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GEOLOGICAL SURVEY

GEOLOGY AND MINERAL RESOURCE POTENTIAL OF THE BENNETT MOUNTAINS WILDERNESS STUDY AREA, CARBON COUNTY, WYOMING

By

Robert J. Walker[1/], H. Roberta Dixon[1], and Margo I. Toth[1/]

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature

[1/]Denver, Colorado

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EXECUTIVE SUMMARY

The U.S. Bureau of Land Management (BLM) has adopted a multi-phase procedure for the integration of geological, energy, and mineral (GEM) resources data for suitability decisions for wilderness study areas. Phase 1 included the gathering of historical GEM resource data and was contracted to Tetra Tech, Inc. (1983). Phase 2 is designed to generate new data to support GEM resources recommendations and was contracted to the U.S. Geological Survey. This report is the result of a Phase 2 study of the Bennett Mountains Wilderness Study Area (WSA) conducted in the summer of 1983 by personnel from the Central Mineral Resources Branch of the U.S. Geological Survey.

The Bennett Mountains Wilderness Study Area (Wy 030-304) comprises 5,722 acres in Carbon County, Wyoming, and lies about 45 mi north of Sinclair, Wyo. The mineral resource appraisal of the study area consisted of geologic mapping at a scale of 1:24,000 combined with stream-sediment and rock-sampling, and subsequent analysis of the samples.

The physiography of the study area resembles a northward-tilting plateau with a hinge-line near the southern rim. The southern flank of the Bennett Mountains is composed of Paleozoic sedimentary rocks that have been folded upward into flatirons with dips of 70°-80° to the south. The northern part of the mountains consists of a complex of Archean igneous and metamorphic rocks. Short, steep-sided, rugged stream canyons cut the crystalline and sedimentary rocks from the crest of the range to the hogbacked plain on the south. North-flowing streams have cut canyons from the crest of the mountains to the range front.

One hundred forty seven stream sites were sampled in the WSA and analyzed by semiquantitative emission spectrography for 50 elements. One hundred sixteen rock samples were collected from representative outcrops of granitic rock, amphibolite, quartz veins, and pegmatites, and from known prospects, and were analyzed in a similar manner.

Stream-sediment samples from the Bennett Mountains Wilderness Study Area had low concentrations of elements associated with mineralized rocks. With the exception of 150 ppm Pb in one sample, no anomalies were present. Rock samples from the study area are also low in mineralizing elements and only one anomaly was present in a sample outside of the northern edge of the study area which contained 30 ppm Sn.

Petroleum resources have low potential in the study area. Aggregate, stone, and cement reserves exist but the remoteness of the area severely diminishes their economic value.

INTRODUCTION

The Wilderness Act of 1964 (PL-577) mandated the withdrawal of major portions of the federal lands in the National Forest System for inclusion into the National Wilderness Preservation System (NWPS). Federal mineral assessments were required to be conducted on lands affected as part of the wilderness land review process.

In 1976, the Federal Land Policy and Management Act (FLPMA, PL 94-579) extended the wilderness review program to the lands administered by the U.S. Bureau of Land Management (BLM). Provisions in this act require the Secretary of the Interior to cause mineral surveys to be conducted prior to his making wilderness recommendations to Congress. Natural or Primitive Areas formally identified prior to November 2, 1975, were termed Instant Study Areas. Wilderness recommendations for these areas were presented to the President prior to July 1, 1980. The remainder of the BLM lands are under review by the BLM to determine which are suitable as wilderness areas for inclusion into the NWPS. The wilderness land review process is being conducted in three steps: inventory, study, and report. After the inventory of BLM lands, the Wilderness Study Areas were designated. The study step in the wilderness review process includes mineral resource appraisals of the Wilderness Study Areas. The BLM has adopted a multi-phase procedure for the integration of geological, energy, and mineral (GEM) resources data into the suitable/unsuitable decision process on the Wilderness Study Areas. The multi-phase approach allows termination of the mineral resource appraisal at the end of Phase 1, which consists mainly of compilation of existing information. If the data gathered in Phase 1 is not adequate, then Phase 2 would generate new GEM resources data needed to permit an assessment of the potential for GEM resources. This report is the result of a Phase 2 study of the Bennett Mountains WSA conducted in the summer of 1983 by the U.S. Geological Survey.

Location

The Bennett Mountains Wilderness Study Area comprises 5,722 acres in Carbon County, Wyo. (fig. 1). It is located about 45 mi north of Sinclair, Wyo., and 38 mi northwest of Hanna, Wyo. The study area can be reached from Sinclair by the Seminoe Road which passes a few miles west of the western boundary. Additional access is provided by the Hanna-Leo Road which joins with the Medicine Bow Road and passes near the east and northeast boundary of the study area. The southern boundary of the study area nearly parallels a Bureau of Reclamation and private ranch road that connects Seminoe Dam with the Hanna-Leo Road, and the northern boundary is close to a private road leading from Black Canyon Ranch to the Hanna-Leo Road. Four-wheel-drive roads in House Gulch and Number One Gulch give access to the eastern and western boundaries, respectively.

Physiography

Physiographically, the study area resembles a plateau that has been tilted down to the north with the hinge line near the southern rim. Elevations range from about 7,800 ft along the crest of the mountains to 6,300 ft along the northern edge of the range. The southern flank of the Bennett Mountains is composed of Paleozoic sedimentary rocks that have been

