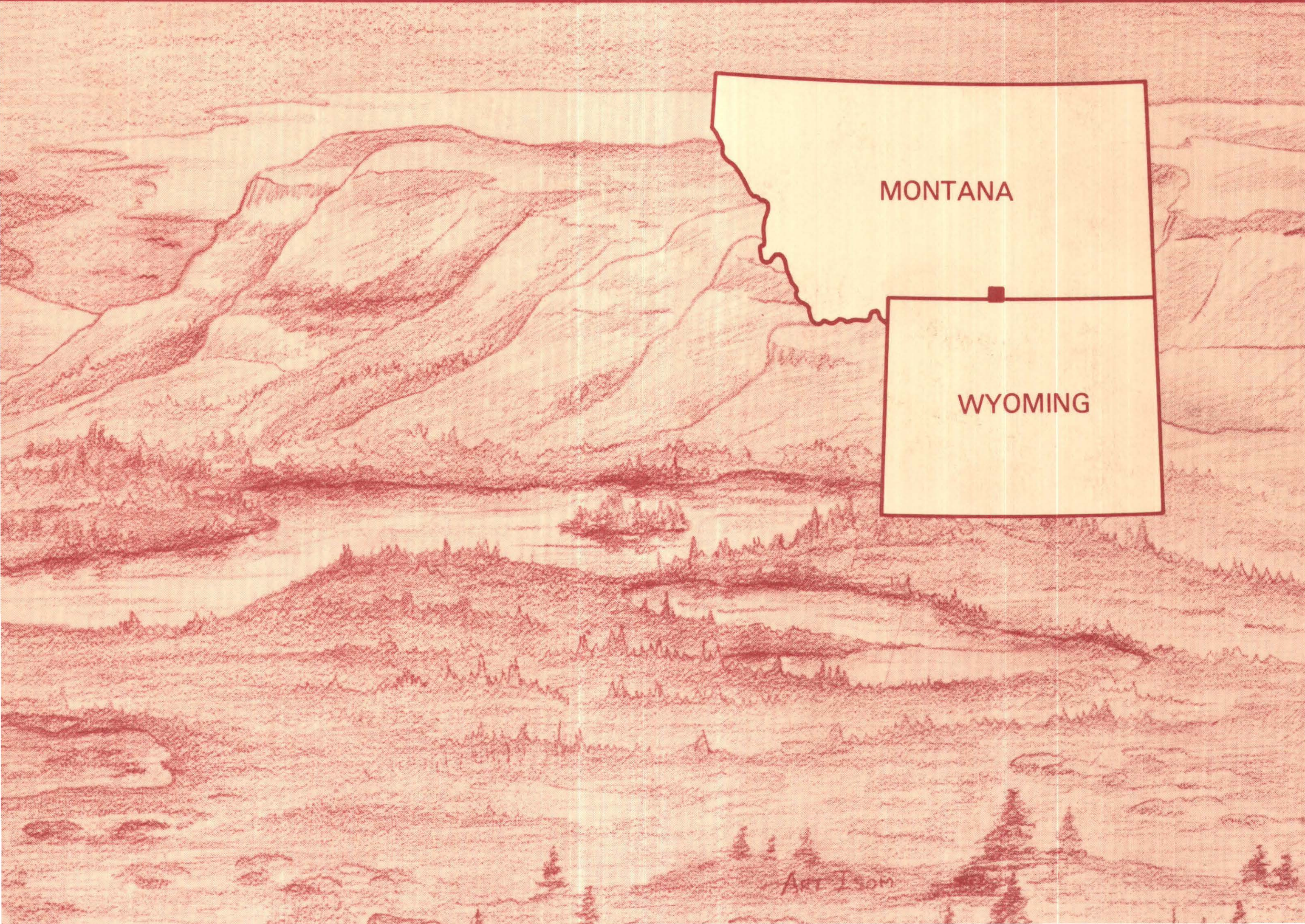
Mineral Resources of the Pryor Mountain, Burnt Timber Canyon, and Big Horn Tack-On Wilderness Study Areas, Carbon County, Montana, and Big Horn County, Wyoming

U.S. GEOLOGICAL SURVEY BULLETIN 1723



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MINERAL RESOURCES OF WILDERNESS STUDY AREAS—
SOUTH-CENTRAL MONTANA AND NORTH-CENTRAL WYOMING

DEPARTMENT OF THE INTERIOR
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STUDIES RELATED TO WILDERNESS

Bureau of Land Management Wilderness Study Areas

The Federal Land Policy and Management Act (Public Law 94–579, October 21, 1976) requires the U.S. Geological Survey and the U.S. Bureau of Mines to conduct mineral surveys on certain areas to determine the mineral values, if any, that may be present. Results must be made available to the public and be submitted to the President and the Congress. This report presents the results of a mineral survey of the Pryor Mountain (MT–067–206) Wilderness Study Area and of parts of the Burnt Timber Canyon (MT–067–205) and Big Horn Tack-On (MT–067–207) Wilderness Study Areas, Carbon County, Montana, and Big Horn County, Wyoming.

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PLATE

[Plate is in pocket]

FIGURES

Mineral Resources of the Pryor Mountain, Burnt Timber Canyon, and Big Horn Tack-On Wilderness Study Areas, Carbon County, Montana, and Big Horn County, Wyoming

By Charles G. Patterson, Margo I. Toth, *and* Dolores M. Kulik
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SUMMARY

The USBM (U.S. Bureau of Mines) and the USGS (U.S. Geological Survey) assessed the identified mineral resources (known) and the mineral resource potential (undiscovered) of the Pryor Mountain (MT–067–206), Burnt Timber Canyon (MT–067–205), and Big Horn Tack-On (MT–067–207) Wilderness Study Areas in Montana and Wyoming. There are no identified resources in the study areas. The mineral resource potential for uranium and vanadium is high or moderate in parts of the Pryor Mountain Wilderness Study Area, high in part of the Burnt Timber Canyon Wilderness Study Area, and moderate in the entire Big Horn Tack-On Wilderness Study Area (fig. 1). The mineral resource potential for uranium and vanadium is low in the remainder of the wilderness study areas. The southern part of the Pryor Mountain Wilderness Study Area has moderate mineral resource potential for bentonite. All three wilderness study areas have low potential for all metals (other than uranium and vanadium), oil and gas, geothermal sources, and high-purity limestone. There is no potential for sand and gravel in the wilderness study areas.

The Pryor Mountain, Burnt Timber Canyon, and Big Horn Tack-On Wilderness Study Areas are at the northeastern edge of the Big Horn Basin (fig. 1), in the central and eastern parts of the Pryor Mountains, a northwest extension of the Big Horn Mountains. The northern and western parts of the study areas are characterized by west-sloping plateaus, which are deeply incised by narrow canyons. Some badlands topography is found in the southern part of the Pryor Mountain Wilderness Study Area. Extensive subterranean drainage over limestone areas plus low rainfall does not allow for perennial streams. Elevations in the study areas range from a high of 8,500 ft (feet) to a low of about 3,760 ft, both in the Pryor Mountain Wilderness Study Area.

Rocks exposed in the study areas consist mainly of folded and faulted Paleozoic (see geologic time chart in Appendix for relative ages) limestone, quartzite, and dolomite, and minor amounts of Mesozoic sandstone and shale; crystalline rocks of Late(?) Archean age occur along a fault to the north. The Madison Limestone of Mississippian age is the major rock unit exposed in the wilderness study areas. Alluvial deposits are present along stream courses and on divides between the streams, and landslide deposits mantle hillslopes underlain by the Gros Ventre Formation.

All three wilderness study areas have been heavily prospected for uranium and associated vanadium. Workings on 500 claims (in 29 claim groups and 2 prospects) were examined for uranium and vanadium and other commodities but no mineral or energy resources were identified. An unquantified but small amount of bentonitic rock lies in the southern part of the Pryor Mountain Wilderness Study Area.

