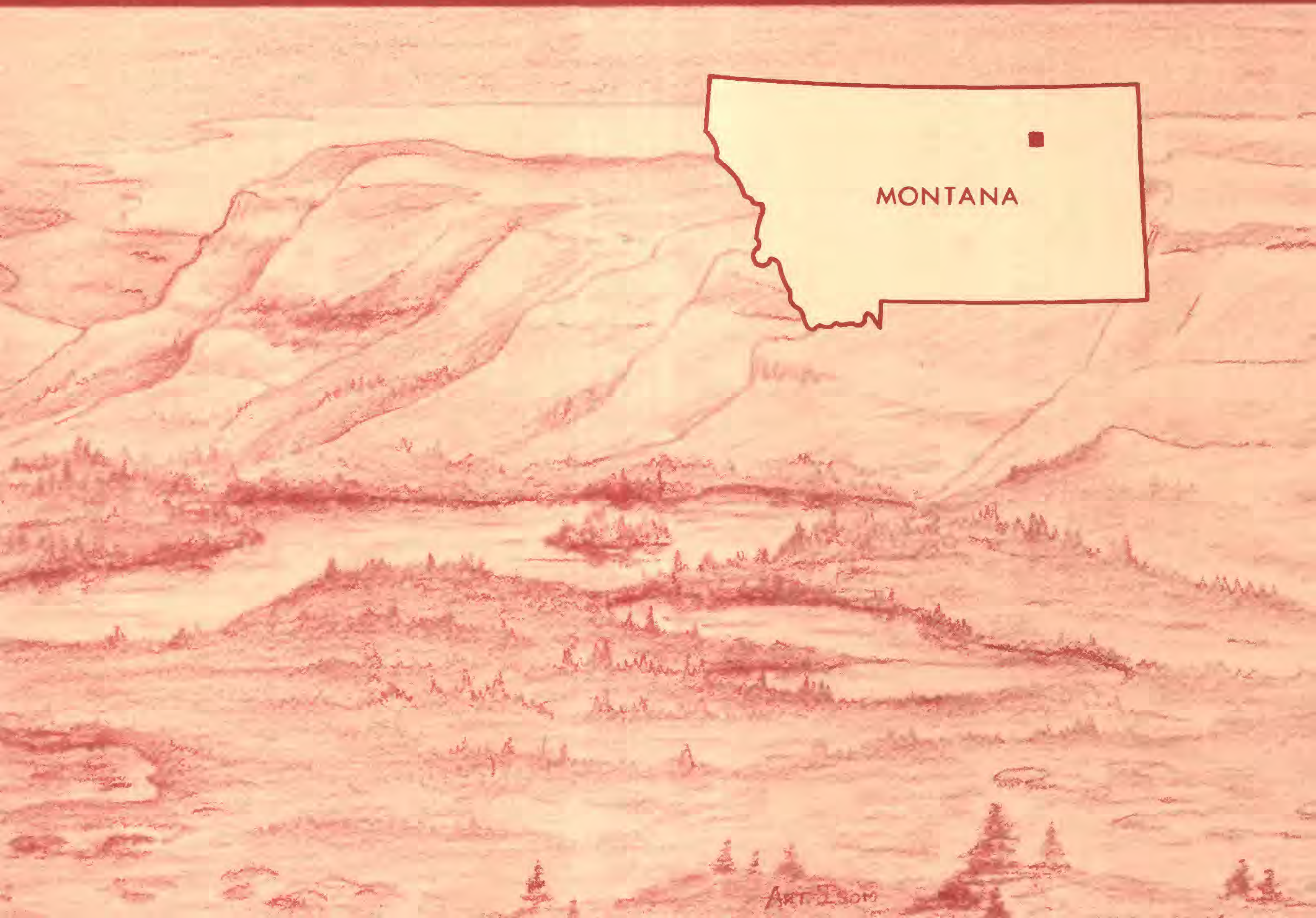
Mineral Resources of the Seven Blackfoot Wilderness Study Area, Garfield County, Montana

U.S. GEOLOGICAL SURVEY BULLETIN 1722–D



Chapter D

Mineral Resources of the Seven Blackfoot Wilderness Study Area, Garfield County, Montana

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U.S. Bureau of Mines

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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 a part of the Seven Blackfoot (MT–024–657–A and –B) Wilderness Study Area, Garfield County, Montana.

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By Robert D. Hettinger *and* Viki Bankey
U.S. Geological Survey

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SUMMARY

Abstract

This report assesses the identified mineral resources (known) and mineral resource potential (undiscovered) of parts of the Seven Blackfoot Wilderness Study Area (MT-024-657A and MT-024-657B; 1,160 and 4,550 acres, respectively). The study areas are individually referred to as segments A and B, respectively. The segments are collectively referred to as the "Seven Blackfoot Wilderness Study Area," the "wilderness study area," or simply the "study area." The study area is located about 30 miles northwest of Jordan, Mont., in the northern Great Plains physiographic province, on the northwestern flank of the Williston Basin.

The wilderness study area has tracts (fig. 1) containing 746,300 short tons of demonstrated subeconomic resources of coal (fig. 2); of this amount, 273,025 short tons of coal may not be of resource quality due to possible high ash contamination as indicated from analyses of weathered surface exposures; these analyses however, may not be representative of the unweathered coal. The wilderness study area has other occurrences of noneconomic coal in beds too thin to be considered a resource. The wilderness study area also has mineral occurrences of kaolinite, montmorillonite, placer gold, and sand and gravel; concentrations of these mineral commodities are small, impure, and are not considered to be resources. Parts of the wilderness study area have (1) a high mineral resource potential for coal, (2) a moderate mineral resource potential for coal and kaolinite, and (3) a low mineral resource potential for montmorillonite, sand, gravel, and placer gold (fig. 1). The entire study area has (1) a moderate energy resource potential for oil and gas, (2) a low mineral resource potential for all metallic minerals and bentonite, and (3) a low geothermal energy resource potential (fig. 1).

Character and Setting

The study area is located about 30 mi (miles) northwest of Jordan, Mont. (fig. 3), in the northern Great Plains physiographic province, north-central Montana, on the northwestern flank of the Williston Basin (fig. 4). The regional topography is characterized by rolling prairies, broad shallow valleys, and scattered buttes. In contrast to the regional setting, the study area is deeply incised by the Missouri River and its tributaries. The resulting rugged badland 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 Jordan.

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 exposed in the study area include the Tullock Member of the Fort Union Formation. In the study area, Upper Cretaceous and Tertiary strata are nearly horizontal. Landslide deposits of Quaternary age flank valley walls and intertongue with Quaternary alluvial deposits that cover valley floors in and adjacent to the wilderness study area. Deposits of glacial till of Pleistocene age occur in thin isolated patches scattered on higher surfaces along the western boundary of segment A. The Judith River Formation, Bearpaw Shale, and Fox Hills Sandstone were deposited in intertonguing offshore-marine, nearshore-marine, and continental environ-

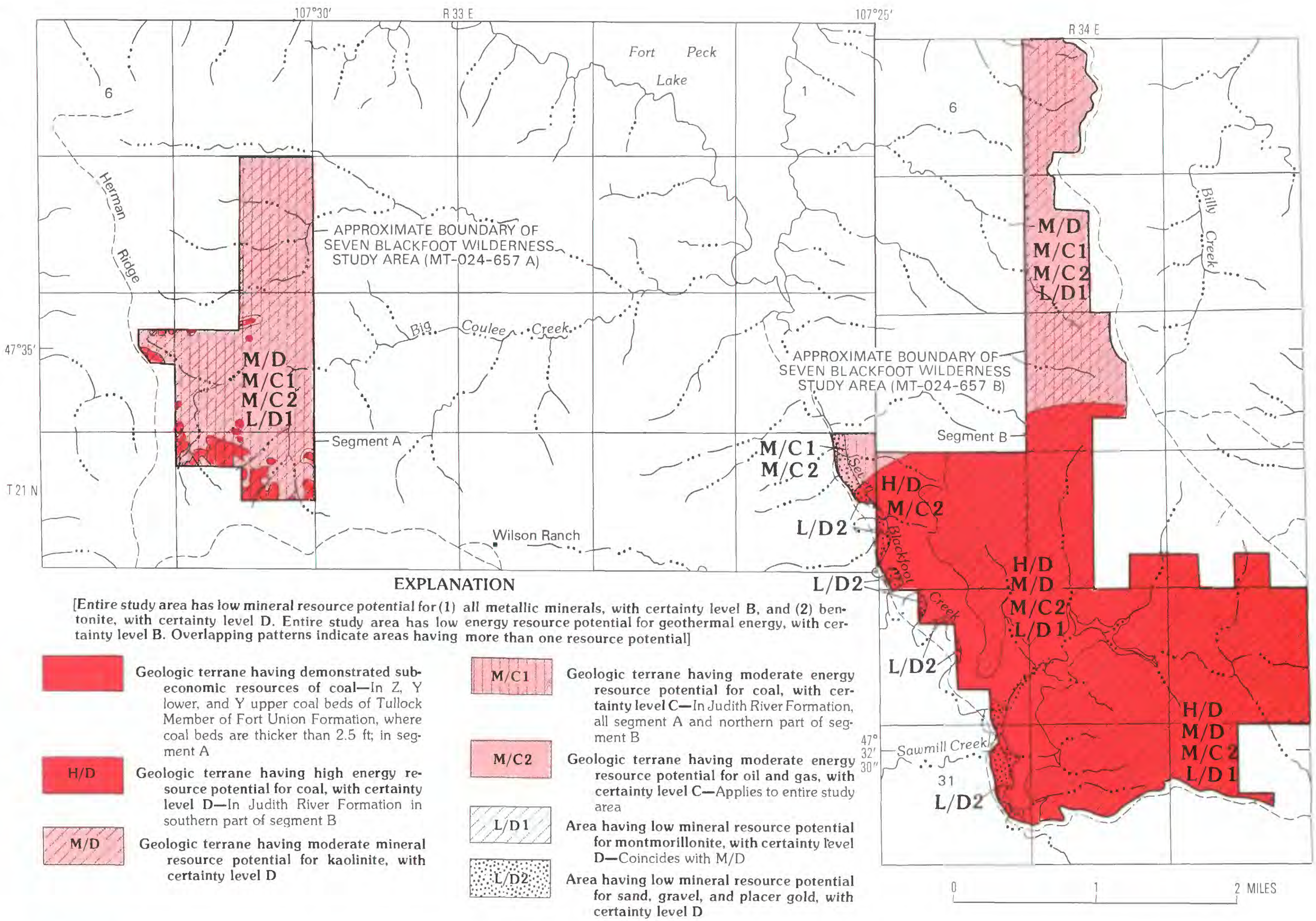


Figure 1. Summary map showing mineral and energy resource potential of the Seven Blackfoot Wilderness Study Area, Garfield County, Montana. Dashed lines indicate unimproved road.

