Mineral Resources of the Buffalo Hump and Sand Dunes Addition Wilderness Study Areas, Sweetwater County, Wyoming

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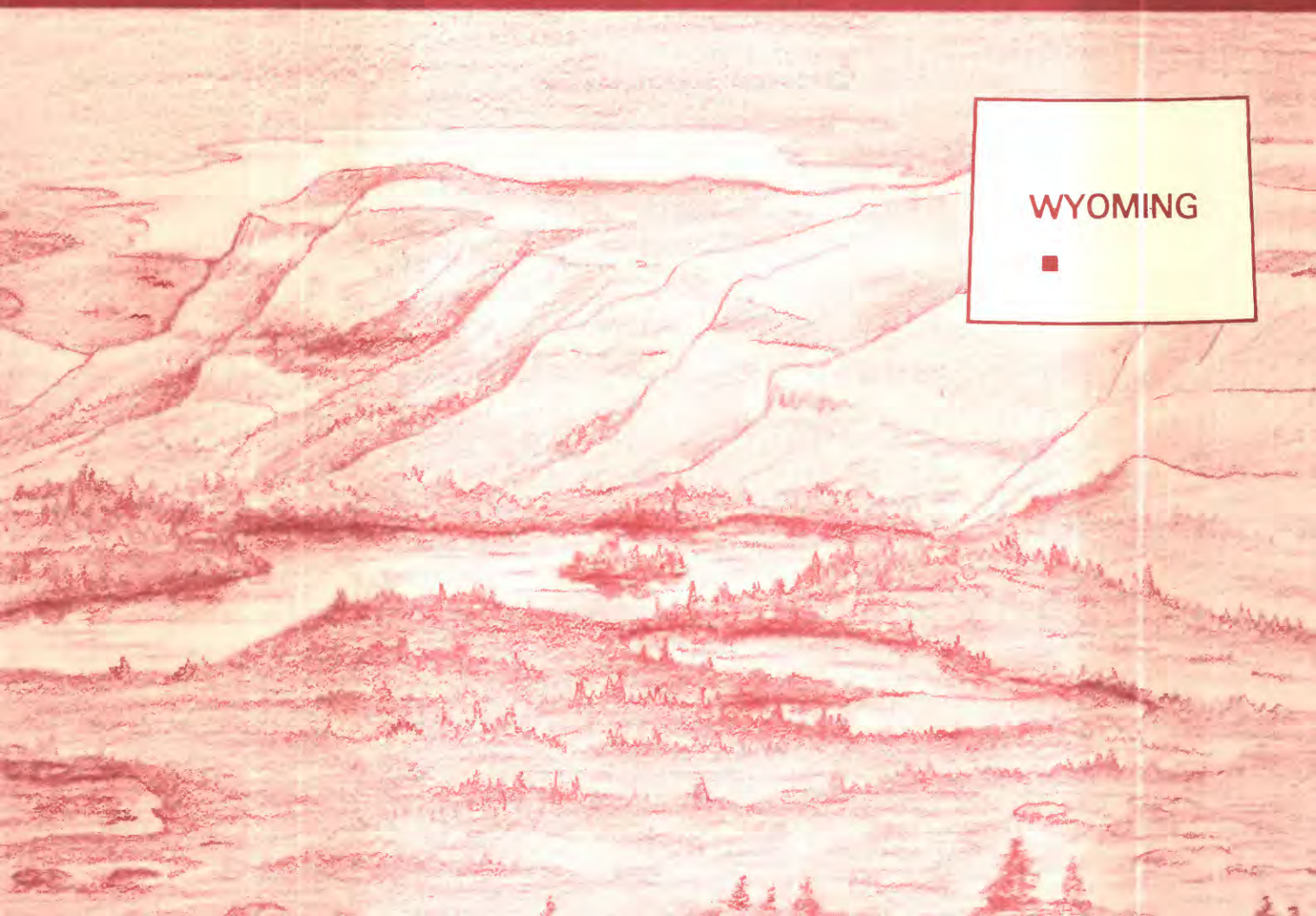

Chapter G

Mineral Resources of the Buffalo Hump and Sand Dunes Addition Wilderness Study Areas, Sweetwater County, Wyoming

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U.S. GEOLOGICAL SURVEY BULLETIN 1757

MINERAL RESOURCES OF WILDERNESS STUDY AREAS—SOUTHERN WYOMING

DEPARTMENT OF THE INTERIOR
MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY
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STUDIES RELATED TO WILDERNESS

Bureau of Land Management Wilderness Study Areas

The Federal Land Policy and Management Act (Public Law 94–479, October 21, 1976) requires the U.S. Geological Survey and the U.S. Bureau of Mines to conduct mineral surveys on certain lands to determine the mineral values, if any, that may be present. Results must be made available to the public and submitted to the President and the Congress. This report presents the results of a mineral survey of a part of the Buffalo Hump (WY–040–306) and Sand Dunes Addition (WY–040–307) Wilderness Study Areas, Sweetwater County, Wyoming.

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Mineral Resources of the Buffalo Hump and Sand Dunes Addition Wilderness Study Areas, Sweetwater County, Wyoming

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ABSTRACT

The Buffalo Hump (WY–040–306) and the Sand Dunes Addition (WY–040–307) Wilderness Study Areas are about 27 mi (miles) north of Rock Springs, Wyo. About 6,306 acres of the Buffalo Hump Wilderness Study Area and about 5,998 acres of the Sand Dunes Addition Wilderness Study Area were studied for this investigation. The wilderness study areas have occurrences of coal, sand, claystone, and shale. The study areas have a moderate potential for undiscovered resources of natural gas and a low potential for undiscovered resources of oil and for geothermal sources. The resource potential is moderate for oil shale in the parts of the study areas that are underlain by oil shale. The mineral resource potential is low for all metals, including uranium.

SUMMARY

Character and Setting

The Buffalo Hump Wilderness Study Area (WY–040–306) and the Sand Dunes Addition Wilderness Study Area (WY–040–307) are in north-central Sweetwater County, about 27 mi north of the town of Rock Springs. At the request of the U.S. Bureau of Land Management (BLM), the U.S. Bureau of Mines (USBM) and the U.S. Geological Survey (USGS) studied about 6,306 acres of the Buffalo Hump Wilderness Study Area and all of the Sand Dunes Addition Wilderness Study Area, which consists of two tracts totaling about 5,998 acres. In this report, the areas studied are referred to as the "the wilderness study areas" or the "study areas." This report expands on earlier studies made of the adjacent Sand Dunes Wilderness Study Area (fig. 1). Results of the earlier studies were reported by Merewether, Kulik, and Ryan (1987) and by Ryan (1985).

Terrain of the wilderness study areas ranges in elevation from about 6,670 ft (feet) to about 7,100 ft and is generally covered with dune sand. Sandstone, mudstone, and shale of, from oldest to youngest, the Lance, Fort Union, Wasatch, Green River, and Bridger Formations underlie the sand and crop out in the vicinity of the study area. The Lance Formation is underlain by a succession of sedimentary formations that have a total thickness of about 15,000 ft.

The wilderness study areas are on the northwestern flank of the Rock Springs uplift, where the strata dip 2–5° west-northwest. Faults are known in nearby areas but not within the study areas themselves.

Identified Resources

The study areas are covered extensively by dune sand, which lies unconformably across the tilted and eroded edges of the sedimentary strata. Analytical tests show that the sand is too poor in silica and too rich in metallic and alkali oxides to be used in special-purpose high-silica sand applications. The sand probably would be suitable for use in mortar, grout, and asphaltic products, but it has no unique qualities, development and transportation costs are high, and unit

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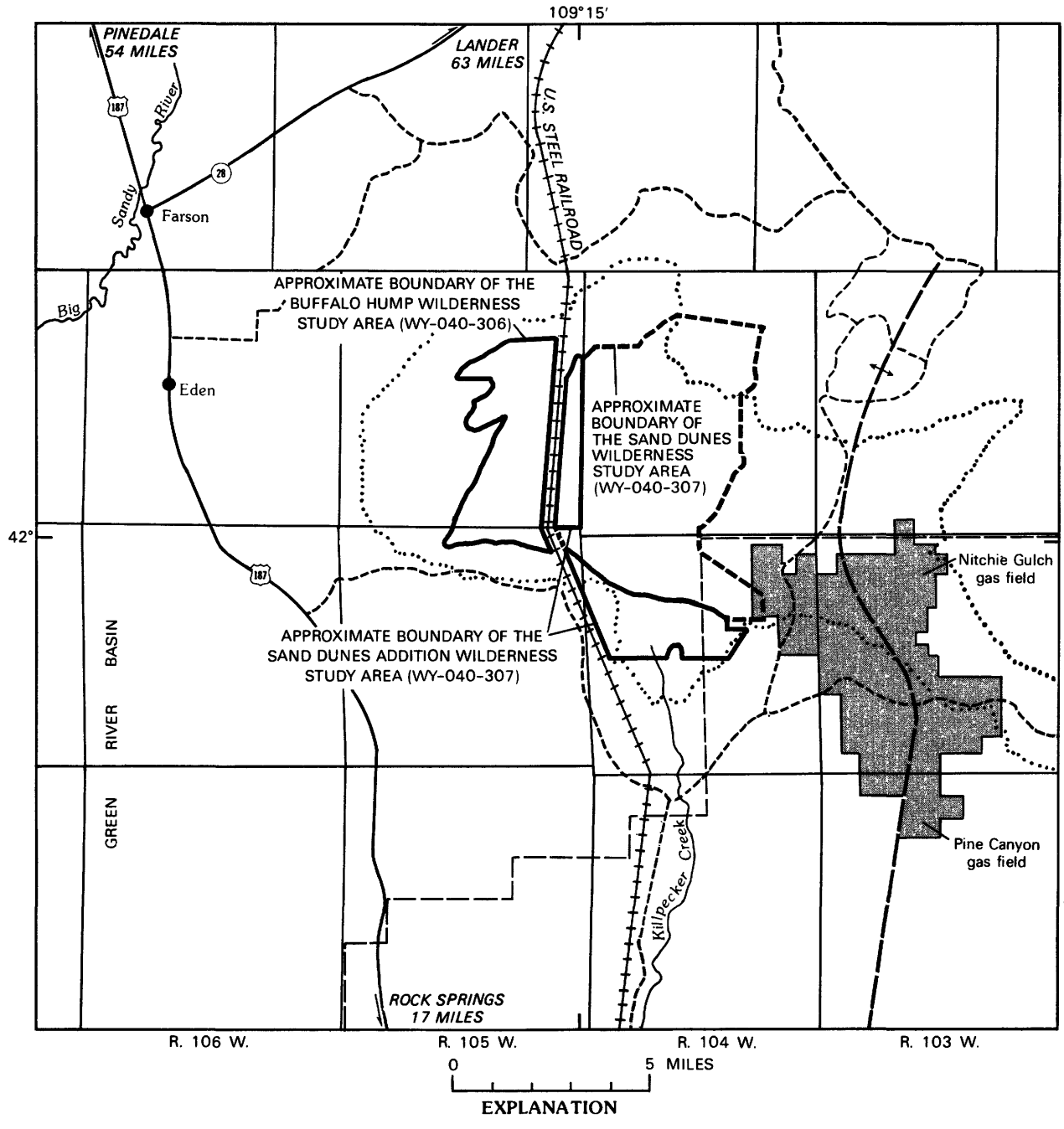


