use, beginning in the early 1900's and continuing to the early 1950's. Recent investigations show that coal beds in the Cow Creek study area are subeconomic, the coal being too thin, low in grade, deeply buried, and irregularly distributed to be mined except for small-scale local use, and only marginally economic in the Antelope Creek study area for use in coal-fired electric power plants. The mineral resource potential for coal resources in the study areas is considered to be low, with a certainty level of C.

Bentonite beds in offshore marine shales, such as the Claggett and Bearpaw Shales, are generally less than 2 ft (feet) thick. Analyses by the U.S. Bureau of Mines indicate some material is suitable for foundry-industry application, lightweight aggregate, and structural clay-product use; however, the clays are generally too thin, too low in grade, and too far from potential markets for development. The resource potential for additional bentonite in the study areas is assessed as low, with a certainty level of C.

No metallic mineral deposits or mineralized zones, mines, or prospects were identified in the study areas. Coal beds and placer deposits do not contain anomalous amounts of any elements. Ultramafic rocks in diatremes and dikes in the Cow Creek study area do not contain anomalous amounts of gold, silver, or platinum-group elements or zeolites. The study areas are assessed as having a low mineral resource potential for all metallic minerals, with a certainty level of C, save for diamonds, for which the Cow Creek study area is assessed as having a moderate potential, with a certainty level of B. No diamonds were detected in ultramafic rocks. Small deposits of zeolites are found in the diatremes in the Cow Creek study area. The mineral resource potential for zeolites is low in both areas, with a certainty level of C.

INTRODUCTION

At the request of the U.S. Bureau of Land Management, 21,590 acres of the 34,050-acre Cow Creek (MT–066–256) Wilderness Study Area and 9,600 acres of the 12,350-acre Antelope Creek (MT–065–266) Wilderness Study Area were studied. In this report, the areas studied are referred to as the "wilderness study areas" or simply the "study areas." They are in the central part of northern Montana, along the north side of the Missouri River, in the Northern Great Plains physiographic province (fig. 2). The study areas are between the Bearpaw Mountains on the northwest, the Little Rocky Mountains on the northeast, and the Judith Mountains on the south. Havre, Mont., is about 60 mi (miles) to the northwest and Lewistown, Mont., about 50 mi to the southwest. Montana State Highway 66 is northeast of the study areas and U.S. Highway 191 is about 4 mi east. Access to the areas is provided mainly by Squaw Creek and Cabin Creek Roads north and east of the Cow Creek study area and by the Powerplant road west and north of the Antelope Creek study area. Within the areas, access is by unpaved roads and jeep trails that may be impassable during wet weather.

Dominant topographic features include flat-top ridges and plateaus, cut by winding coulees, many of which are precipitously steep and narrow, although some have broad flood plains. Elevations range between 3,500

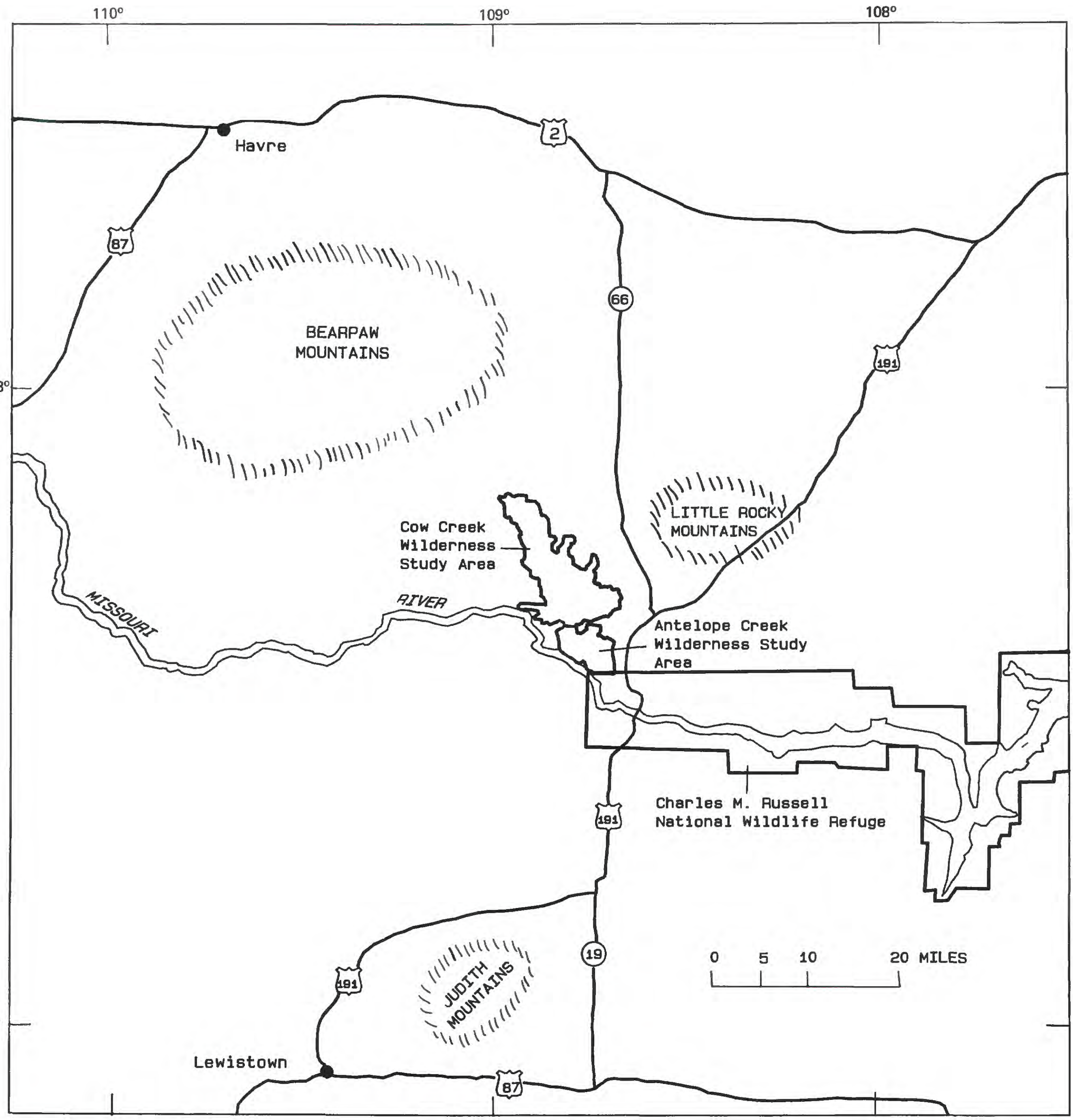

Figure 2. Index map showing location of the Cow Creek and Antelope Creek Wilderness Study Areas, Blaine and Phillips Counties, Mont.

and 2,300 ft. All streams in the area are intermittent and discharge into the Missouri River. Temperatures in the summer may exceed 100 °F and drop below −40 °F in the winter. Thunderstorms are common from spring through fall, accompanied by winds that occasionally exceed 40 mi per hour. A thin snow cover persists during the winter and spring months, but accumulation may be several feet deep after some storms.