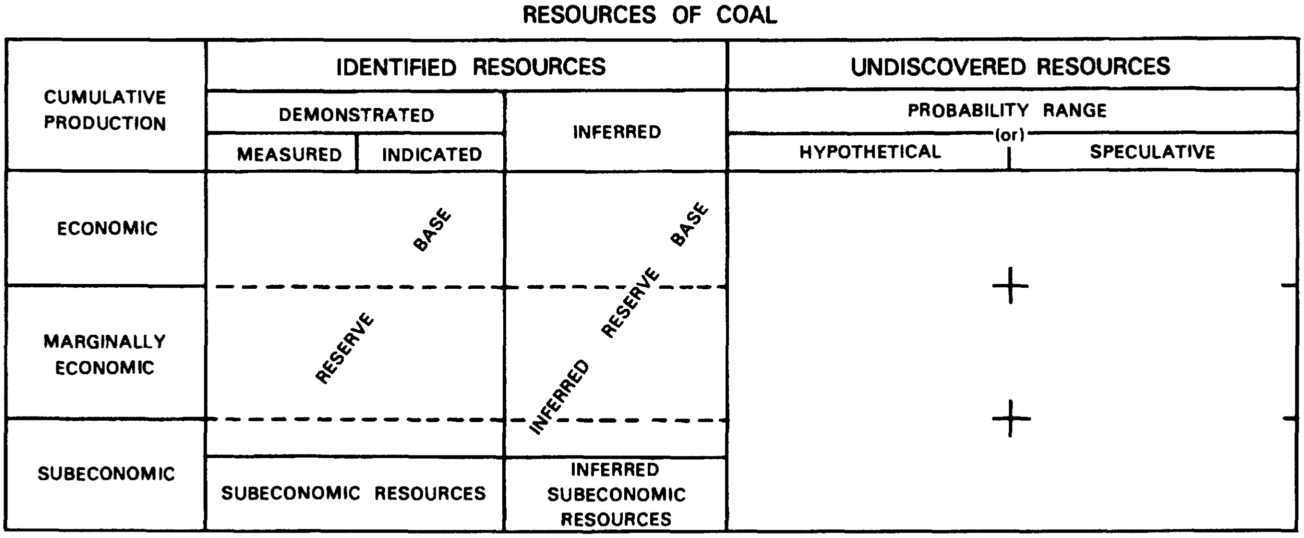


Figure 2. Format and classification of coal resources by reserve and inferred reserve bases and subeconomic and inferred subeconomic resource categories.

ments within the Cretaceous Western Interior seaway. When the seaway withdrew from the region, the Hell Creek and Fort Union Formations were deposited in continental fluvial and flood-plain environments.

Identified Resources and Mineral Resource Potential

Coal beds 0.3–3.7 ft thick occur in the Tullock Member of the Fort Union Formation and underlie about 1,240 acres of the study area. However, according to the classification system of the U.S. Geological Survey (Wood and others, 1983), in most of that area the coal is too thin (less than 30 in.) to be included in resource estimates. None of the coal is thick enough (greater than 60 in.) to be classified as a reserve base. Where the coal beds in the study area are greater than 30 in. thick, they are classified as a subeconomic resource (fig 2) and total 746,300 short tons of coal. The subeconomic resources underlie 92 acres of segment A, have an apparent rank of lignite, and have a maximum overburden of 100 ft. Elsewhere in the study area, the remaining beds of coal have a thickness of less than 30 in. and are classified as other occurrences of noneconomic coal. No additional undiscovered coal beds of resource thickness are likely to occur in the Tullock Member in the study area.

Two thin coal beds, 3 ft and 5 ft thick, were identified in the Judith River Formation at depths of 1,600 and 1,785 ft in a drill hole located in segment B. Those parts of the study area lying within a 3-mi radius from the drill hole are assessed to have a high energy resource potential for coal (in the Judith River Formation), with a certainty level of D. The remainder of the study area, lying beyond the 3-mi radius, is assessed to have a moderate energy resource potential for coal (in the Judith River Formation), with a certainty level of C.

Oil and gas may occur in most Paleozoic and Mesozoic sedimentary rocks in the study area. Low amplitude anticlinal folds may extend northeast across segment A and northwest across segment B, and may form small structural traps for oil and gas. Maximum closure at the base of the Fort Union Formation along the axes of these folds is only 30 ft and reservoir capacity is assumed to be very limited. The depth to which the folds extend cannot be determined from available data. Although the entire study area is under lease for oil and gas, no producing oil and gas wells are located in or near the study area. One well located near the southern boundary in segment B had no shows of oil or gas and the hole was plugged and abandoned. The oil and gas energy resource potential of the entire study area is assessed as moderate, with a certainty level of C (see Goudarzi, 1984, and appendix (this report) for explanation of classification system).

Clay minerals occurring in the study area include kaolinite, montmorillonite, and possibly bentonite. Kaolinite occurs as a matrix in the sandstone of the Colgate Member of the Fox Hills Sandstone. The Fox Hills Sandstone underlies about 4,890 acres of the study area. Samples of kaolinite were tested by the U.S. Bureau of Mines and some were found to be marginally useful for limited industrial purposes but lack the quality to be considered identified resources. 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. Montmorillonitic beds occur in the Hell Creek and Fort Union Formations which together underlie about 4,000 acres of the study area. The beds are generally less than 10 ft thick, laterally discontinuous, and of poor quality. Those parts of the study area underlain by the Hell Creek and Fort Union Formations are assessed to have low mineral resource potential for montmorillonite, with a certainty level of D. Bentonite beds 1–6 ft thick may occur in the Bearpaw Shale which underlies the entire study area. The beds, if present, are obscured by landslide deposits and overlying sedimentary rock. Due to the depth of overburden, the bentonite probably would not be weathered enough to be

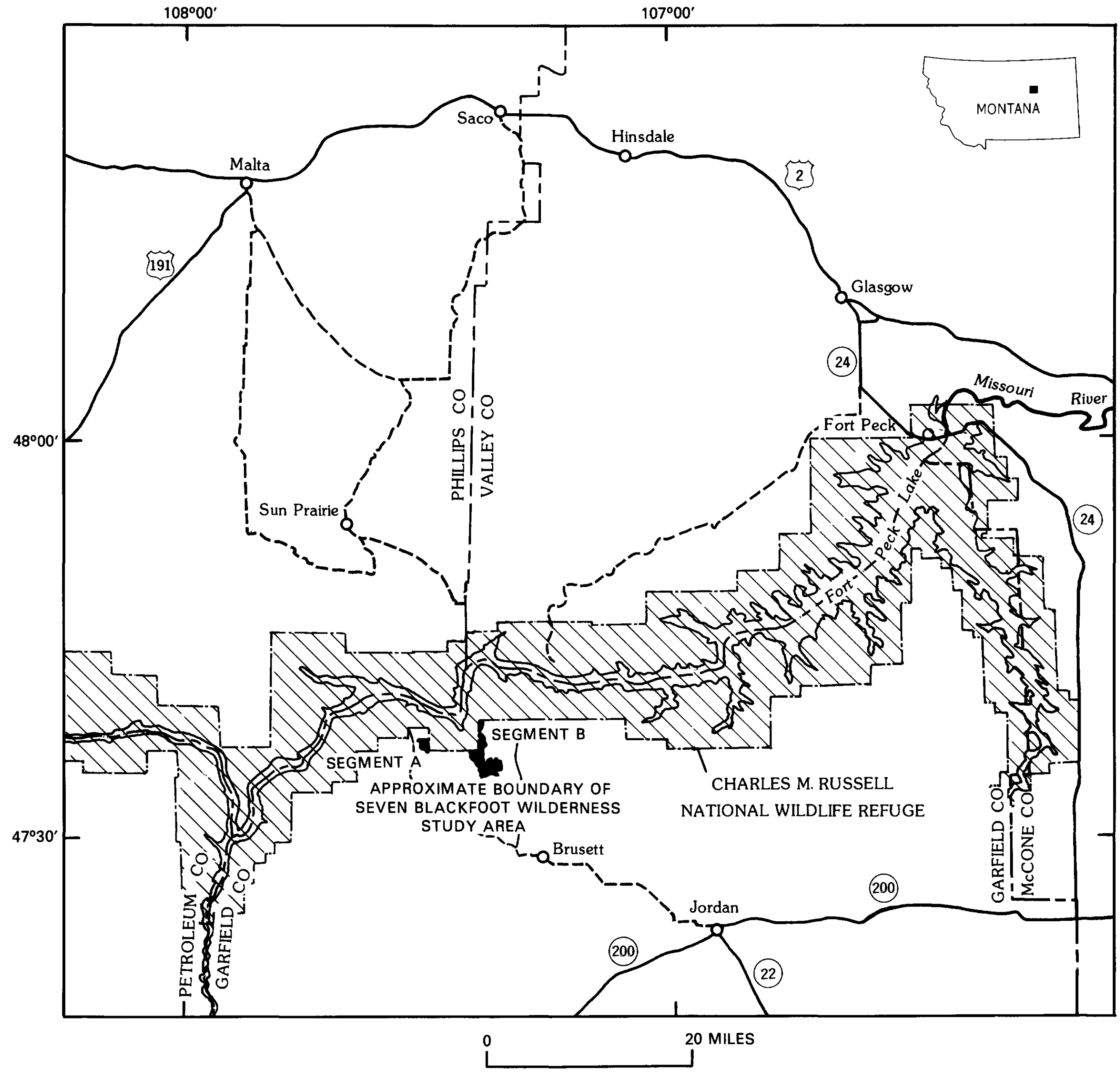


Figure 3. Index map showing location of the Seven Blackfoot Wilderness Study Area, Garfield County, Montana; short-dashed line indicates gravel road.

suitable for most commercial applications. The entire study area is assessed to have a low mineral resource potential for bentonite, with a certainty level of D.

Sand, gravel, and placer gold occur in alluvial deposits concentrated along Seven Blackfoot Creek and its tributaries covering about 150 acres of the study area. These deposits are small, have low gold content, and are contaminated with a high percentage of clay-sized material and landslide debris. Those parts of the study area containing alluvium and colluvium located along Seven Blackfoot Creek and its tributaries are assessed to have a low mineral resource potential for sand, gravel, and placer gold, 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 there are no mines or prospects in the study area. Geologic information leads to the conclusion that the occurrence of mineralized rock in or near the study area is unlikely. The entire study area is assessed to have a low mineral potential for all metallic minerals, with a certainty level of B.

