Mineral Resources of the Sand Dunes Wilderness Study Area, Sweetwater County, Wyoming

U.S. GEOLOGICAL SURVEY BULLETIN 1757–A

Chapter A

Mineral Resources of the Sand Dunes Wilderness Study Area, 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
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STUDIES RELATED TO WILDERNESS

Bureau of Land Management Wilderness Study Areas

The Federal Land Policy and Management Act (Public Law 94–597, October 21, 1976) requires the U.S. Geological Survey and the U.S. Bureau of Mines to conduct mineral surveys on certain areas to determine the mineral values, if any, that may be present. Results must be made available to the public and be submitted to the President and the Congress. This report presents the results of a mineral survey of a part of the Sand Dunes (WY–040–307) Wilderness Study Area, Sweetwater County, Wyoming.

CONTENTS

PLATE

FIGURES

TABLES

Mineral Resources of the Sand Dunes Wilderness Study Area, Sweetwater County, Wyoming

By E. A. Merewether *and* D. M. Kulik
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SUMMARY

The Sand Dunes Wilderness Study Area (WY–040–307) of southwestern Wyoming is in north-central Sweetwater County about 27 mi (miles) 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 an irregularly shaped part of the Sand Dunes Wilderness Study Area, which consists of about 16,280 acres largely within T. 23 N. and T. 24 N., R. 104 W. In this report the area studied is referred to as the "wilderness study area" or the "study area." Investigations of mineral occurrences in and near the wilderness study area during 1984 and 1985 indicated high mineral resource potential for undiscovered deposits of coal, moderate potential for oil shale and natural gas, low potential for oil, and identified resources of claystone, shale, and sand.

Ridges and valleys of the wilderness study area range in elevation from about 7,770 ft (feet) to about 6,700 ft and are generally covered with dune sand. Sandstone, mudstone, and shale of, from oldest to youngest, the Fort Union, Wasatch, and Green River Formations underlie the sand and crop out in parts of the study area. The Fort Union is underlain, in the subsurface, by a succession of sedimentary formations that have a total thickness of about 15,000 ft.

The wilderness study area is on the northwestern flank of the Rock Springs uplift, where the strata dip 3°–5° west-northwest. South of the study area, the surface trace of a thrust fault (Love and Christiansen, 1985) trends north-northeast and might extend northward across the southeastern part of the study area. Northeast of the study area, several normal faults (Bradley, 1926) trend south-southwest, and some of these extend along part of the eastern border of the study area.

Exploration for energy and mineral resources in the wilderness study area probably has been minimal, although the study area is covered by oil and gas leases and has been investigated by means of seismic surveys. Published reports concerning the possible resources of the study area are not available. Furthermore, no mines or boreholes have been found.

The mineral and energy endowment of the wilderness study area includes coal, oil shale, natural gas, oil, claystone and shale, and sand. Coal does not crop out and has not been penetrated by boreholes within the study area. However, coal beds crop out and have been found in boreholes near the study area. The coal is more than 5 ft thick at several nearby outcrops (Schultz, 1909, p. 266; Lord, 1913) and is bituminous and subbituminous in this region (Root and others, 1973). Stratigraphic and structural data from the outcrops and boreholes indicate that some coal beds probably extend into the subsurface of the study area. In the southeastern part of the area, the depths of these beds probably range from less than 100 ft to about 4,000 ft. Consequently, the energy resource potential for coal in the study area is high (fig. 1).

Oil shale underlies dune sand and crops out locally in the wilderness study area and extensively in adjoining areas. Stratigraphic units composed largely of oil shale trend south-southwest across this region and are as much as 80 ft thick (Roehler, 1981). The estimated producible amounts of oil in these units are 2–25 gallons per ton of rock (Roehler, 1981). A few samples of shale from outcrops near the study area were analyzed for oil yield. The richest of these contained about 11 gallons

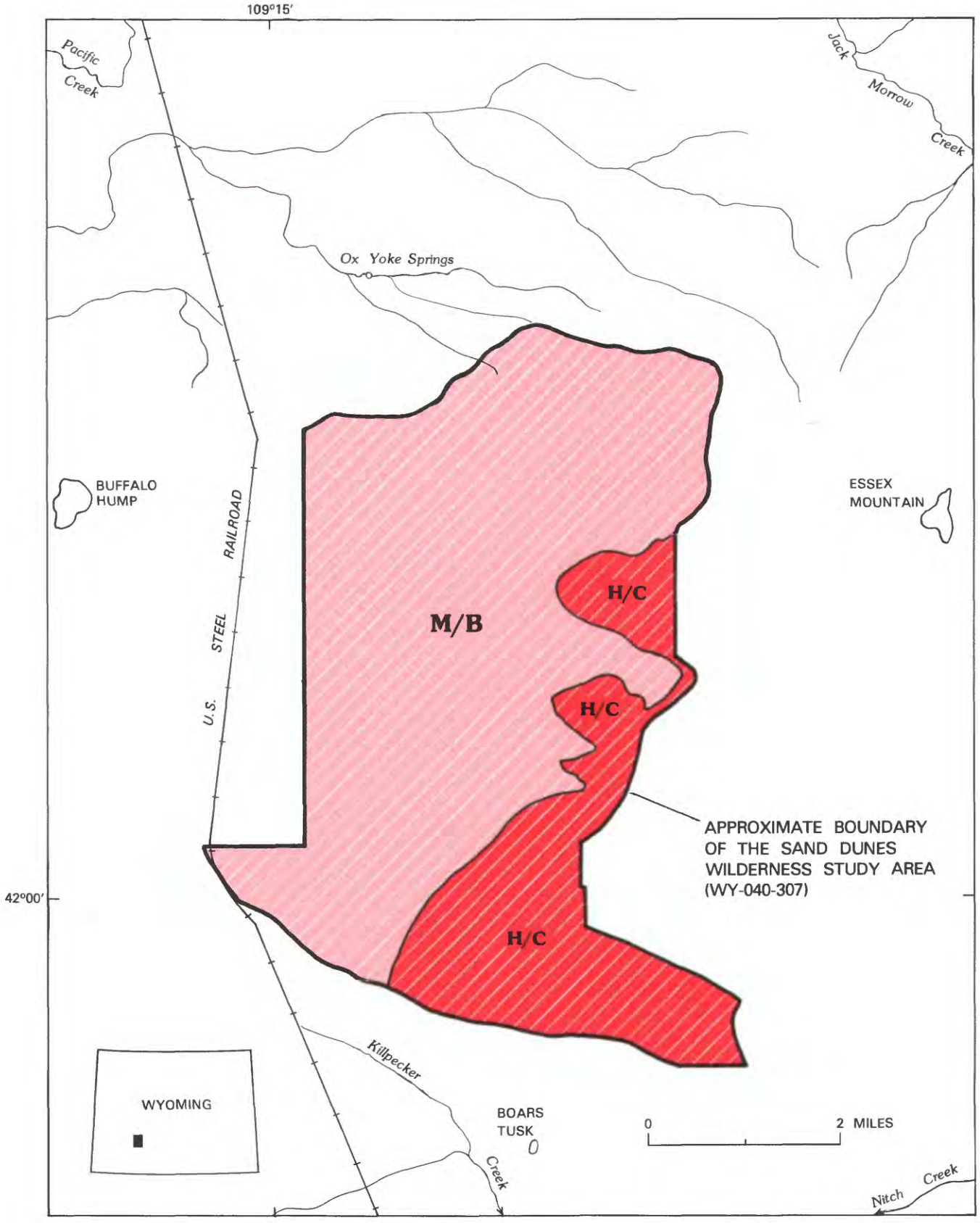

Figure 1 (above and facing page). Mineral resource potential map of the Sand Dunes Wilderness Study Area, Sweetwater County, Wyo. The study area contains identified resources of sand.

EXPLANATION

Geologic terrane having high resource potential for coal

Geologic terrane having moderate resource potential for oil shale

Geologic terrane having moderate resource potential for natural gas and low resource potential for oil, claystone, and shale

of oil per ton of rock. For comparison, the yield of the oil shale in the much larger deposits of northwestern Colorado is commonly more than 25 gallons per ton (W. J. Hail, Jr., U.S. Geological Survey, oral commun., 1986). Consequently, the energy resource potential of the oil shale in the study area is considered moderate.