Early studies pertaining to the geology of the Cow Creek and Antelope Creek study areas are those of Reeves (1924), who produced the first geologic map of the region, Brockunier (1936), and Knechtel (1959). Reeves (1946, 1953) later proposed a gravity-slide mechanism for the folding and faulting of Upper Cretaceous strata in the region, and this model was further substantiated by the work of Hearn (1976) in the Bearpaw Mountains to the northwest. Osgood (1932) described the No. 2 coal mine at the Phillips Powerplant west of the Antelope Creek study area; Fieldner and others (1932) reported results of analysis of coal from the No. 2 mine. Mundorf and others (1953) briefly described the geology along the Powerplant road near the southwest part of the Antelope Creek study area. R.R. Kuhns (1981) prepared a mineral management situation report for the Antelope Creek study area. Information about the gold and diamond potential of the region and the history of mining in or adjacent to the study areas were reported by Dingman (1932), Corry (1933), Lyden (1948), Matson (1960), Erdman and Lemke (1963), Hearn (1968, 1979), Penfold (1982), and Hearn and McGee (1983). The U.S. Army Corps of Engineers and others (1963) studied the geology and mineral resources of the Missouri River basin region, which included part of the study areas. Frahme and others (1979) reported on the geology and mineral resources of the Charles M. Russell National Wildlife Refuge, which adjoins the Antelope Creek Wilderness Study Area (fig. 2).

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). Classification of coal resources in the study areas is based on the U.S. Geological Survey classification system (Wood and others, 1983). Identified resources other than coal 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 undiscovered energy sources (coal, oil, gas, oil shale, and geothermal sources). It is classified according to the system of Goudarzi (1984), which also is shown in the appendix. The potential for undiscovered resources is studied by the USGS.

This study is supplemented by previous reports by USGS personnel regarding the general geology of the region (Reeves, 1924, 1946, 1953; Hearn, 1976; Rice and Shurr, 1983), the petroleum potential of proposed wilderness lands in Montana (Rice, 1980; Rice and Claypool, 1981; Perry and others, 1983), and the mineral potential of the Charles M. Russell Wildlife Refuge (Frahme and others, 1979).

Investigations by the U.S. Bureau of Mines

The Cow Creek and Antelope Creek Wilderness Study Areas were investigated, respectively, by Michael S. Miller and J. Douglas Causey of the USBM from 1984 to 1985, and the results were published (Causey, 1986; Miller, 1986) and are summarized in this report.

The USBM investigations included a literature search and an examination of Blaine and Phillips County and U.S. Bureau of Land Management mining claim and mineral lease records. Montana State Bureau of Mines records were searched and pertinent data compiled. Field studies included a search for all reported mineralized sites within the study areas. Those found were examined and sampled, and mapped if warranted. Mineralized sites close to the study areas were also studied to determine if mineralized zones extend into the study areas and to better understand mineral deposits of the region. Ground and aerial reconnaissance aided in characterizing the extent of the known mineral sites.

Samples from sites in the Cow Creek study area included 8 composites from diatremes, 28 alluvial (placer), 24 clay, and 11 coal or carbonaceous shale samples; in the Antelope Creek study area a total of 9 alluvial (placer), 16 clay, 3 coal, and 5 rock samples were taken.

Coal was sampled by removing 1.5–2.0 ft of the weathered surface and then cutting a channel approximately 4 in. (inches) wide by 2 in. deep. Classification used for coal resources is that of Wood and others (1983) and is shown in figure 3. Clay samples were obtained by removing at least 1.0 ft of weathered surface material and then cutting a channel. All alluvial samples were grab or channel samples of surficial sand and gravel.

The rock samples were crushed, pulverized, split, and analyzed at the USBM Reno Research Center. All rock and placer samples were tested in the laboratory for radioactivity and fluorescence. All rock samples were assayed for gold and silver by a combined fire assay–inductively coupled plasma method at detection limits of 0.007 ppm (parts per million) for gold and 0.3 ppm for silver. Splits from diatreme samples were assayed for gold, silver, platinum, and palladium by the same method, with detection limits for platinum and palladium at 0.01 ppm. Other elements of suspected economic significance were analyzed by atomic absorption, colorimetric, radiometric, or X-ray fluorescence. Representative samples were analyzed for 40 elements (see Causey, 1986) by semiquantitative emission spectrophotometry. X-ray diffraction was used to identify zeolite and clay minerals.

Ultramafic intrusions at mining claims and elsewhere were sampled at the surface. Grab samples, ranging from about 100 to 1,000 pounds, were taken from each diatreme. The samples were crushed to about 0.25 in. maximum diameter and split. Splits were made for quantitative chemical, semiquantitative, and X-ray diffraction analyses. Also, splits from the individual samples at each diatreme were composited into 100-pound archival samples. The remainder of the samples were combined and examined for diamonds in several ways: panning, sluicing, attrition grinding, grease adherence, magnetic separation, chemical digestion, electron microprobe, and optical microscopy.

