Mineral Resources of the Bobcat Draw Badlands Wilderness Study Area, Big Horn and Washakie Counties, Wyoming

U.S. GEOLOGICAL SURVEY BULLETIN 1756–E

Chapter E

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U.S. GEOLOGICAL SURVEY BULLETIN 1756

MINERAL RESOURCES OF WILDERNESS STUDY AREAS—NORTHERN WYOMING

DEPARTMENT OF THE INTERIOR
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U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

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STUDIES RELATED TO WILDERNESS

Bureau of Land Management Wilderness Study Area

The Federal Land Policy and Management Act (Public Law 94–479, October 21, 1976) requires the U.S. Geological Survey and the U.S. Bureau of Mines to conduct mineral surveys on certain lands 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 Bobcat Draw Badlands (WY–010–126) Wilderness Study Area, Big Horn and Washakie Counties, Wyoming.

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Mineral Resources of the Bobcat Draw Badlands Wilderness Study Area, Big Horn and Washakie Counties, Wyoming

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U.S. Geological Survey

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ABSTRACT

The Bobcat Draw (WY–010–126) Wilderness Study Area includes about 17,150 acres and is located about 45 mi (miles) by road west of Worland in the Bighorn basin. The arid landscape comprises treeless uplands drained by intermittent streams.

No identified resources are in the Bobcat Draw Wilderness Study Area. Most of the area is currently under lease for oil and gas. The study area has a high potential for resources of oil and gas and a high potential for subeconomic resources of deeply buried coal. The potential for a deep-seated geothermal energy resource is moderate. The resource potential for oil shale and metals, including uranium, is low.

SUMMARY

Character and Setting

Field investigations to evaluate the mineral and energy resource potential of the Bobcat Draw Badlands (WY-010–126) Wilderness Study Area (fig. 1) were carried out in the summer of 1987. Investigative methods included geologic mapping, geophysical surveys, geochemical and mineralogical sampling and analysis, and stratigraphic studies.

The Bobcat Draw Badlands Wilderness Study Area comprises 17,150 acres, about 27 mi^2 (square miles). By road, it is about 45 mi west of Worland and about 35 mi east of Meeteetse. Minimum distance from a paved road is about 12 mi. Elevations in the study area range between about 4,650 and 5,620 ft. The topography consists of sharply dissected badlands locally surmounted by rolling uplands. The climate is dry; there are no perennial streams and no trees other than scattered cottonwoods along the major drainage courses.

Bedrock exposed at the surface consists of two lightly consolidated formations of Paleogene age (See geologic time chart in Appendix). The Willwood Formation (upper Paleocene and lower Eocene) consists of pale sandstone interbedded with beds of silt and mudstone that are commonly pink, red, or purple. It erodes to form picturesque badlands, banded in red and pale yellow. The overlying Tatman Formation (Eocene) consists of thick beds of brown shale, commonly carbonaceous, thin beds of white-weathering oil shale, and lensing beds of pale sandstone. The Tatman forms rolling topography. Masking the bedrock formations in many parts of the study area are unconsolidated deposits of Quaternary age (glacial age or younger) including stream alluvium, pediment alluvium, and, near the bases of steep slopes, poorly sorted blocky colluvium.

Below the exposed formations lies a great thickness—more than 20,000 ft—of sedimentary rocks. Included are strata representing the Paleozoic, Mesozoic, and Cenozoic eras.

Chemical analyses of stream sediment samples from within and adjacent to the wilderness study area show no significant anomalous concentrations of elements that would indicate mineralization. Slightly anomalous levels or patterns of the elements, cobalt, copper, nickel, and uranium, and the mineral, barite, are considered to represent low level background values deriving from the local chemistry of the Willwood and Tatman Formations.

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The Bobcat Draw Badlands Wilderness Study Area is on the northeast flank of a well-defined gravity low that probably defines the deepest part of the Bighorn basin. It lies northeast of a less well-defined magnetic low that continues to the north-northwest and coincides with or parallels the gravity low. Geophysical data also indicate that east-west oriented structures occur in the dense, relatively magnetic crystalline rocks underlying the sedimentary rocks of the basin.

Mineral Resources

No mineral resources were identified in the Bobcat Draw Badlands Wilderness Study Area. Most of the area is currently under lease for oil and gas. There are three deep drill holes in the immediate vicinity, one a producing gas well.

The Bobcat Draw Badlands Wilderness Study Area has a high resource potential for oil and gas at certainty level B (fig. 2) because it is underlain at many horizons by producing reservoir and source rocks. In the axial region of the Bighorn basin, which includes the study area, the major resource would most likely be gas, with some oil, from unconventional (low-permeability sandstone) reservoirs in the Cretaceous to Tertiary part of the sedimentary section. The resource potential is also high at certainty level B for subeconomic, because deeply buried, subbituminous coal. Overburden on the shallowest expectable coal, in the Fort Union Formation of Paleocene age, would be 2,500 ft or more.

The potential for deep-seated geothermal energy resources is moderate at certainty level B (fig. 2). This evaluation is based on the existence in the area of exploratory drill holes for oil and gas that are deep enough to tap the generally hot waters of the deep subsurface. The study area does not contain thermal springs nor was other evidence of unusually high earth temperatures observed.

Oil shale occurs in the wilderness study area as a persistently present, but sparse, component of the Tatman Formation. The Tatman material tested to date, in this study as well as in previous studies, has proved to be uniformly very low-grade, however. Therefore, the mineral resource potential for oil shale is low at certainty level C. Also low at certainty level C is the potential for resources of uranium and for resources of other metals. Examination of outcrops and chemical analyses of rock and stream-sediment samples produced no evidence of mineralization.

INTRODUCTION

In 1987, the U.S. Geological Survey (USGS) and the U.S. Bureau of Mines (USBM) studied 17,150 acres of the Bobcat Draw Badlands (WY–010–126) Wilderness Study Area. The study of this acreage was requested by the U.S. Bureau of Land Management. In this report, the studied area is called "wilderness study area" or simply the "study area." The Bobcat Draw Badlands Wilderness Study Area is located in Washakie and Big Horn Counties, Wyo., in the Bighorn basin (fig. 1). It is underlain by relatively soft rocks in nearly flat-lying beds. The topography is characterized by ridge-crestal areas of rolling relief surmounting lowlands marked by sharp dissection and abrupt relief. Elevations in the study area range from slightly over 5,600 ft (feet) to about 4,650 ft in the valley of Fifteenmile Creek (pl. 1; fig. 2). The upland part of the study area is accessible from the south over a gravel road (Murphy Draw Road) leading north from Wyoming Route 431. Lowland parts of the study area are accessible from a dirt maintenance road along the buried pipeline (Platte Pipeline) in the valley of Fifteenmile Creek (fig. 2).

This report presents an evaluation of the mineral endowment (identified resources and mineral resource potential) of the Bobcat Draw Badlands Wilderness 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 U.S. Bureau of Mines and the U.S. Geological Survey (1980), which is shown in the Appendix. Identified resources are studied by the USBM. Mineral resource potential is the likelihood of occurrence of undiscovered metals and nonmetals, industrial rocks and minerals, and undiscovered energy resources (coal, oil, gas, oil shale, and geothermal sources). It is classified according to the system of Goudarzi (1984), which is shown in the Appendix. The potential for undiscovered mineral resources is studied by the USGS.

Investigations by the U. S. Bureau of Mines

In 1987, the Bureau of Mines studied the mineral resources of the Bobcat Draw Badlands Wilderness Study Area, Big Horn and Washakie Counties, Wyo., on lands administered by the U.S. Bureau of Land Management. No resources were identified in the study area.

A detailed literature search for geologic and mining information was made by Bureau personnel prior to the field investigation. Bureau of Mines and county records were examined for location of patented and unpatented mining claims, mineral leases and oil and gas leases in and near the study area. The records showed the existence of oil and gas leases, but did not indicate any mineral claims or activity.