No boreholes have been drilled for oil and gas in the wilderness study area, although the reservoir strata of gas fields near the study area are widespread in the region. Large amounts of natural gas have been produced from wells in the Nitchie Gulch and Pine Canyon fields, southeast of the study area. The gas is stratigraphically entrapped in formations that extend northwestward into the subsurface of the study area. These formations and some of the underlying formations could contain large amounts of gas in the study area and adjoining areas. Sparse information indicates that the gas could be in either stratigraphic or structural traps. The resource potential of the wilderness study area for natural gas is deemed moderate.

Oil has not been produced and apparently has not been discovered near the wilderness study area or in the northern part of the Rock Springs uplift. However, the region is not completely explored; the older formations have rarely been penetrated. Information concerning the deeper strata is meager. The resource potential of the wilderness study area for oil cannot be determined.

The likelihood for development of the claystone, shale (excluding oil shale), and sand in the study area is low. Large amounts of these materials are available at the surface, but their composition is inadequate for most commercial uses. Furthermore, abundant supplies of similar claystone, shale, and sand are more accessible in other, nearby areas.

INTRODUCTION

The Sand Dunes (WY–040–307) Wilderness Study Area is in north-central Sweetwater County, southwestern Wyoming, about 27 mi north of Rock Springs and about 10 mi east of the village of Eden (fig. 2). Access to the wilderness study area is by at least 10 mi of unpaved road, north or east from U.S. Highway 191, or southeast from Wyoming Highway 28. The study area is within the Green River drainage system. Drainage in the study area is intermittent. Creeks in the northern part of the study area flow westward to Pacific Creek; those in the southern part of the study area drain southward into Killpecker Creek (fig. 1).

The studied part of the Sand Dunes Wilderness Study Area contains 16,280 acres of sparsely vegetated sand dunes and outcrops of sedimentary rocks. Prominent hills and valleys in the area range in elevation from about 6,700 ft along the southern boundary to about 7,770 ft along the northeastern boundary.

Mineral resources of the wilderness study area were surveyed in 1984 and 1985 by the USBM and the USGS. Personnel of the USBM investigated the mineral occurrences in the study area to appraise mineral reserves and subeconomic resources. The locations of mining claims and oil and gas leases were obtained from BLM and county records. Information pertaining to mining activity, prospective mineral occurrences, and the geology in the region was obtained by both agencies from published and unpublished reports and maps, and both interpreted stratigraphic data, including the depths and thicknesses of coal beds, from geophysical logs of boreholes drilled for oil and gas.

Personnel of the USGS investigated the geology of the region to assess the likelihood of undiscovered mineral deposits. Recent maps that depict the surface geology of the wilderness study area were prepared by Roehler (1977) and by Love and Christiansen (1985). A gravity survey resulting in a complete Bouguer gravity anomaly map was conducted by D. M. Kulik of the USGS. Records and geophysical logs of boreholes drilled for oil and gas near the study area were obtained from the Geological Survey of Wyoming and the USGS. Descriptions of coal beds in the vicinity of the study area were obtained from Schultz (1909), Lord (1913), and Roehler (1981, 1983), and were supplied by R. W. Jones and A. J. VerPloeg (written commun., 1984) of the Geological Survey of Wyoming. Outcrops of oil shale near the wilderness study area, depicted by Roehler (1981), were sampled at three localities for this report. Hydrocarbons in the samples were estimated from pyrolysis assay by T. A. Daws and G. E. Claypool of the USGS, using the Rock–Eval[1] equipment described by Espitalie and others (1977).

Field investigations of the USBM for this report included collecting two shale samples and five claystone samples for slow-firing and preliminary bloating tests by the USBM, Tuscaloosa Research Center, University, Ala. Results of these tests determine the suitability of the shale and claystone for structural clay products (Ryan, 1985). The USBM also collected 16 samples of sand from dunes in the study area; the sand was analyzed for several elements by atomic absorption and for 40 elements by

[1]Use of trade names is for descriptive purposes only and does not imply endorsement by the U.S. Geological Survey.

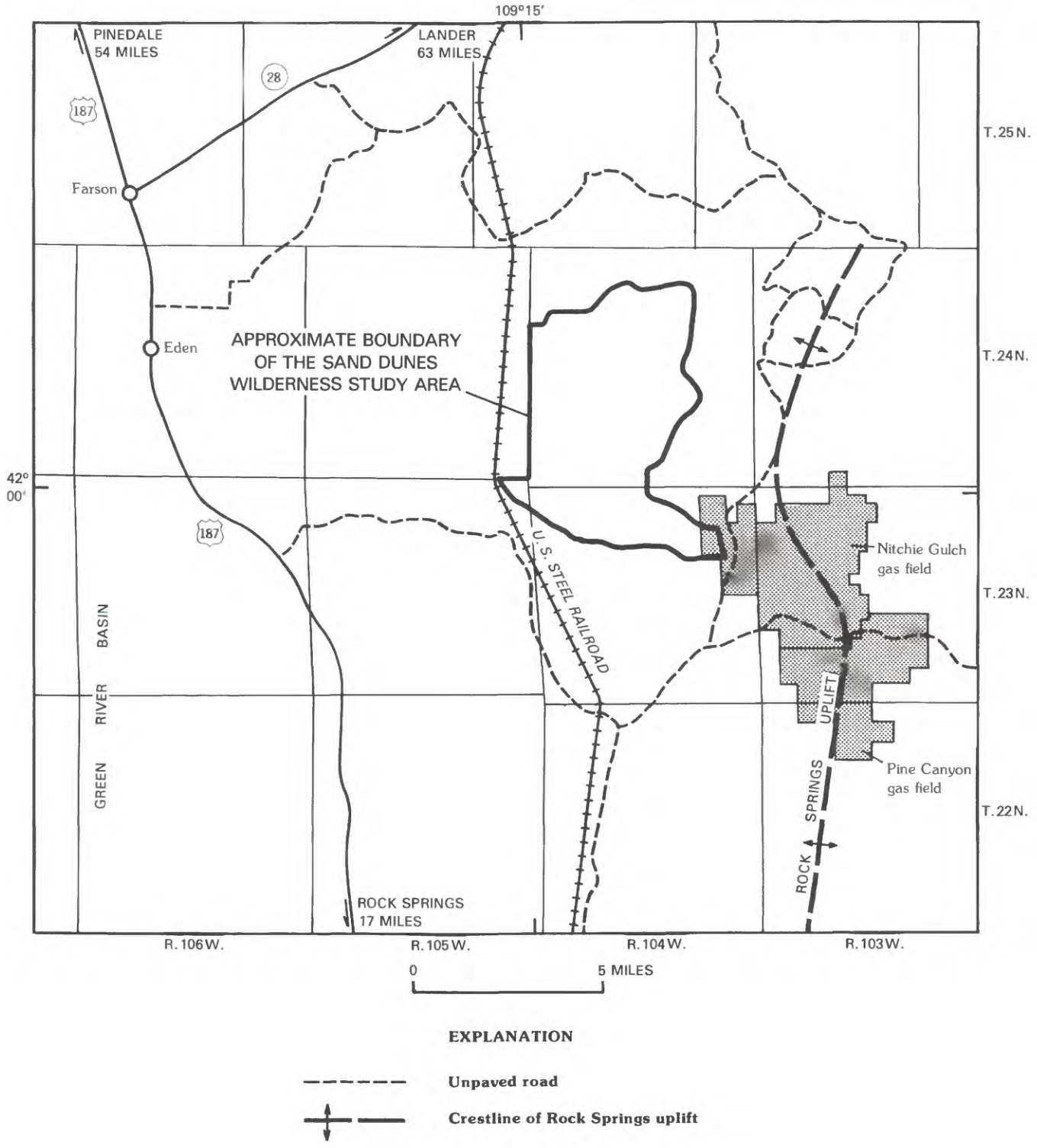

Figure 2. Index map of the Sand Dunes Wilderness Study Area, Sweetwater County, Wyo.

semiquantitative spectrographic methods in facilities of the USBM, Reno Research Center, Reno, Nev. Data from these analyses and grain-size distributions prepared from the samples by Skyline Labs, Inc., Wheat Ridge, Colo., were used to evaluate the usefulness of the sand for various products.

