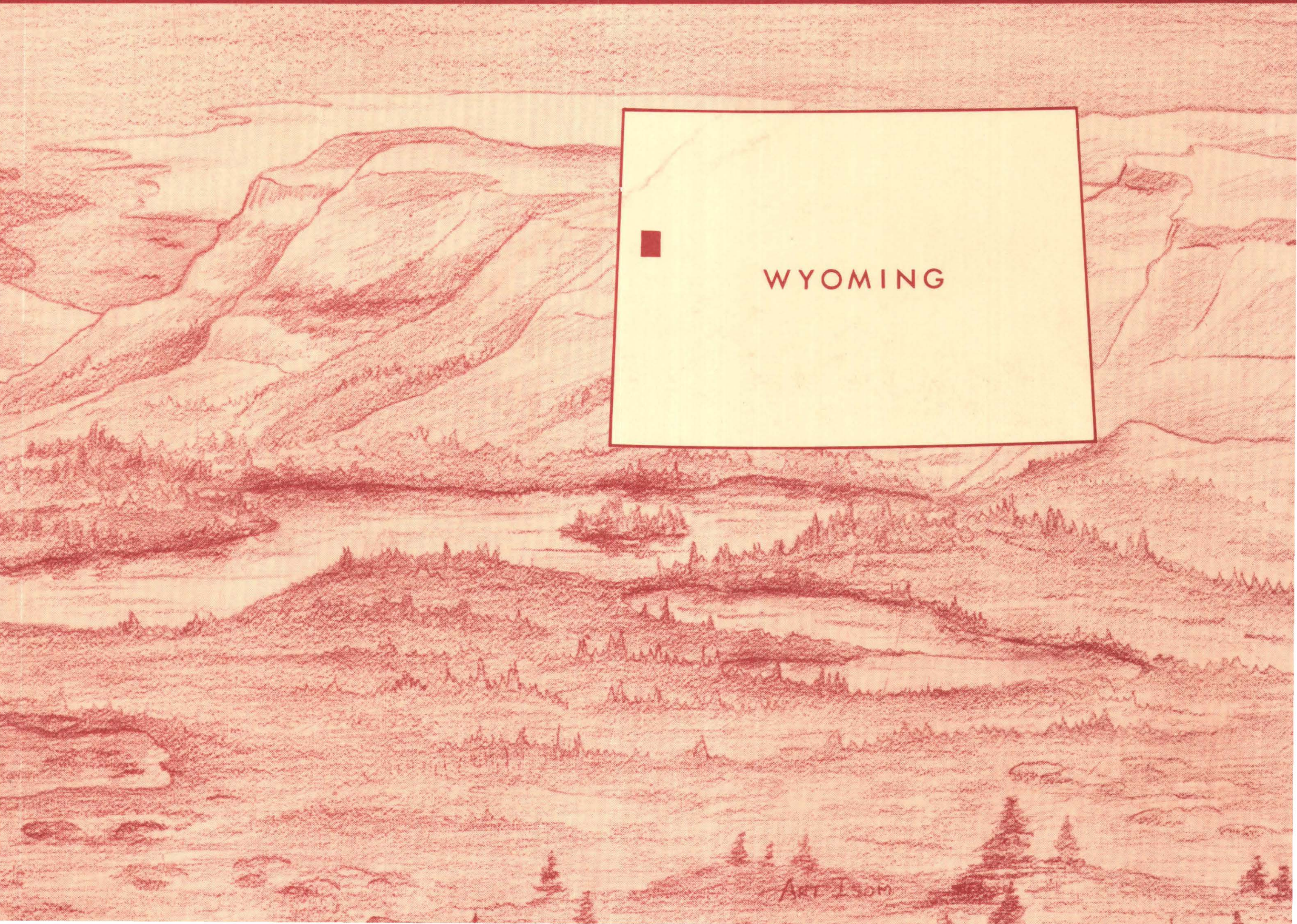
Mineral Resources of the Gros Ventre Wilderness Study Area, Teton and Sublette Counties, Wyoming

U.S. GEOLOGICAL SURVEY BULLETIN 1591



Mineral Resources of the Gros Ventre Wilderness Study Area, Teton and Sublette Counties, Wyoming

By FRANK S. SIMONS, J. DAVID LOVE, WILLIAM R. KEEFER,
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U.S. Geological Survey, and CARL L. BIENIEWSKI
U.S. Bureau of Mines

An evaluation of the mineral
potential of the area

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STUDIES RELATED TO WILDERNESS

DEPARTMENT OF THE INTERIOR
DONALD PAUL HODEL, Secretary

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

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STUDIES RELATED TO WILDERNESS

In accordance with the provisions of the Wilderness Act (Public Law 88-577, September 3, 1964) and the Joint Conference Report on Senate Bill 4, 88th Congress, the U.S. Geological Survey and the U.S. Bureau of Mines have been conducting mineral surveys of areas that are being considered for Wilderness designation. Results of such surveys are submitted to the President and the Congress and are made available to the public. This report presents the results of a geological and mineral survey of the Gros Ventre wilderness study area located in the Bridger-Teton National Forest in west-central Wyoming.

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STUDIES RELATED TO WILDERNESS

Mineral Resources of the Gros Ventre Wilderness Study Area, Teton and Sublette Counties, Wyoming

By Frank S. Simons, J. David Love, William R. Keefer, David S. Harwood, *and* Dolores M. Kulik, U.S. Geological Survey, *and* Carl L. Bieniewski, U.S. Bureau of Mines

SUMMARY

The Gros Ventre wilderness study area has a moderate oil and gas resource potential in possible reservoir rocks beneath the Cache Creek thrust fault in the southwest part of the area, and a high phosphate rock resource potential in the northeast part of the area. The potential for other mineral or energy resources in the area is low. No minerals have been produced from the study area.

The Gros Ventre wilderness study area comprises about 230 mi^2 (600 km^2) of the Bridger-Teton National Forest, directly east of Jackson in west-central Wyoming. The study area covers a large part of the Gros Ventre Range, which rises between the Gros Ventre River to the northeast and the Hoback River to the southwest, both tributary to the Snake River. Figure 1 shows a view of the Gros Ventre Range as drawn for an early geological report on the area. The area was studied for its suitability as a wilderness area by the U.S. Forest Service as part of its roadless area review and evaluation program (RARE II). Nearly all of the area studied and additional roadless land contiguous to the study area, comprising about 448 mi^2 (1,160 km^2), was designated a wilderness area by Congress in 1984. The mineral resources in the area were surveyed in 1974–1977 by the U.S. Geological Survey and the U.S. Bureau of Mines as part of the wilderness suitability studies.

The bedrock of the study area consists of granite, granitic gneiss, and some amphibolite of Precambrian age; a section of Paleozoic sedimentary rocks—mostly limestone, sandstone, shale, and dolomite—about 3,500–4,000 ft (1,000–1,200 m) thick; a section of Mesozoic sedimentary rocks, almost entirely sandstone and shale, about 13,000–15,000 ft (4,000–4,600 m) thick; and a section of Cenozoic (Tertiary) sedimentary rocks that is probably as much as 13,000 ft (4,000 m) thick. Bedrock is concealed by unconsolidated deposits of Quaternary age over about 10-15 percent of the area.

Structurally, the Gros Ventre Range is a northwest-trending, broad anticlinal arch with a gently dipping northeast limb, interrupted by several folds asymmetrical to the southwest and by one fault of substantial displacement, and a steeply dipping, thrust-faulted, structurally complex southwest limb. The central part of the range consists mostly of Paleozoic rocks; Precambrian rocks are restricted to the southwest part, and Mesozoic and consolidated Cenozoic rocks occur for the most part only well down the flanks. Rocks at the southwest crest of the Gros Ventre Range are now 30,000–35,000 ft (9,100–10,700 m) above corresponding rocks in the adjoining Hoback Basin to the southwest; this uplift took place along the northeast-dipping Cache Creek thrust fault and related faults in early Tertiary time.

Areas within the Gros Ventre wilderness study area that have mineral potential are shown on figure 2.

The Little Granite anticline and the possible extension of its northeast flank beneath the Cache Creek thrust fault and inside the southwest border of the study area have a moderate potential for oil and gas (fig. 2). Several formations in the anticline have suitable source and reservoir rocks. No exploratory drilling has been done on the anticline or its flanks near the area. A well drilled in 1977 on Granite Creek about 5 mi (8 km) southwest of the study area had numerous shows of gas. Several other wells, all dry holes, have been drilled within a few miles southwest, south, and southeast of the study area.

No mining has been done in the study area. The only mining nearby has been a small production of coal from the Little Granite Creek coal mine, 3 mi (5 km) south of the study area. Prospecting for minerals has been done in Precambrian rocks of upper Swift and West Dell

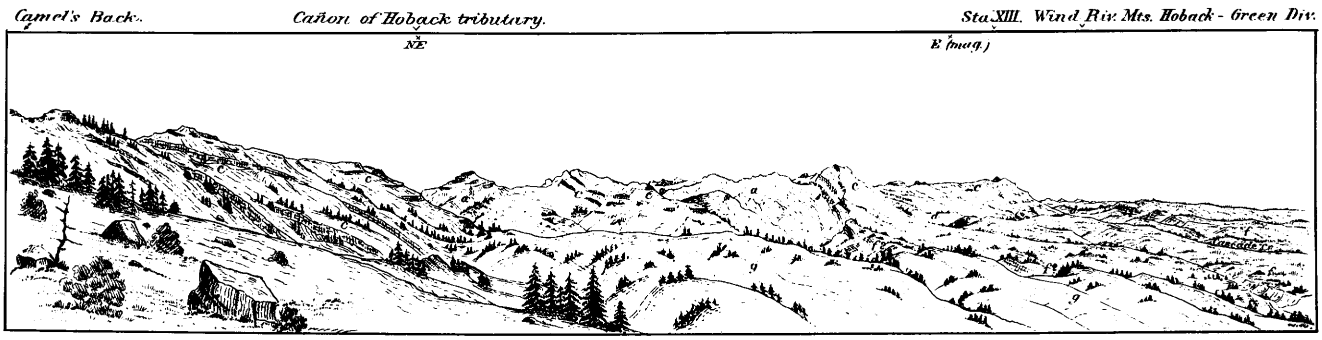


Figure 1. South front of Gros Ventre Range, Wyoming. Rock units indicated are: *a*, Archean (Precambrian of this report); *b*, Silurian (Cambrian, Ordovician, and possibly Devonian of this report); *c*, Carboniferous (possibly includes Devonian of this report); *d*, Jura-Trias; e, Laramie (probably mainly Upper Cretaceous formations of this report); *f*, Tertiary of Hoback's River (probably Pass Peak and Hoback Formations of this report); g, red conglomerate (Hoback Formation of this report). From St. John (1883, pl. 15).

Creeks, in phosphatic rocks of the Phosphoria Formation at several places, in iron-rich shale of the Amsden Formation on the ridge between Box and Bunker Creeks, and in Madison Limestone in upper West Dell Creek.

The other major mineral resource is phosphate rock in the Permian Phosphoria Formation. This formation underlies about 30 mi^2 (80 km^2) on the northeast side of the study area and another 8 mi^2 (20 km^2) on the southeast side (fig. 2). The study area is estimated to contain as much as 500 million tons (450 million t) of phosphate rock, 3 ft (0.9 m) or more thick and containing more than 18 percent P_2O_5. Under economic conditions and mining technology at the time of this study, the phosphate rock resources are classified as identified, inferred, submarginal resources. The phosphate rock also contains uranium, fluorine, chromium, and vanadium that possibly could be recovered as byproducts.

Outcrops of possible coal-bearing strata are restricted to the Frontier Formation, in about 2 mi^2 (5 km^2) of the study area (fig. 2); exposed coal beds are too thin to be of economic interest.

Red shales of the Amsden Formation contain abundant nodules and disseminated grains of hematite (iron oxide) at many places in western Wyoming. The Amsden is widely exposed in the northeastern third of the study area and also forms several isolated outcrops on ridgetops in the western third of the area. Hematite nodules were seen in a few places, but the only concentrations that could possibly provide ore-grade material were in a prospected area on the top of the ridge between Bunker and Box Creeks. The hematite nodules here contain 50 percent iron, but the proportion of nodules in the shale appears to be low and the area of iron-rich shale is too small to be economically significant.

Stream-sediment samples from upper West Fork of Crystal Creek contain anomalous amounts of one or more of the elements lead, nickel, vanadium, and zinc, and one sample from a small outcrop of altered Madison Limestone is anomalously high in all these elements plus molybdenum and silver; however, no mineralized rocks were recognized anywhere else in this drainage and the significance of the stream-sediment samples is not clear. Rubble probably derived from a small vein in Madison Limestone northwest of Pyramid Peak contains anomalous amounts of barium, cobalt, manganese, molybdenum, nickel, and vanadium.

No hot springs are known in the study area, although a few small hot springs occur just south of the area along Granite Creek. The lack of heat sources indicates that the geothermal energy potential is low.

Large quantities of high-quality limestone and dolomite exist in the study area, but they are not considered valuable mineral resources because such rock is readily available nearer to markets in other parts of Wyoming.

INTRODUCTION

The Gros Ventre wilderness study area, in the Gros Ventre Range of northwestern Wyoming, is about 23 mi (37 km) long in an easterly direction by 21 mi (34 km) wide and consists of about 230 mi^2 (600 km^2) within the Bridger-Teton National Forest (fig. 3). Most of the area is in Teton County but about 35 mi^2 (90 km^2) in the southeastern part is in Sublette County.

The terms "Gros Ventre wilderness study area" and "study area" used in this report refer to the area surveyed for mineral resources in 1974–1977. The study area boundary was established by the U.S. Forest Service. As a result of the second roadless area review and evaluation (RARE II) by the Forest Service, done after this mineral survey was finished, a roadless area of 452,600 acres (183,200 ha) (area 4-102) was identified in 1978. In the final environmental statement on RARE II (January 1979), the Forest Service recommended that an

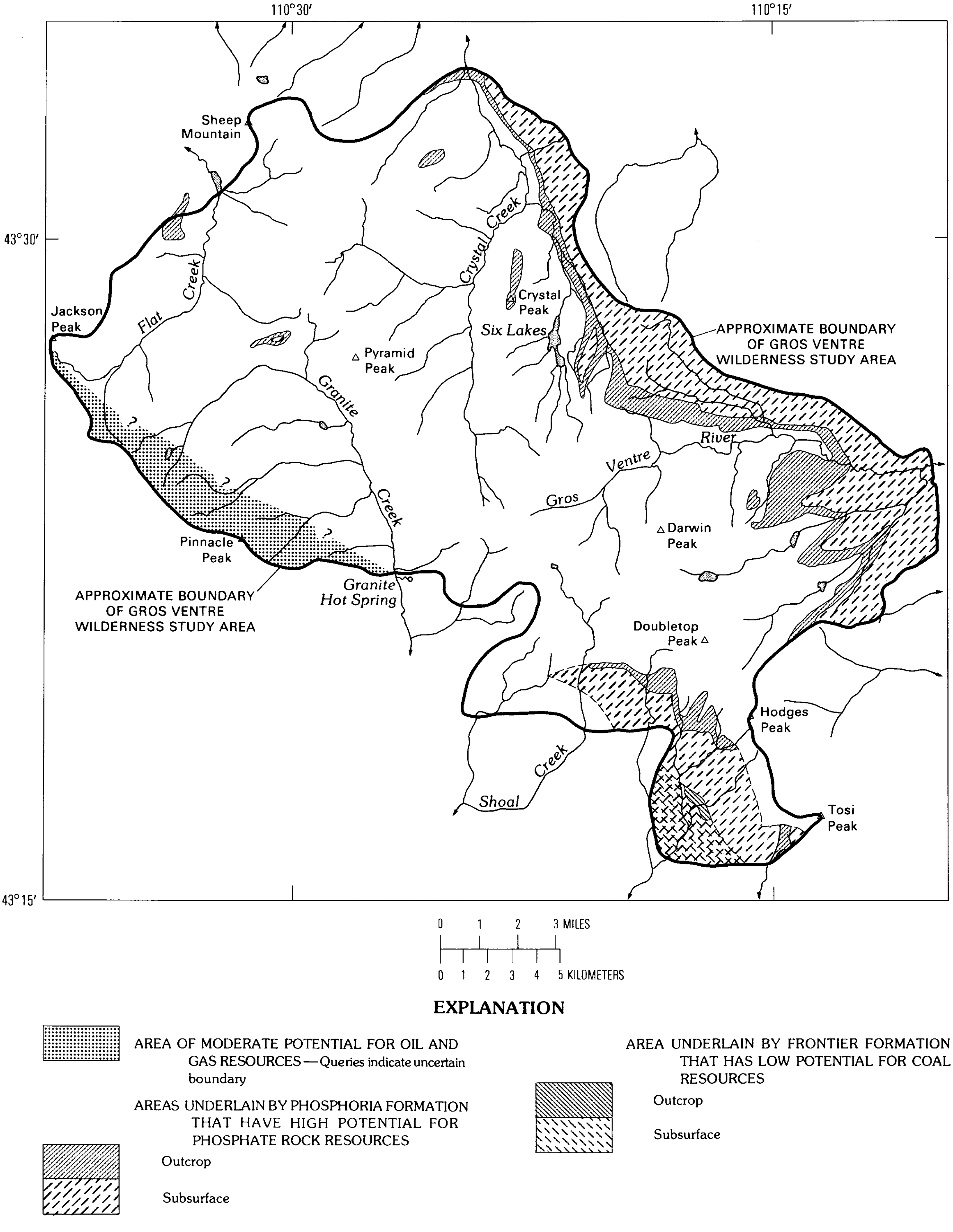


Figure 2. Areas that have potential for mineral resources, Gros Ventre wilderness study area. Degrees of mineral resource potential are from Taylor and Steven (1983).

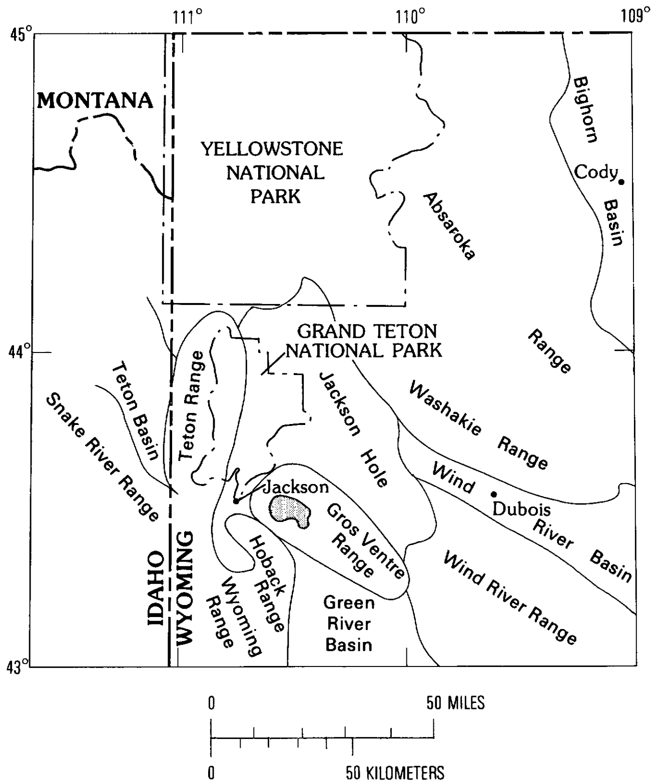


Figure 3. Index map showing location of the Gros Ventre wilderness study area (patterned) and mountain ranges and basins of northwestern Wyoming and adjoining parts of Idaho and Montana.

area of 289,540 acres (117,180 ha) be designated a wilderness area. The Gros Ventre wilderness study area lies entirely within this recommended wilderness area; the principal parts of the recommended wilderness area not included in the study area are in the southwest corner between the crest of the Gros Ventre Range and the Hoback River, along the northeast edge immediately southwest of the Gros Ventre River, and on the west edge between Cache and Nowlin Creeks. In 1984, Congress designated a Gros Ventre Wilderness comprising 287,000 acres (116,000 ha); this area includes almost the entire study area.

The study area is drained mostly by the Gros Ventre River and Flat, Horse, Granite, and Dell Creeks and their tributaries. Altitudes range from 7,000 ft (2,130 m) at Granite Hot Spring to 11,682 ft (3,560 m) on Doubletop Peak. Twenty peaks in the study area exceed 11,000 ft (3,350 m) in altitude, and several dozen others are higher than 10,000 ft (3,050 m). High, steep-walled canyons formed by glaciation transect the area, the more spectacular ones being those of Granite and Crystal Creeks.

The climate of the study area is rigorous, and because of extreme cold and heavy snowfall, access is restricted mainly to July, August, and September. The principal uses of the area are recreation and cattle grazing. No lumbering or mining has been done within the area.

The nearest highways are U.S. 187–189 (where U.S. 187 and 189 join as one) along the Hoback River southwest of the study area and U.S. 26-89-187 (where U.S. 26, 89, and 189 join as one) along the Snake River west of the area. Access to the study area is provided by unpaved roads along Granite, Shoal, and Dell Creeks on the southwest side; along Cache, Sheep, and Flat Creeks on the west side; and along the Gros Ventre River on the northeast side (this road is paved as far as Lower Slide Lake); and from the Green River to Tosi Creek and Darwin Ranch along the east margin (fig. 4). Jackson, Wyo., the largest community near the study area, is about 6 mi (10 km) west of the western boundary. The nearest railhead is at Victor, Idaho, about 24 mi (39 km) west of Jackson.

Previous Work

The first comprehensive geologic work on the study area was by St. John, who as a geologist with the Hayden survey studied and described the stratigraphy and structure of the Gros Ventre Range and the valleys of the Gros Ventre and Hoback Rivers (St. John, 1879, p. 448–456; 1883, p. 208–227). Plate 1 shows areas of later mapping.

In work done by the U.S. Geological Survey for the U.S. Atomic Energy Commission (now Department of Energy) in the early 1950's, Sheldon (1963) estimated uranium and phosphate rock resources in the Permian rocks in western Wyoming, including the Gros Ventre Range.

The mineral resources at two sites located about 5 mi (8 km) from the Gros Ventre study area were studied by the U.S. Bureau of Mines in 1963. One site is north of the study area where Cottonwood Creek enters the Gros Ventre River, and the other is south of the study area where Granite Creek enters the Hoback River; both localities were sites for reservoirs proposed by the U.S. Bureau of Reclamation. According to the unpublished data for this study, potential mineral resources at the sites include coal, phosphate rock, gold, sand, and gravel.

In 1967, the U.S. Bureau of Mines took bulk samples to test for the recovery of gold from the Cretaceous Harebell Formation, Cretaceous and Paleocene Pinyon Conglomerate, and Quaternary alluvium derived from those formations in northwest Wyoming. The nearest of these sampling sites to the study area is about 4 mi (6 km) north of Crystal Creek; neither formation, nor alluvium derived from them, crops out in the study area. The results of the sampling indicated that not enough gold was present to be recovered economically even through improved technology. For most of the

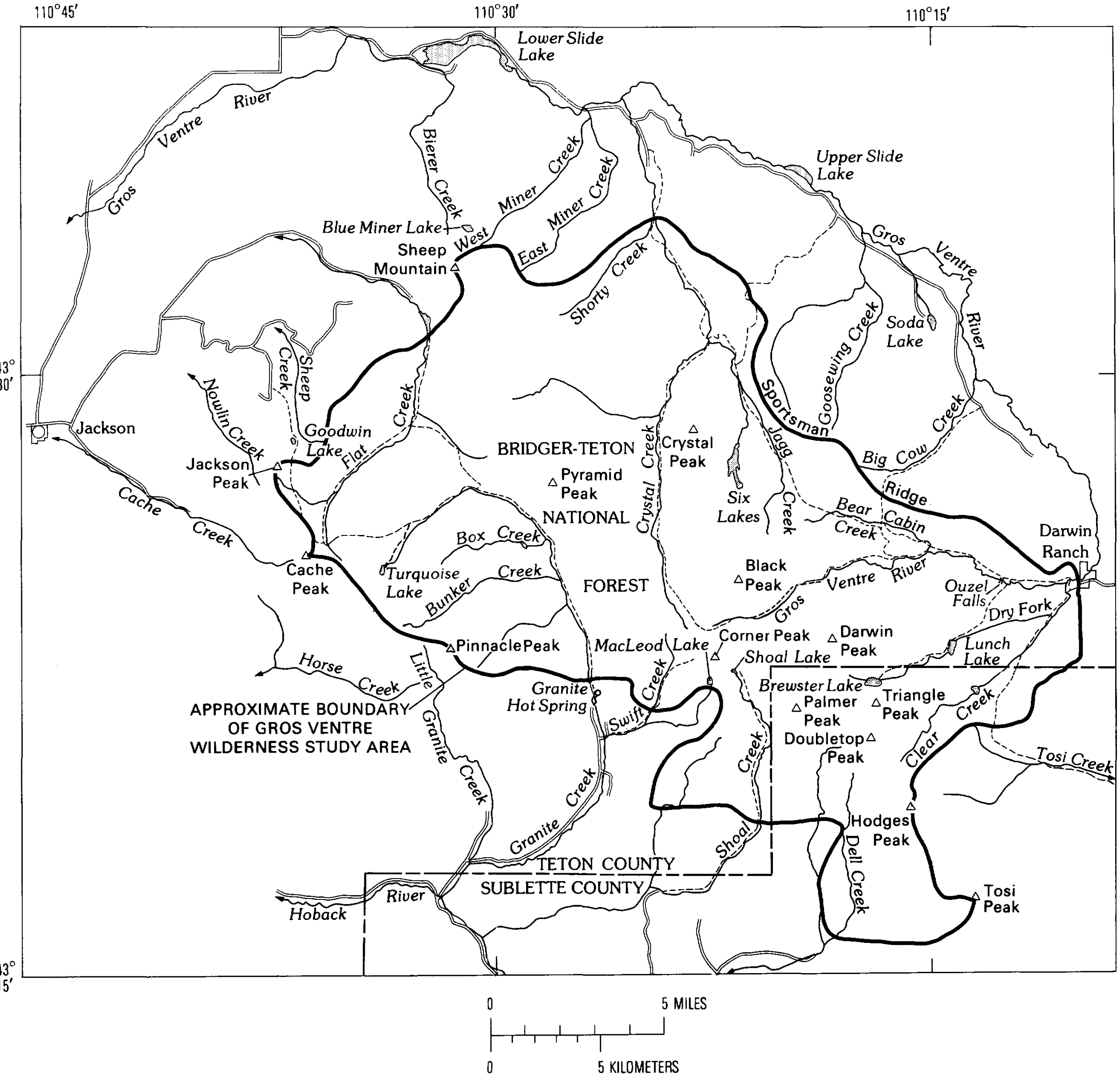


Figure 4. Index map of the Gros Ventre wilderness study area, showing principal geographic features, roads, and main trails.

samples, the gold values ranged from a trace to less than \$0.05 per yd^3 (\$0.07 per m^3) based on a gold price of \$35 per troy ounce.

Present Investigation

This report consists of a geologic and an economic evaluation of the mineral resource potential of the study area. The geologic evaluation consisted of geologic mapping, geochemical sampling, and geophysical surveys, which gave information about various minerals in and near the study area. The U.S. Geological Survey held primary responsibility for this evaluation. The economic evaluation consisted of an examination of mining claims and mineralized areas to determine if extraction of mineral commodities would be profitable under current or future economic conditions. The U.S. Bureau of Mines held primary responsibility for the economic evaluation, although an economic assessment of many mineral commodities was also made informally by the U.S. Geological Survey.

The term "resource," as used in this report, means a concentration of a mineral in such form that its economic extraction is currently or potentially feasible (U.S. Bureau of Mines and U.S. Geological Survey, 1980). Mineral commodities that are or are believed to be in the study area are evaluated according to their potential to constitute a resource. Where sufficient information exists, this probability is given as none, low, moderate, or high (as defined by Taylor and Steven, 1983).

Fieldwork by the U.S. Geological Survey was done during July and August 1975 by F. S. Simons, W. R. Keefer, D. S. Harwood, and J. D. Love, assisted by N. A. Anderson and E. I. Dittmar. Geologic mapping was on 1:24,000-scale topographic quadrangle maps, and geology was compiled on a 1:48,000-scale topographic base map (pl. 1). An aeromagnetic survey of the west half of the study area and vicinity was made in 1965 and of the east half in 1973, and a gravity survey was made in 1975. Geophysical data were interpreted by D. M. Kulik of the U.S. Geological Survey and are shown on plates 1 and 2.

Geochemical sampling was done concurrently with geologic mapping, and 560 rock and stream-sediment samples were collected. In addition, four samples of Precambrian rocks were collected for radiometric age dating. Most analytical work was done in the field under the supervision of W. L. Campbell, U.S. Geological Survey. Uranium and thorium were determined in 66 rocks and 49 stream sediments by H. T. Millard and others, U.S. Geological Survey, Denver, Colo., using a neutron activation method. All sample localities are shown on plate 3.

Prior to fieldwork, the U.S. Bureau of Mines examined land status records of the U.S. Bureau of Land Management in Cheyenne, Wyo., for information about mineral leases and patented claims, and a search was made of records of Sublette and Teton Counties to determine locations of unpatented mining claims. Personnel of the U.S. Forest Service and Wyoming Geological Survey as well as owners of mining claims were contacted regarding mining activity in the area. Fieldwork was conducted during the summer of 1974 and in parts of August 1975 and July 1977. This work consisted of reconnaissance in and around the area, examination of mining claims and mineralized areas, and sampling of prospect workings, rock formations, and stream sediments. Warren Frush assisted in most of the fieldwork, and Lowell Patten and R. Craig Smith of the U.S. Bureau of Mines helped in 1975 and 1977, respectively.

Acknowledgments

The cooperation of officials of the U.S. Forest Service, U.S. Bureau of Land Management, Wyoming Geological Survey, Sublette County, and Teton County is gratefully acknowledged. The investigation also benefited greatly from information supplied by local residents and mining-claim owners. Special thanks are extended to Dr. Don MacLeod of Jackson, Wyo., for valuable information about the area and its history of mining activity.

GEOLOGY

By J. David Love, Frank S. Simons
William R. Keefer, and David S. Harwood
U.S. Geological Survey

Bedrock of the Gros Ventre wilderness study area (called hereafter the "study area") consists mainly of Paleozoic sedimentary rocks; Precambrian granitic and metamorphic rocks underlie about 9 percent of the study area, and Mesozoic sedimentary rocks underlie about 12 percent of the study area. Unconsolidated Cenozoic deposits—alluvium, talus, glacial deposits, and landslide debris—cover 10–15 percent of the study area. Plate 1 shows the surface geology of the study area and the immediately adjacent area.

Precambrian Rocks

Precambrian rocks crop out in two areas along the southwestern boundary of the study area—one near Turquoise Lake and the other around Shoal Lake—and in a very small area south of Sheep Mountain. The total area of the outcrop is about 21 mi^2 (54 km^2). The Precambrian terranes contain a wide variety of gneisses, which occur either as inclusions in granite or as extensive tracts pervasively intruded by granitic dikes and sills.

Biotite-hornblende gneiss (hgn) and biotite gneiss (bgn) near Turquoise Lake are the oldest Precambrian units in the study area. The biotite-hornblende gneiss is a distinctly layered black and white amphibolitic gneiss that contains small bodies of serpentinite (s) and hornblende-clinopyroxene-plagioclase gabbro. The biotite gneiss is a well-layered to streaky rock composed of plagioclase, quartz, and biotite. It contains layers rich in muscovite, biotite, and sericitized porphyroblasts of andalusite. The gneisses are intruded by strongly foliated granitic gneiss (gn) composed of quartz, plagioclase, microcline, biotite, chlorite, and various accessory minerals. Quartz of the gneiss has a bluish cast. This older sequence of orthogneisses and paragneisses is intruded, in turn, by red biotite granite (bg) and by gray biotite-muscovite granite (bmg). The biotite granite is red, pink, salmon, or pinkish gray; is medium to coarse grained and locally pegmatitic; and is composed of about equal amounts of quartz, microcline, and plagioclase, and smaller amounts of biotite, epidote, apatite, sphene, and zircon.

The biotite-muscovite granite is a gray, medium-grained, equigranular to somewhat porphyritic rock composed of quartz, plagioclase, microcline, biotite, muscovite, and the same accessory minerals as the biotite granite. Red biotite granite predominates in the Precambrian terrane near Shoal Lake, but occurs only as a few gently dipping sheets and numerous smaller dikes in the older gneiss sequence near Turquoise Lake. Small, widely scattered diabase dikes intruded the older gneiss sequence before the intrusion of the granites.

Precambrian rocks are cut by faults of several different trends. A major west-northwest-trending fault system displays intense fracturing and rusty staining, particularly on the ridge north of MacLeod Lake. Some north-trending fault zones are highly silicified, and pebbles of silicified breccia from these faults occur in the Cambrian Flathead Sandstone. Many of the north- and northeast-trending faults contain magnetite and (or) hematite and later, east-trending faults contain widely scattered traces of green copper minerals.

Paleozoic Rocks

Lithologic characteristics of the Paleozoic sedimentary rocks in the study area are summarized in table 1, and additional details are given in the text that follows.