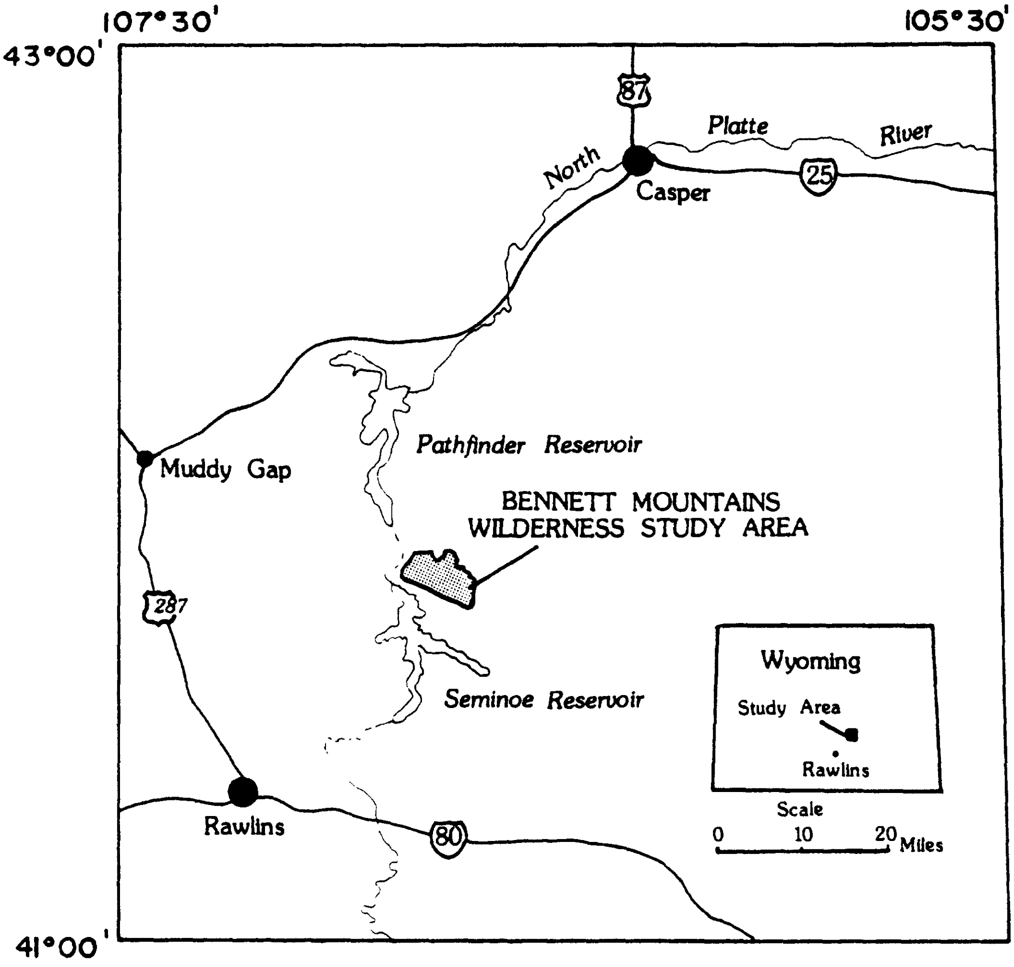

Figure 1.--Map showing location of the Bennett Mountains Wilderness Study Area, Wyoming.

folded and eroded into flatirons with dips of 70°-80° to the south. Short, steep-sided, rugged stream canyons cut the crystalline and sedimentary rocks from the crest of the range to the hogbacked plain on the south. North-flowing streams have cut canyons from the crest to the range front and, while rugged, are much more accessible than the south-facing canyons.

Vegetation is dependent on the relatively scant water of the area and can be divided into two regimes. Most abundant are the sparse and stunted juniper, pine, sagebrush, and scattered bunch grass along the ridge crests and canyon walls where water is scarce and the wind strong. More restricted are thick aspen and cottonwood groves and luxuriant grassy meadows of the canyon bottoms where water is abundant, at least most of the year.

Land status

The entire Bennett Mountains Wilderness Study Area lies within the realm of public lands that are administered by the Bureau of Land Management. The study area is bounded on the north and east by private and state lands and on the south and west by Bureau of Reclamation and Water Power Projects controlled land. Examination of county records for Carbon County show that while mining claims were staked within the study area during the 1950s and 1970s they were not maintained. Research at the Bureau of Land Management office in Rawlins, Wyo., showed no mining claims within the proposed wilderness study area.

Previous investigations

It should be noted that the Bennett Mountains are better known as the eastern Seminoe Mountains in the scant geologic literature of the area. Most of the early geologic work within and adjacent to the Bennett Mountains Wilderness Study Area was completed by graduate students of the University of Wyoming, Laramie, Wyo. The unpublished theses germane to the Seminoe Mountains area include: Ferren (1935), Shoemaker (1936), Isberg (1937), Umbach (1948), Cooper (1951), Finnell (1951b), Allspach (1955), and Bishop (1964). Some of these authors contributed to the Wyoming Geological Association Guidebook of the Sixth Annual Field Conference in 1951 which contains much useful information relating to the Bennett Mountains.

More recently, investigations of the geology in areas near the proposed wilderness have been carried out. These studies have been useful in the evaluation of the Bennett Mountains, especially the geologic maps of Weitz and Love (1952), Merewether (1972), and Love and others (1979). The work of Sherer (1969) provides additional useful information to anyone interested in the Bennett Mountains.

Present investigations

Field investigations were conducted by U.S. Geological Survey personnel Mark A. Arnold, Gary A. Miller, and Robert J. Walker during late June and early July 1983. Geologic mapping and interpretation of the study area had been performed by H. Roberta Dixon of the U.S. Geological Survey during previous field seasons. The 1983 investigation consisted of foot traverses throughout the study area during which rock and stream-sediment samples were collected, prospects were examined, and general reconnaissance for mineralization indicators were carried out. Chemical analyses of the collected samples were performed by the U.S. Geological Survey laboratories, Denver, Colo.

Courthouse records of Carbon County were searched for claim locations at Rawlins, Wyo. Literature research to determine known mineralization was carried out at the U.S. Geological Survey library in Denver, Colo., and the University of Wyoming library, Laramie, Wyo.

The mineral resource potential of the Bennett Mountains Wilderness Study Area was determined based on an evaluation of the available literature, mineralization indicators in the field, and interpretation of the geochemical data.

ACKNOWLEDGMENTS

The personnel of the Bureau of Land Management in Rawlins, Wyo., and the Bureau of Reclamation at Seminoe Dam were very helpful to the present investigation by furnishing information about and access to the study area. A special thanks to the Kortes family of Black Canyon Ranch for allowing passage across their property and for their Western friendliness when meeting strangers.

GEOLOGY

Precambrian geology

By H. Roberta Dixon

The Bennett Mountains Wilderness Study Area is within the eastern half of the Seminoe Mountain uplift, which lies along the southern edge of the Granite Mountains as defined by Love (1970). The Seminoe Mountains are part of a west-northwest-trending ridge of Precambrian rocks which extends from this area west almost to the Wind River Mountains, and which is bounded on the north by the South Granite Mountain fault system. In the Seminoe Mountain area this fault, marked by a zone of intense cataclasis (crushing and deformation) about 65 yd thick, separates two distinct groups of Archean rocks. North of the fault is an alkali granite that is continuous with the granite of Lankin Dome as defined by Peterman and Hildreth (1978). South of the fault, in the Seminoe Mountains proper, the rocks have been subdivided into a complex of metamorphic rocks and three varieties of granite, referred to as the Seminoe Dam granite, the Kortes Dam granite, and white granite.