Figure 1. Location map of the Buffalo Hump and Sand Dunes Addition Wilderness Study Areas, Wyoming. Modified from Merewether, Kulik, and Ryan, 1987.

value is low. Usage would be confined to local markets, and a sufficient supply of similar material exists outside the study areas to satisfy this demand.

The underlying sedimentary strata host coal, oil shale, natural gas, claystone, and shale. Limited drill-hole, outcrop, and geologic evidence indicate that coal of unknown quality

and quantity exists in the Late Cretaceous (see geologic time chart in the Appendix) Rock Springs, Almond, and Lance Formations and Tertiary Fort Union Formation at depths between 1,000 ft and 6,000 ft beneath the study areas. Some coal may occur in the Fort Union Formation less than 1,000 ft beneath the eastern sections of the southern part of the Sand Dunes Addition Wilderness Study Area. None of the coal inside the study areas meets current economic mining criteria, and it is not likely to be developed in the foreseeable future.

Natural gas is being produced near the study areas, which are in large part covered by oil and gas leases. Gas production is from structural and stratigraphic traps in the Early Cretaceous Cloverly Formation and Thermopolis Shale, and Late Cretaceous Frontier Formation. The strata extend beneath the study areas and have been explored by geophysical surveys and by drilling. No discoveries of natural gas or of oil have resulted.

Claystone and shale underlie the study areas but are of low quality and are deeply buried extensions of units exposed outside. No development is likely in the foreseeable future.

Mineral Resource Potential

Oil shale is covered by dune sand in the wilderness study areas but crops out extensively in adjoining areas. Stratigraphic units largely composed of oil shale trend south-southwest across this region and are as much as 240 ft thick. The estimated producible amounts of oil in these units are 2–25 gpt (gallons of oil per ton of rock). A few samples of shale from outcrops near the study areas were analyzed for oil yield as part of an earlier investigation. The richest of these contained about 11 gallons per ton. Consequently, the energy resource potential of the oil shale in the study areas is considered moderate (fig. 2).

Boreholes drilled for oil and gas in the study areas have not been productive, although the reservoir strata of gas fields near the study areas are widespread in the region. Large amounts of natural gas have been produced from wells in the Nitchie Gulch and Pine Canyon fields east and southeast of the study areas. The gas is stratigraphically entrapped in formations that extend northwestward into the subsurface of the study areas. These formations could contain large amounts of gas in the study areas and adjacent areas. Sparse information indicates that the gas could be in either stratigraphic or structural traps. The energy resource potential of the wilderness study areas for natural gas is therefore moderate.

Oil has not been produced and apparently has not been discovered near the wilderness study areas or in the northern part of the Rock Springs uplift. The region is not completely explored; in particular, the older formations have rarely been penetrated. On the basis of the meager information available, the energy resource potential for oil in the wilderness study areas is low.

The wilderness study areas lie in a region that is poor in metallic deposits, and the present investigation has produced no evidence of significant metal mineralization. The mineral resource potential for all metals, including uranium, is low.

The study areas lack hot springs or other evidence of high Earth temperatures at shallow depth. Aquifers containing large quantities of low to moderate temperature thermal water could be present in the deep subsurface, although none are definitely known. The energy resource potential for geothermal sources is low.

INTRODUCTION

In 1988, at the request of the BLM, the USGS and the USBM conducted a mineral investigation of a part of the Buffalo Hump Wilderness Study Area (WY-040–306) and the Sand Dunes Addition Wilderness Study Area (WY–040–307), Sweetwater County, Wyoming. The wilderness study areas comprise 10,300 and 5,998 acres, respectively, of public land administered by the Rock Springs District Office of the BLM. This study focused on 6,306 acres of the Buffalo Hump Wilderness Study Area preliminarily designated suitable for inclusion in the National Wilderness Preservation System by the BLM and also included the total acreage of the Sand Dunes Addition Wilderness Study Area.

As used in this report, the term "Buffalo Hump Wilderness Study Area" refers only to acreage studied for this report. Two discrete tracts make up the Sand Dunes Addition Wilderness Study Area and are referred to individually as the southern part and the western part of the Sand Dunes Addition Wilderness Study Area, in this report. The total studied acreage (all three tracts) will be referred to collectively as "the wilderness study areas" or "the study areas."

The study areas are in north-central Sweetwater County about 27 mi north of Rock Springs and about 10 mi east of the village of Eden (fig. 1). Access to the study areas is by at least 10 mi of unpaved road, northeast or east from U.S. Highway 187, or southeast from Wyoming Highway 28. Within the wilderness study areas as defined above, material at the surface consists mostly of dune sand with small areas of sedimentary rock and of alluvium. Elevations in the study areas range from about 6,670 ft in the valley of Killpecker Creek to 7,104 ft on Buffalo Hump. Sparse vegetation consists of shrubs, forbs, and grasses. The study areas are within the Green River drainage system. Stream flow is intermittent. Drainage, much of it subsurface, is westward to the Big Sandy River and southward into Killpecker Creek (fig. 1).

The USGS and USBM investigated the mineral resources of the adjacent Sand Dunes Wilderness Study Area during 1984–85. The investigation reviewed and summarized available minerals information, appraised mineral reserves and subeconomic resources, and assessed the likelihood of undiscovered mineral resources. Results were reported by Merewether, Kulik, and Ryan (1987) in U.S. Geological Survey Bulletin

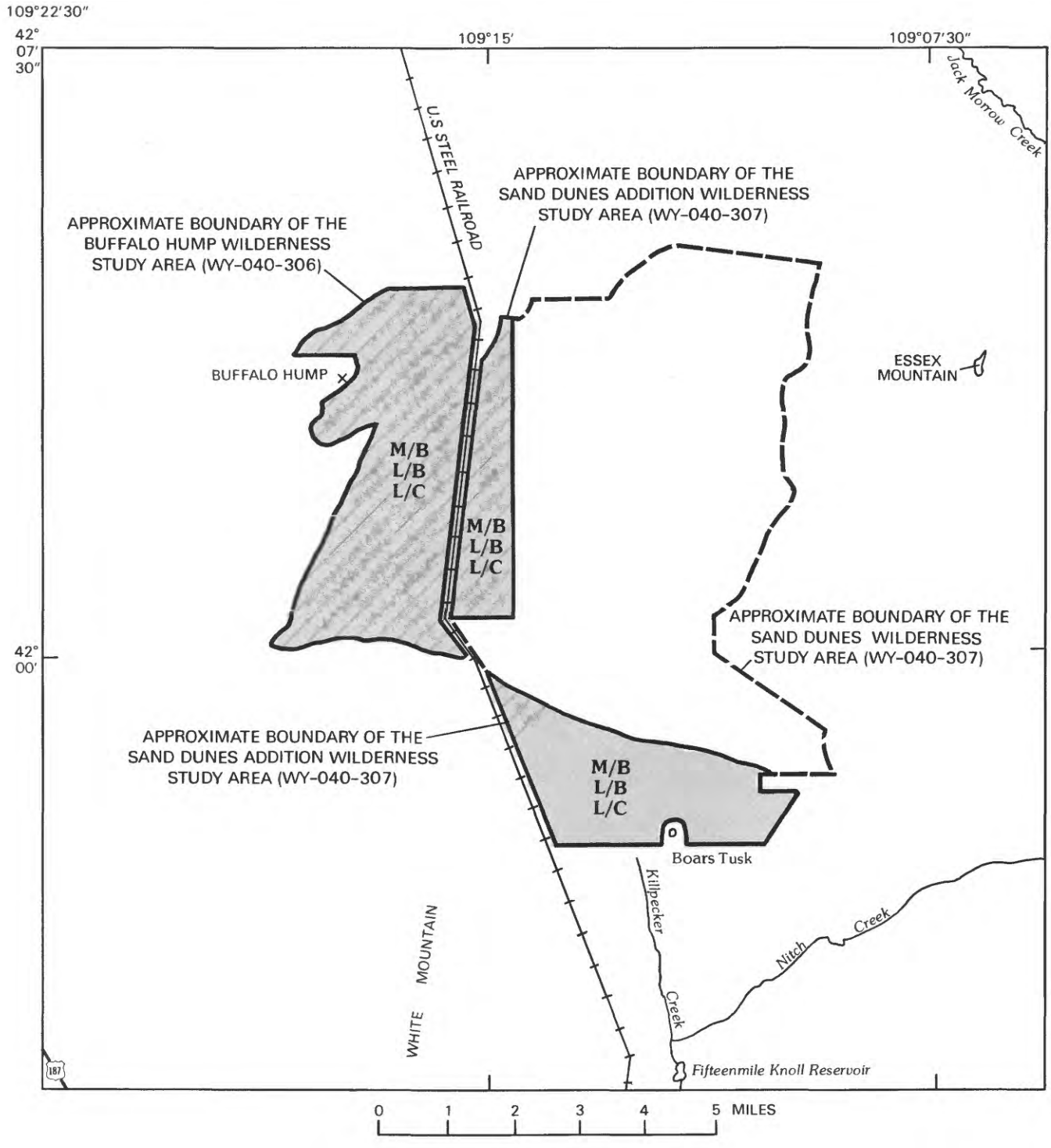


Figure 2 (above and facing page). Identified resources and resource potential of the Buffalo Hump and Sand Dunes Addition Wilderness Study Areas, Wyoming.

