Mineral Resources of the Burnt Lodge Wilderness Study Area, Phillips and Valley Counties, Montana

U.S. GEOLOGICAL SURVEY BULLETIN 1722–A

Chapter A

Mineral Resources of the Burnt Lodge Wilderness Study Area, Phillips and Valley 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

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STUDIES RELATED TO WILDERNESS

Bureau of Land Management Wilderness Study Areas

The Federal Land Policy and Management Act (Public Law 94–579, October 21, 1976) requires the U.S. Geological Survey and the U.S. Bureau of Mines to conduct mineral surveys on certain areas to determine the mineral values, if any, that may be present. Results must be made available to the public and be submitted to the President and the Congress. This report presents the results of a mineral survey of the Burnt Lodge (MT–065–278) Wilderness Study Area, Phillips and Valley Counties, Montana.

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PLATE

[Plate is in pocket]

FIGURES

Mineral Resources of the Burnt Lodge Wilderness Study Area, Phillips and Valley Counties, Montana

By Robert D. Hettinger *and* Viki Bankey
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SUMMARY

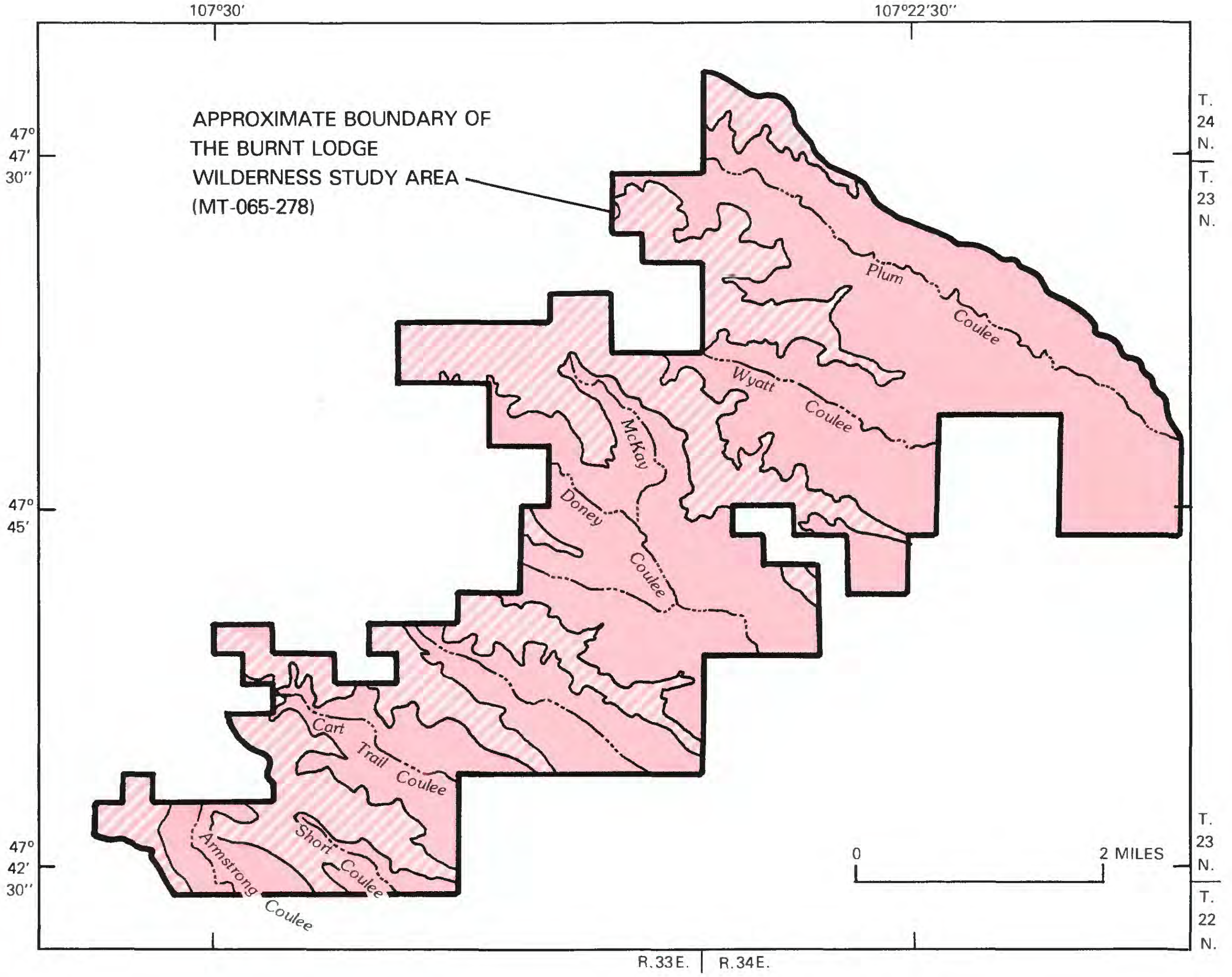
The Burnt Lodge Wilderness Study Area (MT-065-278) has no identified mineral resources. Occurrences of a kaolin-bearing sandstone may have limited use in structural clay products. However, remoteness and inaccessibility of the area make it unlikely that the material could be economically extracted even though some of the material is marginally useful. The area has mineral occurrences of bentonitic clay, sand and gravel, and placer gold. Concentrations of these mineral commodities are very small and are not considered to be resources. Parts of the study area have a moderate mineral resource potential for kaolinite (fig. 1). The entire study area has (1) a moderate energy resource potential for oil and gas and coal, (2) a low geothermal energy resource potential, and (3) a low mineral resource potential for all metallic minerals (including placer gold), bentonite, sand and gravel, and mineralization associated with possible deeply seated diatremes (including the occurrence of diamantiferous rock) (fig. 1).

The study area is located in the northern Great Plains physiographic province, north-central Montana, about 50 mi south-southeast of Malta (fig. 2). The regional topography is characterized by rolling prairies, broad shallow valleys, and scattered buttes. In the vicinity of the study area, the landscape is deeply incised by the Missouri River and its tributaries. The resulting rugged badlands topography, known as the Missouri Breaks, is characterized by numerous deep canyons separated by steep, narrow ridges. The area is accessible by gravel roads from Malta.

Upper Cretaceous (see geologic time chart in Appendix for relative ages) rocks exposed in, and immediately underlying, the study area include, in ascending order, the Judith River Formation (subsurface only), Bearpaw Shale, Fox Hills Sandstone (including the Colgate Member of the Fox Hills Sandstone), and Hell Creek Formation. Tertiary rocks of the Fort Union Formation are exposed west of the study area. Landslide deposits of Quaternary age flank valley walls and intertongue with Quaternary alluvial deposits that cover valley floors throughout the study area. Deposits of glacial till of Pleistocene age occur in thin isolated patches scattered along the higher surfaces and ridge tops in the study area. The Judith River Formation, Bearpaw Shale, and Fox Hills Sandstone were deposited in intertonguing offshore-marine, nearshore-marine, and continental environments within the Cretaceous Western Interior seaway. When the seaway withdrew from the region, the Hell Creek Formation was deposited in a continental fluvial and flood-plain environment along a flat coastal plain.

The study area is located on the northwestern flank of the Williston Basin (fig. 3). In the study area, Upper Cretaceous strata strike about N. 60° E. and dip to the southeast at 10 ft per mi. Only minor faults and folds occur in the study area; some parallel a regional lineament (fig. 3) that trends near the study area. The lineament may reflect zones of weakness in the Precambrian basement rocks and associated faults and joints in overlying sedimentary rocks. On a regional basis, these structural discontinuities may have served as conduits for oil and gas, small intrusions, and mineralizing fluids, although there is no evidence for this within the study area.

Oil and gas may occur in either structural or stratigraphic traps in most Paleozoic and Mesozoic sedimentary rocks beneath the study area. A broad, gentle, anticlinal fold, having about 50 ft of closure in the Upper



EXPLANATION

[Entire study area has low mineral resource potential for (1) bentonite and sand and gravel, with certainty level D, (2) all metallic minerals (including placer gold), with certainty level B, and (3) mineralization and diamantiferous rock associated with possible deeply seated diatremes, with certainty level B. Entire study area has low energy resource potential for geothermal energy, with certainty level B]

Geologic terrane having moderate mineral resource potential for kaolinite, with certainty level D

Geologic terrane having moderate energy resource potential for oil and gas and coal, with certainty level B— Applies to entire study area

Certainty levels

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

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

Figure 1. Summary map showing mineral and energy resource potential of the Burnt Lodge Wilderness Study Area, Phillips and Valley Counties, Montana.