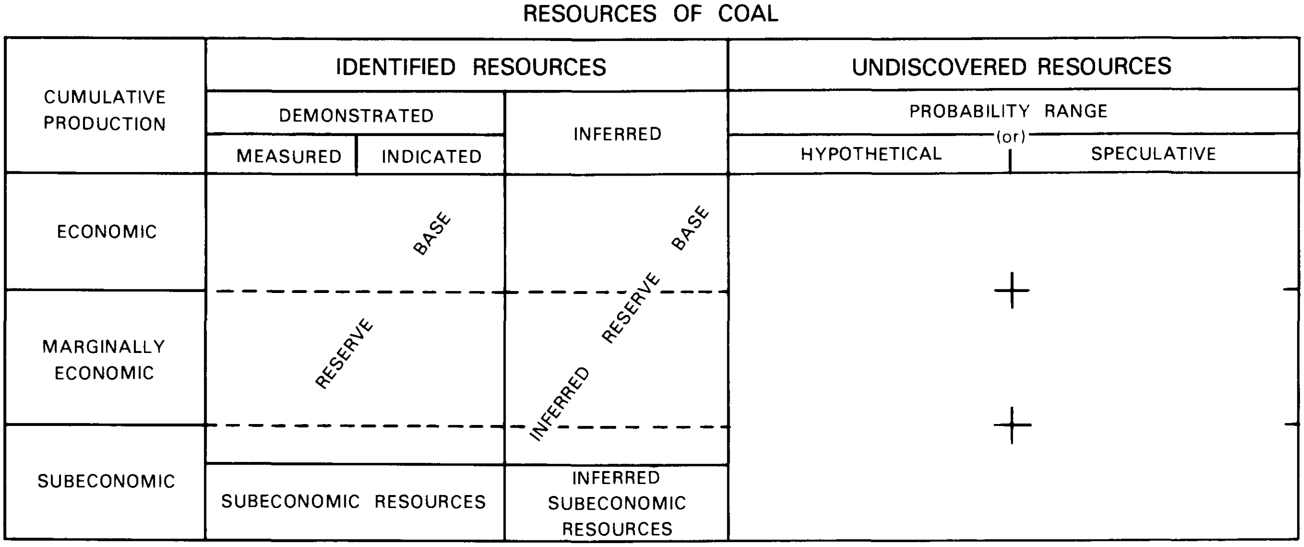

Figure 3. Format and classification of coal resources by reserve and inferred reserve bases and subeconomic and inferred subeconomic resources categories (adapted from Wood and others, 1983).

Coal samples were sealed in plastic bags and sent to the U.S. Department of Energy Pittsburgh Energy Technology Center, Pittsburgh, Pa., for analysis. The tests included proximate and ultimate analysis, heat content, ash content, and grindability index.

Clay samples were sent to the USBM Tuscaloosa Research Center for testing for slow firing, preliminary bloating, viscosity, compression, filtration, and plate water-absorption characteristics. A description of these tests is found in Liles and Heystek (1977) and American Petroleum Institute (1982). Methodology used for plate adsorption tests on bentonite was provided by Hendrick Heystek (written commun., 1984). Evaluation of the clay is based solely on its properties, raw and uncombined, and does not preclude beneficiation of the material or its use in mixes.

Most alluvial samples were collected from dry stream channels. Along the Missouri River, samples weighing approximately 30 pounds were cut from exposed river banks. These samples were concentrated on a Wilfley table at the USBM Western Field Operations Center laboratory in Spokane, Wash., and examined for gold, scheelite, ilmenite, garnet, zircon, and magnetite. When gold was detected, larger particles were hand-picked and weighed along with fine gold recovered by amalgamation. Concentrates were also checked for radioactivity and fluorescence. Additional information is available from the U.S. Bureau of Mines, Western Field Operations Center, E. 360 Third Avenue, Spokane, WA 99202.

Investigations by the U.S. Geological Survey

In 1984 and 1985, the U.S. Geological Survey conducted investigations to assess the mineral resource potential in the Cow Creek and Antelope Creek Wilderness Study Areas. The investigations consisted of a literature review of both published and unpublished geologic data pertaining to the study areas and adjacent region. Field investigations were conducted by E.E. McGregor. Geologic formations and structure were mapped on aerial photographs and transferred to a 1:24,000-scale topographic base map by J.W. M'Gonigle. The resulting geologic map is shown on plate 1, as is the mineral resource potential.

Regional aeromagnetic and gravity anomaly maps were prepared and interpreted by Viki Bankey and M.D. Kleinkopf.

Acknowledgments.—We thank George Mowat of the U.S. Bureau of Land Management in Billings, Mont., for providing information on coal resources and Roger B. Colton of the U.S. Geological Survey for providing aerial photographic interpretations of landslide deposits in the wilderness study areas.

APPRAISAL OF IDENTIFIED RESOURCES

By Michael S. Miller and J. Douglas Causey
U.S. Bureau of Mines

Mining and Mineral Exploration Activity

Mining claim staking and assessment work are the only mineral-related activity in the Cow Creek study area. There are nine mining claims at five sites (Miller, 1986, fig. 2), which were staked from 1977 to 1979 and have been held since by Mr. Charles Hauptman and Mr. John

Lynn (as of 1986), who have conducted several mapping and sampling programs on the claims.

There has been large-scale historic and present-day lode gold and silver mining in the Little Rocky Mountains, about 15 mi northeast of the study areas. Placer gold mining in streams originating in the Little Rocky Mountains has been relatively minor and confined to sites within a few miles of the lode deposits.

The study areas are in the north-central coal field region (Nielsen, 1982, p. 580–581). Probably fewer than 20 claims, some poorly described, were located in or near the southwest corner of the Cow Creek study area near the Shellenberger coal mine in the late 1800's and early 1900's. In the early 1900's, an unknown amount of coal was produced here.

There is no record of any current (as of 1985) mining claims or evidence of exploration for locatable minerals in the Antelope Creek study area; most of the coal was produced from mines outside the Antelope Creek study area. Two coal mines west of the study area were active in the early 1900's. The Phillips Powerplant coal mine in NW¼ sec. 21, T. 23 N., R. 22 E. (No. 9, pl. 1), operated from 1914 to 1924 supplying coal for the Phillips Powerplant. In 1924, workings in this mine extended underground at least 1,200 ft (Osgood, 1932, p. 67). The U.S. Army Corps of Engineers and others (1963, p. 103–104) estimated total production of 200,000 short tons.

