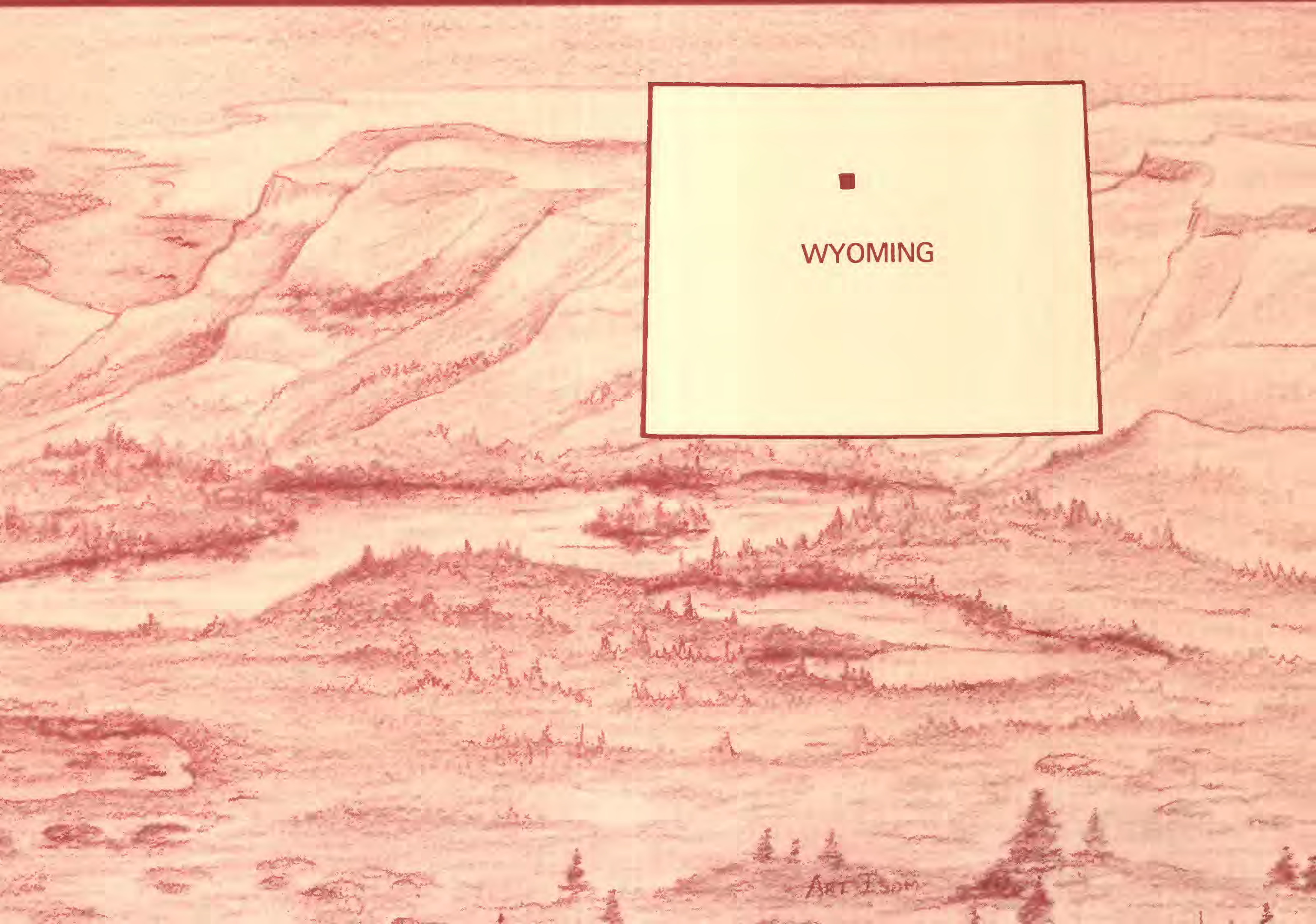
Mineral Resources of the Cedar Mountain Wilderness Study Area, Washakie and Hot Springs Counties, Wyoming

U.S. GEOLOGICAL SURVEY BULLETIN 1756-B



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Chapter B

Mineral Resources of the Cedar Mountain Wilderness Study Area, Washakie and Hot Springs Counties, Wyoming

By CURTIS E. LARSEN, RANDALL H. HILL,
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DAVID C. SCOTT
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U.S. GEOLOGICAL SURVEY BULLETIN 1756

MINERAL RESOURCES OF WILDERNESS STUDY AREAS—NORTHERN WYOMING

DEPARTMENT OF THE INTERIOR
DONALD PAUL HODEL, Secretary

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

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STUDIES RELATED TO WILDERNESS

Bureau of Land Management Wilderness Study Areas

The Federal Land Policy and Management Act (Public Law 94–579, October 21, 1976) requires the U.S. Geological Survey and the U.S. Bureau of Mines to conduct mineral surveys on certain areas to determine the mineral values, if any, that may be present. Results must be made available to the public and be submitted to the President and the Congress. This report presents the results of a mineral survey of the Cedar Mountain (WY–010–222) Wilderness Study Area, Washakie and Hot Springs Counties, Wyoming.