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

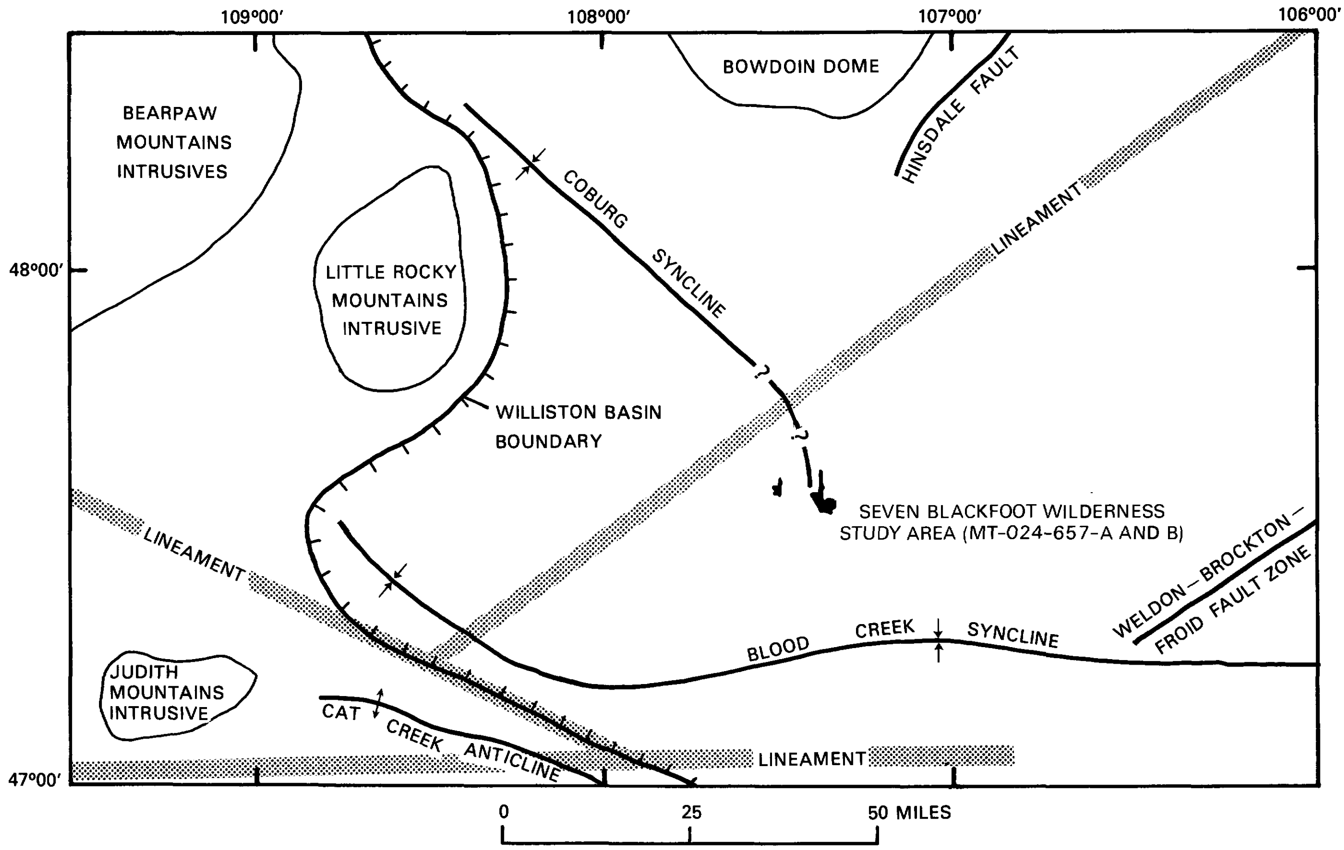


Figure 4. Map showing approximate locations of regional structure features in the vicinity of the Seven Blackfoot Wilderness Study Area, Montana. Modified from Stoner and Lewis (1980). Approximate locations of lineaments from Anna (1986). Axis of Coburg syncline queried where uncertain (based on gravity data).

INTRODUCTION

At the request of the BLM (U.S. Bureau of Land Management), two segments of the Seven Blackfoot Wilderness Study Area (MT–024–657) were studied by the USBM (U.S. Bureau of Mines) and the USGS (U.S. Geological Survey). The locations of segments A (MT–024–657A) and B (MT–024–657B) are shown on figure 1. Segment A is the westernmost area containing 1,160 acres; segment B contains 4,550 acres and is located 4 mi east of segment A. Segments A and B are herein collectively referred to as the "Seven Blackfoot Wilderness Study Area," the "wilderness study area," or simply the "study area." The study area is located in Garfield County, north-central Montana (fig. 3). The wilderness study area is located along the southern boundary of the Charles M. Russell National Wildlife Refuge and is bordered by a combination of public, State, and private lands along its western, southern, and eastern boundaries. The wilderness study area is accessible by gravel roads from Jordan, Mont., located 30 mi to the southeast. Unimproved dirt roads are located along the west and east boundaries of the wilderness study area. Segments A and B are connected by rough jeep tracks across Seven Blackfoot Creek.

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. Dobbin (1922a,b) mapped the townships containing the study area for the purpose of mineral land classification for the USGS. More recent studies were conducted by Anderson (1961), Anderson and Rohrer (1961), 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, mineral, and water resources along the Missouri River valley between the towns of Fort Peck to the east of the study area and Fort Benton about 20 mi to the west. 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 are 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 are described by Zietz and others (1968) and the Bendix Field Engineering Corporation (1983). Regional lineaments related to Precambrian shear zones are mapped and described 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 the USGS (1980), which is shown in the appendix of this report. Identified resources are studied by the USBM and coal resources were studied in conjunction with the USGS. Mineral resource potential is the likelihood of occurrence of undiscovered metals and nonmetals, industrial rocks and minerals, and of undiscovered energy sources (coal, oil, gas, oil shale, and geothermal sources). It is classified according to the system of Goudarzi (1984) and is shown in the appendix. The potential for undiscovered resources is studied by the USGS.

This study is supplemented by previous reports by the USGS regarding the petroleum potential of proposed wilderness lands in Montana (Perry and others, 1983a,b) 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 Seven Blackfoot Wilderness Study Area was examined by Michael S. Miller of the USBM in 1984. Results of this study were released (Miller, 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 study area. The USBM did not evaluate oil and gas or geothermal resources. Geologic libraries, USBM and State of Montana production records and mineral property files, BLM mining-claim and mineral-lease records, and county-claim records were searched for data pertinent to the study area and vicinity. Field studies included ground and air reconnaissance for all mineral occurrences and zones within the study area. Those found were examined, sampled, and mapped, if warranted. Occurrences close to the study area were also examined to determine if any mineralization processes extend into the study area and to better understand deposits of the region.

Nineteen samples including five clay, six coal, and eight alluvial (placer) samples were collected from areas having possible mineral resources. Sample locations and analytical data are given in Miller (1985). All samples were sent to the USBM Reno Research Center for trace element analysis. Gold and silver were analyzed by a combined fire assay-inductively coupled plasma method; other elements of suspected economic significance were analyzed by atomic absorption, colorimetric, radiometric, or X-ray fluorescence. Representative samples were analyzed for 40 elements (Miller, 1985) by semiquantitative emission spectrophotometry to detect unsuspected element concentrations; samples with anomalous elements were then determined by one of the following quantitative methods. X-ray diffraction was used to screen samples for zeolite and clay minerals. Coal samples were analyzed at the U.S. Department of Energy, Pittsburgh, Pa., for moisture, volatile matter, fixed carbon, ash, hydrogen, carbon, nitrogen, sulfur, oxygen, heating value, swelling, and grindability. Clay samples were analyzed at the USBM Tuscaloosa Research Center for water of plasticity, shrinkage, viscosity, compressive strength, filtrates, plate-water absorption, pH, slow firing (color, hardness, shrinkage, absorption, porosity, specific gravity), preliminary bloating (absorption, specific gravity), and refractory characteristics. Heavy minerals from alluvial samples were concentrated and identified with a binocular microscope. If 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.

Investigations by the U.S. Geological Survey

In 1984, the USGS conducted investigations to assess the mineral resource potential of the Seven Blackfoot Wilderness Study Area. The investigation 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, coal beds, and structure were mapped in the field onto aerial photographs and transferred to a 1:24,000-scale topographic base map using a Kern[1] PG–2 photogrammetric plotter. Stratigraphic sections of coal-bearing intervals were measured and described to ascertain the stratigraphy and continuity of coal beds in the Fort Union Formation. Coal resources were determined by R.D. Hettinger and are included in the U.S. Bureau of Mines part of this report. 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, and measured stratigraphic sections are shown on plate 2. Regional gravity and aeromagnetic anomaly maps (figs. 6 and 7, 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 study area; Courteney Williamson (USGS) for providing technical assistance; and J. Douglas Causey (USBM) for assisting with investigations relating to the USBM studies.

APPRAISAL OF IDENTIFIED RESOURCES

By Michael S. Miller
U.S. Bureau of Mines

R.D. Hettinger
U.S. Geological Survey

Mining and Mineral-Exploration Activity

There is no known mineral production from the wilderness study area. No mines or prospects are known to occur in the study area. A small abandoned coal mine, the Kariotis mine, in sec. 7, T. 20 N., R. 34 E., about 3 mi southwest of segment B, produced coal from the Fort Union Formation for domestic use. Minor exploration for placer gold has probably occurred along Seven Blackfoot Creek and its tributaries.

All of the study area is currently under lease for oil and gas. Only one oil and gas well is located in the study area. This well is the Montana Power Co. Federal No. 10–32 located in segment B in sec. 32, T. 21 N., R. 34 E. This well was completed in 1974, it had no shows for oil and gas, and was plugged and abandoned.

Appraisal of Mineral Occurrences Examined

Subeconomic resources of coal were identified in the wilderness study area during this study (pl. 1, fig. 1). Several additional mineral occurrences were also examined; these include concentrations of sand and gravel, clay, placer gold, and coal. Analyses of these mineral commodities (including the subeconomic resources of coal) indicate that none have current economic value. Sample locations and analyses are shown in Miller (1985).

Clays occur in all of the geologic formations exposed in the wilderness study area. Montmorillonitic beds are found in the Hell Creek and Fort Union Formations (see "Geology" section) and occur in silty and sandy beds a few feet thick. Montmorillonite from one sample collected from the Hell Creek Formation in the study area was tested and found to be suitable for structural clay products. Montmorillonite occurrences in the study area are not considered to be a mineral resource due to thin bed occurrences, poor quality, and distance to markets. Kaolinite is found in the Colgate Member of the Fox Hills Sandstone (see "Geology" section). The Colgate Member is 10–30 ft thick and contains 10–15 percent kaolinite in the matrix of the sandstone (Miller and others, 1979). Tests run on four kaolinite samples collected from the Colgate Member in the study area indicate that kaolinite from two localities may be suitable for structural clay and light-duty refractory use; the other two samples were found to be unsuitable for structural purposes. Kaolinite occurrences in the study area are not considered to be a mineral resource due to marginal quality and low concentrations and because equally good or better deposits occur near major markets.

Sand and gravel occurrences, found along Seven Blackfoot Creek and its major tributaries, are tens of feet thick, a few hundred to a thousand feet wide, and hundreds to thousands of feet long. These occurrences are not considered to be economic as they are contaminated by clay and landslide debris from the Bearpaw Shale and are too distant from sand and gravel markets.

Placer gold was found in three of eight samples collected from sand and gravel occurrences along Seven Blackfoot Creek and its tributaries in and near the study area. One of the samples containing gold was located along Seven Blackfoot Creek, the other two were located along a tributary to Seven Blackfoot Creek which trends northeast across secs. 29 and 30, T. 21 N., R. 34 E., in segment B of the study area. The remaining five samples, having no gold, were all located along various tributaries to Seven Blackfoot Creek. The concentrations of gold are very low and are considered to be noneconomic. Using a

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

gold value of $300.00/troy ounce, the placer deposit in Seven Blackfoot Creek has a value of $0.01/cu. yd. (cubic yard), and the placer deposits along the tributary in segment B have a value of $0.02-0.29/cu. yd. The source of gold is unknown but is considered to be distant as no associated heavy minerals indicate a nearby kimberlitic, lamproitic, or igneous source.

Coal Resources

Coal beds 0.3–3.7 ft thick crop out in the Z, Y, X, and L_1 coal zones of the Tullock Member of the Fort Union Formation (see "Geology" section). The areal distribution of the coal beds is shown on plate 1. The stratigraphic distribution is shown on plate 2. Coal bed nomenclature and descriptions are described in the "Geology" section of this report. In segment A coal beds include the Z, Y lower, and Y upper coals. These coals are laterally persistent, thinning to the northeast, cover about 150 acres of land, and have a maximum overburden of about 100 ft. In segment B, coal beds are found in the Z, Y, X, and L_1 coal zones which cover about 1,090 acres of land and have a maximum overburden of about 180 ft. The coals in segment B are lenticular, very thin, and pinch out to the north.

The apparent rank of the Z, Y lower, and Y upper coal beds in segment A is lignite. Five samples were collected from coal-bed outcrops in the study area; sample locations and analyses are given in Miller (1985) and are shown in table 1 of this report. Analyses of these coals indicate that they are high in ash content, have low heat values, and contain 0.0007–0.0012 oz/ton (ounces per ton) gold and 0.00023–0.0009 weight percent uranium. As these analyses are of weathered outcrop samples, they may not be representative of the unweathered coal. An additional analysis of the Z coal bed is given in Anderson and Rohrer (1961) where the Z coal bed was sampled from an auger hole located in sec. 7, T. 20 N., R. 34 E., 2 mi south of the study area. Proximate analyses (on an as-received basis) at that location indicate that the Z coal bed has 26.2 percent moisture, 23.1 percent volatile matter, 26.0 percent fixed carbon, 24.7 percent ash, and a 6,620 Btu per pound heat value.