Field investigations were carried out by the Bureau of Mines in August 1987. Although no mining claims or mining activity have been recorded, traverses across the area were made to determine if ecomomic or subeconomic resources might occur. Eight employee-days were spent in the area. Six rock-chip samples were collected from outcrops; five of these were to evaluate exposed oil-shale beds, and one was to evaluate an iron-stained outcrop. Two stream-sediment samples were taken from

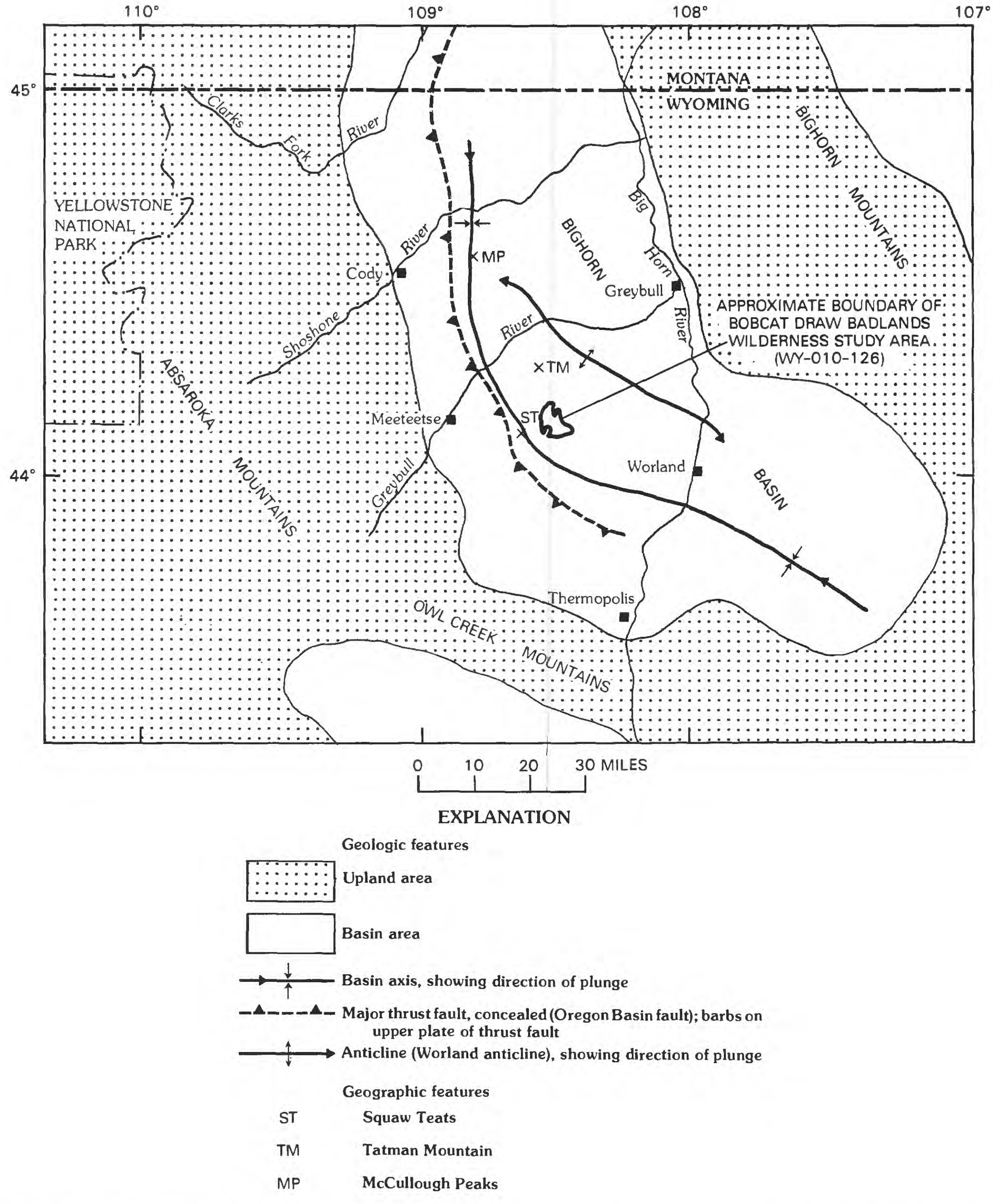


Figure 1. Map of Bighorn basin, Wyoming-Montana, showing geographic setting and major intrabasin structural elements. Structure from Ver Ploeg (1985).

streams that drain the major portion of the area, and scintillometer readings were taken along traverses to investigate the possible presence of exposed radioactive beds as reported in nearby areas by Harris and others (1985).

All eight samples were analyzed by inductively coupled plasma-atomic emission spectrometry for 32 elements by Chemex Labs, Inc., Sparks, Nev., and five oil-shale samples were analyzed for oil content (Fischer-Tropsch process) by J. and A. Associates of Golden,

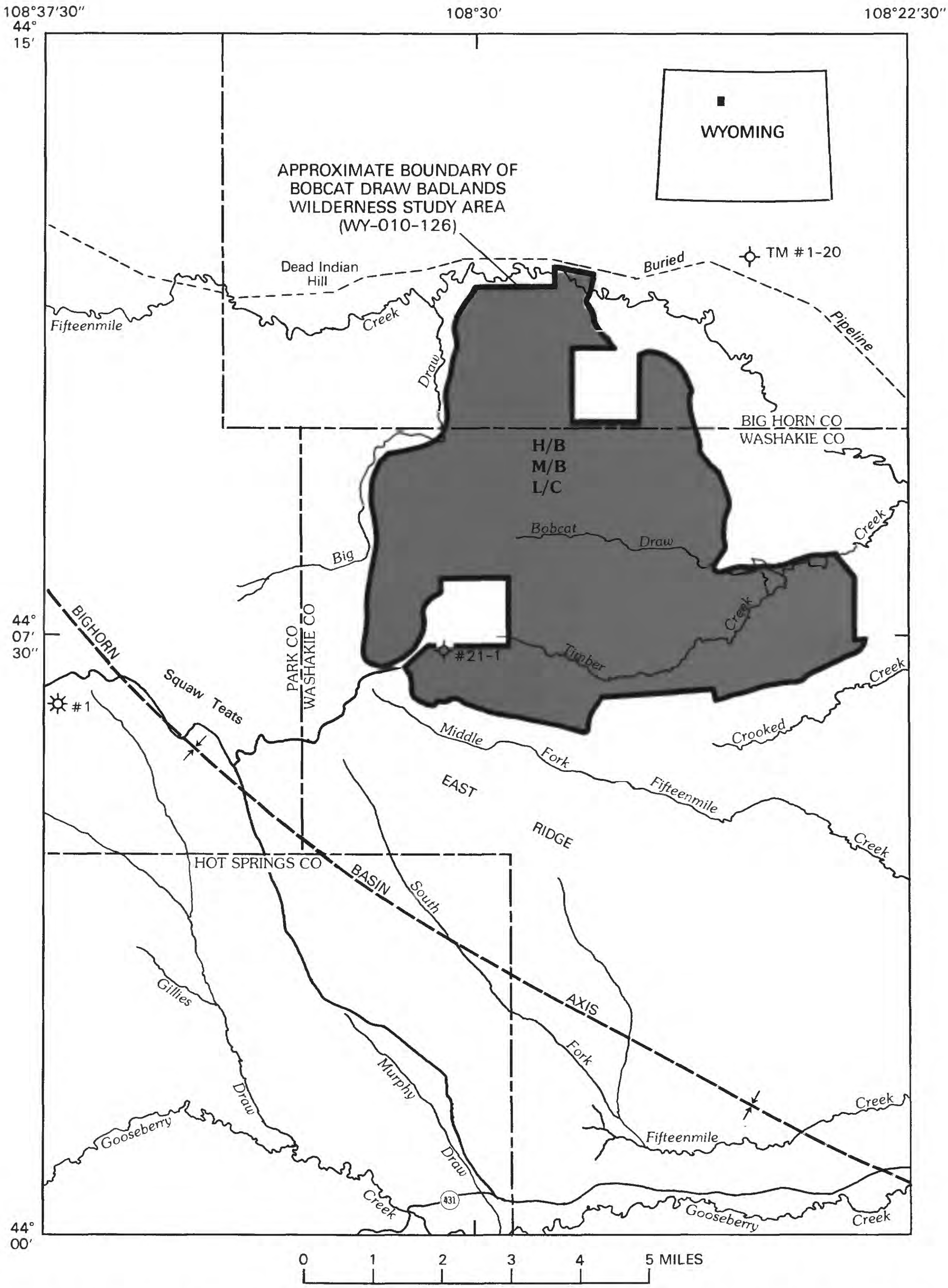
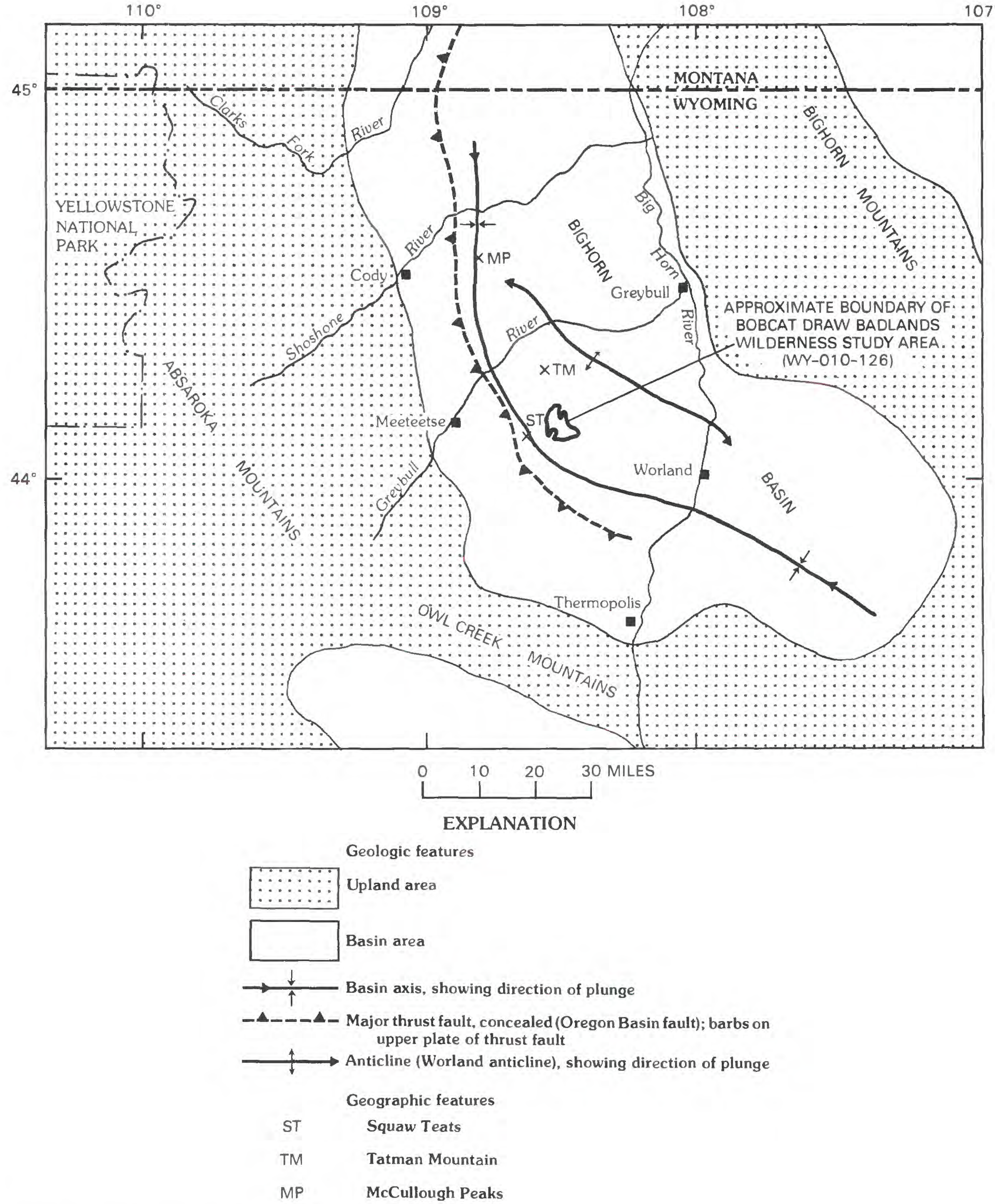