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Mineral Resources of the Cedar Mountain Wilderness Study Area, Washakie and Hot Springs Counties, Wyoming

By Curtis E. Larsen, Randall H. Hill, Dolores M. Kulik, *and* Mark K. Brown
U.S. Geological Survey, *and*

David C. Scott
U.S. Bureau of Mines

SUMMARY

Abstract

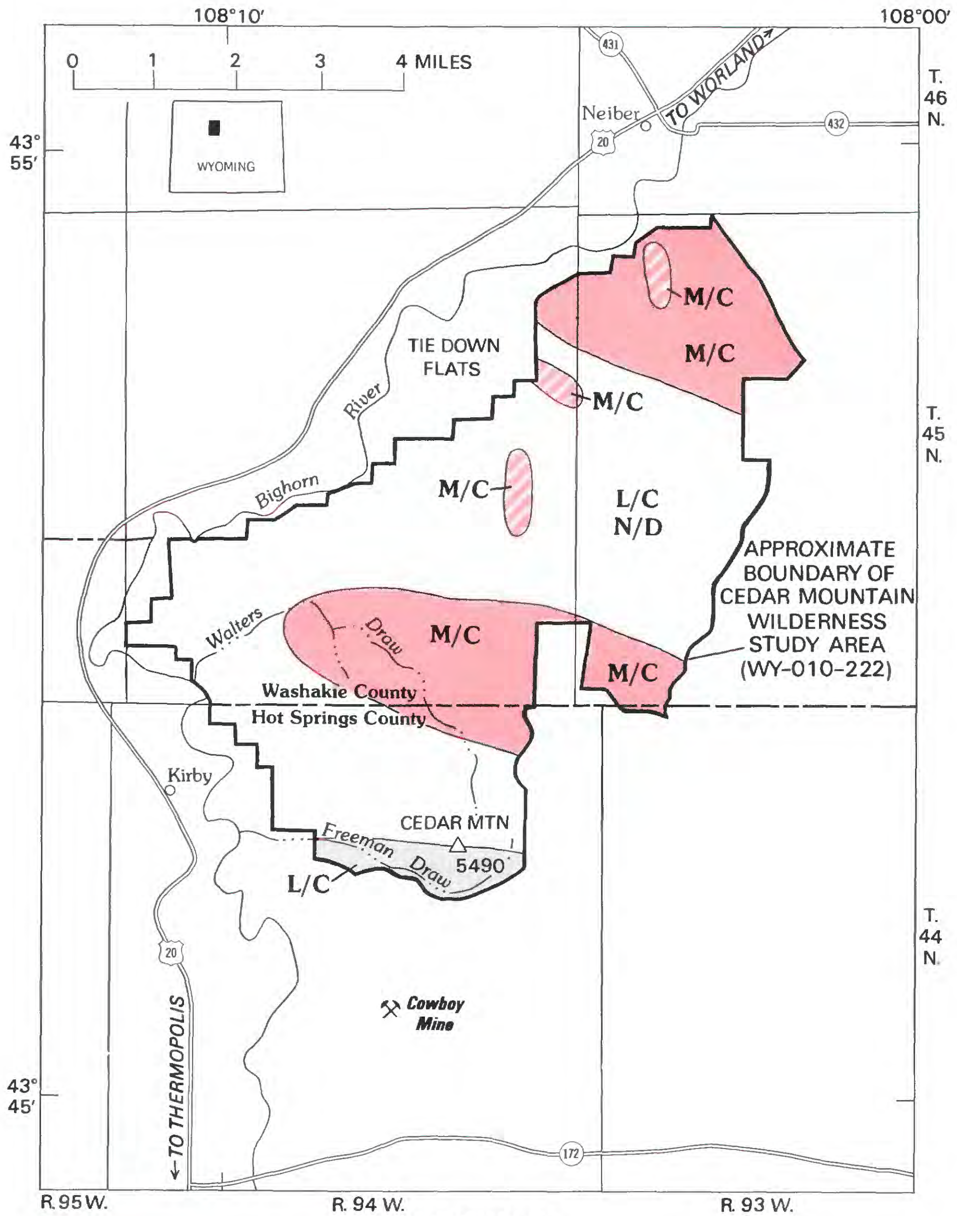
The Cedar Mountain Wilderness Study Area (WY-010-222) consists of approximately 21,570 acres along the east bank of the Bighorn River, east of the town of Kirby, Wyo. The area includes parts of both Hot Springs and Washakie Counties. During the summer of 1986, the U.S. Geological Survey (USGS) and the U.S. Bureau of Mines (USBM) undertook field studies to appraise the identified (known) resources and assess the mineral resource potential (undiscovered) of the study area. No mines or prospects are located within the study area, and it has no identified resources. However, coal was mined from thin discontinuous coal seams within the Upper Cretaceous Mesaverde Formation 2 miles south of the area. This formation is covered by as much as 1,200 feet of the Meeteetse and Lance Formations beneath Cedar Mountain. The resource potential for coal is low in the southernmost part of the study area; the remainder of the area has no potential for coal resources. Anomalous gold concentrations identified in three stream-sediment samples collected near Tie Down Flats indicate a moderate potential for gold resources in the three small drainage basins those samples represent. The study area has no potential for gold resources outside these three drainages, and no potential for resources of other metals, including uranium. An extension of a known oil and gas producing structure, the Neiber anticline, crosses the northeastern part of the area, and another producing structure, the Gebo Dome, is 4 miles southwest of Cedar Mountain. Based on the proximity of these structures, inferred faulting beneath the central part of the area, and oil and gas shows in dry wells drilled within the area, the potential for oil and gas resources is considered moderate for two areas in the north and central parts of the Cedar Mountain Wilderness Study Area, and low for the remainder of the area. The study area also has no potential for sand and gravel resources or for geothermal energy resources.