The USGS (Wood and others, 1983) classifies lignite 2.5–5.0 ft thick, having less than 33 percent ash, and less than 500 ft of overburden as a subeconomic resource. Subeconomic resources are not currently minable and are too thin to be classified as a reserve base. Lignite beds less than 2.5 ft thick or having an ash content which exceeds 33 percent are not considered to be a resource and are referred to as other occurrences of noneconomic coal. All coal resources in the study are included in the *Measured* and *Indicated* reliability categories of Wood and others (1983). *Measured* coal includes all coal within ¼ mi of a thickness measurement and *Indicated* coal extends ½ mi beyond the *Measured* coal to a distance of ¾ mi from a thickness measurement. Resources within the *Measured* and *Indicated* reliability categories are considered to be *Demonstrated* resources.

Demonstrated subeconomic resources totaling 746,300 short tons of coal have been estimated for the Z, Y lower, and Y upper coals underlying 92 acres of segment A (pl. 1, fig. 1). Elsewhere in segment A and in all of segment B, the coal beds are less than 2.5 ft thick and are considered as other occurrences of noneconomic coal. Coal beds less than 2.5 ft are not now, nor are they likely to become, potential coal resources. The Y lower and Y upper coal beds are shown to have very high ash contents (table 1) and on this basis 273,025 short tons of coal may be excluded from the resource estimate cited above; however, as these analyses were obtained from outcrop samples they may not be representative of unweathered coal. For this reason, the high ash contents were not considered as a factor to exclude the Y lower and Y upper coal beds from the resource estimate. Further work is necessary to determine the extent of ash contamination. None of the coal in the study area is currently considered to be a minable resource because of small tonnages, poor heating values, high ash contents, and distances to markets. The small amount of gold and uranium is not of economic interest.

Table 2 shows the distribution of coal tonnage by coal bed and by reliability category.

ASSESSMENT OF POTENTIAL FOR UNDISCOVERED RESOURCES

By R. D. Hettinger and Viki Bankey
U.S. Geological Survey

Geology

Regional Geologic Setting

The Seven Blackfoot Wilderness Study Area is located in the northern Great Plains physiographic province of north-central Montana. Areas south of the wilderness study area are characterized by rolling prairies, broad valleys, and scattered buttes. In the wilderness study area, the landscape is deeply incised by Seven Blackfoot Creek and other tributaries to the Missouri River. About 1 mi north of the study area, the Missouri River widens into Fort Peck Lake (fig. 3). Elevations in the wilderness study area range from 2,290 ft in Seven Blackfoot Creek to 3,225 ft in the northern

Table 1. Coal analyses from the Seven Blackfoot Wilderness Study Area, Montana

Coal bed	Y upper coal[1]	Unnamed coal in Y coal zone[1]	Y lower coal[1]	Z coal[1]	X coal zone[2]
Sample length (in feet)	2.7	0.3	2.7	1.6	0.8
Hardgrove grindability index	113	148	154	72	143
Air-dry coal (as received), Proximate analysis (percent)					
Moisture	19.73	20.11	13.52	26.00	17.57
Volatile matter	25.73	17.24	17.52	28.06	17.70
Fixed carbon	12.44	6.74	14.67	23.35	2.91
Ash	42.10	55.91	54.29	22.59	61.82
Air-dry coal (as received), Ultimate analysis (percent)					
Ash	42.10	55.91	54.29	22.59	61.82
Hydrogen	4.13	3.88	3.12	5.55	3.68
Carbon	21.62	12.59	19.91	33.41	9.84
Nitrogen	0.33	0.65	0.27	0.62	2.82
Oxygen	31.64	26.30	22.26	37.26	20.52
Sulfur					
sulfate	0.13	0.62	0.09	0.42	1.25
pyritic	0.04	0.04	0.05	0.04	0.05
organic	0.01	0.02	0.01	0.11	0.02
Heat content (Btu per pound)					
Air dried, as received	3045	1448	2901	5124	791
Moist, mineral matter free	5577	3603	7009	6768	2230
Ash (°F)					
Initial deformation	2385	2415	2330	2040	2305
Softening temperature	2435	2595	2575	2325	2565
Fluid temperature	2695	2740	2770	2530	2700

[1]Sample collected at stratigraphic section No. 6, sec. 17, T. 21 N., R. 33 E. (see pls. 1 and 2).

[2]Sample collected 2,400 ft south from north line and 800 ft west from east line of sec. 19, T. 21 N., R. 34 E.

Table 2. Distribution of coal resources by coal bed and reliability of estimate for the Seven Blackfoot Wilderness Study Area, Montana

Coal bed	Thickness in ft (excluding partings)	Measured (short tons)	Indicated (short tons)	Total demonstrated (short tons)
Z	2.5-3.4	421,028	52,226	473,254
Y lower	2.5-3.7	138,039[1]	46,602[1]	184,641[1]
Y upper	2.5-3.0	88,383[1]	---	88,383[1]
Totals	---	647,450[2]	98,828[2]	746,278[2]

[1]Coal analyses from outcrops of the Y lower and Y upper coal beds indicate that these coals have high ash contents that do not meet resource quality standards of Wood and others (1983). However, these analyses are of weathered outcrop samples and may not be representative of the unweathered coal deposits. For this reason coal tonnages of the Y lower and Y upper coal beds are included with the subeconomic resource estimates.

[2]Figures include coal tonnage estimates from the Y lower and Y upper coal beds.

part of segment B. The wilderness study area is characterized by plateaus, flat-topped ridges, and rugged badland topography referred to as the Missouri Breaks.

Approximately 8,000–10,000 ft of sedimentary rocks ranging from Cambrian to Tertiary in age, immediately underlying the 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. Lithologies and thicknesses of all rock units occurring at depth are described by Rice (1979).

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 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. 4) 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. 5), a broad, poorly defined regional trough located between the Bowdoin dome and the Little Rocky Mountains intrusion. Strata on both limbs of the Coburg syncline dip at less than 1° toward the synclinal axis. Previous studies terminated the Coburg syncline about 20 mi northwest of the study area. Gravity data (fig. 6) suggest that the Coburg syncline may extend into and terminate in the vicinity of the study area.

Anna (1986) mapped a prominent lineament (fig. 4) based on the geometry of subsurface sedimentary rocks. The lineament trends N. 54° E. about 10–15 mi north of the study area and approximates the position and trend of a steep aeromagnetic gradient that is located 4–12 mi north of the study area (fig. 7). Additional lineaments, indicated by steep gradients on aeromagnetic anomaly data, may be located 15 mi southeast of the study area. A discussion of the aeromagnetic data is included in the "Geophysics" section. Thomas (1974) suggested that such lineaments are the result of a Laramide lateral adjustment of basement blocks along Precambrian shear zones, and that the resulting block framework has affected the regional migration and accumulation of mineralizing solutions, oil, and gas. Anna (1986) cites evidence that Precambrian structural movement along the Precambrian shear zones probably continued into Jurassic and Cretaceous time, was enhanced by the Laramide orogeny, and that the resulting structural systems have influenced the depositional systems and geometry of sediment accumulation during Jurassic and Cretaceous time. 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) that are located 20 mi southeast and 40–60 mi west of the study area, respectively. 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. Except for some minor northeast-trending faults and folds, there is no evidence that any lineaments pass through the study area.

Geologic Structure

Strata in the Seven Blackfoot Wilderness Study Area are nearly horizontal. On the basis of an approximation of the base of the Fort Union Formation throughout the study area, the average strike is about N. 45° E. and the average dip is about 20 ft/mi to the southeast. Structure contours (fig. 5) were drawn at the base of the Fort Union Formation. The base of the Fort Union, where removed by erosion, was restored at about 320–335 ft above the top of the Fox Hills Sandstone. Elevations used for structure contour control were determined from aerial photographs using a Kern PG-2 photogrammetric plotter and USGS 7 ½-minute topographic maps of the area. Unpublished geologic maps by R.D. Hettinger were used to supply a geologic base for areas shown on figure 5 but not included on plate 1.

Structure contour lines (fig. 5) show that very low amplitude folds may occur in and near the study area. Because of the very subtle nature of these folds, additional field studies are necessary to confirm their occurrence and exact locations. Fold angles are less than 1°, and the depth to which the folds extend into the subsurface cannot be determined from available data. Fold axes (fig. 5) trend about N. 45° W. and N. 75° E. Fold axes trending to the northwest roughly parallel the axis of the Coburg syncline, which has been extended through the study area on the basis of the gravity data (see "Geophysics" section), and may be superimposed onto that synclinal fold. Fold axes and faults (fig. 5) trending to the northeast may be related to regional lineaments similar to those mapped and described by Anna (1986) and Thomas (1974).

A low amplitude anticlinal fold may extend about 3 miles across segment B and is paralleled on each flank by low amplitude synclinal folds. The fold extends south of the study area and was mapped by Anderson and Rohrer (1961) in T. 20 N., R. 34 E. Closure over this fold is about 30 ft at the base of the Fort Union Formation. This fold may have been the target of a dry and abandoned drill hole, the Montana Power Co. Federal No. 10–32, located in sec. 32 near the southern boundary of segment B.

A low amplitude synclinal fold may trend northeast through the southern part of segment A. The syncline deforms strata to create a shallow complimentary anticlinal fold on its southern flank. The axis of the anticlinal fold is also located in segment A. Closure over the anticlinal fold is about 30 ft at the base of the Fort Union Formation. The synclinal axis lies in rough alignment with, and is possibly associated with, several faults (fig. 5) which form a small graben located about 1–2 mi east of segment A. Displacement along the faults is about 20 ft.

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 850 to 1,730 ft. The formation is composed of marine sandstone interbedded with nonmarine 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., near the southern boundary in segment B; here the Judith River Formation is 330 ft thick and has a 3-ft-thick coal bed at a depth of 1,600 ft and a 5-ft-thick coal bed at a depth of 1,785 ft. 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 off-shore marine environment. Sediments include dark-gray argillaceous shale and numerous thinly interbedded layers of siltstone, very fine grained orange-