Figure 2 (above and facing page). Map showing location and mineral resource potential of the Bobcat Draw Badlands Wilderness Study Area, Big Horn and Washakie Counties, Wyoming.



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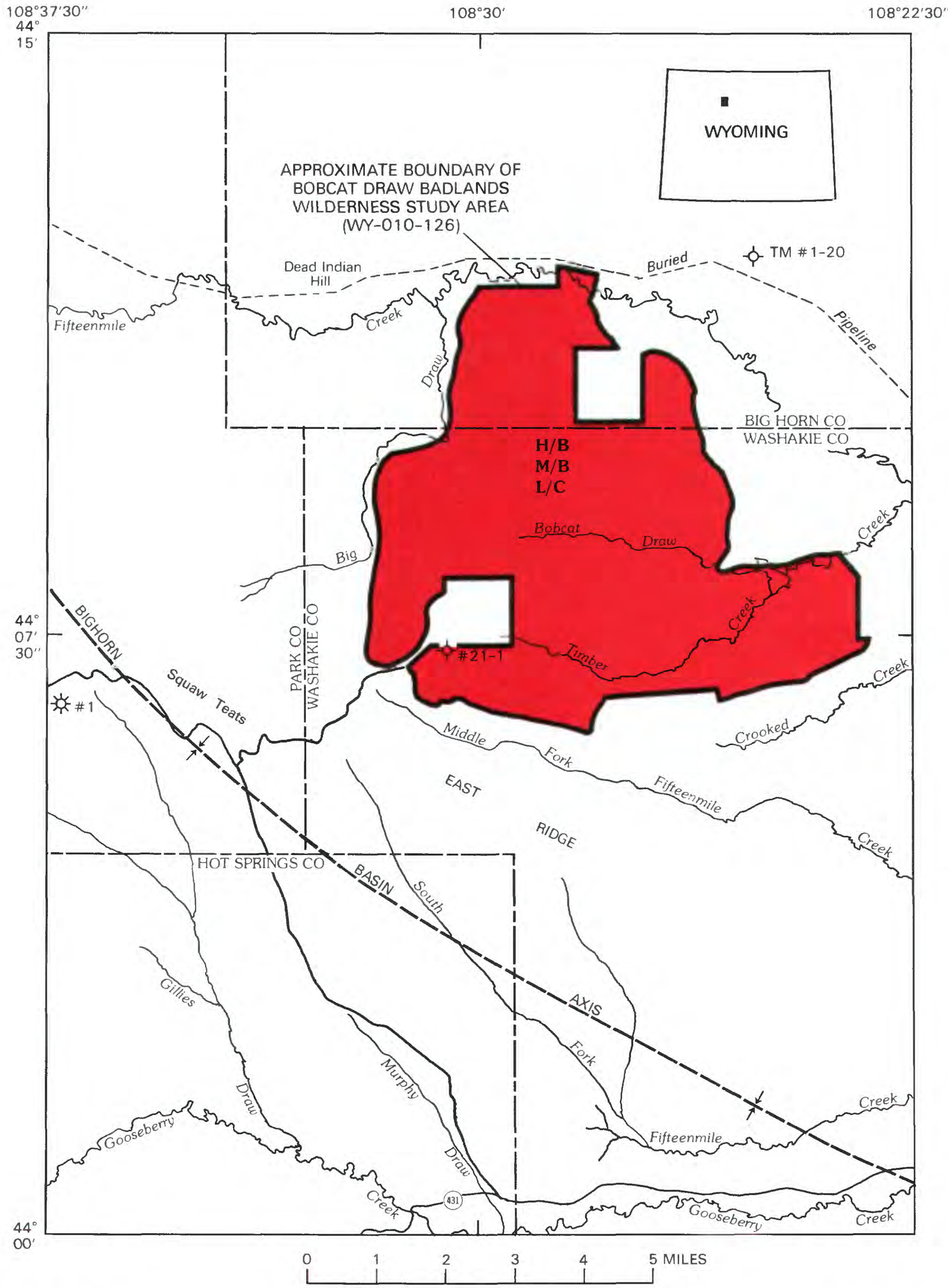


Figure 2 (above and facing page). Map showing location and mineral resource potential of the Bobcat Draw Badlands Wilderness Study Area, Big Horn and Washakie Counties, Wyoming.

EXPLANATION

H/B M/B L/C	Geologic terrane having high energy resource potential for oil and gas and for subeconomic resources of deeply buried coal, with certainty level B, and having moderate energy resource potential for deep-seated geothermal sources, with certainty level B, and having low mineral resource potential for oil shale and metals, including uranium, with certainty level C—Applies to entire study area
	Levels of certainty
B	Available information suggests level of resource potential
C	Available information gives good indication of level of resource potential
	Syncline
	Dry hole
	Gas well

Colo. Complete analytical data are available for inspection at the U.S. Bureau of Mines, Intermountain Field Operations Center, Building 20, Denver, Colorado.