1757–A and by Ryan (1985) in U.S. Bureau of Mines Open-File Report MLA 33–85. The present investigation builds on the previous studies to include a part of the Buffalo Hump Wilderness Study Area and acreage added to the Sand Dunes Wilderness Study Area.

This report presents an evaluation of the mineral endowment (identified resources and mineral resource potential) of the Buffalo Hump and Sand Dunes Addition Wilderness Study Areas and is the product of several separate studies by the USGS and the USBM.

EXPLANATION

M/B L/B L/C	Geologic terrane having moderate resource potential for natural gas with certainty level B, low resource potential for oil and for geothermal sources with certainty level B, and low resource potential for metals, including uranium, with certainty level C—Applies to all parts of wilderness study areas
M/B L/B L/C	Geologic terrane having mineral endowment as above plus moderate resource potential for oil shale with certainty level B—Oil-shale beds in Green River Formation are present in subsurface

Levels of certainty

B	Available information suggests level of resource potential
C	Available information gives a good indication of the level of resource potential

Identified resources are classified according to the system of the U.S. Bureau of Mines and the U.S. Geological Survey (1980), which is shown in the Appendix of this report. Identified resources are studied by the USBM. Mineral resource potential is the likelihood of occurrence of undiscovered metals and nonmetals, industrial rocks and minerals, and of undiscovered energy resources (coal, oil, gas, oil shale, and geothermal sources). It is classified according to the system of Goudarzi (1984), which is shown in the Appendix. Undiscovered resources are studied by the USGS.

Investigations by the U.S. Bureau of Mines

To investigate the mineral resources of the Buffalo Hump and Sand Dunes Addition Wilderness Study Areas, USBM personnel reviewed literature related to the mineral resources and mining activity in the vicinity of the study areas and obtained mining-claim information and land-status records from the BLM State Office, Cheyenne, Wyo. Two USBM geologists spent 2 field days in June 1988, making foot traverses of the areas and examining nearby mineral occurrences. Four dune-sand samples were taken to depths of 36–40 in. (inches) using a post-hole digger. The samples were analyzed for 34 elements using direct irradiation and instrumental neutron activation analysis and for 10 oxides using inductively coupled plasma emission spectrography by Bondar-Clegg, Inc., Lakewood, Colo. Grain-size distributions were determined by Skyline Labs, Inc., Wheat Ridge, Colo. USBM sample data were discussed by McDonnell (1989) and are summarized in this report; complete sample data are available for public inspection at the U.S. Bureau of Mines, Intermountain Field Operations Center, Building 20, Denver Federal Center, Denver, Colo.

Investigations by the U.S. Geological Survey

The study areas were investigated by the U.S. Geological Survey in 1988. A.B. Gibbons prepared a photogeologic map of an area encompassing the wilderness study areas at a scale of 1:24,000 and field-checked the map in September. H.N. Barton conducted rock and stream-sediment sampling in August 1988 and interpreted analytical data from the samples. D.M. Kulik interpreted existing gravity and aeromagnetic data with reference to the study areas.

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

APPRAISAL OF IDENTIFIED RESOURCES

By John R. McDonnell, Jr.
U.S. Bureau of Mines

Past Mineral and Energy Resource Activity

BLM files as of October 1988 showed no mining claims in or near either study area, but the eastern sections of the southern part of the Sand Dunes Addition Wilderness Study Area are included in the Rock Springs Known Recoverable Coal Resource Area (KRCRA) (fig. 3). The only visible mining activity took place at the Houghton (also known as the Hooten or Chilton) mine, about 1.5 mi southeast of the southern part of the Sand Dunes Addition Wilderness Study Area in sec. 24, T. 23 N., R. 104 W. (fig. 3), where coal was mined. No production records were found, but Ryan (1985, p. 9) suggested that the size and type of surface facilities indicated production was minor and probably for local consumption. The mine was reported to have about 65 ft of underground workings, which exploited an 8-ft-thick coal bed (Lord, 1913, p. 1144). This is likely the Deadman coal bed at the base of the Fort Union Formation (H.W. Roehler, U.S. Geological Survey, oral commun., 1988, and Roehler, 1983).

Many sections in and near the study areas are covered by oil and gas leases, and the eastern sections of the southern part of the Sand Dunes Addition

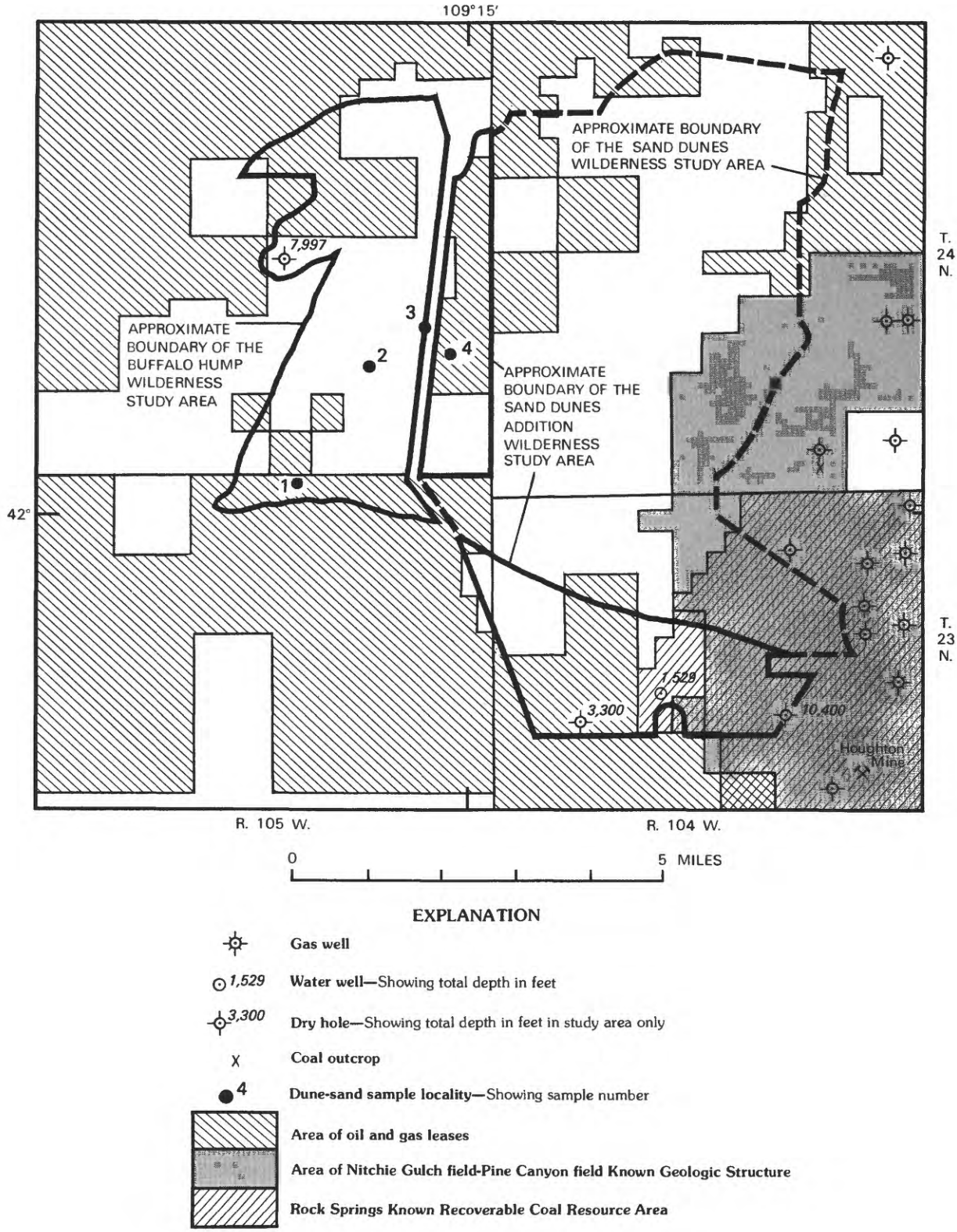


Figure 3. Oil, gas, and coal information and dune-sand sample localities, Buffalo Hump and Sand Dunes Addition Wilderness Study Areas, Wyo. Data compiled from U.S. Bureau of Land Management file data as of October 1988, and from Ryan (1985).

Table 1. Chemical analyses of dune-sand samples from Buffalo Hump and Sand Dunes Addition Wilderness Study Areas, Wyo.

[Values are in percent]

Sample No.	SiO_2	Fe_2O_3	Al_2O_3	CaO	K_2O	MgO	Na_2O	TiO_2	P_2O_5
1	74.7	1.77	12.43	3.31	2.22	0.47	2.79	0.27	0.08
2	77.3	1.47	10.81	2.58	2.41	.10	2.45	.17	.05
3	79.3	1.16	10.31	2.15	2.43	.03	2.46	.12	.05
4	76.7	1.39	11.64	2.77	2.23	.14	2.72	.18	.05
Avg[1]	78.8	1.02	12.5	2.7	1.6	.31	1.6	.18	.03
Range[1]	74.9-80.4	.72-1.50	11.6-14.0	2.1-3.6	1.4-1.8	.20-.47	1.5-1.9	.12-.27	.01-.04

[1]Average (Avg) and range of analyses of 16 dune-sand samples taken from the Sand Dunes Wilderness Study Area, reported by Ryan (1985, p. 11).