Table 1. Summary of geologic data on Paleozoic sedimentary rocks of the Gros Ventre wilderness study area

Formation	Age	Lithology	Measured sections in or near study area		
			Location	Thickness (in feet)	Source of data
Phosphoria Formation and related strata.	Permian-------	Interbedded chert, shale and mudstone, sandstone, dolomite, limestone, phosphorite, and phosphatic shale.	Bierer Creek---------	110+	Swenson (1949, p. 25).
			Darwin Peak----------	174	Sheldon (1957, p. 114).
			Flat Creek-----------	196	Foster (1947, p. 1560-1561).
			Flat Creek-----------	189	Sheldon (1957, p. 169-178).
			Crystal Creek--------	183	Sheldon (1957, p. 114).
DISCONFORMITY			Lower Slide Lake-----	199.5	Wanless and others (1955, p. 36).
			Tosi Creek-----------	154.5	Wanless and others (1955, p. 36).
			Tosi Creek-----------	219	Sheldon (1957, p. 114).
Tensleep Sandstone and Amsden Formation, undivided.	Pennsylvanian and Mississippian.	Sandstone, shale and hematitic shale, limestone, and dolomite.	Flat Creek-----------	350	Swenson (1949, p. 22-23).
			Sheep Creek:		Foster (1947, p. 1557).
			Amsden-------------	299	Bachrach (1956).
			Flat Creek:		Foster (1947, p. 1558).
			Tensleep-----------	298	Bachrach (1956).
UNCONFORMITY			Granite Hot Spring:		Wanless and others (1955, p. 32).
			Darwin Member------	88	
Madison Limestone---	Mississippian-	Limestone, cherty limestone; some dolomite.	Flat Creek-----------	475+	C. M. Love (1968, p. 89-91).
			Granite Hot Spring---	778	Wanless and others (1955, p. 20).
UNCONFORMITY			Sheep Mountain-------	About 1,000	Swenson (1949, p. 19).
			Sheep Mountain?------	1,000	Foster (1947, p. 1555).
Darby Formation-----	Late Devonian.	Thin-bedded dolomite and limestone, variegated shale; some sandstone.	Upper Flat Creek-----	319	C. M. Love (1968, p. 49, 91-94).
			Granite Creek--------	340	Benson (1966, p. 2582).
			Granite Falls--------	312	Foster (1947, p. 1552-1553).
UNCONFORMITY			Sheep Mountain-------	260	Swenson (1949, p. 17)
Bighorn Dolomite----	Ordovician----	Massive dolomite; thin bedded at top.	Bunker Creek---------	445	C. M. Love (1968, p. 46, 95).
			Horse Creek:		Wanless and others (1955, p. 14).
			Massive part only--	288	
			Sheep Creek----------	300-400	Foster (1947, p. 1549).
UNCONFORMITY			Sheep Mountain-------	290	Swenson (1949, p. 12-13).
Gallatin Limestone--	Late Cambrian.	Mottled limestone; thin shale near middle.	Bunker Creek---------	240	C. M. Love (1968, p. 41-42, 96-97).
			Granite Falls--------	181	Foster (1947, p. 1541).
				125+	Shaw and DeLand (1955, p. 39).
UNCONFORMITY?			Sheep Mountain-------	190	Swenson (1949, p. 11).
Gros Ventre Formation.	Middle Cambrian.	Green shale at top and bottom; mottled limestone near middle.	Doubletop Peak-------	769	Blackwelder (1918, p. 418-419).
			Granite Falls--------	586	Foster (1947, p. 1542).
			Sheep Mountain-------	630	Swenson (1949, p. 9-11).
			Upper Flat Creek-----	763	C. M. Love (1968, p. 98-101).
Flathead Sandstone--	Middle Cambrian.	Sandstone, grit, conglomerate; some thin shale.	Upper Flat Creek-----	288	C. M. Love (1968, p. 30-31, 101-103).
UNCONFORMITY			Little Granite Creek-	303	Wanless and others (1955, p. 9-11).
			Sheep Mountain-------	180	Swenson (1949, p. 8).
			Doubletop Peak-------	About 200	Blackwelder (1918, p. 419).

Flathead Sandstone.—The Flathead Sandstone (Middle Cambrian) consists of 200-300 ft (60-90 m) of white, tan, brown, and maroon crossbedded sandstone which is locally conglomeratic. Thin partings of green micaceous shale occur in the upper part. The best exposures are in upper Gros Ventre River valley and upper Flat Creek. Locally the formation forms cliffs, but in most places it is partly concealed by its own talus. The Flathead is unconformable on weathered Precambrian granite.

Gros Ventre Formation.—The Gros Ventre Formation (Middle Cambrian) consists of three members, from oldest to youngest, the Wolsey Shale, Death Canyon Limestone, and Park Shale. The Wolsey is green to gray-green, highly fissile, micaceous shale about 100 ft (30 m) thick; locally it contains abundant small brachiopods. The Death Canyon is a conspicuous cliff-former of hard, blue-gray to dark-gray, fine-grained, thin-bedded limestone, mottled with irregular blotches of brown and tan limestone. At its base is a distinctive bed of brown-weathering dolomite. A thin, green, fissile, micaceous shale in the middle contains abundant trilobites. Total thickness of the Death Canyon is 300-370 ft (90-115 m). The Park Shale Member consists of 150-350 ft (45-105 m) of green to gray, highly fissile, micaceous shale. Some limestones and "edgewise" conglomerates of limestone fragments are present. At the base are numerous algal heads as much as 5 ft (1.5 m) in diameter. The Gros Ventre Formation is best exposed on Palmer Peak.

Gallatin Limestone.—The Gallatin Limestone (Upper Cambrian) is locally divisible into three units: a lower limestone unit (Du Noir Limestone equivalent), a middle, green, fissile shale unit (Dry Creek Shale equivalent), and an upper limestone unit (Open Door Limestone equivalent; Shaw and Deland, 1955). The formation is 200-250 ft (60-75 m) thick. The limestone units are gray to blue gray, massive, and fine grained, and are conspicuously mottled in brown and yellow. They contain abundant "edgewise" conglomerate and closely resemble the Death Canyon Limestone Member of the Gros Ventre Formation. The upper contact in many places is in the lower part of a cliff consisting mainly of Bighorn Dolomite. The Gallatin locally forms cliffs, but in most places it is concealed beneath talus and rockfalls from the overlying Bighorn Dolomite. The formation is well exposed west of Darwin Peak, on the divides between upper Gros Ventre River and Crystal Creek and between Flat and Granite Creeks, and at the head of Dry Fork of Clear Creek.

Bighorn Dolomite.—The Bighorn Dolomite (Ordovician) is divisible into two units, a lower light-gray, mottled, massive, fine-grained dolomite 280-350 ft (85-105 m) thick and an upper, thin-bedded, white to pale-gray dolomite (Leigh Dolomite Member) 30-100 ft (9-30 m) thick. The Bighorn weathers to very rough pitted surfaces and forms conspicuous white cliffs that show well-developed jointing perpendicular to the bedding. This jointing makes the Bighorn especially prone to rock falls; underlying formations in many places, such as in upper Crystal Creek, are covered by enormous accumulations of talus of Bighorn Dolomite fragments.

Darby Formation.—The Darby Formation (Upper Devonian) consists of 300-350 ft (90-105 m) of interbedded, thin-bedded, brownish-gray dolomite and limestone; yellow, tan, and green shale, some showing conspicuous ripple marks; and minor brown sandstone. Some of the carbonate rocks have a petroliferous odor. Locally, near the top, is a bed of massive brown dolomite 50-60 ft (15 to 18 m) thick that weathers to a distinctive knobby surface. Variegated shales are typical of the top of the formation. The Darby forms a slope between cliffs of Bighorn Dolomite below and Madison Limestone above; it generally is poorly exposed, and in many places is completely concealed beneath talus of Madison Limestone.

Madison Limestone.—The Madison Limestone (Mississippian) as mapped may include in its upper part rocks equivalent to the Brazer Limestone of Utah and to the lower Amsden red shale sequence of Wanless and others (1955, p. 30-31). The Madison Limestone consists of 800-1,100 ft (240 to 330 m) of thick- to thin-bedded, light- to dark-gray, fossiliferous limestone, cherty to locally very cherty limestone, and minor dolomite. Some limestone has a petroliferous odor. The Madison is the most widespread formation in the study area, the principal cliff-former, and the formation in which the rugged topography, alpine scenery, and extensive upland surfaces of much of the high Gros Ventre Range are best developed. Complete exposures of the formation in steep to cliffy terrain occur in many places, particularly on Black, Darwin, and Triangle Peaks and in upper Crystal Creek.

Amsden Formation and Tensleep Sandstone, undivided.—The Amsden Formation (Pennsylvanian and Mississippian) and Tensleep Sandstone (Pennsylvanian) appear as a single lithologic unit on plate 1 because their contact could not be consistently located. The map unit comprises, from bottom to top, the Darwin Sandstone Member of the Amsden Formation (light-brown, crossbedded sandstone), 50-100 ft (15-30 m) thick; the unnamed upper part of the Amsden Formation (interbedded red shale and sandstone, gray limestone and dolomite which locally contain large chert concretions, and green to red hematitic shale), 200-300 ft (60-90 m) thick; and the Tensleep Sandstone (light-gray to white, fine- to medium-grained, crossbedded sandstone and light-gray, fine-grained cherty dolomite), 300-350 ft (90-105 m) thick. Some shale beds in the Amsden have abundant small pellets of hematite through a thickness of several feet; these contain as much as 20 percent iron. The Darwin is commonly well exposed at the top of the

Madison Limestone cliff; the remainder of the Amsden is poorly exposed but is easily recognized by its red hematitic shales; and the Tensleep forms conspicuous cliffs and talus slopes. Many large landslides in the Gros Ventre Range have originated by sliding of resistant Tensleep Sandstone over weak shales of the Amsden.

Phosphoria Formation and related strata.—The Phosphoria Formation and related strata (Permian) is lithologically the most diverse sedimentary unit in the study area. For example, although it is in most places less than 200 ft (60 m) thick, the map unit contains sandstone, in part glauconitic, a thin basal conglomerate, siltstone, mudstone, black shale, dolomite and limestone, abundant chert including "tubular" chert (Blackwelder, 1911), and phosphorite and phosphatic shale. On Flat Creek about 3 mi (5 km) west of Sheep Mountain, these rocks display, in a section 189 ft (58 m) thick, all five of the lithologic units proposed by Sheldon (1957) as subdivisions of the Permian in northwestern Wyoming; in this section the Phosphoria and related strata are composed of about 35 percent chert, 20 percent fine-grained clastic rocks, 17.5 percent sandstone, 15.5 percent dolomite, 7.5 percent limestone, 3 percent phosphorite, and 1.5 percent miscellaneous carbonate rocks and include the Park City Formation and Shedhorn Sandstone as well as the Phosphoria.

The Phosphoria Formation and related strata are poorly exposed in most places and support little vegetation; however, they are well exposed where they cross ridge crests, and the thicker chert beds in the upper part form low cliffs throughout the outcrop area. The most extensive exposures are along the south side of Bear Cabin Creek and on lower Crystal Creek (see pl. 4, map D). The map unit also is well exposed on the ridges between Dry Fork of Clear Creek and Clear Creek and between Clear and Tosi Creeks. Tubular chert near the top of the unit is spectacularly displayed on Clear Creek 2.3 mi (3.7 km) southwest of Darwin Ranch. The upper chert-rich part of the Phosphoria tends to slump where the underlying less resistant rocks have been eroded to steep slopes, and huge detached blocks of chert as much as several hundred feet long occur on several ridges, particularly those along Clear Creek.

Phosphate-bearing rocks in the Phosphoria Formation are discussed in more detail in the section on mineral resources.

Mesozoic Rocks

Lithologic characteristics of the Mesozoic sedimentary rocks in the study area are summarized in table 2, and additional details are given in the text that follows. Data obtained during our study are supplemented by information derived from Foster (1947, p. 1562–1588); Love, Johnson, and others (1945); Love, Tourtelot and others (1945); Love, Duncan, and others (1948); Love, Keefer, and others (1951); Wanless and others (1955, p. 39-72); and Love (1956a, p. 76–83).

Dinwoody Formation.—The Dinwoody Formation (Lower Triassic) ranges in thickness from 200 ft (60 m) to more than 300 ft (90 m). Wanless and others (1955), however, reported only 100 ft (30 m) on Dell Creek. This anomalously thin section has not been confirmed by later studies. Typical lithology is tan, yellowish, pale-green, and gray dolomitic siltstone, mudstone, and very fine grained sandstone. Outcrops weather to a characteristic brown color and the rocks break into thin, hard, irregular slabs.

The base of the Dinwoody Formation is marked by a sharp lithologic change from cherty dolomite below to dolomitic siltstone above. The contact between the Dinwoody and the overlying Chugwater Formation is difficult to pick because a sequence of tan, red, and gray siltstones lies between the typical tawny Dinwoody Formation and the red Chugwater Formation. Many pelecypods are present along bedding planes.

The Dinwoody is extensively exposed along the northern flank of the Gros Ventre Range and in a few places along the southern flank near the southeastern margin of the study area. The best exposures in the study area are on the ridge just east of Six Lakes, where the Dinwoody has a massive cliff-forming sandstone about 25 ft (8 m) thick at its base and contains much fine-grained, light-gray to brownish-gray, crossbedded, dolomitic sandstone. The formation also is well exposed on the south side of Tepee Creek near its head.

Chugwater Formation.—The distribution of the Chugwater Formation (Triassic) in the study area is about the same as that of the Dinwoody Formation. The thickness ranges from about 1,100–1,200 ft (335–366 m) on the flanks of the Gros Ventre Range to more than 1,700 ft (518 m) in the thrust plates of the overthrust belt along the southwest margin of the study area.

The Chugwater Formation is subdivided into four members: Red Peak at the base; Alcova Limestone, Crow Mountain Sandstone, and Popo Agie at the top.

The Red Peak Member, 850–950 ft (260–290 m) thick, consists of red gypsiferous siltstone and fine-grained silty red sandstone with some red shale partings. Thin beds of white gypsum form conspicuous bands on the bright-red slopes. Several thin beds of gray silty limestone or limy siltstone are near the top.

The Alcova Limestone Member ranges in thickness from 5-40 ft (1.5–12 m) and consists of gray and purple, laminated, impure, hard limestone with interbeds of red and gray siltstone and white gypsum. The upper limestone bed is widely persistent and provides an excellent stratigraphic marker. In many places, the Alcova is slightly petroliferous.

Table 2. Summary of geologic data on Mesozoic sedimentary rocks of the Gros Ventre wilderness study area

Formation	Age	Lithology	Measured sections in or near study area		
			Location	Thickness (in feet)	Source of data
Harebell Formation--	Late Cretaceous.	Coarse sandstone, grit, and sandstone-chert conglomerate; some shale.	Dell Creek---------------	2,150+ (estimated)	This report.
UNCONFORMITY					
Mesaverde Formation--	Late Cretaceous.	Light-colored, fine- to medium-grained, crossbedded sandstone; some variegated shale; thin coal beds.	Dell Creek---------------	500+ (estimated)	This report.
Lenticular sandstone and shale sequence.	Late Cretaceous.	Gray and tan, thick, lenticular, fine-grained sandstone, gray shale and shaly sandstone, some coal, carbonaceous shale, and marlstone.	Dry Cottonwood Creek----- Fish Creek---------------	2,273 2,415	Love, Duncan, and others (1948, p. 14-17). Love, Duncan, and others (1948, p. 27-28).
Coaly sequence-------	Late Cretaceous.	Gray and brown sandstone, gray shale, numerous coal beds.	Bacon Ridge--------------	1,163	Love, Duncan, and others (1948, p. 37-39).
Bacon Ridge Sandstone.	Late Cretaceous.	Light-gray, fine- to medium-grained, massive, fossiliferous sandstone, shale near top; pearl-gray marker zone 10-50 ft thick (coal, bentonite, tuff, porcellanite, and shale) about 75-200 ft above base.	Bacon Ridge-------------- Fish Creek---------------	955.5 925.5	Love, Duncan, and others (1948, p. 40-41). Love, Duncan, and others (1948, p. 32-34).
Cody Shale-----------	Late Cretaceous.	Gray to dark-gray shale, shaly and fine-grained sandstone; some glauconitic sandstone and a few thin limestone beds; prominently banded.	Upper Slide Lake---------	2,211	Love, Duncan, and others (1948, p. 5-8).
Frontier Formation.	Late Cretaceous.	Gray to tan, fine- to medium-grained sandstone, shale; some black shale, coaly shale, porcellanite, tuff, and bentonite.	Upper Slide Lake--------- Bacon Ridge--------------	1,032 1,099	Love, Duncan, and others (1948, p. 8-11). Love, Duncan, and others (1948, p. 41-43).
Mowry and Thermopolis Shales, undivided.	Early Cretaceous.	Dark siliceous shale, black shale, gray sandstone, some bentonite.	Upper Slide Lake:		
			Mowry Shale------------	1,067	Foster (1947, p. 1573-1575).
			Slate Creek:		
			Thermopolis Shale, units 9 to 13.	228	Foster (1947, p. 1571-1572).
			Lower Slide Lake:		
			Mowry Shale------------	635-685	Love, Keefer, and others (1951).
			Muddy Sandstone Member-	45	
			Thermopolis Shale------	155	
			Bacon Ridge:		
			Mowry Shale------------	635	Love, Duncan, and others (1948, p. 43-44).
			Muddy Sandstone Member-	72	

Cloverly and Morrison(?) Formations, undivided.	Early Cretaceous and Late Jurassic.	Variegated shale, sandstone, fine-grained limestone.	Slate Creek:		
			Thermopolis Shale, units 1-8.	90	Foster (1947, p. 1571-1572).
			Lower Slide Lake:		
			Cloverly Formation-----	237	Foster (1947, p. 1568)
			Stump Sandstone, units 7-14.	192	Foster (1947, p. 1567).
			Lower Slide Lake---------	432	Wanless and others (1955, p. 54).
			Gros Ventre River (Red Hills):		
			Cloverly Formation-----	337-364	Foster (1947, p. 1569).
			Lower Slide Lake---------	660	Love (1956a, p. 76)
			Bacon Ridge--------------	628.5	Love, Duncan, and others (1948, p. 44-47).
LOCAL UNCONFORMITY					
Sundance Formation---	Late and Middle Jurassic.	Gray shale, greenish-gray sandstone; some variegated shale and sandstone, oolitic limestone.	Lower Slide Lake:		
			Stump Sandstone, units 1-6.	156	Foster (1947, p. 1567).
			Twin Creek Formation, units 4-13.	423	Foster (1947, p. 1565-1566).
			Lower Slide Lake:		Wanless and others (1955, p. 52).
			Stump Formation--------	134	
			Gros Ventre Range:		
			Twin Creek Formation---	378	Wanless and others (1955, p. 50).
			Lower Slide Lake:		
			"Upper Sundance"-------	100-110	Love, Keefer, and others (1951).
			"Lower Sundance"-------	440	
UNCONFORMITY					
Gypsum Spring Formation.	Middle Jurassic.	Gray limestone and limestone breccia, red and gray shale.	Gros Ventre River:		
			"Twin Creek Limestone," lower part.	±50	Foster (1947, p. 1566).
			Lower Slide Lake---------	46	Wanless and others (1955, p. 49).
			Lower Slide Lake---------	48+	Love, Keefer, and others (1951).
UNCONFORMITY					
Nugget Sandstone-----	Jurassic(?) and Triassic(?).	Bright orange to buff, fine- to medium-grained massive crossbedded sandstone.	Northern Gros Ventre Range.	260	Swenson (1949, p. 32).
			Dell Creek---------------	325	Wanless and others (1955, p. 47-48).
			Crystal Creek------------	150	Love, Keefer, and others (1951).
			Lower Slide Lake---------	120	Love, Keefer, and others (1951).
UNCONFORMITY					
Chugwater Formation--	Triassic------	Bright-red, thin-bedded siltstone and shale; fine-grained sandstone; thin gray and purple limestone.	Lower Slide Lake:		
			Thaynes Formation------	400	Newell and Kummel (1942, p. 967-969).
			Woodside Formation-----	553	
			Gros Ventre River:		
			Woodside Formation-----	553	Foster (1947, p. 1563).
			Dell Creek:		
			Woodside Formation-----	639	Wanless and others (1955, p. 41).
			Gros Ventre River--------	800+	Swenson (1949, p. 30).
			Lower Slide Lake---------	1210	Love, Keefer, and others (1951)
Dinwoody Formation---	Early Triassic.	Brown to gray, thin-bedded siltstone and sandstone; some shale and fossiliferous limestone.	Lower Slide Lake---------	235-237	Newell and Kummel (1942, p. 969).
			Bierer Creek-------------	200	Swenson (1949, p. 27).
			Crystal Creek------------	200	Swenson (1949, p. 27).
			Gros Ventre River--------	235	Foster (1947, p. 1562).
			Lower Slide Lake---------	230	Love, Keefer, and others (1951).

The Crow Mountain Sandstone Member overlies the Alcova and consists of red to salmon-pink, soft, porous sandstone that contains large frosted and rounded quartz grains in a finer matrix. The sandstone grades upward into shale so the upper contact is arbitrary; the thickness is about 50 ft (15 m). The Crow Mountain Sandstone Member yields oil in several fields 50–75 mi (80–120 km) to the east and northeast of the study area.

The overlying Popo Agie Member consists of 100–200 ft (30–60 m) of ocher and purple claystones, red shales, purple lenticular limestone pellet conglomerates, and red siltstones.

The bright-red Chugwater Formation is the most conspicuous formation in the study area, and together with the overlying bright-orange Nugget Sandstone forms an unbroken line of colorful cliffs and steep slopes about 17 mi (27 km) long on the northeast edge of the study area along Crystal, Jagg, and Bear Cabin Creeks and the Gros Ventre River.

Nugget Sandstone.—The Nugget Sandstone (Jurassic? and Triassic?) has about the same distribution in the study area as the Chugwater Formation. The Nugget ranges in thickness from 375 ft (114 m) in the southwesternmost sections in the thrust belt to 125 ft (38 m) on the north flank of the Gros Ventre Range. The formation wedges out abruptly 6 mi (10 km) still farther north. One of the best sections is on Dell Creek in the southeastern part of the study area.

The Nugget consists of orange-buff to gray, massive sandstone that is predominantly fine grained but which contains scattered large frosted and rounded grains of quartz. Commonly it is crossbedded, soft, porous, and permeable, and crops out in conspicuous cliffs on both sides of the range.

The age of the Nugget is uncertain because it contains no fossils or other datable materials. The physical relations of the Nugget and Chugwater, however, in central Wyoming suggest that the Nugget is entirely of Triassic age (Love, 1957).

The Nugget Sandstone is one of the most important oil- and gas-bearing formations in western Wyoming and so is of more than ordinary interest in the Gros Ventre study area. Azurite, malachite, and silver are present in several places where the Nugget is bleached gray on crests of anticlines 10 mi (16 km) and more southwest of the area (Love and Antweiler, 1973). Although much of the Dell Creek section is bleached, no copper minerals were seen there.

Gypsum Spring Formation.—The Gypsum Spring Formation (Middle Jurassic) consists of 50–150 ft (15–45 m) of red shale, slabby gray dolomite and limestone, and white gypsum. In outcrops, all the gypsum has been leached out of the formation and beds of brecciated carbonate rocks are the chief evidence that it once was present. In subsurface sections, the gypsum (and (or) anhydrite) is invariably present, most of it in one basal bed 20–40 ft (6–12 m) thick. The formation is present in broad exposures along the northeastern edge of the study area and in a few small outcrops on the southern and southwestern flanks of the Gros Ventre Range.

Sundance Formation.—The Sundance Formation (Middle and Upper Jurassic) has about the same areal distribution as the Gypsum Spring Formation. It is readily divisible into two mappable sequences, the nonglauconitic part commonly called "lower Sundance" and the glauconitic part, the "upper Sundance." The lower sequence is 450–550 ft (137–168 m) thick on the north side of the Gros Ventre Range and nearly 800 ft (244 m) thick on the south side of the range, in the overthrust sheets. The rocks comprise gray, limy, plastic to splintery shale, clayey limestone, hard oolitic limestone, and one or more zones of red, soft, plastic shale. Marine fossils, chiefly pelecypods, are abundant at many horizons and indicate a Middle and Late Jurassic age. The incompetent shales are the sites of major landslides in the region.

The upper Sundance strata are 75–140 ft (23–43 m) thick and consist of gray, buff, and green, highly glauconitic, very limy sandstone, and a few thin beds of shale and limestone. Marine fossils are abundant throughout the sequence. The age is Late Jurassic.

Morrison(?) and Cloverly Formations, undivided.—The Morrison(?) Formation (Upper Jurassic) and Cloverly Formation (Lower Cretaceous) are described and mapped as a single unit because no reliable basis for subdivision was found. No fossils of Morrison age have been reported from the area around Jackson Hole, but lithologic units and fossils characteristic of the Cloverly make possible a good correlation of the upper part of the sequence with that formation in central and northern Wyoming. Outcrops are confined to the northeastern and southeastern margins of the study area. The thickness ranges from 600–700 ft (183–213 m).

Three distinctive lithologic sequences are present; the thickness of each differs from one place to another, and the boundaries between the lower two are locally gradational. The lower sequence, 185–250 ft (56–76 m) thick, is buff and gray, chloritic, in part sparkly (quartz crystal) sandstone interbedded with red, green, and gray siltstone and claystone. The overlying sequence, 290–345 ft (88–105 m) thick, is characterized by variegated red, gray, lilac, and pink claystone and thin beds of hard, nodular, dense, cream-colored limestone. Outcrops of the lilac claystone have a puffy appearance because of swelling of bentonitic layers. A 10–20 ft (3–6 m) unit of white, hard, sublithographic limestone in the upper part of the lilac claystone is an excellent horizon-marker, and contains abundant Lower Cretaceous nonmarine invertebrate fossils. The uppermost sequence, 100–150 ft (30–46 m) thick, is commonly known as the rusty beds member of the Cloverly. It consists chiefly of olive-green, gray, and buff, thin-bedded sandstones that weather with a conspicuous rusty color and contain abundant fucoidal markings on bedding planes. These sandstones are interbedded with dark-gray to black silty shales. At some localities a massive sparkly sandstone is present at the base.

The rusty beds form a conspicuous dark-brown ragged cliff throughout most of the area of outcrop, whereas the underlying variegated strata commonly form slopes. The incompetent, bentonitic, lilac claystones are a source of many landslides in the region.

The contact between the Morrison(?) and Cloverly Formations and the underlying Sundance Formation is marked in most places by a change from marine, highly glauconitic sandstone below to nonglauconitic, silty, probably nonmarine sandstone and claystone above. This sequence has yielded major oil and gas production in parts of Wyoming northeast, east, and south of the study area.

Thermopolis and Mowry Shales, undivided.—The Thermopolis and Mowry Shales (Lower Cretaceous) are mapped as a single unit. The lower formation, the Thermopolis Shale, which crops out only along the northeastern and southeastern margins of the study area, consists of two members, a lower black shale member about 200 ft (60 m) thick, overlain by the Muddy Sandstone Member, 50–70 ft (15–21 m) thick. The black shale is soft, fissile, flaky, contains thin bentonite and sandstone beds, and is of marine origin. The Muddy Sandstone Member is composed of gray and greenish-gray, very fine to medium-grained sandstone with lesser amounts of black shale and thin bentonite beds. In some places it forms cliffs. The Muddy is one of the major oil-producing sandstones farther east in Wyoming.

The upper formation, the Mowry Shale, is completely exposed only in one locality along the southeast margin of the study area. A partial section, except for the uppermost beds, is on the divide between Shoal and Dell Creeks, and another partial section, highly contorted, is exposed farther west along the Cache Creek thrust fault. The thickness of the formation is probably between 600–700 ft (183–213 m). The rock is black, hard, siliceous shale that weathers silvery gray, interbedded with lesser amounts of black, soft, fissile shale, cream-colored bentonite, and hard, brittle, silicified tuff and sandstone. The shale is characterized by abundant fish scales.

Frontier Formation.—The Frontier Formation (Upper Cretaceous) is exposed east of Dell Creek near the southeastern margin of the study area. The upper part of the formation, which is in the overriding block of the Cache Creek thrust fault, crops out over a small area on the high divide east of Shoal Creek. The formation consists of about 1,000 ft (305 m) of drab, pepper-and-salt-colored, fine-grained marine sandstone, interbedded with black to dark-gray shale and thin beds of white and pink bentonite and porcellanite. The Frontier Formation is present in the subsurface all along the southwestern margin of the study area. Farther east in Wyoming, it is one of the major oil-bearing targets.

The outcrop east of Shoal Creek is of some interest because it contains a sequence of coal and coaly shale about 8 ft (2.4 m) thick. The following section was measured and sampled (unit 1 is oldest); sample numbers are the same as the unit numbers.

Unit No.	*Description*	*Thickness* (in.)	(cm)
8.	Claystone, dull-gray, plastic, blocky, soft	7	18
7.	Coal and coaly shale, black, soft	12	30
6.	Coal, black, shiny, with partings of hard carbonaceous mudstone; hard; forms rib on outcrop	12	30
5.	Coaly shale, black, soft	20	50
4.	Coal, black, soft, very shaly and impure	16	40
3.	Carbonaceous shale and coal, black, soft	10	25
2.	Carbonaceous shale and coal, black, soft	12	30
1.	Claystone, lead-gray, soft, blocky, plastic	6	15
	Total thickness of coaly zone ..	95	238

The coaly zone (unit 8 in the following section) is within a moderately well exposed sequence of sandstone and shale which is described here because of its potential as an oil and gas reservoir (unit 1 is oldest).

Unit No	*Description*	*Thickness* (ft)	(m)
11.	Shale, gray, sandy, soft, grading up to dark-gray claystone and shale	10	3.0
10.	Sandstone, tan, limy; in part a coquina of oysters, inoceramids, *Cardium*, and so forth, that weather out as free specimens. Zone is near the top of the formation in sections to the north	5	1.5
9.	Sandstone, shale, and claystone, dull-gray, soft, highly fossiliferous in upper part .	15	4.6
8.	Coaly zone described above	8	2.4
7.	Claystone, dull-gray; not distinguishable from unit 1 in coaly zone	3	.9
6.	Covered interval; probably underlain by soft rocks	60	18.3
5.	Sandstone and siltstone, dull-gray, fine-grained, pepper-and-salt appearance, nodular, iron-stained	20	6.1
4.	Sandstone, bluish-white, clean, sparkly, porous, pepper-and-salt appearance, crossbedded; forms prominent rib on outcrop	20	6.1
3.	Covered interval; traces of black carbonaceous and coaly shale	30	9.1
2.	Carbonaceous shale, siltstone, and slabby, very fine grained sandstone	10	3.0
1.	Sandstone, chalky white, soft, bluish on fresh fractures, pepper-and-salt appearance; forms ribs and dip slopes	25	7.6
	Total thickness of measured part of section	206	62.6

The section east of Dell Creek is similar to that described above but is poorly exposed, and locations of the upper and lower contacts are only approximate.

In the Mobil Oil Co., Camp Davis well, 7 mi (11 km) southwest of the study area, below the overriding blocks of the thrust belt, the Frontier has thickened to about 1,300 ft (396 m) and there is a porous sandstone 150 ft (45 m) thick near the top of the formation. This part is a good potential oil and gas reservoir rock in the subsurface along the southwest margin of the study area.

Cody Shale.—The Cody Shale (Upper Cretaceous) crops out in the study area only in one locality, east of Dell Creek, where a few hundred feet of the basal part is exposed. Farther north in Jackson Hole, where it is better known, it consists of about 2,000 ft (610 m) of soft gray marine shale with one persistent sandstone 75 ft (23 m) thick, 400–500 ft (122–152 m) below the top (Love, 1956a). This sandstone contains shows of gas in Jackson Hole so it must be considered as a potential reservoir rock along the southwest margin of the study area. In the Mobil Oil Co., Camp Davis well, a similar sandstone, about 150 ft (46 m) thick, is near the middle of the Cody Shale.

Bacon Ridge Sandstone.—The Bacon Ridge Sandstone (Upper Cretaceous) crops out at one locality on the east side of Dell Creek. The base and top are covered so the thickness is not known. Farther north in Jackson Hole, it is more than 1,000 ft (305 m) thick (Love, 1956a, p. 80) and contains many coal beds. In the Mobil well, mentioned previously, the lower 600 ft (183 m) of the Bacon Ridge is present below the lowest thrust plate. The sequence there consists chiefly of gray, pepper-and-salt-type sandstone that contains seven coal beds 5–10 ft (1.5–3 m) thick. No coals were observed in the section at Dell Creek, but exposures are so poor that some could have been missed.

The Bacon Ridge is distinguished from younger Cretaceous sandstones in that it has a pepper-and-salt appearance whereas the younger ones have many brightly colored grains—red, green, orange, brown, yellow, white, and so on. In addition, sandstones in the Bacon Ridge contain abundant white ornate marine and brackish-water mollusks, whereas no such forms are present in younger rocks.

Sandstones in the Bacon Ridge are as much as several hundred feet thick, are soft and porous, and are prime reservoir rocks for oil and gas along the southwest margin of the study area. Several thousand cubic feet of gas per day were recovered from the Bacon Ridge Sandstone in the Mobil, Camp Davis well. In Jackson Hole, a few large gas seeps are in the Bacon Ridge, and core holes and oil tests yielded small flows of gas.

Coaly sequence and lenticular sandstone and shale sequence.—An unnamed coaly sequence and lenticular sandstone and shale sequence (Upper Cretaceous) are present between the Bacon Ridge Sandstone and the Mesaverde Formation in southeastern Jackson Hole, about 6 mi (10 km) north of the study area (Love, 1956a, p. 81). The coaly sequence overlies and intertongues with the uppermost part of the Bacon Ridge Sandstone, is about 1,000 ft (305 m) thick, and consists of nonmarine gray and brown sandstone, gray shale, and numerous coal beds. The overlying lenticular sandstone and shale sequence consists of about 2,400 ft (732 m) of lenticular gray sandstone and gray shale and siltstone. Brown ironstone concretions are abundant. These rocks should be in the section along and east of Dell Creek but no exposures were seen. They are, however, believed to be present in the subsurface.

Several sandstone lenses in areas to the north are as thick as 100 ft (30 m) or more. Hence they may have some oil and gas potential on the up-dip parts of the Green River Basin along the southwest margin of the study area.