In SW¼SW¼ sec. 15, T. 23 N., R. 22 E. (adjacent to the study area), the Russell coal mine (No. 8, pl. 1) operated from 1931 until the early 1950's. Production from this mine, estimated at 12,500 short tons (U.S. Army Corps of Engineers and others, 1963), supplied coal for local ranches and the towns of Zortman and Landusky. Two adits (one caved and one 30 ft long) in the study area, probably mined during that time, follow a coal bed exposed along the 2,400-ft elevation level on both sides of the Powerplant road. The bed is absent in parts of the area, probably as a result of either normal or thrust faulting.

Mines, Mining Claims, Prospects, and Mineralized Areas

Coal, clays, and precious metals were investigated in the Cow Creek and Antelope Creek study areas; additionally, zeolites and diamonds were investigated in the Cow Creek study area. Samples were described by Miller (1986, tables 1–4 and fig. 4) and by Causey (1986, tables 1–4 and figs. 2 and 3). No metallic mineral deposits or mineralized zones, mines, or prospects were identified in either study area.

Coal in the western part of the Antelope Creek study area is the only identified resource in either study area. The coal (Causey, 1986, table 1), classified as subbituminous C, occurs in 2.3- to 3.5-ft-thick beds, is covered by as much as 500 ft of overburden, and contains 10–20 percent ash and less than 1 percent sulfur. An estimated 0.2 million short tons of measured, 2.0 million short tons of indicated, and 7.0 million short tons of inferred subbituminous C coal resources in the study area (Causey, 1986, fig. 3) were calculated for an average bed thickness of 3.0 ft, a factor of 1,770 short tons/acre foot, and a surface area of 1,765 acres as determined by planimetric measurements. By the criteria established by Wood and others (1983), these resources do not constitute a part of the reserve base.

An analysis of coal from the Phillips Powerplant No. 2 mine (Fieldner and others, 1932, p. 36–37) compares favorably with those for surface samples collected from the same bed in the study area (Causey, 1986, table 1). Although ash content is high, Btu (British thermal unit) and sulfur content compare favorably with coal seams in the Powder River Basin that are being mined to supply coal-fired electric powerplants (Nielsen, 1982, p. 582). This suggests that the coal in the study area is marginally suitable for use in coal-fired electric powerplants. Other subeconomic coal beds in the Cow Creek study area (Miller, 1986, tables 3 and 5) are too thin, low in grade, deeply buried, and irregularly distributed to be mined except for small-scale local, mainly domestic uses, as at the Shellenberger mine (No. 7, pl. 1).

There are no identified resources of clay in either study area. The clays are too low in grade and too far from markets to be mined economically. All clay-bearing units in the study areas are too thin and would require removal of excessive overburden. Of 24 clay samples taken in the Cow Creek study area, 1 is suitable for use as lightweight aggregate (Miller, 1986, table 1). Of 16 clay samples from the Antelope Creek study area, 1 is suitable for structural clay products, 1 for lightweight aggregate, and 6 for foundry sand binder (Causey, 1986, table 2). No samples were suitable for drilling mud or pelletizing (taconite).

The placer deposits in the Cow Creek study area (Miller, 1986, tables 2 and 5) do not contain economic amounts of gold, and only one of nine placer samples from the Antelope Creek study area (Causey, 1986, table 3) contained detectable gold, and that only a trace.

The gold and silver content of coal beds (Miller, 1986, table 4) is too low to be economic in the Cow Creek study area. Ultramafic diatremes in the Cow Creek area contained noneconomic amounts of gold, silver, and platinum-group metals (Miller, 1986, table 5).

The ultramafic rocks in diatremes and dikes at the Hal 1, 2, 3, 18, 19, 21, 22, 23, 24, and 40 claims (pl. 1) and at two unclaimed sites are not economically minable for zeolites because of low grade. No diamonds were detected in the ultramafic rocks in composite samples from eight sites (Miller, 1986, table 5). Establishing presence and grade of diamonds would require large-scale sampling (about 100 tons) at each site, work beyond the scope of this study.

Sand and gravel resources were not found in the study areas.

ASSESSMENT OF POTENTIAL FOR UNDISCOVERED RESOURCES

By James W. Mytton, Viki Bankey, M. Dean Kleinkopf, John W. M'Gonigle, and Edward E. McGregor
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Geology

The Cow Creek and Antelope Creek study areas are underlain by intertonguing transgressive and regressive marine to nonmarine Upper Cretaceous rocks whose gentle regional dip to the southeast is disrupted by normal faults and low- to high-angle reverse faults related to gravity sliding at shallow depth. These rocks are intruded by dikes and pipes of ultramafic material, presumably derived from the lowermost part of the crust or from the top of the upper mantle. Quaternary alluvium and colluvium cover much of the bedrock.

Rocks of Late Cretaceous age, from oldest to youngest, include the upper part of the Colorado Shale, the Eagle Sandstone, Claggett Shale, Judith River Formation, and Bearpaw Shale.

The Colorado Shale is a gray- to brownish-gray transgressive marine shale containing minor brownish-gray siltstone, gray bentonite beds that represent altered volcanic ash, and concretionary limestone lenses. The unit is 750–900 ft thick.

The Eagle Sandstone, a marine to continental regressive unit, consists of light-brown to white sandstone included in the Virgelle(?) Sandstone Member at the base and an unnamed upper part. The upper part consists of interbedded coastal- and delta-plain units of medium-gray to brownish-gray shale and siltstone and some dark-gray carbonaceous mudstone and shale. The Virgelle(?) is 50–150 ft thick and forms vertical cliffs along traces of high-angle normal faults and prominent hogbacks along traces of low-angle reverse faults. The Eagle Sandstone is 150 to more than 200 ft thick.

The Claggett Shale is a brownish-gray to brown transgressive marine shale containing a triple bed of bentonite, possibly equivalent to the Ardmore Bentonite Bed (Rice and Shurr, 1983, p. 339, fig. 2), in the lower 80 ft of the formation and several 0.5- to 4.0-ft-thick beds of limestone concretions in the upper half. Bentonite units in the Claggett Shale range from less than 2 ft to 2.2 ft in thickness. Sandstone, 10–20 ft thick, near the top of the unit, contains marine fossils. The formation is 450 to more than 550 ft thick.

The Judith River Formation, a regressive unit, is predominantly continental and is made up of white, light-yellow, greenish and light-gray siltstone and mudstone, gray carbonaceous shale, and sporadic lenses of subbituminous coal, all deposited in a fluvial to coastal-plain environment. The main coal unit in the Antelope Creek study area is 2.0–3.5 ft thick in exposures along Powerplant road. Concretionary sandstone and siltstone are present, and marl rich in oyster shells is common in the upper part of the Judith River Formation. The Judith River is 500 ft thick locally, but thins eastward into predominantly marine shale.