Mining activity in the Pryor Mountains began with prospecting for radioactive minerals in 1956, and continued in 1957 and in the early 1970's. This led to the discovery of numerous small occurrences and a total production from 19 properties of about 0.5 million pounds of uranium and vanadium. Significant deposits

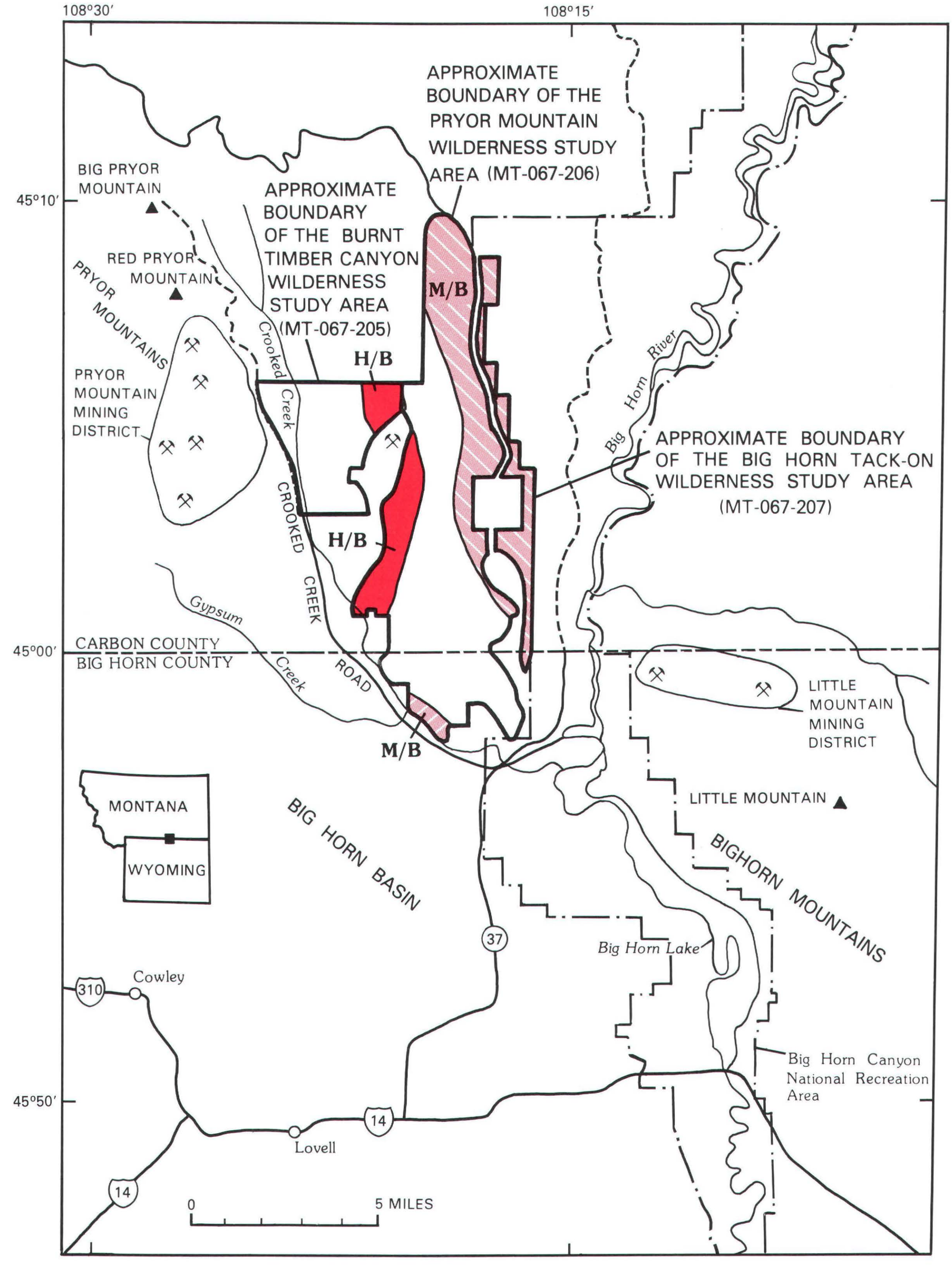


Figure 1 (above and facing page). Mineral resource potential and location of the Pryor Mountain, Burnt Timber Canyon, and Big Horn Tack-On Wilderness Study Areas, Montana and Wyoming.

EXPLANATION

[Unless noted otherwise, the study areas have low potential for all metals, oil and gas, geothermal sources, and high-purity limestone, with certainty level C. The southern part of the Pryor Mountain study area has low potential for uranium and vanadium in the Morrison and Cloverly Formations, with certainty level C. The study areas have no potential for sand and gravel]

- **H/B** Geologic terrane having high mineral resource potential for uranium and vanadium in the Madison Limestone, with certainty level B
- **M/B** Geologic terrane having moderate mineral resource potential for uranium and vanadium in the Madison Limestone, with certainty level B
- **M/B** Geologic terrane having moderate mineral resource potential for bentonite, with certainty level B
- ⚒ Mine
- ------ Unpaved road

of uranium in the region occur on Red Pryor Mountain, to the northwest of the study areas, and at Little Mountain to the southeast. Most of this production was within 5 mi (miles) west of the three study areas. Additional resources exist, but most of these properties have not produced since the late 1950's. A significant, but unquantified uranium-vanadium occurrence located at the East Pryor mine is adjacent to the Pryor Mountain Wilderness Study Area. Abundant local uranium and vanadium reserves outside the study areas, a depressed uranium market, lack of uranium milling facilities, and difficulty of prospecting for new deposits make exploration for new deposits unlikely in the near future.

Outcrops of the basal part of the Thermopolis Shale contain some impure, thin beds of bentonite in the southern part of the Pryor Mountain Wilderness Study Area. Abundant local reserves of better quality and quantity outside the study area preclude development of these occurrences. Limestone and dolomite of agricultural grade occur throughout the study areas. Abundant local supplies outside the study areas and low demand should discourage development in the foreseeable future.

The mineral resource potential for uranium and vanadium in the Madison Limestone is high or moderate in parts of the Pryor Mountain Wilderness Study Area, high in part of the Burnt Timber Canyon Wilderness Study Area, and moderate in the entire Big Horn Tack-On Wilderness Study Area (fig. 1). Elsewhere in the study areas the mineral resource potential for uranium and vanadium in the Madison Limestone is low. Areas of moderate potential are defined by the presence of the Madison Limestone at the surface or in the subsurface, especially where the Madison is overlain by thin remnants of the Amsden Formation and is cut by northwest-southeast-trending fractures, and where iron-stained alteration zones surround the fractures. Areas of high potential are in an area close to the East Pryor mine. At the East Pryor mine, mines on Red Pryor Mountain, and the Little Mountain district, uranium and vanadium minerals were deposited in ancient caves and karst in the upper 200 ft of the Madison Limestone, possibly by the action of low-temperature, low-salinity hydrothermal fluids that leached uranium from volcanic ash of middle Tertiary age during Pliocene-Pleistocene time.

The mineral resource potential for uranium and vanadium in the Morrison and Cloverly Formations is low in the southern part of the Pryor Mountain study area.

The three study areas have low mineral resource potential for all metals (other than uranium and vanadium) and high-purity limestone. The mineral resource potential for bentonite is moderate in outcrops of the Thermopolis Shale in the southern part of the Pryor Mountain Wilderness Study Area. The energy resource potential for oil and gas and geothermal sources is low in the study areas. No thermal springs are active now in the area; the closest active spring is 25 mi to the southwest. The study areas have no mineral resource potential for sand and gravel.

INTRODUCTION

At the request of the BLM (U.S. Bureau of Land Management), the USBM and USGS studied the entire 16,927-acre Pryor Mountain (MT–067–206) Wilderness Study Area, 3,430 acres of the Burnt Timber Canyon (MT–067–205) Wilderness Study Area, and 2,550 acres of the Big Horn Tack-On (MT–067–207) Wilderness Study Area. In this report the studied area is called "wilderness study area" or simply "study area." Because the three areas are adjacent and their geology is similar, they are discussed together.