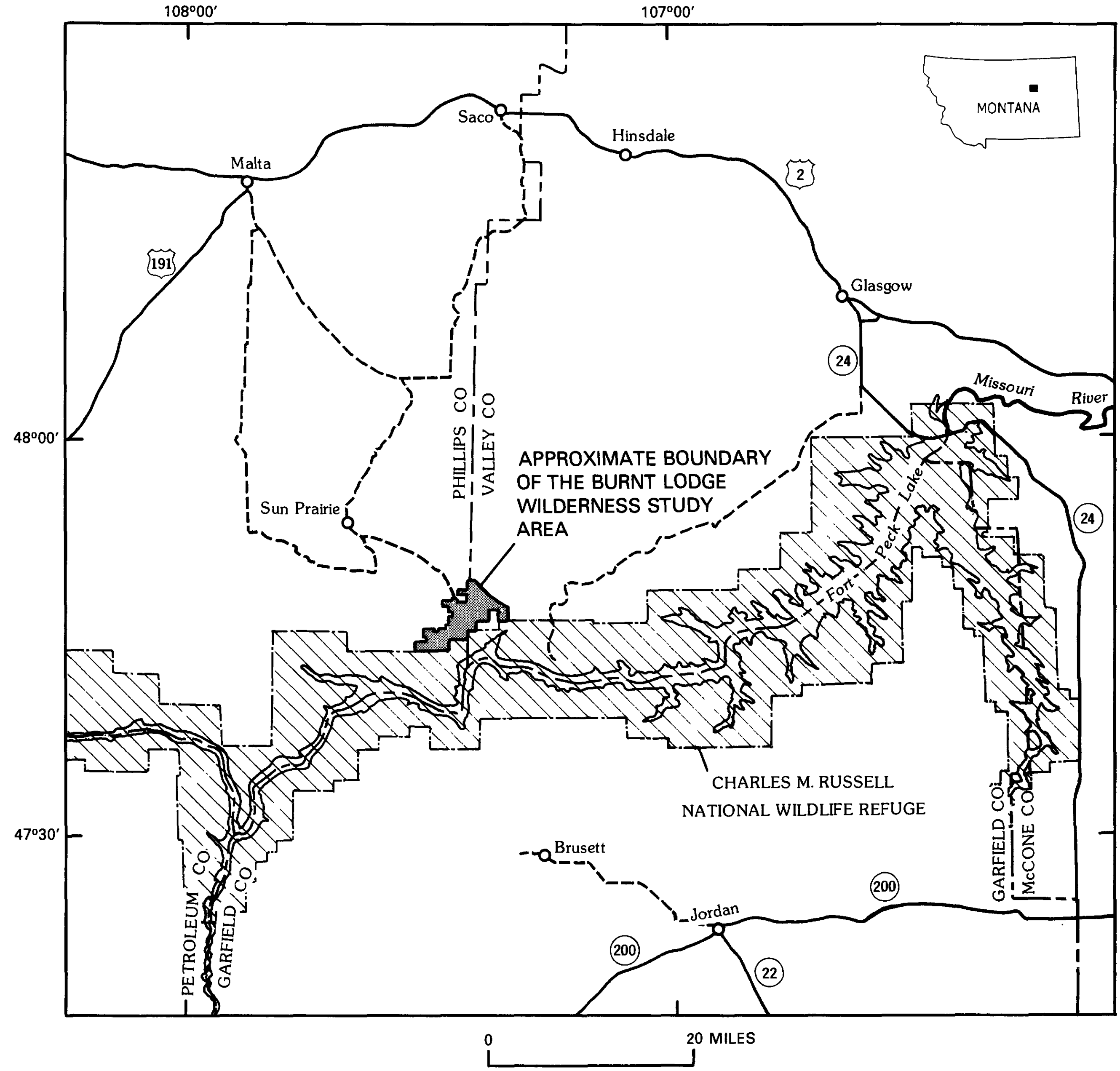


Figure 2. Index map showing location of the Burnt Lodge Wilderness Study Area, Phillips and Valley Counties, Montana. Short dashed lines indicate gravel road.

Cretaceous Fox Hills Sandstone, is inferred to extend northeast across the center of the study area. However, due to the small amount of closure associated with this fold, reservoir capacity is assumed to be small. The amplitude of the fold in the subsurface cannot be determined from available data. The oil and gas energy resource potential of the area is assessed as moderate, with a certainty level of B (see Goudarzi, 1984, and Appendix (this report) for explanation of classification system). Although the entire study area is under lease for oil and gas, no producing oil and gas wells are located in or near the area. Drill-hole information needed for a more adequate assessment is not available.

Subbituminous coal beds of resource thickness (greater than 30 in.) are likely to occur in the Judith River Formation, which underlies the entire study area at depths ranging from 660 to 1,500 ft. The nearest drill hole to penetrate the Judith River Formation is located 12 mi south of the study area. In that drill hole, the Judith River Formation contains two coal beds 3 ft and 5 ft thick. As coal beds in the Judith River Formation developed along coastal marsh environments, which are laterally extensive for many miles, coal beds of similar thickness and abundance are likely to occur beneath the study area. The coal energy resource potential is assessed as moderate, with a certainty level of B.

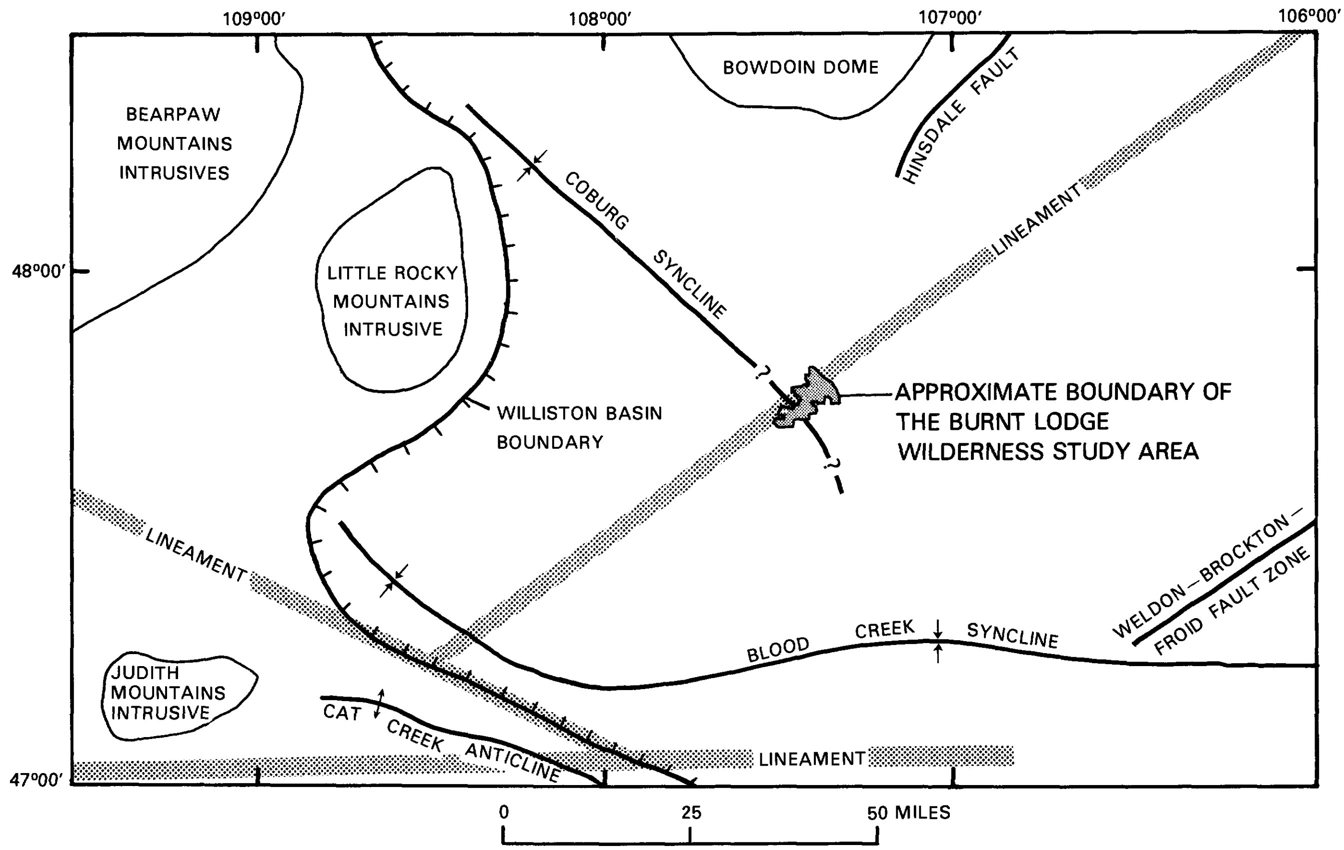


Figure 3. Map showing approximate locations of regional structural features in the vicinity of the Burnt Lodge Wilderness Study Area, Montana. Modified from Stoner and Lewis (1980). Approximate locations of lineaments from Anna (1986). Axis of Coburg syncline queried where uncertain (based on gravity data).