Manuscript approved for publication July 15, 1988.

Character and Setting

The Cedar Mountain Wilderness Study Area (WY-010-222) lies within the Bighorn Basin. It is located on the east bank of the Bighorn River and straddles the boundary between Hot Springs and Washakie Counties. It is approximately 9 miles southwest of Worland and 12 miles northeast of Thermopolis (fig. 1). The study area covers about 21,570 acres. The land surface within the area is characterized by a badlands topography and has a maximum relief of about 1,200 feet. There are no permanent streams within the study area; however, many ravines carry intermittent runoff northward and westward into the Bighorn River.

Gently dipping sandstones interbedded with siltstone and shale underlie most of the area. These dip 10° to 28° to the north and northeast, but two prominent folds—the Neiber anticline and its accompanying syncline—trend west-northwest and east-southeast across the northern portion of the area. These are accompanied by faulting at depth. Closure on the anticlinal structure is sufficient for oil and



EXPLANATION

M/C	Geologic terrane having moderate mineral resource potential for oil and gas, with certainty level C
M/C	Geologic terrane having moderate mineral resource potential for gold, with certainty level C
L/C	Geologic terrane having low mineral resource potential for coal, with certainty level C
L/C	Geologic terrane having low mineral resource potential for oil and gas, with certainty level C—Applies only to that part of study area outside the areas of moderate oil and gas potential described above
N/D	Geologic terrane having no mineral or energy resource potential for any metals, including uranium and gold, nor for coal, geothermal energy, sand, or gravel, with certainty level D—Applies to entire study area for all listed commodities except gold and coal, which have no potential only outside the areas of moderate and low potential described above

Levels of certainty:

C	Data give a good indication of geologic environment and level of mineral resource potential
D	Data clearly define geologic environment and level of mineral resource potential

Figure 1. Mineral resource potential and location of Cedar Mountain Wilderness Study Area, Hot Springs and Washakie Counties, Wyoming.

gas production 2.75 miles east of the study area. The Neiber II Unit field borders the east boundary of the study area in sec. 16, T. 45 N., R. 93 W.

The rocks exposed at the surface belong to the Meeteetse and Lance Formations of Late Cretaceous age (see geologic time chart in Appendix), the Fort Union Formation of Paleocene age, and the Willwood Formation of Eocene age. The Meeteetse and Lance Formations are well exposed along the southern face of Cedar Mountain. Interbedded shales, thin coals, and bentonite beds of the Meeteetse Formation are exposed at the base of Cedar Mountain, and massive sandstones and interbedded gray shales of the Lance Formation form its rugged south-facing slope. The Lance Formation dips beneath the Fort Union Formation in the southwestern part of the study area, east of the town of Kirby. North of that point, most of the study area is covered by a repetitious sequence of as much as 3500 feet of interbedded thin sandstones and shales of the Fort Union. A small part of the overlying Willwood Formation is preserved within the core of the syncline adjacent to the Neiber anticline at Tie Down Flats. Prominent alluvial terrace remnants underlain by sand and gravel locally abut the study area along the Bighorn River. These unconsolidated deposits represent earlier river flood plains and are preserved locally in the mouths of ravines draining into the river.

Mineral Resources

There are no mines or prospects within the Cedar Mountain Wilderness Study Area. Resources commonly associated with the Bighorn Basin are coal, oil, and gas. These resources have been developed near the study area. Coal was mined from the Mesaverde Formation at the Gebo field, 2 miles southwest of Cedar Mountain. Although much of the southern edge of the study area has been leased for coal, no thick coal beds are present at or near the surface within the study area. The nearest mine is the Cowboy Mine, 2 miles south-southwest of Cedar Mountain, where coal was produced from the Mesaverde Formation. The coal-bearing zone in the Mesaverde lies several hundred feet below the surface at the south edge of the study area. Beds of coal or lignite within the Meeteetse Formation crop out at the foot of Cedar Mountain, but they are less than 2 feet thick and have not been mined. Similarly, thin bentonitic shale beds are present within this same formation along the southern edge of the area, but the measured thickness of these beds rarely exceeds a few inches.

Oil and gas exploration has a long history in this portion of the basin. Drilling of the Neiber anticline, which crosses the northern third of the study area, began as early as 1915, but a producing well was not completed in this structure until 1947, when oil was recovered from the Park City Formation. This well is approximately 4 miles east of the study area. Petroleum exploration of the Neiber anticline has continued. An exploratory well was drilled along the crest of this fold 1.5 miles east of the study area in 1984. In spite of these exploratory wells and intensive seismic exploration in the 1940's, no oil or gas has been produced from the geologic structures beneath the study area. Nonetheless, much of the study area is covered by oil and gas leases. Geothermal energy is in evidence at the Thermopolis hot springs, 10 miles to the south, but there is no surface indication of hydrothermal activity within the study area.