The wilderness study areas are mainly in Carbon County, Mont.; the southernmost extent of the Pryor Mountain and Big Horn Tack-On study areas is in Big Horn County, Wyo. Lovell, Wyo., is the nearest town, 14 mi to the south; Billings, Mont., is 40 mi to the north. The Big Horn River and the Big Horn Canyon National Recreation Area are to the east of the Big Horn Tack-On study area, and Crooked Creek is to the west and south of the Burnt Timber Canyon and Pryor Mountain study areas.

Access to the east side of the area is by Route 37 leading north from U.S. Highway 14 to the Big Horn Canyon National Recreation Area. Access to the western part of the area is by Crooked Creek Road leading north from U.S. Highway 14. From Crooked Creek Road, several north-trending unimproved roads or jeep trails provide perimeter access to most of the three study areas. The study areas have moderately rugged terrain, with a steep east-facing cliff in the Big Horn Tack-On study area, and deep south- and southwest-trending canyons in the uplands and badlands topography in the southern part of the Pryor Mountain study area.

The study areas are underlain by folded and faulted rocks of Paleozoic and Mesozoic ages (pl. 1B, fig. 2). The principal rock unit exposed in the study areas is the Mississippian Madison Limestone. Small exposures of granite, schist, and gneiss of Late(?) Archean age occur to the north of the study areas along the Dryhead fault (fig. 2)

Elevations within the study areas range from a high of 8,500 ft in the Pryor Mountain study area to a low of about 3,760 ft near the southern part of the Pryor Mountain study area. A herd of about 100 wild horses inhabits the Pryor Mountain study area.

This report presents an evaluation of the mineral endowment (identified resources and mineral resource potential) of the Pryor Mountain, Burnt Timber Canyon, and Big Horn Tack-On Wilderness Study Areas and is the product of several separate studies by the USBM and USGS. Identified resources are classified according to the system of the USBM and USGS (1980), which is shown in the Appendix. Identified resources are studied by the USBM. Mineral resource potential is the likelihood of occurrence of undiscovered metals and nonmetals, industrial rocks and minerals, and of undiscovered energy sources (coal, oil, gas, oil shale, and geothermal sources). It is classified according to the system of Goudarzi (1984), which is shown in the Appendix. Undiscovered resources are studied by the USGS.

Investigations by the U.S. Bureau of Mines

The USBM reviewed pertinent literature on mines and prospects in the study areas. BLM and county mining records were analyzed in an effort to locate and identify mining claims or claim groups in the field. Mine and prospect evaluations were accomplished in 1985. Two hundred ninety-eight samples were collected from workings or mineralized areas in the study areas. Samples were field checked for relative amounts of radioactivity. Representative splits of the samples were analyzed by inductively coupled argon plasma and fluorimetric procedures. For this report, samples having no significant values means that the sample contained average or below average expected metal content for a given rock type, according to Turekian and Wedepohl (1961). Complete sample analyses and detailed property maps are on file at the USBM, Western Field Operations Center, E. 360 Third Avenue, Spokane, WA 99202.

Investigations by the U.S. Geological Survey

The areas were studied by the USGS during 1985. C.G. Patterson conducted rock and stream-sediment sampling, interpreted analytical data from the samples, compiled a 1:50,000-scale geologic map, and conducted studies of the regional uranium deposits. M.I. Toth assisted in writing and editing of the report, and D.M. Kulik performed regional gravity surveys and compiled existing data on gravity and magnetics.

Acknowledgments.—We thank employees of the BLM in Billings, Mont., for providing us with aerial photographs, boundary maps, and information on mineral resources from their files (Spielman, 1984); Dames and Moore Corp., Denver, Colo., for providing a report of their work on the Little Mountain mining district; D.L. Blackstone, Jr., of the University of Wyoming, for discussions about the geologic structure of the study areas; and R.A. Zielinski and J.D. Love, of the USGS, for many helpful discussions. Analytical work was performed by G.J. Cavallo, L.A. Layman, and R.B. Vaughn, all of the USGS.

APPRAISAL OF IDENTIFIED RESOURCES

By Leon E. Esparza, Steven W. Schmauch, and John R. Benham
U.S. Bureau of Mines

History and Production

No claims were held before 1955 in the Pryor Mountains, and almost all of the claims for uranium or vanadium were held in 1956, 1957, and in the late 1970's. The flurry of prospecting during these years resulted in the designation of the Pryor Mountain mining district, which is centered about 2 mi west of the three study areas (fig. 1).

A total of 315, 141, and 44 claims were staked in the Pryor Mountain, Burnt Timber Canyon, and Big Horn Tack-On study areas, respectively. There are no patented claims in or near the areas, and no geothermal, coal, or oil and gas leases. As of September 1985, the SOS claims (pl. 1A) were the only group of current claims in or adjacent to the study areas.

There has been no production from within the study areas; however, uranium and vanadium have been produced from deposits (not shown) less than 5 mi west of the study areas. The DOE (U.S. Department of Energy)

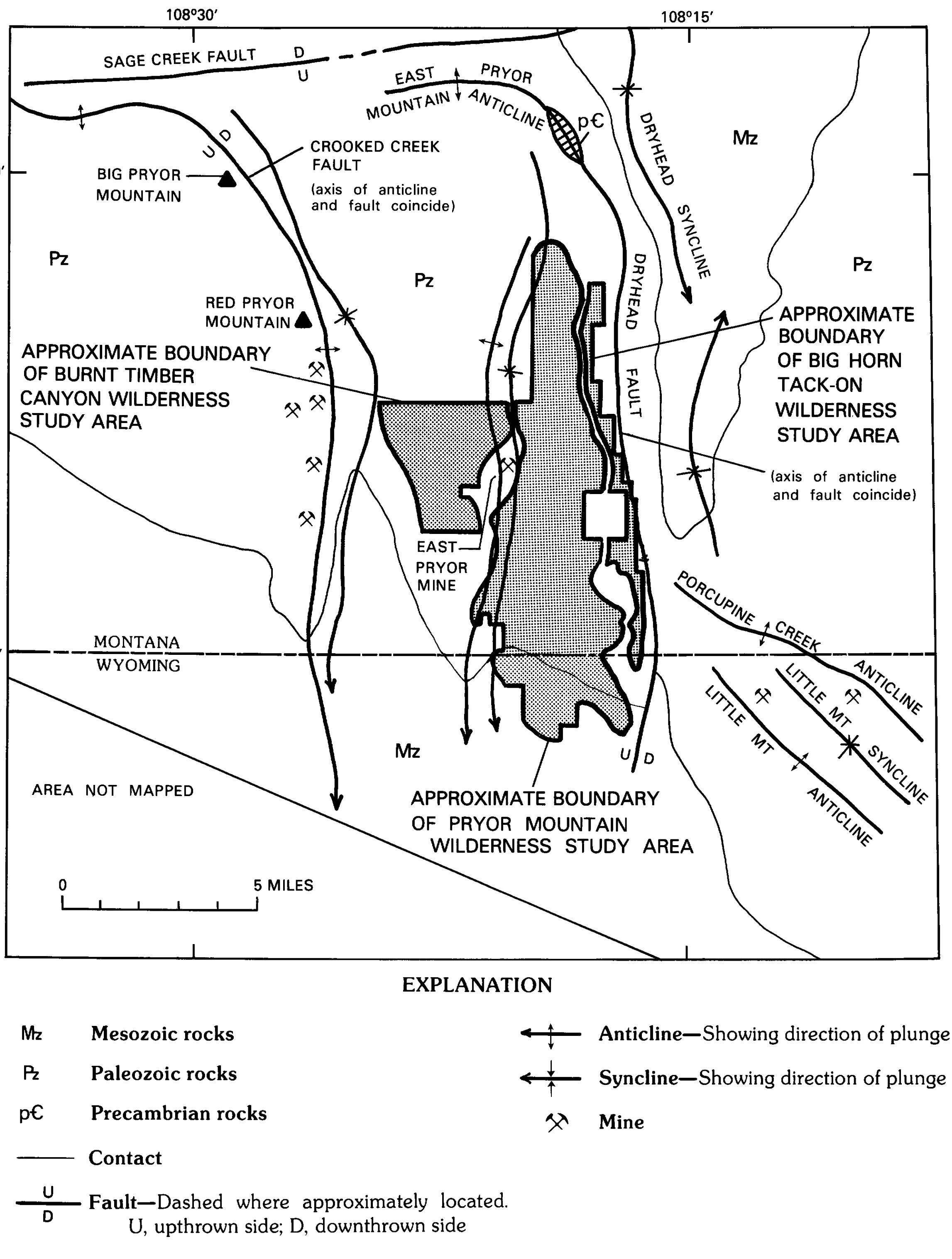


Figure 2. Geologic setting of the Pryor Mountain, Burnt Timber Canyon, and Big Horn Tack-On Wilderness Study Areas and vicinity. (Geology modified from Pierce, 1978; Warchola and Stockton, 1982; McEldowney and others, 1977.)

