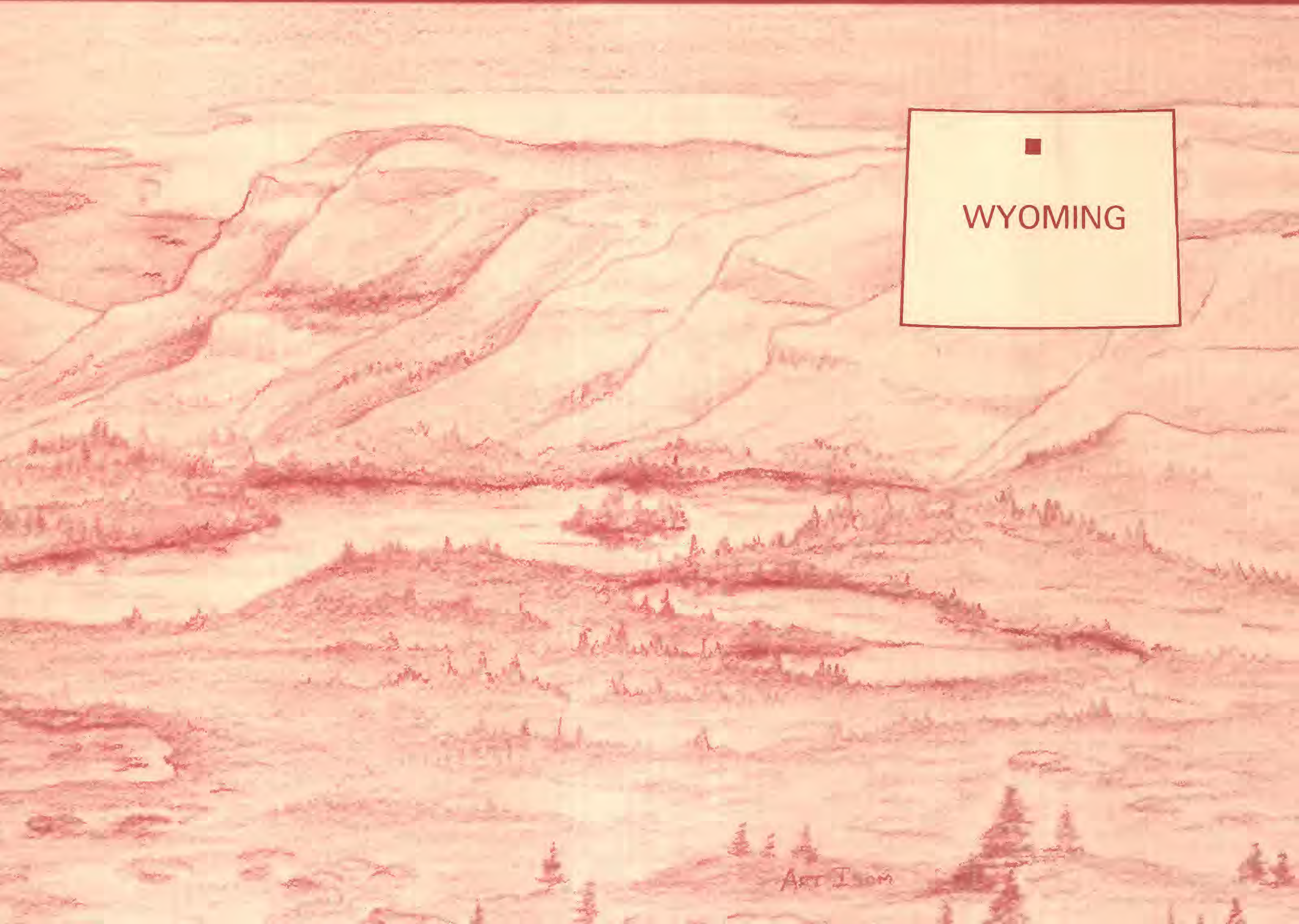
Mineral Resources of the Medicine Lodge, Alkali Creek, and Trapper Creek Wilderness Study Areas, Big Horn County, Wyoming

U.S. GEOLOGICAL SURVEY BULLETIN 1756–A



Chapter A

Mineral Resources of the Medicine Lodge, Alkali Creek, and Trapper Creek Wilderness Study Areas, Big Horn County, Wyoming

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MINERAL RESOURCES OF WILDERNESS STUDY AREAS—
NORTHERN 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 Medicine Lodge (WY–010–240), Alkali Creek (WY–010–241), and Trapper Creek (WY–010–242) Wilderness Study Areas, Big Horn County, Wyoming.

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Mineral Resources of the Medicine Lodge, Alkali Creek, and Trapper Creek Wilderness Study Areas, Big Horn County, Wyoming

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ABSTRACT

The Medicine Lodge Wilderness Study Area (WY-010-240) is an area of 7,740 acres located about 1.2 mi (miles) north of the Taylor Ranch, a campground, picnic, and Indian pictograph site, operated by the State of Wyoming. The Alkali Creek Wilderness Study Area (WY-010-241) is an area of 10,100 acres of public land surrounding 711 acres of private land located 7.5 mi north of Hyattville, Wyo. The Trapper Creek Wilderness Study Area (WY-010-242) is an area of 7,200 acres located 5.5 mi southeast of Shell, Wyo. Geologic, geochemical, geophysical, and mineral surveys of the three wilderness study areas were conducted by the U.S. Bureau of Mines and the U.S. Geological Survey in 1986 in order to appraise the identified resources (known) and assess the mineral resource potential (undiscovered) of the areas. There are inferred subeconomic resources of industrial sand and gypsum in the Alkali Creek Wilderness Study Area, of high-calcium limestone in the Medicine Lodge Wilderness Study Area, and of high-calcium limestone and dolomite in the Trapper Creek Wilderness Study Area. These high-tonnage, low-value resources, however, are too remote to be developed economically. There is a high resource potential for limestone deposits in Trapper Creek and Medicine Lodge Wilderness Study Areas. There is a high resource potential for gypsum in Alkali Creek Wilderness Study Area. Although there is an occurrence of gypsum in the Trapper Creek Wilderness Study Area, there is no potential for gypsum resources. There is low resource potential for industrial sand in Alkali Creek and Medicine Lodge Wilderness Study Areas, and an unknown resource potential for tar (natural bitumen) deposits in Alkali Creek Wilderness Study Area. These surveys further indicate that there is no resource potential for undiscovered oil, natural gas, coal, uranium, other metals, other nonmetals, and geothermal energy in any of the three wilderness study areas.

Manuscript approved for publication, August 17, 1988.

SUMMARY

Character and Setting

The Medicine Lodge, Alkali Creek, and Trapper Creek Wilderness Study Areas are on the western slope of the Bighorn Mountains between the eastern edge of the Bighorn basin and the crest of the mountain range (fig. 1). The areas are underlain by Paleozoic and Mesozoic (see geologic time chart in Appendix) sedimentary rocks that dip gently to the west and southwest. The structure of the rocks was caused by the uplift of the Bighorn Mountains that began in Late Cretaceous and culminated in early Eocene time.

Identified Resources

No mining has occurred within the boundaries of the Trapper Creek, Alkali Creek, and Medicine Lodge Wilderness Study Areas. However, unpatented mining claims within the Alkali Creek Wilderness Study Area indicate that there has been some mineral exploration. Inferred subeconomic resources of industrial sand, gypsum, dolomite, and high-calcium limestone were identified during the study. There are inferred subeconomic high-calcium limestone resources in the Trapper Creek and Medicine Lodge Wilderness Study Areas. There are also inferred subeconomic dolomite resources in the Trapper Creek Wilderness Study Area. The remoteness and inaccessibility of the study areas, however, make economic development of the limestone and dolomite resources unlikely. The friable sand in the Alkai Creek Wilderness Study Area would be suitable only for foundry sand, but the limited supply and remoteness to a market make development of this inferred subeconomic industrial sand resource unlikely. Inferred subeconomic gypsum resources are in the Alkali Creek Wilderness Study Area, and, although the gypsum beds are as much as 25 ft (feet) thick,