Resource Potential

Because identified oil and gas resources exist near the study area and anticlinal structures capable of trapping oil and gas occur within it, a moderate resource potential for oil and gas is assigned to two areas in the north and central parts of the study area, whereas the rest of the study area has low oil and gas resource potential. A low potential for coal resources is assigned to the southernmost part of the study area because demonstrated coal beds exist in that vicinity, but these are all either too thin or too deeply buried to be economically mined; the remainder of the study area has no potential for coal resources. Studies show a moderate potential for gold resources in three small areas (see below) but no potential for gold resources outside these three areas and no potential for resources of any other metals, including uranium. The area also has no resource potential for geothermal energy or for sand and gravel.

Geochemical analyses of rocks and stream sediments taken throughout the area have shown few anomalous concentrations of elements. The determined concentrations for both types of samples were, with few exceptions, within the normal range of background concentrations. Arsenic had anomalous concentrations in two rock samples, where it was associated with fluorapatite. The nonmagnetic heavy-mineral concentrates from stream sediments consistently showed high concentrations of barium, zirconium, and titanium. These were included in the minerals barite, zircon, and rutile respectively. Rock samples from the surrounding areas, however, did not reveal anomalous sources for these minerals, thus reducing the likelihood that they are present in significant amounts. In addition, the alluvium from which the samples were taken is too thin and too sparsely distributed to provide suitable placer deposits. The data, therefore, show no resource potential for these minerals within the study area. Three concentrate samples from the vicinity of Tie Down Flats showed anomalous concentrations of gold (20, 30, and 100 parts per million). One of these samples also had anomalous silver (3 parts per million). A critical examination of rock and stream-sediment samples by atomic-absorption analysis suggests that the source for the gold is not the sandstones of the Fort Union or Willwood Formations. The fine grain size of these sandstones makes them unlikely paleoplacers. Possible source deposits, which have not been tested, are quartzite-cobble gravels that cap the uplands upstream from two of these samples and fine gravel found locally as a basal conglomerate to the Willwood Formation. Gold was mined from the alluvial gravels of the Bighorn and Wind Rivers south of Thermopolis in the early part of this century. These rivers drain crystalline and metamorphic rocks of the Owl Creek Mountains. The fine grain size of the gold made its recovery difficult at that time (Schrader, 1915). The potential for gold resources is therefore considered moderate in the three drainages represented by the anomalous samples. The study area has no potential for gold resources outside these three small drainages.

INTRODUCTION

The U.S. Geological Survey (USGS) and the U.S. Bureau of Mines (USBM) studied 21,570 acres of the Cedar Mountain Wilderness Study Area (WY–010–222) during 1986 to appraise the identified (known) mineral resources and assess the potential for undiscovered mineral resources (mineral resource potential). This study was requested by the Bureau of Land Management (BLM). The USGS and USBM have a joint role in wilderness mineral surveys. Throughout this report, the term "study area" means the entire Cedar Mountain Wilderness Study Area.

Cedar Mountain is the most prominent landmark of the study area. It is an escarpment rising approximately 1,200 feet above the surrounding Bighorn River valley. Its south-facing slope consists of alternating beds of massive sandstone and interbedded mudstones and shales of the Upper Cretaceous Lance Formation. The name Cedar Mountain comes from the abundant juniper vegetation along its slopes and at its summit. This vegetation reflects both the altitude of the mountain and the moisture-retention properties of the sandstones of the Lance Formation. Cedar Mountain lies near the southwest corner of the study area. The remainder of the area extends northward for about 8 miles. It is bounded on the west by the Bighorn River and extends eastward from 3 to 7 miles from the river. The eastern boundary is marked by a frequently traveled dirt road, which provides access to the area from the east. Other access into or across the area by vehicle is possible by 4-wheel-drive roads that date to seismic exploration in the 1940's.

This report presents an evaluation of the mineral endowment (identified resources and mineral resource potential) of the study area and is the product of several separate studies by the USBM and the USGS. Identified resources are classified according to the system of the U.S. Bureau of Mines and U.S. Geological Survey (1980), which is shown in the Appendix. Identified resources are studied by the USBM. Mineral resource potential is the likelihood of occurrence of undiscovered metals and nonmetals, industrial rocks and minerals, and energy sources (coal, oil, gas, oil shale, and geothermal sources). It is classified according to the system of Goudarzi (1984), which is also shown in the Appendix. The potential for undiscovered resources is studied by the USGS.

The USGS geological and geochemical teams collected data, rock samples, and stream-sediment samples during June 1986. Geologic data were used to map and define formation boundaries and geologic structure within the study area and to relate potential mineral resources to the geologic setting. Rock and stream-sediment samples were collected from stream drainages for geochemical analyses. Rock samples were taken along traverses at intervals in the uplands. Rock and stream-sediment samples representing individual drainage basins were collected to identify source areas for minerals.

The USBM team visited the area in July 1986 to search for mines and prospects and to canvass records on file with the BLM District Office in Worland. The USGS visited the area again in September 1986 to measure and sample a detailed stratigraphic section of the Lance and Fort Union Formations. The field data and photogeologic interpretation were used in compiling the reconnaissance geologic map shown in figure 3. These data amplify the earlier mapping of the study area by Weitz and Love (1952), Horn (1963), and Love and Christiansen (1985).