The Bearpaw Shale is a gray to brownish-gray transgressive marine shale and silty shale unit containing light-gray to cream bentonite beds, which are prominent in the lower third of the unit; the bentonite beds are as thick as 2.2 ft, but most are less than 2 ft. Numerous beds containing limestone concretions and iron- and manganese-rich claystone concretions are present. Marine fossils, including ammonites (*Baculites* sp.), important in dating the stratigraphic units, are common. The exposed upper 50–200 ft of the unit contains thin-bedded sandstone and siltstone interbedded with shale and represents a transitional depositional environment from offshore to nearshore marine. The Bearpaw is estimated to be 900–1,000 ft thick, but its total thickness is uncertain because of faulting.

Ultramafic dikes and pipes (diatremes) intruded into the Upper Cretaceous rocks of the study areas are considered possible sources of diamonds, platinum-group metals, gold, and zeolites (Miller, 1986, p. 9). Later alteration (hydrothermal) has produced veinlets and breccia fillings of zeolites in the diatremes. Minerals such as pyrope garnets and chromium diopside, which have been used for prospecting for diamond-bearing rocks (Gold, 1984) are present in the diatremes. The igneous bodies have affinities to kimberlites of South Africa (Hearn, 1968).

Quaternary colluvium consisting of poorly sorted sand, silt, clay, pebbles, and sparse boulders, as large as 3 ft in diameter, has been deposited by slump, sheetwash, and rock fall. Colluvium is as much as 50 ft thick near source areas, thinning downslope to a thin veneer only 1 ft to a few inches thick. Quaternary alluvium composed of fine-grained sand, silt, sandy clay, and clay is present in discontinuous lenses and beds in the Missouri River Valley, along floodplains of intermittent streams that flow toward the Missouri River. The alluvium probably is not more than 25–30 ft thick. Quaternary glacial till, glacial lake deposits, stream, and landslide deposits are widespread in the region of the study areas, but are not depicted on the geologic map (pl. 1). Stream deposits are extensive on some broad floodplains, and landslides are large and widespread, notably in the Bearpaw Shale.

The salient structural feature of the Cow Creek and Antelope Creek study areas is the series of northeast-trending parallel, arcuate belts of faulted and folded Cretaceous rocks (pl. 1) that bound the Bearpaw Mountains uplift on the southeast and are related to southeastward gravity sliding of blocks of Upper Cretaceous strata off the flanks of the uplift during the various stages of doming associated with igneous intrusion and volcanism. Parts of at least a dozen arcuate belts of disrupted strata, 10–20 mi long and as much as 0.5 mi wide (partly shown on pl. 1), are within or adjacent to the study areas. Rocks between the disturbed belts are relatively flat lying, dipping only 1° or 2°, whereas rocks that define the belts are upturned, folded, and offset by low- to high-angle reverse faults and some normal faults. The faults dip as much as 80° and represent upper exposed parts of fault planes that are concave in the direction of the uplift and that flatten out and merge with gravity-slide detachment planes at shallow depths. Strata below gravity-slide or detachment planes are relatively intact, not having been affected by gravity sliding, which involved only the upper part of the Colorado Shale and overlying Cretaceous units (Reeves, 1946). Movement was along bentonitic beds in the Colorado Shale that were inclined only a few degrees off the flanks of the Bearpaw Mountains during the later stages of uplift and volcanism in the mountains (Reeves, 1946). Radial faults, associated with the Bearpaw Mountains uplift, cut the arcuate belts of disturbed Cretaceous strata. A prominent northwest-trending fault in the Cow Creek study area has offset the belts and forms a boundary between two large masses, or groups, of gravity-slide blocks. Such radial faults may reflect movement at depth along basement weakness zones.

The gravity-slide mechanism of Reeves (1946, 1953) for thrusting of Upper Cretaceous rocks on the southern flanks of the Bearpaw Mountains uplift was further substantiated by Hearn (1976) with subsurface data from exploratory drill holes; however, the structure is more complex than Reeves described: two main gravity-slide planes in the Colorado Shale were identified in the Bearpaw Mountains area, one near the base of the shale, just above the Greenhorn Limestone Member, and the other 550 ft above the base, close to bentonite marker bed Y. There are gravity-slide horizons of smaller extent in the Claggett Shale and lower part of the Bearpaw Shale.

Geophysics

Regional aeromagnetic data at a scale of 1:250,000 (fig. 4) were obtained from a NURE (National Uranium Resource Evaluation) survey that covers the Lewistown and Havre 1°×2° quadrangles (Bendix Field Engineering Corp., 1982, 1983). The data across the wilderness study areas are from traverses flown 3 mi apart at an elevation of 400 ft above terrain. The 1975 IGRF (International Geomagnetic Reference Field), updated to the survey date, was removed, and the resulting data were gridded and contoured at a 20-nT (nanotesla) contour interval.

On a regional scale, the Precambrian crystalline basement complex in eastern Montana causes a pronounced northeast grain in both gravity and magnetic maps. The zones of steep gradient and high-amplitude anomalies attest to the presence of a variety of mafic and granitic basement rocks. Locally, in the immediate area of the Cow Creek and Antelope Creek Wilderness Study Areas, the aeromagnetic field (fig. 4) has a pronounced northeast-trending magnetic grain that is evident in the aeromagnetic data but is not observed in the gravity field (fig. 5).

A broad, 100- to 140-nT, positive magnetic anomaly (M1–M1′) trends northeast through the Antelope Creek and Cow Creek Wilderness Study Areas (fig. 4). Rough depth estimates by the straight-line method (Nettleton, 1971) suggest a depth to the magnetic source generating this anomaly that is at or below the crystalline basement as shown on the regional basement map of Montana.

Superimposed on this large magnetic anomaly M1–M1′ are two northwest trends: a magnetic low (T1) culminates in a saddle across the Antelope Creek study area, and a magnetic high (T2) follows the eastern half of the Cow Creek study area. Trend T2 corresponds to the major northwest-trending fault that bisects the Cow Creek study area and suggests that the basement controls this fault. Trend T1 reflects the increased depth of the downthrown block to the south, in accordance with mapped geology.