Mesaverde Formation.—About 100 ft (30 m) of the Mesaverde Formation (Upper Cretaceous) is exposed in the east bank of Dell Creek. Somewhat thicker sections are present both to the southeast and also to the northwest across Dell Creek. Because of a major intra-Cretaceous unconformity that bevels the Mesaverde, its thickness varies from a wedge-edge to more than 1,000 ft (305 m) (Love, 1973, figs. 13–14). The thickness in the Dell Creek area is not known because the base and top are not exposed in the same locality, but at least 500 ft (152 m) is present. The formation consists chiefly of fine- to medium-grained, light-gray to white sandstone whose distinguishing features are a combination of color, porosity, cleanness, crossbedding, and brightly colored grains. Some gray, dull green, and pink shale, claystone, and siltstone and thin coal beds are present.

The Mesaverde Formation has been intersected in several wells drilled within 5–10 mi (8–16 km) south of the study area. Small shows of oil and gas were found, and the sandstones are considered to be possible reservoir rocks along the southwest margin of the area.

Harebell Formation.—Outcrops of the Harebell Formation (Upper Cretaceous) are confined to the Dell Creek area, where it overlies the Mesaverde Formation. The contact is an unconformity of regional extent but one that is not apparent in the local outcrops; for example, the Meeteetse Formation, as much as 900 ft (274 m) thick, is present between the Mesaverde and Harebell Formations in parts of Jackson Hole to the north. In the Dell Creek area, the Harebell is at least 2,150 ft (655 m) thick and is overlapped with an angular unconformity of 35° or more by the Eocene Pass Peak Formation.

The Harebell is easily distinguished from the underlying Mesaverde because of the abundance of coarse-grained rocks—grits, pea-gravel conglomerates, and coarse-grained sandstones—that form the bulk of the exposed section. Some individual, very lenticular conglomerate beds in the basal part of the Harebell Formation on the east bank of Dell Creek are 15 ft (4.6 m) thick. Clasts consist largely of hard, fine-grained, gray sandstones and black and gray cherts of Paleozoic age; they are highly rounded and rarely more than 2 in. (5 cm) in diameter. Between the conglomerates are some fine-grained, massive to crossbedded, gray and tan sandstones and thin, gray and black claystones and shales.

Part of the Harebell sequence has been penetrated in several oil and gas test wells within 10 mi (16 km) of the study area but no good shows were found. Nevertheless, because of the thickness of soft, porous, lenticular sandstones, the Harebell is considered to be a potential oil- and gas-bearing sequence.

Cenozoic Rocks

Lithologic characteristics of Cenozoic sedimentary rocks and unconsolidated deposits in the study area are summarized in table 3, and additional details are given in the text that follows.

Hoback Formation.—The Hoback Formation (Paleocene) is divisible into three sequences: an unnamed lower red conglomerate; the gray main part of the formation; and at the top, the Skyline Trail Conglomerate Member of Dorr and others (1977).

The lower red conglomerate is known only from one area east of Shoal Creek and north of Tin Can Park. Exposures are poor because of abundant landslides and steep terrain. The thickness is uncertain; about 400 ft (120 m) is present but the base is not exposed. The top is cut off by the Cache Creek thrust fault, which brings the Frontier Formation onto the lower conglomerate of the Hoback.

Some conglomerate clasts in this sequence are rounded and others are angular. Almost all are of noncalcareous rocks. A few are of white, soft, very fine grained glauconitic sandstone similar to sandstones in the lower Sundance part of the Jurassic Sundance Formation of central Wyoming. Some rounded boulders near the top are 3 ft (90 cm) in diameter, but most are 1–2 in. (2.5–5 cm). Most boulders are of gray, fine-grained, hard, homogeneous sandstone, probably the Tensleep Sandstone. They are set in a matrix of brick red siltstone and claystone.

The lower part of the conglomerate sequence contains a distinctive red and white, hard claystone and siltstone unit that weathers into unvegetated badlands. No bedding planes are visible, and the debris apparently was dumped with little or no sorting from the rising Gros Ventre arch to the north. Much of the red color may have come from the Chugwater Formation.

The main part of the Hoback Formation is a thick sequence of gray to drab alternating sandstones, siltstones, and claystones, perhaps 10,000 ft (3,050 m) thick in some places. Formerly it was thought to be 16,000 ft (4,900 m) thick (Spearing, 1969), but some of the rocks assigned to the Hoback at the type section may be the lenticular sandstone and shale sequence of Late Cretaceous age. The sandstones in the Hoback become progressively more conglomeratic higher in the section and the claystones become pink. Most clasts are of Paleozoic and Mesozoic rocks, are rounded, and commonly are 2 in. (5 cm) or less in diameter. This conglomeratic sequence grades upward, and westward laterally, into the Skyline Trail Conglomerate Member of Dorr and others (1977).

The Skyline Trail Conglomerate Member is exposed in broad, steeply dissected, treeless uplands on the south side of the Gros Ventre Range west of Granite Creek and outside of the study area. It consists of 3,000 ft (915 m) or more of red conglomerate interbedded with red, gray, and green claystone and siltstone. The member becomes progressively redder near the top. Nearly all the clasts are derived from adjacent Paleozoic and Mesozoic rocks and are moderately rounded. Some boulders are as much as 5 ft (1.5 m) in diameter but most are less than 1 ft (30 cm). From northwest to southeast, the conglomerate facies intertongues with the main part of the Hoback Formation. On the Little Granite anticline (see fig. 9), the base of the conglomerate is only a few hundred feet above Cretaceous rocks, whereas along Granite Creek to the southeast, it is at least 4,000 ft (1,200 m) above Cretaceous rocks. The thickness of the Hoback Formation underlying the crest of the Little Granite anticline is unknown but, on the basis of adjacent outcrops to the southeast, it probably totals no more than 500 ft (150 m).

Vertebrate fossils in the lower part of the Hoback Formation and mollusks in the upper part indicate that it is of Paleocene and could possibly be earliest Eocene age.

Pass Peak Formation.—The Pass Peak Formation of Eocene age (Steidtmann, 1969) is present only in the extreme southeast corner of the study area. It overlaps Upper Cretaceous rocks with an angular unconformity of 35° or more. The Pass Peak Formation here is a conglomerate of well-rounded pebbles, cobbles, and boulders of quartzite in a rusty-colored, coarse-grained sandstone matrix. The thickness exceeds 3,000 ft (915 m) about 2 mi (3.2 km) south of the study area.

Previously, the Pass Peak was thought to have been overridden by the Gros Ventre Range along the Cache Creek thrust fault (Keefer, 1964), but our studies show that the formation overlaps the mountain arch and that the Cache Creek thrust diverges southward into the Green River Basin, as shown on plate 1.

Teewinot Formation.—The Teewinot Formation (Miocene) is present only along the extreme western

Table 3. Summary of geologic data on Cenozoic sedimentary rocks and unconsolidated deposits of the Gros Ventre wilderness study area

Lithologic unit	Age	Lithology and location
Alluvium----	Holocene------	Fluvial deposits of silt, sand, and gravel along present stream valleys. Extensive only in lower Flat and Crystal Creeks and middle and lower Gros Ventre River; upper parts of most drainages are swept clear of alluvium.
Talus-------	Holocene------	Widespread and extensive deposits derived principally from Madison Limestone, Bighorn Dolomite, and Tensleep Sandstone. Very large accumulations on Flat, Granite, Shorty, and Swift Creeks and in Hidden Basin.
Landslide deposits.	Holocene------	Widespread accumulations of completely unsorted angular debris; comprises rockfalls, rockslides, and earthflows.
Rock glaciers.	Holocene and Pleistocene.	Tongue-shaped accumulations of rock debris that show transverse crescentic ridges indicative of recent movement; some may be ice-cored. Five occurrences are shown on plate 1; the largest, at the head of East Miner Creek, is 0.9 mi (1.4 km) long.
Glacial till.	Pleistocene---	Deposits of glacial debris near present canyon bottoms and at higher levels to as much as 2,500 ft (760 m) above present canyon bottoms. Mainly along southwest flank of Gros Ventre Range, also along and above Flat, Crystal, and Granite Creeks. About 25 occurrences are shown on plate 1, in addition to those along the southwest edge of the study area.
Strata of Shooting Iron Ranch.	Quaternary----	Conglomerate, sandstone, variegated bentonite and claystone; about 70 ft (21 m) thick. Small outcrops in upper Flat and Granite Creeks.
UNCONFORMITY		
Teewinot Formation.	Miocene-------	Upper sedimentary limestone breccia; white to pink bentonitic sandstone, tuff, and claystone; basal limestone-sandstone conglomerate; 250 ft (75 m) thick. Only at extreme west end of study area.
UNCONFORMITY		
Pass Peak Formation.	Eocene--------	Quartzite pebble, cobble, and boulder conglomerate; highly rounded clasts; 3,000+ ft (915+ m) thick. Extreme southeast corner of study area.
UNCONFORMITY		
Hoback Formation.	Paleocene-----	Skyline Trail Conglomerate Member, red cobble conglomerate, and variegated claystone and siltstone, 3,000 ft (915 m) thick; middle gray sandstone, siltstone, and claystone about 10,000 ft (3,050 m) thick, conglomeratic toward top; merges westward into, and is overlain eastward by the Skyline Trail Conglomerate Member; lower red pebble conglomerate at least 400 ft (120 m) thick. Southwest edge of study area.

margin of the study area but it provides significant data needed to reconstruct the timing of sedimentation and tectonism in the region during the latter part of Cenozoic time. The basal 250 ft (75 m) of the formation is present on Table Mountain west of Flat Creek; it thickens rapidly westward to more than 6,000 ft (1,830 m) in Jackson Hole where it is involved in major folding and faulting. The Teewinot overlies all older rocks with an angular unconformity.

The formation consists of a basal conglomerate of locally derived Paleozoic rocks, chiefly Madison Limestone and Tensleep Sandstone, overlain by white to pink, soft, bentonitic sandstone, tuff, and claystone that contain some chalky white limestone nodules. The lower 100 ft (30 m) of conglomerate was deposited in a channel cut into Paleozoic rocks and consists largely of subrounded clasts as large as several feet (1 m or more) across. Within the conglomerate are a few interbeds of gray, biotitic, limy sandstone and pink tuff. The upper 100 ft (30 m) of the basal sequence is a breccia that merges laterally with a detached mass of Madison Limestone nearly 0.5 mi (0.8 km) long that slid northeastward during deposition of the Teewinot Formation.

The Teewinot Formation was previously considered to be of middle Pliocene age on the basis of abundant fossils and a K-Ar (potassium-argon) age of 9 m.y. (Love, 1956a, p. 91; Love and Reed, 1968), but the Miocene-Pliocene boundary is now considered by Berggren and Van Couvering (1974) to be about 5 m.y., and by this definition, the Teewinot would be of late Miocene age.

Shooting Iron Formation.—Strata of the Shooting Iron Formation of Pliocene age (Love and Christiansen, 1985) are present at several sites near the heads of Flat and Granite Creeks. This sequence overlaps all older rocks with an angular unconformity and provides some important data on the recency and magnitude of tectonism in the western part of the study area. In this area, the sequence rests on the Amsden, Tensleep, Phosphoria, and Dinwoody Formations and at one place is overlain by glacial till.

The thickest and lithologically most informative section is at the head of Granite Creek, where 72 ft (22 m) was measured. The strata consist of alternating, locally derived, nonvolcanic conglomerate, very soft volcanic sandstone, and pink, gray, green, and yellow bentonitic claystone. Conglomerate clasts are as much as 1.5 ft (0.45 m) across, but most are much smaller. The lithology of the sandstone and claystone is unique in the entire region. Both rocks contain abundant conspicuous red specks of an unidentified mineral and blebs, inclusions, and laminae of bright-green and lemon-yellow, waxy claystone. Elsewhere, this lithology is known only from the Shooting Iron Formation on the floor of Jackson Hole and on the west flank of Sheep Mountain 2 mi (3.2 km) west of the west boundary of the study area. At the Sheep Mountain locality the beds are tilted westward at an angle of 14°.

About 3,000 ft (915 m) northwest of the Granite Creek site is another isolated remnant of these strata. At the base is 60 ft (18 m) of pink, locally derived conglomerate containing a few interbeds of red bentonitic claystone. At the top is 6 ft (1.8 m) of red, very plastic, bentonitic claystone with one 1-in. (3-cm)- thick layer of creamy white, pure bentonite.

Sparse vertebrate fossils and several horizons of abundant mollusks found east of the study area indicate a Pliocene age for the sequence (Love and Christiansen, 1985). The fossils indicate that the sequence is, in part, of lacustrine origin, and therefore was originally deposited in a nearly horizontal position. Our interpretation is that it extended nearly continuously from the head of Granite Creek to the floor of Jackson Hole, and that it was warped and faulted to its present position by later Quaternary tectonic movements. The altitudes of remnants now range from 10,000 ft (3,050 m) at the head of Granite Creek to 6,000 ft (1,830 m) on the floor of Jackson Hole.

Rock glaciers and glacial, landslide, talus, and alluvial deposits.—Rock glaciers are shown at five localities on plate 1. They all occur at the heads of deeply glaciated valleys and at altitudes of about 10,000 ft (3,050 m).

The higher parts of the Gros Ventre Range have been extensively glaciated and, especially east of Granite Creek and south of the range, aprons of thick till mantle the bedrock over large areas. Morainal debris is widespread along bottoms and sides of glaciated canyons.

Landslides are present throughout the area. Especially vulnerable to sliding are Cambrian, Triassic, Jurassic, and Cretaceous shales. The largest earthflow in the area is along Mill Creek southwest of The Elbow, where the Chugwater Formation and younger rocks have slumped over an area more than 2.5 mi (4 km) long and 1.5 mi (2.4 km) wide.

Locally derived deposits of talus are common on steep slopes in many parts of the area. In a few places along the southern front of the Gros Ventre Range, talus breccias are locally cemented and stand as cliffs.

Alluvial deposits are present as thin accumulations of locally derived debris along stream bottoms.

Structure

The Gros Ventre Range is a broad, northwest-trending, asymmetrical anticline that has a gently dipping, structurally simple, northeast flank and a steeply dipping, structurally complex, southwest flank. Superimposed on the northeast flank are various northwest- to north-trending folds and faults, some of which can be traced for 10–12 mi (16–19 km). On this flank, the principal structure is the broad-crested anticline along which an extensive upland surface about 10 mi (16 km) long and as much as 3 mi (5 km) wide is developed on Madison Limestone. The southwest flank of the range, in and near the study area, is in most places a conspicuous, steep and rugged escarpment composed of Precambrian and Paleozoic rocks that have been uplifted thousands of feet along the Cache Creek thrust fault and related faults.

In the northwest part of the study area, the topographic crest of the range is along the southwest escarpment and consists mostly of Precambrian rocks; in the southeast part of the area, the crest is also along the escarpment, but no rocks older than Ordovician are exposed; and in the central part of the area, the crest is not clearly defined but is located well northeast of the escarpment and involves both Precambrian and Paleozoic rocks.

Structural relief within the study area is considerable and is the result of uplifting by both folding and faulting. On the mountain block alone, the structural relief on the Precambrian is about 8,000 ft (2,440 m). In addition, the structural relief from the Precambrian rocks on the crest of the range to those under the overridden northern margin of the Green River Basin may be as much as 20,000–25,000 ft (6,100–7,600 m) (see fig. 9).

Lesser structural elements in the Gros Ventre Range, Green River Basin, and the thrust belt in and near the study area are, from northeast to southwest, the Crystal Creek anticline, Pyramid Peak fault, Flat Creek-Granite Creek syncline, Shoal Creek fault, Elbow Mountain fault, Cache Creek thrust fault, Little Granite anticline, and Jackson thrust fault (pl. 1).

The Crystal Creek anticline is a highly asymmetrical fold that has a gently dipping northeast limb and a southwest limb that dips as steeply as 65° (pl. 1, secs. *A–A′* through *F–F′*). The fold has been traced from the head of East Miner Creek southeastward and southward to the head of Crystal Creek, a distance of about 12 mi (19 km).

The Pyramid Peak fault is named for excellent exposures below Pyramid Peak on the high divide between Granite and Crystal Creeks. The fault has a very sinuous trace but strikes approximately northwest. Its dip varies from nearly flat, as on the ridge 1 mi (1.6 km) northwest of Pyramid Peak, to about 40°–45° SW (pl. 1, secs. *C–C′* and *D–D′*). The fault has been traced along the strike for about 6 mi (9 km) but its location at either end is uncertain. Movement along the fault is reverse, and at the place of apparent maximum displacement, the Bighorn Dolomite is faulted against the Amsden Formation, a stratigraphic throw of at least 1,300–1,400 ft (395–425 m). At two places along the fault it is made up of multiple faults; 1 mi (1.6 km) northwest of Pyramid Peak, slices of tightly folded Madison Limestone and Tensleep Sandstone occur along the fault, and on the ridge crest near the south end of the fault, several slices of Madison Limestone and Darby Formation mark where the fault crosses from one side of the ridge to the other. Two small klippen, remnants of the hanging wall of the fault, occur on the top of the Crystal Creek-Granite Creek divide; the northerly one consists of brecciated Madison Limestone resting on the Amsden Formation, Tensleep Sandstone, and Madison Limestone, and the southerly one is made up of Darby Formation resting on Madison and Amsden.

The Flat Creek-Granite Creek syncline extends from Flat Creek, at the northwest edge of the study area, southeastward to the study area boundary at the mouth of Granite Creek canyon, a distance of about 12 mi (19 km). It has a sinuous trace that varies in direction from northwest to north-northeast. The syncline is asymmetrical, the northeast limb being somewhat steeper than the southwest one, and the asymmetry is thus in the same sense as that of the Crystal Creek anticline (pl. 1, secs. *A–A′* through *E–E′*). The fold is most conspicuous in the middle part of Granite Creek canyon, where the 3,000-ft (915-m)- high northeast wall of the canyon is a dip slope of about 25° on Madison Limestone.

The Shoal Creek fault, in the southeastern part of the study area, extends from the east fork of Swift Creek east-southeastward to upper Tosi Creek, a distance of about 6.5 mi (10.5 km). To the east, displacement on the fault decreases, and the fault ends in the Tensleep and Amsden Formations. At its west end, the fault appears to bend northward and to split into several smaller faults, which finally end about 2.5 mi (4 km) north of the bend as a series of minor breaks between Cambrian and Precambrian rocks. The Shoal Creek fault dips moderately to steeply southward and has a displacement in a normal sense of at least 4,000 ft (1,220 m). On the line of section *G–G′* (pl. 1) the minimum stratigraphic throw is 2,000 ft (610 m), and 3,300 ft (1 km) farther east along the fault the stratigraphic throw is about 3,300 ft (1,000 m).

The Elbow Mountain fault, in the southeast part of the study area, was interpreted previously as a single fault that had a sharp bend at The Elbow (Nelson and Church, 1943, p. 158, fig. 7; Keefer, 1964, p. D23–D24, fig. 2). Recent investigations for this report, however, indicate that two separate faults, the north and east Elbow Mountain faults, are present.

The north Elbow Mountain fault extends for at least 4 mi (6.4 km) south-southeastward from the Shoal Creek fault along the southwest flank of the Gros Ventre Range. The fault dips steeply (85°) and at its southernmost exposure has a stratigraphic throw of more than 2,000 ft (610 m). Toward the north end, displacement on the fault decreases and the fault either ends against or joins the Shoal Creek fault. To the south, the fault disappears beneath a large landslide.

The east Elbow Mountain fault extends from The Elbow east-southeastward beyond the study area almost to the Green River (Keefer, 1964, fig. 2). At its west end the fault trace is covered by landslide debris. The fault dips steeply (70°) and has a stratigraphic throw of about 2,000 ft (610 m).

The Cache Creek thrust fault is the dominant structure along the southwest flank of the Gros Ventre Range. Resistant Precambrian and Paleozoic rocks above were thrust onto soft Mesozoic and Cenozoic rocks. This relationship and subsequent erosion are responsible for the precipitous southwest-facing range front that rises conspicuously above the Hoback basin. As shown on plate 1, the fault extends from upper Cache Creek southeastward to the divide between Shoal and Dell Creeks, a distance of about 17 mi (27 km) and is inferred to extend more than 4 mi (6.4 km) farther south to Dell Creek. The fault is shown by Love and Albee (1972) to extend northwestward along the front of the range past the town of Jackson and into Idaho. The total length of the fault may be as much as 35–40 mi (55–65 km).

Data available on the Cache Creek thrust suggest that the dip is between 30° and 45° northeastward, and a dip of 35° was assumed in constructing sections *B–B′* through *G–G′* (pl. 1). Stratigraphic throw along the thrust cannot be less than about 8,000 ft (2,440 m) (sec. *G–G′*), and if our interpretation of the structure and stratigraphy in the southwest corner of plate 1 is correct, then the throw is about 25,000 ft (7,600 m) (see fig. 9 and discussion in mineral commodities section). Our estimates of stratigraphic throw and displacement are considerably greater than those made for the Cache Creek thrust fault or the Skyline Trail fault (we consider these to be the same fault) by Nelson and Church (1943, p. 151, 153) and Horberg and others (1949, p. 196, 198); the difference results mainly from different interpretations of the thickness of Cenozoic rocks overridden by the upper plate of the Cache Creek thrust. Whatever the interpretation, we believe movement along the Cache Creek thrust must have been substantial, of the order of miles rather than of a few thousand feet.

The Little Granite anticline is discussed more fully in the section on oil and gas potential and is noted only briefly here. The anticline trends northwest across the southwest corner of the mapped area (pl. 1) for a distance of about 5 mi (8 km). It lies entirely outside the study area but is included in this report because of the possible occurrence of oil or gas on its northeast flank under the Cache Creek thrust fault and beneath the study area. At both its northwest and southeast ends, the anticline is overridden by Paleozoic rocks in the upper plate of the southwest-dipping Jackson thrust fault. At the surface, the fold is entirely in the Skyline Trail Conglomerate Member of the Hoback Formation, which here extends down nearly to the base of the Hoback. Dips on the flanks of the anticline are about 30°.

The Jackson thrust fault is exposed only in the southwest corner of the mapped area (pl. 1) and, like the Little Granite anticline, is entirely outside the study area. The fault strikes northwest and dips generally southwest, but because of post-fault folding the fault trace is sinuous. Along the fault, Paleozoic rocks as old as the Tensleep Sandstone and Amsden Formation are thrust over the Skyline Trail Conglomerate Member of the Hoback Formation. The Jackson thrust in this area is the structurally lowest of a group of faults that together characterize the overthrust belt of western Wyoming and eastern Idaho.

The structural history of the Gros Ventre Range and adjacent areas has been presented in many papers, the most recent of which are Love, Reed, and others (1973), Love (1973), Dorr and others (1977), and Love (1977). The present summary is taken from Love (1977).

The ancestral Teton-Gros Ventre uplift formed during Late Cretaceous time as a broad northwest-trending arch that was continuous from the present Gros Ventre Range to the present Teton Range. As the arch rose, some of the soft Upper Cretaceous rocks were eroded from its crest prior to deposition of the Upper Cretaceous Harebell Formation. In latest Cretaceous time, several asymmetric folds with steep southwest flanks developed oblique to and low on the northeast flank of the newly formed Gros Ventre Range; these are all outside the study area. During two subsequent episodes of uplift, in Paleocene and possibly earliest Eocene time, the Gros Ventre arch developed a marked asymmetry, steeper on the southwest flank than on the northeast. Most of the Mesozoic rocks were stripped from the arch and coarse clastic debris derived from Paleozoic rocks was deposited along the southwest flank to form the lower unnamed red conglomerate and the Skyline Trail Conglomerate Member of the Hoback Formation. These rocks were folded shortly thereafter into the northwest-trending Little Granite anticline. At the same time, or perhaps slightly later, the Jackson thrust plate moved northeastward over the anticline. The dominant uplift of the Gros Ventre Range began during earliest Eocene time when the northeast-dipping Cache Creek thrust developed and the overriding mountain block moved southwestward, peeling back the Jackson thrust plate. In early Eocene time, the southeast part of the Gros Ventre Range continued to rise, and large angular masses of Paleozoic and Mesozoic rocks were shed southeastward and incorporated in the Pass Peak Formation; there is no evidence that the Cache Creek thrust cuts the Pass Peak Formation, although most previous reports state that it does. The age of the normal faults in the Gros Ventre Range—Shoal Creek, Elbow Mountain, and so on—is not known; they involve no rocks younger than Triassic.

Post-early Eocene tectonic activity in the Gros Ventre Range occurred, for the most part, west of the study area and is not discussed except for that involving the lacustrine part of the lower Pleistocene Shooting Iron Ranch sequence at the head of Granite Creek (pl. 1). This locality is near the crest of the Gros Ventre Range at an altitude of 10,000 ft (3,050 m), and the sequence can be traced westward to the floor of Jackson Hole at an altitude of 6,000 ft (1,830 m). As this lacustrine sequence was deposited horizontally, the difference in present altitudes is a measure of the amount of subsequent relative uplift of the range. We infer that there was Pleistocene uplift of the range as well as sinking of Jackson Hole.

AEROMAGNETIC AND GRAVITY STUDIES

By Dolores M. Kulik, U.S. Geological Survey

Introduction and Methods

Aeromagnetic and gravity surveys were made of the Gros Ventre wilderness study area to provide additional information on structural relationships and subsurface geology in support of the mineral resource assessment studies of the area. Previous geophysical studies in adjacent Grand Teton National Park and vicinity (Behrendt and others, 1968) provided background information. Aeromagnetic surveys were flown by the U.S. Geological Survey in the western half of the study area in 1965 and in the eastern half in 1973. The surveys were flown at a constant barometric elevation of 12,000 ft (3,700 m) on north and south flight lines at 1 mi (1.6 km) spacing. An ASQ10 Fluxgate[1] magnetometer was used and flight lines were plotted from topographic maps. The flight lines were reestablished on a topographic base from 35 mm film. The magnetic data were reduced to an arbitrary datum and tied to aeromagnetic surveys in the surrounding area.

A total of 63 gravity stations was established in the summer of 1975. Observations were made with a LaCoste and Romberg gravity meter and tied to the International Gravity Standardization Net at Jackson, Wyo. (Defense Mapping Agency Aerospace Center, 1974). Because of rugged terrain, stations within the study area were reached by helicopter; those adjacent to the study area were reached on foot and by four-wheel-drive vehicle. Station elevations were obtained from benchmarks, spot elevations, and contour interpolations on 1:24,000-scale topographic maps with 40-ft contour intervals. Elevations are accurate to ±3–6 ft (1–2 m) in areas of low relief, but may be in error by ±15–30 ft (5–10 m) in more rugged terrain. The resultant error in the Bouguer anomaly data is less than ±2 mGal (milligal).

Gravity meter readings were converted to observed gravity using the International Gravity System Network 1971 values (Defense Mapping Agency Aerospace Center, 1974). The Geodetic Reference System 1967 formula (International Association of Geodesy, 1967) was used to compute theoretical gravity. The gravity data were reduced to Bouguer anomaly values using an assumed average rock density of 2.67 g/cm^3 (grams per cubic centimeter). Terrain corrections were made by hand template through Zone H of Hammer (1939) and to 104 mi (167 km) by digital computer using an unpublished program by R. R. Wahl of the U.S. Geological Survey. The corrections ranged from 1.70 mGal at Antelope Flats west of the study area to 28.08 mGal on Darwin Peak.

Density determinations of 34 rock samples from the study area aided in the interpretation of the gravity data. Rock and density information is given in table 4.

Summary of Area Geology

The Gros Ventre Range is a folded and faulted uplift of Paleozoic sedimentary rocks underlain by Precambrian granites and gneisses. (See geology section.) The sedimentary rocks do not appear to have associated magnetic anomalies. The Precambrian rocks, predominantly layered gneisses, have abundant magnetite, hematite, and limonite along north-northeast-trending faults and fractures and are the source of the magnetic anomalies in the study area and in the southern Teton Range west of the study area (Behrendt and others, 1968).

Along the Cache Creek thrust fault, relatively high-density Precambrian and Paleozoic rocks in the uplifted block of the Gros Ventre Range have overridden relatively low-density Tertiary and Upper Cretaceous rocks that form the north margin of the Green River Basin.

Aeromagnetic Interpretations

The aeromagnetic data (pl. 2) reflect the distribution of crystalline rocks within the study area. The magnetic relief from northeast to southwest is 150 nT (nanotesla) and is caused by the southwest-dipping gradient of 4 nT/km of the Earth's magnetic field. The regional magnetic strike in the area is westerly. In the study area this trend is deflected by north- and northwest-striking structural features.

The major magnetic anomaly is a broad composite high, more than 400 nT in amplitude, extending from

[1]Use of company and trade names in this report is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.

Table 4. Average densities of rock samples of four geologic ages in the Gros Ventre wilderness study area

Unit	Predominant lithologies	No. of samples	Average density (g/cm^3)	Range (g/cm^3)
Precambrian--	Gneiss and layered gneiss------	6	2.78	2.66-3.02
Paleozoic----	Limestone and dolomite---------	4	2.76	2.71-2.82
Mesozoic-----	Sandstones and shales----------	12	2.59	2.52-2.74
Cenozoic-----	Conglomerates, claystones, and poorly-lithified sedimentary rocks.	12	2.57	2.42-2.67

southeast to northwest across the study area. This anomaly outlines the main mass of the Gros Ventre Range, and is caused by Precambrian rocks in the Cache Creek, Pyramid Peak, Shoal Creek, and Elbow Mountain fault blocks. The magnetic maximum (anomaly 1, pl. 2) occurs over the Elbow Mountain fault block, in which Precambrian basement rocks are estimated from the gravity data to be offset 25,000 ft (7.5 km) from those underlying the adjacent Green River Basin to the south. This estimate agrees with estimates from gravity models of 7–8 km of total offset on the Elbow Mountain-Cache Creek faults southeast of the study area by Berg and Romberg (1966) and Pattridge and Van derVoo (1976). The magnetic trend is aligned with the Cache Creek, Elbow Mountain, and Shoal Creek faults from anomaly 1 to anomaly 3 (pl. 2). It is deflected to the north and then to the northwest along the changing trends of the Pyramid Peak fault and the Crystal Creek anticline. The fault-related anomalies form a north-northwest trend beyond the northern boundary of the study area. A poorly defined gradient parallels the Cache Creek fault westward beyond the study area. Anomaly 4, on the west boundary of the study area, is a magnetic high over crystalline rocks that crop out at this locality and dip toward the northwest (J. D. Love, oral commun., 1981).

The magnetic anomalies in the western half of the study area are of lower amplitude than those in the eastern half. The difference is probably caused by a change in lithology and magnetic character of the Precambrian rocks.

Several magnetic highs of small magnitude, superimposed along the major trend, are attributed to outcropping Precambrian crystalline rocks. Anomaly 5 south of Sheep Mountain near the northern boundary of the study area is caused by Precambrian rocks in the upthrown block of the Flat Creek fault. Anomalies 2 and 3 are over outcrops of Precambrian rocks in the upthrown block of the Shoal Creek fault. Anomaly 6 and the adjacent nose to the southeast are associated with Precambrian rocks in the Cache Creek thrust sheet. Field observations of these rocks showed only low concentrations of magnetic minerals, and the low-amplitude magnetic expression does not indicate highly magnetic rocks at depth. Crystalline rocks in the basement are at depths of 4 to 5 mi (7 to 8 km) and do not appear to influence the magnetic data over the thrust sheet.

Relative magnetic lows southwest and northeast of the major high magnetic trend are associated with Phanerozoic sedimentary rocks in the Green River Basin and the valley of the Gros Ventre River, where the depth to crystalline rocks is still greater.

The magnetic low (anomaly 7), which is over Cambrian Flathead sandstone near the head of the Gros Ventre River, may indicate that the immediately subjacent Precambrian rocks have been hydrothermally altered. Samples of Precambrian rocks from this area contain anomalous concentrations of copper, cobalt, barium, vanadium, chromium, nickel, and molybdenum (pl. 4, map B). Another magnetic low (anomaly 8), less than 20 nT in amplitude, is over Precambrian rocks at the head of Granite and Bunker Creeks. Samples of rocks and (or) stream sediments from these two drainage areas contain anomalous concentrations of silver, molybdenum, and the only tin found in the area (pl. 4, maps A and B). The small magnitude of the magnetic anomalies does not indicate buried igneous rocks at depth.

Gravity Interpretations

The major gravity feature (pl. 1) is a high anomaly with relief of more than 50 mGal that trends west to northwest across the study area. The trend parallels the Rock Creek anticline east of the study area boundary and the Crystal Creek anticline in the central and northern parts of the study area. It is caused by Paleozoic rocks, estimated to be as much as 4,000 ft (1,200 m) thick (table 1), and by underlying Precambrian rocks in the cores of the anticlines. The gravity maximum is offset to the northeast from the areas of Precambrian rocks defined by the magnetic maxima. This suggests that the high-density Precambrian rocks thin in the leading edge of the Cache Creek thrust fault which lies on the south flank of the gravity anomaly and that these rocks are underlain by lower density sedimentary rocks of the Green River Basin.

The gravity and magnetic gradients increase where Precambrian and Paleozoic rocks are brought near the surface in the Pyramid Peak, Shoal Creek, and Elbow Mountain faults and the Crystal Creek anticline.

A broad gravity low over the Tertiary sediments in the Green River Basin southwest of the study area continues westward and reflects a deep syncline that connects the Green River Basin and Jackson Hole (Love and Keefer, 1965). The gentle gravity gradient extends north of the basin beyond the overriding edge of the Cache Creek thrust fault from Blackman Creek to the area of normal faulting south of the Crystal Creek anticline. There the Cache Creek thrust fault bends southward and the gravity gradient steepens, indicating that the dip of the fault increases. This suggests that where the Cache Creek thrust fault turns southward into the Green River Basin, it may become a tear fault.