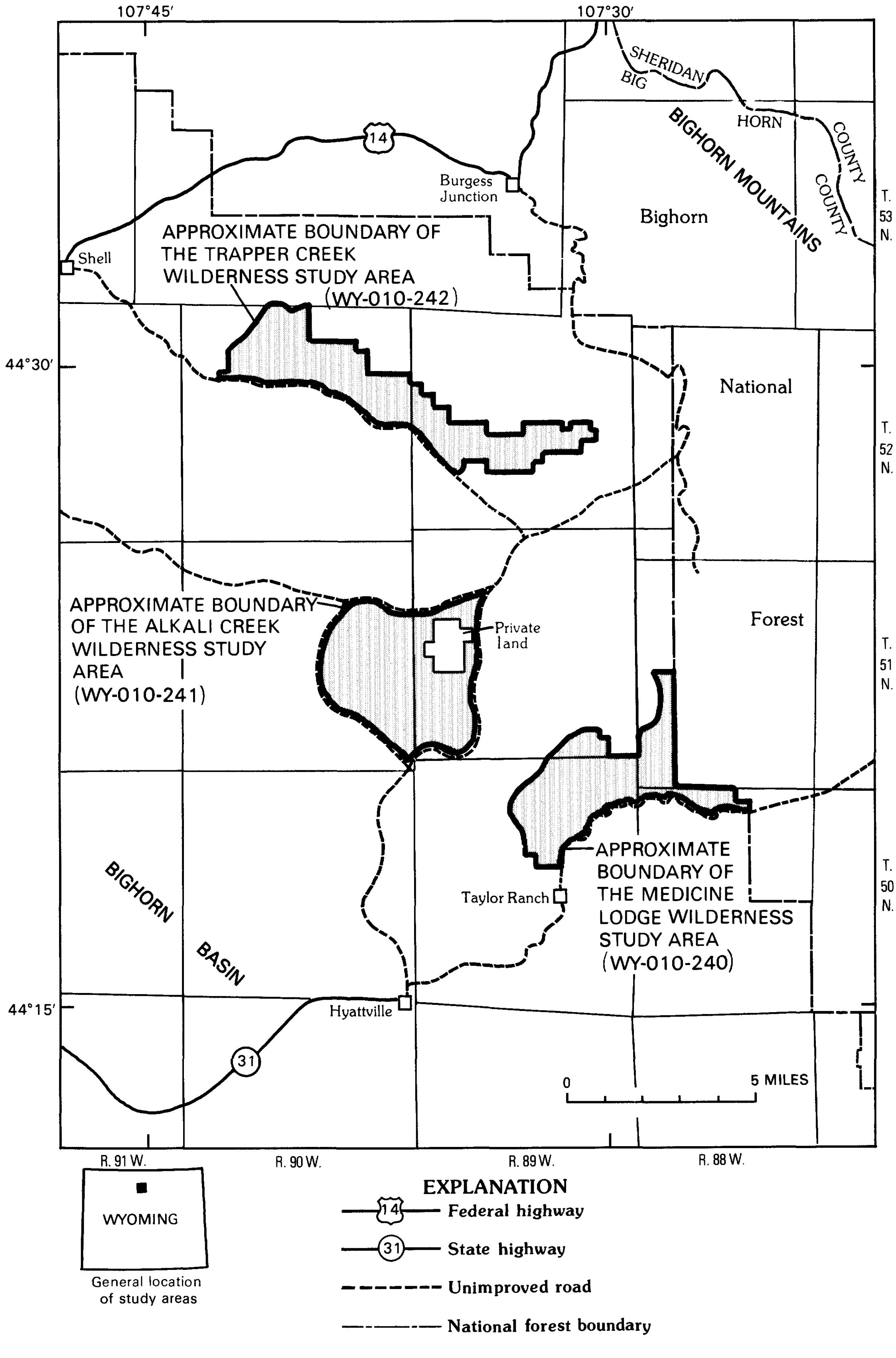


Figure 1. Index map showing the location of Trapper Creek, Alkali Creek, and Medicine Lodge Wilderness Study Areas, Big Horn County, Wyoming.

the fact that they are discontinuous and remote make development of the gypsum unlikely.

Mineral Resource Potential

There is a high resource potential for high-purity limestone from the Madison Limestone in the Trapper Creek and Medicine Lodge Wilderness Study Areas (figs. 2, 4) based on the chemical analyses of several samples. However, the limestone is beneath thick overburden except where exposed in steep canyon walls. The areal exposure of weathered sand of the Tensleep Sandstone is about 8 mi^2 (square miles) in the Alkali Wilderness Study Area and about 4 mi^2 in the Medicine Lodge Wilderness Study Area. The resource potential for sand is low in both study areas because most of the sand is cemented with carbonates or silica (figs. 3, 4). Gypsum of the Goose Egg Formation occurs in the Trapper Creek and Alkali Creek Wilderness Study Areas. The mineral resource potential for gypsum is high in Alkali Creek Wilderness Study Area, but because the gypsum contains impurities of calcite and dolomite, varies in continuity and color, and contains fractures filled with sand and silt, it has no resource potential in the Trapper Creek Wilderness Study Area.

The only commodity with an unknown potential is the tar. About one mile south of the Trapper Creek Wilderness Study Area and 1.5 mi north of the Alkali Creek Wilderness Study Area, the Trapper Canyon tar sands deposit has been mined and processed. The deposit occurs in the upper part of the Tensleep Sandstone and is protected from weathering by the overlying Goose Egg Formation. No deposits of tar were found in the exposed Tensleep Sandstone in the three wilderness study areas; however, in the area of the western and southern parts of Alkali Creek Wilderness Study Area the Tensleep Sandstone is buried by the overlying Goose Egg Formation. The occurrence of buried tar deposits is unknown because no exploratory drilling has been done and there is no indication of any oil seepages.

Based on the geological, geochemical, and geophysical data collected for this report, there is no resource potential for oil, natural gas, coal, uranium, other metals, other nonmetals, and geothermal energy in Trapper Creek, Alkali Creek, and Medicine Lodge Wilderness Study Areas, other than those discussed here. Uranium is associated with the Amsden Formation red beds that fill the cavernous and brecciated karst portion of the upper part of the Madison Limestone in the Pryor-Little Mountain area about 50 mi northwest of the study areas. However, the geological investigations and the geochemical data indicate that there is no potential for uranium resources in these three wilderness areas. The Ordovician carbonates and the underlying Cambrian carbonate formations that overlie the crystalline rocks that form the core of the Bighorn Mountains at depth do not contain the traps needed for hydrocarbon accumulation.

INTRODUCTION

Location

The Medicine Lodge (WY–010–240), Alkali Creek (WY–010–241), and Trapper Creek (WY–010–242) Wilderness Study Areas are east of the Bighorn basin on the western slope of the Bighorn Mountains. The areas are located in Big Horn County, Wyo., southeast of Shell and north of Hyattville (fig. 1). The three areas cover a total of 7,740, 10,100, and 7,200 acres, respectively, and lie in the west-central part of the Sheridan 1° by 2° topographic quadrangle. Medicine Lodge includes parts of Allen Draw and Hyatt Ranch 7 ½-minute topographic quadrangles; Alkali Creek includes parts of Hyatt Ranch, Fitner Reservoir, Brush Butte, and White Sulphur Spring 7½-minute topographic quadrangles; and Trapper Creek includes parts of Brush Butte, White Sulphur Spring, and Black Mountain 7½-minute topographic quadrangles.

Medicine Lodge and Trapper Creek Wilderness Study Areas are areas of deep and narrow canyons that make access very difficult. The elevation at Trapper Creek Wilderness Study Area ranges from 4,760 ft at the western boundary near the mouth of Trapper Creek to 8,440 ft at the eastern boundary. Medicine Lodge Wilderness Study Area has an elevation range from 5,150 ft, about 1.2 mi north of Taylor Ranch, to 8,560 ft at the eastern boundary near Cold Springs Campground. The Alkali Creek Wilderness Study Area has a rolling topography that slopes toward the south. There are a few steep slopes and several natural sandstone amphitheaters. The elevation ranges from 4,917 ft at Alkali Flats to 7,085 ft on the Alkali road near the head of Meyers Spring Draw. The areas are accessible by unpaved roads and jeep trails from U.S. Highway 14 and Wyoming State Highway 31 (fig. 1).

This report presents an evaluation of the mineral endowment (identified resources and mineral resource potential) of the study area and is the product of several separate studies by the U.S. Bureau of Mines (USBM) and the U.S. Geological Survey (USGS). Identified resources are classified according to a modification of the system described by McKelvey (1972) and 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, tar, and geothermal sources). It is classified according to the system of Goudarzi (1984) and is shown in the Appendix. Undiscovered resources are studied by the USGS.