The wilderness study area is entirely south of the South Granite Mountain fault, although the fault zone is included in parts of the northeast boundary. From north to south (Plate 1) the mapped units are the metamorphic complex immediately south of the fault, Kortes Dam granite, and Seminoe Dam granite; the white granite is most abundant in the north, cutting the metamorphic rocks, but occurs throughout the area as dikes in the other granites. Thin diabase dikes, the youngest of the Precambrian rocks, cut all rock units. The Precambrian-Cambrian contact approximately parallels the southern boundary of the area, about 0.5 mi north of the boundary. The contact trends northwest and dips 60°-70° southwest. The Seminoe Dam granite within about 300 yd of the contact acquires a deep-red color, probably as a result of Precambrian weathering prior to deposition of the Cambrian sediments.

Description of Precambrian rocks

Metamorphic complex.--Metamorphic rocks occur along the northern edge of the Bennett Mountains. They are cut out by the South Granite Mountain fault near Hurt Gulch, and increase in thickness to the west. The belt of metamorphic rocks is intruded by white granite on the northern side and by Kortes Dam granite on the south. Immediately south of the fault the rocks are strongly cataclastic, but the effects of the cataclasis are minor to absent about 30 yd away from the fault.

Within the confines of the Wilderness Study Area, the most abundant metamorphic rock is a biotite granite gneiss. The gneiss is light gray, weathering pinkish gray, fine to medium grained, and shows a strong foliation defined by orientation of biotite flakes and, in the biotite-rich varieties, by concentration of biotite flakes in thin laminae. The average composition of the gneiss is shown in table 1, but variations from this average are great; the rock ranges from quartz diorite to granite in composition. Epidote, apatite, sphene, and opaque minerals are common accessories. The gneiss is generally similar in appearance to the Kortes Dam granite, except for the foliation, and where the two are seen in contact, the Kortes Dam granite clearly truncates the foliation of the gneiss.

Other metamorphic rocks, which are more abundant north and west of the wilderness area, are mainly amphibolite and amphibole gneisses and lesser amounts of biotite schist, epidote gneiss, and locally feldspathic quartzite. They are most common north of the granite gneiss, but small lenses of amphibolite and epidote gneiss occur within the granite gneiss. Dark-gray amphibolite forms belts from 3 to 10 yd thick between ribs of white granite. The amphibolite consists primarily of hornblende and sericitized andesine and lesser amounts of quartz, epidote, sphene, and opaque minerals. Locally, the amphibolite contains white knots of sericitized plagioclase 0.5 in. or longer. The amphibole gneiss contains either hornblende or actinolite; hornblende varieties are generally similar to amphibolite except for more abundant quartz and a lighter color, and actinolite varieties are greenish gray with or without quartz. Biotite schist is composed of quartz, plagioclase, and as much as 25 percent biotite. Epidote is more or less abundant in all the varieties, and in some is the only mafic mineral. These various gneisses and schists most likely represent a terrane of metamorphosed volcanic and volcaniclastic rocks.

Kortes Dam granite.--The Kortes Dam granite forms the core of the Bennett Mountains, and is typically, and most freshly, exposed at Kortes Dam. The granite is a massive, uniform, fine- to medium-grained biotite granite that typically contains square feldspar megacrysts about 0.2 in. on a side. Fresh granite, as seen around Kortes Dam and in some of the deeper canyons, is very light gray. Weathered granite, as is most commonly seen on the mountain slopes, is yellowish gray to pale yellowish orange; weathering is deep and fresh samples are hard to collect outside the canyons. The Kortes Dam granite is the most uniform of the various granites in composition and in texture. The average composition is given in table 1, and the ranges given indicate the small variation from this average. Accessory minerals include epidote, apatite, sphene, opaque minerals, and locally garnet. In places alinement of biotite flakes gives the rock a weak foliation, or more commonly a lineation, but neither flow banding nor inclusions were observed in the granite. Small local zones of the Kortes Dam granite are hydrothermally altered. The zones are generally circular to ovoid in shape and a few yards in diameter. Mineralization in the zones is limited to pyrite and hematite after pyrite; limonite staining is pervasive.

Table 1.--Average modal compositions of the granites (in percent) of the Bennett Mountains, showing the compositional range in each unit

	Granite of Lankin Dome	Kortes Dam Granite	Seminoe Dam Granite	White Granite	Granite Gneiss
No. of samples----	13	11	12	9	8
Quartz------------	32±3	31±3	31±3	27±10	36±14
Plagioclase-------	32±8	35±4	37±11	39±29	38±14
K-feldspar--------	31±10	28±4	26±18	30±30	18±15
Biotite-----------	3±3	3±3	2±2	1±1	6±4
Anorthite in plagioclase-----	10-20	8-12	23-28	10-30	14-30

Kortes Dam granite is cut by yellowish-gray, medium-grained, zoned pegmatites that are commonly 1-2 yd thick, and that are unlike the coarse pegmatites of the white granite. Similar pegmatites were not observed in the other granites.

Seminoe Dam granite.--The Seminoe Dam granite, forming the southern edge of the Precambrian rocks of the Bennett Mountains, is typically and most freshly exposed at Seminoe Dam. The common granite is massive, medium grained, and grayish orange pink, although the color deepens to pale reddish brown near the Cambrian contact. It has a gradational contact with the Kortes Dam granite. Away from the contact zone, however, there are distinctive differences between them. Aside from the pinkish color, the Seminoe Dam granite is generally coarser grained, and microcline megacrysts are tabular and as much as 0.5 in. long. The average composition of the Seminoe Dam granite, as given in table 1, is not significantly different from that of the Kortes Dam granite, but the ranges given indicate a much greater variation in composition for the Seminoe Dam granite. In addition, the plagioclase in the Seminoe Dam granite is consistently richer in anorthite. Locally, the Seminoe Dam granite shows a flow foliation and lamination in which laminae contain differing amounts of biotite. In these areas it may also contain small inclusions, of metamorphic rock, mainly amphibolite, commonly less than a yard in diameter. Pegmatites that cut the Seminoe Dam granite appear to be related to the white granite.