Models of the gravity data for the profiles along geologic cross sections *C–C′* and *G–G′* (pl. 1) were calculated using a two-dimensional unpublished computer program by L. E. Cordell of the U.S. Geological Survey and are shown on figures 5*A* and 6*A*. The geologic cross sections *C–C′* and *G–G′* are shown generalized on figures 5*B* and 6*B*. Values of stations within 0.2 mi (0.3 km) of the profiles were projected onto the section and the intervening data were taken from the contours as plotted on the complete Bouguer gravity map (pl. 1) and from supplementary contours not shown.

Paleozoic and Precambrian rocks were considered as one body for modeling purposes, and an average density of 2.77 g/cm^3 was assumed for the body. An average density of 2.59 g/cm^3 was assumed for Mesozoic rocks and 2.57 g/cm^3 for Cenozoic rocks (table 4). Although the absolute values seem high, the density contrasts between the units are within 0.01 g/cm^3 of the values determined for the Teton Wilderness 15 mi (25 km) to the north (Antweiler and others, 1983). Lower densities for Mesozoic and Cenozoic rocks have been reported from farther south in the Green River Basin (Berg and Romberg, 1966), the Great Divide Basin (Case and Keefer, 1966), and the Wind River Basin (Keefer, 1970; Hurich, 1980), but these lower values are not compatible with density measurements of the rock samples collected in the northern Green River Basin near the study area, which are derived from different sources than the rocks farther south in the basin. Densities of the Mesozoic and Cenozoic rocks in the northern part of the Green River Basin may have been increased by the compaction of the rocks caused by loading of the overriding Cache Creek thrust plate.

If the density of the Cenozoic rocks is, in fact, lower than assumed, the thickness of the Tertiary section interpreted on the models would decrease accordingly. It would not significantly alter other interpretations as the mass of the Tertiary rocks influences only a small segment of each model.

The strike of the surface geology at cross section *C–C′* (fig. 5*B*) is west-northwest and that of the gravity contours is more westerly. This difference reflects the effect of the subsurface Tertiary and Mesozoic deposits on the gravity field. The computed gravity profile along cross section *C–C′* (fig. 5*A*) was adjusted to the deflection in strike.

The gravity models shown on figures 5*C* and 6*C*, which are based on geologic cross sections *C–C′* and *G–G′* (figs. 5*B* and 6*B*), yield computed gravity profiles that fail to match observed gravity values (figs. 5*A* and 6*A*). Both models have an excess of high-density rock material underlying the Cache Creek fault block. A better fit was obtained on profile *G–G′* by making two assumptions: first, that the Cache Creek thrust fault dips only 30° (as shown by the straight dashed line on fig. 6*C*), thereby extending the wedge of low-density sedimentary rocks farther beneath the uplifted mountain block. Second, a structural arch was assumed, as shown by the dashed lines on the extended part (left side) of figure 6*C*. The 30° dip is within the range reported as possible for the Cache Creek thrust fault (see description of structure in geology section) and is consistent with informal estimates, based on seismic data from industry, of the dip of the Cache Creek thrust fault west of Jackson, Wyo. The relative thickness of Tertiary and Mesozoic strata in the subsurface cannot be determined with accuracy from

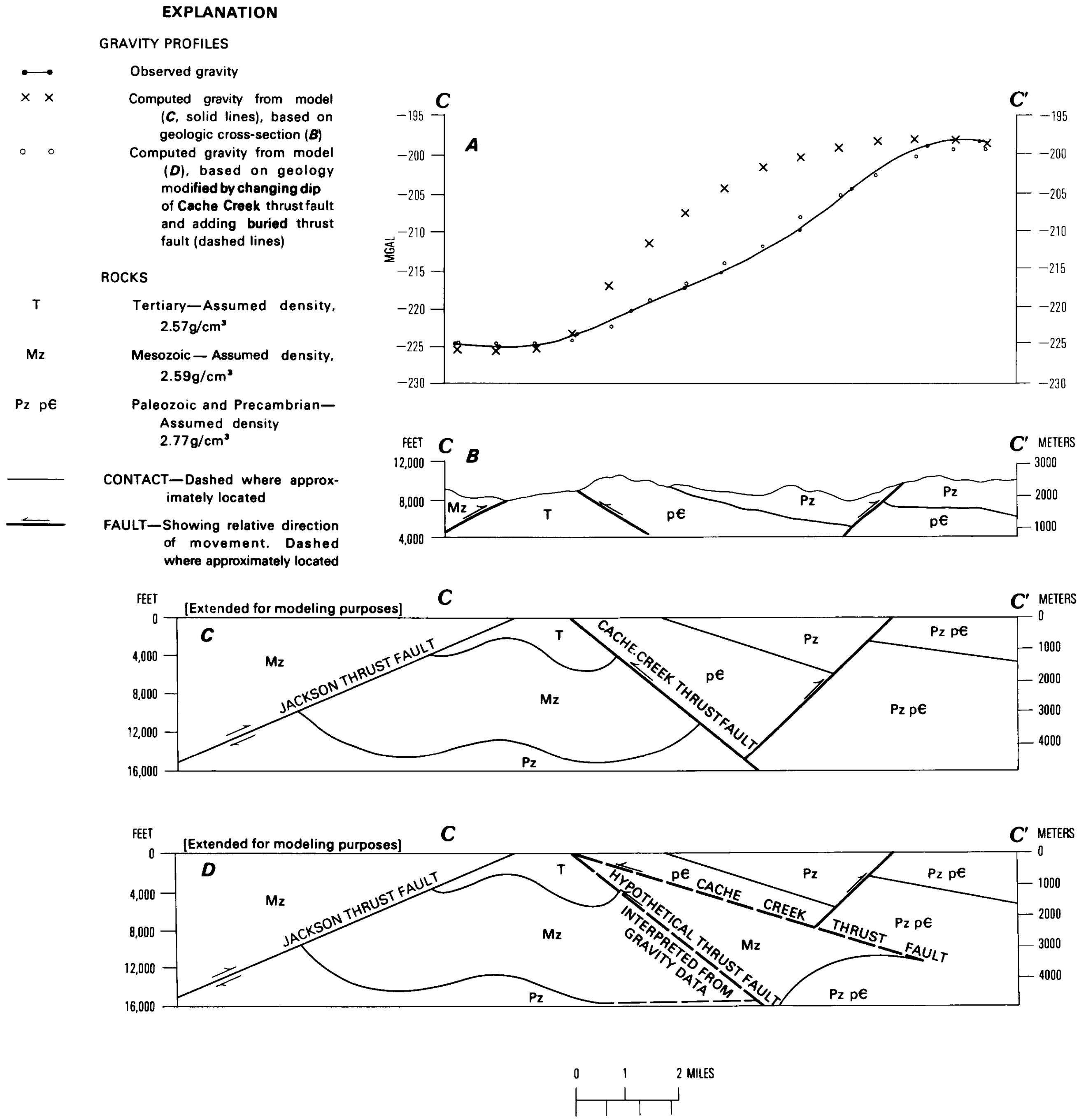


Figure 5. Gravity models and generalized cross sections along line C–C′ (pl. 1). *A*, observed and computed gravity profiles; *B*, geologic cross section as shown on plate 1; *C*, model based on geologic cross section; *D*, model based on modified geology with hypothetical thrust fault (dashed line).

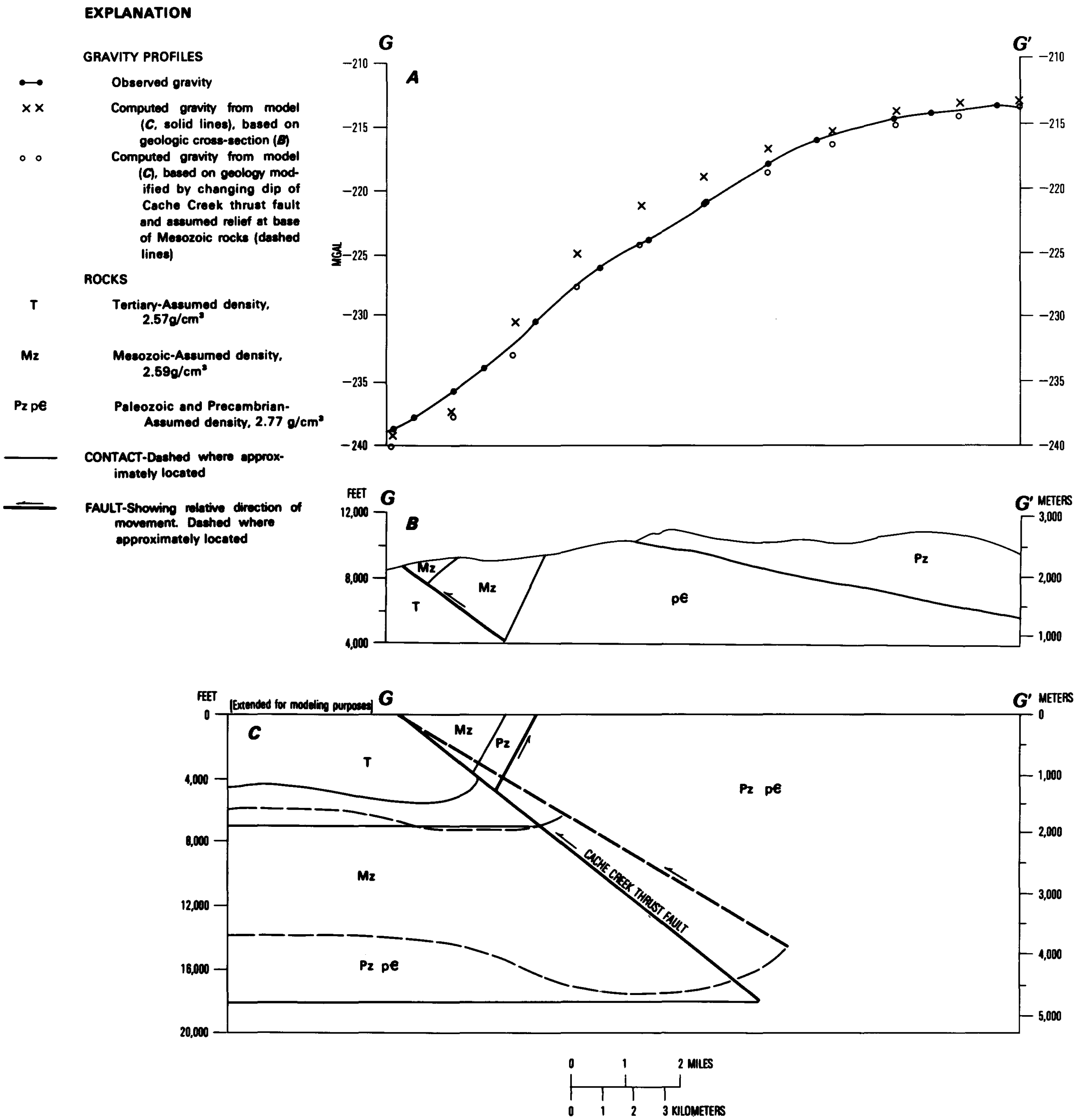


Figure 6. Gravity models and generalized cross sections along line *G–G'* (pl. 1). *A*, observed and computed gravity profiles; *B*, geologic cross section as shown on plate 1; *C*, models based on geologic cross section (solid lines) and on modified geology (dashed lines).

the gravity data because the density contrast between the two units is only 0.02 g/cm^3.

Other discrepancies between computed and observed gravity values have been reported in the Rocky Mountains (Chamberlin, 1935; Behrendt and Thiel, 1963). Berg and Romberg (1966) found that the comparison of observed and computed gravity in the Wind River Mountains also indicated a mass deficiency at depth greater than that expected from geologic and seismic data. They interpreted a low-angle thrust over sedimentary rocks as the most direct explanation of the discrepancy, although that interpretation required an unusually high assumed density contrast (0.3 g/cm^3) between the rocks of basin and mountains. Case and Keefer (1966) reported a similar difference between computed and observed gravity in models of data from the Great Divide Basin and the Granite Mountains. They postulated a buried thrust plate containing Cenozoic and Mesozoic rocks to partly resolve the difference.

There is no geologic evidence to suggest a buried thrust plate beneath the Cache Creek fault at the location of profile *C–C′*. However, a good fit to profile *C–C′* (fig. 5*A*) was obtained by assuming that such a thrust plate containing Mesozoic rocks is present below the Cache Creek fault (fig. 5*D*). Indeed, two thrust faults with a similar relationship are mapped 1.2 mi (2 km) west of Granite Falls, about 3 mi (5 km) southeast of the modeled cross section. Alternatively, the observed gravity profile can be matched by assuming that the Cache Creek thrust fault dips at less than 30° and that drag-folding rather than the buried fault brings Paleozoic rocks into the position shown on figure 5*D*.

Conclusions

Magnetic anomalies in the Gros Ventre wildernesss study area are of small magnitude and do not appear to reflect buried igneous rocks that could contain significant concentrations of ore-forming minerals. Anomaly 7 (pl. 2) could reflect an area of alteration associated with a mineralized body, but surface samples show only noneconomic mineral concentrations. (See mineral commodities section.) A sequence of sedimentary rocks that include reservoir and source rocks is assumed, from geologic mapping and geophysical data, to underlie the Cache Creek fault. These rocks have significant oil and gas potential elsewhere in Wyoming. Gravity data along profile *C–C′* suggest that a buried thrust plate containing additional Mesozoic and perhaps Tertiary sedimentary rocks also underlies that part of the Cache Creek thrust fault.

GEOCHEMISTRY

By Frank S. Simons, U.S. Geological Survey

Sampling and Analytical Program

Geochemical sampling by the U.S. Geological Survey consisted of the collection of 560 samples comprising 283 rock samples and 277 stream-sediment samples; about 85 of these samples were collected outside but close to the study area. Sample localities are shown on plate 3. No pan concentrate samples were taken for this study but many were collected adjacent to the Gros Ventre Range during early studies by the U.S. Geological Survey (Antweiler and Love, 1967; Antweiler and others, 1977).

Stream-sediment samples were collected mainly at stream junctions or at intervals of a mile or so along main streams. Tributaries to main streams are for the most part widely spaced and many are merely steep dry gullies from which no sediment could be obtained. Average sample density is about 1 per mi^2 (0.4 per km^2). Most samples weighed from 4–8 oz (110–220 g). All were dried and screened, and the minus-80-mesh fraction was analyzed semiquantitatively by emission spectrography for 12 elements and was scanned for 18 others. Lower limits of detectability for these elements, in parts per million except where noted, is as follows:

Calcium (Ca)	0.05 pct	Lanthanum (La)	20 ppm
Iron (Fe)	.05 pct	Manganese (Mn)	10
Magnesium (Mg)	.02 pct	Molybdenum (Mo)	5
Titanium (Ti)	.002 pct	Niobium (Nb)	20
Silver (Ag)	.5 pct	Nickel (Ni)	5
Arsenic (As)	200 ppm	Lead (Pb)	10
Gold (Au)	10	Antimony (Sb)	100
Boron (B)	10	Scandium (Sc)	5
Barium (Ba)	20	Tin (Sn)	10
Beryllium (Be)	1	Strontium (Sr)	100
Bismuth (Bi)	10	Vanadium (V)	10
Cadmium (Cd)	20	Tungsten (W)	50
Cobalt (Co)	5	Yttrium (Y)	10
Chromium (Cr)	10	Zinc (Zn)	200
Copper (Cu)	5	Zirconium (Zr)	10

Because the detection limits for zinc (200 ppm) and gold (10 ppm) are high, relative to the amounts that might be expected in stream sediments, all samples were also analyzed for these elements by a more sensitive method of atomic absorption. Finally, 48 samples were analyzed for uranium and thorium by neutron activation.

Rock samples were collected from units of the following ages; the number of samples of each age is given in parentheses: Precambrian (106), Cambrian (14), Devonian (3), Mississippian (21), Pennsylvanian (37), Permian (57), Triassic (4), Jurassic (7), Cretaceous (10), Paleocene-Eocene (5), Pliocene (12), and Holocene (3). Ages of four rock samples are unknown. No samples were collected from the Gallatin Limestone, Bighorn Dolomite, Gypsum Spring Formation, or any formation of Quaternary age except the Shooting Iron Formation sequence because these formations were considered unlikely to contain mineral resources; nor from the Cody Shale, Bacon Ridge Sandstone, lenticular sandstone and shale sequence and coaly sequence, or Frontier and Pass Peak Formations because the outcrop areas of these formations in the study area are very small; nor from the Harebell or Teewinot Formations because they do not crop out within the study area. Samples collected comprised 106 metamorphic and igneous rocks of Precambrian age, of which 40 were altered or mineralized, 82 shales and siltstones, of which 24 were black shales, 30 phosphatic rocks, 22 sandstones, 15 limestones, 2 conglomerates, 2 bentonites, 1 coal, 20 mineralized rocks of Cambrian and younger ages, and three soils. Iron-stained or otherwise mineralized or altered rocks were sampled preferentially; however, except in some Precambrian rocks, little rock alteration was noted in the study area and most of the Paleozoic and younger rocks sampled were unaltered. All samples were analyzed spectrographically for 12 elements and were scanned for 18 others, 65 were analyzed by neutron activation for uranium and thorium, 39 were analyzed colorimetrically for phosphorus, and 9 were analyzed by atomic absorption for iron.

The following terms are used in this report in discussing geochemical data. Background is the range of amounts of a given element that is expectable or normal for a given kind of sample in a given area and comprises amounts less than a selected maximum, or threshold value. Samples that contain the threshold amounts or more of an element are defined as anomalous. For stream-sediment samples, the threshold values for the various elements considered herein were selected so that at least 2.5 percent of the samples contained threshold amounts or more (Lepeltier, 1969, p. 544). For some elements, such as lead and nickel, this procedure probably results in too many anomalous samples (10 percent for lead, 13 percent for nickel), because if the next higher reported value had been used, then fewer than seven samples would have contained anomalous values.

Table 5. Threshold amounts of 13 elements in stream-sediment samples from the Gros Ventre wilderness study area, and number of samples containing at least threshold and more than threshold amounts

[Spectrographic analyses, except as noted, in parts per million. L, detected but below limit of determination]

Element	Threshold	Number of samples with at least threshold amounts	Number of samples with more than threshold amounts
Barium------	1,000	8	1
Boron-------	150	18	3
Chromium----	150	8	2
Copper------	20	21	7
Lanthanum---	100	10	5
Lead--------	70	29	1
Manganese---	1,000	21	7
Molybdenum--	L	3	2
Nickel------	30	35	6
Silver------	0.5	4	4
Vanadium----	100	20	2
Yttrium-----	50	20	8
Zinc--------	[1]200	12	8

[1]Atomic absorption analyses.

Threshold values for various elements in stream-sediment samples from the study area, the number of samples containing at least those amounts, and the number of samples containing more than threshold amounts are given in table 5.

For rock samples, no single threshold values could be chosen because of the large differences in background contents of various elements in different rock types. Instead, thresholds were selected for each of the major rock types sampled and these values, except those for phosphorites, are shown in table 6.

Because not all samples were analyzed for uranium and thorium, data on these elements are not included here but are listed in the section on mineral commodities.

Results of Stream-Sediment Sampling

The distribution of chromium, copper, lead, nickel, vanadium, and zinc in 277 stream-sediment samples is shown by histograms and cumulative frequency curves on figure 7. Cumulative frequency curves for the same elements were also plotted on log-probability coordinates (fig. 8) in order to see whether threshold values might be derived from the curves (Lepeltier, 1969; Parslow, 1974). Curves for all elements except lanthanum are so nearly straight that they yield no information on thresholds; the curve for lanthanum is irregular but has an inflection at 100 ppm (parts per million) and 98

Table 6. Threshold amounts of 13 elements in rock samples from the Gros Ventre wilderness study area
[Spectrographic analyses in parts per million. L, detected but below limit of determination]

Element	Precambrian	Rocks: Cambrian and younger: Black shale	Shale	Sandstone
Barium------	1,000	500	700	200
Boron-------	70	300	300	70
Chromium----	200	1,000	200	100
Copper------	50	50	30	20
Lanthanum---	200	150	100	100
Lead--------	70	50	30	20
Manganese---	1,000	300	700 [1]1,000	500
Molybdenum--	L	15	L	L
Nickel------	100	100	70	30
Silver------	0.5	5	0.5	0.5
Vanadium----	150	200	150	100
Yttrium-----	200	100	50	50
Zinc--------	L	700	L	L

[1]Mesozoic rocks only.

cumulative percent frequency, suggesting a threshold of 100 ppm, the same as in table 5.

Statistical data for barium, manganese, and yttrium are summarized in table 7; these elements are treated in less detail than the preceding ones because they are less significant for evaluation of mineral resources in the study area. Boron was determined only for samples that contained at least 70 ppm (54 samples), and zirconium only for samples that contained at least 500 ppm (13 samples). Silver was detected in only four samples, molybdenum in only three, and gold in only two. The other elements were scanned spectrographically and either were not detected or were detected only in background amounts.

Plate 4, map A, shows the localities of all stream-sediment samples (95) that contain anomalous amounts of one of the elements barium, boron, chromium, copper, gold, lanthanum, lead, manganese, molybdenum, nickel, silver, vanadium, and zinc. Copper, nickel, chromium, and vanadium appear to be most closely associated among the elements considered, particularly copper and nickel; lead is less closely associated with vanadium and lanthanum; and zinc, barium, and manganese do not seem to be associated with any other of these elements. These relations can be deduced from plate 4, map A, and some of them are summarized in table 8. Other relationships evident on plate 4, map A, are as follows:

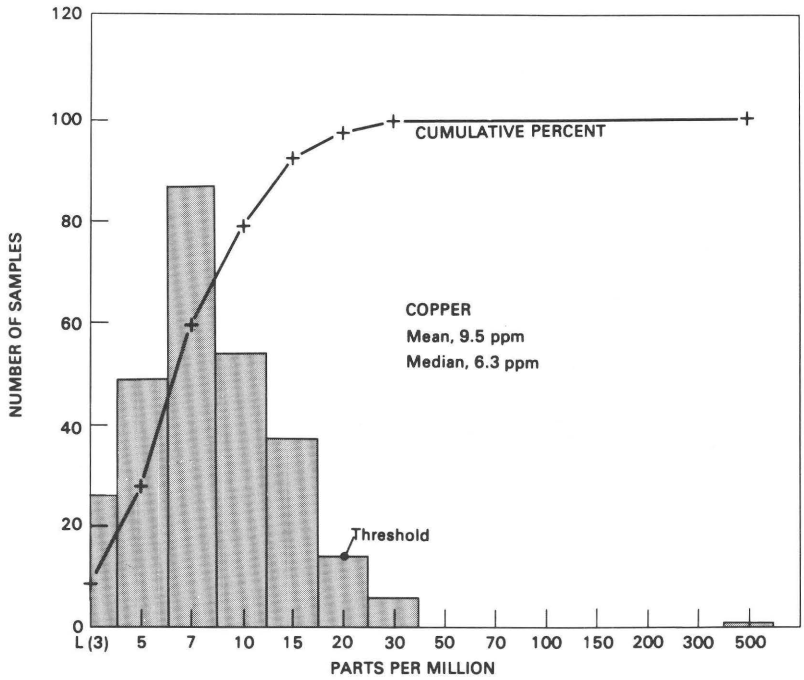
1. The most metal-rich samples, and those anomalous in several elements, are mostly from Bunker and Swift Creeks, whose headwaters are underlain by weakly mineralized or metal-rich Precambrian rocks (see tables 9 and 11), or from drainages such as Jagg, Clear, and Tosi Creeks which are underlain by extensive areas of metal-rich Phosphoria Formation (see tables 13 and 15). West Fork Crystal Creek is an exception because it is a large drainage basin underlain almost entirely by Madison Limestone, yet it yielded eight samples anomalous in at least one element of which six are anomalous in lead, four each in nickel and vanadium, and two each in manganese and zinc. No mineralized or otherwise altered rocks of any appreciable extent were seen in this basin, although a small outcrop of limonitic siltstone containing anomalous amounts of several elements was found in the south fork of the West Fork (sample 0037, table 10). The source of the various metals is unknown. The high zinc content of samples 0244 and 0245, from a tributary drainage in upper Crystal Creek, likewise has no recognized source; this drainage basin is underlain almost entirely by Madison Limestone, and the only altered material sampled in the drainage (sample 0303) contained only background amounts of any element except arsenic (see table 10). Another exception is the upper part of the drainage basin of the Gros Ventre River, from which eight samples anomalous in one or more of the elements barium, copper, lead, manganese, nickel, or vanadium were collected; the area is underlain mainly by Cambrian sedimentary rocks, some of which are known to be high in barium, copper, and vanadium (see tables 13 and 14). A possible exception is the northernmost west-flowing tributary to Flat Creek within the study area, in which four samples are anomalous in copper and (or) nickel, and two are anomalous in boron. Only a small area of Precambrian rocks occurs in this basin, but it could be the source of all three elements.

2. All samples anomalous in lanthanum are from drainages that head in extensive areas of Precambrian rocks (Flat, Bunker, Swift, Shoal, and West Dell Creeks). The lanthanum apparently is derived from those rocks even though only background amounts of lanthanum were detected in all but one Precambrian rock analyzed.

3. About one-half of the samples anomalous in boron, and six of eight samples anomalous in barium, also come from drainages heading in Precambrian rocks; the boron probably is contained in tourmaline derived from those rocks.

4. About one-half of the samples anomalous in manganese are from drainages underlain extensively by Chugwater Formation and Nugget Sandstone, both of which are relatively high in manganese (see table 14).

In summary, 95 of the 277 stream-sediment samples are anomalous in at least one element. Eight of these samples are from drainages north of the study area, and



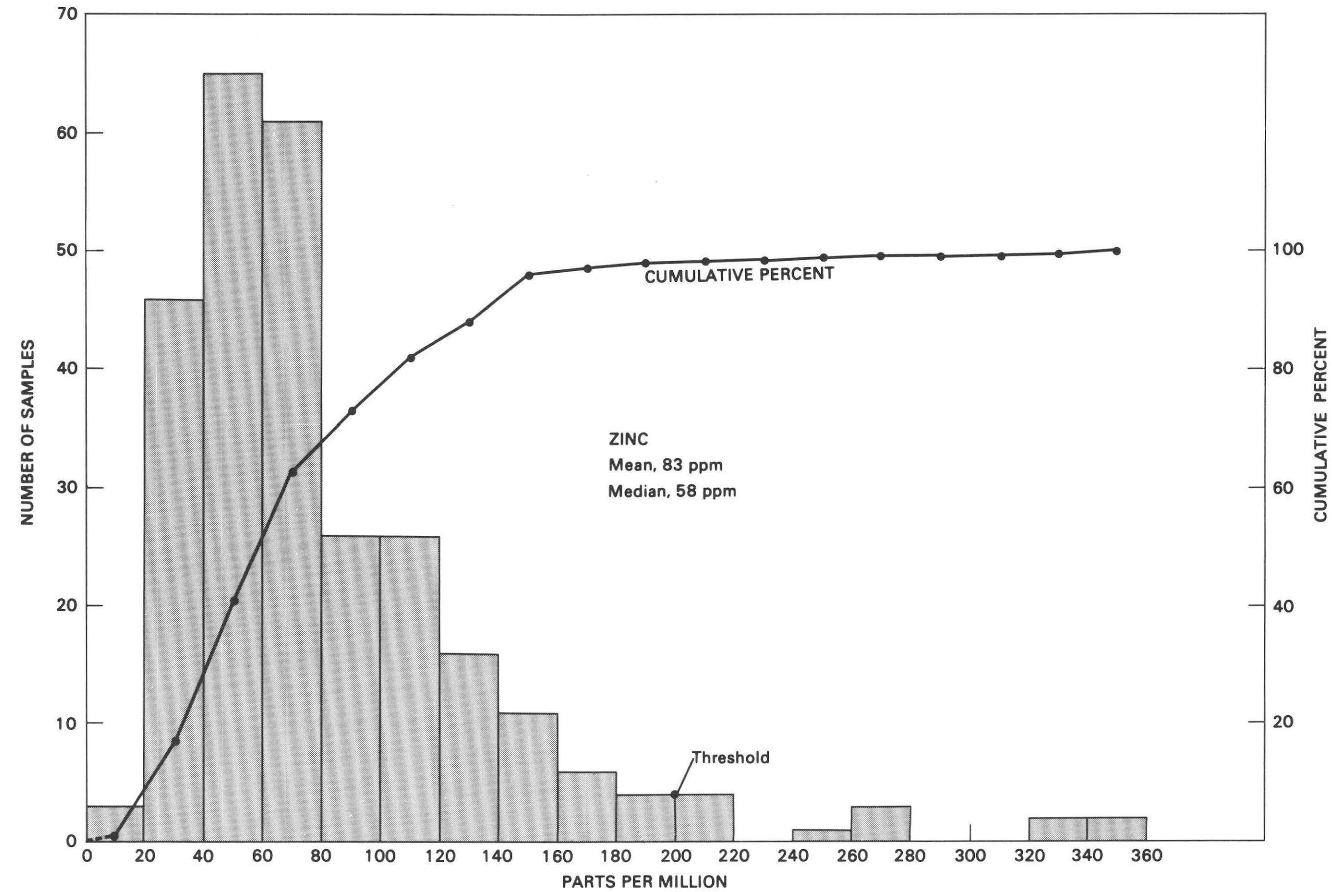
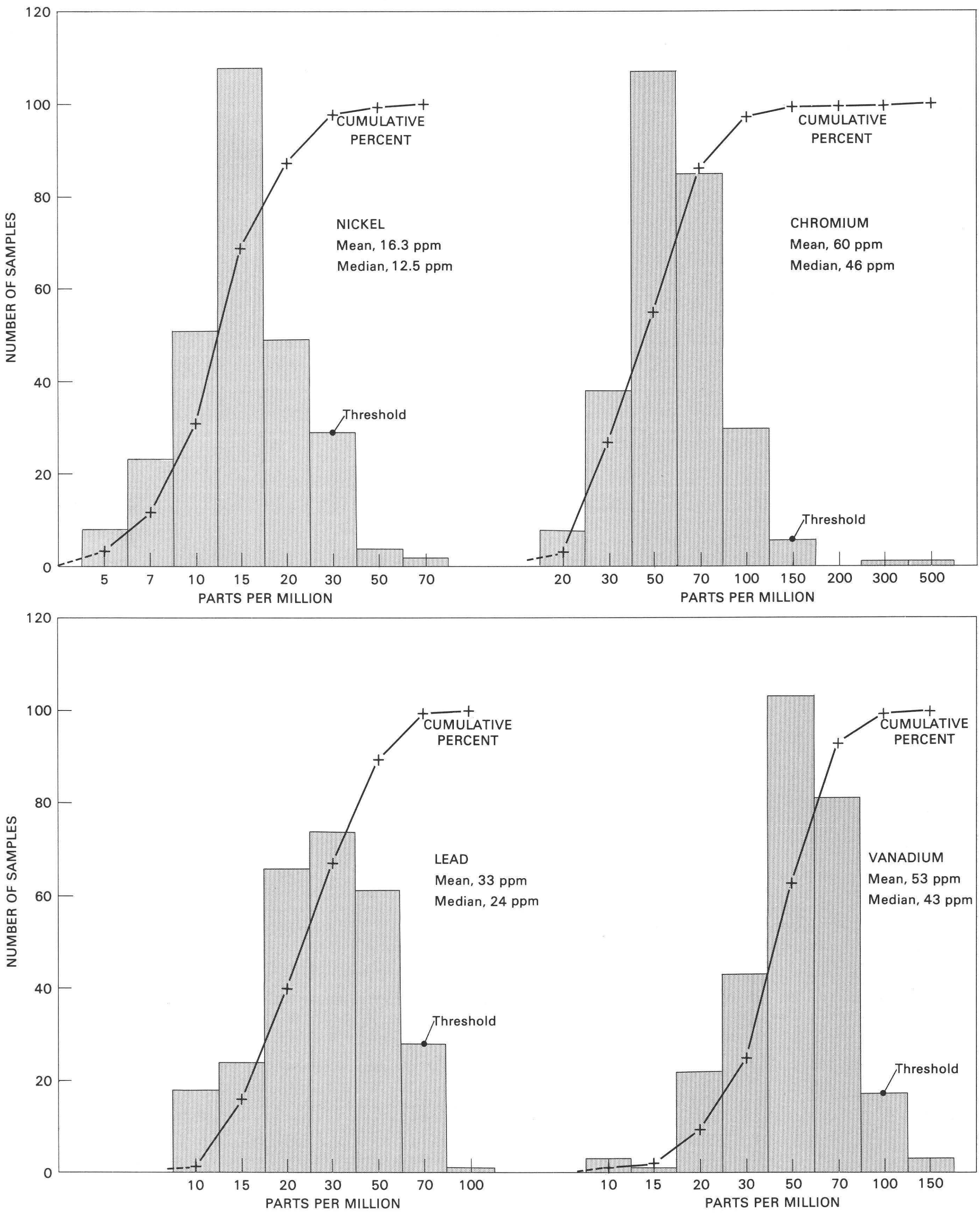


Figure 7(above and facing page). Histograms and cumulative frequency curves showing distribution of 6 elements in 277 stream-sediment samples from the Gros Ventre wilderness study area. Abscissa for zinc is arithmetic; for other elements, logarithmic. L, detected but below limit of determination; value arbitrarily set at 3 ppm.