Investigations by the U.S. Geological Survey

The area was studied by U.S. Geological Survey during 1987. A.B. Gibbons prepared a photogeologic map of the Bobcat Draw Badlands Wilderness Study Area and vicinity at a scale of 1:24,000 and field-checked the map in July. R.R. Carlson conducted rock and stream-sediment sampling in July and interpreted analytic data from the samples. D.M. Kulik made gravity measurements in the area and compiled existing data on gravity and magnetics.

Acknowledgments

We thank employees of the Bureau of Land Management in Worland, Wyo., for providing us with aerial photographs, boundary maps, and information on mineral resources from their files.

APPRAISAL OF IDENTIFIED RESOURCES

By William Lundby
U. S. Bureau of Mines

Mining and Exploration History

About two-thirds of the wilderness study area is under lease for gas and oil (fig. 3). Although uranium occurrences have been reported at Squaw Teats, about 3 mi (miles) southwest of the study area (Harris and others, 1985), Bureau of Land Management records indicate that no mining claims are on record for the area, and no evidence of mining exploration activity was found during the field investigation (Lundby, 1988). Commercial bentonite resources within the Bighorn basin are being mined along the eastern and northeastern flanks of the basin, but there are no known nearby deposits.

Energy and Mineral Resources

During this study, no metallic or energy resources were identified. Sand and gravel deposits in stream channels are of poor quality and lack commercial value because of impurities present.

Uranium

Analytical results from rock and stream-sediment samples collected during this study showed no detectable uranium. Radiometric readings along the field traverses were all at a background level, varying from about 30 to 50 counts per second. (See Lundby, 1988.)

Oil Shale

The Tatman Formation, generally resistant to weathering, is exposed in the higher elevations of the study area. The Tatman is composed of drab to light-tan sandstones intermixed with brown papery carbonaceous and calcareous shale and sparse thin (0.5 to 3 ft) beds of poor-quality oil shale (0.8 to 1.9 gpt (gallons of oil per ton of shale); Lundby, 1988). No oil shales are currently being commercially mined in the United States, even though reserves containing 30 gpt have been delineated.

Industrial Minerals

Stream-channel deposits of sand and gravel in the study area generally are lacking commercial value because the drainages contain mostly fine detrital material derived from the weathering of the Willwood and Tatman Formations. Bentonitic zones in the Willwood Formation appear to be of very poor quality and limited extent and are not considered to be identified resources. Physical properties of bentonitic material in the Willwood of the McCullough Peaks area (fig. 1) are reported in Jeske (1987).

Conclusions

No near-surface radioactive-mineral, oil shale, commercial bentonite, or sand and gravel resources were identified within the study area.

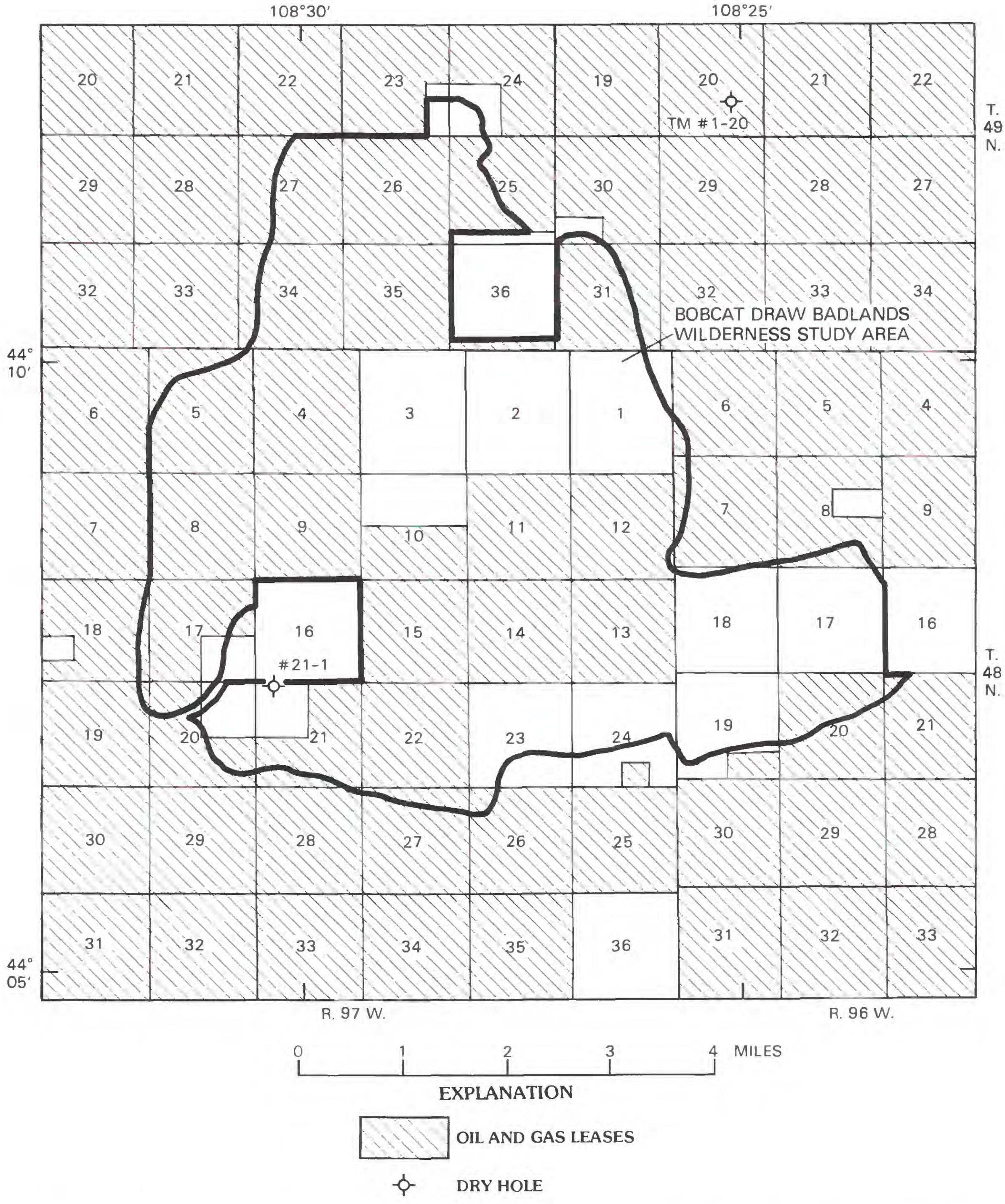


Figure 3. Map showing oil and gas leases and dry holes in and near the Bobcat Draw Badlands Wilderness Study Area, Big Horn and Washakie Counties, Wyoming.

ASSESSMENT OF POTENTIAL FOR UNDISCOVERED RESOURCES

By Anthony B. Gibbons, Robert R. Carlson, and Dolores M. Kulik
U.S. Geological Survey

Geology

Geologic Setting

The Bobcat Draw Badlands Wilderness Study Area is just north of the northwest-trending axis of the Bighorn basin (fig. 1). The Bighorn basin is a deep, asymmetric trough with its steep limb on the southwest. The northeast limb is marked by relatively gentle dips. Within the study area, expression of geologic structure at the surface consists of a southwest dip of the strata that is on the order of 50 ft/mi (feet per mile).

The strong topographic relief of the study area is a geologically young phenomenon. Sand and gravel of the Fenton Pass Formation of probable Pleistocene (glacial) age form the crest of Tatman Mountain (fig. 1) on the north rim of the Fifteenmile Creek drainage (Rohrer and Leopold, 1963). These sediments, deposited by an ancestral trunk drainage that necessarily occupied the lowest tract in this part of the Bighorn basin, now stand at an elevation of about 6,200 ft. The rugged landscape of the study area, all far below the 6,200-ft level, evidently has been carved out since deposition of the Fenton Pass Formation, probably no more than 1.9 million years ago.

The approximately 1,000 ft of rock strata exposed in the study area is underlain in the subsurface by more than 20,000 ft of sedimentary rocks ranging in age from Eocene to Cambrian. The stratigraphy of the area is summarized in table 1. Table 1 is based on well logs down to the top of the Lower Permian Phosphoria Formation; below that, it is as inferred from regional stratigraphic and structural relationships (Stipp, 1952).