Acknowledgments.—The authors gratefully acknowledge the contribution of information to this investigation by officials of Sweetwater County, Wyo., and BLM at Rock Springs, Wyo., by R. W. Jones and A. J. VerPloeg of the Geological Survey of Wyoming, by USBM analysts at the Tuscaloosa Research Center, Tuscaloosa, Ala., and at the Reno Research Center, Reno, Nev., and by T. A. Daws and G. E. Claypool of the USGS, Denver, Colo.

APPRAISAL OF IDENTIFIED RESOURCES

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The mineral commodities recognized in the study area include, at the surface, clay, sand, and oil shale. No other mineral commodities have been identified in the study area, although natural gas and coal could be present in the subsurface. Large quantities of gas and minor amounts of coal have been extracted from areas adjoining the southeastern part of the study area.

Claystone and Shale

Most of the samples of claystone and shale taken from the study area have either high absorption values or high shrinkage values (table 1); consequently, the rocks they represent are generally unsuitable for structural clay products. Two shale units (pl. 1, samples 13 and 15) are marginally suitable for building brick despite short firing ranges. These claystone and shale units generally do not have characteristics that would make their use preferable to other claystone and shale deposits.

Sand

Abundant quantities of sand, an identified resource, overlie the bedrock in the Sand Dunes Wilderness Study Area (pl. 1). The sand is more than 100 ft thick locally (Ahlbrandt, 1973). Chemical analyses (table 2) indicate that this sand contains insufficient silica (less than 99.4 percent) to qualify as glass sand or for many other special-purpose sands. The sand from the dunes is too fine grained for most construction applications (table 3). It is, however, suitable for use as mortar sand, grouting sand, bedding sand, and paving sand as well as for use in asphaltic and abrasive products and in the manufacture of sand-lime brick. The lack of nearby markets precludes the development of the sand deposits at this time.

Natural Gas

The wilderness study area and the surrounding region are covered by oil and gas leases. In the study area, surface evidence of seismic exploration is extensive, but no boreholes have been drilled for oil and gas. Seven wells, drilled within 2 mi of the southern and eastern boundaries of the study area (fig. 3), had initial production rates of from 278,000 to 2,700,000 cubic feet of gas per day (table 4). Five of these wells are within the Nitchie Gulch/Pine Canyon Known Geologic Structure of the BLM, which adjoins the study area on the southeast.

Natural-gas production in the region of the study area has been from sandstone in the Cloverly Formation and in the overlying Thermopolis Shale of Early Cretaceous age and in the Frontier Formation of Late Cretaceous age. These formations have been recognized in boreholes east and west of the study area (fig. 3) and presumably occur beneath the surface of the study area. The Cloverly and Thermopolis were deposited in continental and marine environments, respectively. The Frontier is composed of marine shelf deposits and deltaic and nearshore-marine sediments (Merewether, 1983, p. 122; Finley and others, 1983, p. 273). Sandstone units of the Cloverly, Thermopolis, and Frontier that produce gas in the Nitchie Gulch and Pine Canyon fields (figs. 2, 3) probably extend northwestward into the study area.

Coal

Coal does not crop out within the study area, but it has been produced from the Upper Cretaceous Lance Formation at the Houghton (Chilton) mine (fig. 3, pl. 1), about 1.5 mi southeast of the study area. The regional dip on the northwestern flank of the Rock Springs uplift is 3°–5° west-northwest; consequently, this bed probably extends under the study area. The mined coal bed is 8 ft thick and consists of a 3-ft-thick lower seam and a 5-ft-thick upper seam. This coal is of subbituminous rank and has a low ash and sulfur content (Lord, 1913, p. 316). No production records are available, but the size and type of surface facilities indicate that the production was minor and likely for local consumption. North of the mine, coal crops out near gas well 6 (NW¼SE¼ sec. 35, T. 24 N., R. 104 W.; fig. 3), about 1 mi east of the study area. This coal bed is in the Fort Union Formation and is about 3 ft thick. It has several clay partings and appears to be of low rank. Because of the regional dip, this coal bed probably also extends under the study area. Other nearby occurrences of coal are described below.

Table 1. Results of slow-firing and preliminary bloating tests of claystone and shale samples from the Sand Dunes Wilderness Study Area, Wyoming

[Analyses performed at U.S. Bureau of Mines Tuscaloosa Research Center, University, Ala.; --, not applicable]

Sample 1

TYPE MATERIAL: Clay.

RAW PROPERTIES: Water of plasticity, 24.3 percent. Working properties, plastic. Color, gray. Drying shrinkage, 2.5 percent. Dry strength, good.

pH: 8.1 HCl effervescence, none. Preliminary bloating test, negative.

SLOW-FIRING TEST:

Temperature (°C)	Color (Munsell)	Hardness (Moh's scale)	Linear shrinkage (percent)	Absorption (percent)	Apparent porosity (percent)	Bulk density (g/cm^3)
1,000	5 YR 8/4	3	5.0	28.2	44.4	1.57
1,050	5 YR 8/4	3	5.0	27.0	42.5	1.57
1,100	5 YR 6/4	4	15.0	8.9	18.6	2.08
1,150	--	--	Melted	--	--	--

Sample 2

TYPE MATERIAL: Clay.

RAW PROPERTIES: Water of plasticity, 28.8 percent. Working properties, plastic. Color, brown. Drying shrinkage, 2.5 percent. Dry strength, good.

pH: 8.1 HCl effervescence, none. Preliminary bloating test, negative.

SLOW-FIRING TEST:

Temperature (°C)	Color (Munsell)	Hardness (Moh's scale)	Linear shrinkage (percent)	Absorption (percent)	Apparent porosity (percent)	Bulk density (g/cm^3)
1,000	5 YR 7/6	3	7.5	27.3	42.6	1.56
1,050	5 YR 7/6	3	7.5	26.2	41.2	1.57
1,100	2.5 YR 4/6	4	15.0	11.8	23.0	1.95
1,150	--	--	Melted	--	--	--

Sample 10

TYPE MATERIAL: Clay.

RAW PROPERTIES: Water of plasticity, 22.5 percent. Working properties, plastic. Color, tan. Drying shrinkage, 2.5 percent. Dry strength, good.

pH: 8.3 HCl effervescence, none. Preliminary bloating test, negative.

SLOW-FIRING TEST:

Temperature (°C)	Color (Munsell)	Hardness (Moh's scale)	Linear shrinkage (percent)	Absorption (percent)	Apparent porosity (percent)	Bulk density (g/cm^3)
1,000	5 YR 8/2	3	5.0	34.8	49.4	1.42
1,050	5 YR 8/2	3	5.0	33.7	48.6	1.44
1,100	10 YR 9/2	3	5.0	32.7	47.7	1.46
1,150	2.5 Y 8/4	4	7.5	25.5	41.4	1.62
1,200	5 Y 7/6	6	15.0	12.3	25.5	2.07
1,250	--	--	Melted	--	--	--

Table 1. Results of slow-firing and preliminary bloating tests of claystone and shale samples from the Sand Dunes Wilderness Study Area, Wyoming—Continued

Sample 12

TYPE MATERIAL: Clay.

RAW PROPERTIES: Water of plasticity, 23.0 percent. Working properties, plastic. Color, gray. Drying shrinkage, 5.0 percent. Dry strength, good.

pH: 7.8 HCl effervescence, none. Preliminary bloating test, negative.

SLOW-FIRING TEST:

Temperature (°C)	Color (Munsell)	Hardness (Moh's scale)	Linear shrinkage (percent)	Absorption (percent)	Apparent porosity (percent)	Bulk density (g/cm^3)
1,000	5 YR 7/6	3	5.0	22.4	37.8	1.69
1,050	5 YR 7/6	3	5.0	22.3	37.6	1.68
1,100	5 YR 6/6	3	5.0	19.3	33.9	1.76
1,150	5 YR 5/2	4	12.5	2.7	5.9	2.18
1,200	--	--	Melted	--	--	--

Sample 13

TYPE MATERIAL: Clay.