NUMBER OF SAMPLES
CUMULATIVE PERCENT
NICKEL
Mean, 16.3 ppm
Median, 12.5 ppm
Threshold
PARTS PER MILLION
CUMULATIVE PERCENT
CHROMIUM
Mean, 60 ppm
Median, 46 ppm
Threshold
PARTS PER MILLION
NUMBER OF SAMPLES
CUMULATIVE PERCENT
LEAD
Mean, 33 ppm
Median, 24 ppm
Threshold
PARTS PER MILLION
CUMULATIVE PERCENT
VANADIUM
Mean, 53 ppm
Median, 43 ppm
Threshold
PARTS PER MILLION

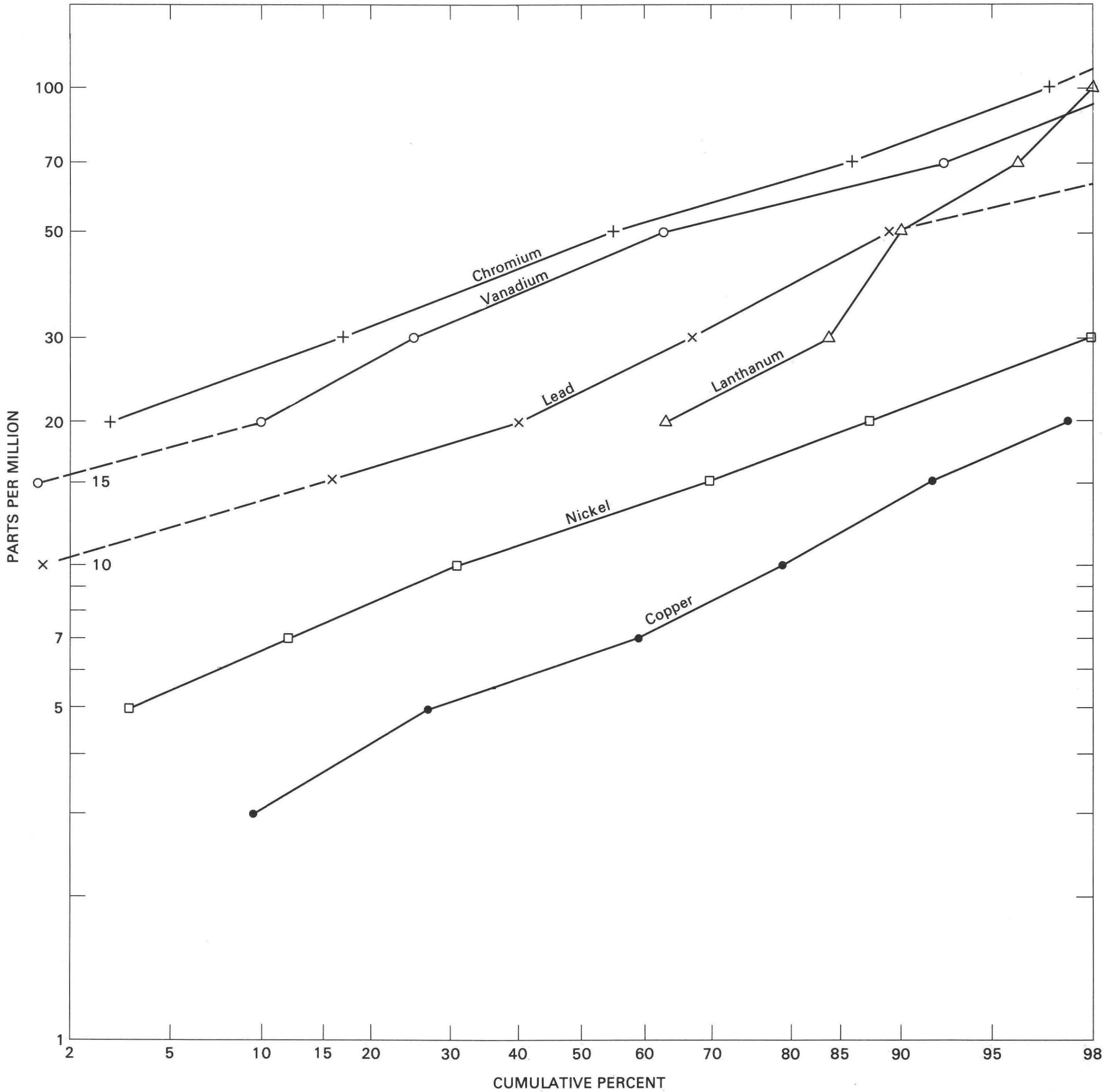


Figure 8. Log-probability graph of 6 elements in 277 stream-sediment samples from the Gros Ventre wilderness study area. Dashed line segments are projections toward cumulative percentages <2 or >99.

seven are from east of the study area. The anomalous elements in most of the samples from within the study area can be interpreted either as having been derived from widely but weakly mineralized Precambrian rocks or as having been original constituents of rocks in the respective drainage basins. Most of the remaining anomalous samples appear to be no more than random occurrences expectable with normal or lognormal distribution of a given element in a group of samples.

Table 7. Means, medians, and thresholds for barium, manganese, and yttrium in 277 stream-sediment samples, Gros Ventre wilderness study area

Element	Mean	Median	Threshold
Barium------	388	270	1,000
Manganese---	452	310	1,000
Yttrium-----	21	16	50

Table 8. Relationships among eight elements in stream-sediment samples, Gros Ventre wilderness study area

Element (total number of samples anomalous)	Number of samples anomalous							
	Chromium	Copper	Lanthanum	Manganese	Nickel	Lead	Vanadium	Zinc
Chromium (8)------	8	5	2	2	6	3	6	4
Copper (21)-------	5	21	1	5	16	6	9	3
Lanthanum (10)----	2	1	10	1	3	5	3	0
Manganese (21)----	2	5	1	21	5	5	3	1
Nickel (35)-------	6	16	3	5	35	9	14	5
Lead (29)---------	3	6	5	5	9	29	10	2
Vanadium (20)-----	6	9	3	3	14	10	20	3
Zinc (12)---------	4	3	0	1	5	2	3	12

Table 9. Samples of Precambrian mineralized or altered rocks that contain anomalous amounts of one or more selected elements, Gros Ventre wilderness study area

[Spectrographic analyses, in parts per million. L, detected but below limit of determination; leaders (---), less than anomalous amounts]

Sample No.	Description	Elements analyzed							
		Ag	Ba	Cr	Cu	Mo	Ni	V	Other
3003	Hematitic zone 2-4 in. (5-10 cm) wide, between gneiss and pink granite.	---	---	---	50	---	---	---	
3004	Magnetite veinlets in fault zone in altered gray granite.	---	---	---	---	70	---	200	
3005	Magnetite-bearing fault zone in amphibolite.	---	---	---	---	15	---	---	
3103	Magnetite-bearing small fault zone in pink granite.	1	---	---	---	---	---	---	Pb (20,000), Au (20), Bi (30), Sn (50),Y (1,000).
3137	Limonitic breccia along major fault in granite and gneiss.	0.7	1,000	---	500	10	---	---	
3147	Prospect pit on silicified magnetite-bearing fault zone in pink granite.	---	---	---	---	---	---	200	Sn (20).
3154	Prospect pit in pyritic metavolcanic rocks.	---	1,000	---	100	---	---	---	
3161	Silicified fault zone 4 ft (1.2 cm) wide containing carbonate cement and chalcopyrite.	---	---	---	3,000	---	---	---	
3168	Prospect pit in silicified pink granite on fault containing magnetite.	---	---	---	---	20	---	150	
3169	Quartz-hematite veinlet in pink granite-	---	---	---	---	---	---	---	La (150), Y (700).
3177	Hematite veinlet in pink granite--------	---	---	---	---	20	---	150	
3178	Hematite veinlet in granite-------------	---	---	---	700	---	---	---	
3181	Sulfide veinlet in granite--------------	---	---	2,000	100	---	100	---	La (200).
3182	Magnetite veinlet in granite------------	---	1,000	---	---	---	---	---	
3184	Silicified fault breccia in granite-----	---	---	---	500	---	---	---	
3187	Magnetite veinlets in fault in pink granite.	1	---	500	---	---	150	200	Zn (L).
3188	Limonitic (magnetite?) fault breccia in granite.	---	1,500	---	---	---	---	---	
3190	Magnetite veinlets in fault in pink granite.	---	---	---	---	---	---	500	La (1,000+).
3193	Carbonate-cemented fault zone 30 ft (9 m) wide in pink granite.	---	---	1,000	---	---	---	---	Mn (5,000).
3195	Limonitic (magnetite?) fault breccia in pink granite.	---	---	---	---	20	---	150	
3198	Hematite veinlet in pink granite--------	---	---	150	---	---	---	---	Co (70).
3213	Brecciated granite----------------------	---	1,000	---	---	---	---	---	

Table 10. Samples of mineralized rock of Cambrian and younger age that contain anomalous amounts of one or more elements, Gros Ventre wilderness study area

[Data for iron in percent, for other elements in parts per million. Iron determined by atomic absorption, other elements spectrographically. L, detected but below limit of determination; n.a., not analyzed; leaders (---), less than anomalous amounts]

Sample No.	Lithology	Formation	Elements									
			Ag	Cr	Cu	Fe	Mo	Ni	Pb	V	Zn	Other
0037	Limonitic siltstone	Madison	2	---	---	n.a.	70	200	70	300	500	
0053	Jasperoid	Phosphoria	1	---	---	n.a.	20	---	---	---	---	
0280	Hematite nodules	Amsden	---	---	---	[1]20+	70	---	70	1,000	---	
0282	Vein material associated with calcite vein.	Madison	---	---	---	n.a.	70	150	---	150	---	Ba (5,000), Mn (5,000), Co (700).
0295	Limonite pellets	Darby	---	---	70	42	---	---	---	---	---	
0303	Fault breccia, Pyramid Peak fault.		---	---	---	n.a.	---	---	---	---	---	As (300).
0304	Hematite nodules	Amsden	---	---	---	46	150	---	100	1,000	---	
0305	Hematite nodules	Amsden	---	---	---	50	150	---	---	200	---	
0313	Hematite nodules	Amsden	---	---	---	[1]20+	150	---	---	1,500	---	
0343	Hematitic shale	Amsden	7	700	200	.3	L	100	500	150	200	
0344	Ocher veinlet	Madison	---	200	---	37	20	---	---	700	---	
0367	Nodular hematite bed.	Amsden	---	---	---	7	---	---	---	---	---	
0368	Limonitic shale	Amsden	---	---	---	27	30	---	---	500	---	
0379	Limonitic sandstone	Amsden	---	---	---	20	5	---	---	---	---	
0383	Fault zone	Madison	---	---	300	n.a.	---	---	---	---	---	
3176	Fault breccia	Flathead	---	---	---	n.a.	10	---	---	---	---	

[1]Spectrographic analysis.

Results of Rock Sampling

Localities of all rock samples are shown on plate 3, and localities of all samples that contain anomalous amounts of at least one element of possible economic interest are shown on plate 4, map B. Rock samples are discussed in two groups: mineralized or altered rocks (plus soils), and apparently unmineralized rocks.

Sampling of Mineralized Rocks

Samples of 60 mineralized or altered rocks and three soils were collected; the rock samples comprised 40 from rocks of Precambrian age and 20 from rocks of Cambrian and younger ages.

Precambrian Rocks

Most samples of mineralized Precambrian rocks are from narrow fault or fracture zones that cut granite and contain a little magnetite or hematite. A few fractures contain pyrite or other sulfide minerals. Molybdenum has been reported from upper Swift Creek but only traces of molybdenite (molybdenum sulfide) were found. Small amounts of jade were found in upper Swift Creek; the mineral was identified by Forest Root of the Wyoming Geological Survey.

Twenty-two samples in which unusual amounts of one or more elements were determined are listed in table 9 and shown on plate 4, map B. The most metal-rich sample is sample 3103, from a narrow fault zone in pink granite in the headwaters of Bunker Creek 4,500 ft (1,375 m) northwest of Pinnacle Peak; it contains 2 percent lead, is one of two rock samples in which tin was determined (50 ppm), and is the only rock sample in which gold (20 ppm) and bismuth (30 ppm) were determined. Although several samples indicate that some mineralization has occurred in the Precambrian rocks (sample 3004—70 ppm molybdenum; sample 3103—various metals; samples 3137, 3161, 3178, and 3184—500 to 3,000 ppm copper), none of the samples represents more than a small volume of rock.

Cambrian and Younger Rocks

Samples of 20 mineralized or altered rocks ranging in age from Cambrian to Permian and of three soils

Table 11. Samples of Precambrian rocks that contain anomalous amounts of one or more selected elements, Gros Ventre wilderness study area

[Spectrographic analyses, in parts per million. L, detected but below limit of determination; leaders (---), less than anomalous amounts]

Sample No.	Elements							
	Ba	Co	Cr	Cu	Ni	Pb	V	Other
				Granite and granitic gneiss				
0003	---	---	---	---	---	70	---	
3006	2,000	---	---	---	---	---	---	
3007	1,000	---	---	---	---	---	---	
3009	1,000	---	---	---	---	---	---	
3021	---	50	---	70	100	---	2,000	
3112	---	100	1,500	---	100	---	---	
3123	2,000	---	---	---	---	---	---	
3124	---	---	---	---	---	---	150	Y (200), La (70).
3144	1,000	---	---	---	---	---	---	
3146	1,000	---	---	---	---	---	---	
3151	---	100	---	---	---	---	150	Be (15).
3155	1,000	---	---	---	---	---	---	
3157	1,500	---	---	---	---	---	---	
3160	1,000	---	---	---	---	---	---	
3174	1,000	---	---	---	---	---	---	
3208	1,000	---	---	---	---	---	---	
				Amphibolite and ultramafic rocks				
3002	---	---	---	---	100	---	---	
3010	---	70	---	---	---	---	---	
3019	---	---	---	50	---	---	---	
3106	---	---	---	---	100	150	200	
3108	---	70	5,000	---	500	---	150	
3113	---	---	---	50	---	---	150	
3138	1,000	---	200	---	---	---	---	
3153	---	70	2,000	---	1,500	---	---	Zn (L).
3170	---	70	1,500	100	700	---	---	
3199	---	70	1,000	---	200	---	---	

overlying major fault zones were analyzed spectrographically, and eight of the rock samples were analyzed quantitatively for iron. Sixteen samples in which unusually large amounts of one or more elements were determined are listed in table 10 and are shown on plate 4, map B. No unusual amounts of any element were found in any soil samples or in four of the rock samples.

Seven of the samples are of hematitic shale or sandstone, or of hematite nodules, from the Amsden Formation. The highest iron content was 50 percent, equivalent to about 70 percent hematite.

Sample 0282, loose lumps of fine-grained, soft, black material that apparently is associated with a vein of banded calcite 3-4 ft (0.9-1.2 m) wide cutting Madison Limestone north of Pyramid Peak, contains a peculiar suite of metals—cobalt, nickel, vanadium, molybdenum, and a little copper, as well as manganese and barium. The sample locality is near the Pyramid Peak fault and the enclosing rocks are folded and faulted. Two small barren prospect pits are a short distance downhill from the sampling site.

Sampling of Unaltered Rocks

Precambrian Rocks

Samples of 66 Precambrian rocks comprise 32 of granite, 10 of amphibolite, 5 of granitic gneiss, 5 of ultramafic rocks, and 14 of other rocks, mainly mylonite and fault breccia. Twenty-six samples contain anomalous amounts of at least one element, and these samples and the respective elements are listed in table 11 and are shown on plate 4, map B. Anomalous amounts of beryllium, lanthanum, yttrium, and zinc occurred in only one sample each, and no sample contained anomalous amounts of boron, manganese, molybdenum, or silver.

Cambrian and Younger Rocks

Shales.—Shales of the study area were more thoroughly sampled than other sedimentary rocks because of the possibility that they might contain economic concentrations of various elements and might be a source of anomalous amounts of these elements in stream-sediment samples (Krauskopf, 1955, p. 417, table II; Vine and Tourtelot, 1970). Analytical results show relatively high concentrations of some elements.

Eighty-one samples of shale and mudstone were analyzed; of these, 24 were black shales, mostly from the Phosphoria Formation. Analytical data are summarized in table 12. The Phosphoria black shales are higher in silver, chromium, lanthanum, nickel, yttrium, and zinc than Vine and Tourtelot's average black shale, are about the same in manganese, molybdenum, lead, and vanadium, and are lower in barium and copper. They are appreciably higher, in all elements but barium and manganese, than the non-black shales from the study area.

Seventeen samples of black shale and 26 samples of other shale contain unusually large amounts of at least one element; these samples and the respective elements are listed in table 13 and also appear on plate 4, map B.

Sandstones, conglomerates, and siltstone.—The 22 sandstones sampled comprise 5 of Flathead Sandstone, 4 of the Darwin Sandstone Member of the Amsden Formation, 2 of the Amsden Formation, 4 of the Nugget Sandstone, 1 each of the Sundance Formation, Cloverly-Morrison(?) Formations, and Mesaverde Formation, and 4 of the Shooting Iron Ranch sequence. The two

Table 12. Content of 13 elements in shales from the Gros Ventre wilderness study area and other areas

[Gros Ventre samples analyzed by semiquantitative spectrography; (20), lower limit of determination; L, detected but below limit of determination; N, not detected; leaders (---), no data available; Max., maximum]

	Element concentration, in parts per million												
	Ag (0.5)	B (70)[1]	Ba (20)	Cr (10)	Cu (5)	La (20)	Mn (10)	Mo (5)	Ni (5)	Pb (10)	V (10)	Y (10)	Zn (200)
Black shale from Phosphoria Formation, average of 11 samples plus average of 9 samples from a single locality													
Average-	3	165	275	800	25	75	140	12	80	25	130	70	[2]515
Range---	N-5	Max. 500	70-700	200-1,500	7-50	20-150	L-300	N-30	10-150	10-100	50-200	20-200	N-1,000
Black shale, average of 4 samples: 1 from Park Shale Member of Gros Ventre Formation and 3 from Mowry Shale													
Average-	N	([3])	600	70	5	30	[4]170	N	12	15	40	15	N
Paleozoic non-black shales, average of 37 samples: 4 from Phosphoria Formation, 21 from Amsden Formation, 1 from Madison Limestone, 2 from Darby Formation, and 9 from Gros Ventre Formation													
Average-	N	[5]145	280	97	11	37	155	([6])	32	16	76	[7]22	N[8]
Range---	---	Max. 500	200-700	30-300	N-70	N-200	N-500	N-20	5-70	N-30	15-200	N-500	---
Mesozoic non-black shales, average of 9 samples: 2 from Mesaverde Formation, 1 from Cloverly and Morrison(?) Formations, 1 from Mowry Shale, 2 from Sundance Formation, 2 from Chugwater Formation, 1 from Dinwoody Formation													
Average-	N	([9])	470	57	8	21	620	N	16	17	60	16	N
Range---	---	Max. 150	150-1,000	N-150	5-20	L-30	15-2,000	---	L-30	N-30	10-150	10-20	---
Cenozoic non-black shales, average of 10 samples: 6 from Shooting Iron Ranch sequence and 4 from Hoback Formation													
Average-	N	N	315	35	7	21	240	N	15	13	52	13	([10])
Range---	---	---	150-200	N-70	L-10	20-30	70-700	---	10-20	N-30	15-100	10-15	---
Average shale (Turekian and Wedepohl, 1961, table 2)													
	.07	100	580	90	45	92	850	2.6	68	20	130	26	95
Average black shale (U.S. and Canada) (Vine and Tourtelot, 1970, table 3)													
	<1	50	300	100	70	30	150	10	50	20	150	30	<300

[1] Amounts <70 ppm not reported, except as in note 5.
[2] Includes four samples in which zinc was not detected.
[3] Boron reported only in sample 0048 (Park Shale Member, 200 ppm).
[4] Does not include sample 2031 (Mowry Shale, 1,500 ppm).
[5] Includes six samples that contain <70 ppm boron.
[6] Molybdenum was detected in only four samples, in amounts ranging from L to 20 ppm.
[7] Does not include sample 0370 (Phosphoria Formation, 500 ppm).
[8] Zinc was detected (L) only in sample 0366 (Amsden Formation).
[9] Boron was reported in amounts ≥70 ppm in only three samples.
[10] Zinc was detected (L) in only three samples.

Table 13. Samples of shale from the Gros Ventre wilderness study area that contain unusually large amounts of one or more minor elements

[Data in parts per million; L, detected but below limit of determination; leaders (---), less than amounts shown in respective columns]

Sample No.	Formation	Element														
		Ag	As	B	Ba	Cd	La	Mn	Mo	Ni	Pb	Zn	Cr	Cu	V	Y
								Black shales								
0016	Phosphoria	5	---	---	---	50	150	---	---	---	---	700	1,000	---	---	200
0035	--do.	---	---	---	700	---	---	---	20	150	---	1,000	1,500	50	200	100
0048	Gros Ventre (Park Shale Member)	---	1,500	---	500	---	---	---	---	---	---	---	---	---	---	---
0082	Phosphoria	5	---	---	---	---	---	---	20	---	---	---	1,000	---	200	---
0177	--do.	---	---	500	500	---	---	300	30	150	---	1,000	1,500	50	---	---
0291	Phosphoria	---	---	---	500	---	---	---	---	---	100	---	1,500	---	---	---
0301	--do.	---	---	---	---	---	---	---	15	---	---	1,000	---	---	---	---
0309	--do.	5	---	---	---	70	150	---	---	---	---	1,000	1,000	---	---	150
0329	--do.	5	---	---	---	---	150	---	---	---	---	---	---	---	---	150
0404[1]	--do.	---	---	300	---	50	---	300	20	---	---	700	---	---	---	---
0405	Phosphoria	---	---	---	---	---	---	---	20	---	---	---	---	---	---	---
0407	--do.	---	---	300	---	---	---	---	20	100	---	---	1,000	50	200	---
0408	--do.	5	---	300	---	---	---	300	20	100	---	---	---	50	200	---
0411	--do.	---	---	300	---	---	---	300	20	100	---	---	---	50	---	---
0414	--do.	---	---	300	---	---	---	300	20	100	---	---	---	50	---	---
2029	Mowry	---	---	---	700	---	---	---	---	---	---	---	---	---	---	---
2031	--do.	---	---	---	700	---	---	1,500	---	---	---	---	---	---	---	---
								Shales								
0079	Amsden	---	---	---	---	---	---	---	---	---	---	---	---	---	---	70
0118	Gros Ventre (Wolsey Shale Member)	---	---	---	700	---	---	---	---	---	30	---	---	---	---	50
0176	Dinwoody	---	---	---	---	---	---	2,000	---	---	30	---	---	---	---	---
0212	Gros Ventre (Wolsey Shale Member)	---	---	---	700	---	---	---	---	---	---	---	---	---	---	---
0213	Gros Ventre (Death Canyon Limestone Member)	---	---	---	700	---	---	---	---	---	30	---	---	---	---	---
0238	Phosphoria	---	---	---	---	---	---	---	---	---	---	---	200	---	---	---
0252	Sundance	---	---	---	1,000	---	---	---	---	---	---	---	---	---	---	---
0253	Chugwater	---	---	---	---	---	---	1,000	---	---	---	---	---	---	---	---
0283	Gros Ventre (Park Shale Member)	---	---	---	1,000	---	---	---	---	---	---	---	---	50	---	---
0287	Amsden	---	---	300	---	---	---	---	15	---	---	---	---	---	---	---
0288	Amsden	---	---	300	---	---	---	---	5	---	---	---	---	---	---	---
0306	--do.	---	---	---	---	---	100	---	---	70	---	---	---	---	---	50
0366	--do.	---	1,000	---	---	---	---	---	20	---	---	---	---	---	200	---
0370	Phosphoria	---	---	---	---	---	200	---	---	---	---	---	300	---	200	500
0384	Gros Ventre (Park Shale Member)	---	---	300	---	---	---	---	---	70	30	---	---	70	---	---
0387	Amsden	---	---	---	---	---	---	---	---	---	30	---	---	30	---	---
0402	Gros Ventre (Park Shale Member)	---	---	500	---	---	---	---	---	70	---	---	---	30	150	---
1001	Amsden	---	---	300	---	---	---	---	---	70	---	---	---	---	---	---
2001	Shooting Iron Ranch Sequence	---	---	---	---	---	---	---	---	---	---	L	---	---	---	---
2003	--do.	---	---	---	---	---	---	---	---	---	---	L	---	---	---	---
2005	Shooting Iron Ranch Sequence	---	---	---	---	---	---	---	---	---	---	L	---	---	---	---
2011	--do.	---	---	---	---	---	---	700	---	---	---	---	---	---	---	---
2014	Hoback	---	---	---	---	---	---	---	---	---	30	---	---	---	---	---
2018	Cloverly and Morrison(?)	---	---	---	---	---	---	---	---	---	---	---	---	---	150	---
2020	Mesaverde	---	---	---	700	---	---	---	---	---	---	---	---	---	---	---
2032	Mowry	---	---	---	700	---	---	---	---	---	---	---	---	---	---	---

[1] Samples 0404 to 0414, inclusive, are from a section of black shale and phosphorite at a single locality on Clear Creek.

conglomerates are from the Hoback Formation (Skyline Trail Conglomerate Member) and Shooting Iron Formation, and the siltstone is a dolomitic variety from the Chugwater Formation. The only unusual amounts of any elements found in these rocks are shown in table 14, and sample localities are shown on plate 4, map B. None of these amounts seem to indicate a possible mineral resource. A panned concentrate of weathered rock at the base of the Flathead Sandstone at triangulation station GROS (sample 2036, not shown in table 14) has 300 ppm lanthanum and 700 ppm yttrium, presumably contained in monazite and xenotime.

Love and Antweiler (1973) reported that the Nugget Sandstone, in places south and west of the Gros Ventre Range, was bleached white to green on or near the crests of anticlines and contained anomalous amounts of copper, silver, and zinc. No similar combination of bleaching and structure was found in the study area, although the Nugget is locally bleached white. Copper was detected in only one sample.

Phosphatic rocks.—Phosphorite and phosphatic mudstone and chert make up a small part of the map unit Phosphoria Formation and related strata of Permian age. The Phosphoria Formation is extensive near the northeast edge of the study area and also underlies smaller areas between Shoal Creek and Elbow Draw in the southeast part of the area and near Horse Creek just southwest of the area (pl. 1; pl. 4, map D). Phosphorite samples from 19 places along the northeast outcrop belt and one site in the southeast outcrop area were analyzed for phosphorus and other elements. Analytical data on the 26 samples collected appear in table 15; data for 3 phosphatic mudstones and 1 phosphatic chert also are given, as well as modal values (see footnote 7, table 15) for 60 samples of phosphorite from the Phosphoria in other parts of the western United States. Phosphorites from the study area are noticeably lower in copper, molybdenum, and nickel, and higher in lead than phosphorites from other areas, but otherwise they seem typical in their minor element content.

Other rocks.—None of the 15 limestones (14 of Madison Limestone and 1 of Park City Formation) or the coal sample from the Mesaverde Formation contain unusual amounts of any element. The average contents, in parts per million, of 9 elements in 14 samples of Madison Limestone are as follows; the maximum values reported are shown in parentheses. No other elements were detected.

Barium	20	(200)	Manganese	40	(200)
Chromium	1.4	(20)	Nickel	<1	(5)
Copper	2	(20)	Vanadium	6	(20)
Lanthanum	7	(20)	Yttrium	<1	(10)
Lead	3.5	(20)			

Bentonites from the Hoback Formation and Shooting Iron Ranch sequence contain 1,500 ppm and 2,000 ppm manganese, respectively.

Table 14. Samples of clastic rocks that contain anomalous amounts of selected elements, Gros Ventre wilderness study area

[Data in parts per million; leaders (---), less than amounts shown in respective columns]

Sample No.	Formation	Lithology	Element Ba	B	Cu	Cr	Mn	V	Zn
0032	Amsden (Darwin Sandstone Member)	Sandstone	---	---	---	---	700	---	---
0033	do.	do.	200	70	---	---	---	---	---
0051	do.	do.	---	70	---	---	---	---	---
0052	Amsden	do.	---	70	---	200	---	---	---
0215	Flathead	do.	700	---	---	---	---	---	---
0236	Nugget (bleached)	Sandstone	200	---	---	---	---	---	---
0237	do.	do.	300	---	---	---	---	---	---
0254	Chugwater	Siltstone	---	---	---	---	1,000	---	---
0382	Amsden	Sandstone	300	---	---	---	700	---	---
1009	Nugget	do.	---	---	---	---	1,000	---	---
1010	Nugget	Sandstone	1,000	100	30	---	---	---	---
2004	Shooting Iron Ranch sequence	do.	---	---	---	100	---	---	---
2009	do.	do.	500	---	---	---	---	100	200
2019	Hoback (Skyline Trail Conglomerate Member)	Conglomerate	---	---	---	---	1,500	---	---
2023	Mesaverde	Sandstone	1,000	---	---	---	---	---	---
2033	Sundance	Sandstone	---	---	---	---	700	---	---
2034	Cloverly-Morrison(?)	do.	---	---	---	---	500	---	---
2035	Flathead	do.	700	---	---	---	---	---	---
2037	do.	do.	1,500	---	---	---	---	---	---

Table 15. Amounts of selected elements in phosphorite, phosphatic mudstone, and phosphatic chert, Phosphoria Formation, Gros Ventre wilderness study area, and modal values in 60 samples of phosphorite from the Phosphoria Formation in the western U.S.

[Semiquantitative spectrographic analyses in parts per million (ppm), except as noted; lower limit of determination for each element except phosphorus is given in parentheses. L, detected but below limit of determination; N, not detected; leaders (---), no data]

Sample No.	Thickness (in.)	Thickness (cm)	P[1]	Ag (0.5)	B (70)[2]	Ba (20)	Cr (10)	Cu (5)	La (20)	Mn (10)	Mo (5)	Ni (5)	Pb (10)	V (10)	Y (10)	Zn (200)	
Phosphorites (26 samples)																	
0015	---	---	12	N	---	200	1,500	10	500	50	N	10	15	500	700	N	
0017	12-24	30-60	9	3	70	300	1,500	20	1,000	150	N	50	20	70	1,000	1,000	
0034	24	60	12	N	---	200	1,000	15	500	N	N	[3]L	150	500	500	N	
0054	6	15	12	5	---	200	1,000	15	500	30	20	15	100	500	500	N	
0080	2-3	5-7.5	12	5	---	300	500	5	1,000	150	5	7	30	300	1,000	N	
0081	4	10	12	5	---	150	700	30	500	50	7	30	20	100	700	500	
0084	4	10	12	N	---	150	700	10	500	20	N	7	20	500	500	N	
0103	---	---	12	N	---	200	700	5	500	70	N	5	20	300	700	N	
0124	2	5	3	1.5	---	200	1,000	10	700	50	N	15	500	300	700	N	
0178	10	25	9	.7	---	150	500	15	500	150	N	50	30	70	300	1,000	
0179	---	---	9	7	---	150	700	15	300	10	N	30	30	200	200	1,000	
0204	2-6	5-15	9	2	---	150	500	7	200	100	N	5	200	200	500	N	
0205	---	---	6	1.5	---	100	500	7	150	50	10	50	20	70	300	500	
0290	120	300	12	2	---	150	300	L	200	10	N	7	30	100	300	L	
0296	few	---	6	1.5	---	50	300	7	200	50	N	20	15	50	200	500	
0298	---	---	9	.5	---	70	500	10	300	70	N	30	20	20	300	300	
0300	24	60	12	N	---	70	500	10	200	20	N	20	70	200	200	300	
0302	few	---	12	N	---	150	300	L	200	70	5	5	20	150	300	N	
0308	6-8	15-20	6	1	---	70	300	7	300	100	N	30	20	50	300	700	
0319	6	15	6	1	---	100	500	15	200	50	N	50	20	70	300	700	
0327	---	---	6	1.5	---	100	200	20	500	30	10	50	70	150	500	N	
0328	---	---	12	2	---	70	700	30	200	L	N	10	30	150	200	N	
0369	48-60	120-150	12	---	---	--	---	---	---	---	---	---	---	---	--	---	
0406	12	30	6	5	70	1,000	700	20	200	700	N	30	30	70	300	1,500	
1002	6	15	9	N	---	200	1,500	10	500	L	L	10	70	200	500	N	
1003	8	20	4.5	3	---	150	1,000	10	500	50	5	20	15	70	500	300	
Average (unweighted)-			9.3	1.9	---	150	705	12	415	[4]54	---	23	[5]43	195	460	[6]320	
Modal values in 60 samples[7]--------			13.4	3	---	100	1,000	100	300	30	30	100	<10	300	300	300	90(U)
Phosphatic mudstones (3 samples)																	
0318	18	45	.6	N	100	200	300	10	20	200	7	50	15	100	20	N	
0409	12	30	.3	N	70	100	300	10	20	700	N	30	10	50	10	N	
0412	12	30	.2	.5	70	200	150	15	20	700	N	70	L	70	L	500	
Phosphatic chert (1 sample)																	
2024	---	---	---	N	---	70	100	N	20	200	N	10	15	30	20	N	

[1]Values for phosphorus are in percent.
[2]Amounts <70 ppm not reported.
[3]For calculating averages, L is assumed to equal one-half of lower limit of determination.
[4]Does not include sample 0406.
[5]Does not include sample 0124.
[6]Average zinc content for 12 samples in which zinc was detected is 690 ppm.
[7]Most frequent value reported in spectrographic analysis; data from Gulbrandsen (1966, table 1, col. 63).

MINERAL COMMODITIES

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This section summarizes the distribution, abundance, and resource potential of fuels, minerals, metals, and other mineral commodities in the study area. Oil and gas possibilities are discussed at some length, commensurate with our belief that a moderate resource potential exists near to, and perhaps within, part of the study area. Phosphate rock is also treated in some detail because phosphatic rocks crop out over, or underlie, a large part of the study area. Discussions of the metals are brief because none of them is believed to have more than a low resource potential.

No exploratory drilling for oil or gas has been done within the study area. A well drilled in 1977 on Granite Creek about 5 mi (8 km) southwest of the study area had numerous shows of gas but it is uncertain as yet whether in commercial amount. Two dry holes were drilled on Tosi and Rock Creeks, respectively, a few miles southeast of the study area, and other dry holes have been drilled a few miles to the south of the study area. No mining has been done within or near the study area except for a small production of coal from a mine on Little Granite Creek 3 mi (5 km) south of the study area. The only prospecting for mineral deposits seems to have been in the Precambrian rocks of upper Swift and West Dell Creeks, in phosphatic rocks of the Phosphoria Formation in several places, in iron-rich rocks of the Amsden Formation on the ridge between Box and Bunker Creeks, and in Madison Limestone in upper West Dell Creek. The U.S. Bureau of Mines contribution to this report gives additional detail on past and present mines and prospects in and near the study area.