A northwest-trending magnetic low (M2) northeast of Cow Creek separates the broad positive anomaly M1–M1′ from two smaller positive anomalies, M3 and M4. These smaller positive anomalies, as well as smaller negative anomaly M5, spatially correlate with the basement uplift associated with the intrusive bodies of the Little Rocky Mountains. Depth estimates place the sources of these small anomalies shallower than the large positive anomaly M1–M1′.

Overall, the aeromagnetic anomaly map shows a northeast-trending grain caused mainly by lithologic contrasts in basement composition, but the grain may show structural zones of weakness in the basement. These zones of weakness could have propagated through overlying sedimentary rocks, influencing sedimentation or causing faulting by rejuvenated movement, as seen in the major northwest-trending fault in this region.

A complete Bouguer gravity anomaly map (fig. 5) was generated from data collected by Bankey and McCafferty (1986) and retrieved from the U.S. Department of Defense data bank (NOAA National Geophysical Data

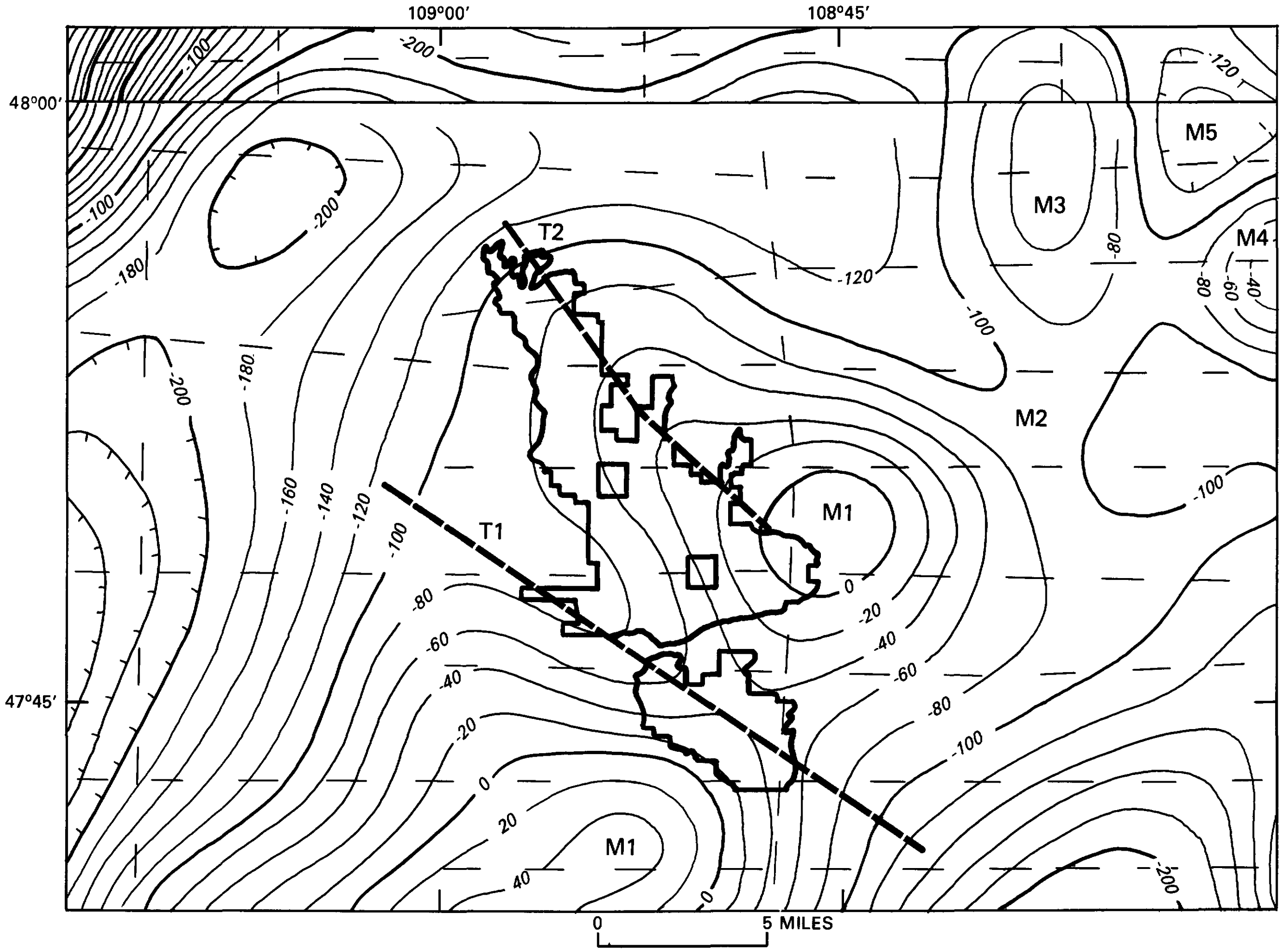

Figure 4. Total-intensity aeromagnetic anomaly map of the Cow Creek and Antelope Creek Wilderness Study Areas and vicinity, Blaine and Phillips Counties, Mont. Contour interval 20 nanoteslas; hachured lines indicate area of closed magnetic low. Light dashed lines are flight lines. M1-M5 and heavy dashed lines T1 and T2 indicate magnetic features discussed in text. Heavy solid line is approximate boundary of the Cow Creek (north) and Antelope Creek (south) study areas. Data for northern part of map area from Bendix (1982), for southern part from Bendix (1983).

Center). Bouguer and terrain corrections were calculated at a density of 2.67 grams per cubic centimeter. The corrected data were gridded at a 1-kilometer spacing and contoured at a 2-milligal interval with computer programs by Webring (1981) and Godson and Webring (1982). Wide station spacing and lack of stations within the wilderness study areas preclude detailed interpretation but help define the regional structural setting.