Acknowledgments.—We owe thanks to the staff of the BLM District Office in Worland for their support during our field work. Roger Inman, Area Manager, and Phil Bigsby, geologist, provided information from their files on access roads and previous geologic studies. Geologists Jeanne Colmer-Briemont and Cathy Humphrey made available subsurface records from oil and gas exploration, and information on the Neiber and Gebo known geologic structures. Ian Larsen made a photographic record of sample localities and the geologic setting of the study area.

APPRAISAL OF IDENTIFIED RESOURCES

By David C. Scott
U.S. Bureau of Mines

A thorough review of pertinent literature on geology, mineralization, and mining activity in the region of the study area was done by the Bureau of Mines prior to the field examination. In July 1986, two Bureau geologists spent four days conducting a field examination that focused on searching for mines, prospects, and mineral occurrences within the study area and as much as 1 mile outside of its boundaries. The examination included reconnaissance by helicopter and four-wheel-drive vehicle. No mines, prospects, or mineral occurrences were found in the study area.

Coal samples were taken from two coal outcrops in the Mesaverde Formation about 1 mile south of the study area (Scott, 1987). Proximate and ultimate analyses of the coal samples were made by Chemex Labs, Inc., Sparks, Nev. Further inquiries can be directed to U.S.

Bureau of Mines, Branch of Mineral Land Assessment, Intermountain Field Operations Center, Building 20, Denver Federal Center, Denver, Colo.

Mining History

The study area is within the Bighorn coal basin of Wyoming, where coal mining dates back to the 1890's. Although no coal was mined in the study area, production from the Gebo coal field, 2 miles southwest of the area, amounted to about 90 percent of total production from the entire Bighorn coal basin. This coal was used for railroad locomotives until the mid-1950's (Glass and others, 1975, p. 226).

As of June 1986, BLM files contained no patented or unpatented mining claims in the study area. Approximately 2 square miles of the extreme southern part of the study area, south of Cedar Mountain, is under coal lease (fig. 2). As of September 1986, more than 90 percent of the study area was covered by oil and gas leases.

Energy Resources

The study area is located in a region known for coal, oil and gas, and geothermal resources. These commodities are discussed separately. No identified resources were found in the study area.

Coal

The coal beds of the Mesaverde Formation, which were mined in the nearby Gebo coal field, also occur directly south of the study area. Figure 2 shows the approximate limits of the coal beds in the Mesaverde Formation. Approximately 1 mile south of the southwestern boundary of the study area, two prospect pits were found in two coal outcrops in the lower unit of the Mesaverde Formation (fig. 2). Both pits are shallow and expose thin, shaly coal beds. Except for the outcrops in these two pits, the extent of the coal is not known.

Coal in the Gebo field ranks as subbituminous A or B, with an average as-received heat value of 10,632 Btu/lb (Glass and others, 1975, p. 226). The two samples of weathered coal taken by the Bureau also ranked subbituminous A and B. Both proximate and ultimate analyses were performed on each coal sample for comparison with samples of coal mined from the nearby Gebo coal field (Scott, 1987). Coal beds sampled by the Bureau were 1 to 1 ½ feet thick, whereas those mined in the Gebo field are 6 to 11 feet thick.

Coal beds sampled by the USBM generally dip 10° toward the study area. Discounting topographic relief, a general dip of 10° on a bed gives about 175 feet of vertical cover in a horizontal distance of 1,000 feet; therefore, the minimum depth of the coal at the southern boundary of the study area is about 875 feet. Based on the projected depth of the coal at the southern boundary of the study area, the thickness of overburden above the coal beds would preclude strip or underground mining of the coal. Depth of overburden aside, both analytical results and thicknesses of these coal beds are not favorable for development of this coal.

Oil and Gas

The study area is within the Bighorn Basin oil and gas province (Spencer, 1983, p. M7), one of the most productive oil and gas basins in the Rocky Mountain region. Most of the oil and gas production comes from structural traps located around the margins of the basin. The primary producing formations are Mississippian carbonate rocks, Pennsylvanian sandstone, Permian carbonate rocks, and Cretaceous sandstone. The deep part of the basin is relatively unexplored by drilling, but probably has been extensively mapped by seismic methods (Spencer, 1983, p. M7).

Three holes have been drilled in the study area, in T. 45 N., R. 93 W. (fig. 2). All of the holes were dry but had shows of oil and gas. The earliest hole, drilled in 1954 in section 29, was 11,972 feet deep and bottomed in the Middle and Upper Pennsylvanian Tensleep Sandstone. In section 7, a hole was drilled in 1963 to a depth of 8,733 feet, bottoming in the Lower Cretaceous Mowry Shale. The most recent hole was drilled in section 5, in 1982, to a depth of 11,582 feet, bottoming in the Tensleep Sandstone. Seven other holes have been drilled within 3 miles of the study area; most of these holes also had shows of oil and gas (U.S. Bureau of Land Management, Worland District Office, unpublished data). The closest producing oil well is 2.75 miles east of the northeast boundary of the study area.