Wilderness Study Area are included in the Nitchie Gulch-Pine Canyon Known Geologic Structure (KGS) of the BLM (fig. 3). In the KGS, outside but within 1 mi of the southern part of the Sand Dunes Addition Wilderness Study Area, natural gas and condensate (liquid hydrocarbons derived from the condensation of vapor or gas) are produced from the Cloverly Formation, Thermopolis Shale, and Frontier Formation, and shows of gas have been found in the Baxter Shale and Rock Springs Formation (Merewether, Kulik, and Ryan, 1987, p. A16). Seismic exploration has been conducted in the vicinity, and four exploratory holes were drilled in the study areas, three in the southern part of the Sand Dunes Addition Wilderness Study Area and one in the Buffalo Hump Wilderness Study Area (fig. 3). No production resulted from any of the drill holes.

Resource Appraisal

Identified mineral resources recognized by Merewether, Kulik, and Ryan (1987) and Ryan (1985) in the Sand Dunes Wilderness Study Area (pl. 1, fig. 1) were sand in wind-blown surficial deposits, claystone, and shale. Sand is also exposed over most of the surface of the neighboring Sand Dunes Addition and Buffalo Hump Wilderness Study Areas, and claystone and shale are widespread in the underlying bedrock. In addition, coal, although not exposed at the surface, occurs in the subsurface of these study areas.

Sand

Active and stabilized sand dunes overlie bedrock and cover a large part of both study areas. Three dune-sand samples taken from the Buffalo Hump Wilderness Study Area and one from the western part of the Sand Dunes Addition Wilderness Study Area were analyzed to determine usage suitability. The analytical data were evaluated and compared to the results of 16 similar samples taken nearby by Ryan (1985, p. 11–12) (tables 1 and 2). Although some variation can be seen, the basic results and conclusions are the same: the silica content (table 1, SiO_2) is too low, and the metal and alkali oxide (table 1, all other oxides) concentrations are too high for the sand to be usable in special-purpose high-silica (greater than 95 percent SiO_2) sand applications, such as glass, foundry, and refractory uses, reservoir fracturing in oil and gas fields, and inert fillers in chemical products. The grain-size analysis (table 2) suggests that the sand is too fine grained for use in most construction applications but would probably be suitable for use in mortar, grout, and asphaltic products. (See Ryan, 1985; Davis and Tepordei, 1985; and individually authored and titled sand-usage discussions in Lefond, 1983.)

The dune sand has no unique qualities, development and transportation costs are high, and unit value is low. Usage would be confined to local communities, which are small, and a sufficient supply of similar material exists outside the study areas to satisfy this limited demand.

Coal

The study areas are in the Green River coal region and are mostly west of the northern end of the Rock Springs coal field (fig. 1). The coal of the Rock Springs coal field is subbituminous and bituminous (Schultz, 1909, p. 273). No coal has been identified at the surface in the study areas, but the underlying Almond, Lance,

Table 2. Grain-size distribution of dune-sand samples from the Buffalo Hump and Sand Dunes Addition Wilderness Study Areas, Wyo.

[U.S. Standard sieves; values are in percent; <, less than]

Sample No.	+10 mesh	10-16 mesh	16-35 mesh	35-60 mesh	60-120 mesh	120-230 mesh	-230 mesh
1	<0.1	0.1	11.9	27.4	59.9	0.3	0.3
2	< .1	< .1	49.2	26.2	23.4	.2	.1
3	< .1	.1	32.1	39.5	28.1	.1	.1
4	< .1	.1	11.0	48.4	40.2	.1	.1
Avg[1]	< .1	< .1	6.0	46.4	47.2	.1	.1
Range[1]	< .1-2.6	< .1-.4	< .1-21.2	19.2-68.0	30.3-77.9	< .1-.6	< .1-.3

[1]Average (Avg) and range of analyses of 16 dune-sand samples taken in the Sand Dunes Wilderness Study Area, reported by Ryan (1985, p. 12).

and Fort Union Formations have exposures of subbituminous coal at localities within 5 mi (Merewether, Kulik, and Ryan, 1987, p. A14). The nearest exposed coal beds are in the Fort Union Formation at the localities given in table 3.

The coal-bearing strata dip 3–8° west-northwest, and Merewether, Kulik, and Ryan (1987, p. A14) reported that coal beds in the Fort Union Formation could be less than 50 ft below the dune sand in the southeastern part of the Sand Dunes Wilderness Study Area, which adjoins the eastern sections of the southern part of the Sand Dunes Addition Wilderness Study Area.

Buried coal beds were identified on logs of three drill holes in the southern part of the Sand Dunes Addition Wilderness Study Area. The drill holes are in secs. 15, 16, and 17, T. 23 N., R. 104 W. (pl. 1, fig. 3, table 4). The hole in sec. 15 (fig. 3, hole 10,400) was geophysically logged below a depth of about 1,000 ft. The logs show numerous coal beds in the Rock Springs Formation below 3,369 ft, where the first coal bed was identified as 5 ft thick (Richard Jones, Wyoming Geological Survey, oral commun., 1985). Geophysical logs of the hole in sec. 17 (fig. 3, hole 3,300) begin at a depth of 165 ft and indicate five coal beds in the Fort Union Formation having thicknesses from 3 ft to 5 ft, at depths between 1,488 ft and 2,377 ft, plus a 20-ft-thick coal bed at 2,310 ft, and two coal beds in the Almond Formation, 7 ft and 11 ft thick, at 2,720 ft and 2,823 ft deep, respectively. The hole in sec. 16 (fig. 3, hole 1,529), was logged lithologically to the surface and shows coal-bed thicknesses of 4 ft, 2 ft, and 1 ft at depths of 1,032 ft, 1,046 ft, and 1,200 ft, respectively. Geologic extrapolation suggests that the coal beds are in the Fort Union Formation.

In the Buffalo Hump Wilderness Study Area, the log for a drill hole in sec. 22, T. 24 N., R. 105 W. (pl. 1; fig. 3, hole 7997; and table 4) shows 15 coal beds in the Fort Union Formation and Upper Cretaceous strata (probably Lance and Almond Formations). The beds

Table 3. Exposed coal beds in the vicinity of the Buffalo Hump and Sand Dunes Addition Wilderness Study Areas, Wyo.

[From Merewether, Kulik, and Ryan (1987)]

Type and location of exposure	Coal thickness (feet)	Distance to wilderness study area	
		Sand Dunes Addition	Buffalo Hump
Outcrop, sec. 35, T. 24 N., R. 104 W.	3	2.5 mi NE of south part of Sand Dunes Addition.	5.5 mi E.
Outcrop, sec. 26, T. 23 N., R. 104 W.	4-5	2.0 mi SE of south part of Sand Dunes Addition.	8.5 mi SE.
Houghton (Chilton) mine, sec. 24, T. 23 N., R. 104 W.	About 8	1.5 mi SE of south part of Sand Dunes Addition.	7.5 mi SE.

Table 4. Data for drill holes in Buffalo Hump and Sand Dunes Addition Wilderness Study Areas, Wyo.

Designation, this report	Name and operator	Location	Total depth (feet)	Results and date of drilling
7,997	Grady Federal 1-Z, Davis Oil Co.	Sec. 22, T. 24 N., R. 105 W.	7,997	[1]Dry hole, 1971.
3,300	Federal-Essex 13-17, Husky Oil Co.	Sec. 17, T. 23 N., R. 104 W.	3,300	[2]Dry hole, 1979.
1,529	No. 1, Boars Tusk Oil Co.	Sec. 16, T. 23 N., R. 104 W.	1,529	No oil or gas, 1927, developed as water well.
10,400	Boars Tusk Federal 1-15, FMC Corp.	Sec. 15, T. 23 N., R. 104 W.	10,400	[1,2]Dry hole, 1980.

[1]Data from Petroleum Information Service.

[2]Data from U.S. Bureau of Land Management records.

range in thickness from 2 ft to 45 ft, have a cumulative thickness of 213 ft, and occur at depths between 4,330 ft and 7,833 ft. This drill hole was geophysically logged to the surface and penetrated the Wasatch Formation at a relatively shallow depth. The Wasatch is coal bearing elsewhere in Wyoming, but the log indicates that the first coal measure occurs in the Fort Union Formation and that the Wasatch has no detectable coal at this locality (Ryan, 1985, and Bureau of Mines file data).

Estimates and projections based on the limited drill-hole, outcrop, and geologic evidence indicate that coal of unknown quality and quantity occurs beneath both the Sand Dunes Addition and Buffalo Hump Wilderness Study Areas at depths greater than 1,000 ft. Merewether, Kulik, and Ryan (1987, p. A14) suggested that coal beds may occur at depths of less than 200 ft in the Sand Dunes Wilderness Study Area, but confirmation is lacking.

Open-pit coal mines are generally less than 200 ft deep and observe a maximum stripping ratio of 15:1 (15 ft of overburden to 1 ft of coal thickness) (Ryan, 1985, p. 10). None of the coal inside the study area is estimated to meet this criterion. Other mining methods are available, but their comparatively high costs and the presence in Wyoming of extensive coal beds that are amenable to open-pit mining would likely preclude development by these other methods.

Claystone and Shale

Low-quality claystone and shale units were determined to be present at shallow depths (estimated to be less than 600 ft) beneath the Sand Dunes Wilderness Study Area by Merewether, Kulik, and Ryan (1987) and Ryan (1985). The units are more deeply buried in the adjacent western part of the Sand Dunes Addition Wilderness Study Area and Buffalo Hump Wilderness Study Area and are not likely to be developed in the foreseeable future.

Conclusions

Dune sand covers a large part of the study areas. Analytical results suggest that the sand would probably be suitable for use in mortar, grout, and asphaltic products, but it has no unique qualities and has a development-return value that restricts use to local markets. Local markets are small, and sufficient material exists outside the study areas to satisfy this demand.