Kaolinite occurs as a matrix in the Colgate Member of the Fox Hills Sandstone. The Fox Hills Sandstone underlies about 35 percent (4,800 acres) of the study area; however, the Colgate Member is occasionally absent from the Fox Hills Sandstone due to changing rock types and localized erosion prior to deposition of overlying sedimentary rocks. The kaolinite was tested by the U.S. Bureau of Mines and found to be marginally useful for limited industrial purposes, but was not considered to be of resource quality. There is no evidence to suggest that within the study area the Colgate Member has concentrations of kaolinite that exceed the quality of the samples collected and tested by the U.S. Bureau of Mines. Those parts of the study area underlain by the Fox Hills Sandstone are assessed to have a moderate mineral resource potential for kaolinite, with a certainty level of D.

Bentonite beds occur in the Bearpaw Shale, which underlies the entire study area. The U.S. Bureau of Mines identified beds that are less than 1 ft thick and considered them to be insignificant. In the study area, the Bearpaw Shale may contain thicker undiscovered bentonite beds covered by thick landslide deposits and overlying sedimentary rock; however, due to the depth of overburden, the bentonite probably would not be weathered enough to be suitable for most commercial applications. The study area is assessed to have a low mineral resource potential for bentonite, with a certainty level of D.

Sand and gravel occurs in thin and narrow alluvial deposits located along numerous drainages in the study area. The alluvial deposits contain a high percentage of clay-size material and minor amounts of gravel-size material. The U.S. Bureau of Mines did not consider these deposits to be of resource quality, and deposits having higher concentrations of gravel are not likely to occur along the drainages in the study area. The study area is assessed to have a low mineral resource potential for sand and gravel, with a certainty level of D.

No significant occurrences of metallic minerals were indicated by chemical and geochemical sampling in or near the study area, and no mines or prospects occur in the study area. Geologic information leads to the conclusion that mineralization in or near the study area is unlikely, and therefore the study area is assessed to have a low mineral resource potential for all metallic minerals (including placer gold), with a certainty level of B.

Diatremes and ultramafic intrusive and extrusive activity along northeast-trending lineaments occur 30 mi southeast and 40–60 mi west of the study area, and some interest for diamonds has been shown in the areas to the west. A similar lineament through the study area has no evidence of igneous activity, but the possibility for such activity and associated mineralization at depth may exist. The mineral resource potential for diamantiferous rock and mineralization associated with possible deeply seated diatremes is low, with a certainty level of B.

No warm springs or other geothermal sources were noted in the study area. The study area is assessed to have a low potential for geothermal energy resources, with a certainty level of B.

INTRODUCTION

At the request of the BLM (U.S. Bureau of Land Management), 13,730 acres of the Burnt Lodge Wilderness Study Area (MT–065–278) were studied by the USGS (U.S. Geological Survey) and the USBM (U.S. Bureau of Mines). In this report the Burnt Lodge Wilderness Study Area is also called the "wilderness study area" or simply "study area". The study area is located in Phillips and Valley Counties, north-central Montana (fig. 2). The study area is bordered to the south by the Charles M. Russell National Wildlife Refuge and by some private and State lands, to the north by public lands, and to the west and east by private lands. The study area is accessible by gravel and dirt roads from Malta, Mont., located 50 mi to the north. Unimproved dirt roads are located along the northeast and northwest boundaries of the wilderness study area, and rough jeep tracks provide access to the study area along the tops of narrow ridges.

Early studies on the stratigraphy and paleontology of Upper Cretaceous and Tertiary rocks in eastern Montana were made by Barnum Brown (1907), R. W. Brown (1939), Dobbin (1924), Dobbin and Reeside (1929), and Perry (1934). Collier (1918) mapped and described the geology of northeastern Montana. More recent studies were conducted by Tschudy (1970), Gill and Cobban (1973), and Archibald (1982). Tertiary intrusive and extrusive rocks near the study area were mapped and described by Matson (1960) and Hearn (1979). Erdmann and Lemke (1963) and Hubbard and others (1963) reported on the geology and on the mineral and water resources along the Missouri River valley between the towns of Fort Peck and Fort Benton. These studies and additional geologic studies in the Fort Peck area by Jensen and Varnes (1964) were conducted to supply geologic data for the Missouri River Basin development program. Additional geologic and hydrogeologic data in the area were presented by Swenson (1955) and Stoner and Lewis (1980). The geology and mineral resources of the Charles M. Russell National Wildlife Refuge were mapped and described by the USGS and USBM (1979). Feltis (1981b) constructed a structure contour map on the top of the Madison Group for an area that includes the wilderness study area. Gravity and magnetic data were described by Zietz and others (1968) and the Bendix Field Engineering Corporation (1983). Regional lineaments related to Precambrian shear zones and Laramide tectonics have been mapped and discussed by Thomas (1974) and Anna (1986).

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

This study is supplemented by previous reports by the USGS regarding the petroleum potential of proposed wilderness lands in Montana (Perry and others, 1983a, 1983b) and the mineral potential of the Charles M. Russell National Wildlife Refuge (USGS and USBM, 1979).

Investigations by the U.S. Bureau of Mines

The Burnt Lodge Wilderness Study Area was examined by J. Douglas Causey in 1984. Results of this study have been released (Causey, 1985) and are summarized in this report.

The USBM mineral survey included a search for information pertaining to current and past mining activities in and near the wilderness study area, but did not include an evaluation of oil and gas or geothermal resources. Geological libraries, USBM production records, and the USBM Mineral Industry Location System were searched for data pertinent to this area. Also, the BLM mining-claim recordation indices, land-status and land-use records, and county-claim records were examined.

A search for mines, prospects, and claims was conducted during June 1984. Twenty seven samples were collected from areas with possible mineral resources; these included 4 clay, 8 rock, and 15 alluvial (placer) samples. Sample localities and analytical data are given in Causey (1985). All samples were sent to the USBM Reno Research Center for analysis. All rock and placer samples were checked for radioactivity and mineral fluorescence. The rock samples were assayed for gold and silver using a combined fire assay–inductively coupled plasma method with detection limits of 0.0002 troy ounces per ton for gold and 0.009 troy ounces per ton for silver. One sample was analyzed for uranium by X-ray fluorescence and another sample for iron and manganese by atomic absorption. The mineral composition of four samples was determined by X-ray diffraction. All of the rock and clay samples were analyzed by semiquantitative spectrophotometric methods for 40 elements (Causey, 1985). Clay samples were tested for slow firing, preliminary bloating, viscosity, compression, filtration, and plate water absorption. Evaluation of the clay is based solely on its own properties and does not consider its use in mixes. Placer samples were collected from many dry stream channels in the wilderness study area. They were concentrated and examined for gold, scheelite, ilmenite, garnet, zircon, and magnetite.

Investigations by the U.S. Geological Survey

In 1984, the USGS conducted investigations to assess the mineral resource potential of the Burnt Lodge Wilderness Study Area. The investigations included field studies and a literature review of published and unpublished geologic data pertaining to the wilderness study area and vicinity. Field investigations were conducted by R. D. Hettinger in June and July of 1984. Geologic formations and structure were mapped on aerial photographs and transferred to a 1:24,000-scale topographic base map using a Kern[1] PG–2 photogrammetric plotter. Landslide deposits were delineated on aerial photographs by R. B. Colton (USGS) and field checked by R. D. Hettinger. The resulting geologic map is shown on plate 1. Regional gravity and aeromagnetic anomaly maps (figs. 5 and 6, respectively) were prepared and interpreted by Viki Bankey and R. D. Hettinger.

Acknowledgments.—We thank employees of the BLM in Billings, Lewistown, Malta, and Miles City, Mont., for providing information on mineral resources from their files; Roger B. Colton (USGS) for providing aerial photographic interpretations of landslide deposits in the wilderness study area; Courteney Williamson (USGS) for providing technical assistance; and Mike Miller (USBM) for assisting with investigations relating to the USBM studies.

APPRAISAL OF IDENTIFIED RESOURCES

By J. Douglas Causey
U.S. Bureau of Mines

Mining and Mineral-Exploration Activity

There is no known mineral production from the Burnt Lodge Wilderness Study Area. The entire wilderness study area is leased for oil and gas; however, there have been no drilling activities by any oil company. There is no record of any mining claims or evidence of exploration for locatable minerals within the wilderness study area.