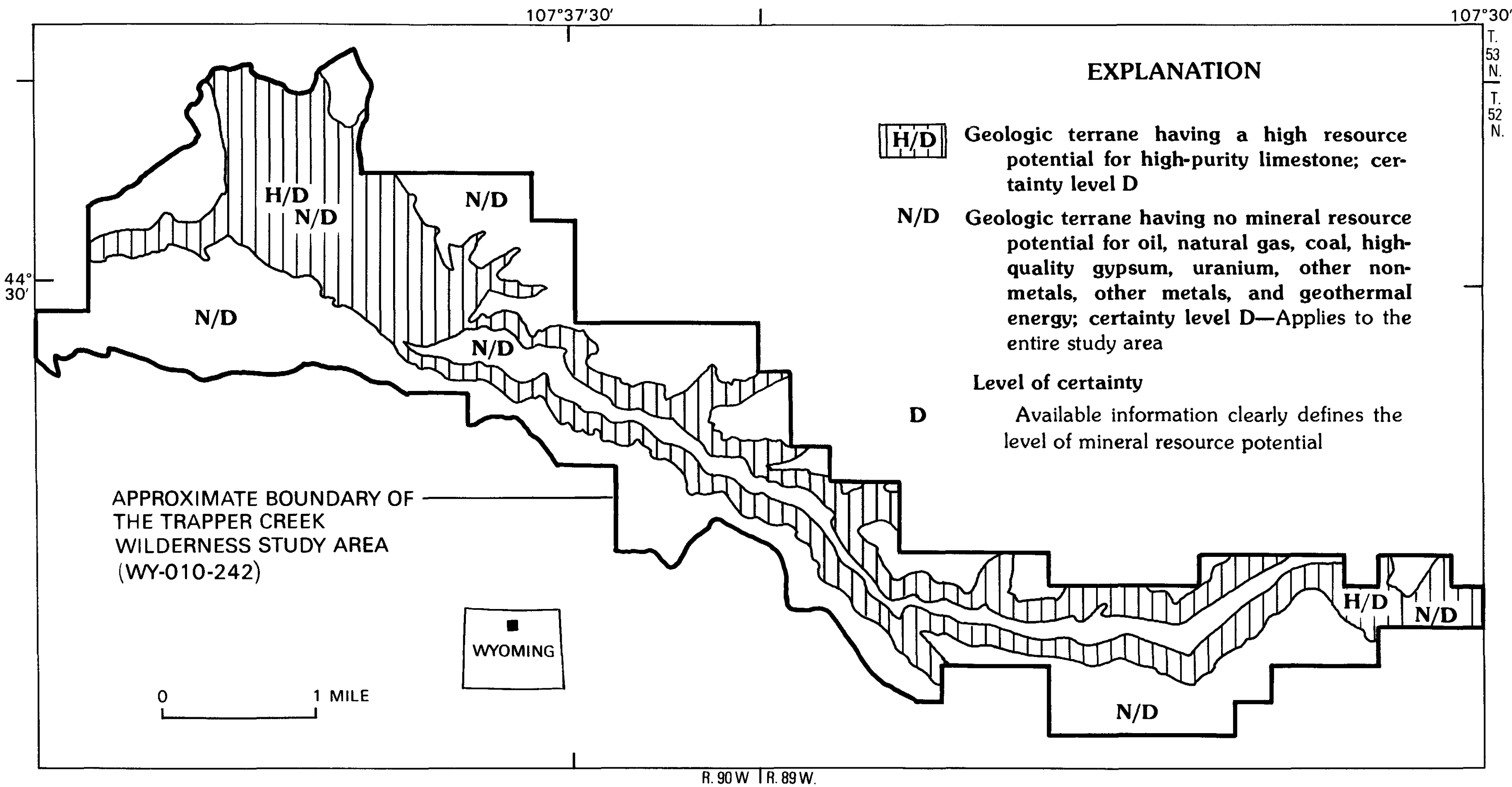


Figure 2. Mineral resource potential of the Trapper Creek Wilderness Study Area, Big Horn County, Wyoming.

Investigations by the U.S. Bureau of Mines

Files at the U.S. Bureau of Land Management (BLM) State Office in Cheyenne, Wyo., were reviewed for patented and unpatented mining claim locations and oil and gas and geothermal leases and lease applications. Lessees, mining claim holders, and persons having knowledge of mineral occurrences and mining activities within and near the study areas were contacted for additional information.

Nineteen samples were collected during the field investigation and were analyzed at the Bureau of Mines Research Center, Reno, Nev., and at commercial laboratories. Five sandstone samples were disaggregated and sieved to determine a particle-size distribution; their silica, iron-oxide, and aluminum-oxide contents were determined by inductively coupled plasma-atomic emission spectroscopy (ICP). Ten gypsum samples were tested for purity and combined water. Four tar sand samples were tested for oil and water saturation. Complete analytical results for all samples are available for public inspection at the Bureau of Mines Intermountain Field Operations Center, Building 20, Denver Federal Center, Denver, Colo.

Investigations by the U.S. Geological Survey

The U.S. Geological Survey assessed the mineral resource potential of the wilderness study areas by integrating and interpreting geologic, geochemical, and geophysical data from existing sources and new investigations. Field mapping, done in 1986, provided most of the geologic and geochemical information. Geologic maps by students at the Geologic Field Camp of the Department of Earth Sciences, Iowa State University, provided supplementary geologic data (Finley, 1985; Manahl, 1985; Ladd, 1986; Kozimko, 1986; and Reppe, 1986). The reconnaissance geochemical survey conducted in Medicine Lodge, Alkali Creek, and Trapper Creek Wilderness Study Areas consisted of collecting 52 stream-sediment samples and 52 heavy-mineral samples (panned concentrates). Chemical analyses of the stream sediments provide data useful in identifying those drainage basins that contain unusually high concentrations of elements that may be related to mineral occurrences. The panned concentrates are a useful sample medium in arid and semiarid environments or in areas of rugged topography where mechanical erosion predominates over chemical erosion. Mineralogical data and supplemental chemical data were obtained from 59 rock samples. The geophysical studies include gravity and magnetic data that are of a reconnaissance nature and are only adequate in defining the regional structural features.

Geologic Setting

The Medicine Lodge, Alkali Creek, and Trapper Creek Wilderness Study Areas are on the western slope of the Bighorn Mountains where the mountains meet the eastern edge of the Bighorn basin. Medicine Lodge and Trapper Creek are two narrow canyons that are more than 800 ft deep. The canyon walls in both areas are composed of Mississippian-age Madison Limestone. In Trapper Creek the canyon has been cut deep enough to expose the Devonian-age Darby Formation and the upper part of the Ordovician Bighorn Dolomite. Above the canyon rims and in the Alkali Creek area, there are rolling grasslands underlain by Mississippian and Pennsylvanian Amsden Formation, Pennsylvanian Tensleep Sandstone, and Permian and Triassic Goose Egg Formation. Above the Goose Egg Formation and outside the wilderness study areas are the red beds of the Triassic Dinwoody Formation.

APPRAISAL OF IDENTIFIED RESOURCES

By Diann D. Gese
U.S. Bureau of Mines

Mining History

The study areas are not in any mining districts. Patented and unpatented mining claims are shown on plate 1 of Gese (1987). Mining claims within and near Alkali Creek Wilderness Study Area were staked for industrial sand in the Tensleep Sandstone (Floyd Whipps, claim holder, Basin, Wyo., written commun., June 1986). Tar sands have been mined intermittently since 1962 at the Trapper Canyon tar sand deposit 1 mi south of the Trapper Creek Wilderness Study Area in secs. 32 and 33, T. 52 N., R. 89 W. Big Horn Tar Sands and Oil Company attempted to mine and process some of the tar sand on the north end of the deposit, but the operation was abandoned in November 1981, when the company was found to be in trespass by the BLM (see Ver Ploeg and De Bruin, 1985). As of September 1981, 7,000 gallons of hydrocarbons had been collected from an open pit mine on the deposit (S.S. Barrell, written commun., 1982). Currently, Bronco Oil and Gas Company, Denver, Colo., is assessing the feasibility of

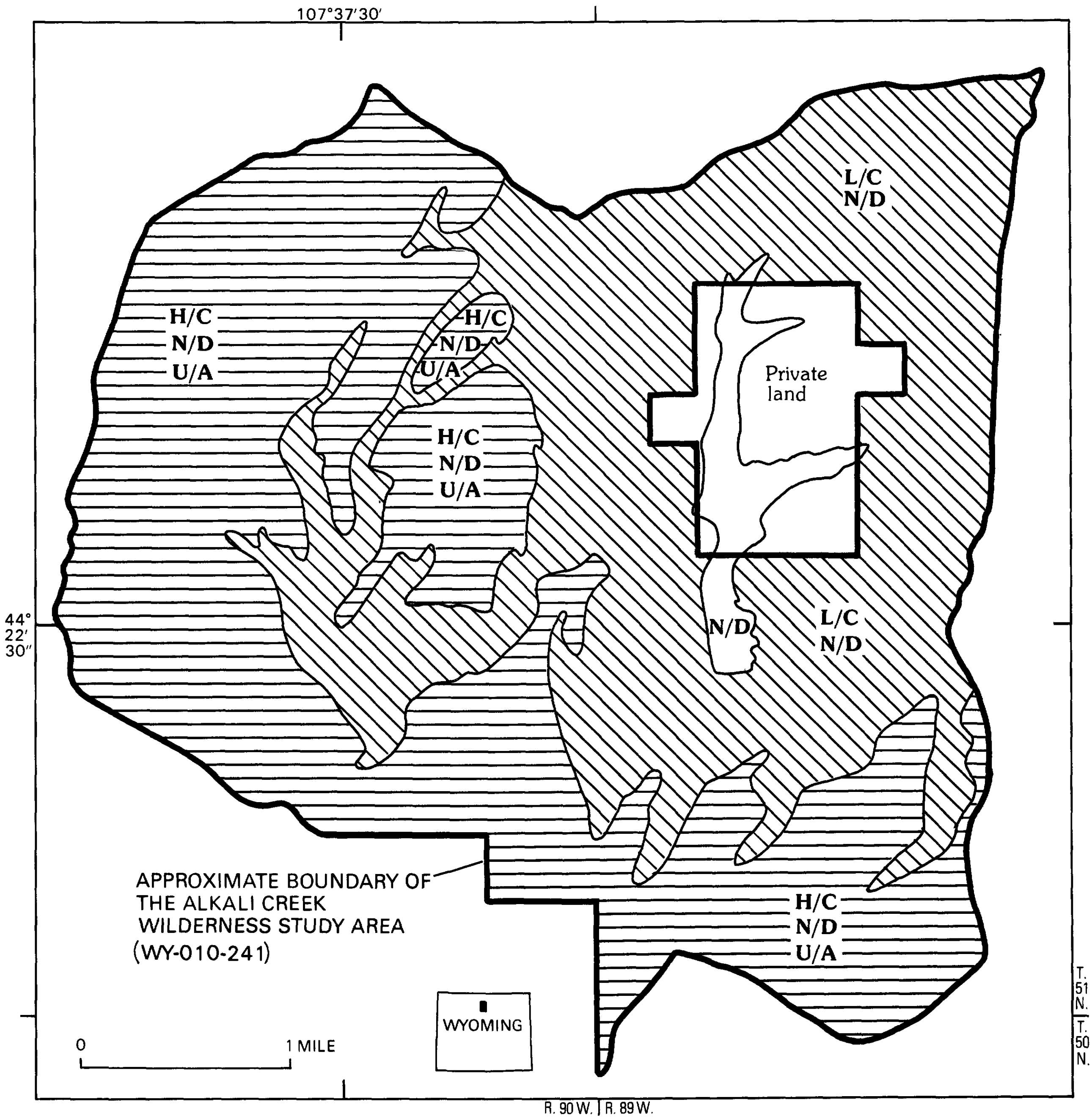


Figure 3 (above and facing page). Mineral resource potential of the Alkali Creek Wilderness Study Area, Big Horn County, Wyoming.

mining the deposit for road asphalt (Joseph Cox, President, Bronco Oil and Gas Company, Denver, Colo., oral commun., November 1986).