Description of Exposed Rock Units

The Bobcat Draw Badlands Wilderness Study Area is underlain by Eocene sedimentary bedrock that is concealed over broad areas by water-laid deposits of Quaternary age (pl. 1). Units are as follows:

Willwood Formation (unit **Twi**, pl. 1).—The oldest exposed unit is the Willwood Formation of late Paleocene and early Eocene age. The Willwood is composed mainly of beds of compact mudstone in shades of yellowish-gray, pink, red, and purple and of yellowish-gray to light-brown sandstone. The formation also includes beds of soft bentonitic shale as much as 15 ft thick and rare beds of carbonaceous shale as much as 5 ft thick. Sandstone beds, locally as much as 30 ft thick, are variably cemented by calcite, and are fine- to medium-grained, commonly crossbedded, and mostly discontinuous. Some sandstone beds fill narrow meandering channels that stand up as sinuous, flat-topped ridges on erosion of the confining mudstone. Segments of one such ridge can be traced on the topographic contours (pl. 1) from SE¼ sec. 7, T. 48 N., R. 96 W., to SE¼ sec. 1, T. 48 N., R. 97 W.; conspicuous crossbedding indicates that the flow of the depositing stream was to the northwest and north.

Van Houten (1944, p. 178) gave a general figure of 2,500 ft for the thickness of the Willwood Formation. A local thickness of 3,270 ft for the Willwood was determined at the site of drillhole TM #1–20 northeast of the study area (pl. 1; fig. 2). Thickness was taken as the vertical distance between the top of the formation, interpolated between mapped contacts on plate 1 and contacts in the Tatman Mountain area to the north (Rohrer, 1964a, b), and the formation base as recognized in the driller's log. Only the uppermost 500 ft of the Willwood is exposed in the study area.

Tatman Formation (unit **Tta**, pl. 1).—The Tatman Formation of Eocene age is composed mainly of brown, brownish-yellow, or brownish-gray beds of soft, bentonitic shale, carbonaceous shale, and oil shale interlayered with beds of yellowish-gray to light-brown sandstone. Minor amounts of limestone also occur. Shale beds are as much as 15 ft thick. Oil shale, characteristically brown or black on a fresh fracture, occurs as hard, fissile, calcareous ledges 0.5 to 3 ft thick that collectively make up an estimated 2 percent of the formation. The white-weathering oil shale generally grades both upward and downward into soft, humic, brown-weathering carbonaceous shale. Shale beds and sequences of shale beds in the Tatman may be traceable laterally for several miles. Most of the sandstone beds are lenticular and less than 15 ft thick. The top of the Tatman Formation is not exposed in the study area; about 550 ft of Tatman strata are preserved in the area.

The Tatman Formation was deposited in a lake, or lakes, that came into existence late in the long episode of early Eocene sedimentation that began with accumulation of the stream-deposited Willwood Formation. Tatman deposition began earliest in the central area of the basin at a time when Willwood sediments were still being laid down by streams entering the basin from the sides. With time, the lakes and their deposits underwent an overall expansion at the expense of the area of Willwood stream deposition (Van Houten, 1944; Rohrer and Smith, 1969, p. 51).

Within the study area, the contact of the Tatman Formation on the Willwood Formation approximates to a simple, concordant plane. Southwestward toward the

Table 1. Stratigraphy of the Bobcat Draw Badlands Wilderness Study Area

[Stratigraphy and nomenclature taken from drillers records. Thicknesses are approximate, taken from well logs and estimated from Stipp, 1952. N/M, not measurable]

Formation	Thickness (ft)
Tertiary	
Tatman Formation	550
Willwood Formation	3270
Fort Union Formation	6231
Cretaceous	
Lance Formation	2386
Meeteetse Formation	(included with Lance)
Mesaverde Formation	1040
Cody Shale	2178
Frontier Formation	585
Mowry Shale	541
Muddy Sandstone	46
Thermopolis Shale	157
Dakota Formation	261
Jurassic	
Morrison Formation	274
Sundance Formation	388
Gypsum Springs Formation	72
Triassic	
Alcova Limestone	14
Red Peak Formation	654
Dinwoody Formation	40
Permian	
Phosphoria Formation	250
Pennsylvanian	
Tensleep Sandstone	375
Amsden Formation	250
Mississippian	
Madison Limestone	450
Devonian	
Three Forks Formation	225
Jefferson Limestone	640
Ordovician	
Bighorn Dolomite	200
Cambrian	
Undifferentiated, but probably includes Gallatin Limestone, Gros Ventre Formation, Flathead Sandstone	1100
Precambrian	
Basement complex composed of crystalline rocks	N/M

rim of the Bighorn basin, however, interfingering of the two units caused by temporary reversals in the expansion of the Tatman lake is observed (Van Houten, 1944). A tongue of the Willwood Formation is shown penetrating the Tatman Formation from the south near the southeast corner of plate 1.

Old pediment deposits (unit **Qpo**, pl. 1).— Unconsolidated silt, sand, and angular, soft-rock gravel of local origin. Deposits form a thin veneer on sloping erosion surfaces that persist as remnants standing above present-day streams. Unit is as much as 5 ft thick.

Pediment and tributary stream alluvium (unit **Qpt**, pl. 1).—Unconsolidated clay, silt, sand, and mostly fine, angular soft-rock gravel of local origin. Along Fifteenmile Creek includes deposits of low terraces and of alluvial fans and cones. In headwaters of tributary streams, includes colluvium. Unit is as much as 30 ft thick.

Alluvium of Fifteenmile Creek (unit **Qal**, pl. 1).—Unconsolidated clay, silt, sand, and sparse gravel. Gravel consists of quartzite and some dark igneous rock as rounded pebbles and cobbles as much as 5 in. (inches) in diameter. Unit includes deposits underlying floodplain and lowest terraces. Thickness as much as 20 ft.

Quiet-water silt and clay (unit **s**, pl. 1).— Unconsolidated silt and clay filling silted reservoir.

Geochemistry

A reconnaissance geochemical survey was conducted in the Bobcat Draw Badlands Wilderness Study Area in July 1987. Stream sediments and panned concentrates derived from stream sediments were collected at 47 sites in and adjacent to the area and represent a sampling density of about one site per 0.6 mi^2. The sediments and concentrates were subsequently prepared and analyzed as minus-80-mesh (less than 0.007 in. in diameter) sediments and nonmagnetic heavy-mineral concentrates, respectively. These sample media represent a composite of rock and soil materials exposed in the drainage basin, upstream of each sample site. The minus-80-mesh sediment gives the general chemical signature of the basin with some enhancement of elements that tend to adsorb on clay minerals. The heavy-mineral concentrate enhances the detection of anomalous elements, including those associated with mineralization that may occur in the drainage basin.

Analytical Methods

The minus-80-mesh sediments were analyzed for 35 elements by a semiquantitative emission spectrographic method (Grimes and Marranzino, 1968) and for 5 elements by inductively coupled plasma atomic emission spectrography as described by Crock and others (1987). Analysis for uranium was by the hot nitric acid digestion method (Procedure B) of O'Leary and Meier (1984). The nonmagnetic heavy-mineral concentrates were analyzed for 37 elements by the Grimes and Marranzino (1968) semiquantitative emission spectrographic method. In addition, mineralogical splits of the concentrates were examined for visible evidence of mineralization or of contamination from human activities in the study area. Analytical data for the samples, a description of the sampling and analytical techniques used, and a sample locality map are in the files of M. J. Malcolm and R. R. Carlson.

Results of Study

Examination of analytical results and comparison to the geology of the area showed no anomalous concentrations, groupings, or patterns of elements associated with mineral deposits. Barite is ubiquitous in the heavy-mineral concentrates, of which it may constitute more than 1 percent. In the absence of other anomalous elements indicating hydrothermal activity, the barite is considered to be of sedimentary origin and of much too low a concentration (less than 0.01 percent barium in the stream sediment) to represent a potentially valuable barite occurrence. Panned concentrates from basins draining mainly Tatman Formation rocks were very slightly elevated in cobalt, copper, and nickel values compared to basins draining mostly Willwood Formation rocks. These differences are attributed to differences in the chemical background levels for the two units, and in no instance did values for any of these three elements exceed 0.005 percent in the heavy-mineral concentrates. Uranium values in the stream sediments presented no anomalous patterns and showed no significant values for the area (ranging from only 0.25 to 3.1 parts per million).