Oil and Gas

The Gros Ventre Range is a Precambrian-cored anticlinal uplift that separates Jackson Hole, a complex structural downwarp, on the north, from the Green River Basin, one of the largest and deepest structural basins in Wyoming, on the south. The Green River Basin contains many oil and gas fields. The southwest flank of the Gros Ventre Range is marked by the Cache Creek thrust fault, along which the range has overridden all potential oil- and gas-producing horizons. The Wyoming-Idaho thrust belt, which impinges on the southwest margin of the Gros Ventre Range, is a series of large thrust masses of Paleozoic and Mesozoic rocks, without Precambrian cores, at least in the Wyoming part. This belt has been the site of intensive oil and gas exploration, beginning in 1976, when several productive fields were found in overriding blocks in southwestern Wyoming.

Two features in or near the study area merit discussion: (1) the Tosi and Rock Creek anticlines, which are in the Gros Ventre Range, and (2) the north margin of the Green River Basin, which was overridden by the Gros Ventre Range. Of these, only the latter appears to have a potential for oil and gas resources.

The Tosi Creek and Rock Creek anticlines extend eastward and southeastward from the east margin of the area. The Tosi Creek anticline is shown on plate 1 just north of the southeast corner of the map area; the Rock Creek anticline is southeast of the map area. Both are eroded into the Madison Limestone, and both were drilled to the Bighorn Dolomite. In the drill hole on the Tosi Creek anticline, fresh water was encountered in the Madison (330 ppm total solids) and Darby Formations (183–229 ppm total solids). These amounts are less than that of Tosi Creek (530 ppm total solids) which flows along the anticline (C. L. Baker, written commun., 1956), and the analyses suggest that the anticline could have been flushed of all significant amounts of oil and gas. No water analyses are available from the drill hole on the Rock Creek anticline, but erosion into the Madison, the lack of major closure, the dry hole, and similarity to the nonproductive Tosi Creek anticline suggest that its oil and gas potential also is negligible.

The most significant oil and gas potential of the study area is in the part along and beneath the Cache Creek thrust fault. Three types of oil and gas traps (fig. 9) may be present here: (1) an anticlinal closure on the Little Granite anticline, which disappears northwestward under the Gros Ventre Range and extends southeastward out of the study area; (2) fault traps where reservoir rocks on the up-dip part of the Green River Basin abut against the Cache Creek thrust; and (3) facies and porosity traps in lenticular Cretaceous sandstones on the up-dip flanks of the Little Granite anticline and on the updip part of the Green River Basin under and adjacent to the Cache Creek thrust.

Little Granite anticline.—The Little Granite anticline, a structural trap, has the most promise for oil and gas accumulation. Its relation to the Gros Ventre Range, the Cache Creek thrust, and to the thrust sheets of the thrust belt are shown on figure 9. An arbitrary thickness of about 500 ft (150 m) of Hoback Formation is shown in this figure on the crest of the anticline. The estimate is based on the position of the Hoback Formation where it overlaps, with an angular unconformity, the Upper Cretaceous lenticular sandstone and shale sequence and coaly sequence, about 2 mi (3 km) southeast of the line of section. The northeast flank of the anticline beneath the study area has not been drilled. One dry hole in sec. 27, T. 39 N., R. 114 W., 4 mi (6.4 km) south of the study area, was drilled to a depth of 4,590 ft (1,400 m),

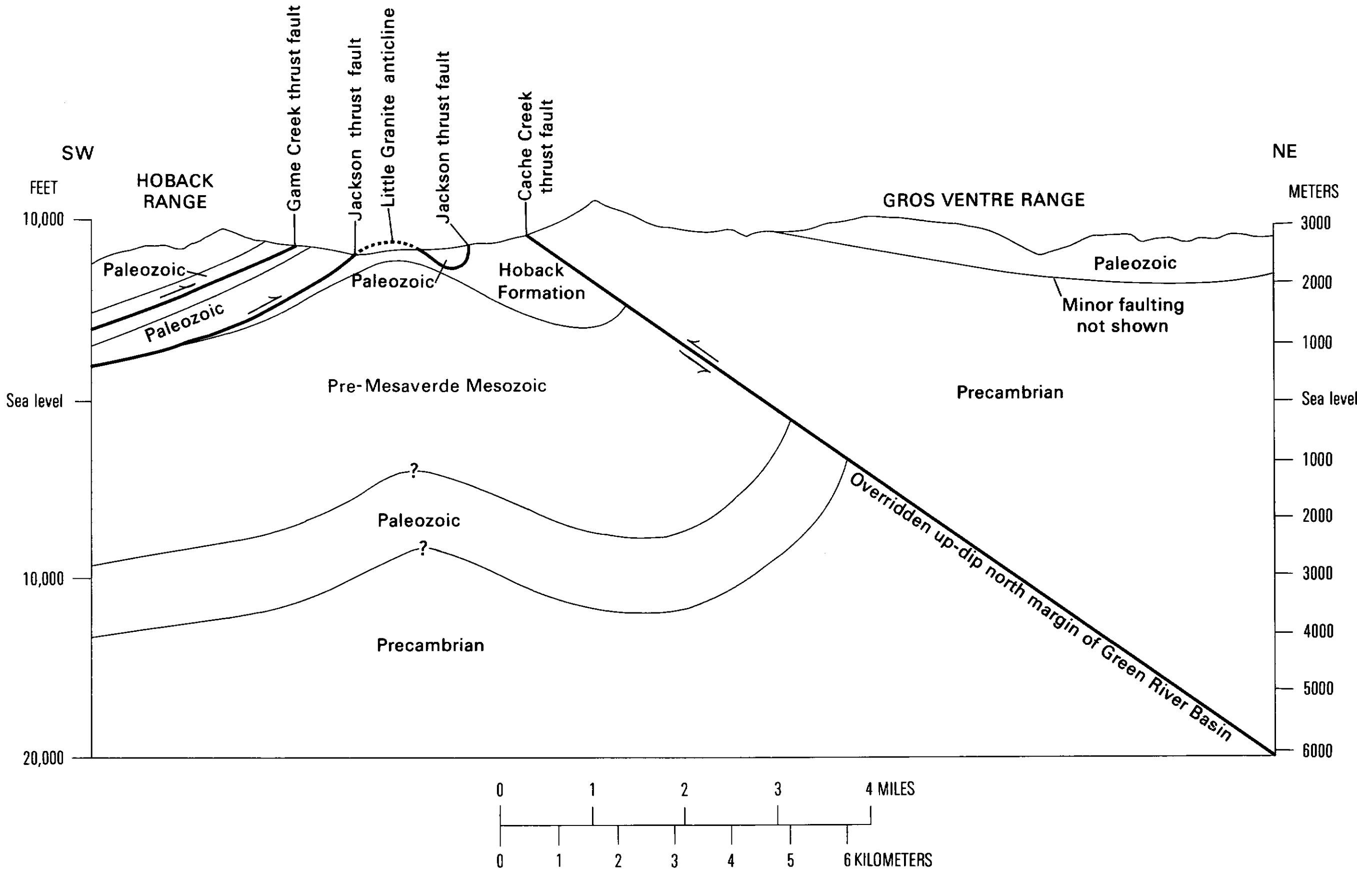

Figure 9. Generalized structure section across the Gros Ventre Range, north end of Green River Basin, Little Granite anticline, and northeast margin of the Wyoming thrust belt. Section about along line *D–D'*, plate 1.

apparently on a separate fold en echelon to the Little Granite Creek anticline.

The following variables are considered in our evaluation of the Little Granite anticline:

1. Reservoir rocks. Potential reservoir rocks are listed in stratigraphic order:

Unnamed lenticular sandstone and shale sequence and coaly sequence.—Unpredictable because of lenticularity of sandstones. Some sandstones are known to be more than 100 ft (30 m) thick, and if they are in a good structural position on the anticline they might yield oil and gas.

Bacon Ridge Sandstone.—A prime target for oil and gas exploration. Sandstones are thick, porous, permeable, largely marine, and are underlain by several thousand feet of marine Cody Shale which is a good source rock. Large gas seeps occur in this sandstone in Jackson Hole, and core holes and oil tests found small amounts of gas.

Cody Shale.—A sandstone about 150 ft (45 m) thick is in the middle of the Cody Shale. It is generally fine grained and tight but is overlain and underlain by thick marine shale that is a good source rock. Either it or a similar sandstone in a comparable stratigraphic position yielded small gas shows in wells in Jackson Hole.

Frontier Formation.—The Frontier is a prime target for exploration in most of Wyoming. Sandstones in this formation yield large amounts of oil and gas in the Bighorn and Wind River Basins to the east and southeast, and the La Barge platform and Moxa arch areas to the south in the Green River Basin. The sandstones are somewhat lenticular and have variable porosity and permeability. In Jackson Hole, good shows of oil and gas were encountered in wells on at least one anticline. A soft porous sandstone 150 ft (45 m) thick near the top of the Frontier is present in the Mobil Oil Co., Camp Davis well 7 mi (11 km) southwest of the Little Granite anticline. If this sandstone and similar ones lower in the section are present on the anticline, they would be excellent targets.

Muddy Sandstone Member of Thermopolis Shale.—This sandstone yields major amounts of oil and gas in many parts of Wyoming. The Muddy has good potential for production from stratigraphic as well as structural traps owing to its lenticularity and variable porosity and permeability. These factors are unknown in the area of the Little Granite anticline but the Muddy could be a good target because it is overlain and underlain by marine black shales that are potential source rocks.

Morrison(?) and Cloverly Formations.—Elsewhere in Wyoming, the Cloverly Formation is a prolific producer of oil and gas. Similar sandstones are present in the Little Granite area so they are considered to be potential hydrocarbon reservoirs, especially because they are overlain by marine black shale and underlain by marine gray shale and petroliferous limy sandstone.

Nugget Sandstone.—This is one of the prime targets on the Little Granite anticline. The sandstone is thick, porous, and permeable. Four mi (6 km) to the north in Jackson Hole, cores of the Nugget on the Sohare anticline were oil-stained, and in the thrust belt to the southwest there has been prolific production of light oil in several fields. The possibility for oil and gas accumulation in the Nugget of the Little Granite anticline probably is excellent.

Phosphoria Formation and related strata.—In the west half of Wyoming, dolomites in the Phosphoria Formation and its equivalents have yielded large amounts of high sulfur oil. The closest good shows to the study area were in the Kucera, Govt. No. 2 well on the Bacon Ridge anticline 4 mi (6 km) east of the map area. Nonflammable gas (nitrogen) was found in the Phosphoria on the Ramshorn anticline 10 mi (16 km) to the north. The Phosphoria equivalents are slightly petroliferous, especially in the black shale and porous dolomite facies, throughout the study area. On the basis of these considerations, the Phosphoria and equivalents are believed to be a prime target, but they would be deep, perhaps 12,000 ft (3,600 m) along the line of section (fig. 9).

Tensleep Sandstone.—The Tensleep Sandstone, 300–350 ft (90–105 m) thick, is a porous and permeable reservoir and is a major oil and gas objective on this anticline. Generally the porosity and permeability are best in the upper part of the formation. Elsewhere in Wyoming, the Tensleep is a prolific producer of high sulfur oil and gas. Slight shows of oil were found in cores in the upper part of the Tensleep in a well on the Red Hills anticline 4 mi (6 km) north of the study area.

Darwin Sandstone Member of the Amsden Formation.—This sandstone is 70–100 ft (21–30 m) thick and has the same general appearance as the Tensleep Sandstone except for being darker, coarser grained, and less brittle. Although casehardened on some outcrops, it is generally moderately porous in subsurface section. It was saturated with highly volatile light oil in the Kucera, Govt. No. 2 well on the Bacon Ridge anticline 4 mi (6 km) east of the study area. This sandstone is considered to be a moderately good target on the Little Granite anticline.

Madison Limestone.—The Madison Limestone, which ranges in thickness from 900–1,100 ft (275–335 m), is considered to have major oil and gas possibilities. It yields high sulfur oil and gas in many fields farther east in Wyoming. In the study area it is petroliferous on all outcrops. Because parts of the limestone section are easily dissolved by ground water, it is the most abundantly cavernous formation in the region. Zones of significant porosity occur near the top and in the lower 100 ft (30 m) of the formation. Partial sections were drilled on the Rock Creek and Tosi Creek anticlines. Baker (1956; also written commun., 1956) reported much water but no oil in the Madison. Both anticlines, however, have been eroded into the Madison so any oil probably escaped long ago to the surface or was flushed out by the water.

Darby Formation.—The Darby Formation, which ranges from 150–350 ft (75–105 m) in thickness, has not yielded any appreciable amounts of oil and gas anywhere in Wyoming, yet it cannot be discounted. Dolomites throughout the area are petroliferous, and wells on both the Rock Creek and Tosi Creek anticlines had oil shows. Dolomites in the Darby on outcrop have low porosity; they would probably need to be brecciated to be a good reservoir rock.

2. Source rocks. Source rocks are abundant, thick, and distributed throughout the section from Devonian to Paleocene. They are described in the section on reservoir rocks. Studies of vitrinite reflectance (a measure of the amount of metamorphism of vitrain) by oil companies show that none of many samples was even moderately metamorphosed, and therefore (although dependent in part on depth of burial and type of organic matter) they have the potential for yielding oil and gas. Gas would be the most likely hydrocarbon to be found below about 20,000 ft (6,100 m) owing to expected high degree of thermal maturation.
3. Structural trap. The Little Granite anticline has more than 5,000 ft (1,525 m) of reversal on both northeast and southwest flanks where it can be measured (fig. 9). The amount of closure to the southeast is not known and to determine it probably will require detailed mapping south of the study area, as well as geophysical work. To the northwest, the anticline disappears under the Cache Creek thrust, which presumably closes it off somewhere outside the southwest part of the study area.
4. Age of folding. The Little Granite anticline was folded after deposition of the Skyline Trail Conglomerate Member of the Hoback Formation in early Eocene time before deposition of the Pass Peak Formation. The anticline was overridden first by the Jackson thrust and later by the Cache Creek thrust. In general, throughout intermontane basins of the Rocky Mountain region, the old folds (early Laramide) tend to be more prolific producers than the younger ones. In terms of this perspective, the Little Granite anticline would be intermediate in age.
5. Competence of fold. In the thrust belt area directly to the southwest, none of the surface anticlines have roots that extend to the Precambrian rocks. To the north, however, in Jackson Hole, all the anticlines

that have been drilled have roots into the Paleozoic and presumably to the Precambrian. Without drilling, the presence of Paleozoic roots under the Little Granite anticline cannot be confirmed, but it is our opinion that the fold involves both Paleozoic and Precambrian rocks, as is shown on figure 9. Whether or not roots are present affects the number of potential oil- and gas-producing zones.

6. Effects of later tilting. Regional studies show that much of the study area was tilted westward in late Cenozoic time, some parts more than others (see discussion of the Shooting Iron Formation in geology section). This tilting would increase the closure on the northwest end of the Little Granite anticline and decrease it on the southeast end. Presumably, this tilting occurred after oil and gas emplacement, if any. To determine the original site of oil and gas accumulation (where at least some of the oil and gas might still remain), which is generally on the apex of an anticline, the fold would have to be rotated upward and clockwise (in a model oriented in the conventional northward direction). The amount of tilting of the original water-oil interface (if any), the amount of oil and gas migration after Pleistocene tilting, and the nature and effects of water drive cannot be determined in an undrilled area. Whether the time interval between Laramide folding and late Cenozoic tilting was sufficient to stabilize the sites of any oil and gas accumulation that may have occurred, and to prevent any Pleistocene migration, is not known. Information on these subjects is critical to evaluate correctly the oil and gas potential on the Little Granite anticline.
7. Depth of erosion. This is not a factor. Erosion has not exposed any potential oil and gas zones.

Traps against the Cache Creek thrust fault.—If the interpretation shown on figure 9 is correct, there would be a minimum of about 5 mi (8 km) displacement at the line of section along the Cache Creek thrust. On outcrops there is a zone of intense to moderate brecciation of the rocks on both sides of the fault, the amount depending on the brittle or plastic nature of the rocks at a given site. Fault slices of Paleozoic and Mesozoic rocks, some many thousands of feet out of stratigraphic position, have been dragged up along the major thrust. Where shales are involved, they could effectively seal off the main and subsidiary fault planes, thereby preventing leakage of oil and gas. Because of the thickness of sedimentary rocks (approximately 4,000 ft (1,220 m) of Paleozoic, 15,000 ft (4,570 m) of Mesozoic, and 13,000 ft (3,960 m) of Paleocene) overridden by Precambrian along the thrust, there is a likelihood of many zones of brecciation in which oil and gas could have accumulated and been sealed off against the thrust. Hydrocarbons could have migrated updip as much as 15,000 ft (4,570 m) from the syncline between the Little Granite anticline and the thrust. Thus, there are good possibilities of oil and gas entrapment against this fault, but more geophysical work is needed to determine the dip of the thrust plane, structural complications below the main thrust, and the depth of the syncline under the thrust.

Facies and porosity traps.—Figure 9 shows the magnitude of updip areas along the flanks of the Little Granite anticline and the syncline to the northeast of it at one line of section. These updip areas will, of course, vary in magnitude and steepness to the northeast and southwest of this section, but it provides a useful example for discussion.

Evaluation of facies traps is dependent largely on adequate data on regional and local lithologic variations in the rock units. Those most likely to have facies traps are, from oldest to youngest, Morrison(?) and Cloverly Formations, Muddy Sandstone Member of Thermopolis Shale, Frontier Formation, Bacon Ridge Sandstone, lenticular sandstone and shale sequence and coaly sequence, Mesaverde Formation, Harebell Formation, and the lower part of the Hoback Formation. Until several deep wells are drilled on these updip flanks, the possibilities of oil and gas accumulation in such facies traps cannot be evaluated.

Phosphate Rock

The Phosphoria Formation of Permian age contains all known phosphate rock in the study area. It is exposed intermittently near the northeast edge of the area from lower Crystal Creek southeastward to the headwaters of Tosi Creek (pl. 4, map. D), a distance of about 20 mi (32 km), where it dips gently northeastward and ranges in thickness from 140 to 200 ft (45–60 m). It also is present in the southeastern part of the study area between Shoal Creek and Elbow Draw, a distance of 7 mi (11 km), and in a small area at the head of Horse Creek, just outside the western margin of the study area.

The Phosphoria Formation is estimated to underlie an area of about 30 mi^2 (80 km^2) along and within the northeast edge of the study area. An additional 8 mi^2 (20 km^2) is present in the southeastern part; this estimate is generalized because of structural complications.

Detailed sampling and measuring of sections of the Phosphoria Formation in the southwest part of the study area was done by Blackwelder in 1911 (Sheldon, 1963). Additional sampling and measuring were done along the western, northern, and southeastern borders by Sheldon (1957, 1963). As part of the present study, phosphorite beds were sampled at 13 localities along the northeast area of outcrop and at 7 other places (pl. 4, map D), and analytical data on the 26 samples collected are presented in table 15. Phosphorite beds range in thickness from a few inches (a few cm) to 10 ft (3 m), the thickest being along the north and east outcrops. Most beds are 2-6 in. (5-15 cm) thick, and only at five sampled localities are phosphorite beds more than 12 in. (30 cm) thick. The phosphorus content ranges from 3 to 12 percent (7 to 28 percent P_2O_5), and the unweighted average is 9 percent phosphorus (21 percent P_2O_5).

A significant tonnage of commercial grade phosphate rock is likely in two localities: in the vicinity of sample 0290 between Dry Fork of Clear Creek and Clear Creek, where the thickness of phosphate rock is 10 ft (3 m) and grade is 12 percent phosphorus (28 percent P_2O_5), and in the vicinity of sample 0369 on East Miner Creek, where the thickness is 5 ft (1.5 m) and grade 12 percent phosphorus (28 percent P_2O_5). Whether these deposits could be mined depends on access and economic conditions. In most places in the study area, the phosphorite beds are too thin, too low grade, or dip too steeply to be of economic interest at present. The U.S. Bureau of Mines analysis discusses the economic potential of phosphate rock in the study area in its section on mineral commodities.

The phosphorite of the Phosphoria Formation contains associated elements such as uranium, vanadium, chomium, and fluorine. Their possible economic significance has been noted by many geologists (Love, 1961; Sheldon, 1963), and some values are summarized by Gulbrandsen (1966, p. 774-776). The analytical data on phosphorites from the study area (table 15) suggest that minor elements would contribute only marginally to the value of the phosphate rock if it were to be mined. Nevertheless, analyses of mudstone and phosphorite in the thrust belt facies of the Phosphoria about 6 mi (9.5 km) west of the study area show much higher contents of silver (as much as 70 ppm) and vanadium (as much as 0.35 percent) (Love and Albee, 1972, table 1). These elements are discussed in their respective sections below; they are also discussed in the section on phosphate rock by the U.S. Bureau of Mines.

Chromium and Nickel

Chromium and nickel are discussed together because of their common geochemical association. Anomalous amounts of chromium were found in 8 stream-sediment samples, 6 samples of mineralized rock, 6 samples of Precambrian rock of which 5 are amphibolites, and 11 other rocks of which 7 are black shales. All phosphorite samples contained 200 ppm or more chromium. The highest chromium content was 5,000 ppm, in a Precambrian amphibolite (sample 3108). Anomalous amounts of nickel were found in 35 stream-sediment samples, 5 samples of mineralized rock, 8 samples of Precambrian rock of which 6 are amphibolites, and 10 samples of other rocks of which 6 are black shales. Small amounts of nickel (maximum 70 ppm) also occur in all samples of phosphatic rock. The highest nickel content, 1,500 ppm, was in a Precambrian serpentinite (sample 3153). As noted in the geochemistry section, the number of stream-sediment samples anomalous in nickel may be much too large; perhaps it should be only 6 rather than 35. Six of the stream-sediment samples anomalous in chromium are also anomalous in nickel, as are 11 of the 23 rock samples.

Most of the rock samples containing anomalous chromium and (or) nickel are either black shales or amphibolites, and the chromium and nickel are considered to be primary constituents, because the amounts of both elements are within the range commonly assigned to the respective rock types; for data on amphibolites from a comparable terrane, see Armbrustmacher and Simons (1977) and for data on black shales, see Vine and Tourtelot (1970). Ultramafic rocks that are the typical hosts for chromium deposits are lacking in the study area except for a few very small bodies of serpentinite in Precambrian terrane at the heads of Bunker, Granite, and Swift Creeks, and none of the nickel occurrences is believed to be significant economically. The probability that even small deposits of either metal exist in the study area is extremely low.

Copper

Copper was found in anomalous amounts in 21 stream-sediment samples, 10 samples of mineralized rocks, and 15 samples of other rocks. The highest copper content was 3,000 ppm (0.3 percent) in sample 3161 from a chalcopyrite-bearing silicified fault zone 4 ft (1.2 m) wide in Precambrian granite. No other sample contained more than 700 ppm copper, and most contained only 30-70 ppm. Chalcopyrite was seen at several places in areas of Precambrian rocks, but only in amounts too small to be of economic interest. Concentrations of copper in other rocks were very low (maximum 300 ppm), and no area warranting further prospecting was revealed by stream-sediment sampling. The likelihood that copper deposits exist in the study area is therefore quite low.

Iron

Some prospecting for iron in hematitic red shales and mudstones of the Amsden Formation has been done in the study area. The Amsden is 200-300 ft (60-90 m) thick and occurs extensively in the northeastern part of the study area and less extensively in the central and southeastern parts. The proportion of the formation that consists of red beds, which are the most likely sources of iron, is probably less than 10 percent.

Table 16. Analytical data on samples of iron-rich rocks from the Amsden Formation, Gros Ventre wilderness study area

[Iron analyzed by atomic absorption, data in percent; Mo, Pb, and V analyzed spectrographically, data in parts per million. L, detected but below limit of determination; leaders (---), not detected]

Sample No.	Lithology	Thickness in.	Thickness cm	Element Fe	Element Mo	Element Pb	Element V
0280	Hematite nodules-------	([1])		[2]20+	70	70	1,000
0304	Hematite nodules-------	([3])		46	150	100	1,000
0305	Hematite nodules-------	Float---------		50	150	---	200
0313	Hematite nodules-------	Float---------		[2]20+	150	---	1,500
0343	Red shale containing hematite nodules-----	8-12	20-30	0.3	L	500	150
0367	Red shale containing hematite nodules-----	6	15	7	---	---	---
0368	Rusty brown limonitic shale----------------	12	30	27	30	---	500

[1]Collected from a bed 9 ft (2.7 m) thick; only a small part of the bed is hematite nodules.

[2]Spectrographic analysis.

[3]Collected from a bed 10-15 ft (3-4.5 m) thick; the nodules are mainly near the top.

Samples of shale and mudstone were collected from the Amsden at 22 localities. Analytical data on the seven more iron-rich samples appear in table 10 and sample localities are shown on plate 4, map B. Data on certain elements in the iron-rich samples are summarized in table 16. Data on other samples that contain anomalous amounts of at least one element are given in table 13.

The highest grade and probably the thickest section of iron-rich rocks is represented by sample 0305, from the crest of the ridge between Box and Bunker Creeks. A few small pits have been dug in these rocks, but the total area that can possibly be underlain by Amsden Formation is confined to the narrow ridge crest and could provide only a small tonnage of iron-rich material.

Nowhere in the study area does the iron-rich part of the Amsden Formation appear to be either high enough in iron, or thick enough, to constitute an iron resource.

A zone of shale containing abundant pellets of limonite occurs near the top of the Darby Formation in upper Clear Creek. Only float was seen and the thickness of the zone is unknown but must be small. A sample of the pellets (No. 0295, table 10) contained 42 percent iron and a trace of copper.

The iron minerals magnetite, hematite, and limonite are abundant along faults and fractures in Precambrian rocks of upper Flat, Granite, Bunker, and Swift Creeks; but the amounts are too small to constitute possible sources of iron ore.

Lead

Lead was found in anomalous amounts in 29 stream-sediment samples, 6 samples of mineralized rock, and 9 samples of other rocks. The highest lead content, 20,000 ppm or 2 percent, was in a galena-bearing sample (No. 3103, table 9) from a narrow magnetite-rich fault zone in Precambrian granite in upper Bunker Creek; no other sample of mineralized Precambrian rock contained anomalous amounts of lead. The only other samples containing more than 100 ppm lead were one of iron-rich shale (see section on iron) and one of unaltered Precambrian amphibolite; three samples of phosphorite, for which no thresholds have been established, also contained more than 100 ppm lead. Six of the anomalous stream-sediment samples, all containing 70 ppm lead, are from upper West Fork Crystal Creek; their significance is not known, but no mineralized rock of any appreciable extent was recognized in that drainage. Most other anomalous stream-sediment samples are from areas of Precambrian rocks and are believed to reflect the original lead content of the rocks. Our sampling did not reveal any area in which deposits of lead are likely to occur.

Molybdenum

Molybdenum was detected in 3 stream-sediment samples, 18 samples of mineralized rock, and 14 samples of other rocks, as well as in 8 samples of phosphorite and 1 sample of phosphatic mudstone. The highest molybdenum content was 150 ppm, in 3 samples of hematite nodules from the Amsden Formation. The only molybdenum mineral identified was a trace of molybdenite (molybdenum sulfide) at a prospect pit in Precambrian dark-green biotite schist in upper Swift Creek. Many of the anomalous molybdenum analyses are of iron-rich

Table 17. Average uranium and thorium contents and ranges of contents, and average thorium-uranium ratios of stream-sediment samples and of five groups of rock samples, Gros Ventre wilderness study area
[Leaders (---), no data]

Sample type	No. of samples	Uranium content (Parts per million)		Thorium content (Parts per million)		Thorium-uranium ratio
		Average	Range	Average	Range	
Stream sediments--	48	3.6	1.2- 37.4	13.4	1.5-39.5	3.7
All shales--------	38	6.9	0.5- 86.5	11.4	3.5-25.3	1.7
Black shales------	13	8.6	2.5- 20.8	7.8	3.5-16.5	0.9
Phosphorites------	11	69.6	31.6-115.0	15.5	2.3-35.1	0.22
Sandstone---------	1	1.5	---	7.8	---	5.2
Precambrian rocks-	15	3.4	0.9- 10.9	27.7	4.1-51.1	8.1

rocks (see section on iron) or of black shales. The other anomalous samples are widely scattered and do not seem to point out any area of molybdenum mineralization.

Uranium and Thorium

The uranium and thorium contents of 48 stream-sediment samples and 65 rock samples were determined by neutron activation analysis. Analytical data are summarized in table 17.

Localities of all analyzed samples are shown on plate 4, map C. Among stream-sediment samples, 6 contained 5 ppm or more uranium, and 14 samples contained 15 ppm or more thorium; localities of these samples are shown by separate symbols on plate 4, map C. All samples high in uranium are also high in thorium. Among rock samples, 15 contained 10 ppm or more uranium, and 15 contained 20 ppm or more thorium; localities for these samples also are shown separately on plate 4, map C. Uranium found in phosphate rock in the study area is also discussed in the section on mineral commodities prepared by the U.S. Bureau of Mines.

Of the six stream-sediment samples that are highest in uranium, five are from drainages underlain by Precambrian granitic rocks. However, only one of the Precambrian rocks analyzed contained above average amounts of uranium, and the stream-sediment sample that had the highest uranium content, 37 ppm, is from the Bunker Creek drainage, in which the highest uranium content of the three rocks analyzed was 6 ppm. Nevertheless, the broad association of high-uranium stream-sediment samples with Precambrian terrane suggests that the uranium probably is a primary constituent of the Precambrian rocks and is not indicative of uranium mineralization. Sample 0181, from a west-sloping tributary of Granite Creek just upstream from Granite Hot Spring, contained 7 ppm uranium and 22 ppm thorium. The thorium could be derived from shales of the Cambrian Gros Ventre Formation, which contain 15–25 ppm thorium, but the source of the uranium is not known inasmuch as none of the rock formations in the corresponding drainage basin is known to contain more than 5 ppm uranium.

All but one of the stream-sediment samples relatively high in thorium are from drainages underlain extensively by Precambrian granitic rocks, or Cambrian Flathead Sandstone, or both, and the thorium presumably is in heavy minerals derived from these rocks. Sample 0195, from the inlet stream of Brewster Lake in the Dry Fork of Clear Creek drainage, contained 15 ppm thorium; the drainage basin above is underlain mostly by lower Paleozoic carbonate rocks, and the only likely source of the thorium is shale of the Devonian Darby Formation, which contains 7–11 ppm thorium.

Anomalous amounts of uranium or thorium in stream sediments do not appear to be consistently associated with anomalous amounts of other elements. For example, of the six samples highest in uranium, one is also anomalous in copper and vanadium (sample 0001), one in lanthanum (sample 0149), and one in nickel and boron (sample 0181), and three are not anomalous in any other element. Among samples highest in thorium (other than the six that are also high in uranium), one is also anomalous in copper and boron (sample 0050), one in copper (sample 0195), one in boron (sample 0276), and one in barium (sample 0110), and four are not anomalous in any other element.

All but one of the uranium-rich rock samples (sample 3211, Precambrian granite, 11 ppm uranium) are from the Phosphoria Formation, and all but one of the samples containing 60 ppm or more uranium (sample 0370, of shale, 86.5 ppm uranium) are of phosphorite. The average uranium content of phosphorites, 69.6 ppm, is somewhat lower than the 93 ppm reported for 75 samples of phosphorite from the Meade Peak Member of the Phosphoria Formation by Gulbrandsen (1975, table 10). Of the 15 rock samples that contained 20 ppm or more thorium, 6 are of Precambrian granitic rocks and 5 are phosphorites; the other 4 are shales, 2 from the Cambrian Gros Ventre Formation and 2 from the Pennsylvanian part of the Amsden Formation. Except for sample 3206, of Precambrian granite from the head of West Dell Creek (51 ppm thorium), none of the thorium values is notably high and no thorium mineralization is indicated by our data.

Neither uranium nor thorium appears to be associated with unusually large amounts of other elements in samples of Precambrian rocks. None of the six samples relatively high in thorium contain anomalous amounts of any other element, nor does the one sample moderately high in uranium.

Vanadium

Anomalous amounts of vanadium were determined in 20 stream-sediment samples, 7 samples of Precambrian mineralized rocks, 8 samples of Cambrian or younger mineralized rocks, and 15 samples of other rocks comprising 6 Precambrian rocks, 7 Paleozoic shales, 1 Lower Cretaceous shale, and 1 Cenozoic sandstone. The highest vanadium content was 2,000 ppm, in a magnetite-rich sample (sample 3201) from a fractured Precambrian granite. Most anomalous stream-sediment samples are from drainages heading in Precambrian terrane or underlain extensively by shale-rich sedimentary rocks, and in these samples vanadium is associated with chromium, copper, and nickel. Four samples from the West Fork of Crystal Creek are anomalous in vanadium, and some of them are also anomalous in lead, zinc, and nickel (see section on lead).

Eight of the 13 samples of Precambrian rocks that contained anomalous amounts of vanadium are magnetite-rich, and 5 of the 8 samples of younger mineralized rocks containing anomalous vanadium are hematite-rich (see section on iron); vanadium seems clearly to be associated with iron in these samples.

Amounts of vanadium in shales and phosphorites from the study area are typical for these rock types.