West of long 109° W. a gravity gradient zone trends slightly northeast (fig. 5). This gradient zone has a definite east-west deflection (D1) that is related to shallow structure or lithology, but continuation of this deflection to the east across the wilderness study areas is uncertain due to lack of station control. No east-west trending structure has been mapped farther east. A southeast-trending gradient zone (G2) passes through the Antelope Creek study area (fig. 5). This southeast gradient generally corresponds to the southeast-trending anomalies T1 and T2 on the magnetic anomaly map (fig. 4). Gradient G2 and positive anomaly A2 reflect the thicker, denser sediments on the downthrown fault block. North of the Antelope Creek study area, the gravity field is almost constant except for a small positive anomaly (A1) that straddles the northern boundary of the Cow Creek study area. This constant field may be the result of the lack of gravity stations, or it may be real. This field contrasts with the small positive and negative gravity anomalies (A3–A6) related to the intrusive bodies of the Little Rocky Mountains to the north and east. The small positive anomaly A1 on the northern boundary may also indicate a small uplift in the basement or an igneous intrusion; however, it does not correspond with a magnetic anomaly.

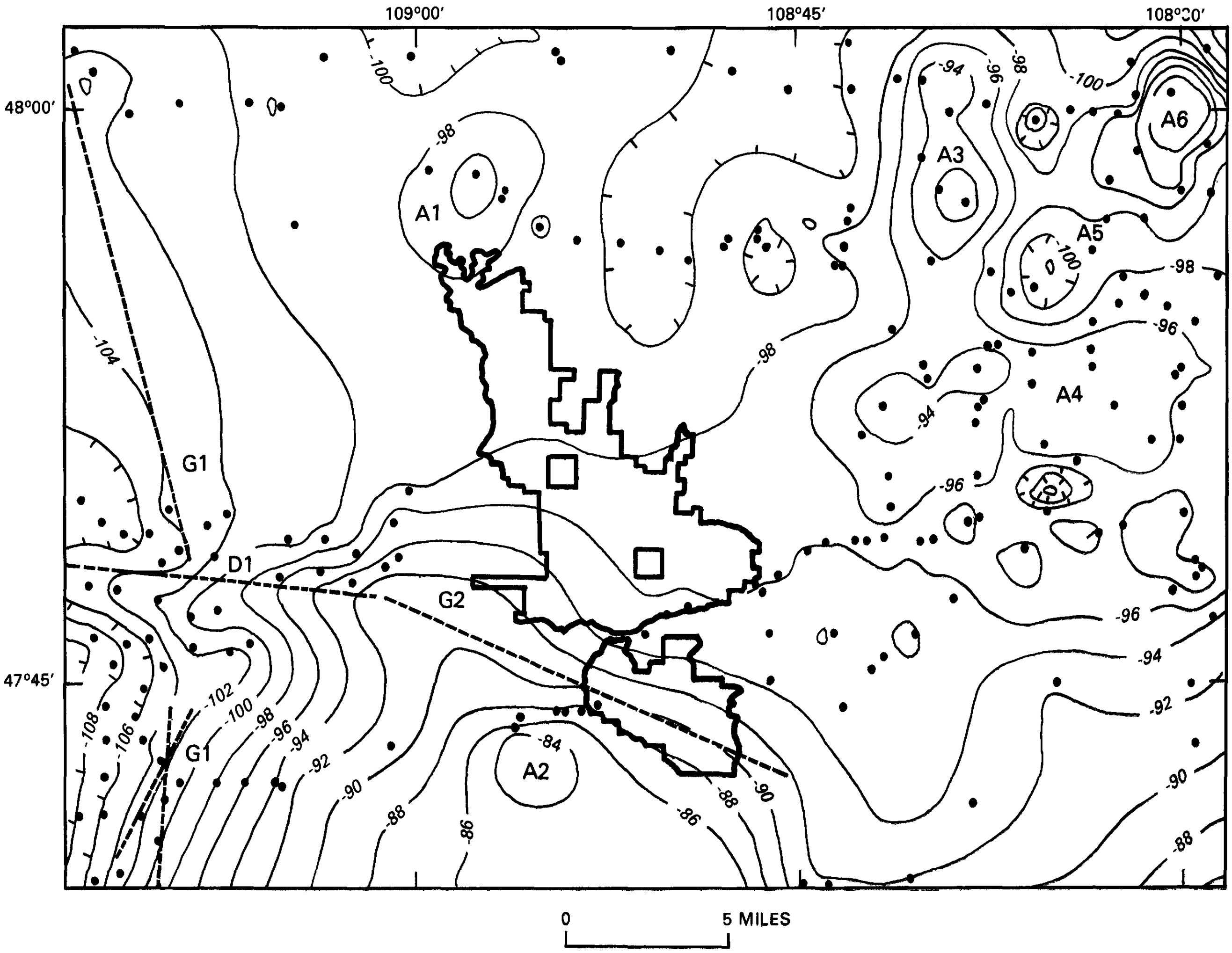

Figure 5. Complete Bouguer gravity anomaly map of the Cow Creek and Antelope Creek Wilderness Study Areas and vicinity, Blaine and Phillips Counties, Mont. Contour interval 2 milligals; hachured lines indicate area of closed gravity low. Dots are gravity-measurement stations. A1–A6, and dashed lines D1, G1, and G2 indicate gravity features discussed in text. Heavy solid line is approximate boundary of the Cow Creek (north) and Antelope Creek (south) study areas.

The gravity map (fig. 5) does not share the northeast-trending grain of the aeromagnetic map (fig. 4) except along the gradient west of long 109° W. (G1). The lack of correspondence emphasizes that the sources of the magnetic anomalies are related to the basement, whereas the gravity anomalies reflect both basement lithology and sedimentary rocks. The broad positive gravity anomaly A2 and the magnetic anomaly southwest of Antelope Creek (M1) reflect the thicker sediments and deeper basement of the downdropped block south of the basement-controlled, northwest-trending fault mentioned earlier. The smaller gravity and magnetic anomalies associated with the Little Rocky Mountains may also be caused by one common source.

Mineral and Energy Resources

Metallic Minerals

As stated previously, no metallic mineral deposits or mineralized zones, mines, or prospects were identified in the Cow Creek and Antelope Creek study areas. Insignificant or trace amounts of gold were found in placer samples taken in the Cow Creek and Antelope Creek study areas (Miller, 1986, table 2; Causey, 1986, table 3). Insignificant amounts of gold and silver were found in coal beds of the Cow Creek study area, and low concentrations of gold, platinum, and palladium were found in ultramafic rocks from diatremes and dikes in the Cow

Creek study area (Miller, 1986, tables 4 and 5). Because the geologic setting of the areas does not suggest additional mineralization, both study areas are assessed as having a low mineral resource potential for all metallic minerals, with a certainty level of C.