White granite.--The white granite is most abundant on the north side of the Bennett Mountains, within the metamorphic complex and between it and the Kortes Dam granite, but small dikes, a few yards thick, cut all mapped units. The color is commonly white, but it becomes pink where the host rock is pink from Precambrian weathering; in stream valleys the granite has a rusty weathering stain. The white granite is the most variable of the granitic rocks both in texture and composition which ranges from aplite to coarse pegmatite; the common medium-grained rock is commonly a graphic granite. The average composition given in table 1 has little significance; the rock ranges in composition from quartz diorite to alkali granite. It commonly contains rarely more than 1 percent biotite, and 2-3 percent epidote; locally it may contain garnet and, where cataclastic or hydrothermally altered, may contain actinolite needles. The white granite is altered in zones where the adjacent Kortes Dam granite is hydrothermally altered.

Diabase.--Dark-gray to black, fine-grained diabase dikes, rarely more than 2 yd thick, cut all the Precambrian rock units of the area. The dikes commonly have a north-northwest trend and a steep to vertical dip, although some have moderate to shallow dip. They can be traced 1.2-1.8 mi along strike. All of the diabase examined in thin section has been altered and consists primarily of green hornblende and calcic andesine to sodic labradorite, mostly sericitized. A fairly fresh diabase, sampled west of this area, indicates the original diabase contained pyroxene and olivine. The most strongly altered diabase is commonly sheared, and consists primarily of chlorite, epidote, and amphibole.

Granite of Lankin Dome.--The proposed wilderness area does not include the rocks north of the South Granite Mountain fault, with the possible exception of the area near Indian Springs and Spencer Gulch, where the granite of Lankin Dome is mylonitized (sheared and pulverized) along the fault. The mylonite is a hard, dense, ultrafine-grained rock in which the constituent minerals have been thoroughly granulated, although even the most strongly granulated rocks contain a few small feldspar clasts. Locally, quartz, chlorite, or epidote, or a combination of them, were introduced during cataclasis. The mylonites are atypical rocks that are localized along the fault, although shearing is apparent in some rocks elsewhere.

Discussion

The ages and correlatives of the Precambrian rocks of the Bennett Mountains are not definitely established, although some estimates can be made. The relative ages of the rocks can be established within limits; that is, the oldest and the youngest can be defined. The oldest rocks are clearly the metamorphic rocks. The hornblende and biotite-rich gneisses and schists probably represent an ancient volcanic terrane. Whether the granite gneiss is an intrusive rock or a metavolcanic rock cannot be determined at the present time, although the large compositional variation would suggest a volcanic protolith. Peterman and Hildreth (1978) report a Rb-Sr age of 2,860±80 m.y. for similar quartzofeldspathic gneisses of the Northern Granite Mountains. They interpret this age to date the time of metamorphism of the rocks, and, on the basis of their data, suggest a possible original age of 3.2-3.3 b.y. ago (Peterman and Hildreth, 1978, p. 12).

The age relationships of the three mapped varieties of massive granite, granite of Lankin Dome, Kortes Dam granite, and Seminoe Dam granite, are not known. It is possible they are all phases of the same batholith, and there is some radiometric data to support this interpretation, or at least the correlation of the granite of Lankin Dome and the Kortes Dam granite; however, no analytical work has been done on the Seminoe Dam granite. Rosholt and Bartel (1969) and Rosholt and others (1973) studied the U-Th-Pb systematics of a number of both surface and core samples of the granite of Lankin Dome and the Kortes Dam granite. Data points for the two granites fall on the same $^{206}Pb/^{204}Pb$ plotted against $^{207}Pb/^{204}Pb$ isochron, and they consider this evidence that the two granites are comagmatic (Rosholt and others, 1973, p. 994). The age defined by the isochron was 2,700±80 m.y., which they indicate is a maximum age because of Cenozoic migration of uranium from the system. A somewhat younger age is suggested by other studies. Ludwig and Stuckless (1978) report a zircon U-Pb age of 2,595±40 m.y. for the granite of Lankin Dome. Peterman and Hildreth (1978) report a Rb-Sr age of 2,550±60 m.y. for the same granite, although their study included the same samples from Kortes Dam as used by Rosholt and others (1973), and again the data points for the Kortes Dam rocks fell on the isochron defined by the Lankin Dome granites. There is enough scatter in the data, however, that before a definite correlation and age assignment can be made, the Kortes Dam granite and the Seminoe Dam granite should be studied as individual units, rather than combined with other granites.

The youngest granitic rock of the Bennett Mountains is the white granite, as it crosscuts all other granites. How much younger it is cannot be determined, and possibly it is a late differentiate of the massive granites. The youngest Precambrian rock of the area is diabase, as it crosscuts all rocks, including the white granite. Peterman and Hildreth (1978) give an $^{39}Ar/^{40}Ar$ age of approximately 2,600 m.y., determined on labradorite from a diabase in the northern Granite Mountains, and conclude the diabase intruded shortly after intrusion of the granite.

The South Granite Mountain fault is considered to be a Precambrian fault because of the development of mylonite along its trace, although it was apparently reactivated during the Laramide. All Precambrian rocks, including diabase dikes, have been mylonitized in the fault zone. Radiometric studies of mineral separates (Rosholt and others, 1973; Peterman and Hildreth, 1978) indicate a disturbance during which various isotopes were redistributed in the mineral phases within the rocks. The data indicate the disturbance took place about 1,300 m.y. ago and reached its greatest intensity near the Seminoe Mountains (Rosholt and others, 1973, p. 999; Peterman and Hildreth, 1978, p. 16). The cause of this disturbance could have been the same stress system that resulted in cataclasis along the fault, thus setting an approximate age of 1,300 m.y. for initial movement of this part of the South Granite Mountain fault system.

Phanerozoic geology

By Robert J. Walker

The following section of this report is a compilation of the works of: Ferren (1935), Shoemaker (1936), Umbach (1948), Cooper (1951), Finnell (1951b), Thomas (1951), Carpenter and Cooper (1951), and Curtis (1951). The Phanerozoic section of the Bennett Mountains Wilderness Study Area is composed of sedimentary Paleozoic and Mesozoic rocks, and while Cenozoic rocks are abundant in the area they do not occur within the wilderness boundary.