Zinc

Anomalous amounts of zinc were found in 12 stream-sediment samples, in 3 samples of mineralized rock, and in 11 samples of other rocks, mostly black shales, as well as in 14 samples of phosphatic rocks. The highest zinc content was 1,500 ppm in sample 0406 of phosphorite, and several samples of phosphorite and black shale contained 1,000 ppm zinc. The highest zinc content of rocks other than phosphorite or black shale was 500 ppm in sample 0037 of limonitic siltstone from upper West Fork Crystal Creek. None of the rock samples is representative of a sufficient volume of rock to suggest zinc mineralization of economic significance. The only stream-sediment samples for which the likely source of the anomalous zinc content is not known are two from a tributary of upper Crystal Creek (see geochemistry section). No area in which deposits of zinc are likely to occur was recognized in the study area.

Other Elements

This section discusses elements that were detected in only a few samples (arsenic, beryllium, bismuth, cadmium, gold, and tin), or were detected only in low concentrations (cobalt, silver), or were not considered to be significant for evaluation of mineral resources of the study area (barium, boron, lanthanum, manganese, and yttrium).

Arsenic.—Arsenic was detected in only three samples: black shale from the Park Shale Member of the Gros Ventre Formation (sample 0048, 1,500 ppm); breccia from the Pyramid Peak fault (sample 0303, 300 ppm); and red hematitic shale from the Amsden Formation (sample 0366, 1,000 ppm). Sample localities are shown on plate 4, map B. The lower limit of detectability of arsenic by the spectrographic method is so high, 200 ppm, that samples containing appreciable amounts, perhaps as much as 100 ppm, might not be identified.

Barium.—Barium was found in amounts of as much as 1,500 ppm in stream-sediment samples and as much as 5,000 ppm in mineralized rocks, 1,500 ppm in sandstone, 1,000 ppm in shale, and 1,000 ppm in phosphorite. Localities of anomalous stream-sediment samples are shown on plate 4, map A, and those of rock samples except phosphorite are shown on plate 4, map B. Six of the eight stream-sediment samples anomalous in barium are from drainages that head in Precambrian granitic rocks, some of which contain anomalous amounts of barium (tables 9 and 11), and two are from the upper Gros Ventre River drainage, an area underlain extensively by Flathead Sandstone which seems to be consistently high in barium (table 14). None of the samples of mineralized rocks contains unusually large amounts of barium. Other rocks of the study area contain only ordinary amounts of barium (tables 12, 14, and 15). No economically significant deposits of barite (barium sulfate) are likely to be present in the study area.

Beryllium.—Beryllium was determined spectrographically only in samples that contained several times the lower detection limit of 1 ppm. It was reported only in sample 3151 of a magnetite-rich mylonite zone in Precambrian granite in upper Swift Creek; this sample contained 15 ppm beryllium.

Bismuth.—Bismuth was detected in only one sample in the amount of 30 ppm (sample 3103, table 9).

Boron.—Boron was not considered important enough to be determined spectrographically in every sample and, therefore, was reported only if it was present in amounts of 70 ppm or more. Localities of anomalous samples are shown on plate 4, maps A and B. Amounts of 150 ppm or more were found in 18 stream-sediment samples; the highest amount was 300 ppm. More than half of these came from drainages underlain extensively by Precambrian rocks, and the boron probably is in the mineral tourmaline, which contains about 3 percent boron. Other anomalous stream-sediment samples are from widely separated localities in the study area.

Boron was reported in only one sample of Precambrian rock (mineralized sample 3187, table 9, magnetite veinlets in granite, 150 ppm). It was reported in amounts of 300 ppm or more in several samples of black shale and shale (table 13) and in amounts of 70 ppm or more in four samples of sandstone (table 14). Although the average boron content of shales and black shales in the study area is somewhat higher than for those rocks in general (table 12), it is not so high as to suggest the occurrence of boron deposits.

Cadmium.—Cadmium was detected in only five samples from the Phosphoria Formation, three of black shale (samples 0016, 0309, and 0404), and two samples of phosphorite (samples 0179 and 0406); localities of the black shale samples are shown on plate 4, map B. All these samples also contain 700 ppm or more zinc, with which cadmium is geochemically associated. Amounts of cadmium range from 50 to 100 ppm and are approximately proportional to amounts of zinc. Inasmuch as zinc deposits of economic interest are not likely to occur in the study area, the amounts of cadmium to be expected are insignificant.

Cobalt.—Cobalt was detected in 11 samples of Precambrian rocks, in amounts ranging from 50 to 100 ppm. Seven of these samples are of mafic or ultramafic rocks and the cobalt content is not unusual (Parker, 1967, p. D13). The other four are of magnetite- or hematite-bearing rocks rich in iron with which cobalt is associated geochemically.

The highest cobalt content reported was 700 ppm, in sample 0282 (table 10).

Gold.—Gold was detected in only one sample (3103) collected along a fault in sulfide-bearing, magnetite-rich Precambrian granite. This sample also contained lead, silver, bismuth, tin, and yttrium (table 9). Because the lower limit of detectability for gold by spectrographic analysis is 10 ppm, appreciable amounts of gold might be undetected in rock samples; on the other hand, no gold was found in stream-sediment samples, which were analyzed by atomic absorption having a lower limit of detection of 0.05 ppm. The study area seems to be very low in gold, and the resource potential is low.

Lanthanum and yttrium.—Lanthanum and yttrium were analyzed spectrographically in all samples in order to determine the abundance of the rare-earth metals. Lanthanum was found in amounts of 100 ppm or more in 10 stream-sediment samples (pl. 4, map A), all of which came from drainages underlain largely by Precambrian rocks (see geology section). It occurs in the amounts of 150 ppm in three black shales and 100 and 200 ppm, respectively, in two shales (table 13). Lanthanum also occurs in all phosphorites sampled, in amounts of from 150 to 1,000 ppm (table 15). A panned concentrate of heavy minerals from weathered basal Flathead Sandstone contained 300 ppm lanthanum as well as 700 ppm yttrium (see geochemistry section).

Yttrium was found in amounts of 50–100 ppm in 20 samples of stream sediment, in amounts of 200 ppm or more in three samples of Precambrian rocks (tables 9 and 11), and in amounts of 100–200 ppm in black shales from the Phosphoria Formation, and 50–500 ppm in other shales (table 13). It also occurs in all samples of phosphorite in amounts of 200–1,000 ppm (table 15).

None of the occurrences of either lanthanum or yttrium suggests the occurrence of deposits of rare-earth metals in the study area.

Manganese.—Manganese was detected in amounts of 1,000 ppm or more in 21 stream-sediment samples (pl. 4, map A). The highest content was 5,000 ppm in sample 0130 from a tributary drainage of lower Gros Ventre River that is underlain in part by the manganese-rich Dinwoody Formation. Several other anomalous samples are from drainages underlain by manganese-rich formations such as the Chugwater Formation and Nugget Sandstone.

Manganese was detected in amounts of 5,000 ppm in two samples of mineralized rocks (tables 9 and 10); in amounts of 300–1,500 ppm in six black shales, and in amounts of 700–2,000 ppm in three samples of other shales (table 13); and in amounts of 500–1,500 ppm in seven samples of sandstone (table 14). One phosphorite sample contained 700 ppm manganese, but most contained only 10–100 ppm (table 15). Except in the samples of mineralized rocks, which represent very small amounts of material, the manganese reported probably was an original constituent of the rocks. No manganese deposits are likely in the study area.

Silver.—Silver was detected in amounts ranging from 0.7–5 ppm in four stream-sediment samples (pl. 4, map A); three of these samples are from drainages underlain widely by the Phosphoria Formation which contains silver-bearing black shale and phosphorite. Silver also was reported in six samples of mineralized rocks in amounts of 0.7–7 ppm (tables 9 and 10). It also occurs in the amount of 5 ppm in 5 samples of black shale from the Phosphoria Formation (table 13), and in amounts of 0.5–7 ppm in 18 out of 26 samples of phosphorite from the Phosphoria (table 15). These occurrences of silver do not seem indicative of silver mineralization anywhere in the study area.

Tin.—Tin was detected in only two samples: sample 3103 of sulfide-bearing Precambrian rocks in upper

Bunker Creek (table 9, 50 ppm), and sample 3147, from a prospect pit on a silicified magnetite-rich fault zone in Precambrian granite in upper Swift Creek (table 9, 20 ppm). Neither occurrence suggests a tin deposit.

Coal

Outcrops of possible coal-bearing rocks are restricted to the southeast corner of the study area, where they are exposed in or inferred to underlie an area of about 2 mi^2 (5 km^2). Coal was seen only in the Frontier and Mesaverde Formations. Coal beds in the Frontier are as much as 16 in. (40 cm) thick, and a sequence of coal and coaly shale east of Shoal Creek is 7.8 ft (2.4 m) thick (see measured section in discussion of Frontier Formation). Coal beds of the Mesaverde also are thin. The area of possible occurrence of coal-bearing formations within the study area is small, and the known coal beds are thin and shaly.

Coal occurs in western Wyoming in several formations of Late Cretaceous age (from oldest to youngest, Frontier Formation, Bacon Ridge Sandstone, lenticular sandstone and shale sequence and coaly sequence, and Mesaverde Formation). Some coal has been mined from a bed 4 ft (1.2 m) thick in Upper Cretaceous rocks at the Little Granite Creek mine 3 mi (5 km) south of the study area (Schroeder, 1976).

Construction Materials

Small deposits of gravel and sand exist along the lower parts of Flat and Crystal Creeks and Gros Ventre River in the study area, but none of these materials has been produced. Vast amounts of suitable material are present in much more accessible places outside the study area along the lower Gros Ventre and Snake Rivers.

No rock of any kind has been quarried within the study area, although large amounts of construction material have come from quarries in volcanic and sedimentary rocks to the west around Jackson (Love and Albee, 1972). Although some of the Precambrian crystalline rocks, particularly the orbicular granite of upper Shoal Creek, would make attractive building stone, the areas are nearly inaccessible. Limestone abounds in the study area, but the same rocks are more readily available in other, more accessible places.

Geothermal Energy Resources

No hot springs were seen in the study area and none has been reported. The only hot spring near the area is Granite Hot Spring on the east side of Granite Creek just south of the boundary of the study area; this spring is the site of a small recreational development. It is reported to flow 130 gallons per minute at a temperature of 110°F (43°C) (Stearns and others, 1937, p. 189; Waring, 1965, p. 49). U.S. Forest Service records at Jackson, Wyo., showed that in 1976 the low temperature of the hot spring for the year was 82°F (28°C), which occurred from May 29 through June 2, and the high temperature was 112°F (44°C), which occurred from January 16 through January 28. The heat source for Granite Hot Spring is unknown; no post-Cambrian igneous rocks occur within the study area and except possibly for the spring itself there is no evidence for the existence of any unexposed near-surface igneous rocks. The water in the Granite Hot Spring probably was heated at depth because of the geothermal gradient, and the Cache Creek thrust fault may have been the conduit up which the hot water migrated.

Many of the sedimentary formations underlying the study area have rocks suitable as reservoirs for geothermal fluids, but because of the lack of heat sources the potential for geothermal energy resources in the area is low.

ECONOMIC EVALUATION OF MINERAL POTENTIAL

By Carl L. Bieniewski
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Mining History and Production

Prospecting, mining, and oil and gas exploration in or near the Gros Ventre wilderness study area has been minor and mostly unsuccessful. No mineral production is attributed to the study area.

Prospectors, lured by gold in the Snake River, came into the Jackson Hole area in the latter half of the 19th century. Gold in the Snake River and the source rocks (Pinyon Conglomerate and Harebell Formation) continues to attract prospectors. However, because the gold is in very small particles that are difficult to recover, none of these ventures has been successful.

Deadman's Bar, at the Snake River outlook on U.S. Highways 26, 89, and 187 about 8 mi (13 km) northeast of Moose, is the site of the best known gold-mining venture in the Jackson Hole area (Hayden, 1956). In 1886, four men were prospecting for gold at this location; however, only one left the scene alive. He admitted killing the other three in self defense and, for lack of any evidence, was not convicted of murder.

The latest gold venture near the study area was in 1963, when a mill was constructed on the Gros Ventre River near the junction with Crystal Creek to recover gold from stream and bench-placer deposits. A few years later the mill was dismantled. According to U.S. Bureau of Mines records, no gold production has been reported from this venture.

About 1892, the Jackson Hole Coal Co. was formed and mined coal that cropped out on the north side of the Gros Ventre River near what is now Upper Slide Lake (fig. 4) (Hayden, 1956). Later, some coal was mined on Cache Creek about 6 mi (9.7 km) southeast of Jackson. The official records do not show how much coal was mined in the early days. The coal operation nearest the study area is the Granite Creek Mine on Little Granite Creek, about 3 mi (5 km) south of the study area. This mine dates from 1928 and has been operated intermittently until the present time. According to records of the Wyoming State Mine Inspector, about 6,100 tons (5,534 t) of coal were produced from the mine between 1939 and 1949; no production is recorded since 1949.

No exploratory drilling for oil and gas has been done within the study area. More than 25 holes have been drilled within 10 mi (16 km) of the study area, starting in 1947. A well started in 1976 on Granite Creek, about 5 mi (8 km) southwest of the study area, was completed as a gas well in July 1977 and then shut in. None of the other holes produced oil or gas; however, four had oil shows.

Sampling and Analytical Results

A total of 78 samples were collected in or near the study area—22 panned concentrates, 47 chip samples, 8 grab samples, and 1 water sample. The localities of the samples are shown on plate 3. Before the samples were submitted for analysis, they were checked for radioactivity with a geiger counter. All the samples, except the water sample, were analyzed spectrographically and fire-assayed for gold and silver. Some samples, such as those of phosphate rock and limestone, were analyzed for specific chemical compounds by other analytical methods. Significant results of the spectrographic analyses and all the fire-assay results are shown in table 18. Additional analytical results of specific interest are shown as footnotes in table 18 or in other tables.

Prospects and Mineralized Areas

Swift Creek

Swift Creek is a small stream with headwaters in the south-central part of the study area. The stream flows southwesterly entering Granite Creek about 2 mi (3.2 km) south of the study area. At the upper end of Swift Creek are Precambrian and Cambrian rocks that have been cut by north- and east-trending faults. The Precambrian rocks are granites and gneisses and the Cambrian rocks are limestones, shales, sandstones, and conglomerates. A mafic dike, approximately 25 ft (7.6 m) wide and striking S. 27° E., is exposed in this area.

A group of mining claims named Ulys 1–18 was located in 1963 at the upper end of Swift Creek. The recorded claim notices state that the minerals discovered were jade and others. Prospect workings include small pits, trenches, and shallow shafts. Analyses of samples taken at these workings revealed some anomalous mineral values.

A chip sample (No. 20) taken across a 5-ft (1.5-m) face of a small pit in granite analyzed spectrographically 80 ppm cobalt, 2,000 ppm chromium, 2,000 ppm nickel, 400 ppm lead, and 1,000 ppm tin, but by other analytical methods 150 ppm cobalt, 0.39 percent (3,900 ppm) chromium, 0.16 percent (1,600 ppm) nickel, 110 ppm Pb, and less than 0.01 percent (100 ppm) tin. A grab sample (No. 26) of the dump by a small trench fire-assayed 0.3 oz silver/ton (10.3 g/t) and the spectrographic analysis showed 2,000 ppm chromium, 80 ppm copper, and 600 ppm nickel. The dump consisted mostly of biotite, serpentine, and schist. A piece of schist from the dump contained a speck of molybdenite; however, molybdenum values were not anomalous in any samples from this area. Another piece of schist from the dump contained a speck of a light-green mineral that was identified as jadeite. A grab sample (No. 25) from a small pit fire-assayed 0.4 oz silver/ton (13.7 g/t), but the spectrographic analysis revealed no anomalous values.

The mafic dike in the area is exposed across a width of 15 ft (4.6 m) in a narrow gorge; analysis of a chip sample (No. 18) taken across the exposure showed nothing of mineral significance.

Assays of the two panned concentrate samples (Nos. 19 and 21), taken from stream alluvium in the area, showed no gold and only a trace of silver, and nothing else of mineral significance.

The mineralization indicates that metalliferous mineral deposits could be present; however, the sampling results were not encouraging. Consequently, the potential for such deposits is considered low.

Dell Creek and West Dell Creek

Groups of lode mining claims were located during 1969 at the headwaters of Dell Creek and West Dell Creek in the southernmost part of the study area. In the recorded claim notices, uranium is mentioned as the valuable mineral discovered. Placer mining claims were located during 1973 in the same vicinity. According to the owner of the placer claims, uranium was the sought-after mineral commodity. Most of the lode mining claims and all the placer mining claims are in the study area in unsurveyed T. 39 N., R. 112 W. These mining claims are located in an area where the Phosphoria Formation crops out. Here and in other parts of the study area, this formation consists partly of phosphate rocks that contain uranium. A chip sample (No. 41), taken across a 18-in. (46-cm) bed of phosphate rock exposed along Dell Creek, analyzed 29.8 percent P_2O_5 and 0.01 percent U_3O_8. Based on the work of Sheldon (1963) on phosphate rock, the U_3O_8 content of the sample is typical of the phosphate rock in the Gros Ventre Range. Phosphate rock and its importance in the study area are discussed in a separate section in this report. A sample (No. 39) of water, taken from a small sulfurous spring along Dell Creek about 1/2 mi (0.8 km) southwest of sample 41, was analyzed for Cu, Pb, Zn, Mo, U, P, F, and SO_4; but the results revealed nothing of any mineral importance.

At the headwaters of West Dell Creek, about 1 mi (1.6 km) west of Doubletop Peak, are two prospect pits about 100 ft (30 m) apart. Two adits lie about 500 ft (150 m) southeast of a steep part of West Dell Creek, about 1/2 mi (0.8 km) north of West Dell Falls. According to a local resident, these prospect workings (pits and adits) were excavated in the 1930's.

The two prospect pits—7 and 8 ft (2.1 m and 2.4 m) long, 4 ft (1.2 m) wide, and 2 ft (0.6 m) deep—are in a shear zone in granite; the fractures are filled with quartz containing specular hematite. Some quartz was iron stained. Samples (Nos. 42–50) of quartz veinlets, granite with quartz stringers, granite with hematite, and granite were collected from in and around the pits. The spectrographic analyses of two samples showed 500 ppm vanadium and those of five samples showed from 100 to 700 ppm lead; however, none of these values are considered to constitute any significant mineral potential.

The two adits are in Madison Limestone that is on the downthrown side of the nearby Shoal Creek fault. Granite is exposed on the upthrown side. The portal of the lower adit, which was driven 8 ft (2.4 m), is 30 ft (9.2 m) above and 30 ft (9.2 m) west of the portal of the upper adit, which was driven 17 ft (5.2 m). The adits followed small fractures filled mostly with iron oxides. Samples (Nos. 51–56) taken of the fracture fillings and limestone showed nothing of mineral significance.

Other Areas

About 1/2 mi (0.8 km) south of Pinnacle Peak, and just outside the southwest edge of the study area, is an alteration zone at the contact of the Cambrian Flathead Sandstone and Precambrian granite. A fault with slight displacement lies a few hundred feet north of this zone. Analyses of a chip sample (No. 64) consisting of rock chips taken every 1 ft (0.3 m) along 25 ft (7.6 m) in the altered quartzite, and of a chip sample (No. 65) consisting of rock chips taken every 1 ft (0.3 m) along 18 ft (5.5 m) in the altered granite, did not show any anomalous values. A panned-concentrate sample (No. 63) of alluvium in a small intermittent stream was taken about 1/4 mi (0.4 km) southwest of the alteration zone. Analysis of this sample showed neither gold nor silver or anything else of mineral importance.

According to recorded notices, three mining claims were located in 1922 in the vicinity of Shoal Lake, which is in the south-central part of the study area. However, the descriptions of the claims in the notices are so vague that their exact location cannot be determined. Nothing was found in the Shoal Lake area to show where the claims may have been staked, but alteration in granite is evident immediately north of the lake. A northeast-trending fault, with both sides in granite, goes through this area. Samples (Nos. 30–36) of altered and unaltered rock were collected; the samples consist mostly of granite with some magnetite, hematite, and quartz. Examination of the samples revealed only minor alteration, mostly chloritic, and some iron-staining, probably due to hydrothermal activity associated with the fault. Analyses of the samples did not show anomalous values or anything of mineral significance to warrant further investigation.

At the top of the eastern part of the ridge between Box Creek and Bunker Creek in the southwest part of the study area are two prospect pits dug into iron-mineralized rock. One pit is 5.5 ft (1.7 m) in diameter and 2 ft (0.6 m) deep and the other, which is 32 ft (9.8 m) away, is 4.5 ft (1.4 m) in diameter and 1.5 ft (0.5 m) deep. A mining claim, Marble F, located in 1966, was in sec. 24, T. 40 N., R. 114 W., according to the recorded notice. The notice states that the deposit discovered consisted of iron and other valuable minerals. The exact location of the claim cannot be determined from the description of the claim in the records, but the claim is probably in the vicinity of the two pits. On the top of the eastern part of the ridge is a small remnant of Pennsylvanian rocks that rests on Mississippian Madison Limestone. The iron mineralization is in rocks of the Amsden Formation and appears to be confined to an area about 150 ft (46 m) in an east-west direction and 100 ft (31 m) in a north-south direction, and may be as much as 25 ft (7.6 m) deep. Limonite is present as pisolites as much as 0.25 in. (0.6 cm) in diameter in red-brown shaly matrix and hematite, in discontinuous layers.

Grab samples (Nos. 66–67) of the dumps analyzed 13.6 and 7.5 percent Fe. Analysis of a specimen (No. 68) of a rock containing hematite showed 39.9 percent Fe. A specimen (No. 69) consisting of the pisolites separated from the matrix analyzed 30.7 percent Fe. Harrer (1966) discussed similar deposits in the Amsden Formation in other places in Wyoming and concluded that such deposits are small and erratic in quality. The deposit on the ridge between Box Creek and Bunker Creek appears to be similar to those in the Amsden Formation that were discussed by Harrer and, therefore, it is considered to be of little economic importance.

Table 18. Analyses of samples from and near the Gros Ventre wilderness study area

[Fire assays, semiquantitative spectrographic analyses, and other analytical work performed at Reno Metallurgy Research Center, U.S. Bureau of Mines, Reno, Nev., except for water analyses of sample 39, which was performed by Skyline Labs Inc., Denver, Colo. Detection limits used for spectrographic analyses are in parentheses under elements listed. The following elements were not found above detection limits except as noted at end of table: As, Be, Bi, Cd, Co, Ga, La, Li, Mo, Nb, Pt, Sb, Sc, Sn, Sr, Ta, Te, W, and Zn. Ca, Na, and Si detected in many samples but are not considered significant. Symbols used: *, additional data given by sample number in footnote at end of table; NA, not analyzed by fire assay or spectrography; Tr, trace amount; leaders (---), not detected; >, greater than amount shown; <, less than amount shown; M, major quantity (usually greater than 7 percent). In footnote ( ) means results obtained by analytical method other than fire assay or spectrography. Sample localities designated by township (T) north, range (R) west, 6th Principal Meridian, and section (S); because townships are mostly unsurveyed, localities are approximate]

Sample No.	Locality S. T. R.	Fire assay (oz/ton)		Semiquantitative spectrographic analyses, in parts per million								
		Au	Ag	B (100)	Cr (30)	Cu (20)	Ni (20)	P (6,000)	Pb (100)	V (60)	Y (10)	Zr (70)
1	14-40-112	---	---	100	100	<20	<20	---	---	<60	---	---
2	14-40-112	---	---	200	100	30	<20	<6,000	---	<60	<10	---
3	14-40-112	Tr	---	<100	60	<20	<20	>30,000	---	<60	50	---
4	14-40-112	---	0.1	100	100	30	<20	<6,000	---	<60	---	---
5	14-40-112	---	---	100	---	<20	<20	>30,000	---	<60	<10	600
6	20-40-112	Tr	---	---	---	---	---	<6,000	---	<60	---	---
7	20-40-112	---	Tr	---	---	---	---	---	---	<60	---	---
8	33-41-113	---	---	---	<30	<20	<20	---	---	<60	---	---
9	34-42-113	---	---	---	---	<20	---	---	---	<60	---	100
10	34-42-113	---	---	---	100	30	---	>30,000	---	<60	100	---
11	34-42-113	Tr	---	<100	300	<20	---	>30,000	---	<60	200	<70
12	34-42-113	Tr	---	200	100	20	80	>30,000	---	500	200	<70
*13	34-42-113	Tr	---	---	500	30	20	>30,000	---	500	300	<70
*14	34-42-113	---	---	<100	500	20	40	>30,000	---	500	300	<70
15	32-41-114	Tr	---	<100	<30	100	---	---	1,500	<60	---	1,000
16	3-40-114	---	Tr	---	---	---	---	---	---	<60	---	---
17	9-40-114	Tr	---	100	30	300	50	---	<100	100	---	600
18	34-40-113	Tr	---	300	60	40	80	---	<100	60	30	200
19	34-40-113	Tr	---	100	60	40	80	---	<100	60	30	300
*20	34-40-113	Tr	---	---	2,000	20	2,000	---	400	<60	---	---
21	34-40-113	Tr	---	---	300	20	60	---	100	<60	---	100
22	34-40-113	---	---	---	60	<20	100	---	<100	<60	---	<70
23	34-40-113	---	.1	---	---	20	100	---	<100	<60	---	<70
24	34-40-113	---	---	---	---	<20	40	---	<100	<60	---	<70
25	34-40-113	---	.4	---	30	20	40	---	<100	<60	---	<70
*26	34-40-113	---	.3	200	2,000	80	600	---	<100	100	---	<70
27	13-39-113	Tr	---	---	300	<20	---	---	---	60	50	5,000
28	12-39-113	Tr	---	---	100	20	---	---	200	100	---	70
29	6-39-113	Tr	---	---	60	<20	---	---	---	60	---	100
30	36-40-113	---	---	---	---	30	---	---	---	100	---	---
31	36-40-113	Tr	---	---	---	30	---	---	---	60	---	---
32	1-39-113	Tr	---	---	---	---	---	---	---	200	---	<70
33	1-39-113	Tr	---	---	---	---	---	---	---	<60	---	<70
34	1-39-113	Tr	---	---	60	---	---	---	---	<60	---	600
35	1-39-113	Tr	---	---	---	---	---	---	---	200	---	---
36	1-39-113	Tr	---	---	1,000	---	200	---	---	100	---	---
37	17-39-111	Tr	---	100	60	<20	---	---	<100	<60	---	600
38	29-39-112	Tr	---	<100	---	40	---	---	100	<60	---	---
*39	28-39-112	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
*40	28-39-112	.02	---	100	---	30	---	10,000	100	<60	---	---

Table 18. Analyses of samples from and near the Gros Ventre wilderness study area—Continued

Sample No.	Semiquantitative spectrographic analyses, in percent						Remarks
	Al (0.003)	Ba (0.1)	Fe (0.004)	Mg (0.0004)	Mn (0.003)	Ti (0.001)	
1	1.0	---	2.0	5.0	0.02	0.05	Outcrop-chip 1.0 ft (0.3 m).
2	1.0	---	.2	1.5	.02	.05	Outcrop-chip every 1 ft (0.3 m) over 36 ft (11.0 m).
3	.3	---	.4	.2	.003	.05	Outcrop-chip 0.7 ft (21.3 cm).
4	1.0	---	1.0	3.0	.02	.05	Outcrop-chip 1.4 ft (0.4 m).
5	.3	---	.4	.4	.01	.2	Outcrop-chip 0.4 ft (12.2 cm).
6	.01	---	.03	.1	<.003	---	Outcrop-chip specimen.
7	.01	---	.01	3.0	<.003	---	Do.
8	.01	---	3.0	.2	<.003	---	Do.
9	.7	---	2.0	4.0	.05	.01	Stream-panned concentrate.
10	1.3	---	.4	.8	.006	.02	Outcrop-chip 1.2 ft (0.4 m).
11	.7	---	.4	.4	.006	.05	Outcrop-chip 0.75 ft (22.9 cm).
12	3.0	---	1.0	.4	.006	.1	Outcrop-chip 2 ft (0.6 m).
*13	.3	---	.2	.2	.006	.02	Outcrop-chip 1 ft (0.3 m).
*14	.7	---	.2	.6	.01	.05	Outcrop-chip 3.3 ft (1.0 m).
15	M	---	4.0	2.0	.1	.4	Stream-panned concentrate.
16	.01	---	.02	.2	<.003	---	Outcrop-chip specimen.
17	M	---	M	2.0	.2	.4	Stream-panned concentrate.
18	M	---	M	2.0	.2	.4	Outcrop-chip 15 ft (4.6 m).
19	M	---	M	.2	.2	.4	Stream-panned concentrate.
*20	.7	---	M	M	.2	.2	Pit-face-chip 5 ft (1.5 m).
21	M	---	M	.1	.2	.2	Stream-panned concentrate.
22	M	0.1	M	5.0	.1	.1	Pit-dump-grab every 4 ft (1.2 m).
23	1.0	.1	2.0	.2	.05	.02	Pit-dump-grab every 3 ft (0.9 m).
24	2.0	.1	M	2.0	.05	.05	Do.
25	M	.1	2.0	.4	.02	.05	Pit-dump-grab every 2 ft (0.6 m).
*26	M	---	M	M	.8	.2	Pit-dump-grab every 1 ft (0.3 m).
27	.7	---	M	.6	.2	.4	Stream-panned concentrate.
28	.3	---	M	.2	.01	.2	Do.
29	1.0	---	1.0	3.0	.02	.2	Do.
30	M	---	M	.4	.02	.1	Outcrop-chip specimen.
31	M	---	7.0	2.0	.03	.03	Do.
32	1.0	---	M	.4	.02	.02	Do.
33	M	.2	2.0	.4	.02	.02	Do.
34	M	.4	M	3.0	.1	.4	Do.
35	3.0	---	M	.2	.02	.1	Do.
36	3.0	---	M	M	.1	.1	Do.
37	1.3	---	7.0	.2	.006	.1	Stream-panned concentrate.
38	3.0	---	4.0	2.0	.2	.05	Do.
*39	NA	NA	NA	NA	NA	NA	Spring-water.
*40	.7	---	3.0	1.0	.05	.05	Stream-panned concentrate.

ADDITIONAL DATA

13. 200 ppm (parts per million) La
14. 200 ppm La, 1,000 ppm Sr
20. 80 ppm (150 ppm) Co, (0.39 pct.) Cr, (0.16 pct.) Ni, (110 ppm) Pb, 1,000 ppm (<0.01 pct.) Sn
26. 40 ppm Co
39. (0.01 mg/l) Cu, (<0.01 mg/l) Pb, (<0.01 mg/l) Zn, (<0.005 mg/l) Mo, (<2 ppb) U, (<0.01 mg/l) P, (0.38 mg/l) F,(1,000 mg/l) SO_4
40. 80 ppm Co

Table 18. Analyses of samples from and near the Gros Ventre wilderness study area—Continued

Sample No.	Locality S. T. R.	Fire assay (oz/ton) Au	Ag	Semiquantitative spectrographic analyses, in parts per million B (100)	Cr (30)	Cu (20)	Ni (20)	P (6,000)	Pb (100)	V (60)	Y (10)	Zr (70)
*41	28-39-112	Tr	---	100	500	40	40	>30,000	---	<60	300	---
*42	16-39-112	---	---	---	---	30	---	---	400	500	---	100
*43	16-39-112	Tr	---	---	---	20	---	---	100	100	---	100
*44	16-39-112	---	---	---	---	<20	---	---	---	100	---	100
45	16-39-112	---	---	---	---	30	---	---	700	60	---	100
46	16-39-112	Tr	---	---	---	20	---	---	400	60	---	100
47	16-39-112	Tr	---	---	---	<20	---	---	---	<60	---	---
48	16-39-112	Tr	---	---	---	30	---	---	---	---	---	---
49	16-39-112	Tr	---	---	---	---	---	---	---	500	---	---
50	16-39-112	Tr	---	---	---	20	---	---	---	100	---	---
51	17-39-112	---	---	---	---	---	---	---	---	---	---	---
52	17-39-112	---	---	---	---	---	---	---	---	---	---	---
53	17-39-112	Tr	---	---	---	---	---	---	---	---	---	---
54	17-39-112	Tr	---	---	---	---	---	---	---	---	---	---
55	17-39-112	Tr	---	---	---	---	---	---	---	---	---	---
56	17-39-112	Tr	---	---	---	---	---	---	---	---	---	---
57	32-40-111	Tr	---	400	600	<20	---	>30,000	---	<60	200	100
*58	1-41-115	---	---	100	500	<20	---	>30,000	100	1,000	300	<70
59	1-41-115	---	---	100	1,000	20	30	>30,000	---	500	200	<70
*60	1-41-115	Tr	---	100	500	30	40	>30,000	---	60	300	<70
61	1-41-115	Tr	---	200	1,000	40	80	>30,000	---	60	200	<70
62	16-41-114	Tr	---	100	30	20	---	---	---	<60	---	<70
63	4-39-114	---	---	---	<30	<20	20	---	<100	<60	90	600
64	4-39-114	---	Tr	---	30	<20	---	---	<100	<60	---	<70
65	4-39-114	---	Tr	---	<30	<20	---	---	---	---	---	<70
*66	15-40-114	---	.1	200	60	<20	200	---	<100	100	---	<70
*67	15-40-114	---	Tr	500	60	20	100	---	200	100	---	<70
*68	15-40-114	---	.1	200	60	<20	100	---	400	100	---	<70
*69	15-40-114	---	.3	500	100	<20	200	---	<100	200	---	<70
70	9-38-112	---	---	200	200	<20	<20	<6,000	<100	60	<10	6,000
71	9-38-112	---	Tr	<100	<30	<20	<20	<6,000	<100	<60	<10	4,000
72	9-38-112	---	---	200	300	<20	<20	<6,000	<100	80	200	10,000
73	14-38-112	---	---	300	80	<20	<20	<6,000	<100	100	100	10,000
74	28-40-111	---	---	<100	<30	<20	<20	20,000	<100	<60	<10	<70
75	28-40-111	---	Tr	200	<30	<20	<20	<6,000	<100	<60	90	800
76	21-40-111	---	---	<100	<30	<20	<20	<6,000	<100	<60	<10	800
77	14-40-112	---	---	<100	<30	<20	<20	<6,000	<100	<60	<10	200
78	22-40-112	---	Tr	<100	<30	<20	<20	<6,000	<100	<60	200	5,000

Table 18. Analyses of samples from and near the Gros Ventre wilderness study area—Continued

Sample No.	Semiquantitative spectrographic analyses, in percent						Remarks
	Al (0.003)	Ba (0.1)	Fe (0.004)	Mg (0.0004)	Mn (0.003)	Ti (0.001)	
*41	1.3	---	.4	1.0	0.01	0.1	Outcrop-chip 1.5 ft (0.5 m).
*42	M	---	M	2.0	.05	.1	Pit-chip specimen.
*43	M	---	M	.4	.01	.1	Do.
*44	M	---	M	3.0	.05	.05	Do.
45	2.0	---	M	.4	.05	.02	Do.
46	1.0	---	M	.4	.02	.05	Do.
47	2.0	---	7.0	.1	.006	.02	Pit-chip specimen.
48	.3	---	1.0	.1	.006	---	Do.
49	5.0	---	M	2.0	.05	.1	Do.
50	1.0	---	M	.1	.01	.02	Do.
51	.04	---	M	.05	.02	---	Adit-face-chip specimen.
52	.04	---	.3	.4	.02	---	Do.
53	.1	---	M	.05	.01	.006	Adit-rib-chip specimen.
54	.2	---	M	.05	.01	.01	Adit-face-chip 0.3 ft (9.1 cm).
55	.04	---	M	.05	.01	.003	Adit-face-chip 0.8 ft (24.4 cm).
56	.1	---	M	.05	.01	.01	Adit-dump-grab specimen.
57	2.0	---	2.0	2.0	.01	.05	Outcrop-chip 2.5 ft (0.8 m).
*58	.3	---	.2	.4	.05	.02	Do.
59	.3	---	.4	.6	.01	.05	Outcrop-chip 1 ft (0.3 m).
*60	.3	---	1.0	.4	.05	.05	Outcrop-chip 0.5 ft (15.2 cm).
61	5.0	---	1.0	.8	.01	.1	Do.
62	5.0	---	1.0	5.0	.05	.05	Stream-panned concentrate.
63	3.0	---	4.0	.1	.01	.09	Do.
64	3.0	---	1.0	.1	.01	.2	Outcrop-chip every 1 ft (0.3 m) over 25 ft (7.6 m).
65	M	<.1	2.0	1.0	.02	.2	Outcrop-chip every 1 ft (0.3 m) over 18 ft (5.5 m).
*66	2.0	---	M	1.0	.02	.2	Pit-dump-grab every 1 ft (0.3 m).
*67	M	.1	M	2.0	.1	.4	Do.
*68	2.0	---	M	.4	.2	.1	Outcrop-chip specimen.
*69	M	---	M	1.0	.02	.1	Do.
70	1.0	1.0	M	1.0	.05	2.0	Stream-panned concentrate.
71	1.0	<.1	1.0	.6	.01	.7	Do.
72	4.0	.3	M	2.0	.5	7.0	Do.
73	3.0	<.1	7.0	.3	.1	7.0	Do.
74	2.0	<.1	6.0	3.0	.06	.5	Do.
75	1.0	<.1	6.0	4.0	.04	<.001	Do.
76	2.0	<.1	4.0	3.0	.03	.1	Do.
77	2.0	<.1	6.0	4.0	.1	.5	Do.
78	2.0	<.1	2.0	3.0	.01	2.0	Do.