production and reserve data (Luther Smith, written commun., 1985) for the Pryor Mountain–Little Mountain mining districts indicate that about 223,000 pounds of U_3O_8 (uranium oxide), at an average ore grade of 0.36 percent, were produced from 19 properties, and that 236,000 pounds of V_2O_5 (vanadium pentoxide), at an average ore grade of 0.416 percent, were produced from 15 properties. Reserves for deposits outside the study areas were estimated by the DOE[1] to be about 420,000 pounds of U_3O_8, at an average ore grade of 0.07 percent. Ore reserve estimates for V_2O_5 are not available. No reserves were estimated for inside the study areas.

Exploration for these deposits generally involved a combination of seismic or gravimetric surveys to identify drilling targets. Subsequent mining of these deposits involved drifting and sinking declines and using crawler tractors with hydraulic front-end loaders. Workings were advanced either along a mineralized zone in a solution cavity or toward a drill hole that had shown radioactivity. In some instances, ore was mined from drifts and stopes, sometimes using wheelbarrows and hand labor to remove material from small solution cavities. Mining rates were generally less than 500 tons per month. Ore was shipped by truck to the long-since dismantled Susquehanna–Western Mill at Riverton, Wyo. The price of uranium and current (1987) market conditions are not favorable for development of uranium-vanadium resources from this area for the foreseeable future.

The East Pryor mine (pl. 1A) is likely to have had production of uranium-vanadium ore, perhaps as much as 200 tons, but tonnage and grade information are not available.

Mineral Reserves and Identified Resources

There are no identified resources in any of the study areas.

In the upper 200 ft of the Madison Limestone, a 10- to 60-ft-thick zone of solution cavities formed along joints, fractures, bedding planes, or evaporite beds. Many of the cavities are filled with angular limestone fragments from a few inches to several feet across and with red clay silt from the overlying Amsden Formation. Some cavities have been partly or completely filled with cryptocrystalline silica (Garrand and others, 1982), and others are open. Uranium and vanadium minerals are concentrated in a small percentage of solution cavities in the Madison Limestone and in small depressions at the Madison Limestone–Amsden Formation contact. The uranium minerals tyuyamunite and metatyuyamunite occur as coatings or earthy crusts within the solution cavities (Hart, 1958; Garrand and others, 1982). Vanadium-bearing minerals are associated with the uranium minerals; both the vanadium and uranium minerals occur along with calcite, limonite, hematite, gypsum, barite, opal, and, occasionally, fluorite or celestite interbedded with silt and clay (Hart, 1958). Workings at and near the East Pryor mine (pl. 1A) contain the yellow and green secondary uranium minerals uranophane and liebigite, which occur as thin coatings on brecciated rocks filling some solution cavities in the Madison Limestone.

In the Pryor Mountain mining district, there are several hundred uranium occurrences and deposits. Most have only a trace of mineralized material. Deposits west of the study areas contain as much as 8,000 tons of uranium ore, but most are less than 500 tons. The grade of these nearby deposits averages 0.50 percent U_3O_8 and ranges from 0.60 to 0.70 percent V_2O_5 (Hart, 1958). Similar deposits may exist within parts of the study areas; however, none were found. Detailed geologic mapping followed by seismic and gravimetric surveys are required to define drilling targets. Closely spaced drilling might identify uranium-bearing solution cavities below the surface.

Sample analyses indicate that elevated concentrations of V_2O_5 occur on the SOS claims (650 ppm (parts per million)) and USM claims (235.7 ppm) in the Pryor Mountain study area; on the George claim group (321 ppm), Owl-Wash claim group (267 ppm), and unknown claim group (250 ppm) in the Burnt Timber Canyon study area; and on the Midland Empire claim group (375 ppm) in the Bighorn Tack-On study area (pl. 1A). Most of the previous exploration on these and the other claims was by bulldozer-made pits, cuts, or trenches on or near the Madison–Amsden contact. Also, sample analyses from the East Pryor mine indicate the presence of uranium-bearing solution cavities. Samples from two adits and one pit on this property indicate near ore-grade uranium concentrations (from about 2,000 to over 5,000 ppm U_3O_8), but tonnage and grade were not estimated because the continuity of grade is highly erratic and uncertain. No resources were identified; however, short drill holes—less than 100 ft long—near the portal of one adit might locate uranium resources if they exist.

Sandstone beds in the Morrison and Cloverly Formations are slightly uraniferous in other parts of Wyoming. These formations are exposed in the southern part of the Pryor Mountain study area, but samples from them did not indicate the presence of identified resources.

Less than 2 mi southeast of the Pryor Mountain study area, several beds of bentonite in the upper part of the Cretaceous Thermopolis Shale and the overlying Shell Creek Shale are currently mined (1985) by the American Colloid Company and Wyoming Bentonite, Inc. Only the basal part of the Thermopolis Shale is present south of Britton Spring in the Pryor Mountain study area (C.G. Patterson and Dick Brown, oral commun., 1985). Wolfbauer (1975) indicated that beds of bentonite in this basal part of the Thermopolis Shale are scarce. Our sample data indicate that the bentonitic material within the study area is not of commercial quality. It could, however, be mixed with nearby sources of bentonite if a specific market were created with a need for the physical

[1]The reserve classification used by the DOE differs from the USBM and USGS classification system (USBM and USGS, 1980). DOE reserves are based on "forward costs," which include total operating and capital costs but not expenditures made prior to the time of the estimate, such as exploration, land acquisition, or mine development costs. More detailed information is in U.S. Department of Energy (1980).

properties of this blended material. At present, bentonite does not constitute an identified resource.

The Madison Limestone crops out or lies at depth over much of the study areas' extent. The calcium oxide content is 80–85 percent, which is not high purity but is suitable for many uses. This limestone is used elsewhere for construction, agriculture, and in the processing of sugar beets. Because there are deposits closer to consumer locations, it is unlikely that limestone from the study areas will be a marketable commodity for the foreseeable future. The economics for sand and gravel are similar to that of limestone. There are no unique or commercially valuable qualities that would indicate identified resources.

ASSESSMENT OF POTENTIAL FOR UNDISCOVERED RESOURCES

By Charles G. Patterson, Margo I. Toth, and Dolores M. Kulik
U.S. Geological Survey

Geologic Setting

The Pryor Mountains are a northwest-trending extension of the Big Horn Mountains, and are on the northeast margin of the Big Horn Basin. The Pryor Mountain, Burnt Timber Canyon, and Big Horn Tack-On Wilderness Study Areas constitute a large fault block that occupies the southeast quadrant of the Pryor Mountains. This block is bounded on the east by the Dryhead fault and fold system, on the west by the Crooked Creek fault, and on the north by the Sage Creek fault. To the south the rocks dip gently into a south-plunging anticline (pl. 1B, fig. 2). The northeast edge of the block experienced the greatest uplift along the Dryhead fault. The Dryhead and Crooked Creek faults are steeply inclined where exposed, but become flatter with depth. They may be classified as thrust faults on this basis.