Coal of unknown quality and quantity occurs beneath the study areas at depths between 1,000 ft and 6,000 ft, and some coal may occur less than 1,000 ft beneath the eastern sections of the southern part of the Sand Dunes Addition Wilderness Study Area. Detailed subsurface data are lacking, but none of the coal is estimated to meet criteria for development in the foreseeable future.

Low-quality claystone and shale have been identified nearby in stratal units that underlie the study areas, but they are not likely to be developed in the study areas in the foreseeable future.

ASSESSMENT OF POTENTIAL FOR UNDISCOVERED RESOURCES

By Anthony B. Gibbons,
Harlan N. Barton, and Dolores M. Kulik
U.S. Geological Survey

Geology

Geologic Setting

The rocks in the Buffalo Hump and Sand Dunes Addition Wilderness Study Areas are mainly sedimentary and are commonly overlain by sand dunes. At several localities in the region, the sedimentary formations are intruded by bodies of igneous rocks, as at Boars Tusk (pl. 1). The outcropping formations in the wilderness study areas dip about 2–4° west-northwest and are on the northwestern flank of the Rock Springs uplift, a structurally high area that trends north (fig. 1). Adjoining the western flank of the Rock Springs uplift is the large structural depression of the Green River basin. Both of these structural features developed mainly in Late Cretaceous and Tertiary time (see geologic time chart in Appendix). Along the western flank of the Rock Springs uplift, the surface trace of an eastwardly dipping thrust fault extends northward to within about 1 mi of the southern border of the southern part of the Sand Dunes Addition Wilderness Study Area (Love and Christiansen, 1985, and pl. 1). Several steeply dipping faults crop out northeast of the study areas (pl. 1, and Bradley, 1926). No faults have been recognized within the Buffalo Hump and Sand Dunes Addition Wilderness Study Areas.

Rock Units

The outcropping sedimentary rocks of the study areas (table 5) have been assigned, in ascending order, to the Lance Formation of latest Cretaceous age, to the Fort Union Formation of early Tertiary (Paleocene) age, and to the Wasatch, Green River, and Bridger Formations of early Tertiary (Eocene) age. Underlying the Lance in the subsurface is a sequence of formations that is about 15,000 ft thick (Jensen, 1972) and that ranges in age from early Paleozoic (Cambrian) at the base to Late Cretaceous at the top. The strata of Paleozoic age are about 2,800 ft thick and consist mainly of carbonate rocks and sandstone, which were deposited in marine environments. They are overlain by lower and middle Mesozoic (Triassic and Jurassic) formations at the base of a thick Mesozoic subsurface section (fig. 5). The Triassic and Jurassic strata have an aggregate thickness of about 2,700 ft and are composed of sandstone, shale, and limestone of marine and continental origin (Pipiringos and O'Sullivan, 1978, p. A13–A15). Thicknesses of some of these formations were determined from geophysical logs of boreholes near the study area (Merewether, Kulik, and Ryan, 1987).

The upper Mesozoic (Cretaceous) strata of the wilderness study areas are 9,000–10,000 ft thick and consist largely of shale and sandstone, which were deposited in marine and continental environments. Lower Cretaceous rocks below the surface of the area are assigned to the Cloverly Formation and Thermopolis Shale. The Cloverly is 80–100 ft thick and is composed of sandstone units and intervening shale units. The Thermopolis is 200–220 ft thick and consists of shale and sandstone. Both formations contain gas in nearby areas.

Upper Cretaceous rocks in the region comprise, from oldest to youngest, the Mowry Shale, Frontier Formation, Baxter Shale, Blair Formation, Rock Springs Formation, Ericson Sandstone, Almond Formation, Lewis Shale, Fox Hills Sandstone, and Lance Formation (table 5). The Mowry is about 300 ft thick and consists of siliceous shale. Near the wilderness study areas, the Frontier Formation is about 570 ft thick and consists mostly of interstratified units of shale and sandstone. Some of these sandstone units contain gas in nearby fields. The Baxter Shale, 3,600–4,000 ft thick, and the overlying Blair Formation, about 810 ft thick, are composed mainly of shale and sandstone. Overlying the Blair is the Rock Springs Formation, which is about 1,810 ft thick and consists of shale, siltstone, sandstone, and several beds of coal. This coal has been mined at many localities on the Rock Springs uplift (Root and others, 1973). The Ericson Sandstone is largely sandstone and is probably 510–560 ft thick. Rocks of the Almond Formation, 450–480 ft thick, include sandstone, siltstone, shale, and coal. On the Rock Springs uplift, coal beds in the Almond are generally thin and are rarely mined. The Lewis Shale is 300–400 ft thick and consists of sandstone, siltstone, and shale. In much of Wyoming, the Fox Hills Sandstone and overlying Lance Formation include sandstone, siltstone, shale, and coal. In the vicinity of the study areas, the Fox Hills is as much as 400 ft thick. Coal beds in the Lance crop out and have been mined on the flanks of the Rock Springs uplift (Root and others, 1973).

Tertiary strata in the vicinity of the wilderness study areas have been assigned to, from oldest to youngest, the Fort Union Formation of Paleocene age and the Wasatch, Green River, and Bridger Formations of Eocene age (table 4). These rocks were deposited in continental environments. The Fort Union in the area is 2,500–3,000 ft thick (McDonald, 1972) and consists mostly of sandstone, shale, and coal. Some of the coal beds were mined along the eastern flank of the Rock Springs uplift. The Fort Union crops out east and

Table 5. Formations of Mesozoic and Cenozoic age in the Buffalo Hump and Sand Dunes Addition Wilderness Study Areas, Wyo.

[*, outcropping formations and members; Do., ditto]

Age	Formation	Approximate thickness (feet)	Predominant lithology
Tertiary (Eocene)	Bridger Formation*	160+	Mudstone and sandstone.
	Laney Member of the Green River Formation*	150+	Mudstone and oil shale.
	Wilkins Peak Member of the Green River Formation*	100-240	Do.
	Tipton Shale Member of the Green River Formation*	160-310	Oil shale, sandstone, and limestone.
	Wasatch Formation*	2,000-2,500	Sandstone, shale, and mudstone.
Tertiary (Paleocene)	Fort Union Formation*	2,500-3,000	Sandstone, shale, and coal.
Late Cretaceous	Lance Formation*	200-400	Sandstone, siltstone, shale, and coal.
	Fox Hills Sandstone	100-150	Sandstone, siltstone, and shale.
	Lewis Shale	300-400	Siltstone, shale, and sandstone.
	Almond Formation	450-480	Sandstone, shale, and coal.
	Ericson Sandstone	510-560	Sandstone.
	Rock Springs Formation	1,810	Shale, siltstone, sandstone, and coal.
	Blair Formation	810	Shale and sandstone.
	Baxter Shale	3,600-4,000	Shale and siltstone.
	Frontier Formation	570	Sandstone and shale.
Late(?) Cretaceous	Mowry Shale	300	Shale and bentonite.
Early Cretaceous	Thermopolis Shale (within Dakota of drillers)	200-220	Shale and sandstone.
	Cloverly Formation (within Dakota of drillers)	80-100	Sandstone and shale.
Late Jurassic	Morrison Formation	200-250	Sandstone and mudstone.
Middle Jurassic	Curtis of drillers	100-135	Limestone, shale, and sandstone.
	Entrada of drillers	83-95	Sandstone and shale.
	Carmel of drillers	40-165	Limestone, red shale, anhydrite, and dolomite.
Jurassic(?) and Triassic(?).	Nugget Sandstone	500	Sandstone, siltstone, and shale.
Late and Early Triassic.	Chugwater Group	1,400	Claystone, mudstone, and siltstone.

northeast of the southern part of the Sand Dunes Addition Wilderness Study Area where it is overlain by the Wasatch Formation (pl. 1). The Wasatch is composed mostly of sandstone and mudstone and is 2,000–2,500 ft thick (McDonald, 1972).

Overlying the Wasatch is the Tipton Shale Member of the Green River Formation, 160 to 310 ft thick. The Tipton characteristically has ledge-forming limestone sequences at base and top. The intervening strata are predominantly algal limestone and blue-green to green mudstone with minor sandstone and oil shale at outcrops near Essex Mountain (fig. 2). South of the study areas at the north end of White Mountain (pl. 1, fig. 2), the same stratigraphic interval consists mostly of sandstone and shale (H.W. Roehler, U.S. Geological Survey, written commun., 1988). The Tipton is overlain by the Wilkins

Peak Member of the Green River Formation, a white-weathering sequence of oil shale and mudstone 100 to 240 ft thick. The last stage of predominantly lacustrine Green River deposition is marked by the Laney Member, which overlies the Wilkins Peak. In the vicinity of the study areas, the Laney is at least 150 ft thick and consists mainly of tan-weathering mudstone and oil shale. The youngest Eocene unit known in the vicinity is the mostly fluviatile Bridger Formation. The Bridger is composed mainly of gray-brown sandstone and mudstone. It is preserved in the study areas only at Buffalo Hump (pl. 1), where about 150 ft of Bridger strata rest with apparent conformity on the Laney Member of the Green River.

Igneous rock of Quaternary age (McDowell, 1971) is represented by stocks intrusive into the Wasatch Formation at Matthews Hill and Boars Tusk (pl. 1). The rock is of the rare variety called wyomingite, which, with related highly potassic rocks, forms a scatter of volcanic necks and small lava flows, the Leucite Hills volcanic field, on the north end of the Rock Springs uplift (Cross, 1897; Carmichael, 1967; Ogden, 1979). The geologically brief Leucite Hills volcanic episode is of particular interest to science because it occurred in a region remote from other centers of volcanism during the long period of tectonic quiet that followed the Laramide orogeny and because it produced unusual lavas. Boars Tusk, a notable landmark (fig. 4), defines the northwest corner of the Leucite Hills volcanic field and is the type outcrop of wyomingite, second rarest of the Leucite Hills lava types. Hence, it is a scientifically important site. Boars Tusk is not part of the area recommended for protection as wilderness, however, as it is in a small tract of unprotected land inset into the southern part of the Sand Dunes Addition Wilderness Study Area (fig. 2, pl. 1).