Appraisal of Mineral Occurrences Examined

No mineral resources were identified in the wilderness study area during this study. However, several mineral occurrences were examined. These occurrences include kaolinite, bentonite, sand and gravel, and placer gold.

Kaolinite is a clay constituent of the Colgate Member of the Fox Hills Sandstone (see "Geology" section). Samples of the Colgate Member taken from the Charles M. Russell National Wildlife Refuge contain 10–15 percent kaolinite (Miller and others, 1979). Analyses of four samples from the study area indicate the clay is marginally suitable for structural clay products and light-duty refractories because it would produce a fairly soft product. Due to the high firing temperatures needed to process this clay, the energy demand would exceed that needed to process other clay deposits. In addition, distance from market and inaccessibility to the area make it unlikely that the material could be economically extracted at the present time. For the reasons listed above, kaolinite is not considered to be a mineral resource within the study area.

Bentonite is found in thin beds in the Bearpaw Shale. The bentonite may be suitable for use as a binder for foundry sands or taconite pellets (Frahme, 1979). However, the bentonite is not considered to be a significant mineral occurrence as it is in beds that are very thin (less than 1 ft thick) and which are generally deeply buried beneath landslide debris and overlying rock.

Minor amounts of sand and gravel occur in the wilderness study area in thin alluvial deposits along coulee drainages. Rapid erosion scours the drainages and sediment flushing prevents the accumulation of sizeable deposits. Deposits generally contain less than 10 cubic yards of material, in which there is very little gravel-size material. Four placer samples collected from the drainages contain trace amounts of flour gold that lack economic significance.

ASSESSMENT OF POTENTIAL FOR UNDISCOVERED RESOURCES

By R. D. Hettinger and Viki Bankey
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Geology

Regional Geologic Setting

The Burnt Lodge Wilderness Study Area is located in the northern Great Plains physiographic province of

[1]Any use of trade names in this report is for descriptive purposes only and does not imply endorsement by the USGS.

north-central Montana. North of the wilderness study area, the topography is characterized by rolling glaciated prairies, broad valleys, and scattered buttes. In the wilderness study area, the landscape is deeply incised by tributaries of the Missouri River. About 1 mi south and southeast of the study area the Missouri River widens into Fort Peck Lake (fig. 2). Elevations in the wilderness study area range from 2,280 ft near the east boundary in Timber Creek to 3,142 ft near the southwest boundary on an unnamed ridge just north of Armstrong Coulee. The wilderness study area is characterized by rugged badlands topography referred to as the Missouri Breaks. Narrow ridges and deep canyons (coulees) trend northwest across the study area and parallel the structural dip of the area.

Approximately 8,000–10,000 ft of sedimentary rocks, ranging from Cambrian to Tertiary in age, underlie the study area. Rock units exposed in, and immediately underlying, the wilderness study area include the Upper Cretaceous Judith River Formation (subsurface only), Bearpaw Shale, Fox Hills Sandstone, and Hell Creek Formation, and the Tertiary Fort Union Formation. Rice (1979) described the lithology and thickness of all rock units occurring at depth in the vicinity of the wilderness study area.

Sediments of the Judith River Formation, Bearpaw Shale, and Fox Hills Sandstone accumulated in the trough occupied by the Cretaceous Western Interior seaway, which persisted for about 50 million years in northeastern Montana (Frahme, 1979). During this time, sediments were deposited in transgressive and regressive sequences of intertonguing offshore-marine, nearshore-marine, and continental environments. Approximately 70 million years ago regional uplift forced the seaway from the area. The offshore-marine deposits of the Bearpaw Shale and the nearshore-marine deposits of the Fox Hills Sandstone were then covered by continental fluvial and flood-plain deposits of the Hell Creek Formation and Fort Union Formation. Erosion has removed much of the sediment deposited since Tertiary time. During the Pleistocene, the region was extensively glaciated by continental ice sheets that advanced to the south from Canada. A thick mantle of glacial till was deposited as the glaciers retreated to the north at the end of the Pleistocene. Erosion by the Missouri River and its tributaries has deeply incised the area to produce the present badlands topography typical of the wilderness study area.

The study area is located on the north limb of the Blood Creek syncline in the northwest part of the Williston Basin (fig. 3) as delineated by Bayer (1983). Regionally, strata on the north limb of the Blood Creek syncline are nearly horizontal, striking about N. 45° E. and dipping 20–30 ft/mi to the southeast. Northwest of the study area, the regional strike changes to the west and northwest in the vicinity of the Coburg syncline (fig. 3), a broad, poorly defined regional trough located between the Bowdoin dome and Little Rocky Mountains intrusive. Strata on both limbs of the Coburg syncline dip at less than 1° toward the synclinal axis. Previous studies terminated the Coburg syncline about 10 mi northwest of the study area. Gravity data (fig. 5) and detailed mapping of the study area (pl. 1) suggest that the Coburg syncline may extend through the study area.

Anna (1986) mapped a prominent lineament (fig. 3) based on the geometry of subsurface sedimentary rocks. The lineament trends N. 54° E. adjacent to the study area and approximates the position and trend of a steep aeromagnetic gradient that passes through the study area (Zietz and others, 1968; fig. 6, this report). A discussion of the aeromagnetic data is included in the "Geophysics" section. In the study area, the presence of the lineament is further supported by northeast-trending faults and fold axes (pl. 1). Thomas (1974) suggested that such lineaments are the result of a Laramide lateral adjustment of basement blocks along early Precambrian shear zones, and that the resulting block framework has affected the regional migration and accumulation of mineralizing solutions, oil, and gas. Frahme (1979) suggested that Tertiary intrusive and extrusive activity has occurred along similar lineaments located south and west of the Charles M. Russell National Wildlife Refuge. Presumably, these are the localities described by Matson (1960) and Hearn (1979), respectively located 30 mi southeast and 40–60 mi west of the study area. The areas described by Hearn (1979) include diatremes and ultramafic dikes that have excited an interest in diamonds (Miller, 1986). In the study area, there is no evidence in surface exposures of igneous activity or associated mineralization. Such activity, if it occurs, would probably be deeply buried.

Geologic Structure

Strata in the Burnt Lodge Wilderness Study Area are nearly horizontal. The average strike is N. 59° E. and the average dip is 10 ft/mi to the southeast, based on an approximation of the top of the Fox Hills Sandstone throughout the wilderness study area. Some minor folding and faulting occur in the study area, with fold angles of less than 1° and displacement along fault planes ranging from 10 to 40 ft. The approximate locations of faults and inferred locations of fold axes are shown on plate 1. The locations of faults are based on field mapping, and the inferred locations of fold axes are based on the configuration of structure contour lines constructed on the top of the Fox Hills Sandstone (pl. 1). Elevations at the top of the Fox Hills Sandstone were determined from aerial photographs using a Kern PG–2 photogrammetric plotter and USGS 7½′ topographic maps of the area. Local structural patterns related to differential compaction of sediments, camber and slump of strata into valleys, and the unconformable contact between the Fox Hills Sandstone and Hell Creek Formation are not indicated by the structure contour lines (pl. 1).