Description of Rock Units

The wilderness study areas are underlain by a sequence of sedimentary rocks ranging in age from Mississippian to Cretaceous. The Madison Limestone outcrops over much of the study areas, with the overlying Amsden, Tensleep, and Park City Formations cropping out in the southern parts of the study areas. The Pryor Mountain study area also contains outcrops of the Chugwater Formation, Ellis Group, Morrison Formation, Cloverly Formation, and Thermopolis Shale. Quaternary deposits consist of terrace deposits, alluvium, and colluvium. Descriptive studies of these units have been done by Lageson and others (1979) and Richards (1955). A description of the rock units that crop out in the study areas follows (pl. 1B).

Madison Limestone (unit Mm)—This formation consists of four units, in ascending order: gray, massive limestone, about 190 ft thick, with a conspicuous layer of chert nodules 40 ft above the base; grayish-purple to reddish-brown, somewhat silty, occasionally ripple-marked, fossiliferous limestone, about 95 ft thick; light-gray, finely crystalline limestone and dolomite, about 200 ft thick; limestone breccia overlain by silty dolomite, in turn overlain by limestone breccia that occupied ancient caves, which together with an uppermost cliff-forming limestone constitute the Bull Ridge Member of the Madison Limestone, from 145 to 360 ft thick. Total thickness of the Madison is from 625 to 840 ft.

Amsden Formation (unit ℙa)—The basal 50 ft of the Amsden is equivalent to the Darwin Sandstone Member and consits of red shale, siltstone, and minor sandstone; it lies atop the irregular, karstified and channeled upper surface of the Madison Limestone. The upper 150 ft of the Amsden is equivalent to the Horseshoe Shale Member, and consists of interbedded red shale, limestone, dolomite, and sandstone. Some gray and red chert occur in limestone near the middle of the Horseshoe Member.

Tensleep Formation (unit ℙts)—The Tensleep is composed mainly of yellow to yellowish-gray, fine- to medium-grained crossbedded sandstone. Some thin limestone and chert are present, especially in the southern end of the Pryor Mountain study area. Unit is about 110 ft thick.

Park City Formation (unit Ppc)—The Park City consists of red shale and siltstone, wavy laminated cherty limestone, dolomite, and gypsum. It is as much as 100 ft thick, but generally averages 75 ft thick.

Chugwater Formation (unit ŦRc)—The Chugwater consists of thinly bedded red to dark-red shale, siltstone, and sandstone, with thin interbedded limestone near the top of the unit. Gypsum occurs as veinlets throughout the unit. The Chugwater is as much as 675 ft thick.

Ellis Group (unit Je)—Three formations are included in the Ellis Group, in ascending order: the Piper, the Rierdon, and the Swift Formations. From bottom to top, the Piper consists of massive gypsum and red beds, gray limestone, and red siltstone and shale; it is 200 ft thick in the southern part of the Pryor Mountains. The Rierdon and Swift Formations are grayish-green and olive-gray, laminated to thin-bedded shale and sandstone. The Rierdon is about 300 ft thick, the Swift about 70 ft thick. Total thickness of the Ellis Group is about 570 ft.

Morrison Formation (unit Jm)—The Morrison consists of thin crossbedded gray to greenish-gray or white sandstone and siltstone, and massive yellowish-brown mudstone. The Morrison is about 175 ft thick and forms slopes.

Cloverly Formation (unit Kcv)—The Cloverly consists of three units: a lower, discontinuous Pryor Conglomerate Member, a middle member, and an upper member (sometimes called the "rusty beds"). The Pryor Conglomerate Member is a discontinuous, lenticular quartz and chert sandstone to coarse conglomerate as much as 50 ft thick. The middle member is a variegated red to gray bentonite mudstone that may be as much as 140 ft thick. It is overlain by a sequence of flaggy, medium-bedded, yellowish-red, fine- to medium-grained sandstone and brown siltstone, with ripple marks and worm tubes, and some thin, dark-gray interbedded shale. The upper member may be as much as 250 ft thick. Total thickness is 600 ft.

Thermopolis Shale (unit Kt)—Only the basal part of the Thermopolis is exposed in the southern part of the Pryor Mountain study area; here it consists of dark-gray to black laminated shale and siltstone, and some thin impure bentonite beds. The Thermopolis is over 400 ft thick.

Quaternary deposits (units Qt, Qal, and Qlc)—Quaternary deposits consist of gravels, sands, and silts of old (Qt) and modern (Qal) stream channels. Landslide or extensive slope-wash deposits (Qlc) are mainly derived from the unstable Gros Ventre and Gallatin Formations, which crop out on the northeast and east sides of the study areas.

Geochemistry

Analytical Methods

Stream-sediment samples were collected from first- and second-order drainages in and near the Pryor Mountain, Burnt Timber Canyon, and Big Horn Tack-On Wilderness Study Areas (pl. 1A). At each sample locality a heavy-mineral-concentrate sample and a minus-80-mesh sample were collected and analyzed.

Heavy-mineral-concentrate samples were collected by panning a composite sample of stream sediment to a residue of denser minerals. Samples were processed to obtain nonmagnetic, heavy-mineral concentrates for analysis. The mineralogy of the concentrates was determined using an X-ray diffractometer and a binocular microscope.

The minus-80-mesh fraction of the stream sediments was analyzed semiquantitatively for 31 elements by a six-step, direct-current arc, optical-emission, spectrographic method (Grimes and Marranzino, 1968) and for uranium and thorium using a delayed neutron activation technique (Millard, 1976).

Results of Study

Stream-sediment samples from the Pryor Mountain, Burnt Timber Canyon, and Big Horn Tack-On Wilderness Study Areas did not contain anomalous amounts of any elements. Drainages below once-active mines in known deposits just outside the study areas displayed geochemical signatures in excess of unmined areas, and contained uranium, barite, and fluorite (pl. 1A). The presence of barite and fluorite in the heavy-mineral-concentrate samples correlated with the higher uranium values. Results from these drainages were compared to results from drainages within the study areas to see if geochemical signatures characteristic of mineralization occurred. Heavy-mineral-concentrates from all drainages within the Madison Limestone within the study areas were low in uranium and thorium and displayed little or no barite or fluorite. Drainages in the southern part of the Pryor Mountain study area cross outcrops of the Cloverly and Morrison Formations, which are slightly higher in background uranium values than the Madison Limestone (pl. 1A); this is not thought to indicate the presence of mineralized rock, as the Cloverly and Morrison Formations tend to have higher background values of uranium than the Madison, due to the large fraction of volcanically derived sediments, especially in the Morrison (Garrand and others, 1982).