RAW PROPERTIES: Water of plasticity, 25.1 percent. Working properties, plastic. Color, brown. Drying shrinkage, 5.0 percent. Dry strength, good.

pH: 8.1 HCl effervescence, none. Preliminary bloating test, negative.

SLOW-FIRING TEST:

Temperature (°C)	Color (Munsell)	Hardness (Moh's scale)	Linear shrinkage (percent)	Absorption (percent)	Apparent porosity (percent)	Bulk density (g/cm^3)
1,000	2.5 YR 6/8	3	7.5	21.8	37.4	1.71
1,050	2.5 YR 6/6	4	7.5	21.7	37.4	1.72
1,100	2.5 YR 5/6	4	10.0	18.7	33.4	1.78
1,150	--	--	Melted	--	--	--

Sample 15

TYPE MATERIAL: Clay.

RAW PROPERTIES: Water of plasticity, 20.9 percent. Working properties, plastic. Color, brown. Drying shrinkage, 5.0 percent. Dry strength, good.

pH: 7.8 HCl effervescence, none. Preliminary bloating test, negative.

SLOW-FIRING TEST:

Temperature (°C)	Color (Munsell)	Hardness (Moh's scale)	Linear shrinkage (percent)	Absorption (percent)	Apparent porosity (percent)	Bulk density (g/cm^3)
1,000	5 YR 6/8	3	5.0	19.4	34.4	1.77
1,050	5 YR 6/8	3	5.0	19.3	34.3	1.77
1,100	2.5 YR 6/6	4	7.5	16.7	30.6	1.83
1,150	2.5 YR 3/4	6	12.5	1.4	3.1	2.26
1,200	--	--	Melted	--	--	--

Table 1. Results of slow-firing and preliminary bloating tests of claystone and shale samples from the Sand Dunes Wilderness Study Area, Wyoming—Continued

Sample 21

TYPE MATERIAL: Clay.

RAW PROPERTIES: Water of plasticity, 25.6 percent. Working properties, plastic. Color, gray. Drying shrinkage, 5.0 percent. Dry strength, good.

pH: 7.7 HCl effervescence, none. Preliminary bloating test, negative.

SLOW-FIRING TEST:

Temperature (°C)	Color (Munsell)	Hardness (Moh's scale)	Linear shrinkage (percent)	Absorption (percent)	Apparent porosity (percent)	Bulk density (g/cm^3)
1,000	2.5 Y 9/2	3	5.0	36.9	51.3	1.38
1,050	2.5 Y 9/2	3	5.0	36.8	51.0	1.39
1,100	2.5 Y 9/4	3	10.0	28.6	44.2	1.55
1,150	2.5 Y 8/4	4	17.5	11.5	23.6	2.05
1,200	--	--	Melted	--	--	--

Table 2. Chemical composition of samples of dune sand from the Sand Dunes Wilderness Study Area, Wyoming
[All values in percent except P_2O_5, in parts per million]

Sample No. (pl. 1)	SiO_2	Fe_2O_3	Al_2O_3	CaO	K_2O	MgO	Na_2O	TiO_2	P_2O_5
3	74.9	1.50	14.0	3.6	1.6	0.47	1.9	0.27	370
4	79.4	.89	12.2	2.6	1.6	.27	1.6	.14	390
5	77.0	1.10	13.5	3.2	1.5	.36	1.8	.19	410
6	79.3	.79	12.5	2.5	1.5	.23	1.6	.13	280
7	78.2	1.00	12.9	2.6	1.8	.31	1.8	.17	290
8	80.4	.72	12.2	2.3	1.6	.20	1.6	.12	200
9	80.3	.82	13.3	2.3	1.6	.23	1.7	.16	370
11	79.8	.78	13.0	2.1	1.6	.23	1.7	.14	320
14	78.2	1.10	12.9	2.7	1.7	.30	1.7	.16	300
16	80.0	.90	11.7	2.4	1.8	.29	1.6	.14	260
17	78.2	1.20	12.7	3.0	1.5	.42	1.6	.23	230
18	78.4	1.30	11.9	2.8	1.4	.42	1.5	.24	330
19	78.8	1.30	11.6	2.8	1.6	.42	1.5	.23	320
20	79.5	1.10	11.7	2.5	1.7	.31	1.5	.18	340
22	79.1	.96	12.2	2.6	1.6	.29	1.6	.16	220
23	79.9	.82	12.4	2.5	1.7	.24	1.6	.15	130

Data from geophysical logs are available for boreholes in the vicinity of the study area (table 4) drilled deeper than 1,000 ft, but boreholes drilled for gas and oil in deep potential reservoirs generally are not attended by a geologist or logged until the depth penetrated is at least 1,000 ft. Consequently, there are few lithologic or geophysical logs for shallower depths from which to identify coal beds in the region. There are no boreholes in the study area. Geophysical logs of some boreholes, which are less than 2 mi east and south of the study area (fig. 3), indicate as many as 20 coal beds, 3–20 ft thick, at depths of less than 5,000 ft. The log of borehole 1, west of the study area (fig. 3), indicates 15 coal beds, which range in thickness from 2 ft to 45 ft and have a cumulative total thickness of 213 ft. A 32-ft-thick bed was recognized at a depth of 5,845–5,877 ft and a 45-ft-

Table 3. Distribution of grain sizes in samples of dune sand from the Sand Dunes Wilderness Study Area, Wyoming
[U.S. Standard sieves used for analyses. Values in weight percent; <, less than]

Sample No. (pl. 1)	+10 mesh	10–16 mesh	16–35 mesh	35–60 mesh	60–120 mesh	120–230 mesh	–230 mesh
3	2.6	<0.1	<0.1	19.2	77.9	0.1	0.1
4	<0.1	< .1	8.6	60.5	30.8	.1	.1
5	< .1	< .1	.2	45.0	54.8	<.1	<.1
6	< .1	< .1	1.4	68.0	30.6	<.1	<.1
7	< .1	< .1	.7	55.0	44.1	.1	.1
8	< .1	< .1	2.7	63.9	33.3	.1	.1
9	< .1	< .1	1.2	42.1	56.7	<.1	<.1
11	< .1	< .1	3.5	50.9	45.3	.2	.2
14	< .1	< .1	3.3	66.4	30.3	.1	.1
16	< .1	< .1	16.1	51.3	32.3	.1	.1
17	< .1	< .1	1.4	26.6	72.0	.1	<.1
18	< .1	.1	14.6	21.6	62.8	.6	.3
19	< .2	.4	21.2	35.5	42.2	.4	.1
20	< .1	< .1	13.1	48.5	38.3	<.1	<.1
22	< .1	< .1	5.3	36.5	58.3	<.1	<.1
23	< .1	< .1	2.5	51.8	45.6	<.1	<.1

thick bed was identified at a depth of 6,850–6,895 ft. The coal beds in the Green River basin (fig. 2) are generally discontinuous and cannot be traced laterally without boreholes. However, special high-density seismic surveys could possibly delineate the lateral extent of the thicker coal beds, even at the depths recorded for hole 1 (table 4).

Although coal probably underlies the study area, its quality, thickness, and depth are unknown. Exploitation of the coal would depend mainly on those three factors. The maximum depth for open-pit coal mines is generally about 200 ft (Richard Jones, Wyoming Geological Survey, oral commun., 1984). Extensive coal beds in other areas of Wyoming have a maximum stripping ratio of about 15/1. High development costs would probably preclude the establishment of an open-pit mine for most of the coal in the study area. In-place mining (gasification) is practical only in beds at least 20 ft thick, although mining of multiple, thinner seams is presently being tested (Warren Westphal, Westphal Associates Inc., oral commun., 1984).

Conclusions

Sand, claystone, and shale crop out within the study area. They are generally of low quality but are suitable for some building products. The local market for these products is small. Existing sources nearer to the major markets are capable of supplying the anticipated demand.