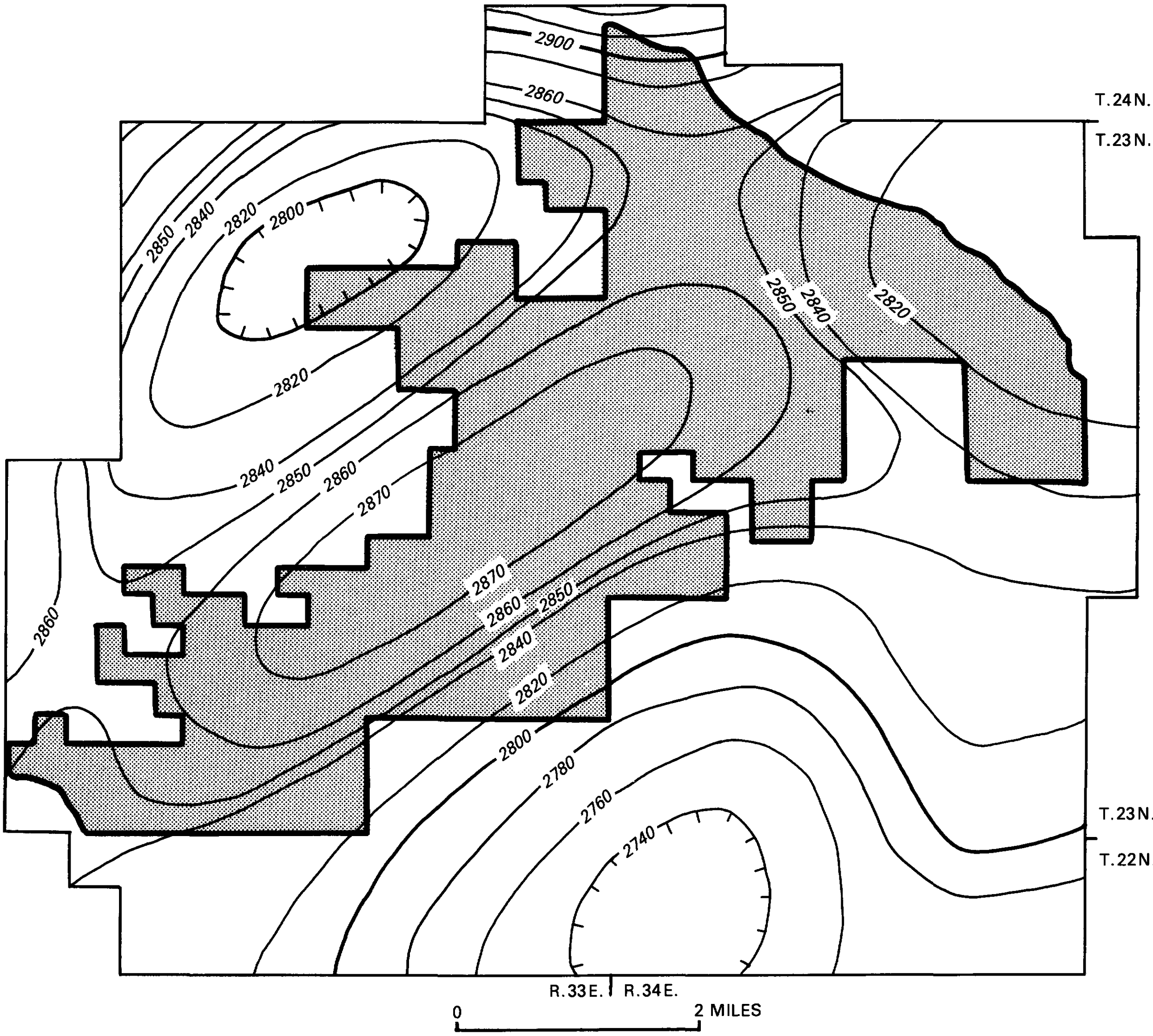


Figure 4. Map showing configuration of computer-smoothed structure contours approximating the top of the Fox Hills Sandstone in the Burnt Lodge Wilderness Study Area (shaded) and vicinity, Montana. Hachures indicate closed basin. Contour interval 10 and 20 feet. Datum is mean sea level.

Faults and fold axes trend to the northeast at approximately N. 60° E. and N. 25° E., and to the northwest at approximately N. 45° W. Structural trends to the northeast are probably related to the regional lineament mapped by Anna (1986) and may have resulted from a Laramide readjustment of the Precambrian shear zones similar to the processes discussed by Thomas (1974) and Anna (1986). Structural trends to the northwest may be related to the possible extension of the Coburg syncline through the study area (see "Geophysics" section).

The axis of a low-amplitude anticlinal fold is inferred through the center of the study area. A computer-smoothed model of the structure contour map (fig. 4) emphasizes the fold, which trends at N. 55° E., is 6 mi long and 2 mi wide, and has an estimated maximum closure of about 50 ft at the top of the Fox Hills Sandstone. The depth to which the fold extends into the subsurface cannot be determined due to a lack of seismic and drill-hole data.

Description of Map Units

Upper Cretaceous Judith River Formation (subsurface only).—Although the Judith River Formation does not crop out in the wilderness study area, it underlies the entire study area. Depths to the top of the formation range from 660 to 1,500 ft. The Judith River Formation is composed of marine sandstone interbedded with non-marine mudstone, sandstone, and lignite (Rice, 1979). The nearest drill hole that penetrates the formation is the Montana Power Co. Federal No. 10–32 located in sec. 32, T. 21 N., R. 34 E., 12 mi south of the wilderness study area; here the Judith River Formation is 330 ft thick. To the west, the formation consists of quartz sandstone overlain by a widespread low-grade coal zone (Frahme, 1979). The formation thins to the east and grades into a predominantly marine sandstone with thin shale and siltstone interbeds (Rice, 1979). The Judith River Formation grades upward into the Bearpaw Shale.

Upper Cretaceous Bearpaw Shale (unit Kb, *pl. 1).*—The Bearpaw Shale is the oldest formation exposed in the study area. It consists of sediments that accumulated in an offshore-marine environment. Sediments include dark-gray argillaceous shale and numerous thinly interbedded layers of siltstone, very fine grained orange-brown sandstone, and bentonite. Limy concretions containing marine fossils are common. A laterally continuous bentonite bed (named the Siparyann bed) as much as 6 ft thick may occur 80–200 ft above the base of the formation (Miller and others, 1979).

The total thickness of the Bearpaw Shale is estimated from the Montana Power Co. Federal No. 10–32 drill hole to be about 1,140 ft. Only the upper 480 ft of the formation are exposed in the wilderness study area. The Bearpaw Shale is almost completely covered by a thick mantle of landslide debris throughout the study area. The Bearpaw Shale is conformable with, and grades into, the overlying Fox Hills Sandstone.

Upper Cretaceous Fox Hills Sandstone (unit Kfh, *pl. 1).*—The Fox Hills Sandstone represents the final stage of marine sedimentation in the area and formed in a regressive shoreline environment of the Cretaceous Western Interior seaway (Gill and Cobban, 1973). The Fox Hills Sandstone is divided into a lower shaly unit and an upper sandstone unit.

The lower shaly unit is transitional and conformable with both the underlying Bearpaw Shale and the overlying upper sandstone unit. The lower unit is 20–25 ft thick and consists of soft, yellow-brown to grayish-brown, very fine grained to fine-grained, moderately sorted to well-sorted, planar-bedded sandstone, and silty sandstone and sandy shale. The lower unit forms gentle slopes, is shaly near its base, and increases upward in sand content.

The upper sandstone unit consists of yellow-brown, very fine grained to medium-grained, silty, micaceous, poorly cemented, crossbedded sandstone, which locally undergoes a lateral facies change with the Colgate Member. The Colgate Member is a light-gray to brownish-white, kaolinitic, silty, very fine grained to fine-grained sandstone with interbedded siltstone and shale. The Colgate Member is as much as 30 ft thick. Fossil plants suggest that part of the Colgate Member may be nonmarine in origin (Brown, 1939). Sedimentary structures in the Colgate Member include large-scale sets of inclined cross stratification and occasional trough stratification. The cross-strata are as much as 15 ft long and 0.2–2.0 ft thick and alternate in composition from silty shale to carbonaceous shale to sandstone. Thin stringers of carbonaceous material often occur at bounding surfaces between individual cross-strata. Sets of cross-strata are inclined from a few degrees to about 15°. Horizontal layers of carbonaceous mudstone and shale, 1–3 ft thick, frequently occur near the base and top of the upper sandstone unit. The upper sandstone unit varies in thickness from 0 to 30 ft, and forms a resistant, fluted cliff throughout most of the wilderness study area. Variation in thickness is mainly due to erosion of the upper sandstone unit prior to deposition of the overlying Hell Creek Formation.

Upper Cretaceous Hell Creek Formation (unit Khc, *pl. 1).*—The Hell Creek Formation was deposited by a fluvial system in a coastal flood-plain environment and consists of lenticular beds, which include yellow-brown, fine- to coarse-grained, poorly cemented sandstone, light-gray siltstone, dark-brown carbonaceous shale, varicolored (purple, gray, green, and brown) mudstone, thin claystone composed of bentonite and montmorillonite, and thin silty limestone and ironstone. Dinosaur bone fragments are common in the formation. In the wilderness study area, the basal Hell Creek Formation is often marked by a medium-grained to very coarse grained, fluvial, cliff-forming sandstone as much as 50 ft thick. This basal sandstone was observed to occupy channels that have erosionally cut into, and occasionally removed, the upper sandstone unit of the Fox Hills Sandstone. In the absence of the basal sandstone, the base of the Hell Creek Formation is marked by gray and greenish-gray mudstone or a carbonaceous coaly mudstone unit, forming a sharp and apparently nonerosional contact with the Fox Hills Sandstone. The basal contact of the formation is considered to be disconformable with the underlying Fox Hills Sandstone (Jensen and Varnes, 1964). However, this disconformable relationship does not represent a major break in sedimentation (Dobbin and Reeside, 1929).