Energy Resources

Oil and gas leases cover parts of all three wilderness study areas (Gese, 1987). These leases reflect interest in the area for possible tar sand deposits. Spencer (1983, p. 7–8) rated the study areas as having a "low to zero" petroleum potential due to flushing of the reservoir rocks by meteoric water and absence of structural traps.

Uranium deposits have been mined in the karst topography in the Madison Limestone in the Pryor-Little Mountain area about 50 mi northwest of the study areas. Deposits in the upper 200 ft of the Madison Limestone occur as enrichments in silt-clay-rock cave fillings. The uranium deposits are high grade (0.50 percent U_3O_8) but are small and irregularly distributed. Five mines in

EXPLANATION

H/C U/A Geologic terrane having a high resource potential for gypsum, certainty level C; and an unknown resource potential for tar (natural bitumen), certainty level A

L/C Geologic terrane having a low resource potential for industrial sand; certainty level C

N/D Geologic terrane having no mineral resource potential for oil, natural gas, coal, uranium, other nonmetals, other metals, and geothermal energy; certainty level D—Applies to the entire study area

Levels of certainty

A Available information is not adequate for determination of 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

the Pryor-Little Mountain area had a total monthly production of about 700 tons (U.S. Atomic Energy Commission, 1959; McEldowny and others, 1977). Madison Limestone crops out throughout Medicine Lodge and Trapper Creek Wilderness Study Areas; however, no uranium occurrences have been discovered in the two study areas.

The Trapper Canyon tar sand deposit is between the Trapper Creek and Alkali Creek Wilderness Study Areas. Bronco Oil and Gas Company currently holds the leases covering the Trapper Canyon deposit. They estimate that 1.9 million barrels of oil exist in place on the 67-acre deposit.

Appraisal of Sites Examined

Inferred subeconomic resources of industrial sand, gypsum, dolomite, and high-calcium limestone were identified within one or more of the three study areas. These commodities were sampled and appraised. A tar sand deposit, which occurs 1 mi south of the Trapper Creek Wilderness Study Area, was also sampled and appraised.

Industrial Sand

Industrial sand has a high silica (SiO_2) content and consists mostly of quartz grains (Davis and Tepordei, 1985, p. 697). Most industrial sand is named according to its specific use and must meet rigid purity and silica specifications.

Five chip samples from the Tensleep Sandstone in the Alkali Creek Wilderness Study Area (pl. 1, USBM samples BM8–12) were evaluated for suitability as an industrial sand. The samples contained from 90.4 to 99.9 percent SiO_2, 0.59 to 2.2 percent Al_2O_3, and 0.15 to 0.27 percent Fe_2O_3 (table 1). By American Society for Testing and Materials (ASTM) standards, the high iron-oxide content and the fine granularity of the samples would make them suitable only for foundry sand (tables 1, 2) (Davis and Tepordei, 1985, p. 697; Coope and Harben, 1977, p. 16–17). Glass and optical sand should not

Table 1. Analytical data for sandstone samples from Alkali Creek Wilderness Study Area

[All determinations by ICP (inductively coupled plasma atomic emission spectroscopy). See plate 1 for sample localities]

Sample No.	Chip length (ft)	SiO_2	Al_2O_3	Fe_2O_3
		(percent)		
BM-8	4.0	91.0	2.20	0.27
BM-9	4.0	91.4	.87	.22
BM-10	5.0	97.5	1.00	.15
BM-11	1.5	99.9	.59	.24
BM-12	4.5	95.8	1.40	.20

Table 2. Sieve analysis of sandstone samples from Alkali Creek Wilderness Study Area

[U.S. Standard Series sieves. See plate 1 for sample localities]

Sample No.	Mesh interval (all analyses are in percent)						
	+20	−20+40	−40+60	−60+80	−80+100	−100+140	−140
BM-8	2.55	0.77	1.86	3.93	7.15	25.00	58.74
BM-9	16.61	2.6	2.29	11.69	26.26	22.49	18.03
BM-10	.88	.07	1.5	8.1	21.73	26.83	40.92
BM-11	1.5	.42	1.2	17.66	35.4	24.88	18.95
BM-12	1.5	.01	.39	1.66	4.8	12.78	56.42

contain more than 0.06 percent iron oxide and should be retained on a 140-mesh sieve (Bates, 1969, p. 101–102). A more accurate appraisal of the iron-oxide content of the sandstone would require analysis of an unweathered rock sample. In addition to the high iron-oxide content and extreme fineness, the remoteness of the sandstone makes its development unlikely, except for possible local use.

Gypsum

Gypsum beds as thick as 25 ft are interbedded with sandstone in the Alkali Creek Wilderness Study Area (pl. 1, USBM samples BM5–7, 13, 15, and 18). In outcrop, the gypsum beds are discontinuous and contain impurities as sandstone-filled fractures. Chemical analyses of outcrop samples showed the gypsum content to range from 73.3 to 94.5 percent (table 3). Most commercial gypsum mined today is between 85 and 95 percent pure (Appleyard, 1983, p. 775). For mining consideration, gypsum is a high-tonnage, low-value commodity; proximity relative to a market place is its most important economic factor. Although the gypsum is a minable grade, the beds are too thin, discontinuous, and remote to be developed commercially at the present time.

Limestone and Dolomite

Madison limestone and Bighorn dolomite crop out in the Trapper Creek Wilderness Study Area, and Madison Limestone crops out in the Medicine Lodge Wilderness Study Area. Material from these formations has been used as aggregate lime for cement and for agricultural and industrial purposes in other parts of Wyoming (Tetra Tech, Inc., Pasadena, Calif., written commun., September 1983). These rock units in the wilderness study areas have no unique characteristics that would make them usable. According to the USGS analytical results (table 7) this limestone would be considered high-calcium limestone. The remoteness and general inaccessibility of the two formations within the study areas make development unlikely at the present time.

Tar Sand

Tar sand has been mined and processed at the Trapper Canyon tar sand deposit 1 mi south of Trapper Creek Wilderness Study Area. The deposit occurs in the upper 10- to 40-ft eolian sequence of the Tensleep Sandstone over an area of about 67 acres (Ver Ploeg and De Bruin, 1985, p. 21). Drilling by Bronco Oil and Gas Company through the tar zone found it to be as thick as 36 ft with 9–77 ft of overburden (Ver Ploeg and De Bruin, 1985, p. 20). The exposed tar zone is as thick as 23 ft.

Four chip samples taken by the USBM from the tar zone at Trapper Canyon tar deposit showed the bitumen content (oil saturation) ranging from 4.7 to 12.5 percent (11.3 to 30.0 gal/ton) with a water content of 0.5 to 1.8 percent (1.3 to 4.2 gal/ton) (table 4). Drill core taken during Ver Ploeg and DeBruin's (1985, p. 15) study of the tar sand deposits had an oil saturation ranging from 7.9 to 15.1 percent. Major tar sand deposits in the United States have a bitumen content between 4 and 22 percent (Spencer and others, 1969, p. 6).

Bronco Oil and Gas Company is assessing the feasibility of mining the 1.9-million-barrel Trapper Canyon tar deposit for road asphalt. The deposit would be open-pit mined, processed on site, and trucked 17 mi to the railroad siding in Hyattville, Wyo. In 1980, they estimated the extracting and processing costs to be about $10.00 per barrel (Joseph Cox, President, Bronco Oil and Gas Company, Denver, Colo., oral commun., December 1986). The value per ton for road asphalt is $110.00 or $20.00 per barrel (FOB Denver) (Engineering News Record, 1986, p. 34).