Industrial and Nonmetallic Minerals

Bentonite deposits are in the Claggett Shale, Bearpaw Shale, and the Judith River Formation in both of the study areas. However, the beds are thin and impure. The potential for bentonite resources in the study areas is therefore considered to be low, with a certainty level of C.

Small, impure deposits of zeolites are found in diatremes in the Cow Creek study area. Other types of deposits of zeolites in the study areas are unlikely, and the mineral resource potential for zeolites is considered to be low in both study areas, with a certainty level of C.

Ultramafic rocks in diatremes contain pyrope garnet and chromium diopside, minerals that indicate the possible presence of diamonds. Ultramafic rocks were mapped only in the Cow Creek study area. Although no diamonds were detected in the relatively small volume of rock samples or placer samples tested by the U.S. Bureau of Mines (Miller, 1986), the resource potential for diamonds in the diatremes is considered to be moderate in the Cow Creek study area, with a certainty level of B. Elsewhere in the Cow Creek study area and in the Antelope Creek study area, additional occurrences of diatremes and associated placer deposits are unlikely, and the resource potential for diamonds is low, with a certainty level of C.

Energy Sources

Township reports of the USBM dating back to the 1920's and 1930's concluded that no coal of classifiable thickness (22 in.) was identified in the field in the study areas, and prospects of thicker coal were negligible. Impure coal, the highest grade being subbituminous, and carbonaceous shale were observed in the Judith River Formation and Eagle Sandstone in fault blocks, but prospects for other discoveries were poor because of poor exposures.

More recent investigations, however, classify coal as a subeconomic resource in the western part of the Antelope Creek study area, as described above (Miller and Causey, this report), and by Causey (1986). In the remainder of the Antelope Creek study area and throughout the Cow Creek study area, coal beds are thin, impure, and irregularly distributed. The energy resource potential for coal is considered to be low in both study areas, with a certainty level of C.

On a regional scale, numerous accumulations of natural gas are contained in sandstone units in the Eagle Sandstone (Rice, 1980, p. 336). Natural gas entrapped in the Eagle Sandstone is at shallow depths and is of biogenic origin (Rice and Claypool, 1981, p. 16), probably generated in the surrounding shale, which is rich in organic matter, and stratigraphically trapped in permeable reservoirs of the Eagle Sandstone during the Late Cretaceous. Around the Bearpaw Mountains, gas is trapped by gravity-slide blocks that flank the uplift (Perry and others, 1983, p. G3). Faulting and folding associated with gravity sliding of Cretaceous rocks, related to plainsward tilting of strata during Eocene uplift and intrusive activity in the Bearpaw Mountains, created structural traps in the slide blocks that are the primary traps today (Rice, 1980, p. 336). Major gas production near the study areas is on the north flank of the Bearpaw Mountains (Rice, 1980, p. 317, fig. 1). The area of gravity-slide blocks on the south flank, which includes the Cow Creek and Antelope Creek study areas, is within a region of natural gas production. Perry and others (1983, p. G17) assigned a high gas potential to the study areas, the natural gas being contained primarily in Cretaceous units. The best prospects for gas reservoir rocks in the study areas would be the sandstone in the Eagle Sandstone and in the Judith River Formation. The energy resource potential for gas is considered to be high, with certainty level B.

No exploratory holes for oil and gas have been drilled in the study areas. If oil is present in the study areas, it would most likely occur at depth in older Mesozoic and Paleozoic rocks below the detachment horizons of the gravity slide blocks because some of the older rocks were probably buried deeply enough to have generated liquid hydrocarbons in this region (Rice, 1979, p. 72). The most probable traps for oil would be stratigraphic because the strata beneath the slide blocks are thought to be largely unfolded and unfaulted and dipping gently eastward (see Hearn, 1976). Such traps would be difficult to predict with the limited amount of subsurface information currently available near the study areas. Perry and others (1983, p. G17) assigned a medium to low oil potential to the general area. The energy resource potential for oil in the study areas is considered to be low, with a certainty level of B.

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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.

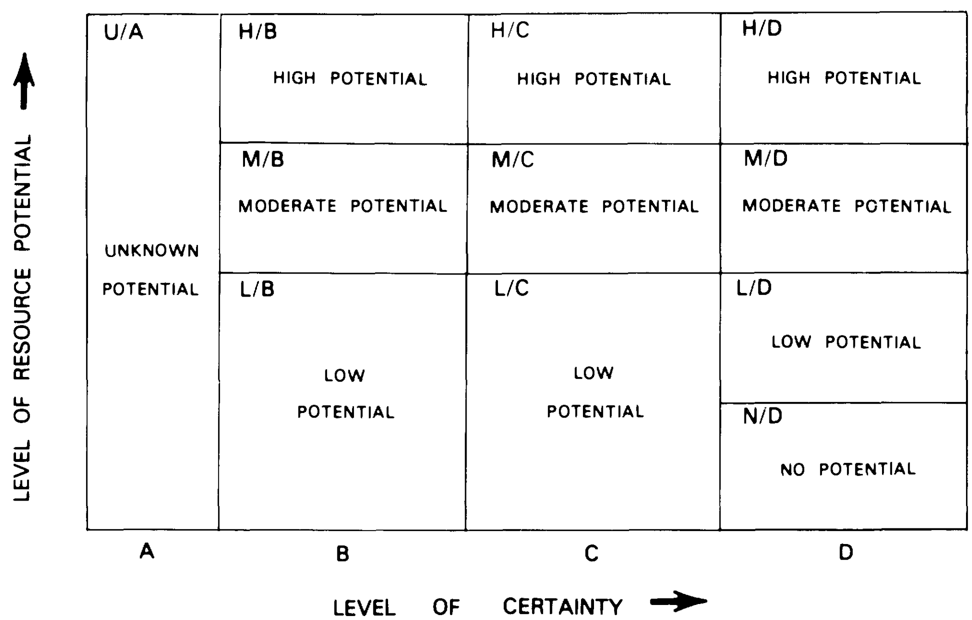
MODERATE mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence, where interpretations of data indicate a reasonable likelihood of resource accumulation, and (or) where an application 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:

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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 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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