About 295 ft of the Hell Creek Formation are exposed in the wilderness study area; the top of the formation and the overlying Tertiary rocks have been removed by erosion. The Hell Creek Formation reaches a total thickness of 320 ft at the Shoemaker triangulation station located in sec. 16, T. 23 N., R. 33 E., about 1 mi west of the wilderness study area. The contact between the Hell Creek Formation and the overlying Fort Union Formation is conformable (Tschudy, 1970). The Hell Creek Formation forms steep slopes and rounded ridge tops typical of badlands topography throughout the wilderness study area.

Tullock Member of the Paleocene Fort Union Formation (unit Tft, *pl. 1).*—No deposits of the Tullock Member of the Fort Union Formation occur in the wilderness study area; however, several small isolated deposits of the Tullock Member were mapped about 1 mi west of the wilderness study area and are shown on plate 1. The Tullock Member consists of pale-orange to pale-yellow, fine-grained, soft, silty, lenticular sandstones interbedded with thin beds of gray shale, brown carbonaceous shale, and coal. These isolated deposits were mapped as the Tullock Member on the basis of a 0.5-ft coal bed which occurs at a stratigraphic position similar to that described by both Collier (1918) and Tschudy (1970). The total preserved thickness of what is probably the basal Tullock Member is 15 ft at the Shoemaker triangulation station, sec. 16, T. 23 N., R. 33 E. The remainder of the formation has been removed by erosion.

Quaternary surficial deposits (units **Qac, Qls, Qt,** *pl. 1).*—Quaternary surficial units mapped on plate 1 include undifferentiated alluvium and colluvium (**Qac**), landslide deposits (**Qls**), and glacial till (**Qt**). Quaternary deposits such as slope wash, terrace gravels, and eolian deposits were not mapped.

Undifferentiated deposits of alluvium and colluvium (**Qac**) are mapped along the coulee drainages. Alluvial deposits consist of clay, silt, and sand derived locally from the Bearpaw Shale, Fox Hills Sandstone, and Hell Creek Formation. Minor amounts of gravel and cobbles derived from glacial till are also present. As mapped, the undifferentiated alluvium and colluvium include some interbedded landslide deposits, some slope wash material, low-level terrace deposits, and alluvial fan deposits. The thickest alluvium occurs in Timber Creek and in the Plum Coulee drainage, where accumulation may be as much as 30 ft. Alluvial deposits occurring along the drainages of other coulees are thin and discontinuous.

Landslide deposits (**Qls**) of Quaternary age flank valley walls and intertongue with Quaternary alluvial deposits that cover valley floors throughout all of the coulees in the wilderness study area. Numerous slump-earth flow deposits containing debris from the Hell Creek Formation, Fox Hills Sandstone, and Bearpaw Shale have glided down over the underlying Bearpaw Shale and Fox Hills Sandstone and have coalesced to form a thick mantle of debris that obscures much of the Bearpaw Shale and Fox Hills Sandstone in the wilderness study area. The landslide deposits show signs of movement characterized by scarps, transverse ridges, and transverse cracks. The thickness of the landslide deposits may be as much as 50 ft (R. B. Colton, oral commun., 1986).

Deposits of glacial till (**Qt**) occur as thin isolated patches of unconsolidated gravel, cobbles, and boulders as much as 2 ft in diameter. The till remnants are found scattered on ridge tops throughout the wilderness study area. The composition of cobbles and boulders is highly variable, and includes gray limestone, sandstone, sedimentary quartzite, granite, and various types of metamorphic rock. Fullerton and Colton (1986) have correlated the glacial till in this area with the till at Markles Point, located 1 mi southwest of the west end of the Fort Peck Dam. The till is Illinoian (late middle Pleistocene) in age (Fullerton and Colton, 1986).

Eolian and slope wash deposits (not mapped) consist of clay, silt, and fine sand, and occur on many of the higher surfaces throughout the wilderness study area. These deposits are less than 3 ft thick.

Geochemistry

The USBM collected 27 samples for chemical analysis from outcrops and stream sediments in the wilderness study area. Sample localities, analyses, descriptions, and results are discussed in Causey (1985) and are summarized in the USBM section of this report. No additional chemical analyses were conducted for this study. A mineral survey of the Charles M. Russell National Wildlife Refuge (Frahme, 1979) provides regional geochemical data that are applicable to the Burnt Lodge Wilderness Study Area. The refuge is contiguous to the Burnt Lodge Wilderness Study Area (fig. 2) and its geologic setting is nearly identical to that of the wilderness study area. A total of 442 rock, stream-sediment, and panned-concentrate samples were collected throughout the refuge. Twenty-two rock samples were collected immediately south of the wilderness study area from exposures of the Bearpaw Shale, Fox Hills Sandstone, and Hell Creek Formation. Three stream-sediment samples and one panned-concentrate sample were collected from streams that drain the wilderness study area. The drainages are Killed Woman Creek, Doney Coulee, McCarty Coulee, and Timber Creek. All samples collected in the refuge were analyzed for 30 elements by a semiquantitative emission spectrographic technique (Grimes and Marranzino, 1968). Selected shale samples were also analyzed for Al_2O_3, and selected sandstone samples were also analyzed for uranium and thorium.

Results

Results from the chemical studies of the Burnt Lodge Wilderness Study Area (Causey, 1985) and the geochemical studies of the Charles M. Russell National Wildlife Refuge (Frahme, 1979) indicate that the Burnt Lodge Wilderness Study Area shows no evidence of significant mineralization.

Analyses of samples of the Bearpaw Shale were compared to average elemental values for three other populations of black Cretaceous shales in the United States (Frahme, 1979). Several samples of the Bearpaw Shale collected from the refuge immediately south of the wilderness study area are slightly enriched in one or more of the metals aluminum, titanium, boron, barium, beryllium, lanthanum, and zircon. Clay samples collected from the Bearpaw Shale between 9 and 16 mi west of the wilderness study area contained as much as 17.0 percent

Al_2O_3 and may indicate the presence of an aluminum-rich horizon of unknown extent (Frahme, 1979). Frahme did not consider the Al_2O_3 values to be high enough to indicate the presence of an aluminous shale, and stated that shales of this quality are common throughout the United States. Two outcrop samples collected from the Hell Creek Formation south of the wilderness study area, between Killed Woman Creek and Timber Creek, were slightly enriched in molybdenum when compared to other samples in the refuge (Frahme, 1979). Frahme (1979) did not consider any of the samples in the refuge to show evidence of significant mineralization. Frahme (1979, p. 22) stated that "The area is lacking in evidence of mineral occurrence such as areas of altered rock that are characteristic of mineralized areas elsewhere."

Geophysics

Gravity and aeromagnetic anomaly data, shown on figures 5 and 6, respectively, provide information about the regional geologic setting and structural framework in which the Burnt Lodge Wilderness Study Area is located. The gravity data are primarily influenced by near-surface, nonmagnetic, folded sedimentary rocks; and the aeromagnetic data are influenced by magnetically variable Precambrian basement rocks. The differences in rock sources results in a lack of correlation between the gravity and aeromagnetic anomaly maps.