Geophysics

Geophysical data provide information on the subsurface distribution of rock masses and the structural framework. Gravity and magnetic studies were undertaken as part of the mineral resource assessment of the Bobcat Draw Badlands Wilderness Study Area. The gravity survey coverage is generally sparse, allowing only regional interpretation. In this study area, however, some local interpretation is warranted, as explained below.

The gravity data were obtained in and adjacent to the study area in 1987, and were supplemented by data maintained in the files of the Defense Mapping Agency of the Department of Defense. The data are shown as a complete Bouguer anomaly map in figure 4. Stations measured for this study were established using Worden gravimeter W-177. The stations were tied to the International Gravity Standardization Net 1971 (U.S. Defense Mapping Agency Aerospace Center, 1974) at base station ACIC 1651–1 at Cody, Wyo. Station elevations were obtained from benchmarks, spot elevations, and estimations from topographic maps at 1:24,000 scale and are accurate to ± 20 ft. The error in the Bouguer value, which is less than ± 1.2 mGal (milligals), is due to errors in elevation control. Bouguer anomaly values were computed using the 1967 gravity formula (International Association of Geodesy, 1967) and a reduction density of 2.67 g/cm^3 (grams per cubic centimeter). Mathematical formulas are given in Cordell and others (1982). Terrain corrections were made by computer for a distance of 100 mi from the station using the method of Plouff (1977).

A major gravity low is associated with the Bighorn basin (fig. 4). Gravity values increase to the west, south, and east as higher density rocks of the flanking ranges are approached. The axis of the gravity low remains close to the mapped axis of the Bighorn basin in the northern part of the area of figure 4 but is strongly divergent in the southern part of the map, as in the vicinity of point A. The gravity data indicate that the structurally deepest part of the basin lies near the bounding Oregon Basin fault and that low density sedimentary rocks extend southwestward beneath the fault, particularly in the area of anomaly B. The high gravity nose (C) suggests that a mass of relatively high-density basement rocks extends into the basin beneath this part of the mapped axis.

A residual intensity magnetic anomaly map is shown in figure 5. The data north of lat 44° N. are from the Cody quadrangle (U.S. Department of Energy 1982a), and the data south of lat 44° N. are from the Thermopolis quadrangle (U.S. Department of Energy 1982b). Flight lines were flown east-west at 3- to 5-mile intervals and 400 ft above the ground surface.

Large magnetic highs (F and G) are caused by bodies of relatively high magnetic susceptibility in the basement beneath the sedimentary rocks of the basin. Extending across the southern part of the area of figure 5, the magnetic low (H) culminates to the south of the map area in the area north of the town of Thermopolis (fig. 1) and adjacent Hot Springs State Park. At its culmination, the low is bounded by steep gradients on both north and south. It may be caused by a linear body of low magnetic susceptibility that is fault-bounded, or more likely, by a broad fault zone that has acted as a conduit for hydrothermal fluids. A less conspicuous magnetic low occurs southwest of the wilderness study area and trends north-northwest. Passing between magnetic highs G and F, it is roughly parallel to a segment of the Oregon Basin fault and in partial coincidence with the gravity low associated with the Bighorn basin. This low may also reflect hydrothermal alteration along a fault zone.

In the study area, both gravity and magnetic data indicate local structural complications. The regionally smooth gravity gradient is interrupted over the study area by east-west-trending gravity noses (D and E, fig. 4). These noses suggest that east-west-trending faults and (or) folds are present in the subsurface. Magnetic data, though widely spaced and flown parallel to the local east-west structures interpreted from gravity, also exhibit a high nose (E) in the northern part of the study area (fig. 5). Magnetic anomalies indicate changes in the lithology or depth of crystalline basement rocks; therefore, the magnetic anomaly indicates that the faults interpreted from the gravity data affect the basement rocks. The correlation of these east-west-trending structures within the Bighorn basin with the trends of regional magnetic anomalies suggests that the east-west structures may be controlled by faulting at depth in the basement, whereas the northwest-trending structures, such as the Worland anticline, which are not expressed in the magnetic data, may be confined to the sedimentary section.

Mineral and Energy Resource Potential

Oil and Gas

The Bobcat Draw Badlands Wilderness Study Area is part of the Bighorn Basin petroleum province, a prolific producer in the past, and lies in a broad tract that is generally favorable for the occurrence of hydrocarbon resources. It is underlain by thick sequences of sedimentary rocks that include known reservoir beds, such as those of the Frontier Formation, Muddy Sandstone, and Cloverly Formation ("Dakota" of drillers), all Cretaceous, and of the Phosphoria Formation (Permian), Tensleep Sandstone (Pennsylvanian), and Madison Limestone (Mississippian). The Phosphoria also includes recognized hydrocarbon source rocks for petroleum. The U.S. Bureau of Land Management (1986, ch. III, p. III–23) assigns the study area a high potential for the occurrence of oil and gas. Spencer (1983, p. M7) also assigns the study area a high potential for undiscovered hydrocarbon accumulations. In the axial region of the Bighorn basin, which includes the study area, the major resource would be gas, with some oil, localized in stratigraphic traps in low-permeability sandstones (Spencer, 1987) of the Cretaceous to Tertiary section as well as in conventional reservoirs.

Geophysical data assembled for this investigation point to the possible presence of structural traps. Basement rocks of the Rocky Mountain foreland are