ADDITIONAL DATA

41. 1,000 ppm Sr
42. 80 ppm Co
44. 150 ppm Co
58. 200 ppm La, 1,000 ppm Sr
60. 200 ppm La
66. 30 ppm Mo, (13.6 pct.) Fe
67. (7.5 pct.) Fe
68. 500 ppm (<60 ppm) Mo, (39.9 pct.) Fe
69. 70 ppm Mo, (30.7 pct.) Fe

Mineral Commodities

Coal

Coal has been mined close to the study area from the Jackson coalfield, in Coal Mine Draw near Upper Slide Lake just north of the study area, and from the Green River coalfield, along Cache Creek and Little Granite Creeks southwest of the study area. The coal mines in these vicinities are shown on figure 10. The thickest coal bed—4 ft (1.2 m)—was mined along Little Granite Creek, and produced 6,100 tons (5,534 t) of coal between 1939 and 1949. The production from the other areas is unknown, but probably was not large because

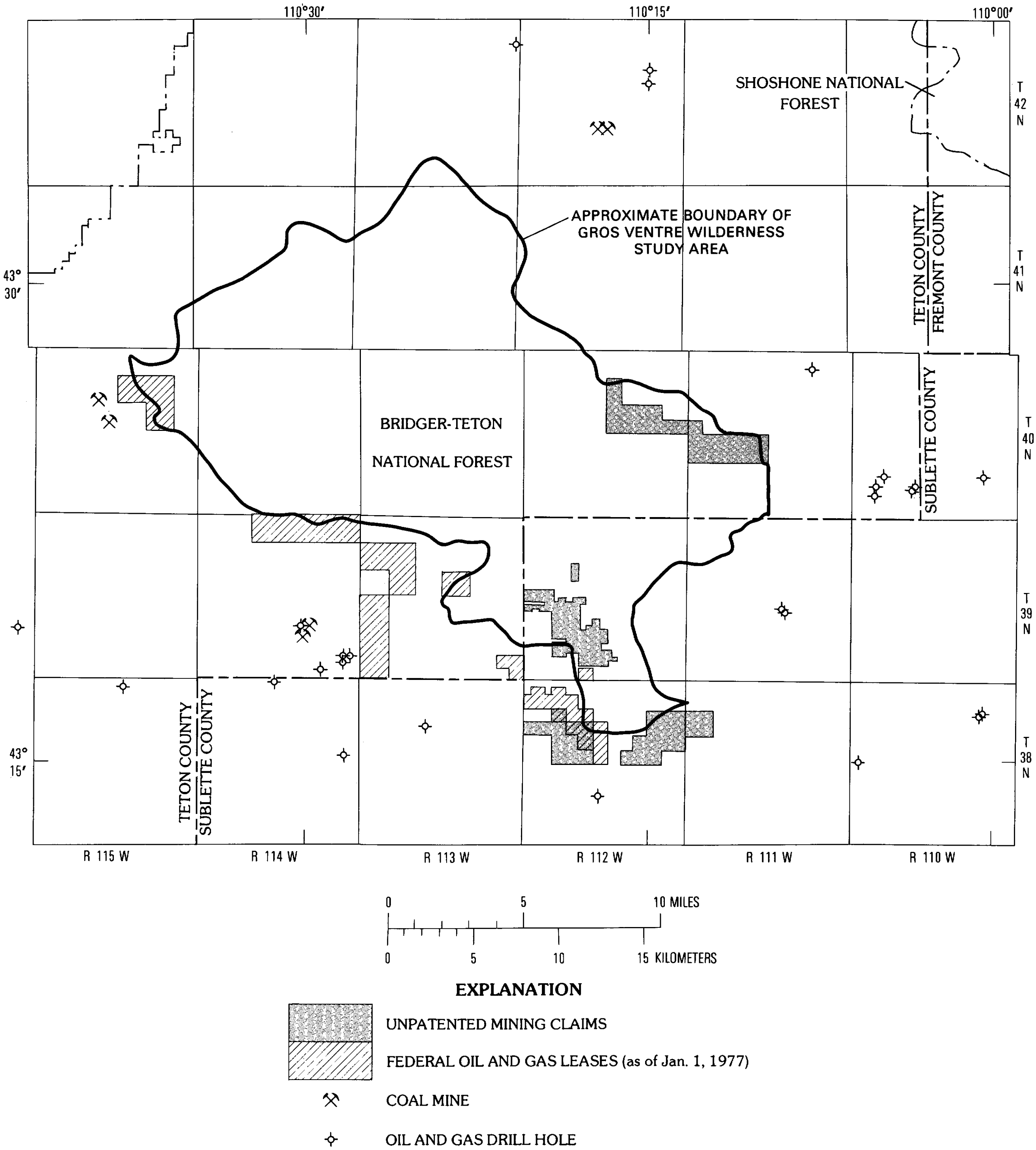

Figure 10. Location of coal mines, oil and gas drill holes, mining claims, and Federal oil and gas leases in and near the Gros Ventre wilderness study area.

the coal was used locally for domestic purposes when the town of Jackson and nearby communities were small.

Coal-bearing formations are present in the study area only in the extreme southeast part, where an 8-ft (2.4-m) section of the Frontier Formation contains two thin beds of coal 12 in. (30 cm) and 16 in. (40 cm) thick, separated by 20 in. (50 cm) of coaly shale (see geology discussion). This section is exposed along a steep hillside about 1 mi (1.6 km) east of Shoal Creek, and is too thin and shaly to be of economic interest. The coal potential is considered low, and the coal is classified as an identified, inferred, subeconomic resource.

Oil and Gas

The study area was withdrawn from further oil and gas leasing on June 14, 1972, at the request of the U.S. Forest Service. Existing oil and gas leases in the study area at the time of the withdrawal would still be in effect until terminated or canceled. Oil and gas leases in effect as of the end of 1976 are shown on figure 10. No oil and gas exploration holes have been drilled on these leased areas nor anywhere else in the study area. Twenty-six oil and gas exploration holes have been drilled within 10 mi (16 km) of the study area through the end of 1977; the locations of the holes are shown on figure 10. No commercial quantities of oil and gas were discovered, but oil shows were reported in drill holes in the SE¼SE¼ sec. 1, T. 42 N., R. 113 W.; NE¼NE¼ sec. 31, T. 40 N., R. 110 W.; SW¼NE¼ sec. 22, T. 39 N., R. 111 W.; and NE¼NW¼ sec. 36, T. 39 N., R. 114 W.

In July 1976, Rainbow Resources, Inc. started drilling an exploration oil and gas hole on Granite Creek in the SW¼SE¼ sec. 35, T. 39 N., R. 114 W., about 5 mi (8 km) southwest of the study area. The hole was completed as a gas well in July 1977 and then shut in. The individual well record shows that the hole was drilled to a total depth of 16,711 ft (5,096 m) and bottomed in the Frontier Formation. Initial production was reported as 725 MCF (thousand cubic feet) (20.5 thousand cubic meters) of gas and 115 bbls (barrels) of water per day. The producing horizon was the Frontier Formation at depths between 15,952 and 16,232 ft (4,865 to 4,951 m). Five holes previously drilled within 2 mi (3.2 km) of this hole were relatively shallow, ranging from 3,000 to 9,148 ft (915 to 2,790 m) in depth, and had no gas production reported.

The oil field nearest to the study area is the Dubois field in Fremont County, Wyo., about 30 mi (48 km) northeast of the study area. This field was discovered in 1946. The 1977 oil production from the six wells operating in this field was 11,299 bbls and the total cumulative production through 1977 was 169,662 bbls (Wyoming Oil and Gas Conservation Comm., 1977). The oil came from the Permian Phosphoria Formation. The nearest gas field is the Merna field in Sublette County, about 15 mi (24 km) south of the study area. Since its discovery in 1966, the production through 1977 from the only gas-producing well in the field totaled 5,567 MCF (158 Mm^3) (Wyoming Oil and Gas Conservation Commission, 1977).

Oil and gas shows in oil and gas drill holes near the study area, and favorable sedimentary rocks and geologic structures such as faults and anticlines, indicate that parts of the study area may have good potential for discovery of oil and gas. See the section on mineral commodities prepared by the U.S. Geological Survey for a detailed discussion of geologic features in and near the study area with potential for oil and gas resources.

Phosphate Rock

The Gros Ventre wilderness study area contains a considerable quantity of phosphate rock and other mineral commodities such as uranium, vanadium, chromium, and fluorine that are found in the phosphate rock. Phosphate rock is the main source of phosphorus, an important plant nutrient and a basic ingredient for many agricultural fertilizers. The United States contains some of the largest phosphate rock resources in the world. The United States' total resources consist of 2,500 million tons (2,268 million t) of phosphate rock classified as reserves and 4,500 million tons (4,082 million t) classified as other resources. A considerable part of the United States reserves and other resources of phosphate rock are in the western phosphate field, which is in parts of Montana, Idaho, Wyoming, and Utah. The balance of the reserves and other resources are in the southeastern United States, especially in Florida, North Carolina, and Tennessee. The U.S. Bureau of Mines (Stowasser, 1975) has projected that the United States reserves of phosphate rock, particularly from Florida and North Carolina, may be depleted near the end of this century. After 1985, it may be difficult to supply the world demand for phosphate rock from the known world reserves. The study area is estimated to contain at least 250 million tons, and perhaps as many as 500 million tons, of potentially mineable phosphate rock. This represents, respectively, about 3 to 7 percent of total known U.S. resources. The phosphate rock resource in the study area is not known to be economically recoverable at present, and hence is not classed as reserves.

Minerals associated with phosphate rock, including uranium, vanadium, chromium, and fluorine, are potential byproducts and coproducts of phosphate-rock processing. They are discussed by Service and Popoff (1964), in the first of five reports on the resources and industry of the western phosphate field.

Sheldon (1963) sampled phosphate rock in the Gros Ventre Range and calculated the amount of phosphate rock and the amount of uranium associated with the phosphate rock. Figure 11 shows outcrops and resource blocks determined by Sheldon (1963, pl. 10) of the

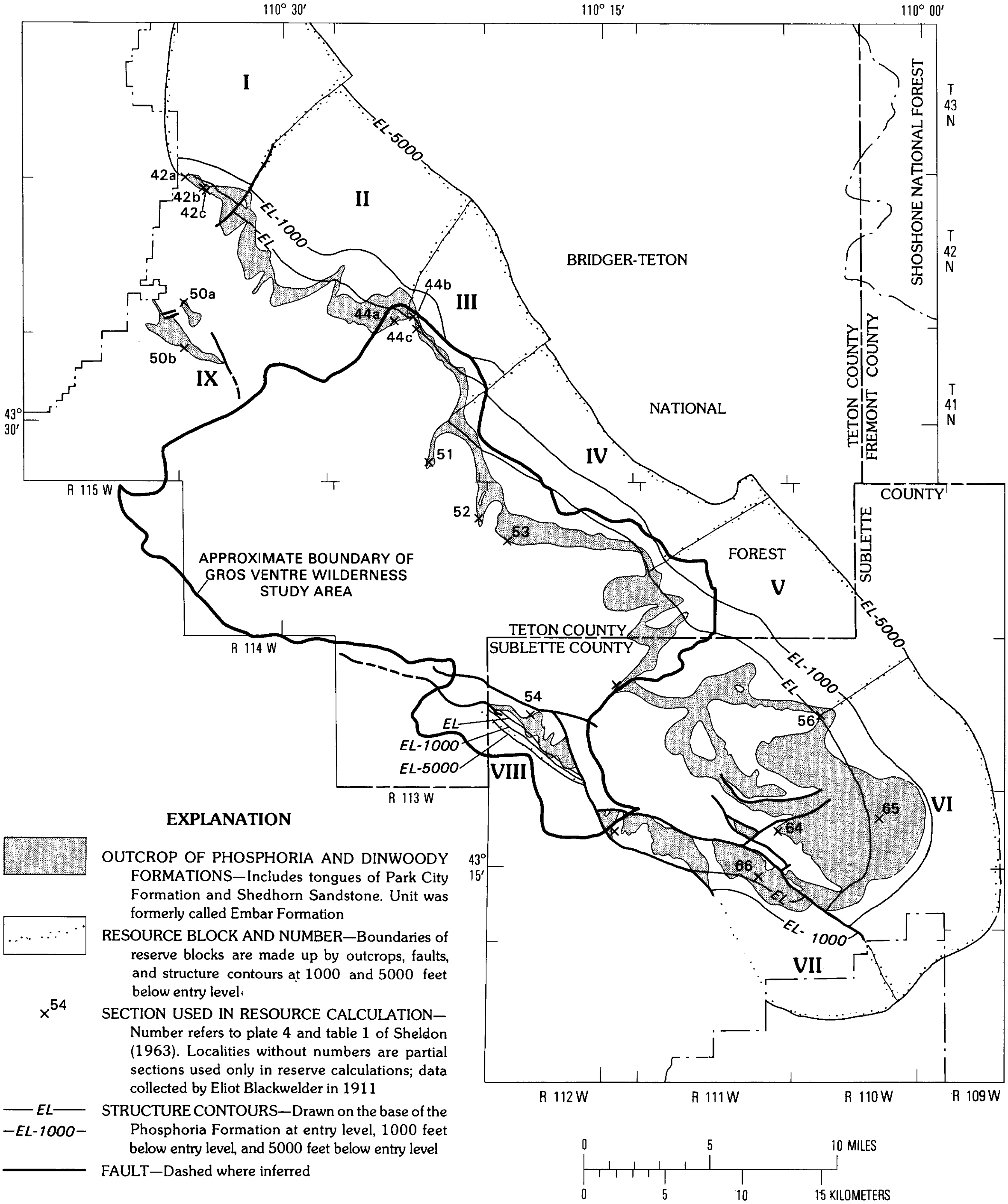

Figure 11. Outcrops and resource blocks of Phosphoria Formation and related strata in the Gros Ventre Range.

Permian Phosphoria Formation in and near the study area. Tables 19, 20, and 21 are essentially the same as tables 7, 12, and 21 in Sheldon's report. Table 19 shows the thickness and grade of phosphatic and uraniferous beds used in calculating the quantity and grade of phosphate rock and uranium. Table 20 gives the phosphate resources, and table 21 gives the uranium resources by the individual resource blocks shown on figure 11. Where Sheldon (1963) used the terms "reserves" and "reserve" in his report, the terms "resources" and "resource" are used in the corresponding tables and figure in this report. These changes in terms were made to conform with the definitions used now by the U.S. Bureau of Mines and U.S. Geological Survey (1980) and to avoid the possible inference that the phosphate rock in the Gros Ventre Range can be mined profitably under present economic conditions. The phosphate rock resources determined by Sheldon should be classified as identified, inferred, submarginal resources.

Table 22 lists the analyses of the phosphate rock and phosphatic shale sampled in and near the study area during this investigation; the localities of these samples are shown on plate 3. The P_2O_5 content of the sampled phosphate rock was usually higher than that reported by Sheldon (1963). The analyses of uranium, fluorine, chromium, and vanadium indicate that the phosphate rock contains these mineral commodities, especially uranium and fluorine, in quantities so that they possibly could be recovered as byproducts during processing of the phosphate rock. The analysis of the sample (No. 2) of the phosphatic shale indicates that this rock is not a valuable resource for phosphorus at this time.

Of the nine resource blocks that Sheldon (1963) determined for the Gros Ventre Range, block VIII is totally within the study area, and parts of blocks II, III, IV, V, and VII are also within it (fig. 11). However, because the Phosphoria Formation that crops out in the northeast part of the study area dips to the northeast, most of the phosphate rock and uranium in blocks II, III, IV, and V are outside the study area. In tables 20 and 21, no quantities of phosphate rock and uranium are shown for blocks III and VII. The reason is that Sheldon (1963) used 3 ft (0.9 m) as the minimum thickness of phosphate rock that could be considered minable, and the average thickness in both blocks is less than 3 ft (0.9 m). For determining the quantities of phosphate rock and uranium in all blocks, Sheldon (1963) used 18 percent P_2O_5 as the cutoff grade for phosphate rock. Furthermore, he determined for each block the quantities of phosphate rock and uranium above and below an entry level, which would be the mine opening to provide

Table 19. Thickness and grade of phosphatic and uraniferous beds used in calculations of phosphate and uranium resources in the Gros Ventre Range
[Data are from Sheldon (1963, table 7). Leaders (---), no data]

Stratigraphic section[1]	18–24 percent P_2O_5					24–31 percent P_2O_5					>31 percent P_2O_5				
	Thickness		Grade (percent)			Thickness		Grade (percent)			Thickness		Grade (percent)		
	ft	(m)	P_2O_5	eU	Chem U	ft	(m)	P_2O_5	eU	Chem U	ft	(m)	P_2O_5	eU	U
42a	---	---	---	---	---	2.5	(0.76)	24.1	---	---	---	---	---	---	---
42b	3.7	(1.13)	23.3	---	---	---	---	---	---	---	---	---	---	---	---
42c	---	---	---	---	---	3.4	(1.04)	24.9	0.007	0.007	---	---	---	---	---
44a	---	---	---	---	---	[2]7.2	(2.20)	25.9	---	---	3.0	(0.92)	31.5	---	---
44b	1.5	(.46)	20.2	0.007	0.004	---	---	---	---	---	---	---	---	---	---
44c	---	---	---	---	---	1.8	(.55)	28.8	---	---	---	---	---	---	---
51	---	---	---	---	---	[2]4.7	(1.43)	29.0	---	---	3.0	(.92)	32.0	---	---
52	---	---	---	---	---	---	---	---	---	---	2.8	(.85)	33.6	---	---
53	---	---	---	---	---	[2]4.0	(1.22)	28.9	---	---	3.0	(.92)	32.0	---	---
Sec. 13, T. 39 N., R. 112 W.	---	---	---	---	---	7.5	(2.29)	24.9	---	---	---	---	---	---	---
56	[2]5.3	(1.62)	19.2	.005	.005	2.3	(.70)	28.6	.008	.010	---	---	---	---	---
64	[2]3.9	(1.61)	23.7	---	---	---	---	---	---	---	---	---	---	---	---
65	---	---	---	---	---	3.8	(1.16)	24.4	---	---	---	---	---	---	---
66	2.2	(.67)	23.2	---	---	---	---	---	---	---	---	---	---	---	---
Sec. 12, T. 38 N., R. 112 W.	---	---	---	---	---	2.2	(.67)	24.9	---	---	---	---	---	---	---
54	---	---	---	---	---	---	---	---	---	---	4.6	(1.40)	33.4	---	---
50a	---	---	---	---	---	---	---	---	---	---	3.6	(1.10)	32.4	---	---
50b	---	---	---	---	---	[2]4.1	(1.25)	27.1	.008	.008	2.7	(.82)	32.4	0.010	0.010

[1]See Sheldon (1963) for description.
[2]Includes beds in the next higher grade range.

Table 20. Phosphate resources in the Gros Ventre Range

[Data are from Sheldon (1963, table 12). Metric equivalents given in parentheses. Leaders (---), no resources]

Resource block (fig. 11)	mi^2 (km^2) (Corrected for dip)			Phosphate rock		Millions of tons (t) of phosphate rock with P_2O_5 >18 percent		
	Above entry level	Entry level to 1,000 ft (305 m) below entry level	1,000 ft (305 m) to 5,000 ft (1,525 m) below entry level	Average thickness ft (m)	Average grade percent P_2O_5	Above entry level	Entry level to 1,000 ft (305 m) below entry level	1,000 ft (305 m) to 5,000 ft (1,525 m) below entry level
I	0.8 (2.07)	2.4 (6.22)	46.7 (120.95)	3.2 (0.98)	24.1	6.2 (5.6)	18.6 (16.9)	362.3 (328.7)
II	8.2 (21.24)	9.3 (24.09)	39.7 (102.82)	3.0 (0.92)	31.5	------------Included below------------		
				7.2 (2.20)	25.9	143.1 (129.8)	162.3 (147.2)	692.9 (628.6)
III	1.5 (3.89)	4.0 (10.36)	18.6 (48.17)	<3.0 (<0.92)		---	---	---
IV	13.0 (33.67)	12.8 (33.15)	28.3 (73.30)	3.0 (0.92)	32.5	------------Included below------------		
				4.3 (1.31)	29.0	135.5 (122.9)	133.4 (121.0)	295.0 (267.6)
V	24.9 (64.49)	9.4 (24.35)	35.8 (92.72)	6.4 (1.95)	22.1	370.2 (335.9)	139.8 (126.8)	532.3 (482.9)
VI	20.6 (53.35)	16.2 (41.96)	43.5 (112.67)	4.3 (1.31)	22.4	205.8 (186.7)	161.8 (146.8)	434.6 (394.3)
VII	8.4 (21.76)	5.1 (13.21)	18.3 (47.40)	<3.0 (<0.92)		---	---	---
VIII	2.1 (5.44)	1.1 (2.85)	6.4 (16.58)	4.6 (1.40)	33.4	24.5 (22.2)	12.8 (11.6)	74.6 (67.7)
IX	2.4 (6.22)	None	None	3.3 (1.01)	32.4	------------Included below------------		
				4.1 (1.25)	27.1	23.8 (21.6)	---	---
Total resources--------------------------------				million tons (million t)		909.1 (824.7)	628.7 (570.3)	2,391.7 (2,169.8)

access to the phosphate rock. The entry level usually was assumed to be at the elevation of the lowest outcrop of the phosphatic beds.

The amount of phosphate rock in block VIII, plus that in block IV above the entry level within the study area, is at least 247.4 million tons (224.4 million t) containing more than 24 percent P_2O_5; this rock also contains 23.4 million tons (21.2 million t) of uranium. If some phosphate rock below the entry level of block IV and some in blocks II and V is included, then the study area may have as much as 500 million tons (454 million t) of phosphate rock containing more than 18 percent P_2O_5; this rock also contains about 30 million tons (27 million t) of uranium. In addition to these quantities of phosphate rock and uranium, there are probably large tonnages of phosphate rock less than 3 ft (0.9 m) thick and containing less than 18 percent P_2O_5 and 0.005 percent U. Considerable exploration work, including much drilling and more sampling of exposed phosphate rock, would be needed to determine precisely the quantity and grade of phosphate rock present in the study area.

Other Commodities

About 50 percent of the rock that crops out in the study area is Madison Limestone. Table 23 lists the chemical analyses of three samples (Nos. 6, 8, and 16) of Madison Limestone and a sample (No. 7) of dolomite

Table 20. Phosphate resources in the Gros Ventre Range—Continued

Resource block (fig. 11)	Millions of tons (t) of phosphate rock with P_2O_5 >24 percent: Above entry level	Entry level to 1,000 ft (305 m) below entry level	1,000 ft (305 m) to 5,000 ft (1,525 m) below entry level	Millions of tons (t) of phosphate rock with P_2O_5 >31 percent: Above entry level	Entry level to 1,000 ft (305 m) below entry level	1,000 ft (305 m) to 5,000 ft (1,525 m) below entry level
I	6.2 (5.6)	18.6 (16.9)	362.3 (328.7)	---	---	---
II	------------Included below------------			62.3 (56.5)	70.7 (64.1)	301.8 (273.8)
	143.1 (129.8)	162.3 (147.2)	692.9 (628.6)	---	---	---
III	---	---	---	---	---	---
IV	------------Included below------------			98.8 (89.6)	97.3 (88.3)	215.2 (195.2)
	135.5 (122.9)	133.4 (121.0)	295.0 (267.6)	---	---	---
V	---	---	---	---	---	---
VI	---	---	---	---	---	---
VII	---	---	---	---	---	---
VIII	24.5 (22.2)	12.8 (11.6)	74.6 (67.7)	24.5 (22.2)	12.8 (11.6)	74.6 (67.7)
IX	------------Included below------------			20.1 (18.3)	---	---
	23.8 (21.6)	---	---			
	333.1 (302.1)	327.1 (296.7)	1,424.8 (1,292.6)	205.7 (186.6)	180.8 (164.0)	591.6 (536.7)

from the Darby Formation taken in the study area; the locality of these samples is shown on plate 3. Sample 6 was taken near the base of the Madison Limestone, sample 8 near the top, and sample 16 near the middle. The analyses of the limestone indicate that it is of high quality and could be used for most chemical and agricultural purposes. The analysis of dolomite also indicates that it is of high quality and usable as flux in steel-making and for making magnesian limes. Large quantities of limestone and dolomite are easily accessible in the study area, especially in the vicinity of Flat, Crystal, and Granite Creeks, but are not considered as valuable mineral resources because such commodities are much more readily available in other places nearer to the market areas.

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Table 21. Uranium resources in the Gros Ventre Range

[Data are from Sheldon (1963, table 21). Metric equivalents given in parentheses. Leaders (---), no resources]

Resource block (fig. 11)	Phosphate rock: Average thickness feet (m)	Phosphate rock: Average grade percent U	Millions of tons (t) of phosphate rock with U >0.005 percent: Above entry level	Entry level to 1,000 ft (305 m) below entry level	1,000 ft (305 m) to 5,000 ft (1,525 m) below entry level
I	3.2 (0.98)	0.007	6.2 (5.6)	18.6 (16.9)	362.3 (328.7)
II	3.0 (0.92)	.010	------------Included below------------		
	7.2 (2.20)	.008	143.1 (129.8)	162.3 (147.2)	692.9 (628.6)
III	<3.0 (<0.92)	---	---	---	---
IV	3.0 (0.92)	.010	------------Included below------------		
	4.3 (1.31)	.009	135.5 (122.9)	133.4 (121.0)	295.0 (276.6)
V	6.4 (1.95)	.007	370.2 (335.9)	139.8 (126.8)	532.3 (482.9)
VI	4.3 (1.31)	.007	205.8 (186.7)	161.8 (146.8)	434.6 (394.3)
VII	<3.0 (<0.92)	---	---	---	---
VIII	4.6 (1.40)	.010	24.5 (22.2)	12.8 (11.6)	74.6 (66.7)
IX	3.01 (1.25)	.010	-----------Included below-----------		
	4.1 (1.25)	.008	23.8 (21.6)	---	---
Total resources		thousand tons (thousand t)	909.1 (824.7)	628.7 (570.3)	2,391.7 (2,169.8)

Table 21. Uranium resources in the Gros Ventre Range—Continued

Resource block (fig. 11)	Millions of tons (t) of phosphate rock with U >0.010 percent			Thousands of tons (t) of U		
	Above entry level	Entry level to 1,000 ft (305 m) below entry level	1,000 ft (305 m) to 5,000 ft (1,525 m) below entry level	Above entry level	Entry level to 1,000 ft (305 m) below entry level	1,000 ft (305 m) to 5,000 ft 1,525 m) below entry level
I	---	---	---	0.4 (0.3)	1.3 (1.2)	25.4 (23.0)
II	62.3 (56.5)	70.7 (64.1)	301.8 (273.8)	-----------Included below-------------		
	---	---	---	11.4 (10.3)	13.0 (11.8)	55.4 (50.3)
III	---	---	---	---	---	---
IV	98.8 (89.6)	97.3 (88.3)	215.2 (195.2)	-----------Included below-------------		
	---	---	---	12.2 (11.1)	12.0 (10.9)	26.6 (24.1)
V	---	---	---	25.9 (23.5)	9.8 (8.9)	37.3 (33.8)
VI	---	---	---	14.4 (13.1)	11.3 (10.2)	30.4 (27.6)
VII	---	---	---	---	---	---
VIII	24.5 (22.2)	12.8 (11.6)	74.6 (67.7)	2.4 (2.2)	1.3 (1.2)	7.5 (6.8)
IX	20.1 (18.3)	---	---	------------Included below------------		
	---	---	---	1.9 (1.7)	---	---
205.7 (186.6)	180.8 (164.0)	591.6 (536.7)	68.6 (62.2)	48.7 (44.2)	182.6 (165.6)	

Table 22. Analyses of phosphate rock and phosphatic shale sampled in and near the Gros Ventre wilderness study area

[Leaders (---), not detected; ppm, parts per million]

Sample No.	Thickness (ft)	Thickness (m)	P_2O_5 (percent)	F (percent)	U (percent)	Cr (ppm)	Mo (ppm)	V (ppm)
			Phosphate rock					
3	0.7	(0.21)	27.8	3.1	0.008	60	---	<60
5	.4	(.12)	25.5	3.2	.005	---	---	<60
10	1.2	(.37)	31.5	2.6	.009	100	---	<60
11	.75	(.23)	30.6	2.9	.007	300	---	<60
12	2.0	(.61)	27.5	2.1	.008	100	---	500
13	1.0	(.31)	29.7	3.2	.012	500	---	500
14	3.3	(1.01)	30.7	3.1	.012	500	---	500
41	1.5	(.46)	29.8	3.0	.009	500	---	<60
57	2.5	(.76)	28.6	2.0	.002	600	---	<60
58	2.5	(.76)	30.7	2.8	.007	500	---	1,000
59	1.0	(.31)	40.0	3.2	.006	1,000	---	500
60	.5	(.15)	30.7	2.3	.006	500	---	60
61	.5	(.15)	25.7	1.7	.004	1,000	---	60
			Phosphatic shale					
2	36.0	(10.98)	2.3	0.5	<.001	100	<20	<60

Table 23. Analyses of limestone and dolomite sampled in the Gros Ventre wilderness study area

[Data are in percent. Percentages total more than 100 because of the statistical spread of analysis due to the method of determination]

Constituent (symbol)	Limestone Sample 8	Limestone Sample 16	Limestone Sample 6	Dolomite Sample 7
Calcium carbonate[1] ($CaCO_3$)--	100.71	100.56	101.17	Not determined.
Silica (SiO_2)----------------	0.38	0.24	0.16	0.38
Iron oxide (Fe_2O_3)----------	.06	.05	.04	.05
Alumina (Al_2O_3)-------------	.19	.12	.14	.21
Lime (CaO)------------------	56.96	56.90	57.50	31.96
Magnesia (MgO)--------------	.66	.18	.80	21.10
Titanium oxide (TiO_2)-------	.02	.02	.03	.02
Volatile matter-------------	43.75	43.66	43.67	46.86
Moisture--------------------	.04	.01	.06	.03
Total (without $CaCO_3$)-----	102.06	101.18	101.68	100.61

[1]For limestone samples, percent calcium carbonate ($CaCO_3$) is calculated by adding lime (CaO) and volatile matter which may be considered as carbon dioxide (CO_2).

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