Methods

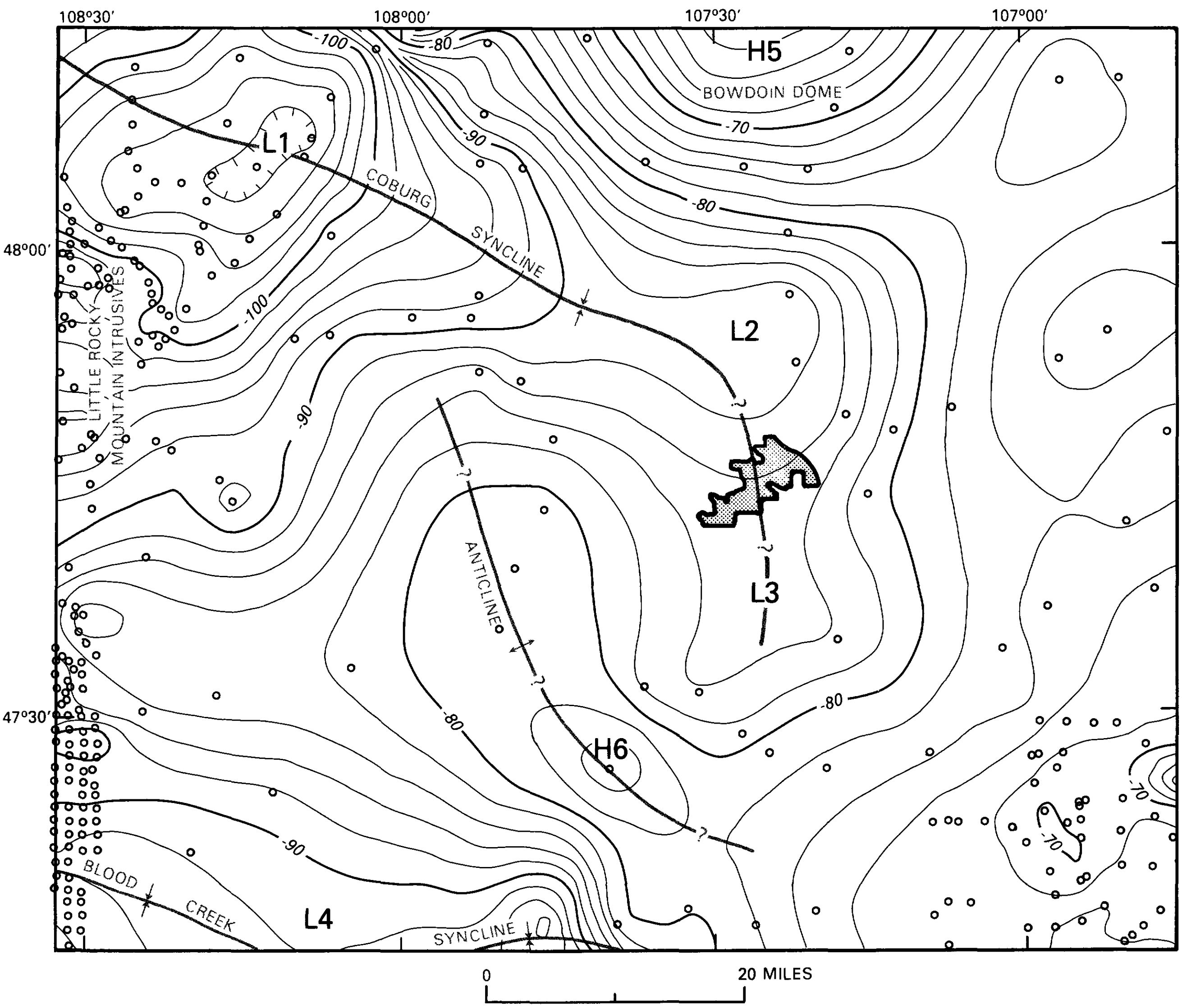
A complete Bouguer gravity anomaly map (fig. 5) was generated using gravity values selected from the data base established by the U.S. Department of Defense. These data were reduced using a density of 2.67 grams per cubic centimeter, gridded at a 1-km spacing, and contoured at an interval of 2 milliGals using computer programs by Webring (1981) and Godson and Webring (1982). The wide station spacing precludes detailed interpretations within the Burnt Lodge Wilderness Study Area but gives a regional structural setting.

Regional aeromagnetic data (fig. 6) were obtained from a NURE (National Uranium Resource Evaluation) survey that covered the Jordan 1°×2° quadrangle (Bendix Field Engineering Corp., 1983). These data were collected from a grid of flight lines spaced at 6 mi north to south and at 18 mi east to west. The flight lines were flown 400 ft above the terrain. Two east-west flight lines provide control across the northern and southern boundaries of the study area. The 1975 International Geomagnetic Reference Field, updated to the survey date, was removed, and the resulting data were gridded and contoured at a 20-nanoTesla contour interval.

Results

The gravity anomaly map (fig. 5) is dominated by high and low gravity values that are interpretated as, and related to, structural features mapped by Dobbin and Erdmann (1955), Stoner and Lewis (1980), and Feltis (1980a, 1980b, 1981a, and 1981b). Gravity highs are associated with uplift of dense Paleozoic and Precambrian rocks and stripping of less dense Cenozoic and Mesozoic rocks. The broad gravity lows are associated with downwarping of these dense rocks and a thickening of the less dense rocks. The Burnt Lodge Wilderness Study Area is located over a broad south- and southeast-trending gravity low (fig. 5), which extends between L1, L2, and L3. From L1 to L2, this broad gravity low is associated with the Coburg syncline. The gravity low changes direction at L2 and trends south through the study area. Although previous structural mapping does not show a continuation of the Coburg syncline beyond L2, the gravity low from L2 to L3 may represent a flattened continuation and eventual terminus of the syncline several miles south of the study area. Other structural features indicated on the gravity map include an east-west-trending gravity low at L4 (corresponding to the Blood Creek syncline), a gravity high at H5 (corresponding to the Bowdoin dome), and a gravity high at H6. The gravity high at H6 trends southeast from the Little Rocky Mountains intrusive to the vicinity of Brusett (fig. 2) and may represent the complementary anticlinal fold that should occur between the Blood Creek syncline and the Coburg syncline.

The aeromagnetic anomaly map (fig. 6) is dominated by high- and low-amplitude anomalies separated by steep gradient zones. The magnetic anomalies and gradients trend northeast and match a regional pattern described by Zietz and others (1968). A crude depth estimate, using the straight-line method (Nettleton, 1971), gives a depth to the magnetic source of about 20,000 ft, well below the surface of the Precambrian basement; so the magnetic anomalies probably reflect rock types of various intermediate to mafic compositions within the Precambrian basement complex. Shallow intrusions cannot be detected due to the wide spacing of flight lines over the area. Low magnetic anomalies are located both north and south of the study area, and high anomalies are located southeast and southwest of the study area. A steep gradient zone trends northeast beneath the study area and approximates the position of a regional lineament (fig. 3) mapped by Anna (1986). This gradient zone in the magnetic field may represent a shear zone or zone of weakness in the Precambrian basement complex that may propagate faulting or jointing through overlying sediments. This steep gradient, like others on the aeromagnetic anomaly map, are of limited interest. In other parts of Montana, such gradient zones commonly correspond to regions of significant hydrothermal alteration and



EXPLANATION

Gravity contours—Hachures indicate closed gravity low. Contour interval 2 milliGals

o **Gravity station**

L1 **Gravity low**—Referred to in text

H5 **Gravity high**—Referred to in text

Figure 5. Complete Bouguer gravity anomaly map of the Burnt Lodge Wilderness Study Area (shaded) and vicinity, Montana. Structural features are approximately located; queried where uncertain.

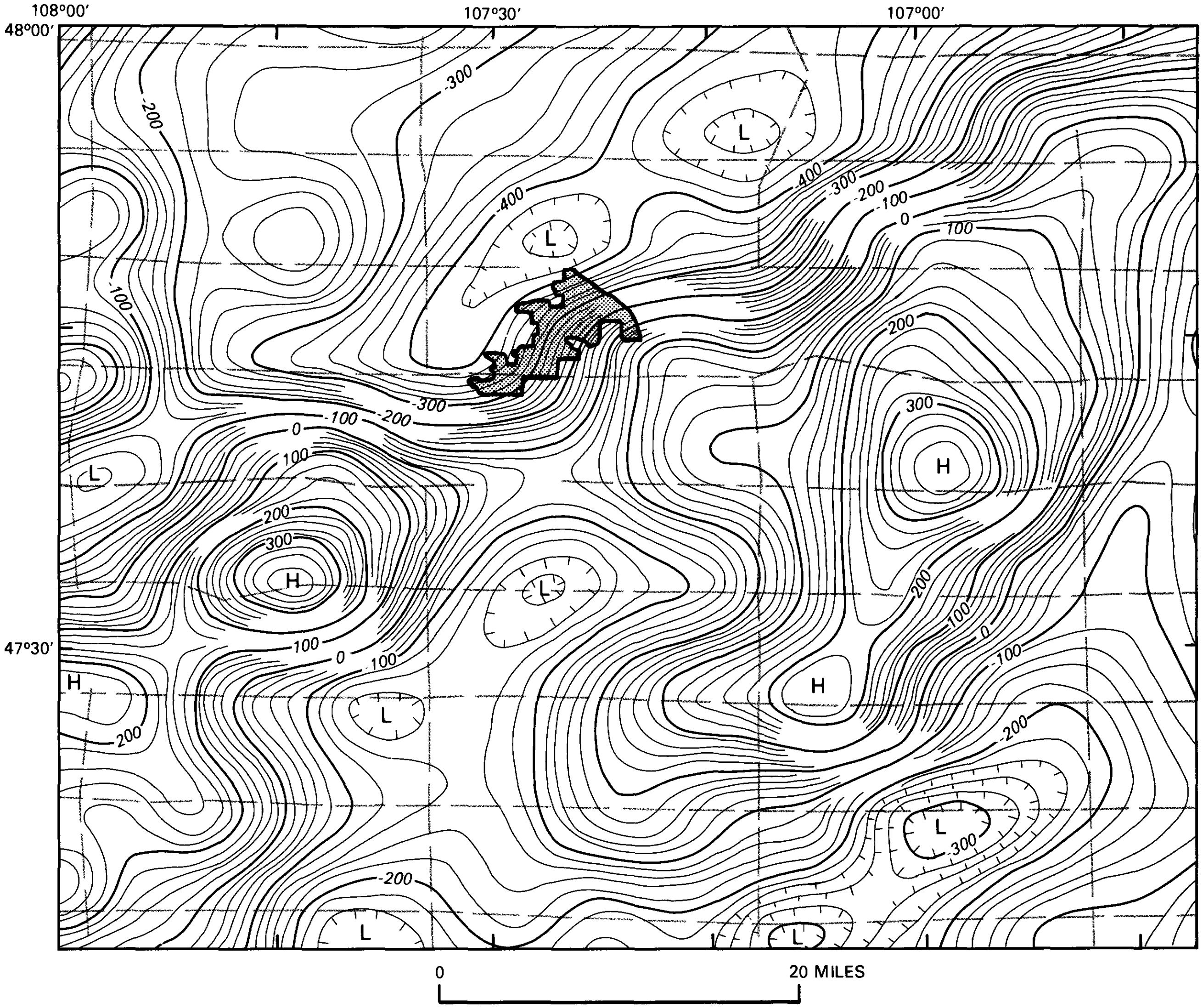
emplacement of mineral-bearing solutions. In the study area, such alteration, if it occurs, would probably be deeply buried.