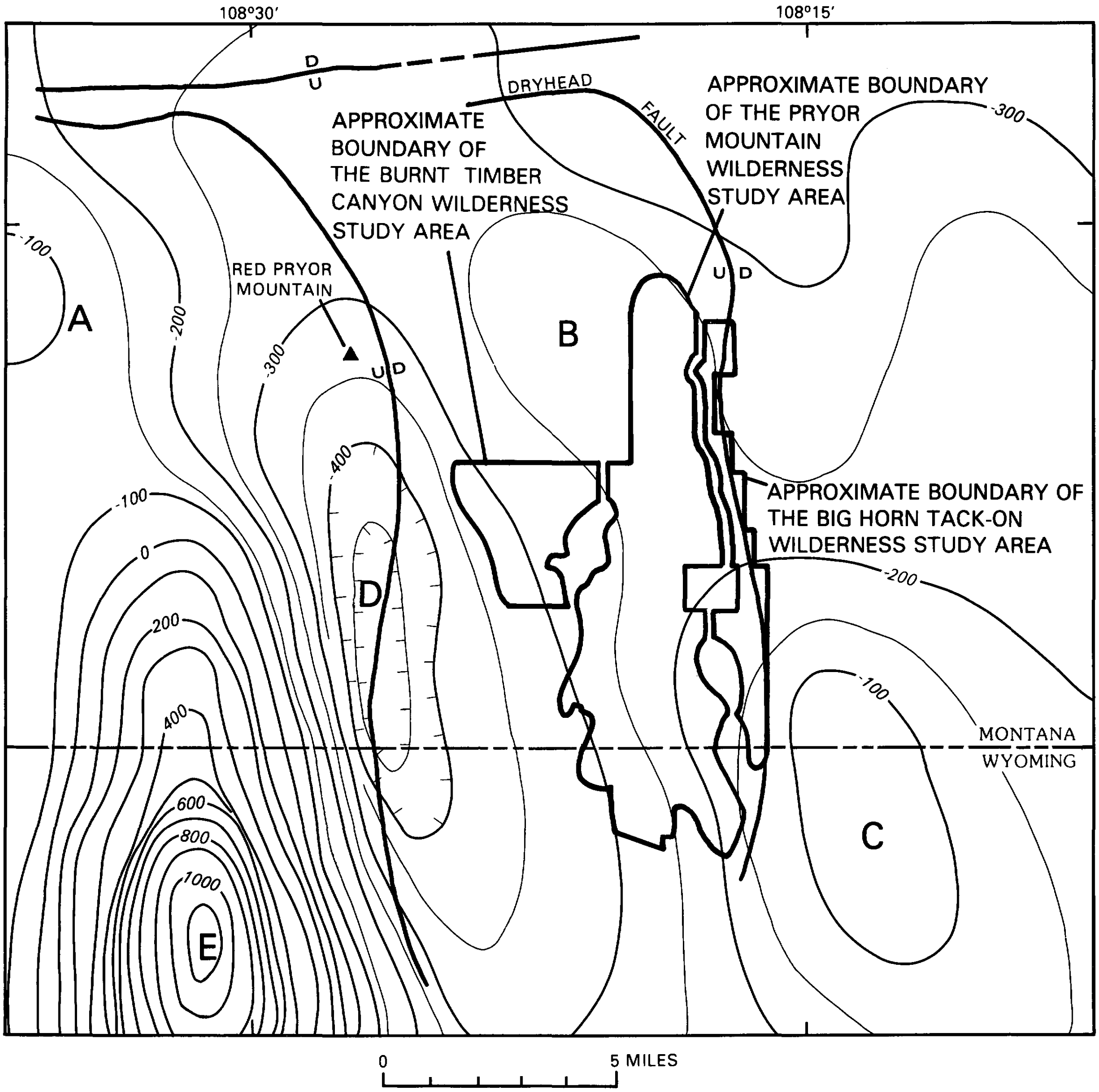
Geophysics

Geophysical data provide information on the subsurface distribution of rock masses and the structural framework. Aeromagnetic and gravity studies were undertaken as part of the mineral resource evaluation of the Pryor Mountain, Burnt Timber Canyon, and Big Horn Tack-On Wilderness Study Areas.

Aeromagnetic Data

The aeromagnetic data shown on figure 3 are from the U.S. Department of Energy (1982a, b). Flight lines were flown at a spacing of 5 mi and 400 ft above terrain. Magnetic values increase where crystalline rocks are brought nearer the surface by high-angle reverse faulting (anomalies A and B), and values decrease where nonmagnetic sedimentary rocks thicken on the flanks of the fault-bounded blocks. High anomaly C occurs over the leading edge of a northeastward-dipping thrust plate. Low anomaly D occurs where nonmagnetic Paleozoic strata dip steeply, resulting in a thick vertical mass of sedimentary rocks in the upper fault block overlying a thick section of nonmagnetic sedimentary rocks on the flank of the lower block.

High anomaly E reaches a maximum of over 1,100 gammas and continues southward. The magnitude of the anomaly suggests an intrusive source, probably near the top of autochthonous basement rocks.



EXPLANATION

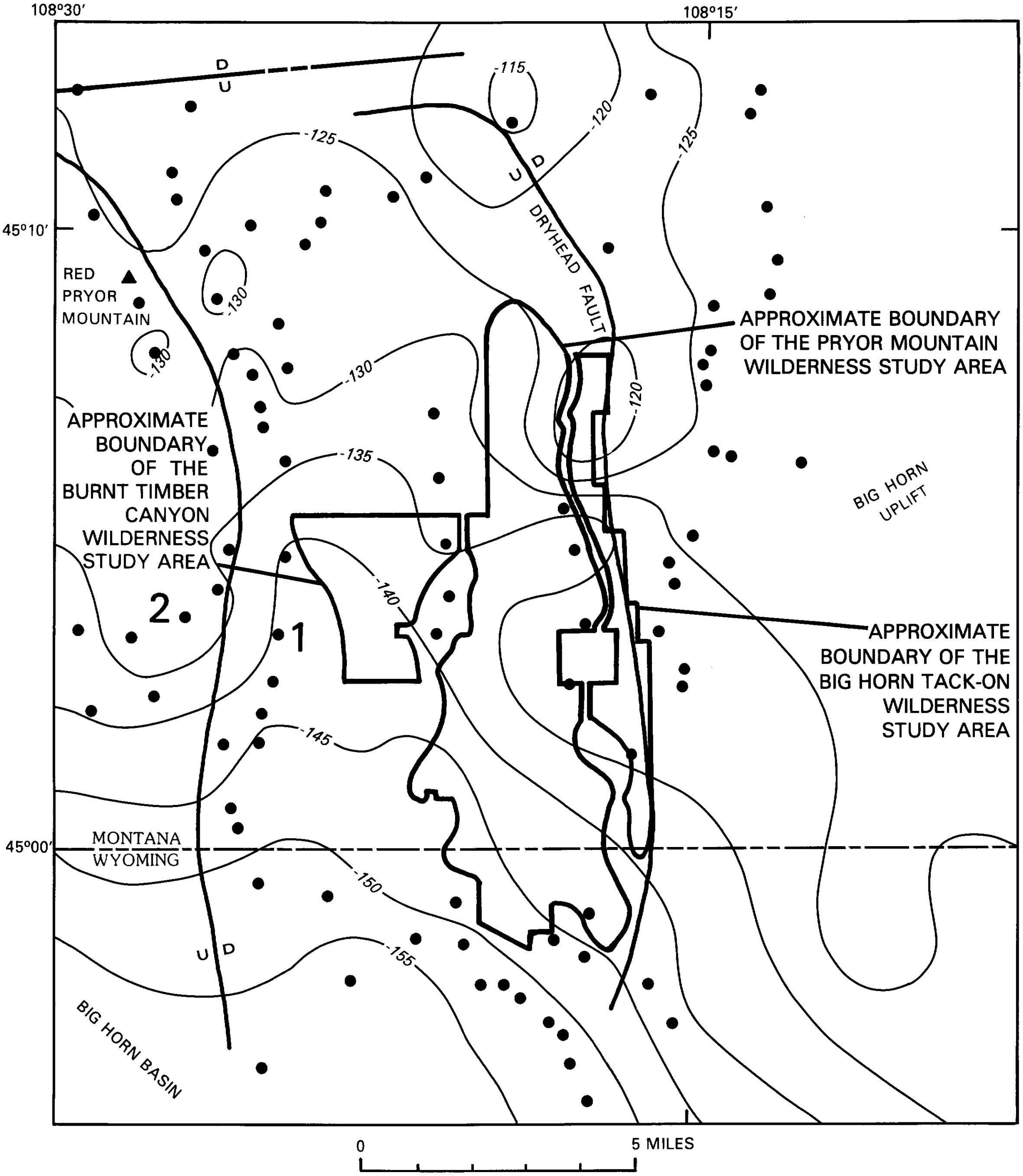
-400	**Aeromagnetic contour**—Contour interval 50 and 100 gammas. Hachures indicate closed lows
A	**Aeromagnetic anomaly**—Referred to in text
U / D	**Fault**—Dashed where approximately located. U, upthrown side; D, downthrown side

Figure 3. Total intensity aeromagnetic contours of the Pryor Mountain, Burnt Timber Canyon, and Big Horn Tack-On Wilderness Study Areas and vicinity. Data from U.S. Department of Energy (1982a, b).