Formations that contain oil and gas near the study area also underlie the study area. The primary drilling targets are marine and nonmarine sandstone units of the Cretaceous Cloverly, Thermopolis, and Frontier Formations. Sandstone units that produce gas in the Nitchie Gulch and Pine Canyon fields probably extend northwestward into the study area.

Coal has been mined within 1.5 mi of the study area, but it does not crop out within the study area. Coal of unknown rank and quality probably is below the surface of the study area, although geophysical logs of boreholes outside the study area indicate that most of the coal may be at depths too great for current mining practices.

ASSESSMENT OF POTENTIAL FOR UNDISCOVERED RESOURCES

By E. A. Merewether and D. M. Kulik
U.S. Geological Survey

Geology

The rocks in the vicinity of the Sand Dunes Wilderness Study Area 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. The outcropping formations in the wilderness study area (pl. 1) dip about 4° west-northwest and are on the northwestern flank of a north-trending, structurally high area named the Rock Springs uplift (fig. 2). Adjoining the western flank of the Rock Springs uplift is a large structural depression named the Green

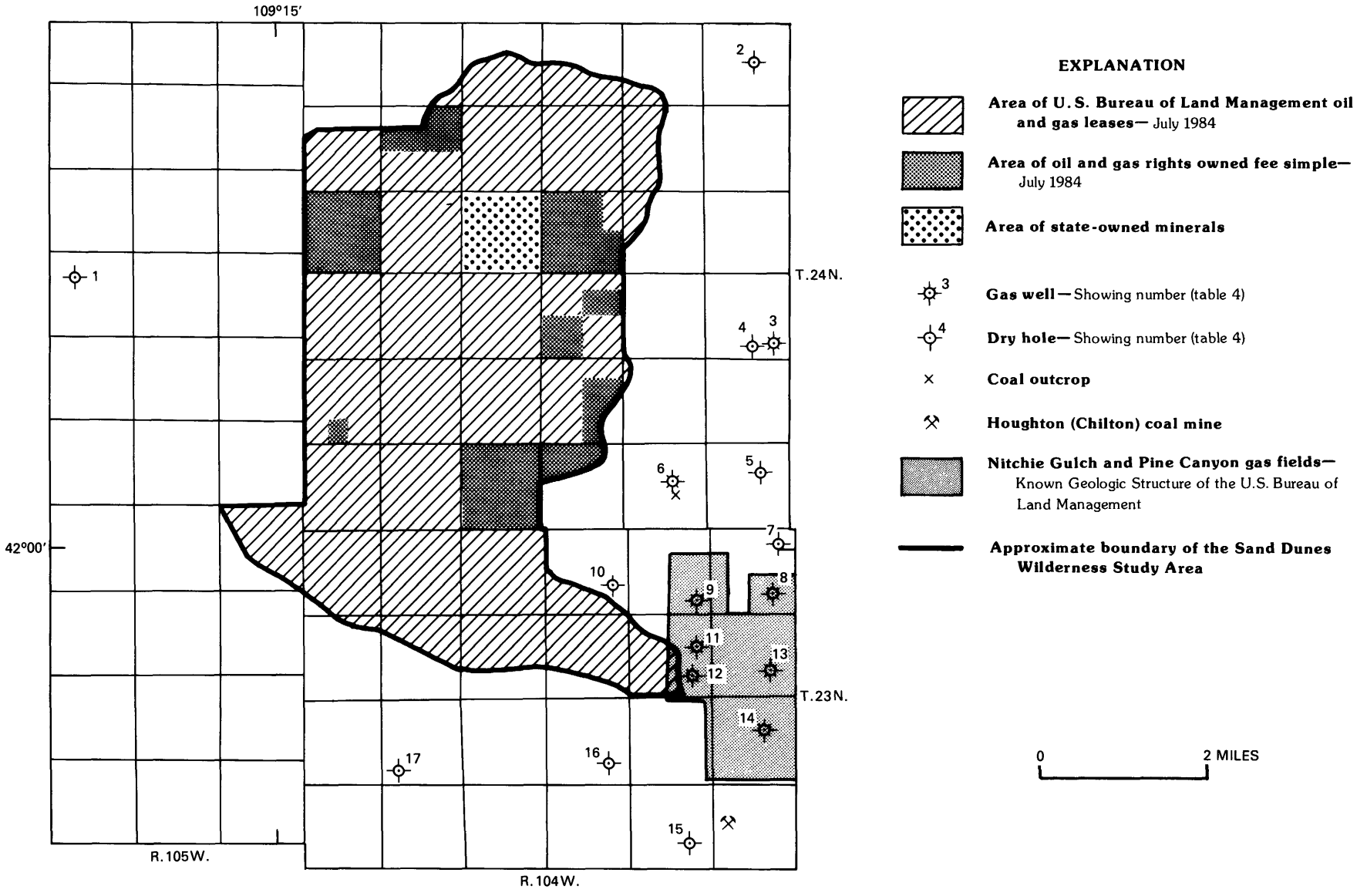

Figure 3. Map showing land status of the Sand Dunes Wilderness Study Area, Sweetwater County, Wyo., and gas wells, dry holes, and coal occurrences in the vicinity.

Table 4. Data from boreholes drilled for oil and gas in the vicinity of the Sand Dunes Wilderness Study Area, Wyoming
[MCFGPD, thousand cubic feet gas per day; bbls, barrels; do, ditto]

Borehole No. (fig. 3)	Lease name	Operator	Date completed	Collar elevation (ft)	Total depth (ft)	Producing formations and depths (ft)	Initial production
1	Grady-Federal 1-Z	Davis Oil Co.------	1-11-71	6,858	7,997	None---	Dry and abandoned.[1]
2	Federal 1-1------	H. L. Brown, Jr.---	1-03-84	7,591	8,104	None---	Dry and abandoned.[2]
3	Federal 44-24----	Houston Oil and Minerals Corp.	11-22-80	7,075	10,730	Frontier (9,549-9,655)	278 MCFGPD.[1]
4	Government-Dune 1	Kirby Royalties Inc.	11-14-63	7,043	5,500	None---	Dry and abandoned.[1]
5	Trask-State 36-1-	Rock Hill Industries.	3-28-69	7,026	878	None---	Dry and abandoned.[1]
6	Goodstein-Federal 1-35.	Florida Exploration Co.	3-25-81	7,019	10,130	Frontier (9,265-9,371)	638 MCFGPD; 7 bbls oil/day.[2]
7	Indian Gap Unit 1	Gulf Oil Corp.-----	12-01-55	6,936	10,066	None---	Dry and abandoned.[1]
8	Jamieson A 1-----	Texas Oil and Gas Corp.	3-03-79	6,892	9,308	Frontier	Show of gas.[2]
9	Winston-Federal 1	--------do---------	10-31-79	6,942	9,770	Frontier (8,656-8,806) Thermopolis (9,346-9,355)	800 MCFGPD.[2]
10	C & K-Federal 1	--------do----------	11-07-80	6,810	9,550	None---	Dry and abandoned.[1]
11	Sand Dunes-Federal 1.	--------do----------	10-09-80	6,891	9,554	Frontier (8,614-8,775)	476 MCFGPD.[1]
12	Government-Amax 11-10.	Sunset International Petroleum Co.	4-01-67	6,816	9,585	Frontier (8,656-8,756)	330 MCFGPD; 1.7 bbls distillate/day.[1]
13	Rogers 1-12----	Amax Petroleum Co.--	11-23-65	6,892	9,017	Frontier (8,067-8,234)	2,700 MCFGPD.[1]
14	Government 7-13.	Terra Resources Inc.	8-09-73	6,876	8,400	Frontier (8,242-8,246)	344 MCFGPD.[1]
15	Chilton-Federal 1-23.	Amoco Production Co.	6-02-79	6,746	9,681	None---	Dry and abandoned.[2]
16	Boars Tusk-Federal 1-15.	--------do----------	Suspended	6,816	10,400	None---	Dry and abandoned.[2]
17	Federal-Essex 13-17.	Husky Oil Co.-------	6-04-79	6,717	3,300	None---	Dry and abandoned.[2]

[1]Data from Petroleum Information Service.