Table 3. Analytical data of gypsum samples from Alkali Creek Wilderness Study Area

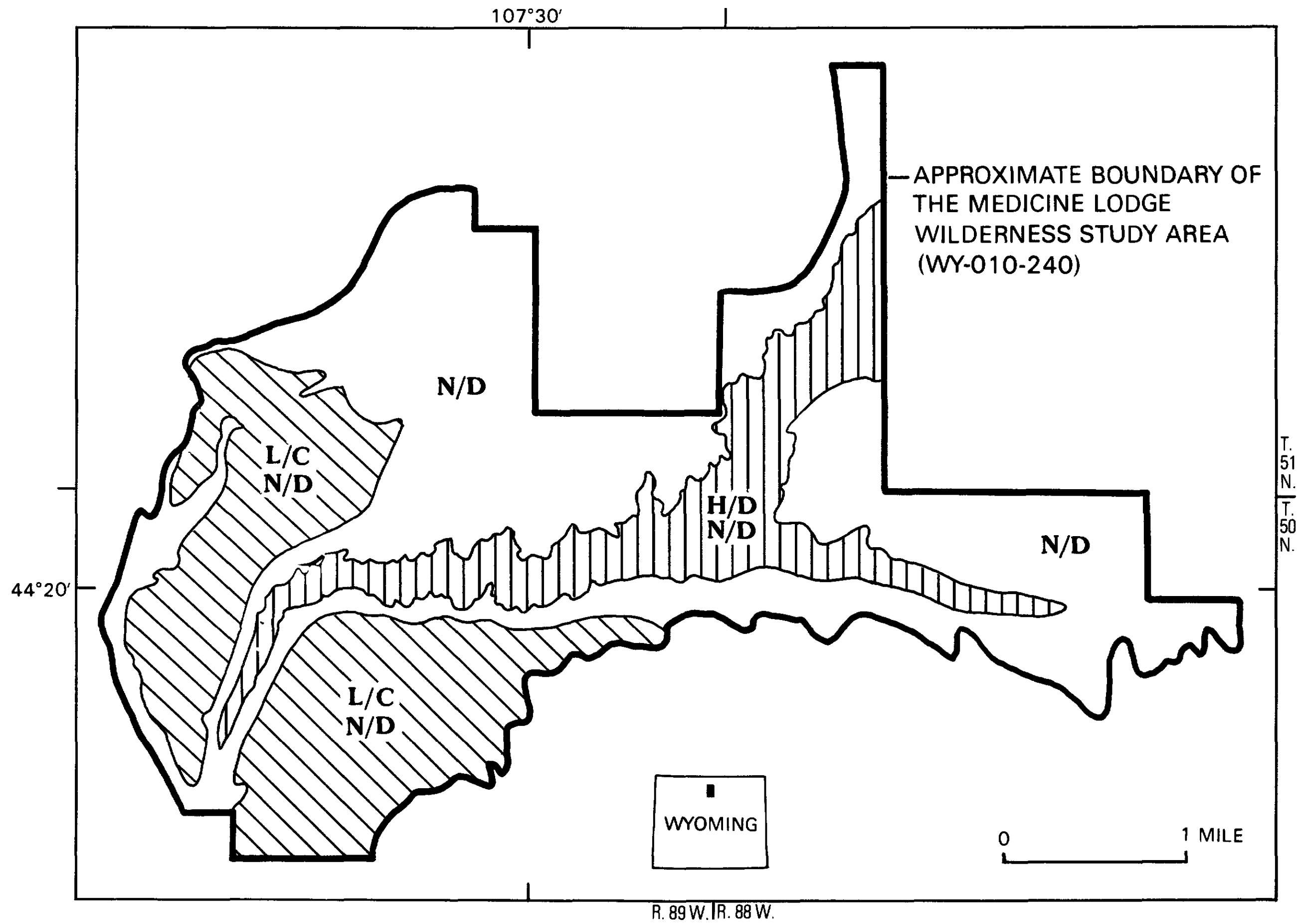
[See plate 1 for sample localities]

Sample No.	Chip length (ft)	Combined H_2O (percent)	$CaSO_4 \cdot 2H_2O$ (percent)
BM-5	2.0	19.80	92.89
BM-6	4.0	19.45	90.51
BM-7	2.3	19.52	90.68
BM-13	2.0	18.84	88.07
BM-15	3.2	20.08	94.51
BM-18	5.0	19.22	90.08

Table 4. Analysis of samples from Trapper Canyon tar deposit

[See plate 1 for sample localities]

Sample No.	Oil		Water	
	(weight percent)	(gallons per ton)	(weight percent)	(gallons per ton)
BM-1	11.6	27.9	1.8	4.2
BM-2	12.5	30.0	0.9	2.2
BM-3	4.7	11.3	1.3	3.2
BM-4	7.0	16.7	0.5	1.3



EXPLANATION

H/D Geologic terrane having a high resource potential for high-purity limestone; certainty level D

L/C Geologic terrane having a low resource potential for industrial sand; certainty level C

N/D Geologic terrane having no mineral resource potential for oil, natural gas, coal, uranium, other nonmetals, other metals, and geothermal energy; certainty level D—Applies to the entire study area

Levels of certainty

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

Figure 4. Mineral resource potential of the Medicine Lodge Wilderness Study Area, Big Horn County, Wyoming.

Conclusions

Inferred subeconomic resources of industrial sand and gypsum are within Alkali Creek Wilderness Study Area, dolomite and high-calcium limestone are within Trapper Creek Wilderness Study Area, and high-calcium limestone is within Medicine Lodge Wilderness Study Area. All four commodities are high-tonnage, low-value commodities that are too remote to be developed economically at the present time. An estimated 1.9 million barrels of oil are reported to exist in the 67-acre Trapper Canyon tar sand deposit about 1 mi south of the Trapper Creek Wilderness Study Area.

ASSESSMENT OF POTENTIAL FOR UNDISCOVERED RESOURCES

By John Hosterman, Randall H. Hill, and Dolores M. Kulik
U.S. Geological Survey

Geology

The Bighorn Mountains east of the three wilderness study areas consist of a northwest-trending core of exposed metamorphic and igneous rocks of Precambrian age with a sequence of Paleozoic, Mesozoic, and Cenozoic sedimentary rocks along the western flank. The sedimentary rocks dip to the west and southwest away from the mountain core and into the Bighorn basin where they are covered by a thick sequence of continental sedimentary rocks of Tertiary age.

Description of Rock Units

The oldest sedimentary formation in the three wilderness study areas is the Bighorn Dolomite of Ordovician age. This dolomite was first described by Darton (1904) from exposures on the eastern slope of the Bighorn Mountains. Only the upper 200 ft of the formation are exposed in the canyon of Trapper Creek. This upper sequence consists of light cream and light brown finely crystalline dolomite with some chert. The beds are massive toward the base of the exposure but thin toward the top. The exposed surface of this dolomite is characteristically pitted when subjected to weathering.

Overlying the Bighorn Dolomite and exposed in Trapper Creek is the Devonian Darby Formation, named by Blackwelder (1918) for exposures in the canyon of Darby Creek on the western slope of the Teton Range. The Darby Formation rests unconformably on the Bighorn Dolomite and is separated from the overlying Madison Limestone by an erosional surface. The Darby is a finely crystalline, light-gray to greenish-gray dolomite and silty dolomite with some interbedded dolomitic shale and siltstone. The Darby Formation usually forms gentle covered slopes that are in contrast to the shear canyon walls formed by the Bighorn Dolomite and the Madison Limestone. Because the Darby Formation is only about 100 ft thick, it is not shown as a separate unit on plate 1 and is included with the Bighorn Dolomite.

The Madison Limestone of Mississippian age was named by Peale (1893) for limestone found in the Madison Range of southern Montana. In the vicinity of the three wilderness study areas, the Madison Limestone can be divided into six informal members. The basal member consists of shale, siltstone, and silty dolomite. This member is overlain by a thick-bedded dolomite and dolomitic limestone member. The third member consists of crossbedded crinoidal dolomite, thick-bedded oolitic limestone, and silty, thin-bedded, and fine-grained limestone. Overlying this member is the cherty dolomite member composed of shattered and brecciated thin-bedded, fine-grained dolomite and dolomitic limestone. The cherty dolomite is overlain by cherty, fine- to coarse-grained, thick-bedded crinoidal limestone and dolomite. The sixth member is composed of shale, siltstone, and fine- to medium-grained limestone or dolomite with some chert. This member commonly has sinkholes and solution caves that are known to contain deposits of uranium elsewhere. However, there was no indication of uranium deposits in either Medicine Lodge or Trapper Creek Wilderness Study Areas. The total thickness of the Madison Limestone in these wilderness study areas is about 600–700 ft.

The Amsden Formation unconformably overlies the Madison Limestone and fills irregularities and solution cavities in the karst topography developed on the limestone surface. The Amsden Formation was named by Darton (1904) from Amsden Creek, a branch of the Tongue River, west of Dayton, Wyo. The Amsden Formation is considered to be both Mississippian and Pennsylvanian in age. The lower part of the Amsden Formation is composed of chiefly shale, siltstone, and mudstone that are poorly exposed and weather to reddish soil slopes that are commonly covered by talus and chert from the upper part. The upper part of the Amsden Formation consists of cherty limestone and dolomite with interbedded sandstone and shale. An outstanding characteristic of the Amsden Formation is the carbonate beds that contain red, brown, and black chert in nodules, lenses, or veins. The total thickness of the Amsden Formation in the study areas is about 200 ft.

The Pennsylvanian Tensleep Sandstone was named by Darton (1904) from outcrops of sandstone east of Ten Sleep, Wyo. The Tensleep Sandstone ranges in thickness from about 100 ft at the western edge of the Trapper Creek Wilderness Study Area to about 200 ft in the Alkali Creek Wilderness Study Area. The lower part of the formation consists of minor amounts of interbedded light-gray, fine- to medium-crystalline dolomite, red and green mudstone beds in white to gray sandstone cemented with carbonate. The upper part of the formation is composed of very fine grained to fine-grained well-sorted quartz sand that is either not cemented or cemented with silica or carbonate. These eolian sands are thick bedded and finely laminated with large-scale crossbedding. The tar sand deposits found in secs. 32 and 33, T. 52 N., R. 89 W. occur in these crossbedded eolian sands.