Geothermal Energy

Although the region just south of the study area is well known for thermal springs, the USBM investigation found no record of geothermal waters or leasing activity in the study area. The thermal waters near Thermopolis are about 10 miles southwest of the study area; the source of heat for these thermal waters has not been identified (Breckenridge and Hinckley, 1978, p. 40).

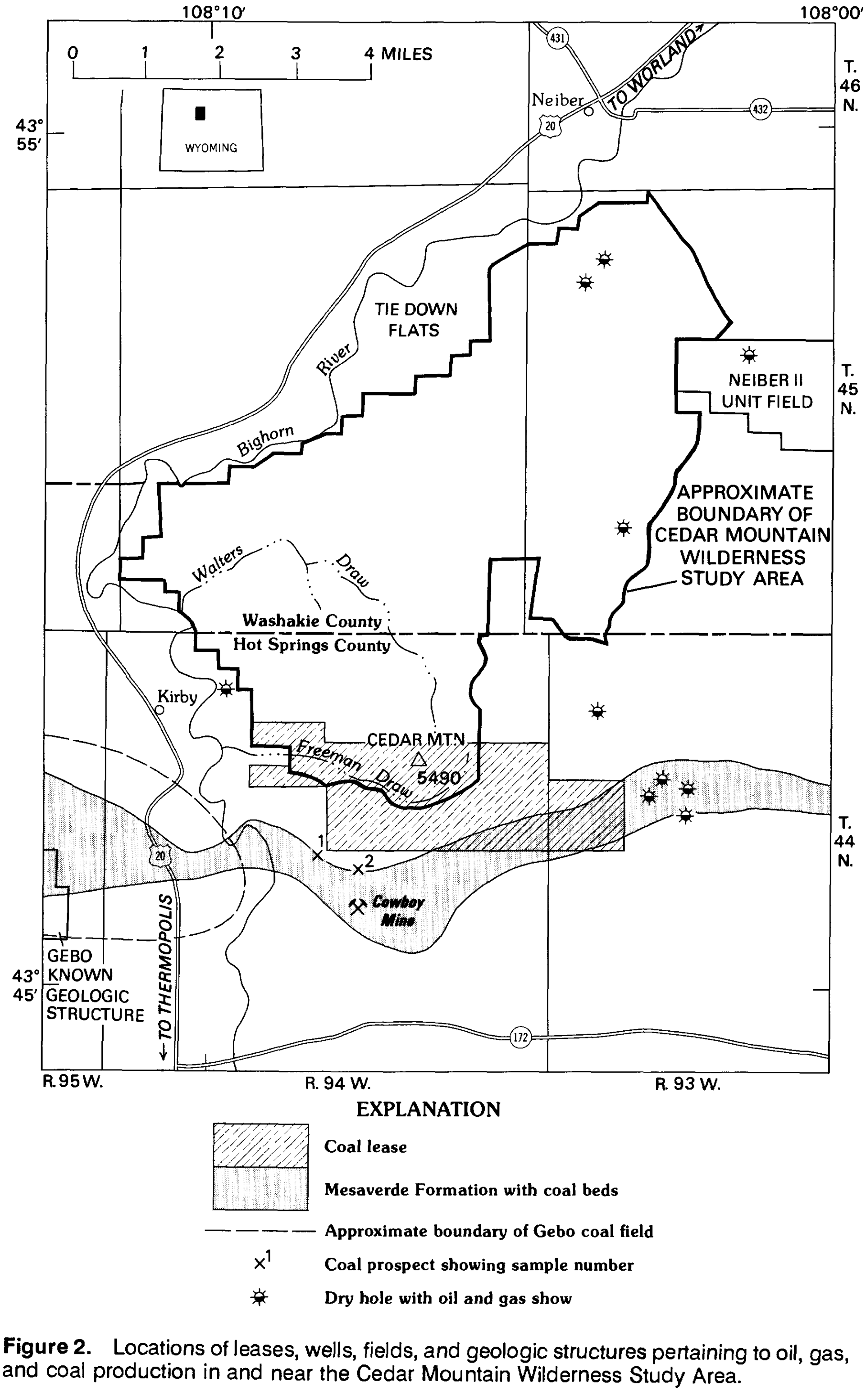


Figure 2. Locations of leases, wells, fields, and geologic structures pertaining to oil, gas, and coal production in and near the Cedar Mountain Wilderness Study Area.

ASSESSMENT OF POTENTIAL FOR UNDISCOVERED RESOURCES

By Curtis E. Larsen, Randall H. Hill, Dolores M. Kulik, and Mark K. Brown, U.S. Geological Survey

Geology

The Cedar Mountain Wilderness Study Area lies near the southern margin of the Bighorn Basin. Along the margins of the basin, Paleozoic, Mesozoic, and Cenozoic sedimentary rocks dip toward the axis of the basin. The study area includes the contact between the northeastward dipping Mesozoic and Cenozoic rocks (fig. 3). Upper Cretaceous sandstones and shales dip beneath sandstones and mudstones of Tertiary age at Cedar Mountain. Coal-bearing beds of the Upper Cretaceous Mesaverde Formation crop out south of the study area but lie several hundred feet beneath Cedar Mountain. Paleozoic rocks known for oil and gas production elsewhere in the basin lie at still greater depth. The Tensleep Sandstone, for example, is found between 11,000 and 12,000 feet beneath the surface near the north boundary of the area.