Mineral and Energy Resource Potential

The mineral and energy resource potential of the study area is summarized on figure 1 and plate 1.

Metallic Minerals

No metallic mineral deposits or mineralized zones, mines, or prospects were identified in the wilderness study area or surrounding areas. Although some samples collected in and near the wilderness study area show a slight enrichment in one or more of the metallic elements aluminum, titanium, boron, barium, beryllium, lanthanum, zir-



EXPLANATION

-200 **Aeromagnetic contours**—Hachures indicate closed aeromagnetic low. Contour interval 20 nanoTeslas

L **Aeromagnetic low**

H **Aeromagnetic high**

Flight lines

Figure 6. Aeromagnetic anomaly map of the Burnt Lodge Wilderness Study Area (shaded) and vicinity, Montana.

con, molybdenum, and placer gold, none were considered significant enough to indicate mineralization in the area (Frahme, 1979; Causey, 1985). As the geologic information portrays an environment in which mineralization in or near the study area is unlikely, the area is assessed to have a low mineral resource potential for all metallic minerals (including placer gold), with a certainty level of B.

A lineament trending northeast through the study area may indicate the presence of a deeply seated Precambrian shear zone with associated hydrothermal alteration and emplacement of mineral-bearing solutions. Diatremes and ultramafic rock have been intruded through fracture zones associated with similar lineaments located 30 mi southeast and 40–60 mi west of the study area, and the areas to the west have excited an interest for diamonds.

In the study area, there is no evidence in surface exposures of igneous activity or associated mineralization; however, the possibility exists for the occurrence of mineralization and diamantiferous rock associated with deeply seated diatremes. The mineral resource potential for such diamantiferous rock and mineralization is low, with a certainty level of B.

Industrial and Nonmetallic Minerals

Industrial minerals found in the study area include the clay minerals kaolinite and bentonite, and deposits of sand and gravel. These occurrences have been described by the USBM (Causey, 1985) and are discussed in a previous section of the present report. Causey (this report) considers the deposits of kaolinite to be marginally useful for some industrial purposes. Known deposits of bentonite and sand and gravel were considered insignificant. None of the mineral occurrences were considered to be of resource quality.

Kaolinite occurs as a matrix in the Colgate Member of the Fox Hills Sandstone. The Fox Hills Sandstone underlies about 35 percent (4,800 acres) of the study area. The Colgate Member contains 10–15 percent kaolinite and ranges from 0 to 30 ft thick. The Colgate Member may be absent from the Fox Hills Sandstone due to (1) removal by erosion prior to deposition of the overlying sedimentary rocks and (2) lateral facies changes from the Colgate Member to a yellow-brown, fine- to medium-grained sandstone. There is no evidence to suggest that kaolinite occurring in the Colgate Member exceeds the quality or quantity determined from the samples tested by the USBM. Those parts of the study area underlain by the Fox Hills Sandstone are assessed to have a moderate mineral resource potential for kaolinite, with a certainty level of D. Areas where the Colgate Member are disturbed by landslide movement were not considered in the assessment of mineral resource potential.

Bentonite beds less than 1 ft thick occur in the Bearpaw Shale and are not considered significant by the USBM (Causey, 1985). The Hell Creek Formation may contain thin, silty, and lenticular bentonite beds of poor quality (Miller and others, 1979). Additional bentonite beds similar to those identified by Causey (1985) may occur in the Bearpaw Shale and a thick bentonite bed 1–6 ft thick, named the Siparyann bed, may occur near the base of the Bearpaw Shale at depths ranging from 600 to 1,300 ft. Various other bentonite beds may occur in the Belle Fourche and Mowry Shales at depths of about 3,400 and 3,500 ft, respectively. Bentonite beds covered by more than 35 ft of overburden may not be weathered enough to have qualities suitable for industrial applications (Miller and others, 1979). Due to the steep terrain in the study area, beds of bentonite are rapidly covered by overburden exceeding 35 ft. The study area is assessed to have a low mineral resource potential for bentonite, with a certainty level of D.

Sand and gravel occurs in narrow alluvial deposits located along numerous drainages in the study area. These deposits are generally thin, discontinuous, and contaminated with abundant clay-size material derived from the Bearpaw Shale. Deposits as thick as 30 ft occur along the Plum Coulee drainage. Deposits of sand and gravel in the study area were not considered to be of resource quality (Causey, 1985), and the likelihood that deposits of better quality occur in the study area is low. The study area is assessed to have a low mineral resource potential for sand and gravel, with a certainty level of D.

Energy Sources

The study area is located in the Williston Basin, which is one of the most important oil-producing basins in North America (Perry and others, 1983a). The entire study area is under lease for oil and gas; however, no oil and gas holes are located in or near the study area. About 8,000–10,000 ft of sedimentary rock underlie the study area; all geologic systems except the Cambrian System are potentially productive for hydrocarbons (Rice, 1979). Although most of the oil and gas fields in the vicinity of the study area are structural traps, some recent discoveries are stratigraphically controlled (Rice, 1979). Structural traps and fracture zones may occur in the wilderness study area. A low-amplitude anticlinal fold 2 mi wide and 6 mi long is inferred across the wilderness study area. Maximum closure observed on the Fox Hills Sandstone at the axis of the fold is about 50 ft, so reservoir capacity is assumed to be limited. The depth to which the fold extends into the subsurface is not known. The oil and gas potential of the wilderness study area was assessed by Perry and others (1983a, 1983b). They stated (1983a, p. G 17) that oil and gas accumulations in Paleozoic sedimentary rocks would be "stratigraphic in nature with local structural enhancement (Rice, 1979). Significant biogenic gas resources may be present in Upper Cretaceous reservoirs similar to those in adjacent areas (Rice, 1979)."

The oil and gas energy resource potential of the wilderness study area was assessed as medium (approximately equivalent to moderate of the Goudarzi classification (1984)) by Perry and others (1983a, 1983b). The level of certainty is B as there are no exploratory drill holes in or near the wilderness study area.

The energy resource potential for coal is assessed as moderate, with a certainty level of B. No coal beds of resource thickness (greater than 30 in. for subbituminous coal (Wood and others, 1983)) crop out in the study area; however, coal beds of resource thickness are likely to occur in the Judith River Formation, which underlies the wilderness study area at depths from 660 to 1,500 ft. A widespread coal zone was noted by Frahme (1979) in outcrops of the Judith River Formation 55 mi west of the wilderness study area. In a drill hole located 12 mi south of the wilderness study area (Montana Power Co. Federal No. 10–32, sec. 32, T. 21 N., R. 34 E.), the Judith River Formation contains a 3-ft coal bed 80 ft below the top of the formation, and a 5-ft coal bed 270 ft below the top of the formation. As coal beds in the Judith River Formation accumulated in coastal marsh environments, which are laterally continuous for many miles, it is likely that coal beds of similar thickness and abundance also occur in the Judith River Formation below the wilderness study area.

There are no known geothermal energy sources within the wilderness study area (Sonderegger and Bergantino, 1981). No warm springs or other geothermal sources were noted during this investigation. The geothermal energy resource potential of the wilderness study area is assessed as low, with a certainty level of B.

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APPENDIX

DEFINITION OF LEVELS OF MINERAL RESOURCE POTENTIAL AND CERTAINTY OF ASSESSMENT

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.

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 by the U. S. Geological Survey, 1986

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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