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

River basin. Both of these structural features developed mainly in Late Cretaceous (see geologic time chart in appendix) and Tertiary time. Along the western flank of the Rock Springs uplift, the surface trace of a thrust fault extends northward nearly to the southern border of the wilderness study area (Love and Christiansen, 1985) (pl. 1) and could extend into the study area. The dip of the thrust surface is eastward. Several normal faults are northeast of the study area, and their surface traces trend north-northeast (Bradley, 1926). The downthrown block of most of these faults is on the east. No faults have been recognized on the surface within the Sand Dunes Wilderness Study Area, although some of those northeast of the study area extend along part of the eastern border (pl. 1). Sparse stratigraphic data from the geophysical logs of boreholes in the region (table 4) indicate that the rock units of the study area may have been downfaulted relative to the units in the adjoining area to the east.

The outcropping sedimentary rocks of the wilderness study area (table 5) have been assigned, in ascending order, to the Fort Union Formation of early Tertiary (Paleocene) age and the Wasatch and Green River Formations of early Tertiary (Eocene) age. Underlying the Fort Union in the subsurface is a sequence of formations that is about 15,000 ft thick (table 5; 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 Mesozoic (Triassic and Jurassic) formations, which 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.

The upper Mesozoic (Cretaceous) strata of the wilderness study area are 9,000–10,000 ft thick and consist largely of shale and sandstone, which were deposited in marine and continental environments. Beneath the surface of the area, Lower Cretaceous rocks are assigned to the Cloverly Formation, Thermopolis Shale, and Mowry Shale. The Cloverly is about 80–100 ft thick and is composed of sandstone units and intervening shale units. The Thermopolis is about 200–220 ft thick and consists of shale and sandstone. Both formations contain gas in nearby areas. The Mowry is about 300 ft thick and consists of siliceous shale.

Upper Cretaceous rocks in the region comprise, from oldest to youngest, the Frontier Formation, Baxter Shale, Blair Formation, Rock Springs Formation, Ericson Sandstone, Almond Formation, Lewis Shale, Fox Hills Sandstone, and Lance Formation (table 5). Near the wilderness study area, the Frontier 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, about 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 about 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 area, the Fox Hills is as much as 150 ft thick, and the Lance 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 area have been assigned to, from oldest to youngest, the Fort Union Formation of Paleocene age, and the Wasatch and Green River Formations of Eocene age (table 5). These rocks were deposited in continental environments. The Fort Union in the area seemingly 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 near the southeastern corner of the study area. On the northwestern flank of the uplift, the Fort Union is overlain by the main body of the Wasatch, which is composed largely of sandstone and mudstone and is 2,000–2,500 ft thick (McDonald, 1972). Outcrops along the eastern border of the study area include an upper part of the main body and the overlying Tipton Tongue of the Green River Formation. The Tipton Tongue is about 60–80 ft thick and consists mostly of oil shale, sandstone, and limestone (Roehler, 1981). These rocks are overlain by the outcropping New Fork Tongue of the Wasatch Formation, which is probably 70–220 ft thick and is composed largely of sandstone and oil shale (Roehler, 1981). Overlying the New Fork are strata that grade northward into the Cathedral Bluffs Member of the Wasatch and southward into the Wilkins Peak Member of the Green River. Roehler (1981) indicated that these strata are 150–180 ft thick and that they consist mostly of mudstone and oil shale. This unit is overlain by the Laney Member of the Green River Formation, which is at least 80 ft thick and is composed largely of oil shale and mudstone (Roehler, 1981). These strata are the youngest rocks in the wilderness study area. Much of the Wasatch and Green River Formations in the area is covered by sand dunes of Quaternary age.

Table 5. Formations of Mesozoic and Cenozoic age in the Sand Dunes Wilderness Study Area, Wyoming
[*Outcropping formations and members; Do., ditto]

Age	Formation	Approximate thickness (ft)	Predominant lithology
Tertiary (Eocene)---	Laney Member of Green River Formation*-------	80+	Mudstone and oil shale.
	Wilkins Peak Member of Green River Formation*	150-180	Do.
	New Fork Tongue of Wasatch Formation*--------	70-220	Sandstone and oil shale.
	Tipton Tongue of Green River Formation*------	60-80	Oil shale, sandstone and limestone.
	Main body of Wasatch Formation*----------	2,000-2,500	Sandstone 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.
Early Cretaceous----	Mowry Shale----------	300	Shale and bentonite.
	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.
Late and Middle Jurassic.	Sundance Formation----------	450-500	Limestone, shale, and sandstone.
Middle Jurassic-----	Carmel Formation (lower part)----------	50	Sandstone, limestone, and shale.
	Gypsum Spring Formation----------	100-150	Limestone, claystone, and siltstone.
Jurassic(?) and Triassic(?).	Nugget Sandstone----------	500	Sandstone, siltstone, and shale.
Late and Early Triassic.	Chugwater Group----------	1,400	Claystone, mudstone, and siltstone.

The wilderness study area is within the Killpecker dune field. Unconsolidated sand at the surface of the study area and adjoining areas is commonly in the form of both active and dormant dunes, including dome, transverse, barchan, parabolic, reactivated, and irregular dunes (Ahlbrandt, 1973). 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 intermit-

tently active and record the climatic fluctuations associated with the stades and interstades of glaciation during the past 20,000 years (Ahlbrandt, 1973).

Geophysics

Gravity studies were performed as part of the mineral resource evaluation of the Sand Dunes Wilderness Study Area to provide information about the subsurface distribution of rock units and about the structural framework. In 1984 and 1985, gravity was measured at about 85 new stations in and near the study area (fig. 4). This information was subsequently combined with data from files maintained by the Defense Mapping Agency of the U.S. Department of Defense.

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 km around each station, using the method of Plouff (1977). The data are shown contoured on a complete Bouguer gravity anomaly map (fig. 4).

The gravity values in the vicinity of the wilderness study area decrease northward, from –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 the northward thickening of the sedimentary rocks in the region. The normal faults mapped northeast of the study area are not expressed in the gravity data at this contour interval. As there are significant density contrasts between the carbonate and siliciclastic rocks in the subsurface of the region, the lack of expression probably indicates that major offsets (several hundred feet) are absent along the normal faults.

Energy and Mineral Resources

The energy source materials of the study area include coal, oil shale, and oil and gas. Mineral commodities of the study area include claystone, shale, and sand. The energy and mineral resource potential are classified according to the system of Goudarzi (1984) (see appendix).

Coal

On the Rock Springs uplift, the Rock Springs Formation contains bituminous coal, and the progressively younger Almond, Lance, Fort Union, and Wasatch Formations contain subbituminous coal (Root and others, 1973). Some of this coal crops out in the northwestern part of the uplift, east and southeast of the wilderness study area, and some probably occurs beneath the surface of the study area. Coal beds in the Almond Formation, which crop out 1–2 mi southeast of the study area, are about 8 ft thick (Schultz, 1909). The coal at the Houghton (Chilton) mine (fig. 3, pl. 1), about 1.5 mi southeast of the study area, is in the Lance Formation and is about 8 ft thick. At outcrops about 2.5 mi southeast of the study area (pl. 1), a coal bed in the Fort Union Formation is 4–5 ft thick. East of the study area about 1.5 mi (pl. 1), another coal bed in the Fort Union is about 3 ft thick. Coal beds also have been recognized on geophysical logs of boreholes in the vicinity of the study area. Using outcrops, depths from the logs, and the structural dip, beds of coal and the enclosing formations can be projected into the subsurface of the wilderness study area. The shallowest coal would be in the southeastern part of the study area (fig. 1; sec. 11, T. 23 N., R. 104 W., pl. 1) in the Fort Union Formation beneath sand dunes. Where the dune sand is less than 50 ft thick, the coal in the Fort Union could be less than 50 ft below the ground surface. Below the Fort Union in this part of the study area, the Upper Cretaceous coal beds would occur intermittently between depths of about 200 ft and 4,000 ft. Nearby and downdip, in sec. 9, T. 23 N., R. 104 W. (pl. 1), a coal bed within the Wasatch Formation might be at a depth of 500–600 ft, and the coal-bearing Fort Union is about 1,800 ft deep.