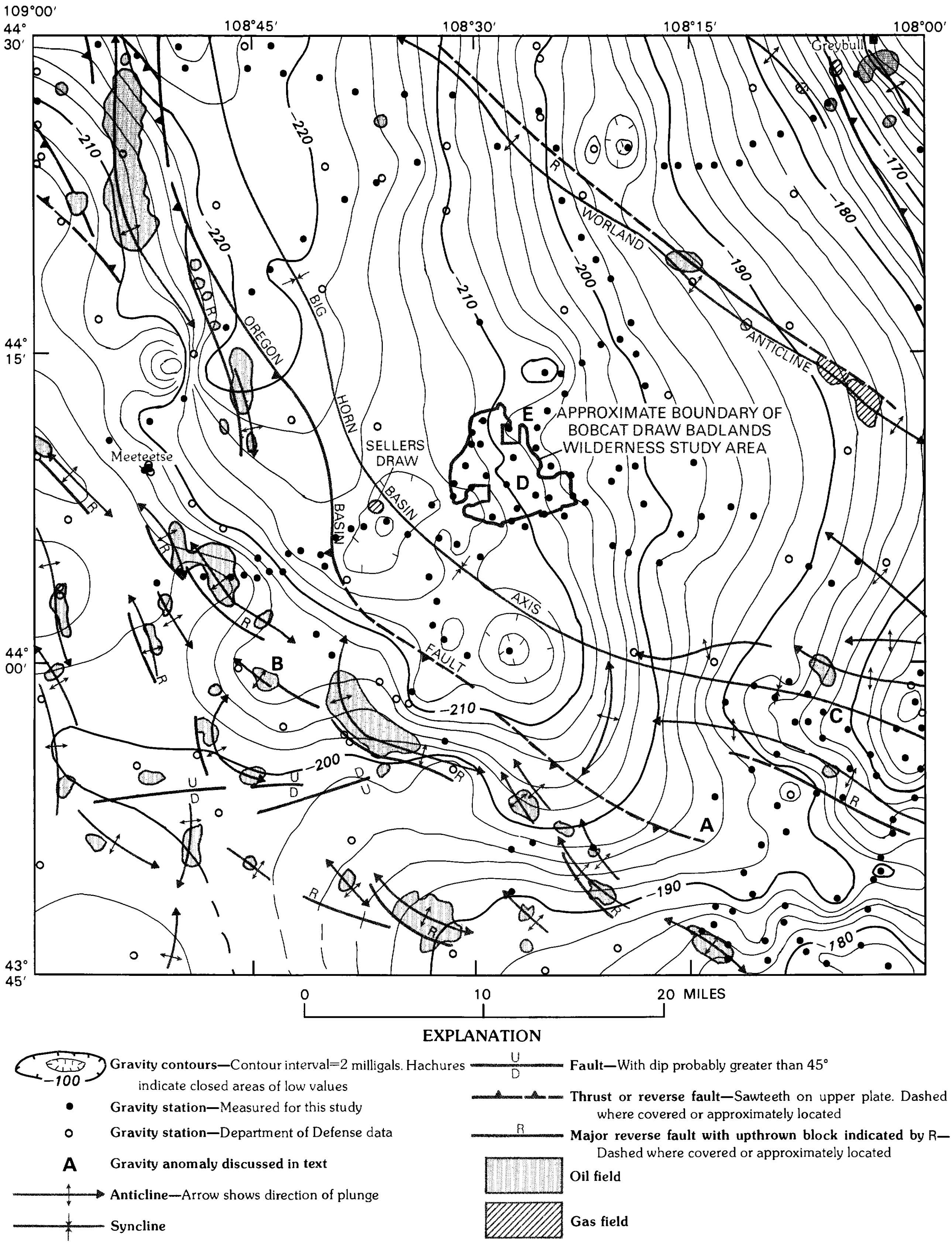
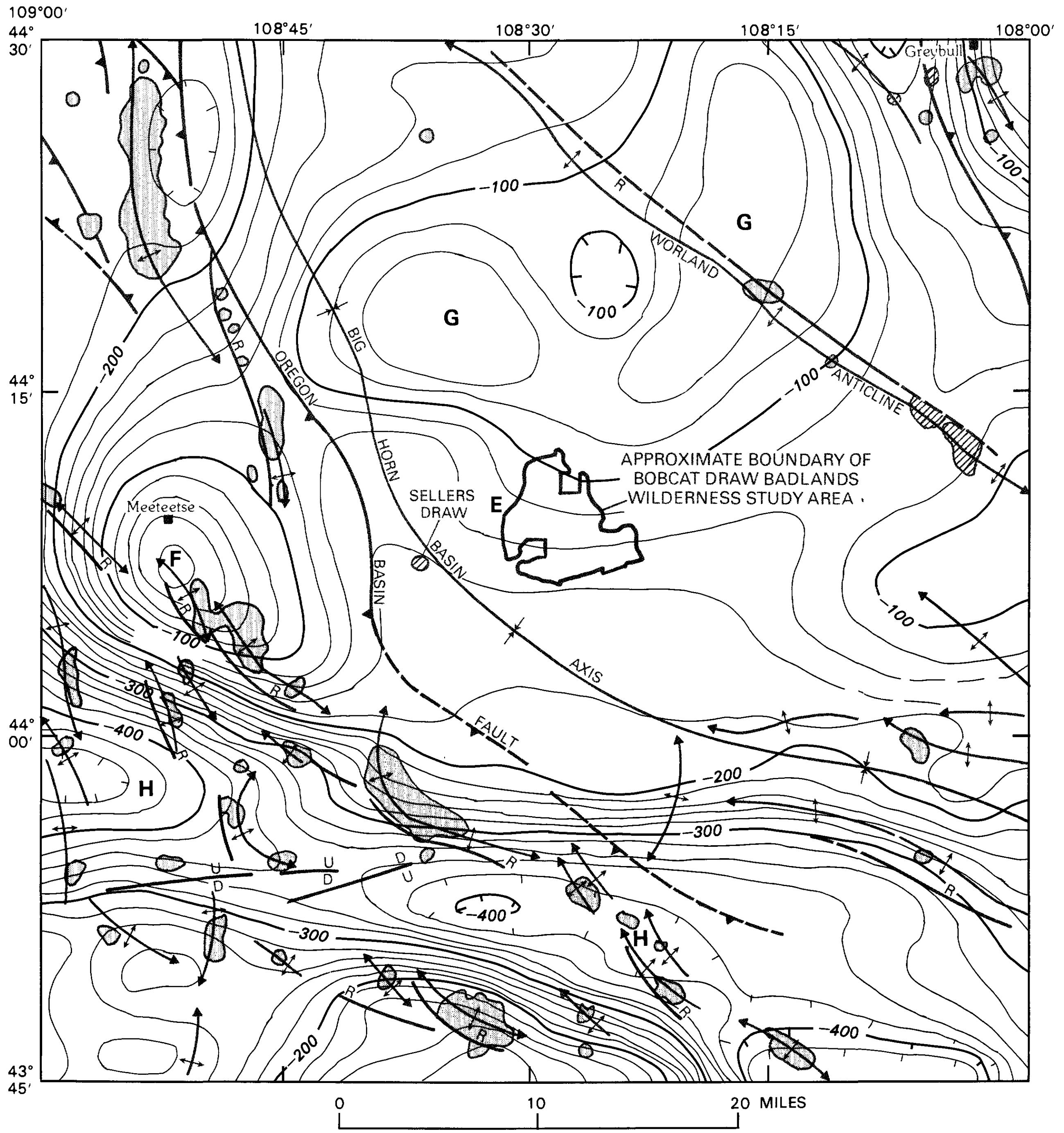


Figure 4. Complete Bouguer gravity anomaly map of the Bobcat Draw Badlands Wilderness Study Area and surrounding area. Structure from Ver Ploeg (1985). Contour interval = 2 mG (milligals).



EXPLANATION

- **Aeromagnetic contours**—Contour interval=20 nanoTeslas. Hachures indicate closed areas of low values
- E **Aeromagnetic anomaly discussed in text**
- **Anticline**—Arrow shows direction of plunge
- **Syncline**
- **Fault**—With dip probably greater than 45°
- **Thrust or reverse fault**—Sawteeth on upper plate. Dashed where covered or approximately located
- R **Major reverse fault with upthrown block indicated by R**—Dashed where covered or approximately located
- **Oil field**
- **Gas field**

Figure 5. Residual intensity aeromagnetic anomaly map of the Bobcat Draw Badlands Wilderness Study Area and surrounding area. Structure from Ver Ploeg (1985). Contour interval = 20 nT (nanoTeslas).

commonly offset along faults that formed or were reactivated during the Laramide orogeny in Late Cretaceous to Eocene time. The overlying sedimentary rocks were also affected by this deformation, and structures favorable for hydrocarbon accumulation may be present along basement-cored faults and (or) associated folds. The potential of the wilderness study area for undiscovered resources of oil and gas is high with certainty level B.

Geothermal Sources

The study area is without hot springs or other evidence of earth temperatures that are exceptionally high in relation to depth. Geothermal energy would have to come from the deep subsurface where high temperatures are usually present.

Much of the Bighorn basin is underlain by aquifers under strong artesian pressure that contain thermal waters with temperatures greater than 122°F (Heasler and others, 1983). In most parts of the basin, including the part in which the study area is located, the increase of temperature with depth is in the normal range, about 16°F per 1,000 ft, so that thermal water would occur only at great depth. However, where it could be tapped by an existing drillhole, deep thermal water may constitute a resource (Heasler and others, 1983).

The stratigraphically highest of the thermal aquifers is the Tensleep Sandstone of Pennsylvanian age (table 1). In the axial region of the Bighorn basin, the Tensleep occurs at a depth of 18,000–22,000 ft. However, of the three deep oil and gas tests drilled in the vicinity of the study area (pl. 1; fig. 2; table 2), two are inferred to have been completed within 2,000 ft of the top of the Tensleep. The third, well #1, 23,081 ft deep, actually passed through the expected position of the Tensleep, which appears to be missing or displaced by structural deformation at this site.

Where an aquifer is encountered at the extreme depths attained by the oil and gas tests cited, its temperature can be expected to be high. The highest temperature recorded in the Bighorn basin, about 306°F, was encountered at a depth of approximately 23,000 ft (Heasler and others,1983). This is about the same as the total depth of well #1. In view of the depths already reached by drilling for oil and gas, it is possible that a test drillhole in the wilderness study area could be developed into a source of geothermal energy producing steam or hot water. The resource potential for deep-seated geothermal energy is moderate with certainty level B, based on sparse information. Key evaluative data that are lacking include the local earth temperatures at the depth of the Tensleep Sandstone and the local permeability of the Tensleep.