The sedimentary rocks exposed at the surface of the study area belong to four formations of Late Cretaceous and Tertiary age. The lowermost is the Upper Cretaceous Meeteetse Formation. It consists of interbedded shale, siltstone, bentonite, and coal (Horn, 1963). These easily eroded sediments are generally poorly exposed, but excellent exposures are found in the eastern portion of Freeman Draw, sec. 12, T. 44 N. R. 94 W. The upper 300 feet of the Meeteetse Formation is exposed at the base of Cedar Mountain, where it is overlain by massive sandstones of the Upper Cretaceous Lance Formation. Near the contact between these formations are paleochannels within the lowest sandstone beds of the Lance. These are filled with apparent siltstone and thin coal beds of Meeteetse affinity. This relationship suggests a conformable contact between these formations.

The Lance is mostly sandstone and includes gray shale and carbonaceous shale in its lower part. The sandstones contain ovoid calcareous concretions. Horn (1963), on the basis of mappable lithologic units, considered it to be 700 to 1,000 feet thick in the study area. We found 1,200 feet of Lance strata, including about 800 feet exposed on the south face of Cedar Mountain. The contact between the Lance and Meeteetse Formations can be traced in outcrop along the western boundary of the area until it dips beneath the ground surface in sec. 5, T. 44 N., R. 94 W.

The contact between the Lance and the overlying Paleocene Fort Union Formation, which contains the earliest Tertiary rocks of the Bighorn Basin, is less clear. The Lance and Fort Union are difficult to differentiate from one another in the Cedar Mountain area. Elsewhere in the Bighorn Basin an angular unconformity is locally present between the Lance and Fort Union Formations (Weitz and Love, 1952; Horn, 1963). In the study area, however, depositional environments were apparently gradational, leaving few clear lithologic breaks to aid mapping. To maintain continuity with the earlier mapping efforts, we have followed Horn (1963) by placing the Lance-Fort Union contact at the base of the first carbonaceous beds above the relatively organic-free sandstones and shales of the Lance. This choice is in contrast with recent work by Hartman (1986), who has studied the fossil vertebrate fauna from the Cretaceous-Tertiary boundary just east of Cedar Mountain and argued, on the basis of paleontology, that much of the Lance Formation should be included within the Fort Union.

A detailed stratigraphic section measured from the base of Cedar Mountain to Tie Down Flats identified as much as 3,500 feet of Fort Union rocks in the area. This is consistent with Moore's (1961) isopach map of the Fort Union Formation and Jepsen and Van Houten's (1947) type section for the Polecat Bench Formation (equivalent to Fort Union) farther to the north in the Bighorn Basin. Similarly, as Jepsen and Van Houten have suggested, the Fort Union rests conformably on the Lance.

The Fort Union Formation covers nearly the entire surface of the study area. It dips gently northward at about 10° to 15° from its contact with the Lance Formation at Cedar Mountain until it is overlain by the Willwood Formation of Eocene age in the core of the Neiber syncline at Tie Down Flats.

The Fort Union is a drab, repetitive sequence of light-gray siltstones and yellowish brown sandstones. Using Horn's (1963) definitions, which include coals and lignites within the Fort Union rather than in the Lance Formation, the base of the Fort Union is marked by a yellowish-brown siltstone containing prominent thin lignite beds. These organic-rich beds are overlain by alternating gray siltstones and thin, yellowish-brown sandstones. Calcareous ovoid concretions within sandstones, a characteristic of the Lance Formation, persist for at least 300 feet above the lignite beds at the base of the section before giving way abruptly to ferruginous concretions that cap thin sandstone beds. The ferruginous concretions continue upward throughout the stratigraphic section.

Siltstone and shale predominate in the Fort Union; sandstones in the unit rarely exceed 10 feet in thickness. Deposition was apparently cyclic. Fine-grained lacustrine