Coal beds neither crop out nor have been penetrated by boreholes within the wilderness study area. Nevertheless, the resource potential for coal in the study area is high with a certainty level of C, a high potential determined from dependable information. The formations that contain coal at nearby outcrops on the Rock Springs uplift are in the subsurface of the study area. In the study area, this coal is of unknown thickness and quality and is generally at least 1,000 ft deep. However, thick beds of coal probably occur in the southeastern part of the study area, at depths of less than 200 ft, within the range of open-pit mining.

Oil Shale

Most of the following information, which pertains to strata of Eocene age and to the constituent oil shale, was obtained from Roehler (1981). Outcrops of the Wasatch and Green River Formations in the vicinity of the Sand Dunes Wilderness Study Area consist of the main body of the Wasatch, the Tipton Tongue of the Green River, the New Fork Tongue of the Wasatch, the Wilkins Peak Member of the Green River or Cathedral Bluffs Member of the Wasatch, and the Laney Member of the Green River. The Tipton consists largely of oil shale at outcrops near the study area and is about 60 ft thick in sec. 24, T. 23 N., R. 105 W. (stratigraphic section 20, Roehler, 1981) and about 80 ft thick in secs. 25 and 36, T. 25 N., R. 103 W. (stratigraphic section

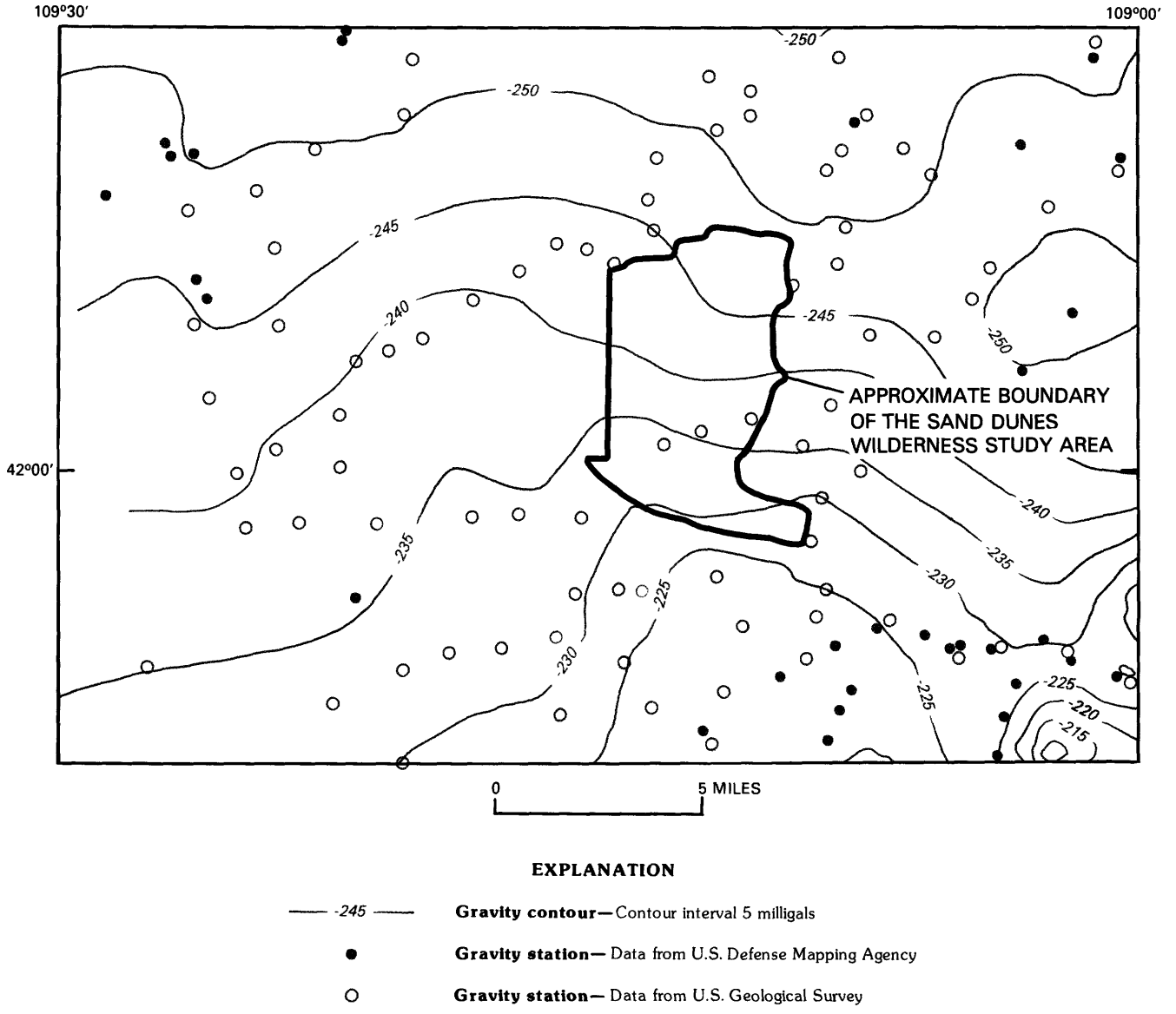

Figure 4. Complete Bouguer gravity anomaly map of the Sand Dunes Wilderness Study Area and vicinity, Sweetwater County, Wyo. Mapped by D. M. Kulik, 1985.

21, Roehler, 1981). Estimated producible amounts of oil in the Tipton at these localities range from 2 to 25 gallons per ton of rock. The Wilkins Peak is composed mainly of oil shale and mudstone and is about 180 ft thick at stratigraphic section 20. Estimates of the amounts of oil in most of the oil shale of the Wilkins Peak at stratigraphic section 20 are 2–15 gallons per ton of rock. The basal unit of the Laney, which at stratigraphic section 20 consists largely of oil shale and is about 60 ft thick, contains as much as 2–15 gallons of oil per ton of rock.

Samples from outcrops of the Tipton at three localities near the wilderness study area were analyzed by pyrolysis for oil yield, using the Rock-Eval procedure of Espitalie and others (1977). The samples from Roehler's (1981) stratigraphic section 20, south of the study area (pl. 1), and from sec. 13, T. 24 N., R. 104 W., east of the study area (pl. 1), contained only traces of hydrocarbons. However, the possible oil yield for the sample from sec. 27, T. 25 N., R. 102 W., about 9 mi east-northeast of the study area, is about 11 gallons per ton of rock.

Oil-shale-bearing members of the Green River Formation commonly underlie sand dunes and rarely crop out within the wilderness study area. The thickness and possible yield of units of oil shale within the study area have not been determined. However, the sparse data from the surrounding region indicate that the resource potential of the oil shale in the Sand Dunes Wilderness Study Area is moderate, with a certainty level of B, interpreted from meager information.

Oil and Gas

The strata in the subsurface of the wilderness study area have not been explored for oil and gas by drilling, even though some of those formations contain gas in nearby fields (fig. 2). In the Nitchie Gulch field, which overlaps a southeastern part of the study area, methane is produced from the Cloverly and Frontier Formations, and shows of gas were found in the Baxter Shale and the Rock Springs Formation (Tatar and others, 1979). The estimated ultimate 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 area. In the Pine Canyon field, gas and condensate (liquid hydrocarbons having API (American Petroleum Institute) gravity more than 60°) are produced from the Cloverly, Thermopolis, and Frontier Formations, 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, Morrison, Cloverly, Thermopolis, Frontier, and Blair Formations.