Paleozoic rocks

The Paleozoic section of the study area includes Cambrian, Mississippian, Pennsylvanian, and Permian rocks with no Ordovician, Silurian, or Devonian strata present. The general feeling is that the Ordovician to Devonian rocks were never deposited rather than that they were removed before the Mississippian. All of the sedimentary rocks within the study area have been folded on the south side of the range. The dips are greatest near the Precambrian core of the mountains (70^{o}-80^{o} south) and decrease to the south. The Paleozoic rocks have been eroded to distinctive flatirons while the Mesozoic rocks are more subdued and have gentler dips.

Cambrian.--The Cambrian rocks of the Wilderness Study Area lie with angular unconformity upon the Precambrian granitic rocks described in the previous section. The Cambrian strata consist of predominately maroon to dark-brown, coarse- to medium-grained sandstone. The unit ranges from 345 ft thick in the western Seminoe Mountains (Cooper, 1951) to roughly 120 ft thick in the eastern Seminoes (Shoemaker, 1936). The base of the sandstone is a coarse-grained arkosic conglomerate averaging 12 ft in thickness. This is overlain by roughly 200 ft of conglomeratic sandstone and an upper unit of glauconitic green sandy shales. The upper portions of the unit are often a quartzite, especially where it has been deformed.

These rocks have been variously termed Flathead Sandstone (Middle Cambrian) and Deadwood Sandstone (Upper Cambrian), usually based on lithologic similarities. This report follows the nomenclature of Thomas (1951) and designates these rocks Flathead-Deadwood Sandstone because of the uncertainty of its identity.

Mississippian.--Disconformably overlying the Flathead-Deadwood Sandstone is about 270 ft of Madison Limestone. The base of the Madison is a thin-bedded, conglomeratic, red to pink, medium- to coarse-grained sandstone and gray dolomitic limestone (Cooper, 1951). This basal portion was often confused with the top of the Flathead-Deadwood Sandstone and, where both units are thin, mapped as the Cambrian unit. The Madison grades upward into pure, gray, massive, crystalline limestone gradually losing its sand and dolomite component. The top of the Madison is karsted (channeled and chambered by solution), and Cooper (1951) reports three unconformities within the unit.

Pennsylvanian.--The sandstones, shales, and limestones of the Amsden Formation rest unconformably on the karst surface of the Madison Limestone. The Amsden Formation ranges from 112 ft to roughly 200 ft in thickness and is divided into two parts. The lower portion of the unit consists of bright-red shales and sandstones while the upper is predominately limestone and shale. The Amsden Formation is weakly resistant to weathering and forms a strike valley between the resistant Madison Limestone below and the Tensleep Sandstone above.

Straddling the Pennsylvanian-Permian boundary is the Tensleep Sandstone. This unit is made up of white to tan or buff, festoon crossbedded, fine-grained quartz sandstone. Near the base of the approximately 250 ft of Tensleep Sandstone are two thin beds of gray crystalline limestone. The Tensleep thickens to the west of the study area, and Cooper (1951) reports 540 ft of Tensleep Sandstone in the western Seminoe Mountains.

Permian.--The Permian rocks of the Bennett Mountains Wilderness Study Area have been known as the Embar Formation, the intertongued Phosphoria and Dinwoody Formations, and more recently the Goose Egg Formation (used by this report). Whatever its official designation, it consists of red arenaceous shales and argillaceous sandstones intercalated with thin beds of gypsum and limestone (Ferren, 1935). The Goose Egg Formation ranges from 250 to 300 ft in thickness and disconformably overlies the Tensleep Sandstone. The shales are typically brick red and contain the lenticular gypsum which has a considerable range in purity. The limestones are usually gray to lavender and the sandstones buff to gray in color. The contact with the overlying Chugwater Formation is not clear but is sometimes placed at the top of the highest limestone within the Goose Egg Formation (Cooper, 1951).

Mesozoic rocks

Triassic.--Like the Goose Egg Formation, these rocks have been named differently depending on the author, though some form of Chugwater is always used. The early workers (Ferren, 1935; Shoemaker, 1936; and Umbach, 1948) divided the section as follows: Chugwater Shale (Permo-Triassic), Alcova Limestone (Triassic), and Jelm Formation (Triassic). The more recent literature names the unit Chugwater Formation which contains the Alcova Limestone Member and the Jelm Member. The lower portion of the Chugwater lies conformably on the Goose Egg Formation and consists of roughly 500 ft of red shales and sandy shales with minor buff-colored sandstones, particularly near the top. This is followed by the Alcova Limestone Member which, though only 15-20 ft thick, is a conspicuous unit within the study area. The Alcova Limestone is a thinly laminated, gray to lavender, crenulated, ribbon limestone which shows much internal brecciation. The Jelm Member of the Chugwater Formation consists of 150 to 400 ft of alternating beds of red, white, and yellow sandstones with red sandy shales. According to Shoemaker (1936), there is considerable variation in the lithology of the Jelm Member depending on locality.

Jurassic.--Only a small portion of the southern tip of the study area contains Jurassic strata. This has been mapped by H. R. Dixon as the Sundance-Morrison. The Sundance Formation unconformably overlies the Chugwater Formation and consists of a basal 100 ft of buff-colored, medium-grained, crossbedded sandstone. This is overlain by soft, red, gypsiferous shales and fine-grained sandstones that are nonglauconitic. Disconformably above these shales and sands are highly glauconitic dark shales, gray-green limestones, and thin crossbedded sandstones (Cooper, 1951). The total thickness for the glauconitic and nonglauconitic portion of the Sundance Formation is roughly 200 ft. The Morrison Formation consists of purple, pink, and green variegated claystone with an aggregate thickness of nearly 200 ft.

Cretaceous.--The southern border of the study area is bounded by the Cretaceous Cloverly Formation. This unit consists of a basal conglomerate with rounded quartz, chert, and siliceous shale pebbles interbedded with fine- to medium-grained crossbedded sandstones (Reynolds, 1968). Outcrops of this unit form hogbacks at the southern end of the study area. The Cloverly Formation is overlain by the Thermopolis Shale and other undifferentiated Cretaceous units.