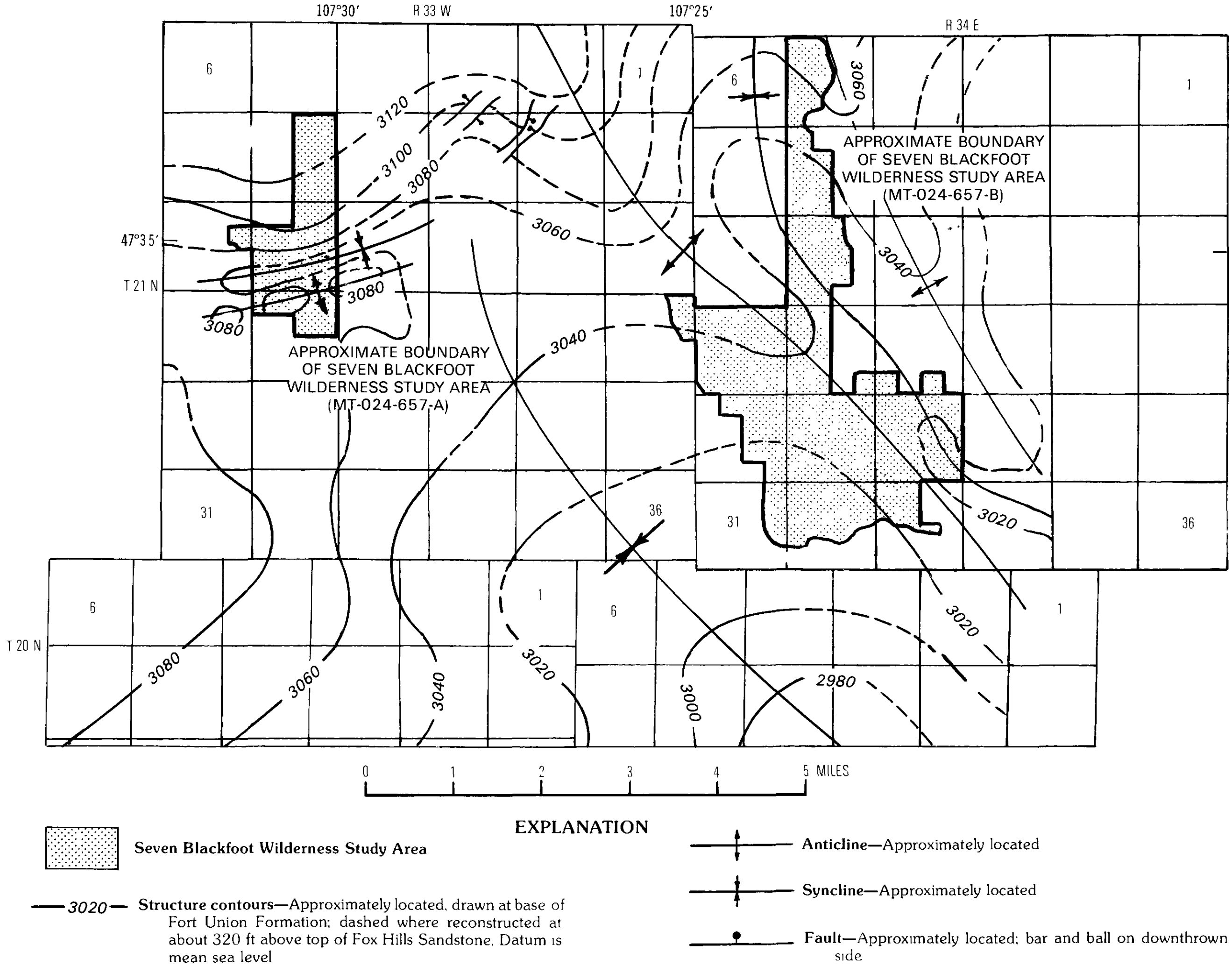


Figure 5. Structure contour map showing possible low amplitude folds in the Seven Blackfoot Wilderness Study Area and vicinity, Montana.

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 hole to be about 1,140 ft. Only the upper 320 ft of the formation subcrop beneath landslide deposits in the wilderness study area and about 500 ft subcrop beneath landslide deposits just north of segment A. 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 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 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 10–30 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 sparse trough stratification; at other locations within the study area, the Colgate Member appears to be massive. Cross-strata are as much as 15 ft long and as much as 2.0 ft thick, and they range in composition from silty shale to carbonaceous shale to sandstone. Sets of cross-strata are inclined from a few degrees to about 15°. Horizontal layers of carbonaceous mudstone and shale, 1–3 ft thick, commonly occur near the base and top of the upper sandstone unit. The upper sandstone unit varies in thickness from 10 to 30 ft, and it 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 part of the Hell Creek Formation is commonly 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 non-erosional 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 320–335 ft of the Hell Creek Formation are exposed in the wilderness study area. The contact between the Hell Creek Formation and overlying Fort Union Formation is conformable (Tschudy, 1970). The formation forms steep slopes typical of the badlands topography throughout the wilderness study area.

Paleocene Fort Union Formation.—In the western part of the Williston Basin, the Paleocene Fort Union Formation consists of, in accending order, the Tullock, Lebo Shale, and Tongue River Members. Only the Tullock Member crops out in the wilderness study area. In the vicinity of the study area, the base of the Tullock Member is mapped at the base of the first continuous coal zone (the Z coal) that occurs 320–335 ft above the top of the Fox Hills Sandstone. Stratigraphic and palynology studies by Tschudy (1970), conducted east of Seven Blackfoot Creek in segment B, sec. 29, T. 21 N., R. 34 E., show that this coal bed marks the position of the Cretaceous-Tertiary time boundary. Tschudy considered the contact between the Hell Creek and Fort Union Formations to be conformable. The Lebo Shale Member overlies the Tullock Member and is tentatively mapped on plate 1 in areas to the south and east of the study area. On plate 1, the base of the Lebo Shale Member is mapped at the base of the U coal zone as shown on plate 2. The U coal zone is equivalent to the UV and U coal beds of Anderson and Rohrer (1961) and the Barker lignite bed of Dobbin (1922b). The U coal zone contains a high content of crystalline volcanic material and may be equivalent to the Big Dirty coal bed of Connor (1984).

Tullock Member (unit Tft *and* Tfts, *pl. 1).*—The total thickness of the Tullock Member in the vicinity of the study area is 190 ft. About 100 ft of the Tullock Member crops out in segment A, and about 180 ft crops out in segment B. In this report the Tullock Member has been divided into a lower unit (Tft, pl. 1) and an upper unit (Tfts, pl. 1). The lithologies and stratigraphic relationships of the lower and upper units are shown on plate 2.

The lower unit is 60–80 ft thick in segment A. The contact between the lower and upper unit rises stratigraphically to the northeast. In segment B the lower unit is 60–100 ft thick. The upper 20 ft of the lower unit intertongues with the upper unit. The lower unit is similar in appearance to the underlying Hell Creek Formation and was included with the Lance (Hell Creek) Formation by Dobbin (1922a,b). It consists of lenticular beds of olive-brown and brownish-gray sandstone, siltstone, mudstone, and claystone (montmorillonite), and includes subordinate and laterally persistant beds of paper shale, carbonaceous shale, and coal. Lateral accretion sets of fine- to coarse-grained sandstone, siltstone, and mudstone occur in what is interpreted to be point bar and abandoned channel-fill deposits to 20 ft in thickness. Mudstone, claystone, carbonaceous shale, paper shale, and coal occur as flood-plain and paludal deposits in horizontally bedded units a few feet to 20 ft thick. Coal beds are less than 4 ft thick.

The upper unit is 120 ft thick in areas south and east of the study area. Only 20 ft of the upper unit are preserved in segment A and 90 ft are preserved in segment B. The upper unit marks a distinct lithologic change from the lower unit and was referred to as the "yellow beds" by Dobbin (1922a,b). It consists of massive, pale-yellowish-orange, fine- to medium-grained sandstone with subordinate units of gray shale and coal.

Sandstone units are 10–40 ft thick. In places, trough crossbedding and ripple bedding were observed in the upper unit; however, sedimentary structures were difficult to observe due to the friable nature of the sandstone. The sandstone units are separated by gray shale units 1–10 ft thick which contain thin lenticular coal beds generally less than 2 ft thick.

Lebo Shale Member (unit Tfl, *pl. 1).*—Only 40 ft of the Lebo Shale Member crops out near the study area. The remainder of the member has been removed by erosion. The contact between the Tullock Member and Lebo Shale Member is mapped on plate 1 at the base of the U coal zone (pls. 1 and 2). The U coal zone is characterized by a high content of crystalline volcanic debris and numerous thin ash layers which indicate an increase in volcanic activity in the region. The U coal zone is overlain by grayish-yellow, fine-grained sandstone similar to that occurring in the upper unit of the Tullock Member.

Coal in the Tullock and Lebo Shale Members (units Z, Y, Y_l, Y_u, X, L, L_1, *and* U, *pl. 1).*—Coal zone nomenclature used in this report is adopted from Anderson (1961) and Anderson and Rohrer (1961). Measured stratigraphic sections showing coal bed thicknesses and correlations are shown on plate 2; the locations of the measured sections and coal-bed outcrops are shown on plate 1. Coal resources and coal quality are discussed in the "Coal resources" section of this report. The Z coal zone (Z, pl. 1) occurs at the base of the Tullock Member. The Y coal zone (Y, pl. 1) occurs 50–60 ft above the base of the Tullock Member and intertongues with the lower and upper units of the Tullock Member. The X coal zone (X, pl. 1) is located in the northern part of segment B, 90 ft above the base of the Tullock Member and just below the upper unit of the Tullock Member. Here, the contact between the lower and upper units rises stratigraphically from the southwest in the study area. Local coal zones occur in the upper unit of the Tullock Member and are designated as the L coal zone (L, pl. 1) west of Seven Blackfoot Creek and as the L_1 coal zone (L_1, pl. 1) east of Seven Blackfoot Creek. No attempt was made to correlate the L and L_1 coal zones to each other. The U coal zone (U, pl. 1) occurs south and east of the study area at the base of the Lebo Shale Member.

In the wilderness study area, laterally persistent coal beds crop out in the lower unit of the Tullock Member, and a few thin and lenticular coal beds crop out in the upper unit. In segment A, coal beds occur in the Z and Y coal zones which underlie about 150 acres of land. In segment B, coal beds occur in the Z, Y, X, and L_1 coal zones which cover 1,090 acres of land.

In the study area the Z coal zone contains one coal bed with thin carbonaceous shale and argillaceous partings and is locally overlain by thin coal seams a few tenths of a foot thick. In segment A, the Z coal bed is 1.3–3.4 ft thick (excluding partings). In segment B, the Z coal bed is 0.5–1.8 ft thick (excluding partings) and pinches out locally.

In segment A, the Y coal zone contains the Y lower coal bed (Y_l, pl. 1), Y upper coal bed (Y_u, pl. 1), and thin lenticular unnamed coal beds. The Y lower coal bed is separated from the Y upper coal bed by an interval 10–15 ft thick containing olive-brown mudstone, brownish-black to gray paper shale, and locally a fine-grained, pale-yellowish-orange sandstone tongue of the upper unit. The Y lower coal bed is 2.2–3.7 ft thick (excluding partings) and thickens to 6.0 ft along Herman Ridge just west of segment A. The Y upper coal bed is 1.6–3.0 ft thick. In the southern parts of segment B the Y coal zone contains two coal beds 1.4 and 2.5 ft thick (excluding partings). The coal beds thin rapidly to the north and pinch out about 1.5 mi north of the southern boundary of segment B.

The X coal zone occurs only in the northern parts of segment B and contains two impure coal beds 0.3–2.5 ft thick.

The L local coal zone crops out south of segment A and contains two coal beds 1.9–2.5 ft thick (excluding partings). The L_1 local coal bed crops out in segment B and varies in thickness from 1.1 to 1.4 ft.

The U coal zone is 35 ft thick and contains a lower coal bed 11.7 ft thick and an upper coal bed 9.6 ft thick; these beds correlate with the UV and U beds, respectively, of Anderson and Rohrer (1961). The coal beds contain numerous carbonaceous shale and argillaceous partings as thick as 0.3 ft. The coal is highly contaminated with volcanic material.

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 surficial deposits such as slope wash, terrace gravels, and eolian deposits were not mapped.

Undifferentiated deposits of alluvium and colluvium (Qac) are mapped along Seven Blackfoot Creek and its tributaries. Alluvial deposits consist of clay, silt, and sand derived locally from the Bearpaw Shale, Fox Hills Sandstone, Hell Creek, and Fort Union Formations. 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 Seven Blackfoot Creek where accumulation may be as thick as 30 ft. Alluvial deposits occurring along other drainages in the study area are thin and discontinuous.

Landslide deposits (Qls) of Quaternary age flank valley walls and intertongue with alluvial deposits along the valley floors of Seven Blackfoot Creek and its tributaries, and along the Missouri River Valley north of the study area. Numerous earth-flow deposits containing debris from the Hell Creek Formation, Fox Hills Sandstone, and Bearpaw Shale have slumped down over the underlying formations, and have coalesced to form a thick mantle of debris that obscures much of the Bearpaw Shale and Fox Hills Sandstone in the study area. The landslide deposits show signs of recent 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 along the west boundary of segment A as thin isolated patches of unconsolidated gravel, cobbles, and occasional boulders as much as 1 ft in diameter. 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 study area. These deposits are probably less than 3 ft thick.