Unconformably overlying the Tensleep Sandstone is the Permian and Triassic Goose Egg Formation. The Goose Egg was first described and named by Burk and Thomas (1956) from an outcrop near the Goose Egg Post Office, about 10 mi southwest of Casper, Wyo. The Goose Egg Formation grades into the Phosphoria Formation and equivalent rocks and the overlying Dinwoody Formation to the west. The Phosphoria-age rocks contain the source rocks for most of the oil that has been discovered in the Bighorn basin. The Goose Egg Formation is composed of dark-red, thin-bedded siltstones interbedded with greenish-gray, thin-bedded, fine-grained dolomite and dolomitic limestone. The formation contains two beds of gypsum 5–8 ft thick in the

Alkali Creek Wilderness Study Area. The total thickness of the Goose Egg Formation is unknown in the three wilderness study areas because the top part of the formation has been removed by erosion.

Alluvium and older alluvial sediments occur in the Alkali Creek valley along the southern boundary of Alkali Creek Wilderness Study Area. Two water wells have been dug in the alluvial sediments.

Structure

The major structural trend of the Medicine Lodge, Alkali Creek, and Trapper Creek Wilderness Study Areas is a gentle west and southwest dip of 5–8 degrees. This gentle dip and the topographic slope of the area between the Bighorn basin and the crest of the Bighorn Mountains give a dip-slope feature to the upland areas. Several reversals in the regional dip of the Tensleep Sandstone in the northern part of the Alkali Creek Wilderness Study Area produce a series of small anticlines and synclines of which the most continuous is the Black Mountain Anticline (Ver Ploeg and De Bruin, 1985). An east-west fault in Alkali Creek Wilderness Study Area is easily recognized by its topographic expression. The relative movement is down on the south side, which brings the upper part of the Tensleep Sandstone in contact with the lower part. The fault dies out to the west and was not traced to the east, and the maximum displacement in the area is about 50 ft. In the Trapper Creek Wilderness Study Area there is a monocline that steepens the regional dip to more than 35 degrees. The strike of the monocline axis is almost north-south.

Geochemistry

A reconnaissance geochemical survey was conducted in Medicine Lodge, Alkali Creek, and Trapper Creek Wilderness Study Areas to assist in the mineral resource assessment. Fifty-two stream-sediment samples from alluvium and 52 heavy-mineral samples (panned concentrates of the stream sediments) were selected as a representative composite of rock and soil exposed in the drainage basin upstream from the sampling site. Chemical analyses of these stream sediments provide data useful in identifying those drainage basins that contain unusually high concentrations of elements that may be related to mineral occurrences. Studies have shown that heavy-mineral concentrates derived from stream sediments are a useful sample medium in arid and semiarid environments or in areas of rugged topography where mechanical erosion predominates over chemical erosion (Overstreet and Marsh, 1981; Bugrov and Shalaby, 1975).

Fifty-nine rock samples were collected to represent the rock formations exposed in the vicinity of the stream-sediment samples. The actual areal extent of the geochemical information represented by a specific rock sample is not known, but the rock sampling was designed to provide some information on the chemical nature and the mineralogical composition of the rock units present.

Sample Preparation

Before chemical analyses were made, the following procedures were used in sample preparation. The dry stream-sediment samples were sieved through 80-mesh stainless-steel sieves. The minus 80-mesh material was ground to less than 100 mesh and saved for chemical analysis. The panned-concentrate samples were separated into light and heavy fractions by using bromoform (a heavy liquid with specific gravity of 2.86). The light fraction was discarded. The heavy fraction (material of specific gravity greater than 2.86) was further separated into three fractions (strongly magnetic, weakly magnetic, and nonmagnetic) using an adjustable magnetic separator. The nonmagnetic heavy-mineral fraction was ground and saved for chemical analysis. This procedure results in a sample that may contain ore-forming and ore-related minerals. This selective concentration of minerals permits determinations of some elements that are not easily detected in bulk stream-sediment samples. The rock samples were crushed and pulverized to at least minus 100 mesh and saved for chemical and mineralogical analyses.

Chemical Analysis

Three types of samples—the stream-sediment samples, the nonmagnetic heavy-mineral concentrate samples, and the rock samples—were analyzed for 31 elements using a six-step, semiquantitative emission spectrographic method (Grimes and Marranzino, 1968). No additional analyses were made on the nonmagnetic heavy-mineral concentrates due to the limited amount of sample material. The stream-sediment samples and rock samples were also analyzed for arsenic, bismuth, cadmium, and zinc using an inductively coupled argon plasma-atomic emission spectrograph (Crock and others, 1987); uranium was analyzed using fluorimetry (O'Leary and Meier, 1984). The mineralogy of the rock samples was determined by X-ray diffraction to determine the presence of any ore-forming minerals and to compare the results with the chemical analyses.

The threshold values, defined as the upper limit of normal background values, were determined for each element by inspection of frequency distribution histograms for all three types of samples. A chemical value higher than the threshold values is considered anomalous and worthy of scrutiny as a possible indication of mineralization.

Discussion

The geochemical concentrations for nearly all rock and stream-sediment samples from the three wilderness study areas are well within normal background values. One exception is a rock sample (a siltstone) from the Goose Egg Formation within the Alkali Creek Wilderness Study Area that has 16.0 parts per million (ppm) uranium. The areal extent of this uranium anomaly is extremely limited because no other rock sample or stream-sediment sample had uranium concentrations above the threshold value.

The geochemical analyses of the nonmagnetic heavy-mineral concentrates from Alkali Creek Wilderness Study Area reflect high concentrations of barium, strontium, and zirconium. The analyses of concentrates from Trapper Creek Wilderness Study Area show a small number of samples rich in barium and strontium, but none were higher than expected in samples from a carbonate terrane. Six samples contain zirconium and 14 samples showed no zirconium. The analyses of concentrates from Medicine Lodge Wilderness Study Area reflect a moderate number of samples with high barium, strontium, and zirconium.

The X-ray diffraction traces of the nonmagnetic heavy-mineral concentrates within the three wildernesss study areas show that the major heavy minerals are barite, celestite, zircon, and apatite. The barite and celestite are probably authigenic in the alluvium. Zircon and apatite, accessory minerals in the country rock, were removed by weathering and erosion, concentrated by stream action in the alluvium, and further concentrated by panning and removal of magnetic fractions.

There is no evidence from the geochemical data of any ore-forming or ore-related mineral assemblages that would indicate the occurrence of ore deposits within Trapper Creek, Alkali Creek, and Medicine Lodge Wilderness Study Areas.

Geophysics

Gravity and magnetic studies were undertaken as part of the mineral resource potential study of the Medicine Lodge, Alkali Creek, and Trapper Creek Wilderness Study Areas; they provide information on the subsurface distribution of rock masses and structural framework. The gravity and magnetic data are of a reconnaissance nature and are adequate only to define regional structural features.

Gravity data were obtained in and adjacent to the study areas in 1985 and 1986, and were supplemented by data maintained in the files of the Defense Mapping Agency of the U.S. Department of Defense. Stations measured were established using Worden gravimeter W–1771. The data 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 estimates from topographic maps at 1:24,000 and 1:62,500 scales, and are accurate to ±20 to 40 ft. The error in the Bouguer value is less than 2.5 mGal (milligals) for errors in elevation control. The Bouguer values were computed using the 1967 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). The data are shown as a complete Bouguer map with a contour interval of 5 mGal (fig. 5).

Magnetic data are from the U.S. Department of Energy (1982). Flight lines were flown from east to west at 2- to 5-mi intervals and 400 ft above ground level. The data are shown as a residual intensity magnetic map with a contour interval of 100 gammas (fig. 6).

A gravity high (see "A" on fig. 5) is associated with rocks of the Bighorn Mountains uplift to the east and northeast of the three wilderness study areas. The gravity values decrease to the west across the wilderness study areas where the crystalline rocks are at a greater depth. The gravity gradient increases sharply southwest of the wilderness study areas across the bounding thrust of the Bighorn uplift in the west-central part of the map. The continuation of the gravity gradient beyond the mapped thrust suggests that the fault continues subsurface along the gravity gradient. The gravity contours parallel the fault mapped in the Alkali Creek Wilderness Study Area (pl. 1) and suggest, as do the magnetic data (fig. 6), that the crystalline rocks are offset by the fault. The gravity low (see "B" on fig. 5) is associated with Tertiary sedimentary rocks.