Structure

Dominating the regional structure of the Bennett Mountains Wilderness Study Area is the Sweetwater Arch or Uplift. This is a broad anticlinorium roughly 100 mi long and 40 mi wide, trending approximately west-northwest. The southern flank of this structure is formed by the Freezeout Hills, Shirley Mountains, Seminoe Mountains, and Ferris Mountains, and the northern flank formed by the Rattlesnake Hills. The core of the Sweetwater Arch has been downfaulted along the normal faults that bound the northern front of the Seminoe and other mountain ranges mentioned. Carpenter and Cooper (1951) suggest that the Sweetwater Arch formed in response to Laramide tectonism and have identified thrust faulting to the south along the southern flank of the Sweetwater Arch. They feel that the movement along these gently north-dipping thrusts was in response to failure resulting from the intense Laramide folding. They place the age of the collapse of the Sweetwater Arch along the normal faults that bound the ranges as post-Miocene. As H. R. Dixon (this report) has pointed out, this normal fault (South Granite Mountain fault) is a Precambrian feature that has been reactivated during the Tertiary. Following the collapse of the Sweetwater Arch in the post-Miocene the entire region has been uplifted to its present elevation, probably during the late Tertiary.

For a more detailed examination of the structure around the Bennett Mountains Wilderness Study Area, the reader is directed to Shoemaker (1936), Cooper (1951), and Finnell (1951b).

GEOCHEMISTRY AND GEOPHYSICS

A geochemical survey of the Wilderness Study Area included the sampling of stream sediments and rocks for analysis by semiquantitative emission spectrography. Sample localities are shown on plate 2.

Sample design

Stream-sediment samples were collected from all the major and most of the minor drainages of the study area (147 total). Because an orientation survey of the study area had not been performed to determine the best stream-sediment fraction to analyze, stream sediments were analyzed as whole samples, though predominately fine material was collected.

Rock samples were collected from typical outcrops of the area, pegmatites and aplites, and locations indicating possible mineralization (116 total). Typical outcrops were sampled to determine the background levels of the various elements and are primarily of granitic composition. Diabase dikes and amphibolite bodies of the study area were considered together as mafic rocks because of the difficulty distinguishing them in the field; both weather readily. Few of the sedimentary rocks were sampled because of the difficult access.

Analytical methods

All samples collected were analyzed using six-step semiquantitative optical emission spectrography (Myers and others, 1961) by the U.S. Geological Survey laboratories, Denver, Colo. Samples were analyzed for 50 elements, listed with their determination limits in table 2. The results for each element, are reported as mid-points of geometric brackets within each order of magnitude (i.e., 0.7, 0.5, 0.3, 0.2, 0.15, and 0.1.). The precision of the results is approximately one standard deviation per bracket.

The analyses were done by M. J. Malcolm and N. M. Conklin under project leader J. L. Seeley, Branch of Analytical Laboratories, U.S. Geological Survey, Denver, Colo.

Results of geochemical survey

Reconnaissance geochemical sampling of the Bennett Mountains Wilderness Study Area was conducted out to determine whether any mineralization as present within the study area at depth or unrecognizable at the surface. With the exception of the prospect pits described previously, no mineralization was discovered during the course of the investigation. Similarly, there are no reports of economic mineralization in the availaable literature.

The stream-sediment samples from the Bennett Mountains Wilderness Study Area only had detectable concentrations of B, Ba, Be, Co, Cr, Cu, Nb, Ni, Pb, Sc, Sn, Sr, V, Y, and Yb. The analytical data for each of these elements were composited into histograms and anomalous samples were defined as the higher population wherever a well-defined separation was present in the data. None of the detected elements showed any anomalous concentrations except for one sample which contained 150 ppm Pb; the source of the Pb is unknown but the sample was taken from a drainage underlain by granitic rock. In general, all the elements were present in low concentrations.

Rock samples had detectable concentrations of the same elements as the stream-sediments with the addition of La. A clear separation in the data existed for five samples, which were at least four spectrographic intervals higher in Co, Cu, Cr, Ni, and V. These higher concentrations reflect the different chemistry of diabase and amphibolite compared to granitic rocks, and the samples are not considered anomalous. With the exception of one sample outside the northern edge of the wilderness (GM 348) with 30 ppm Sn and 70 ppm Y, none of the rocks showed anomalous concentrations of the detected elements.

It is interesting to note that the samples from prospect pits in the study area had metal concentrations at or below the median for the various rock types. The only higher concentrations they had were in Fe.

Geophysical study

Examination of the aeromagnetic map of the Seminoe Mountains (Philbin and McCaslin, 1966) showed nothing significant within the Bennett Mountains Wilderness Study Area. There is a magnetic high of 180 gammas (2,020 gammas to 2,200 gammas) located near the mouth of Number Three Gulch just north of the study area.

Table 2.--Elements looked for and their approximate lower limits of detection by semiquantitative 6-step emission spectroscopy (L. L. Jackson, written communication, 1983).

Element	6-Step	Element	6-Step
	%		%
Al	0.01	Na	0.05
Ca	0.002	P	0.2
Fe	0.001	Si	0.002
K	0.7	Ti	0.0002
Mg	0.002		
parts per million		parts per million	
Ag	0.5	Nb	10
As	1000	Ni	3
Au	20	Pb	10
B	20	Pd	2
Ba	2	Pt	50
Be	1.5	Rh	2
Bi	10	Sb	150
Cd	50	Sc	5
Ce	200	Sn	10
Co	3	Sr	5
Cr	1	Ta	500
Cu	1	Te	2000
Ga	5	Th	200
Ge	10	Tl	50
Hf	100	U	500
In	10	V	7
La	30	W	100
Li	100	Y	10
Mn	1	Yb	1
Mo	3	Zn	300
		Zr	10

ENERGY AND MINERAL DEPOSITS

Known prospects, mineral occurrences, and mineralized areas

The available literature and the current field investigation provide no evidence of mines or mineral production within the Bennett Mountains Wilderness Study Area. It should be noted that there has been sporadic mineral production in areas surrounding the Bennett Mountains. Most notable of these are the ferrous, base, and precious metal mines and prospects in the western Seminoe Mountains. The occurrences reported from the literature are listed in the following portion of this report; their purpose is to show the extent of mineralization in the Bennett Mountains area.