The wilderness study areas are within the Killpecker dune field. Unconsolidated fine sand of Quaternary age covers most of the surface of the study areas and occurs as both active and dormant dunes, including dome, transverse, barchan, parabolic, and irregular dunes (Ahlbrandt, 1975). The active dunes are as much as 150 ft high. The dune field is unidirectional, reflecting the prevailing westerly winds of the region, and the sand is derived mainly from the Laney Member of the Green River Formation. Dunes in the field have been intermittently active and record the climatic fluctuations associated with the stades and interstades of glaciation during the past 20,000 years (Ahlbrandt, 1975).

Alluvium of Quaternary age covers a considerable area at the head of Killpecker Creek (pl. 1). The alluvium consists of unconsolidated, very light gray to very light yellow silt and clay. As mapped, this unit includes small areas of dune sand. Also included are areas of fine-grained sediments perhaps deposited in temporary ponds resulting from damming of streamflow by migrating sand dunes.

Geochemistry

A reconnaissance geochemical survey was conducted in the Buffalo Hump and Sand Dunes Addition Wilderness Study Areas during August 1988.

Sample Media and Collection

Minus-80-mesh stream sediments, heavy-mineral panned concentrates derived from stream sediments, and rocks were selected as sample media.

Stream-sediment samples represent a composite of rock and soil exposed in the drainage basin upstream. Their analysis provides information that helps identify those basins containing unusually high concentrations of elements that may be related to mineral occurrences.

Chemical analysis of heavy minerals concentrated from stream sediments provides information about the chemistry of certain high-density, resistant minerals eroded from the drainage basin upstream. The removal of most of the rock-forming silicates, clays, and organic material permits the determination in the concentrate of some elements that are commonly not detectable in bulk stream sediments by the analytical methods available. Some of these elements can be constituents of minerals related to ore-forming processes rather than rock-forming ones.

Rock samples were collected to provide information on geochemical background values and to detect any possible mineralization. Visibly altered and mineralized samples that might disclose suites of elements associated with mineralization were not found. A total of 14 rock samples were collected from 3 sites, 6 from Buffalo Hump, 1 from an outcrop capping a knoll to the north and east of of the study areas in the southwest corner of sec. 23, T. 24 N., R. 104 W., and 7 from Boars Tusk.

Bulk stream-sediment and heavy-mineral-concentrate samples were collected from sites on active alluvium of six first- or second-order ephemeral streams with drainage basins ranging from 0.1 to 2.0 square miles. One of these sites was on a drainage on the northwest flank of Buffalo Hump, and the remainder were to the north of the eolian sand belt shown on plate 1. Most parts of the study areas lack a developed drainage system due to the thick veneer of wind-deposited sand. Sufficient nonmagnetic heavy-mineral-concentrate sample for analysis (5 milligrams) was recovered from all six sites.

Sample Analysis

Stream-sediment, heavy-mineral concentrate, and rock samples were all analyzed using a semiquantitative emission spectrographic method for the following 37

elements: antimony, arsenic, barium, beryllium, bismuth, boron, cadmium, calcium, chromium, cobalt, copper, gallium, germanium, gold, iron, lanthanum, lead, magnesium, manganese, molybdenum, nickel, niobium, palladium, phosphorus, platinum, scandium, silver, sodium, strontium, thorium, tin, titanium, tungsten, vanadium, yttrium, zinc, and zirconium (J.H. Bullock, Jr., and others, unpub. data, 1989).

In addition, stream-sediment and rock samples were analyzed for antimony, arsenic, bismuth, cadmium, gold, thorium, uranium, and zinc by specific chemical and instrumental methods (J.H. Bullock, Jr., and others, unpub. data, 1989).

Results

Anomalous values, defined as being above the upper limit of normal background values, were determined for each element by inspection of the analytical data rather than by statistical techniques. A small number of samples (6 six stream sediment and heavy mineral concentrate, and 14 rock) were collected, and many elements had only a few measurable occurrences. For some elements (Ag, As, Au, Bi, Cd, Mo, Sb, Sn, W, Th, U), any occurrence above the detection limit would be anomalous.

Heavy-mineral concentrates from three of the four sample sites making up the northerly group of sites had low but slightly anomalous values, 100 ppm (parts per million), for one or two of the elements, tin, copper, and chromium. These slightly anomalous values from an unknown source are not believed to indicate mineralization.

Rock samples taken at Boars Tusk, in an enclave excluded from the wilderness study areas but near the southern boundary of the southern part of the Sand Dunes Addition Wilderness Study Area (pl. 1, fig. 4), contained from 300 ppm to 1,000 ppm chromium and 100 ppm to 200 ppm nickel. Boars Tusk is an intrusion of wyomingite, an igneous rock of unusual composition, and the anomalous chromium and nickel values are probably a characteristic of this rock type. One sample contained 200 ppm lead, 20 ppm uranium, and 11 ppm thorium. These anomalous values are probably associated with the emplacement of the igneous stock and the accompanying weak hydrothermal system.

No anomalous values were obtained in the analyses of stream sediments.

Geophysics

Gravity studies were performed in the region encompassing the Buffalo Hump and Sand Dunes Addition Wilderness Study Areas as part of the mineral resource evaluation of the adjacent Sand Dunes Wilderness Study Area (Merewether, Kulik, and Ryan, 1987). In order to provide information about the subsurface distribution of rock units and the structural framework, gravity was measured at about 85 new stations during 1984 and 1985 in the region shown on figure 5. These data were subsequently combined with data from files maintained by the U.S. Defense Mapping Agency, Aerospace Center (1974).

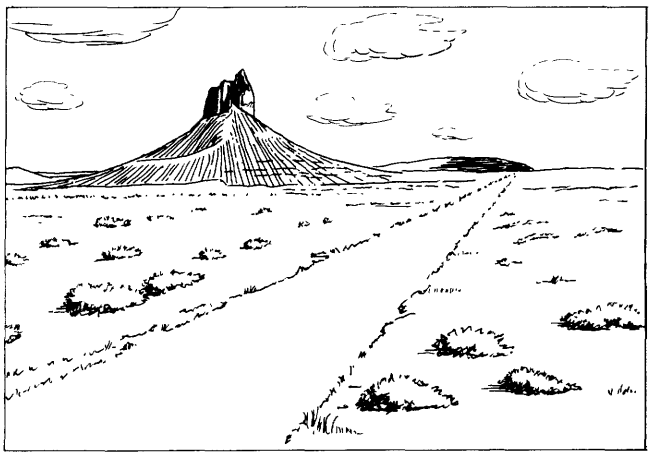


Figure 4. Boars Tusk, a volcanic neck of wyomingite lava, at the southern border of the southern part of the Sand Dunes Addition Wilderness Study Area. Mineralization accompanying emplacement of Boars Tusk in Pleistocene (glacial) time is marked by anomalous values of lead, uranium, and thorium. View is to the east from alluvial flats at the head of Killpecker Creek. The road shown marks the southern boundary of the southern part of the Sand Dunes Addition Wilderness Study Area, left side of road, at most places in field of view. Boars Tusk is excluded from the wilderness study area by an embayment of the boundary.

Bouguer gravity 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. Terrain corrections were made by computer for a distance of 167 kilometers around each station, using the method of Plouff (1977). The data are shown contoured on a complete Bouguer gravity anomaly map (fig. 5). No additional data were added for this study.

The gravity values in the vicinity of the wilderness study areas decrease northward, from about -225 mGal (milligals) near the southern border of the study area to -250 mGal north of the area. The gradient is associated with the decreasing relief on the Rock Springs uplift and with northward thickening of the sedimentary rocks in the region. The steeply dipping faults mapped northeast of the study areas (pl. 1) are not expressed in the gravity data at this contour interval.

Magnetic data for the area north of lat 42° N. are published in U.S. Department of Energy (1982a), and to the south of that latitude in U.S. Department of Energy