The highest magnetic values at the eastern edge of the map are associated with the exposed crystalline rocks of the Bighorn uplift. The magnetic low (see "A" on fig. 6) is caused by nonmagnetic Cambrian rocks preserved between the crystalline rocks and the bounding thrust of the Bighorn uplift. Moderately high magnetic values in the southwestern part of the map are part of a more extensive magnetic high that extends 15–20 mi southwest of the map area. The more extensive magnetic high and a coincident gravity high are interpreted here to be caused by crystalline rocks in a thrust plate beneath the sedimentary rocks of the Bighorn basin. The magnetic

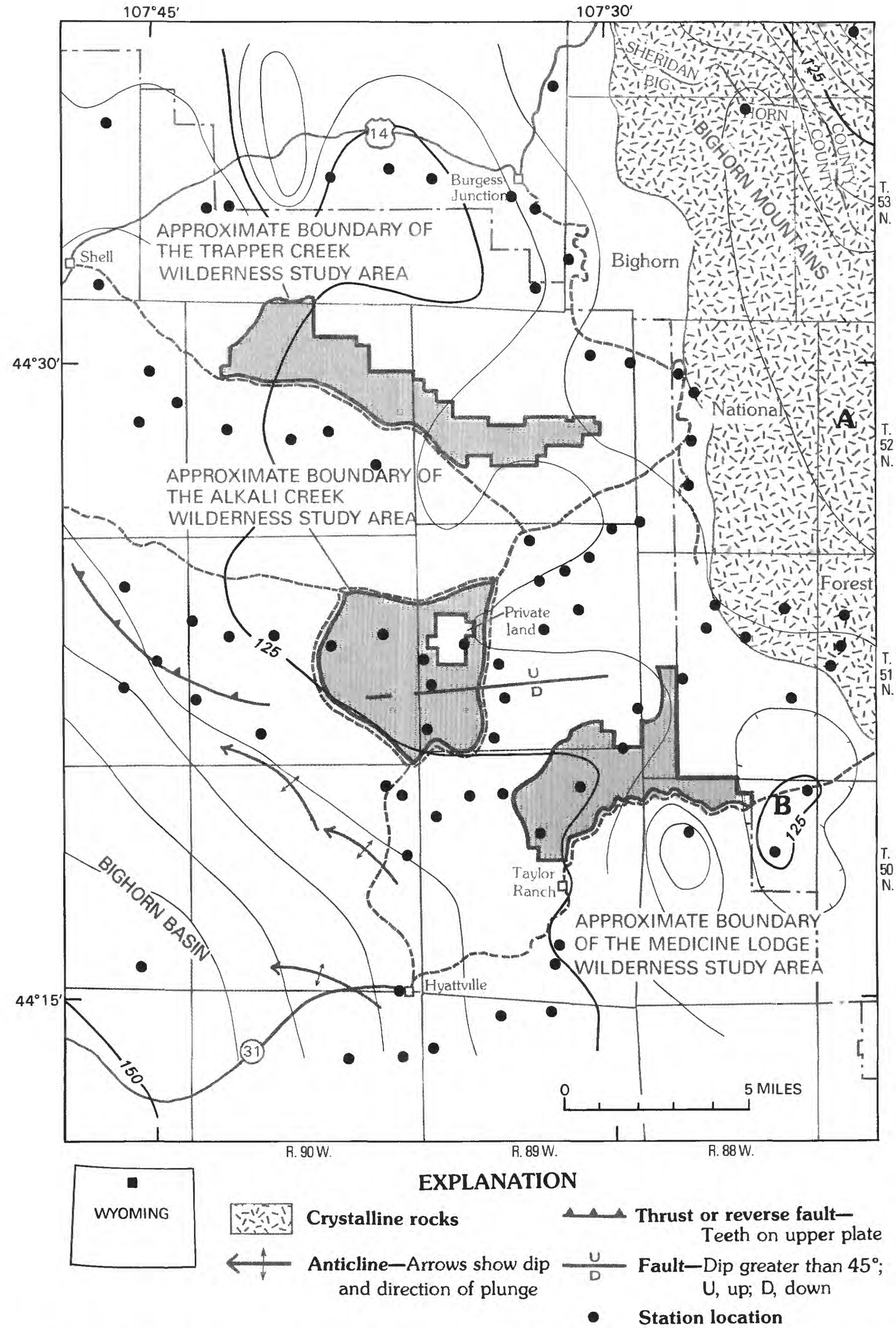


Figure 5. Complete Bouguer gravity anomaly and generalized structure map (Ver Ploeg, 1985) of Trapper Creek, Alkali Creek, and Medicine Lodge Wilderness Study Areas and adjacent areas. Contour interval, 5 milligals. A, High gravity anomaly; B, low gravity anomaly.

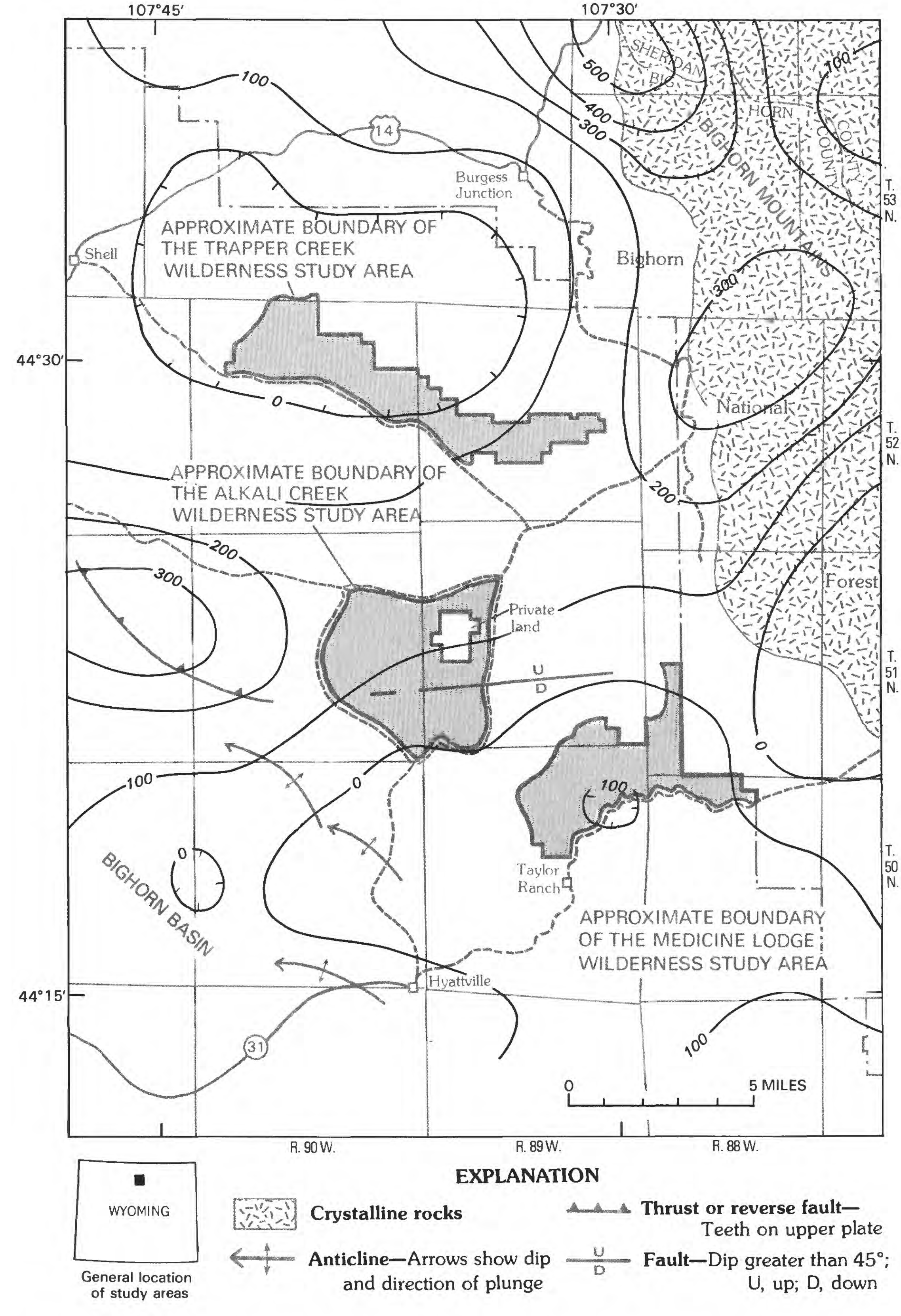


Figure 6. Residual intensity magnetic anomaly and generalized structure map (Ver Ploeg, 1985) of Trapper Creek, Alkali Creek, and Medicine Lodge Wilderness Study Areas and adjacent areas. Contour interval, 100 gammas.

gradient associated with the fault mapped in the Alkali Creek Wilderness Study Area suggests, as do the gravity data, that the fault offsets crystalline rocks and is continuous with the major thrust that curves to the northwest.

Mineral and Energy Resources

Sand

The Tensleep Sandstone contains 70–98 percent quartz (SiO_2) sand (table 5). The feldspar content in all samples studied ranged from 1 to 4 percent. Many sandstone beds are cemented with calcite or dolomite (USGS samples GS-4 and GS-9, table 5), other beds are cemented with silica, and a few beds are quite friable because they either had no cement originally or were leached of carbonate cement. The Alkali Creek Wilderness Study Area has an areal extent of exposed Tensleep Sandstone of about 8 mi^2 and the Medicine Lodge Wilderness Study Area has an areal extent of about 4 mi^2. The potential for industrial sand resources is low (certainty level C) in the Alkali Creek and Medicine Lodge Wilderness Study Areas because most of the sand is cemented with one of the carbonates or, less commonly, with silica.