The thermal maturity of the sedimentary rocks in the study area was estimated from maps of the thermal maturity of southwestern Wyoming (Merewether and others, in press). These maps were derived mainly from reflectance values for vitrinite particles in samples of cores. Vitrinite is a common constituent of the coalified plant material in sedimentary rocks. Vitrinite reflectance is widely used to assess the thermal maturity of sedimentary organic matter because it increases with increasing paleotemperature and depth. The reflectance is determined generally from optical measurements of the reflectivity of vitrinite particles at random orientation in oil. Median reflectance values of 0.6 and 1.3 percent generally define the maturity of rocks that have generated oil. Reflectance values of more than 0.7 percent characterize rocks that have generated gas. Maximum generation of gas generally begins when the reflectance is about 1.3 percent. The estimated vitrinite reflectance for the ground surface of the study area is 0.4–0.5 percent. Extrapolated reflectance values of 0.6 percent and 1.3 percent in the area are at depths of about 6,500 ft and about 13,000 ft, respectively. 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.

In southwestern Wyoming, source rocks for oil and gas are common within the lower Tertiary and Cretaceous formations, and they probably occur within many of the older formations. All strata in the wilderness study area, at depths below about 6,500 ft, are thermally mature (Merewether and others, in press); consequently the source rocks below that depth presumably have generated hydrocarbons. Reservoir beds for gas have been found in several formations at nearby gas fields, and they could extend into the vicinity of the study area. 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). Stratigraphic traps are common in nearby gas fields in several formations that are also in the subsurface of the study area and adjoining areas. Structural traps could have been formed in the Sand Dunes Wilderness Study Area and in contiguous areas by the doming of the Rock Springs uplift and the faulting along the eastern border of the study area.

The geology in the vicinity of the wilderness study area and the stratigraphy at nearby gas fields indicates 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 area 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. Consequently, the resource potential for oil in the region is low, with a certainty level of B, interpreted from scant data.

Claystone and Shale

The Sand Dunes Wilderness Study Area contains claystone and shale at scattered outcrops and at shallow depths beneath dune sand. Large amounts of these rocks presumably are available in the study area. The mineral resource potential of the area for concentrations of clay and shale is low, with certainty level C, derived from adequate data.

Sand

Most of the surface of the wilderness study area consists of dune sand. The volume of sand in the study area is very large. The mineral resource potential of the special-use sand (see USBM section above) is low, with certainty level C, interpreted from adequate information.

RECOMMENDATIONS FOR FUTURE WORK

The mineral endowment of the Sand Dunes Wilderness Study Area includes claystone and shale, sand, and oil shale; it probably includes coal and natural gas and possibly includes oil. An appraisal of the resources of coal in the study area must be derived from information concerning the depth, thickness, and quality of the coal beds. Obtaining this information would require drilling or excavating at several sites in the area as well as analyzing many samples of coal. These investigations are not presently recommended, mainly because abundant supplies of excellent coal are available at more accessible localities in Sweetwater County.

Assessing and appraising the resources of oil shale in the wilderness study area would require measuring and sampling outcrops and excavating or drilling at several sites to obtain samples and determine thicknesses. The samples would be analyzed for oil content. These activities are not recommended at this time, largely because major deposits of superior oil shale are available in more accessible areas in Wyoming, Colorado, and Utah.

The resources of oil and gas in the wilderness study area cannot be appraised until several more boreholes have been drilled in the vicinity and have penetrated at least the known gas-bearing formations of the region. Additional geophysical surveys of the area might contribute to the recognition of structural traps for oil and gas. Geochemical studies of the area might locate undiscovered shallow pools of gas. However, the moderate potential for gas within the study area is apparently no greater than the potential of other areas in the Rocky Mountains.

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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.

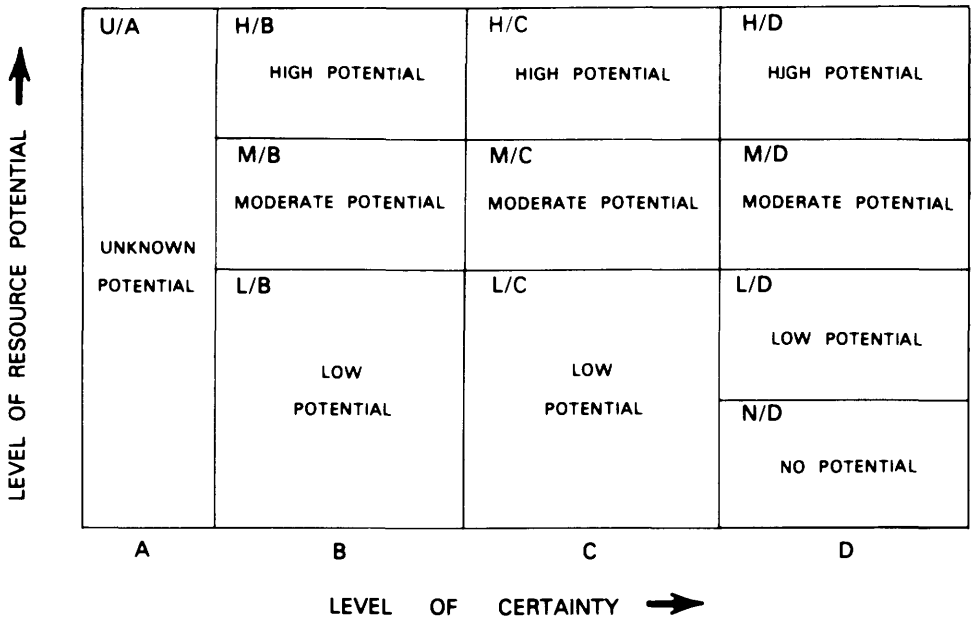
MODERATE mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence, where interpretations of data indicate a reasonable likelihood of resource accumulation, and (or) where an application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

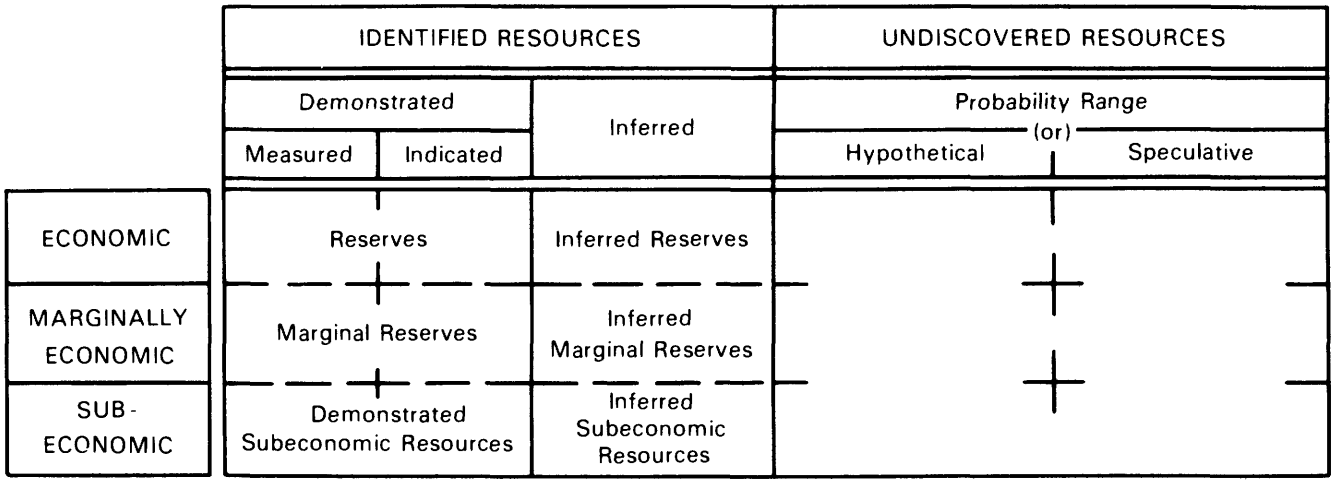
Abstracted with minor modifications from:

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



Major elements of mineral resource classification, excluding reserve base and inferred reserve base. Modified from U. S. Bureau of Mines and U. S. Geological Survey, 1980, Principles of a resource/reserve classification for minerals: U. S. Geological Survey Circular 831, p. 5.

GEOLOGIC TIME CHART

Terms and boundary ages used by the U. S. Geological Survey, 1986

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.

* U.S. GOVERNMENT PRINTING OFFICE 1987: 773-047/46022