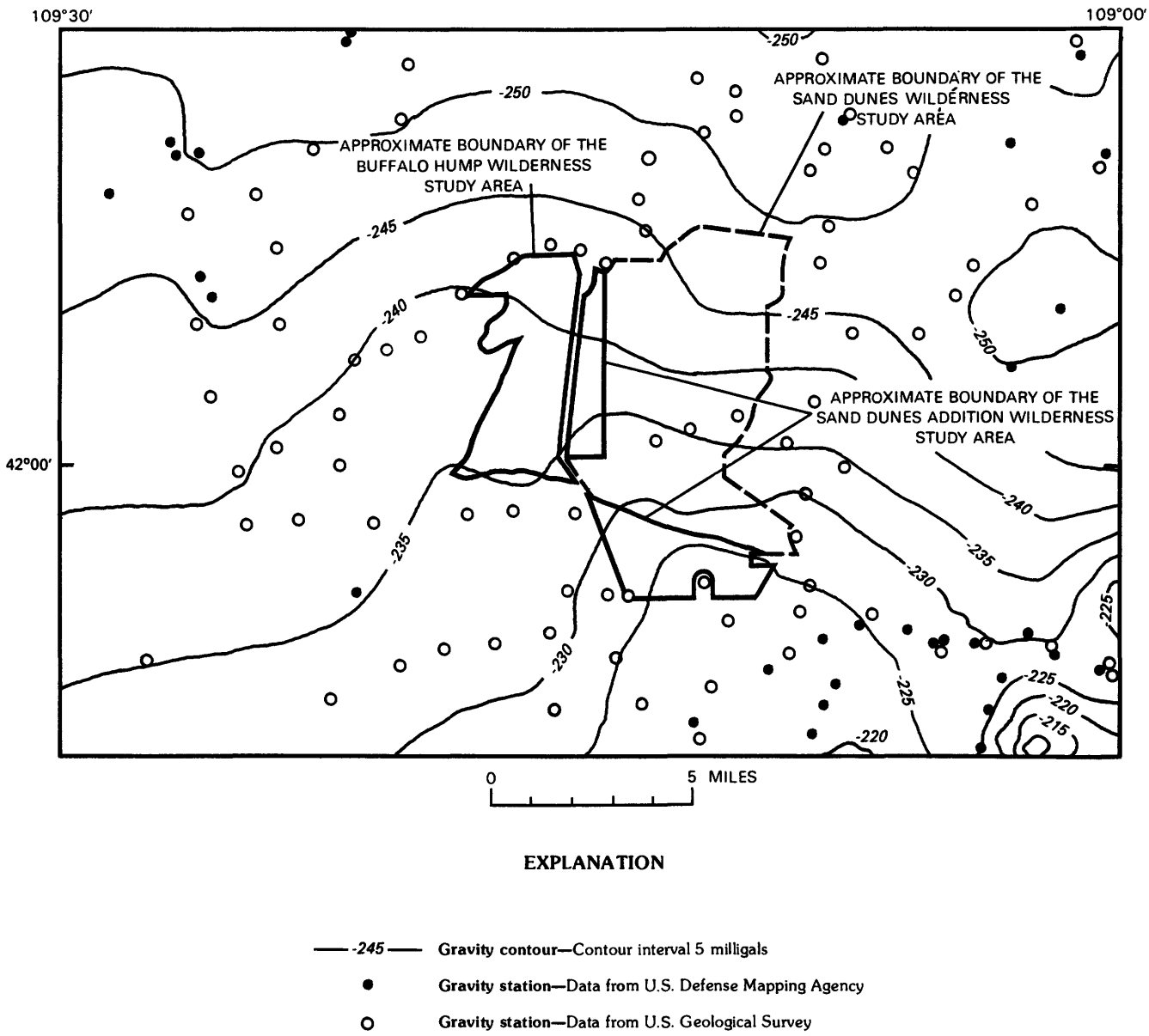


Figure 5. Complete Bouguer gravity anomaly map of the Buffalo Hump and Sand Dunes Addition Wilderness Study Areas and vicinity, Wyoming. Mapped by D.M. Kulik, 1985.

(1982b). The study area lies within a broad regional low associated with deep basement and thick sedimentary deposits of the Green River and Great Divide basins to the northwest and east of the study area, respectively. Total magnetic relief across the study area is only about 30 nanoteslas, and detail is insufficient to define structure or lithologic distribution; therefore the map is not included in this report.

Mineral and Energy Resources

In addition to coal, sand, claystone, and shale, which are discussed in the section on "Appraisal of Identified Resources" above, the study areas have potential for resources of oil shale, oil and gas, metals, including uranium, and geothermal energy.

Oil Shale

Most of the following information on oil shale in the Green River Formation was obtained from Roehler (1981). Outcrops of the Green River Formation in the vicinity of the Buffalo Hump and Sand Dunes Addition Wilderness Study Areas consist of the Tipton Shale Member, the Wilkins Peak Member, and the Laney Member, in ascending order. The Tipton contains a substantial proportion of oil shale at outcrops in the

vicinity of the study areas and is as much as 310 ft thick (table 5). Estimated producible amounts of oil in the Tipton range from 2 to 25 gpt (gallons of oil per ton of rock). Results of analysis for oil yield of samples from outcrops of the Tipton at three localities near the wilderness study areas were reported by Merewether, Kulik, and Ryan (1987). Samples from Roehler's (1981) stratigraphic section 20, south of the study areas, and from sec. 13, T. 24 N., R. 104 W., east of the study areas (pl. 1), contained only traces of hydrocarbons. However, the possible oil yield for a sample from sec. 27, T. 25 N., R. 102 W., about 10 mi east-northeast of the study areas, is about 11 gpt. The Wilkins Peak Member of the Green River Formation is 100–240 ft thick in the vicinity of the study areas and is composed mainly of oil shale and mudstone. Estimates of the amounts of oil in most of the oil shale in the Wilkins Peak are 10–15 gpt. The Laney Member has a basal unit that consists largely of oil shale and is about 60 ft thick southwest of the study areas in sec. 24, T. 23 N., R. 105 W. (Roehler, 1981, stratigraphic section 20). Estimated producible amounts of oil in the Laney range from 2 to 15 gpt.

Oil-shale-bearing members of the Green River Formation generally underlie sand dunes within the wilderness study areas. The thickness and possible yield of units of oil shale within the study areas have not been locally determined. However, the sparse data from the surrounding region indicate yields of 2 to 25 gpt. For comparison, the yield of the oil shale in deposits southwest of the study areas in the central part of the Green River basin is commonly more than 25 gpt (Root and others, 1973). The energy resource potential of the oil shale in the Buffalo Hump and Sand Dunes Addition Wilderness Study Areas is moderate, with a certainty level of B, interpreted from meager information.

Oil and gas

The strata in the subsurface of the wilderness study areas have been explored for oil and gas by drilling. No oil or gas has been discovered, even though some of the formations penetrated contain gas in nearby fields (figs. 1, 3). In the Nitchie Gulch field, just east of the southern part of the Sand Dunes Addition Wilderness Study Area, methane is produced from stratigraphic traps in the Cloverly and Frontier Formations (table 5), and shows of gas were found in the Baxter Shale and the Rock Springs Formation (Tatar and others, 1979). The estimated reserves of gas in the field, as of 1978, were about 86,720 million cubic feet (Tatar and others, 1979). In that area the oldest formation penetrated by a borehole was the Nugget Sandstone of Triassic(?) and Jurassic(?) age. The Pine Canyon field is south of the Nitchie Gulch field and is about 3.5 mi southeast of the study areas. In the Pine Canyon field, gas and condensate (liquid hydrocarbons having API (American Petroleum Institute) gravity more than 60°) are produced from stratigraphic traps in the Cloverly Formation, Thermopolis Shale, and Frontier Formation, and shows of gas have been found in younger Cretaceous formations (George, 1979). The estimated ultimate reserves of gas in the field, as of 1978, were about 20,500 million cubic feet (George, 1979). In the Pine Canyon field, the oldest formation recognized in a borehole is the Morrison of Late Jurassic age. Other fields in the northern part of the Rock Springs uplift produce gas from the Nugget Sandstone, Morrison and Cloverly Formations, Thermopolis Shale, and Frontier and Blair Formations.

The thermal maturity of the sedimentary rocks in the study areas was estimated from maps of the thermal maturity of southwestern Wyoming made on the basis of reflectance values for vitrinite particles in samples of cores (Merewether, Krystinik, and Pawlewicz, 1987). Apparently, the strata at depths of more than about 6,500 ft in the area have sufficient maturity for the generation of oil and gas. Source rocks for oil and gas are common at depths below 6,500 ft within the lower Tertiary and Cretaceous formations of southwestern Wyoming and probably occur within many of the older formations. Presumably such deeply buried source strata in the wilderness study areas have generated hydrocarbons.

Reservoir beds for gas have been found in several formations in nearby gas fields and could extend into the vicinity of the study areas. In this region, gas can be concentrated in stratigraphic traps (bodies of permeable rocks enclosed in impermeable rocks) and in structural traps (folded or faulted bodies of permeable rocks). As noted above, stratigraphic traps are common in nearby gas fields in several formations that are also in the subsurface of the study areas and adjoining areas. Structural traps as well could exist in the Buffalo Hump and Sand Dunes Addition Wilderness Study Areas as a result of the doming of the Rocks Springs uplift or of the faulting east and northeast of the study areas (pl. 1).

The geology in the vicinity of the wilderness study areas and the stratigraphy at nearby gas fields indicate that the resource potential of the region for natural gas in stratigraphic or structural traps is moderate with certainty level B, determined from indirect evidence. Past exploration for oil and gas within the study areas and within contiguous areas to the north, west, and south has been negligible and does not preclude the discovery of hydrocarbons in those regions.

Oil-bearing strata apparently have not been found in the vicinity of the wilderness study area or in the northern part of the Rock Springs uplift. However, the region has not been completely explored; few boreholes near the study area penetrate rocks older than the Morrison Formation of Jurassic age. Formations of early Mesozoic and Paleozoic ages in the region have rarely

been penetrated by drilling. The stratigraphic information concerning these older rocks is insufficient for the identification of source rocks, reservoir beds, and traps for petroleum. The resource potential for oil in the study areas is low, with a certainty level of B, interpreted from scant data.

Metals, Including Uranium

The wilderness study areas contain no evidence of mining activity and lie in a broad area lacking known metallic deposits (Root and others, 1973). Metallic mineralization documented at Boars Tusk in the course of this study and believed associated with emplacement of the stock is weak and apparently highly localized. The wilderness study areas have low mineral resource potential for metals, including uranium, with certainty level C.

Geothermal Sources

The study area is without hot springs or other evidence of Earth temperatures that are unusually high in relation to depth. The thermal gradient typical of the Green River basin is only in the normal range at about 13° F/1,000 ft (Heasler and others, 1983). Geothermal energy would have to come from the deep subsurface where high temperatures are usually present. Thermal water from the deep subsurface can constitute a resource where it can be tapped in sufficient quantity by an existing drill hole (Heasler and others, 1983). It is possible that one or more aquifers capable of delivering significant quantities of low to moderate temperature thermal water (195 ° F, or less) underlie the study areas at depths no greater than those attained by exploratory drilling to date. No such aquifer is known at present, however. Coupled with the lack of indications of thermal water at shallow depth, this lack of aquifer means that the wilderness study areas have a low resource potential for geothermal energy with certainty level B, based on sparse information.

REFERENCES CITED

Ahlbrandt, T.S., 1974, Dune stratigraphy, archaeology, and the chronology of the Killpecker Dune Field, *in* Wilson, M., ed., Applied geology and archaeology—the Holocene history of Wyoming: Geological Survey of Wyoming Report of Investigations 10, p. 51–60.