Wilson (1955) reported that copper has been extracted from the Ferris Mountains located to the west of the study area. Bishop (1964) describes a number of prospects in the western Seminoe Mountains that contain copper mineralization. The majority of these prospects were in quartz veins and are located in secs. 20, 26, 29, and 32 of T. 26 N., R. 85 W. Further mentions of copper mineralization in the Seminoe Mountains area are made by Endlich (1877), Aughey (1886), and Isberg (1937) who reported chalcopyrite and covellite at a number of prospects.

Gold has been mined from a number of localities near the Bennett Mountains Wilderness Study Area. Aughey (1886) and Bishop (1964) reported free gold in quartz veins from a mine in sec. 29, T. 26 N., R. 84 W., as well as other mines in the Seminoe district to the west of the study area. The closest gold prospect to the study area is in the Shirley Mountains to the northeast. Shoemaker (1936) reported on a prospect in sec. 3, T. 25 N., R. 83 W., that "hoped" to hit ore at depth. The adit had been placed on surface exposures of quartz veins.

It has been mined in the western Seminoe Mountains as reported by Hendricks (1902), Lovering (1929), Bayley (1965), Blackstone (1965), and Klein (1980).

Small amounts of uranium have come from the Pedro Mountains north of the study area (sec. 14, T. 27 N., R. 84 W.) in association with a graphite layer (Love, 1954a). Finnell (1951a) reported anomalous radioactivity just east of the study area in sec. 14, T. 25 N., R. 83 W. There has been some uranium production from the Shirley Mountains to the northeast as secondary mineralization in calcite veins within the Tensleep Sandstone (Love, 1954b), a unit which is found within the study area. At some distance from the study area, the Shirley Basin has had significant uranium production from the Wind River formation of Eocene age. Other uranium prospects/mines within the general vicinity (about 10 mi) of the Bennett Mountains Wilderness Study Area are reported in: sec. 11, T. 24 N., R. 82 W.; secs. 30 and 31, T. 25 N., R. 84 W.; sec. 36, T. 25 N., R. 82 W.; and sec. 14, T. 27 N., R. 84 W.

Commercial deposits of gypsum have been reported in the Chugwater Formation (Gist, 1957; Maravich, 1940) in the Freezeout Hills and Seminoe Mountains areas. The Chugwater Formation occurs within the southern boundary of the study area but only small amounts of gypsum float were noted during the course of the investigation.

Knight (1898) and Boyle (undated) report on the use of a Cambrian sandstone found north of Rawlins for dimension stone. This is probably the Flathead-Deadwood Sandstone that crops out within the study area. The Alcova Limestone has been quarried in the area north of Rawlins for use as a flux and as building stone (Schrader and others, 1916). The Alcova Limestone is exposed in the southern portion of the study area along with the Madison Limestone and the limestone members of the Amsden and Goose Egg Formations.

Many of the reported mineral occurrences of the Seminoe Mountains are based on the 19th century mineral survey carried out by Aughey (1886). In this report he cited rare arsenopyrite in the eastern Seminoe Mountains (Bennett Mountains of this report), a few aquamarine specimens from the southeastern Seminoes, one corundum crystal from the Platte River area of the range, and fluorite in the limestone south of the Seminoe Mountains. Aughey's 1886 report also stated that some small quantities of sphalerite had been found in the Seminoe Mountains and that foliated talc occurred at the Deserted Treasure Mine in the western Seminoe Mountains. Other authors have pointed out that lead, silver, gold, and zinc have been produced from the Spanish Trails mining group in the Ferris Mountains to the northwest of the study area. One prospect in this area (T. 26 N., R. 86 W.) reportedly contained 31.7 percent lead, 0.01 oz/ton gold, and 18.2 oz/ton silver, but the vein apparently died out at depth.

Jade has been found as float in the pediment gravels north of the Seminoe Mountains and in an inclusion of epidote-monzonite in Precambrian granite in sec. 12, T. 26 N., R. 83 W., outside the study area.

Salt and sodium sulfate have been produced commercially from areas west of the Bennett Mountains (Young, 1951).

Secs. 21 and 22, T. 26 N., R. 85 W., in the western Seminoe Mountains have yielded quantities of asbestos (Bishop, 1964).

Although no mineralization was noted during the present investigation, a number of prospects were observed and examined. They are restricted to the eastern portion of the study area and in general are related to east-west-trending faults. Typically, there is strong hematitic staining and silicification on the southern side of the fault and argillic alteration with minor silicification and no iron oxides on the northern side of the fault. Brief descriptions and locations of the individual prospects are given in Appendix 1.

Known mineral deposits

There are no known mineral deposits within the Bennett Mountains Wilderness Study Area.

Oil and gas possibilities

The Tensleep Sandstone and Madison Limestone are important oil and gas reservoirs in many areas of Wyoming, including Wertz dome in Carbon County. The Wertz field lies west of the study area and has been described by Krampert (1951). Finnell (1951b) speculated that the intensely faulted anticline in secs. 24 and 25, T. 25 N., R. 83 W. (outside the study area), may be a trap for petroleum. He also suggested that faulting along the southern boundary of the Seminoe Mountains might provide traps for oil and natural gas.

Land classification

Land classification decisions were made on the basis of field investigations, geochemical study, and historical research. The classification scheme used by the Bureau of land Management is given in table 3, and the land classification decisions are presented in table 4 where the overall potential of the Bennett Mountains Wilderness Study Area is summarized.