Table 2. Data on oil and gas test wells in and near Bobcat Draw Badlands Wilderness Study Area, Wyoming

[From individual well records in files of U.S. Bureau of Land Management, Worland District, Worland, Wyoming]

Designation	Operating Company	Field	Location	County	Drilling Date(s)	Productive Formation	Lowest Formation Tested	Total Depth (ft)
#1	American Quasar Petroleum Company of New Mexico	Sellers Draw Unit II	SE¼SW¼ sec. 21, T. 48 N., R. 98 W. (See fig 2)	Park	1974–1977	Muddy	Phosphoria	23,081
#21–1	American Quasar Petroleum Company	Ridge Unit	NW¼NW¼ sec. 21, T. 48 N., R. 97 W. (See fig 2; pl. 1)	Washakie	1978–1979		"Dakota" of drillers	18,286
TM #1–20 (Tatman Mtn.)	Santa Fe Energy Company	Wildcat	NW¼SE¼ sec. 20, T. 49 N., R. 96 W. (See fig. 2; pl. 1)	Big Horn	1981		Morrison	16,145

Oil Shale

The Tatman Formation contains thin beds of oil shale that make up less than 5 percent of the formation. In tests made in support of this investigation (Lundby, 1988) and an earlier study (Rohrer and Smith, 1969), oil shale samples from the Tatman proved without exception to be very low grade. The energy resource potential for oil shale is low, with certainty level C.

Coal

Coal beds of subbituminous rank are present in the subsurface over most of the Bighorn basin (Glass, 1978). In the study area, however, the known coal-bearing formations are buried by coal-poor strata belonging to the Willwood and Tatman Formations to a minimum depth of 2,500 ft. Beneath these formations is the Fort Union Formation of Paleocene age (table 1), which commonly contains thick, continuous beds of subbituminous coal. Such coal in the upper half of the Fort Union would meet the definition of subeconomic coal resources (Wood and others, 1983). They would be classed as subeconomic because of the depth—more than 1,000 ft—at which they occur. The study area has a high resource potential for subeconomic resources of coal with a certainty level of B.

Uranium

The likelihood of undiscovered resources of uranium at or near the surface in the wilderness study area is very slight. Absence of evidence of prospecting or mining activity and consistently low levels of radioactivity observed on the outcrop indicate that there is little uranium in the surface rocks. Chemical analyses of surface samples of rock and stream sediment collected during this study show no anomalous concentrations of uranium (Lundby, 1988; and data in the files of M.J. Malcolm and R.R. Carlson). The subsurface is largely unexplored, but appears unpromising. Both the Tertiary rocks and the Upper Cretaceous rocks of the Bighorn basin, together comprising 15,000 ft of strata down to the base of the Frontier Formation, are characteristically uranium-poor (Harris, 1983, p. 171). The study area is assigned a low resource potential for uranium with certainty level C.

Metals Other Than Uranium

The Bobcat Draw Badlands Wilderness Study Area has a low mineral resource potential for metals other than uranium with certainty level C. This evaluation is based the absence of favorable environments for metallic deposits, the lack of any mineralized rock or geochemical anomalies, and the lack of mines or prospects within the area.

REFERENCES CITED

Cordell, Lindreth, Keller, G.R., and Hildenbrand, T.G., 1982, Bouguer gravity map of the Rio Grande Rift, Colorado, New Mexico, and Texas: U.S. Geological Survey Geophysical Investigations Series Map GP–949, scale 1:1,000,000.

Crock, J.G., Briggs, P.H., Jackson, L.L., and Lichte, F.E., 1987, Analytical methods for the analysis of stream sediments and rocks from wilderness study areas: U.S. Geological Survey Open File Report 87–84, p. 22–28.

Glass, G.B. 1978, Wyoming coal fields, 1978: Geological Survey of Wyoming Public Information Circular no. 9, 70 p.

Goudarzi, G.H., compiler, 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.

Harris, R.E., 1983, Uranium and thorium in the Bighorn Basin, *in* Boberg, W.W., ed., Geology of the Bighorn Basin: Casper, Wyoming, Wyoming Geological Association Guidebook, Thirty-fourth Annual Field Conference, p. 171–177.

Harris, R.E., Hausel, W.D., and Meyer, J.E., 1985, Metallic and industrial minerals map of Wyoming: Geological Survey of Wyoming Map Series 14, scale 1:500,000.

Heasler, H.P., Hinckley, B.S., Buelow, K.G., Spencer, S.A., and Decker, E.R., 1983, Geothermal resources of Wyoming: National Geophysical Data Center, National Oceanic and Atmospheric Administration, scale 1:500,000.

International Association of Geodesy, 1967, Geodetic Reference System, 1967: International Association of Geodesy Special Publication No. 3, 116 p.

Jeske, R.E., 1987, Mineral investigation of the McCullough Peaks Wilderness Study Area (WY–010–335), Park County, Wyoming: U.S. Bureau of Mines Open File Report MLA 74–87, 17 p.

Lundby, William, 1988, Mineral investigation of the Bobcat Draw Badlands Wilderness Study Area (WY–010–126), Big Horn and Washakie Counties, Wyoming: U.S. Bureau of Mines Open File Report MLA 24–88, 16 p.

O'Leary, R.M., and Meier, A.L., 1984, Analytical methods used in geochemical exploration: U.S. Geological Survey Circular 948, p. 42–45.

Plouff, Donald, 1977, Preliminary documentation for a FORTRAN program to compute gravity terrain corrections based on topography digitized on a geographic grid: U.S. Geological Survey Open-File Report 77–535.

Rohrer, W.L., 1964a, Geology of the Sheep Mountain quadrangle, Wyoming: U.S. Geological Survey Geologic Quadrangle Map GQ–310, scale 1:24,000.

——— 1964b, Geology of the Tatman Mountain quadrangle, Wyoming: U.S. Geological Survey Geologic Quadrangle Map GQ–311, scale 1:24,000.

Rohrer, W.L., and Leopold, E.B., 1963, Fenton Pass Formation (Pleistocene?), Bighorn Basin, Wyoming: Article 71 *in* U.S. Geological Survey Professional Paper 475–C, p. C45–C48.

Rohrer, W.L., and Smith, J.W., 1969, Tatman Formation, *in* Barlow, J.A., ed., Symposium on Tertiary rocks of Wyoming: Casper, Wyoming, Wyoming Geological Association, Guidebook for Field Trips, 1969, p. 49–54.

Spencer, C.W., 1983, Petroleum potential of wilderness lands in Wyoming, *in* Miller, B.M., ed., Petroleum potential of wilderness lands in the western United States: U.S. Geological Survey Circular 902–A–P, p. M1–M10.

——— 1987, Hydrocarbon generation as a mechanism for overpressuring in the Rocky Mountain region: American Association of Petroleum Geologists Bulletin, v. 71, no. 4, p. 368–388.

Stipp, T.F., 1952, Paleozoic formations of the Big Horn Basin, Wyoming: Wyoming Geological Association, Guidebook, Seventh Annual Field Conference, Southern Big Horn Basin, Wyoming, p. 126–128.

U.S. Bureau of Land Management, 1986, Grass Creek/Cody Wilderness Suitability Environmental Impact Statement, Preliminary Final Report, Worland District, 247 p. [unpublished report in the files of the Bureau of Land Management, Worland, Wyoming].

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. Defense Mapping Agency, Aerospace Center, 1974, World Relative Gravity Reference Network, North America, Part 2: Defense Mapping Agency Aerospace Center Reference Publication 25, with supplement updating Gravity Standardization Net, 1971, 1635 p.

U.S. Department of Energy, 1982a, Cody quadrangle: Residual Intensity Magnetic Anomaly Contour Map, GJM–099, pl. 4, scale 1:250,000.

——— 1982b, Thermopolis quadrangle: Residual Intensity Magnetic Anomaly Contour Map, GJM–095, pl. 4, scale 1:250,000.

Van Houten, F.B., 1944, Stratigraphy of the Willwood and Tatman Formations in northwestern Wyoming: Geological Society of America Bulletin, v. 55, p. 165–210.

Ver Ploeg, A.J., 1985, Tectonic map of the Bighorn Basin, Wyoming, oil and gas development posted through July, 1985: Geological Survey of Wyoming Open-File Report 85–11, 1 sheet, scale 1:250,000.

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

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:

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 (or)	
	Measured	Indicated		Hypothetical	Speculative
ECONOMIC	Reserves		Inferred Reserves		
MARGINALLY ECONOMIC	Marginal Reserves		Inferred Marginal Reserves		
SUB-ECONOMIC	Demonstrated Subeconomic Resources		Inferred Subeconomic Resources		

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

GEOLOGIC TIME CHART

Terms and boundary ages used in this report

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

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

[2] Informal time term without specific rank.

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