_____1975, Comparison of textures and structures to distinguish eolian environments, Killpecker Dune Field, Wyoming: The Mountain Geologist, v. 12, no. 2, p. 61–73.

Bradley, W.H., 1926, Shore phases of the Green River Formation in northern Sweetwater County, Wyoming: U.S. Geological Survey Professional Paper 140–D, p. 121–131.

Carmichael, I.S.E., 1967, The mineralogy and petrology of the volcanic rocks from the Leucite Hills, Wyoming: Beitrage zur Mineralogie und Petrologie, v. 15, p. 24–66.

Cross, Whitman, 1897, Igneous rocks of the Leucite Hills and Pilot Butte, Wyoming: American Journal of Science, 4th ser., v. 4, p. 115–141.

Davis, L.L., and Tepordei, V.V., 1985, Sand and gravel, *in* Mineral facts and problems: U.S. Bureau of Mines Bulletin 675, p. 689–703.

George, G.R., 1979, Pine Canyon, *in* Bradley, W. A., and others, Wyoming oil and gas fields symposium, greater Green River Basin, v. 1: Casper, Wyo., Wyoming Geological Association, p. 278–280.

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

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

International Association of Geodesy, 1967, Geodetic Reference System, 1967: International Association of Geodesy Special Publication 3, 116 p.

Jensen, F.S., 1972, Thickness of Phanerozoic rocks, *in* Geologic atlas of the Rocky Mountain region, United States of America: Denver, Rocky Mountain Association of Geologists, p. 56.

Lefond, S.J., ed., 1983, Industrial minerals and rocks (5th ed.): New York, American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., v. 1 and 2, 1,446 p.

Lord, N.W., 1913, Analyses of coals in the United States with descriptions of mine and field samples collected between July 1, 1904, and June 30, 1910: U.S. Bureau of Mines Bulletin 22, 1,200 p.

Love, J.D., and Christiansen, A.C., 1985, Geologic map of Wyoming: Washington, D. C., U.S. Geological Survey, scale 1:500,000, 3 sheets.

McDonald, R.E., 1972, Eocene and Paleocene rocks of the southern and central basins, *in* Geologic atlas of the Rocky Mountain region, United States of America: Denver, Rocky Mountain Association of Geologists, p. 243–256.

McDonnell, J.R., Jr., 1989, Mineral resources of the Sand Dunes Additional (WY–040–307) and a part of the Buffalo Hump (WY–040–306) Wilderness Study Areas, Sweetwater County, Wyoming: U.S. Bureau of Mines Open-file Report MLA 14–89, 16 p.

McDowell, F.W., 1971, K-Ar ages of igneous rocks from the western United States: Isochron/West, no. 2, p. 1–16.

Merewether, E.A., Krystinik, K.B., and Pawlewicz, M.J., 1987, Thermal maturity of oil and gas bearing formations in southwestern Wyoming and northwestern Colorado: U.S. Geological Survey Miscellaneous Investigations Map I–1831, scale 1:1,000,000.

Merewether, E.A., Kulik, D.M., and Ryan, G.S., 1987, Mineral resources of the Sand Dunes Wilderness Study Area, Sweetwater County, Wyoming: U.S. Geological Survey Bulletin 1757–A, 20 p.

Ogden, P.O., 1979, The geology, major element geochemistry, and petrogenesis of the Leucite Hills volcanic rocks, Wyoming: Laramie, University of Wyoming Ph.D. thesis, 135 p.

Pipiringos, G.N., and O'Sullivan, R.B., 1978, Principal unconformities in Triassic and Jurassic rocks, western interior United States—A preliminary survey: U.S. Geological Survey Professional Paper 1035–A, 29 p.

Plouff, Donald, 1977, Preliminary documentation for a FORTRAN program to compute gravity terrain corrections based on topography digitized on a geographic grid: U.S. Geological Survey Open-File Report 77–535, 45 p.

Roehler, H.W., 1981, Correlation of Eocene rocks in measured sections in the southeast and west parts of the Rock Springs coal field, Wyoming: U.S. Geological Survey Oil and Gas Investigations Chart OC–111, 2 sheets.

_____ 1983, Stratigraphy of Upper Cretaceous and Lower Tertiary outcrops in the Rock Springs uplift, Wyoming: U.S. Geological Survey Miscellaneous Investigations Series Map I–1500, 1 sheet.

Root, F.K., Glass, G.B., and Lane, D.W., 1973, Geologic map atlas and summary of economic mineral resources, Sweetwater County, Wyoming: Geological Survey of Wyoming County Resource Series, no. 2, 9 sheets.

Ryan, G.S., 1985, Mineral investigation of the Sand Dunes Wilderness Study Area, Sweetwater County, Wyoming: U.S. Bureau of Mines Open-file Report MLA 33–85, 17 p.

Schultz, A.R., 1909, The northern part of the Rock Springs coal field, Sweetwater County, Wyoming, *in* Coal fields of Wyoming: U.S. Geological Survey Bulletin 341–B, p. 256–282.

Tatar, P.J., Jones, D.F., and Zlomke, Mike, 1979, Nitchie Gulch, *in* Bradley, W.A., and others, Wyoming oil and gas fields symposium, greater Green River basin, v. 2: Casper, Wyo., Wyoming Geological Association, p. 264–265.

U.S. Bureau of Mines and U.S. Geological Survey, 1980, Principles of a resource-reserve classification for minerals: U.S. Geological Survey Circular 831, 5 p.

U.S. Defense Mapping Agency, Aerospace Center, 1974, World Relative Gravity Reference Network, North America, Part 2: Defense Mapping Agency Aerospace Center Reference Publication 25, with supplement updating Gravity Standardization Net, 1971, 1,635 p.

U.S. Department of Energy, 1982a, Residual intensity magnetic anomaly map, Lander quadrangle, Wyoming: GJM–093, PR no. 82–82, pl. 4.

U.S. Department of Energy, 1982b, Residual intensity magnetic anomaly map, Rock Springs quadrangle, Wyoming: GJM–073(82), PR no. 82–82, pl. 4.

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.

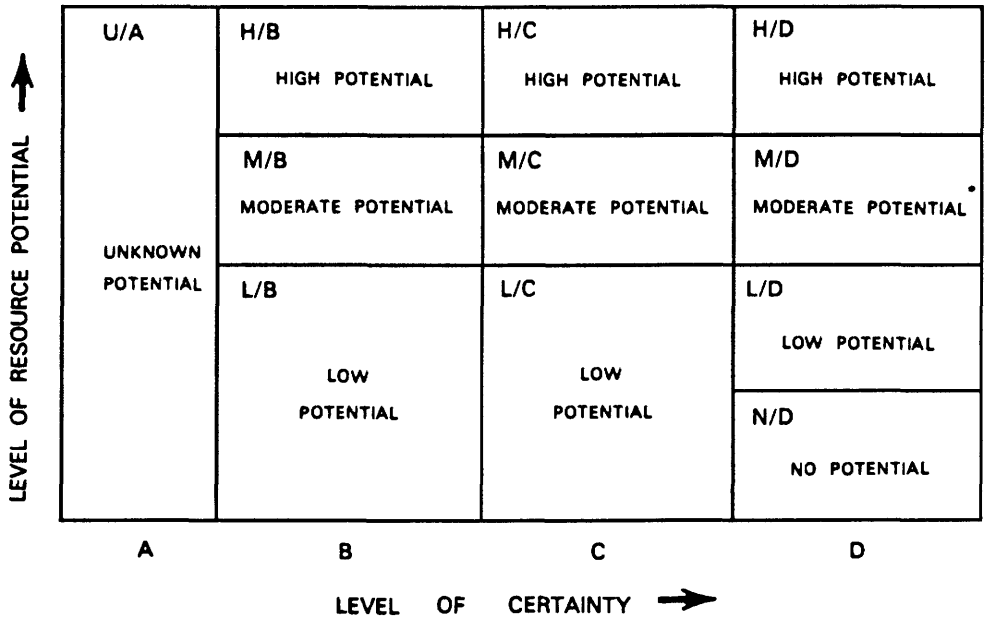
MODERATE mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence, where interpretations of data indicate a reasonable likelihood of resource accumulation, and (or) where an application 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.

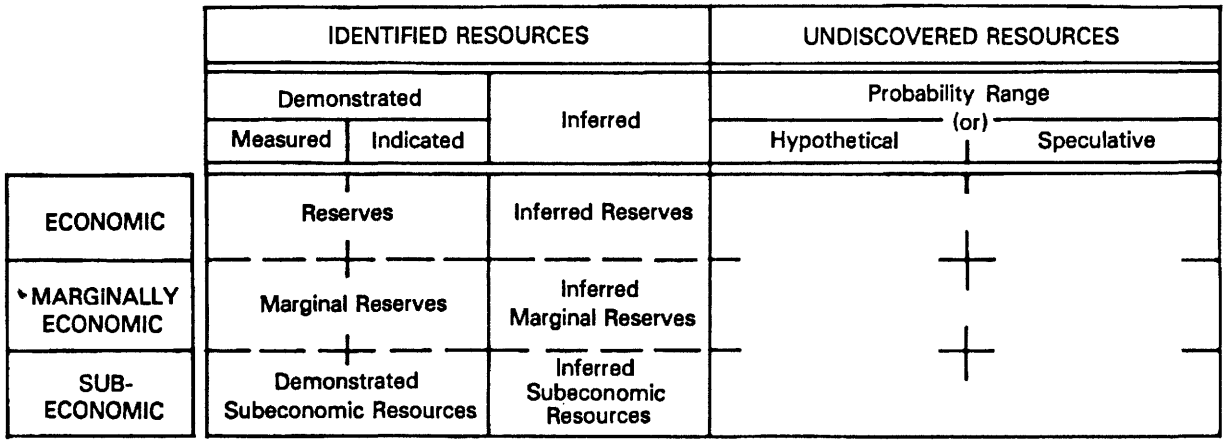
Abstracted with minor modifications from:

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



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 Early	96 138
		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				
pre-Archean[2]		3800?			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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