Table 3.--Favorability/Resource Potential Classification for BLM Mineral Resource Reports

Level of Favorability	Level of Certainty
Resource potential cannot be classified	
0. Favorability unknown; information on the likelihood of presence of mineral resources is inadequate for classification; equates with UNKNOWN potential.	A. The available data are not sufficient for determination of the degree of favorability for the occurrence of mineral resources.
Resource potential can be classified	
1. The nature of the geologic environment, and, the geologic processes that have acted in the area, indicate no favorability for the presence of mineral resources; equated with NO resource potential.	B. The available data are adequate to give an indication of the degree of favorability, but lack key evidence that would help define geologic environments or activity of resource-forming processes.
2. The nature of the geologic environment, and, the geologic processes that have acted in the area, indicate low favorability for the presence of mineral resources; the data define a geologic environment permissive for the presence of mineral resources but there is no evidence of the action of processes of resource accumulation; equates with LOW resource potential.	C. The available data provide a good indication of the degree of favorability, but are minimal in terms of definition of degree of activity of possible resource-forming processes, and nature of geologic environment.
3. The nature of the geologic environment, and, the geologic processes that have acted in the area, indicate moderate favorability for the presence of mineral resources; the data define a geologic environment favorable for the presence of mineral resources; evidence is present of the action of processes likely to form resources; equates with MODERATE resource potential.	D. The available data define the geologic environment and the degree of activity of possible resource-forming processes with considerable certainty; key evidence to interpretation of the presence or absence of appropriate ore deposit types is available.
4. The nature of the geologic environment, and, the geologic processes that have acted in the area, indicate high favorability for the presence of mineral resources; the data define a geologic environment highly favorable for the presence of mineral resources, and strongly support the interpretation that resources are probably present; evidence is compelling for the activity of processes likely to form resources; equates with HIGH resource potential.	
Reserves have been discovered	
5. Reserves have been discovered	E. The available information is adequate to identify reserves, and to specify to varying degrees of certainty, the quantity and grade of valuable materials in a well-defined area.

Table 4.--Favorability and level of certainty of mineral potential within the Bennett Mountains Wilderness Study Area

Metals	2/C
Uranium and thorium	2/C
Shale and clay	2/C
Stone and aggregate	3/D
Gypsum	2/B
Oil and gas	2/B
Coal	1/D

Comparison of the geology of the study area to that of the ranges to the east and west indicated that base and precious metal mineralization is possible within the Bennett Mountains Wilderness Study Area. The most likely occurrence would seem to be metalliferous veins emplaced during Laramide or younger plutonism. Because the purpose of this study is to determine the likelihood of mineral resources within the study area, other deposit types were considered and this appraisal is not restricted to vein-type mineralization.

Based on an examination of the chemical data and the field evidence of the area, it is felt that metalliferous deposits are unlikely and that the metallic resource potential of the Bennett Mountains Wilderness Study Area is low.

The Amsden, Goose Egg, and Chugwater Formations all occur within the southern boundary of the study area. Each contains shaly members, but it is felt that the limestone and sandstone interbeds plus the abundant iron oxides render them unsuitable for ceramic or related manufacturing. A further consideration is the remoteness of the study area and the cost of transportation which must be included in resource potential evaluation. While no tests were performed on these units to determine if they do have resource potential for the ceramic industry, the cost of transportation would seem to invalidate any such potential. Thus the resource potential of the shales and clays of the Bennett Mountains Wilderness Study Area is considered to be low.

Significant resources of stone exist within the boundaries of the Wilderness Study Area. The Flathead-Deadwood Sandstone which crops out in the southern portion of the study area has been used for dimension and building stone in other parts of Wyoming. The Madison and Alcova Limestones have been quarried for use as building stone and flux and have potential as a source of cement. The Precambrian crystalline rocks as well as the Phanerozoic sandstones and limestones would make excellent road metal and aggregate. Transportation costs effectively render the Flathead-Deadwood, Madison, and Alcova units of the Bennett Mountains Wilderness Study Area noneconomic with regard to stone and aggregate resources. Thus, while reserves of stone and aggregate are present within the study area, there is low potential.

A low resource potential for gypsum is estimated for the study area, in part because more favorably located deposits of gypsum in commercial quantities are found in other locations in Wyoming.

As indicated earlier, the Tensleep Sandstone and the Madison Limestone are notable petroleum producers in other parts of Wyoming. Within the study area these units are nearly vertical and thus are ineffective as anticlinal traps. The possibility that faulting along the southern margin of the Bennett Mountains may have created fault traps for oil and natural gas must be considered. If in fact such traps exist, their producing potential would be very low with respect to the study area. The volume of Tensleep Sandstone and Madison Limestone occurring within the Bennett Mountains Wilderness Study Area is small compared to that required for a viable oilfield. Because of these limitations, the oil and natural gas potential of the study area must be considered low.

No evidence of coal or peat accumulation was noted within or adjacent to the Bennett Mountains Wilderness Study Area during this investigation, though coal is produced from units higher in the stratigraphic section than occur within the study area.

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Appendix I
Brief Description of Prospects

Prospects (identified by sample numbers, see Plate 2)

RW83084-86 - NW1/4SW1/4NW1/4 sec. 9, T. 25 N., R. 83 W.
Prospect on fault trending approximately east-west. Host rock is granite that has been ground up and partially silicified in a 1 to 1 1/2 ft zone following the trace of the fault. Barren quartz is associated with the fault in the prospect and quartz float can be seen uphill to the west for about 25 ft. Sense of motion along the fault is unknown. The south side of the fault is moderately to strongly hematitically stained while the north side has been argillized and somewhat bleached. No sulfides were noted.

RW83088-90 and GM8365 - SW1/4NE1/4SW1/4 sec. 8, T. 25 N., R. 83 W.
Prospect pit on quartz-hematite vein, approximately 4 ft thick, trending approximately N20W. The vein is exposed in the pit for 12 ft and by surface float to the north for about 50 ft. The vein is in granite and may be fault related. The pit is inclined at about 75^{o} and follows the vein for about 20 ft. The west wall of the pit shows leached cubic casts of sulfides (pyrite?) in quartz while the west side consists of bleached, silicified, and quartz-veined granite. Quartz-epidote fragments can be seen among the float along with vuggy quartz, hematite crystals in quartz, and some minor pyrite.

RW83119-121 - NE1/4SW1/4SW1/4 sec. 9, T. 25 N., R. 83 W.
Similar to pit 84-86. Fault zone in granite trending N45W. Strong hematitic staining and argillation/silicification on southwest side of fault while the NE side is only argillized. Fault dips steeply to the SW. Using float the fault can be traced approximately 20 ft to the NW.

GM8364 - SW1/4NE1/4SE1/4 sec. 8, T. 25 N., R. 83 W.
Prospect in hematitically stained and sheared granite.

RW83122-124 and GM8335 - Center of sec. 6, T. 25 N., R. 83 W.
Largest prospect pit of the area, approximately 10 ft x 15 ft. Host is medium-grained granular granite that has been strongly argillized and silicified.

Prospect west in a near-vertical fault trending N70W that has associated quartz-pyrite veins. Strong hematite/limonite staining within the immediate area and 10-20 ft adjacent to pit area.