Geochemistry

Methods

The USBM collected 19 samples for chemical analyses from outcrops and stream sediments in the wilderness study area. Sample locations, analyses, descriptions, and results are discussed in Miller (1985), and are summarized in the part of this report concerning the appraisal of identified resources. 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 Seven Blackfoot Wilderness Study Area. The refuge is contiguous to the Seven Blackfoot Wilderness Study Area (fig. 3) and its geologic setting is nearly identical to that of the wilderness study area. Frahme (1979) collected for analyses a total of 442 rock, stream-sediment, and panned-concentrate samples throughout the refuge. Thirty-two of these rock samples were collected immediately north of the wilderness study area from exposures of the Bearpaw Shale, Fox Hills Sandstone, Hell Creek Formation, and Fort Union Formation; and three stream-sediment samples and one panned-concentrate sample were collected from streams that drain the wilderness study area. The drainages are Devils Creek (about 3 mi west of segment A), Seven Blackfoot Creek, and Billy Creek. All samples collected in the refuge were analyzed for 30 elements by a semi-quantitative emission spectrographic technique (Grimes and Marranzino, 1968). Stream sediments and panned concentrates were additionally analyzed for gold, copper, lead, and zinc by atomic absorption methods; selected shale samples were also analyzed for Al_2O_3; and selected sandstones were also analyzed for uranium and thorium (Frahme, 1979).

Results

Results from the chemical studies of the Seven Blackfoot Wilderness Study Area (Miller, 1985) and geochemical studies of the Charles M. Russell National Wildlife Refuge (Frahme, 1979) indicate that the Seven Blackfoot Wilderness Study Area shows no evidence of mineralized rock. Miller (1985; this report) detected trace amounts of gold in alluvial samples and traces of gold and uranium from coal beds in the study area. These concentrations are very low and noneconomic (see section of this report concerning appraisal of identified resources). Frahme (1979, p. 22) did not consider any of the samples from the wildlife refuge to show evidence of mineralized rock and states that "The area is lacking in evidence of mineral occurrences such as areas of altered rock that are characteristic of mineralized areas elsewhere."

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 just north of the study area are slightly enriched in one or more of the metals aluminum, titanium, boron, barium, beryllium, lanthanum, and zirconium. Clay samples collected from the exposures of Bearpaw Shale located 9–16 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 (20–24 percent Al_2O_3), and stated that shales of this quality are common throughout the United States.

Analyses of other samples collected from the refuge just north of the study area show that one sample from the Hell Creek Formation is slightly enriched in arsenic, and one sample from the Fort Union Formation located along Seven Blackfoot Creek is slightly enriched in molybdenum (Frahme, 1979). These samples are enriched only by comparison to other samples in the refuge and not for sedimentary rocks in general (Frahme, 1979).

Geophysics

Gravity and aeromagnetic anomaly data (figs. 6 and 7, respectively) provide information about the regional geologic setting and structural framework in which the Seven Blackfoot 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 influences by rock sources result in a lack of correlation between the gravity and aeromagnetic anomaly maps.

Methods

A complete Bouguer gravity anomaly map (fig. 6) 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 Seven Blackfoot Wilderness Study Area but gives a regional structural setting.

Regional aeromagnetic data (fig. 7) were obtained from a NURE (National Uranium Resource Evaluation) survey that covered the Jordan 1°x2° 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 near the northern and southern boundaries of the wilderness 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

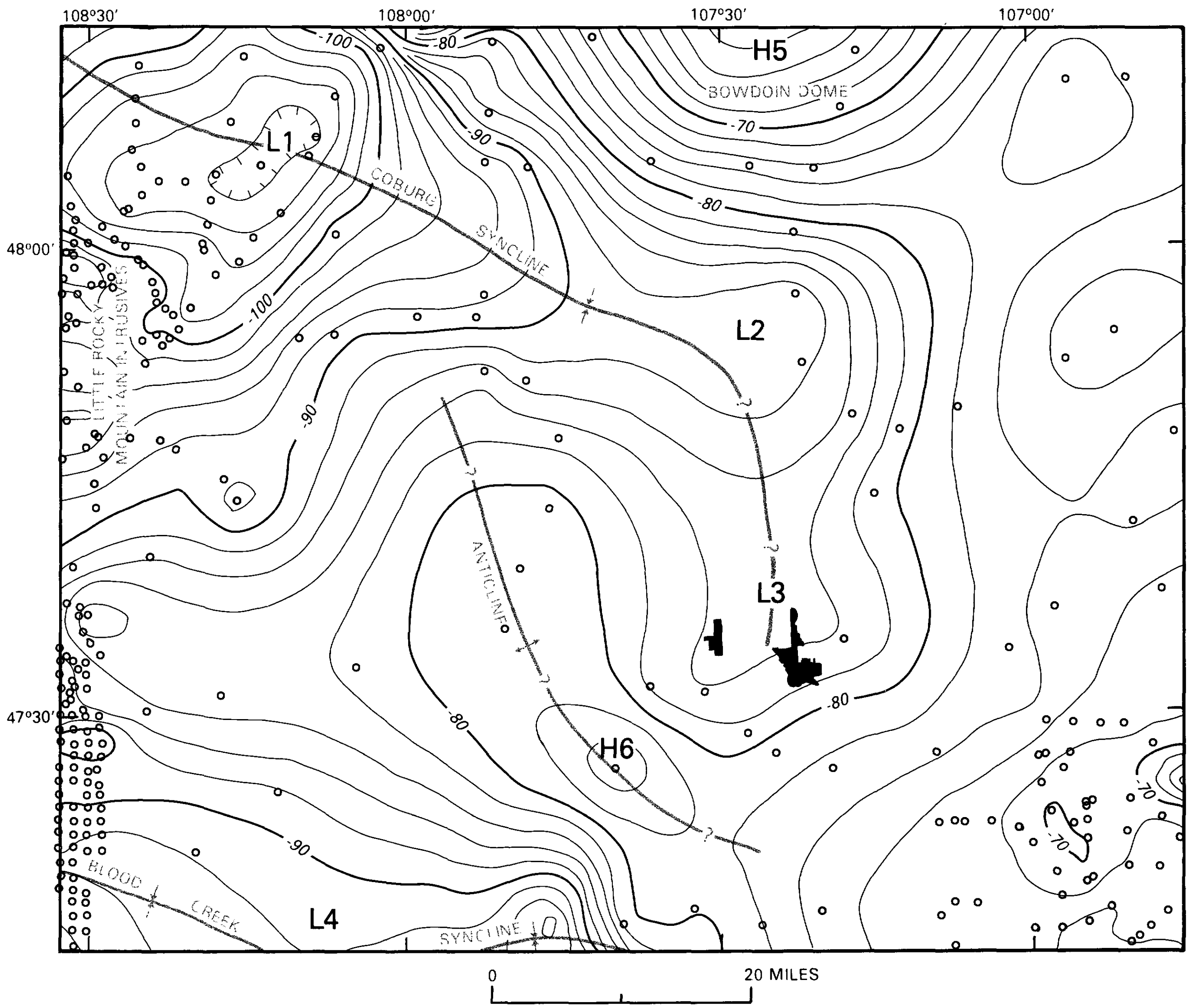
The gravity anomaly map (fig. 6) is dominated by high and low gravity values that are interpreted as, and related to, structural features mapped by Dobbin and Erdmann (1955), Stoner and Lewis (1980), and Feltis (1980a,b; 1981a,b). Gravity highs are associated with uplift of dense Paleozoic and Precambrian 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 Seven Blackfoot Wilderness Study Area is located over a broad south- and southeast-trending gravity low (fig. 6) which extends between L1, L2, and L3. This broad gravity low from L1 to L2 is associated with the Coburg syncline. The gravity low changes direction at L2 and trends south into 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 in the vicinity 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 high anomaly at H6 trends southeast from the Little Rocky Mountains intrusive to the vicinity of Brusett (fig. 3) 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.

The study area is located over a negative magnetic anomaly and between positive magnetic anomalies located 10 mi to the west and 16 mi to the east. Steep gradients trending to the northeast are located 4–12 mi to the north and 15 mi to the southeast of the study area. The gradient located 4–12 mi to the north approximates the position of a regional lineament (fig. 4) mapped by Anna (1986) and discussed in the regional geologic setting section of this report. These gradient zones in the magnetic field may represent shear zones or zones of weakness in the Precambrian basement complex that may propagate faulting or jointing through overlying sediments. These steep gradients, like others on the



EXPLANATION

-80 **Gravity contours**—Hachures indicate closed gravity low. Contour interval 2 milliGals

o **Gravity station**

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

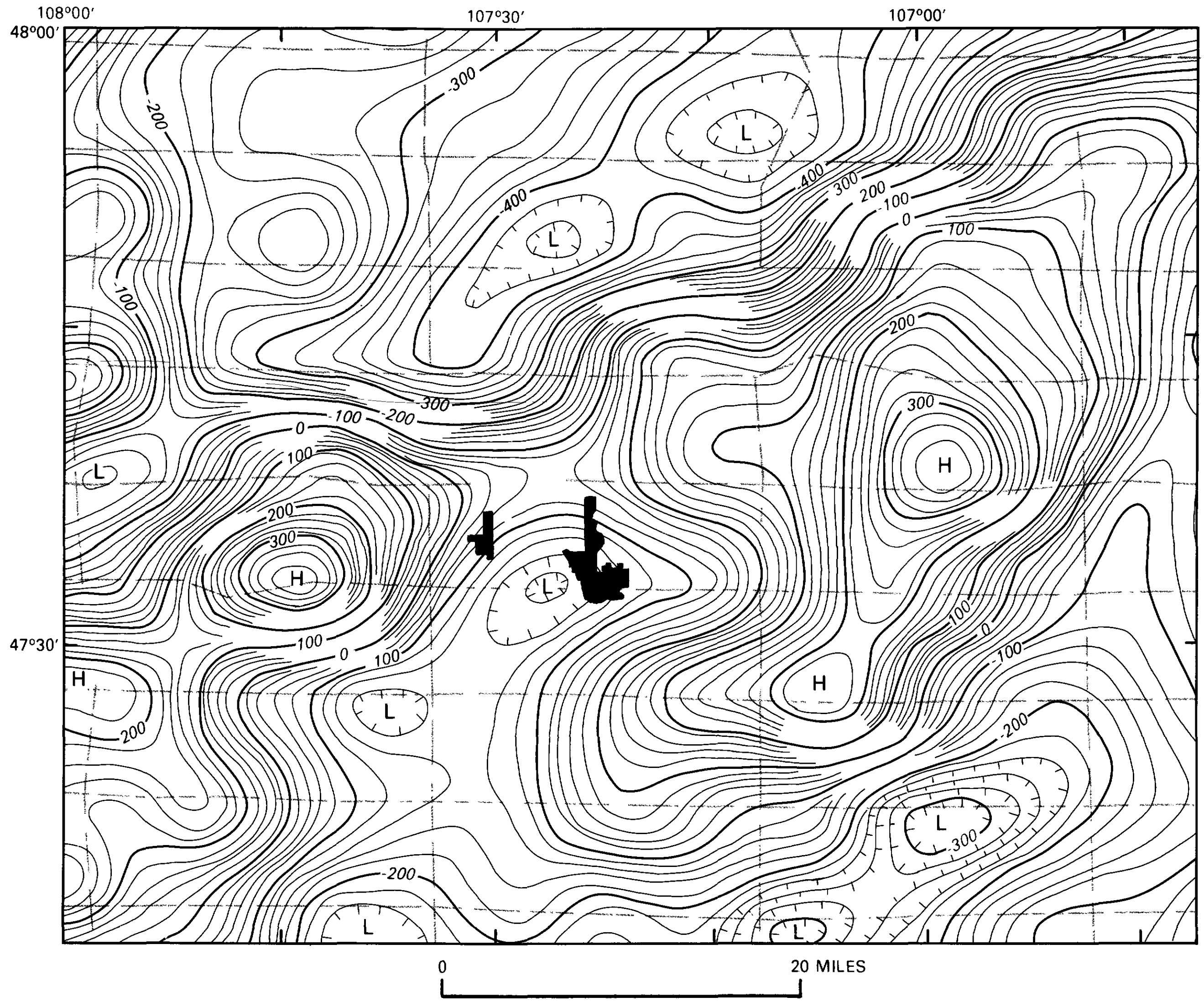
H5 **Gravity high**—Referred to in text

Figure 6. Complete Bouguer gravity anomaly map of Seven Blackfoot Wilderness Study Area (shaded) and vicinity, Montana. Structural features are approximately located; queried where uncertain.

aeromagnetic anomaly map, are of limited interest. In other parts of Montana, such gradient zones commonly correspond to regions of significant hydrothermal alteration and emplacement of mineral-bearing solutions. In the study area, no evidence was found in surface exposures of hydrothermal alteration or emplacement of mineral-bearing solutions; 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.