Gravity Data

The gravity data (fig. 4) were obtained in and adjacent to the study area in 1985, and were supplemented by data maintained in the files of the Defense Mapping Agency of the Department of Defense. Stations measured by the author were established using a Worden[2] gravimeter W–177. The data were tied to the International Gravity Standardization Net 1971 (U.S. Defense Mapping Agency

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



EXPLANATION

— -140 — **Gravity contour**—Contour interval 5 milligals

2 **Gravity anomaly**—Referred to in text

● **Gravity station**

U/D **Fault**—Dashed where approximately located. U, upthrown side; D, downthrown side

Figure 4. Complete Bouguer gravity contours of the Pryor Mountain, Burnt Timber Canyon, and Big Horn Tack-On Wilderness Study Areas and vicinity.

Aerospace Center, 1974) at base station ACIC 1651–1, Cody, Wyo. Station elevations were obtained from benchmarks, spot elevations, and estimates from 1:24,000-scale topographic maps, and are accurate to ±20 ft. Errors in elevation control for the gravity data are less than 1.5 mGal (milligals). Bouguer anomaly values were computed using the 1967 gravity formula (International Association of Geodesy, 1967) and a reduction density of 2.67 grams per cubic centimeter. Mathematical formulas for computing Bouguer anomaly values are given in Cordell and others (1982). Terrain corrections were made by computer for a distance of 167 km from the station using the method of Plouff (1977).

Bouguer values are generally low (−150 to −175 mGals) over the Big Horn Basin, southwest of the study areas. Bouguer values are higher (−150 to −125 mGals) in the study areas, in the Big Horn uplift east of the study areas, and at Red Pryor Mountain northwest of the study areas, where crystalline basement rocks and dense Paleozoic rocks are at or near the surface.

A low (anomaly 1, fig. 4) is located adjacent to the western boundary of the study areas and coincides with the eastern flank of the aeromagnetic low (anomaly D, fig. 3). The low axis of the magnetic anomaly is associated with the vertically thick section of nonmagnetic Paleozoic rocks in the upper (Red Pryor Mountain) block. The low axis of the gravity anomaly is located just east of the magnetic axis and is associated with lower density rocks younger than the Paleozoic limestone and dolomite that are preserved on the flank of the lower (East Pryor Mountain) block. The gravity low does not extend west of the bounding fault of Red Pryor Mountain, and suggests that the overlap of the two blocks is minimal and that the Red Pryor Mountain plate does not overlie any appreciable thickness of the younger rocks.

A high gravity nose (anomaly 2, fig. 4) coincides with the lowest magnetic values and indicates that only high-density, nonmagnetic Paleozoic rocks are present in both the upper and lower blocks at this location.

Mineral and Energy Resource Potential

Karst-Hosted Uranium-Vanadium in the Madison Limestone

The Model

The Pryor Mountain, Burnt Timber Canyon, and Big Horn Tack-On Wilderness Study Areas are between two uranium-vanadium-producing districts: the Pryor Mountain mining district to the west and northwest and the Little Mountain mining district to the east and southeast (fig. 1). The uranium-vanadium deposits occur along the crest of anticlines in karst depressions and fractures, or as cave fillings in outcrops of the upper 200 ft of the Madison Limestone in the Bull Ridge Member (McEldowney and others, 1977); limestone is the principal rock type exposed in the study areas. The deposits were discovered in 1955 and have been studied and described by Hart (1958), Hauptman (1956), McEldowney and others (1977), Garrand and others (1982), Warchola and Stockton (1982), and Spielman (1978, 1983, 1984).

The following description is in part from the previously mentioned authors, and in part from USGS field investigations in 1985. In general, the deposits consist of fracture coatings and fracture fillings, open-space fillings as crusts on walls, or interbedded with silts and muds on cave floors. Principal ore minerals are tyuyamunite and metatyuyamunite, both calcium-uranium vanadates. Gangue minerals include limonite, probably derived from the oxidation of pyrite, generally radioactive green calcite, golden barite, dark-purple fluorite, celestite, pyrite or marcasite, and a black crust of a manganese mineral, possibly pyrolusite. Alteration zones on Red Pryor Mountain, which are probably related to ore deposition, include bleaching and staining of rocks containing iron oxides to produce a banded appearance, and extensive replacement of limestone by sugary, yellow-brown chert. The deposits of Little Mountain (fig. 1) do not show extensive alteration at any distance from the mine workings, and would have been more difficult to detect on the basis of alteration alone.

Other features associated with the deposits were determined from detailed examination of local mines. The karst features that may host the deposits are sometimes detectable by a careful measurement of attitudes of the Madison Limestone. The depressions (karsts) may be as large as 250 ft in diameter with only slight inward dips of 1–3°. Fractures associated with known deposits exhibit only minor increases in radioactivity, no more than twice background when measured directly over the fracture. Fractures trending about N. 65° W. were measured at the deposits on Red Pryor Mountain, and at the deposits lying between the Pryor Mountain and Burnt Timber Canyon study areas (near the East Pryor mine, fig. 1). Whereas the karst and cave breccias are cemented with reddish-brown sands and silts similar to the Darwin Sandstone Member of the Amsden Formation, generally the ore deposits were overlain by thin, residual layers of deep-red shale of the Horseshoe Shale Member of the Amsden. The exact relationship of the reddish-brown Horseshoe Member to uranium deposits is uncertain, but was consistently observed in the districts studied.

The origin of the deposits is not well known; several theories have been advanced. McEldowney and others (1977) summarized much early work and added observations gained from an extensive drilling and sampling program performed by Dames and Moore, Inc., of Denver for Virginia Nuclear Corp., in 1977 (unpub. data). McEldowney stated that the uranium deposits were formed during the Pliocene and Pleistocene Epochs by groundwater leaching of volcanic ash deposited on an exposed Madison Limestone surface earlier in the Tertiary. Although the deposits now are well above the groundwater table, groundwater tables would have been higher in the past as major downcutting by the Big Horn River was just beginning by post-Miocene time (Reheis, 1985; McKenna and Love, 1972). Possible source rocks for the uranium are likely to have been tuffs of Eocene, Oligocene, Miocene, or Pleistocene age. Mineralogical studies by the USGS of stream sediments downstream from uranium deposits disclosed flakes of biotite in the sediments, which could not have been derived from the Madison Limestone, but which could have been derived from tuffs of Eocene, Oligocene, or Miocene age, although not from Pleistocene tuffs, which do not contain biotite (Zielinski, 1983; G.A. Izett, oral commun., 1986). Precipitation mechanisms require a vanadium source to precipitate uranium from solution as the relatively insoluble tyuyamunite (Langmuir, 1978). The vanadium may have originated in the Park City Formation (Rubey, 1943), or from vanadium-rich oil (Stone, 1967) that may have seeped up from depth along fractures.

Thermal springs emanating from fractures were found in caves in the Madison Limestone 15 mi to the south of the study areas by Egemeier (1972); they were depositing black, uranium-rich muds along the cave floor. The temperature of these springs ranges from 17–34 °C; their total dissolved solids content is 325–455 ppm. Egemeir reported drops of oil floating in some spring pools. These spring waters might resemble the ore-forming solutions of the Red Mountain, Pryor Mountain, and Little Mountain districts. Salinity of fluids found in fluid inclusions in barite crystals collected by the USGS from a mine on Red Pryor Mountain was 3.6–3.8 percent by weight (36,000–38,000 ppm) (Jim Reynolds, Fluid, Inc., oral commun., 1985), which is similar to the value of 3.18 percent (31,800 ppm) for formation waters of the Madison as reported by Stone (1967). The thermal waters observed by Egemeir, although much more dilute, may represent a mixture of meteoric water with oil-bearing, high-salinity, deep-basin brines, which mingle to produce the observed spring chemistry.