Table 5. Analysis of sandstone samples from the Tensleep Sandstone in the Alkali Creek and Medicine Lodge Wilderness Study Areas

[Analyses (in percent) by F.W. Brown and Hezekiah Smith, U.S. Geological Survey. See plate 1 for sample localities]

Sample No.--	[1]GS-6	[1]GS-4	[2]GS-9
SiO_2	95.6	86.8	69.1
Al_2O_3	1.2	1.9	1.6
Fe_2O_3	0.12	0.33	.26
FeO	.08	.04	.08
MgO	.11	.50	2.6
CaO	.88	4.6	12.1
Na_2O	.01	.04	.02
K_2O	.88	1.5	1.0
TiO_2	.09	.06	.12
P_2O_5	.02	.04	.05
MnO	.01	.01	.02
H_2O+	.13	.37	.35
H_2O-	.11	.22	.13
CO_2	.60	3.6	11.4
Total----	99.8	100.0	98.8

[1]From Alkali Creek Wilderness Study Area.

[2]From Medicine Lodge Wilderness Study Area.

Gypsum

The Goose Egg Formation in the Alkali Creek Wilderness Study Area contains at least two beds of gypsum in the SW¼NW¼ sec. 31, T. 51 N., R. 89 W. Here the beds are 5–8 ft thick and about 15 ft apart. The lower bed is 50 ft above the Tensleep-Goose Egg contact. The lower bed is hard white gypsum with no impurities. The upper bed is sugary textured white gypsum that contains about 5 percent calcite. Other outcrops of gypsum are in the NE¼SW¼ sec. 25, T. 51 N., R. 90 W. and in the NE¼SW¼ sec. 22, T. 51 N., R. 90 W. White, almost pure gypsum occurs in the southern part of Alkali Creek Wilderness Study Area in a belt that extends for about 4 mi. The chemical analyses of three USGS samples of gypsum from Alkali Creek Wilderness Study Area are given in table 6. The resource potential of gypsum in the Alkali Creek Wilderness Study Area is high (certainty level C).

Another occurrence of gypsum, also in the Goose Egg Formation, is in the SW¼NE¼ sec. 8, T. 52 N., R. 90 W. This outcrop, in the Trapper Creek Wilderness Study Area, contains only one bed of gypsum and covers an area of less than 25 acres. At this locality the gypsum has no resource potential (certainty level D) because it is red and light greenish gray, contains impurities of calcite and dolomite, varies in thickness and continuity, and contains fractures filled with silt and sand.

Limestone

Limestone and dolomite beds occur in the Bighorn Dolomite, the Madison Limestone, and the Amsden Formation. Most of the samples analyzed from these formations contained both $CaCO_3$ and $MgCO_3$. However, one sample of Madison Limestone from the Medicine Lodge Wilderness Study Area contained 97 percent $CaCO_3$ and 2 percent SiO_2, and two samples of Madison Limestone from the Trapper Creek Wilderness Study Area averaged 99.5 percent $CaCO_3$ (table 7). On the basis of very few samples, there is a high potential (certainty level D) for high-purity limestone in the Madison Limestone of Trapper Creek and Medicine Lodge Wilderness Study Areas. However, except for the limestone exposed in canyon walls, it occurs beneath a thick overburden of Amsden Formation cherty dolomite and Tensleep Sandstone, making extraction difficult.

Table 6. Analysis of gypsum samples from the Goose Egg Formation in the Alkali Creek Wilderness Study Area

[Analyses (in percent) by F.W. Brown and Hezekiah Smith, U.S. Geological Survey. See plate 1 for sample localities]

Sample No.--	GS-2	GS-3	GS-5
SiO_2	0.88	0.87	2.0
Al_2O_3	.10	.09	.07
Fe_2O_3	.15	.16	.14
FeO	--	--	--
MgO	.06	.11	.11
CaO	32.5	34.0	32.4
Na_2O	.07	.07	.05
K_2O	<.01	<.01	<.01
TiO_2	.02	.02	.01
P_2O_5	.02	.02	.02
MnO	.01	.01	.01
H_2O+	.70	.50	.40
H_2O-	20.0	17.1	19.8
CO_2	<.01	.03	.15
SO_3	46.	47.	45.
Total----	100.5	100.0	100.2

Table 7. Analysis of samples from the Madison Limestone from Medicine Lodge and Trapper Creek Wilderness Study Areas

[Analyses (in percent) by F.W. Brown and Hezekiah Smith, U.S. Geological Survey. See plate 1 for sample localities]

Sample No.--	GS-7	GS-12	GS-19
SiO_2	2.2	0.65	0.46
Al_2O_3	0.14	.09	.18
Fe_2O_3	.07	.08	.04
FeO	.08	.08	.12
MgO	.42	.29	.20
CaO	54.3	55.0	55.2
Na_2O	.12	.06	.06
K_2O	<0.01	<0.01	.05
TiO_2	.01	.01	.01
P_2O_5	.02	.03	.02
MnO	.02	.02	.02
H_2O+	.45	.04	.18
H_2O-	.05	.13	.12
CO_2	43.4	44.5	44.2
Total----	101.3	101.0	100.9

Tar (Natural Bitumen)

Tar or natural bitumen was not found in any of the three wilderness study areas. However, there are two deposits of tar sand located between Alkali Creek and Trapper Creek Wilderness Study Areas in secs. 32 and 33, T. 52 N., R. 89 W. The earliest reference to this deposit was by Darton (1906). Some attempts were made in the past to develop the deposit, but due to leasing problems only 7,000 gallons of hydrocarbons have been produced from the tar as of September 1981.

The Trapper Canyon tar sand is located on two hills about one-half mile apart that are capped by the Goose Egg Formation. The tar is in the sand of the upper 10–40 ft of the Tensleep Sandstone. The sand containing tar ranges in thickness from 0 to 23 ft, the overburden ranges in thickness from 9 to 77 ft, and the tar saturation ranges from 7.9 to 15.1 percent (Ver Ploeg and De Bruin, 1985).

Outcrops of the upper part of the Tensleep Sandstone in the three wilderness study areas were examined for evidence of tar accumulation. The western half of Alkali Creek Wilderness Study Area is the only area that is underlain by the upper part of the Tensleep and capped by the Goose Egg Formation; there has been no exploratory drilling and no test pits dug and there is no evidence of oil seepages. The resource potential for tar deposits in this study area is unknown (certainty level A).

Other Mineral and Energy Resources

Uranium minerals occur in the upper part of the Madison Limestone according to Osterwald and others (1966). Apparently the uranium is associated with the Amsden Formation red beds that fill the cavernous and brecciated karst portion of the upper part of the Madison. The Amsden Formation-Madison Limestone contact was extensively checked with a scintillation counter for uranium anomalies. The results indicate that there is no resource potential (certainty level D) for uranium in the three wilderness areas.

The Trapper Creek, Alkali Creek, and Medicine Lodge Wilderness Study Areas are underlain by a thin sequence of Paleozoic sedimentary units covering crystalline basement rocks that lack significant stratigraphic or structural traps needed for hydrocarbon amassment. According to Spencer (1983), this type of geologic environment is not favorable for the accumulation of oil and gas. On this basis, the three wilderness study areas have no resource potential (certainty level D) for oil (excluding tar) and natural gas.

Based on the geological, geochemical, and geophysical data collected for this report, there is no resource potential for coal, other metals, other nonmetals, and geothermal energy in the three wilderness study areas (certainty level D), other than those mentioned earlier here.

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APPENDIX

DEFINITION OF LEVELS OF MINERAL RESOURCE POTENTIAL AND CERTAINTY OF ASSESSMENT

Definitions of Mineral Resource Potential

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

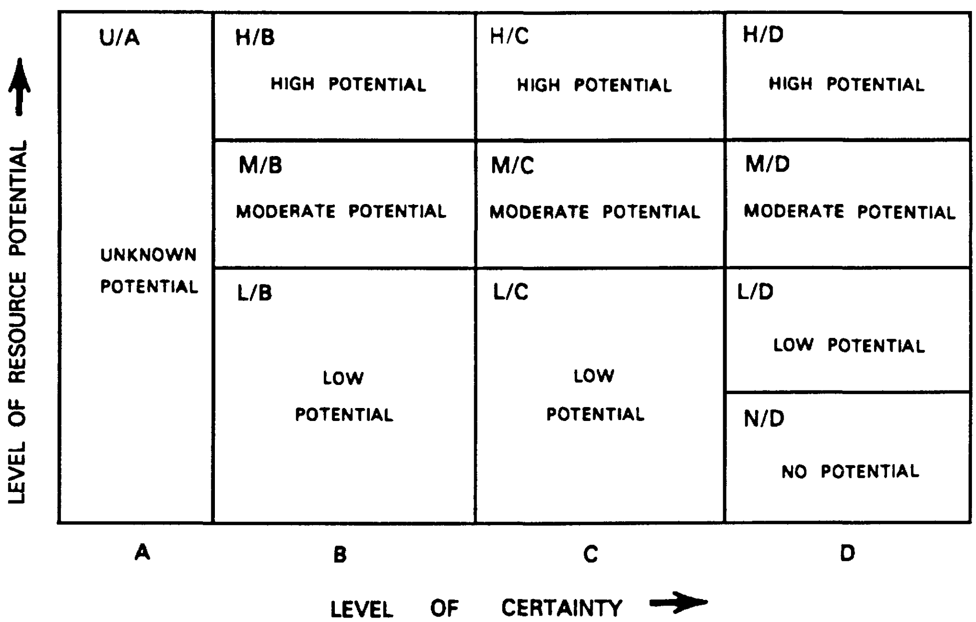
MODERATE mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence, where interpretations of data indicate a reasonable likelihood of resource accumulation, and (or) where an application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

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

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

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

Levels of Certainty



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

Abstracted with minor modifications from:

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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