EXPLANATION

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

L **Aeromagnetic low**

H **Aeromagnetic high**

Flight lines

Figure 7. Aeromagnetic anomaly map of the Seven Blackfoot Wilderness Study Area (shaded) and vicinity, Montana.

Metallic Minerals

No metallic mineral deposits or mineralized zones, mines, or prospects were found in the wilderness study area or surrounding areas. Although some chemical and geochemical samples collected in and near the wilderness study area show a slight enrichment in one or more of the metallic elements aluminum, arsenic, titanium, boron, barium, beryllium, lanthanum, molybdenum, gold, and uranium, none were considered significant enough to indicate that mineralization has occurred in the area (Frahme, 1979; Miller, 1985). As the geologic information portrays an environment in which mineralization in or near the study area is unlikely, the entire study area is assessed to have a low mineral resource potential for all metallic minerals, with a certainty level of B.

No significant amounts of placer gold were detected in chemical or geochemical studies conducted in or adjacent to the study area (Frahme, 1979; Miller, 1985). Placer gold was detected in three samples collected from alluvium in Seven Blackfoot Creek and its tributaries. Concentrations of gold are very low and are not considered to be economic. The source of gold is unknown and probably distant. Those parts of the study area containing alluvium and colluvium deposits along Seven Blackfoot Creek and its tributaries are assessed to have a low mineral resource potential for placer gold, with a certainty level of D.

Industrial and Nonmetallic Minerals

Industrial minerals found in the study area include the clay minerals kaolinite and montmorillonite, and sand and gravel. These occurrences have been described by the USBM (Miller, 1985) and are discussed above. Miller (this report) considers some of the deposits of kaolinite and montmorillonite to be marginally useful for some industrial purposes. Deposits of sand and gravel are considered to be noneconomic. None of the mineral occurrences are 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 all of segment A (1,160 acres) and 3,730 acres of segment B. The Colgate Member contains 10–15 percent kaolinite and ranges from 10 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. Two of four kaolinite samples tested by the USBM were found to be suitable for structural clay and light-duty refractory use; the other two were found to be unsuitable for structural purposes. 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 of the Fox Hills Sandstone are disturbed by landslide movement are not considered in the assessment of mineral resource potential.

Montmorillonite occurs in thin, lenticular beds in the Hell Creek Formation and the lower unit of the Tullock Member of the Fort Union Formation which together underlie about 4,000 acres of the study area. The USBM sampled one bed from the Hell Creek Formation in segment B and found the clay to be suitable for structural clay products, but generally considered the beds to be of poor quality and too thin to be a resource. Additional undiscovered beds of montmorillonite are likely to occur in both the Hell Creek and Fort Union Formations. These beds, if present, were deposited in fluvial environments adjacent to stream channels and are likely to be sandy and silty, of poor quality, and laterally discontinuous. There is no evidence to suggest that undiscovered beds of montmorillonite would exceed the quality or quantity described by the USBM. Those parts of the area underlain by the Hell Creek Formation and lower unit of the Tullock Member of the Fort Union Formation are assessed to have a low mineral resource potential for montmorillonite, with a certainty level of D.

Undiscovered beds of bentonite are likely in the Bearpaw Shale, which underlies the entire study area but is generally covered by thick landslide deposits and overlying sedimentary rock. The beds, if present, are likely to range from less than 1 to 6 ft in thickness, and are likely to be lenticular although some of the thicker beds may be laterally continuous for many miles (Frahme, 1979). A thick and laterally continuous bed, named the Siparyann bed, may occur near the base of the Bearpaw Shale at depths ranging from 800 ft to 1,500 ft beneath the study area. Additional thin, silty, and lenticular bentonite beds may occur in exposures of the Hell Creek and Fort Union Formations (Frahme, 1979) and deep in the subsurface in the Claggett, Bell Fourche, and Mowry Shales (Rice, 1979). Bentonite covered by more than 35 ft of overburden may not be sufficiently weathered to have qualities suitable for industrial application (Miller and others, 1979). Due to the steep terrain in the study area, beds of bentonite are generally covered by overburden exceeding 35 ft. The entire study area is assessed to have a low mineral resource potential for bentonite, with a certainty level of D.

Sand and gravel occur in alluvium and colluvium along Seven Blackfoot Creek and its tributaries, covering about 150 acres of the study area near the western boundary of segment B. The sand and gravel occurrences are probably less than 30 ft thick and are contaminated with landslide debris and abundant clay-size material derived from the Bearpaw Shale. The USBM did not consider these occurrences to be economic due to contamination by clay-sized materials and the distance from sand and gravel markets. No other significant sand and gravel occurrences are found in the study area. Those parts of the study area containing alluvium and colluvium deposits along Seven Blackfoot Creek and its tributaries are 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). About 8,000–10,000 ft of sedimentary rock underlie the study area; all geologic systems except the Cambrian System are potentially hydrocarbon hosts (Rice, 1979). The oil and gas potential of the entire wilderness study area was assessed as medium by Perry and others (1983a,b). They state that oil and gas accumulations in Paleozoic sediments would be "* * * stratigraphic in nature with local structural enhancement * * *. Significant biogenic gas resources may be present in Upper Cretaceous reservoirs similar to those in adjacent areas * * *" (Perry and others, 1983a, p. G17). Structural traps and fracture zones may occur in the wilderness study area and surrounding areas. A low amplitude anticlinal fold may extend for 3 mi northwest across segment B of the wilderness study area; and a second fold may extend for 1 mi northeast across segment A. Maximum closure measured on the base of the Fort Union Formation along the axes of these folds is about 30 ft, so that reservoir capacity is assumed to be limited. The depth to which the folds extend into the subsurface cannot be determined from available data. The folds may only be the result of differential compaction of underlying sediments and not structural in nature.

The entire study area is under lease for oil and gas. The only drill hole in or near the study area is the Montana Power Co. Federal No. 10–32 located at the south boundary of segment B, near the anticlinal fold axis discussed above. This drill hole was drilled in 1974 to a depth of 7,065 ft. The hole was cased, perforated, tested, and produced only water; there were no shows of oil or gas. The casing was removed and the well was plugged and abandoned.

The oil and gas energy resource potential of the entire study area is assessed as moderate, with a certainty level of C.

Two coal beds 3 and 5 ft thick, and of unknown quality and lateral extent, are identified in the Judith River Formation at depths of 1,600 and 1,785 ft in the Montana Power Co. Federal No. 10–32 drill hole located within the southern boundary of segment B. These coal beds are the products of peat accumulation in coastal marsh environments which are laterally continuous for many miles, and additional coal beds are likely to occur. As the Judith River Formation underlies the entire study area, those parts of the study area lying within a 3-mi radius from the drill hole are assessed to have a high energy resource potential for coal, with a certainty level of D. The remainder of the study area, lying beyond the 3-mi radius, is assessed to have a moderate energy resource potential for coal, with a certainty level of C. A 3-mi radius is used as it defines the area which includes measured, indicated, and inferred coal resources (Wood and others, 1983).

Known occurrences of coal are found in outcrops of the Tullock Member of the Fort Union Formation. These beds are discussed under the appraisal of identified resources section of this report and are shown on figure 1 and plate 1. Where the coal beds are less than 2.5 ft thick they are not now, nor are they likely to become, potential coal resources. Two coal beds, the Y lower and Y upper coal beds may be contaminated with high ash contents. Further work is necessary to determine the extent of ash contamination. If these beds are found to be extensively contaminated with ash they are not now, nor are they likely to become, potential coal resources.

The study area is in a region of Montana that, according to Sonderegger and Bergantino (1981), is expected to contain geothermal resources suitable for direct heat applications. There are no known geothermal energy sources in or near the wilderness study area (Sonderegger and Bergantino, 1981). No warm springs or other potential geothermal sources were noted during this investigation. The geothermal energy resource potential of the entire study area is assessed as low, with a certainty level of B.

REFERENCES CITED

Anderson, G.E., 1961, Township report for T. 20 N., R. 33 E., M.P.M., Montana: U.S. Geological Survey unpublished data (available at U.S. Bureau of Land Management, Billings, Montana).

Anderson, G.E., and Rohrer, W.L., 1961, Township report for T. 20 N., R. 34 E., M.P.M., Montana: U.S. Geological Survey unpublished data (available at U.S. Bureau of Land Management, Billings, Montana).

Anna, L.O., 1986, Geologic framework of the ground-water system in Jurassic and Cretaceous rocks in the Northern Great Plains, in parts of Montana, North Dakota, South Dakota, and Wyoming: U.S. Geological Survey Professional Paper 1402–B, 36 p.

Archibald, J.D., 1982, A study of Mammalia and geology across the Cretaceous-Tertiary boundary in Garfield County, Montana: University of California Publications in Geological Sciences, v. 122, 36 p.

Bayer, K.C., 1983, Generalized structural, lithologic and physiographic provinces in the fold and thrust belts of the United States: Reston, Va., U.S. Geological Survey, 2 sheets, scale 1:2,500,000.

Bendix Field Engineering Corporation, 1983, Jordan quadrangle; residual intensity magnetic anomaly contour map: GJM Report 304 (83), scale 1:250,000.

Brown, Barnum, 1907, The Hell Creek beds of the Upper Cretaceous of Montana—Their relations to contiguous deposits, with faunal and floral lists and discussion of their correlation: American Museum of Natural History Bulletin 23, p. 823–845.

Brown, R.W., 1939, Fossil plants from the Colgate Member of the Fox Hills Sandstone, and adjacent strata: U.S. Geological Survey Professional Paper 189–I, p. 239–275.

Collier, A.J., 1918, Geology of northeastern Montana: U.S. Geological Survey Professional Paper 120, p. 17–39.

Connor, C.W., 1984, Ash-fall sequences in a Paleocene coal—Potential indicator of synchroneity between Montana and Wyoming basins, *in* Houghton, R.L., and Clausen, E.N., eds., 1984 Symposium on the Geology of Rocky Mountain Coal: North Dakota Geological Society Publication 84–1, p. 137–151.

Dobbin, C.E., 1922a, Township report for T. 21 N., R. 33 E., M.P.M., Montana: U.S. Geological Survey unpublished data (available at U.S. Bureau of Land Management, Billings, Montana).