Map and field observations of uranium deposits on Red Pryor Mountain show a relationship to a regional zone of fractures that trend about N. 65° W., and are on a line that includes the East Pryor group of mines and the Little Mountain deposits. Deposits occur where this fracture line intersects the crest of an anticline, regardless of the trend of the anticline. The shallow intrusion inferred by the magnetic data may have provided a hydrothermal heat source for fluids leaching and depositing uranium.

Criteria developed for evaluating the resource potential for karst-hosted uranium-vanadium deposits in the Bull Ridge Member of the Madison Limestone include the presence of barite and fluorite in stream sediments, anomalously high (>4 ppm) amounts of uranium in the minus-80-mesh fraction of stream sediments, twice background or greater radioactivity along fractures, the presence of alteration zones of bleaching or staining by iron oxides, the presence of dark-red Horseshoe Shale Member of the Amsden, fractures trending N. 65° W. or approximately along the line connecting the Red Pryor Mountain and Little Mountain deposits, location on or near the crest of an anticline, the presence of karst and cave features as indicated by gently inward-dipping strata (Maslyn, 1977), and possibly the presence of brown, sugary chert replacement zones in the limestone.

Samples bearing anomalous uranium values and abundant barite and fluorite are present only in stream sediments directly below once-active mines (pl. 1A). Mining activities alone may have created that set of anomalies. In no part of the study areas were anomalies of this type seen, and no areas of anomalous radioactivity were found near karst pits or fractures. Sugary chert zones were observed in scattered locations in the northernmost end of the Pryor Mountain study area.

Resource Potential

Areas adjacent to the East Pryor group of mines and claims along the N. 65° W. trend of the anticlinal crest in the Pryor Mountain and Burnt Timber Canyon study areas have high mineral resource potential for uranium and vanadium based upon their favorable position, but with certainty level B due to lack of geochemical, mineralogical, and radiometric anomalies. Part of the Pryor Mountain study area and the entire Big Horn Tack-On study area have moderate potential, with certainty level B, where Madison Limestone is exposed along the crest of the East Pryor Mountain anticline and along the N. 65° W. trend. The remainder of the Pryor Mountain and Burnt Timber Canyon study areas have low mineral resource potential for karst-hosted uranium-vanadium deposits, with certainty level C.

Tabular Uranium-Vanadium Deposits in the Morrison and Cloverly Formations

The Model

Uranium-vanadium deposits occurring in tabular, fluvial, channel sandstone encased in bentonitic mudstone are found in the Morrison and Cloverly Formations in Wyoming and the Colorado Plateaus Province (Finch, 1967). These deposits are often associated with accumulations of black, carbonaceous, woody "trash" that may have served as a reductant to precipitate uranium-vanadium minerals. Favorable criteria for the presence of such ore deposits include presence of carbonaceous "trash" in tabular or lenticular fluvial sandstone bodies encased in bentonitic mudstone, anomalous radioactivity (2–10 times background), and anomalous amounts of uranium in the minus-80-mesh fraction of stream sediments.

Resource Potential

Areally limited outcrops of the Morrison and Cloverly Formations occur in the southern part of the Pryor Mountain study area (pl. 1B); these formations have been eroded from the Burnt Timber Canyon and Big Horn Tack-On study areas. These outcrops were surveyed by hand-held scintillometer traverse, and by stream-sediment sampling. No anomalous radioactivity was detected, and stream-sediment values of 4–5 ppm (pl. 1A) were not considered anomalous, as they were derived from a bentonitic terrane (Whitlock and Van Eeckhout, 1980). The mineral resource potential for tabular uranium-vanadium deposits in the Morrison and Cloverly Formations is low in the southern part of the Pryor Mountain study area, with certainty level C.

Metals other than Uranium and Vanadium

The Pryor Mountain, Burnt Timber Canyon, and Big Horn Tack-On study areas have low mineral resource potential for all metals, excluding uranium and vanadium, with certainty level C. This is based upon the lack of mines or prospects within the areas, the lack of any mineralized rock or geochemical anomalies, and the absence of favorable environments for metallic deposits.

Bentonite

Bentonite deposits in northern Wyoming have been described by Wolfbauer (1975). Several thin (<2 ft) seams of impure bentonite occur in the lower part of the Thermopolis Shale in exposures near Crooked Creek in the southern part of the Pryor Mountain study area. The mineral resource potential for bentonite is moderate, with certainty level B.

Limestone

The Madison Limestone crops out or lies at depth over much of the study areas' extent. This limestone is used elsewhere for construction, agriculture, and food processing. Chemical analyses of the Madison Limestone and field observations by USBM personnel revealed no occurrence of chemical-grade (high-purity) limestone in the area. There is low mineral resource potential for high-purity limestone in the study areas, with certainty level C.

Sand and Gravel

Deposits of sand and gravel may be found along stream courses in the study areas. These deposits are composed mainly of poorly graded limestone fragments and clay derived from disintegration and dissolution of the Madison Limestone. Deposits along Big Coulee, in the southern part of the Pryor Mountain Wilderness Study Area, are derived from clay-rich units such as the Chugwater, Morrison, and Cloverly Formations and the Ellis Group. Both types of stream deposits are unsuitable for construction purposes due to their composition and grading. There is no mineral resource potential for sand and gravel in the study areas.

Geothermal Sources

Egemeier (1972) reported thermal springs with temperatures ranging from 17 to 34 °C depositing radioactive black muds within caves at the level of the Bighorn River where it cuts through the Sheep Mountain anticline, 25 mi to the south of the study areas. Bleached zones and iron staining suggest hot spring activity adjacent to mineralized fractures in the uranium mining district on Red Pryor Mountain. A well near Frannie, Wyo., in the Big Horn Basin southeast of the study areas, had a temperature of 37 °C at a depth of 1,372 ft (Heasler, 1983). However, absence of modern geothermal activity within the study areas indicates a low energy resource potential, with certainty level C.

Oil and Gas

The Madison Limestone is a favorable reservoir rock in the subsurface, and many producing oil wells exist in the Big Horn Basin adjacent to the study areas (Stone, 1967). However, Spencer and Powers (1983) interpreted the oil and gas resource potential as nonexistent because of removal of oil by flushing by meteoric waters in the exposed reservoir rocks, and because of lack of strong structural closure to form an oil pool. The energy resource potential for oil and gas is low in the study areas, with certainty level C.

Recommendations for Further Work

To confirm the presence or absence of any uranium-vanadium deposits in the Madison Limestone along the N. 65° W. trend that includes the East Pryor mine, closely spaced core drilling would be necessary. Suspected cave or karst features (as indicated by careful dip measurements) that might also host uranium-vanadium deposits might also be investigated by drilling.

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APPENDIX

DEFINITION OF LEVELS OF MINERAL RESOURCE POTENTIAL AND CERTAINTY OF ASSESSMENT

Definitions of Mineral Resource Potential

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

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

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

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

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

Levels of Certainty

LEVEL OF RESOURCE POTENTIAL →

U/A UNKNOWN POTENTIAL	H/B HIGH POTENTIAL	H/C HIGH POTENTIAL	H/D HIGH POTENTIAL
	M/B MODERATE POTENTIAL	M/C MODERATE POTENTIAL	M/D MODERATE POTENTIAL
	L/B LOW POTENTIAL	L/C LOW POTENTIAL	L/D LOW POTENTIAL
			N/D NO POTENTIAL
A	B	C	D

LEVEL OF CERTAINTY →

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

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RESOURCE / RESERVE CLASSIFICATION

	IDENTIFIED RESOURCES			UNDISCOVERED RESOURCES	
	Demonstrated		Inferred	Probability Range (or)	
	Measured	Indicated		Hypothetical	Speculative
ECONOMIC	Reserves		Inferred Reserves		
MARGINALLY ECONOMIC	Marginal Reserves		Inferred Marginal Reserves		
SUB-ECONOMIC	Demonstrated Subeconomic Resources		Inferred Subeconomic Resources		

Major elements of mineral resource classification, excluding reserve base and inferred reserve base. Modified from 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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