_____ 1922b, Township report for T. 21 N., R. 34 E., M.P.M., Montana: U.S. Geological Survey unpublished data (available at U.S. Bureau of Land Management, Billings, Montana).

_____ 1924, The continuity of lithologic units in the Fox Hills, Lance, and Fort Union Formations of eastern Montana, and its bearing on the Laramide problem: Baltimore, Md., Johns Hopkins University, Ph.D. thesis, 101 p.

Dobbin, C.E., and Erdmann, C.E., 1955, Structure contour map of the Montana plains: U.S. Geological Survey Oil and Gas Investigations Map OM-178-A, scale 1:500,000.

Dobbin, C.E., and Reeside, J.B., Jr., 1929, The contact of the Fox Hills and Lance Formations: U.S. Geological Survey Professional Paper 158–B, p. 9–25.

Erdmann, C.E., and Lemke, R.W., 1963, Geology and mineral resources of Missouri River Valley between head of Fort Peck Reservoir and Morony Dam, appendix III *in* U.S. Army Corps of Engineers and U.S. Bureau of Reclamation, Joint report on water and related land resources development for Missouri River, Fort Peck Reservoir to vicinity of Fort Benton, Montana: p. III–1 to III–122.

Feltis, R.D., 1980a, Structure contour map of the top of the Madison Group, Havre 1°×2° quadrangle, north-central Montana: Montana Bureau of Mines and Geology, Geologic Map 9, scale 1:250,000.

_____ 1980b, Structure contour map of the top of the Madison Group, Lewistown 1°×2° quadrangle, north-central Montana: Montana Bureau of Mines and Geology, Geologic Map 12, scale 1:250,000.

_____ 1981a, Glasgow 1°×2° quadrangle, northeastern Montana, structure contour map of the top of the Madison Group: Montana Bureau of Mines and Geology, Geologic Map 18, scale 1:250,000.

_____ 1981b, Jordan 1°×2° quadrangle, northeastern Montana, structure (configuration) contour map of the top of the Madison Group: Montana Bureau of Mines and Geology, Geologic Map 16, scale 1:250,000.

Frahme, C.W., 1979, Geology and evaluation of the mineral resources of the Charles M. Russell Wildlife Refuge, Chapter B *in* U.S. Geological Survey and U.S. Bureau of Mines, Mineral resources of the Charles M. Russell Wildlife Refuge, Fergus, Garfield, McCone, Petroleum, Phillips, and Valley Counties, Montana: U.S. Geological Survey Open-File Report 79–1204, p. 5-42.

Fullerton, D.S., and Colton, R.B., 1986, Stratigraphy and correlations of the glacial deposits on the Montana Plains, *in* Richmond, G.M., and Fullerton, D.S., eds., Quaternary glaciation of the Northern Hemisphere: Elmsford, N.Y., Pergamon Press, p. 69–82.

Gill, J.R., and Cobban, W.A., 1973, Stratigraphy and geologic history of the Montana Group and equivalent rocks, Montana, Wyoming, and North and South Dakota: U.S. Geological Survey Professional Paper 776, 37 p.

Godson, R.H., and Webring, M.W., 1982, CONTOUR—A modification of G.I. Evendon's general purpose contouring program: U.S. Geological Survey Open-File Report 82–797, 73 p.

Goudarzi, G.H., 1984, Guide to preparation of mineral survey reports on public lands: U.S. Geological Survey Open-File Report 84–787, 42 p.

Grimes, D.J., and Marranzino, A.P., 1968, Direct-current arc and alternating-current spark emission spectrographic field methods for the semiquantitative analysis of geologic materials: U.S. Geological Survey Circular 591, 6 p.

Hearn, B.C., Jr., 1979, Preliminary map of diatremes and alkalic ultramafic intrusions in the Missouri River Breaks and vicinity, north-central Montana: U.S. Geological Survey Open-File Report 79–1128, scale 1:125,000.

Hubbard, C.R., Roby, R.N., Henkes, W.C., and Biggs, P., 1963, Mineral resources, appendix IV *in* U.S. Army Corps of Engineers and U.S. Bureau of Reclamation, Joint report on water and related land resources development for Missouri River, Fort Peck Reservoir to vicinity of Fort Benton, Montana: p. IV–1 to IV–68.

Jensen, F.S., and Varnes, H.D., 1964, Geology of the Fort Peck area, Garfield, McCone, and Valley Counties, Montana: U.S. Geological Survey Professional Paper 414–F, 49 p.

Matson, R.E., 1960, Petrography and petrology of Smoky Butte intrusives, Garfield County, Montana: Bozeman, Mont., Montana State University, M.S. thesis, 71 p.

Miller, M.S., 1985, Mineral resources of the Seven Blackfoot study area, Garfield County, Montana: U.S. Bureau of Mines Mineral Land Assessment Open-File Report, MLA 4–86, 13 p.

_____ 1986, Mineral resources of the Cow Creek Wilderness Study Area, Blaine and Phillips Counties, Montana: U.S. Bureau of Mines Mineral Land Assessment Open-File Report, MLA 3–86, 27 p.

Miller, M.S., Schumacher, O.L., Hamilton, M.M., and Rigby, J.G., 1979, Economic appraisal of the Charles M. Russell Wildlife Refuge, Chapter D *in* U.S. Geological Survey and U.S. Bureau of Mines, Mineral resources of the Charles M. Russell Wildlife Refuge, Fergus, Garfield, McCone, Petroleum, Phillips, and Valley Counties, Montana: U.S. Geological Survey Open-File Report 79–1204, p. 82–178.

Nettleton, L.L., 1971, Elementary gravity and magnetics for geologists and seismologists: Society of Exploration Geophysicists Monograph Series 1, 121 p.

Perry, E.S., 1934, Geology and artesian water resources along Missouri and Milk Rivers of northeastern Montana: Montana Bureau of Mines and Geology Memoir 11, p. 1–34.

Perry, W.J., Jr., Rice, D.D., and Maughan, E.K., 1983a, Petroleum potential of wilderness lands in Montana, *in* Miller, B.M., ed., Petroleum potential of wilderness lands in the Western United States: U.S. Geological Survey Circular 902–G, p. G1–G23.

——— 1983b, Petroleum potential of wilderness lands, Montana: U.S. Geological Survey Miscellaneous Investigations Series Map I–1541, scale 1:1,000,000.

Rice, D.D., 1979, Hydrocarbon evaluation of the Charles M. Russell Wildlife Refuge, Chapter C, *in* U.S. Geological Survey and U.S. Bureau of Mines, Mineral resources of the Charles M. Russell Wildlife Refuge, Fergus, Garfield, McCone, Petroleum, Phillips, and Valley Counties, Montana: U.S. Geological Survey Open-File Report 79–1204, p. 43–81.

Sonderegger, J.L., and Bergantino, R.N., compilers, 1981, Geothermal resources of Montana: Montana Bureau of Mines and Geology Hydrogeologic Map 4, scale 1:1,000,000.

Stoner, J.D., and Lewis, B.D., 1980, Hydrogeology of the Fort Union coal region, eastern Montana: U.S. Geological Survey Miscellaneous Investigations Series Map I–1236, scale 1:500,000.

Swenson, F.A., 1955, Geology and ground-water resources of the Missouri River Valley in northeastern Montana: U.S. Geological Survey Water Supply Paper 1263, 46 p.

Thomas, G.E., 1974, Lineament-block tectonics—Williston-Blood Creek Basin: American Association of Petroleum Geologists Bulletin, v. 58, no. 7, p. 1305–1322.

Tschudy, R.H., 1970, Palynology of the Cretaceous-Tertiary boundary in the northern Rocky Mountain and Mississippi Embayment regions, *in* Kosanke, R.M., and Cross, A.T., eds., Symposium of palynology of the Late Cretaceous and Early Tertiary: Geological Society of America Special Paper 127, p. 65–111.

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, 5 p.

U.S. Geological Survey and U.S. Bureau of Mines, 1979, Mineral resources of the Charles M. Russell Wildlife Refuge, Fergus, Garfield, McCone, Petroleum, Phillips, and Valley Counties, Montana: U.S. Geological Survey Open-File Report 79–1204, 185 p.

Webring, M.W., 1981, MINC—A gridding program based on minimum curvature: U.S. Geological Survey Open-File Report 81–1224, 43 p.

Wood, G.H., Jr., Kehn, T.M., Carter, M.D., and Culbertson, W.C., 1983, Coal resource classification system of the U.S. Geological Survey: U.S. Geological Survey Circular 891, 65 p.

Zietz, Isidore, Hearn, Carter, and Plouff, Donald, 1968, Preliminary interpretation of aeromagnetic amd gravity data near the Large Aperture Seismic Array, Montana: U.S. Geological Survey Open-file Report 68–340, 23 p.

*U.S. GOVERNMENT PRINTING OFFICE: 1988-0-573-047/66065

APPENDIX

DEFINITION OF LEVELS OF MINERAL RESOURCE POTENTIAL AND CERTAINTY OF ASSESSMENT

Definitions of Mineral Resource Potential

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

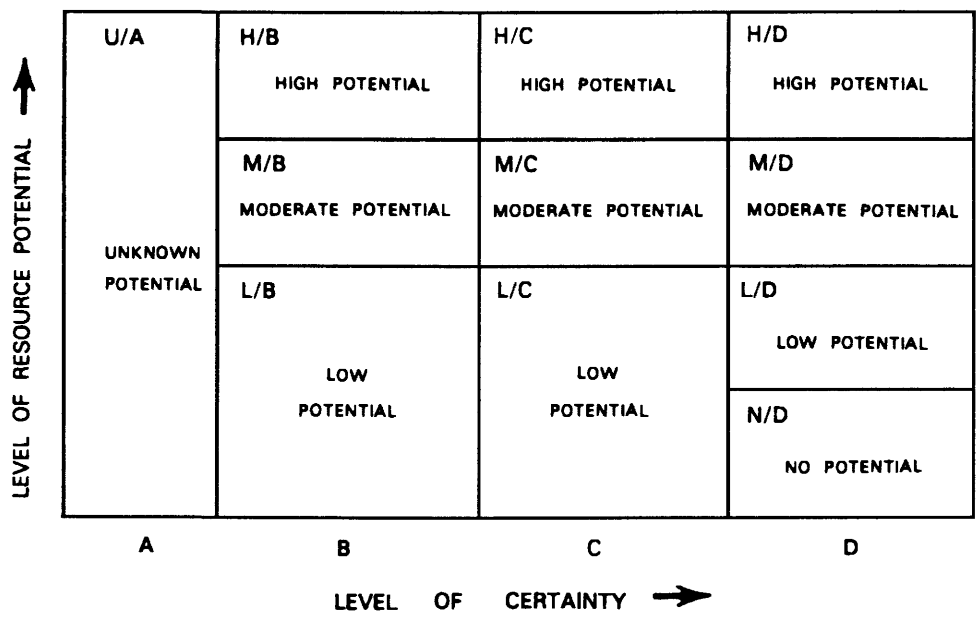
MODERATE mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence, where interpretations of data indicate a reasonable likelihood of resource accumulation, and (or) where an application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

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

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

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

Levels of Certainty



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

Abstracted with minor modifications from:

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

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

Goudarzi, G. H., compiler, 1984, Guide to preparation of mineral survey reports on public lands: U.S. Geological Survey Open-File Report 84–0787, p. 7, 8.

RESOURCE / RESERVE CLASSIFICATION

	IDENTIFIED RESOURCES			UNDISCOVERED RESOURCES	
	Demonstrated		Inferred	Probability Range	
	Measured	Indicated		Hypothetical	(or) 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.

Mineral Resources of Wilderness Study Areas—Eastern Montana

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