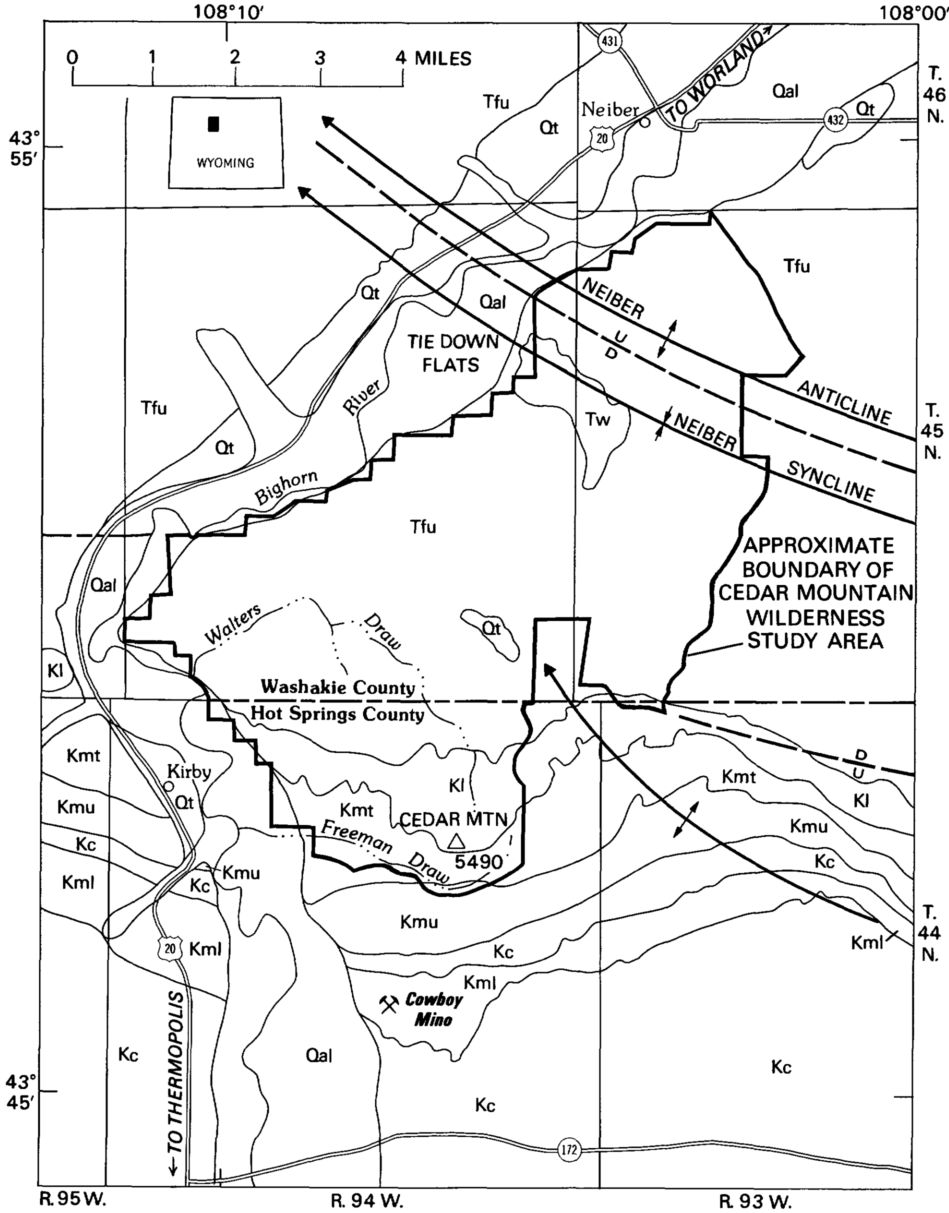
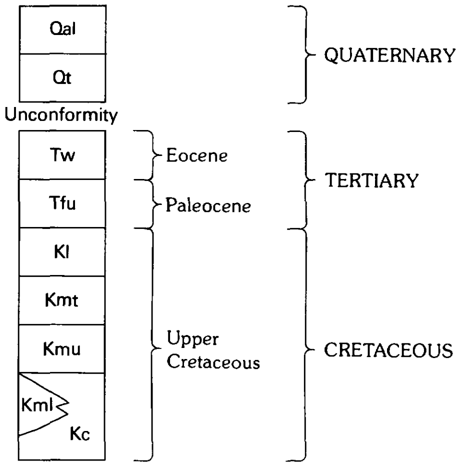


Figure 3 (above and facing page). Generalized geology of the Cedar Mountain Wilderness Study Area. Geology mapped in 1986 by C.E. Larsen and M.K. Brown, partly based on earlier mapping by Weitz and Love (1952), Horn (1963), and Love and Christiansen (1985).

sediments are overlain by sandstones indicative of lakeshore and river environments. Iron oxide concretions and crusts—many containing plant fossils—cap the sandstones. Each sandstone, in turn, is covered by another siltstone-sandstone-concretion sequence. These cyclic units average about 20 feet in thickness in the lower portion of the formation. In the middle portion of the formation siltstones tend to predominate. Here, some individual siltstone beds are 60 to 80 feet thick. These fine-grained, easily erodible sediments are well exposed along Walters Draw (secs. 33, 34, and 35, T. 45 N., R. 94 W.) and beneath the adjacent high ridge (altitude 5360 feet) in section 35, where they are protected from further erosion by a thick quartzite cobble and gravel deposit of probable early Pleistocene or late Tertiary age.

The thick siltstones of the middle portion of the section are overlain by approximately 500 feet of closely spaced cyclic units that average 10 to 15 feet thick. The uppermost 1,000 feet of the Fort Union Formation, however, is also predominantly siltstone. While the sandstones that cap each cyclic unit are generally less than 5 feet thick, the underlying siltstones range in

CORRELATION OF MAP UNITS



LIST OF UNITS

Qal	**Alluvium (Quaternary)**
Qt	**Terrace deposits (Quaternary)**
Tw	**Willwood Formation (Eocene)**
Tfu	**Fort Union Formation (Paleocene)**
Kl	**Lance Formation (Upper Cretaceous)**
Kmt	**Meeteetse Formation (Upper Cretaceous)**
	Mesaverde Formation (Upper Cretaceous):
Kmu	**Upper member**
Kml	**Lower member**
Kc	**Cody Shale (Upper Cretaceous)**

Contact

Subsurface fault—Approximately located; U, upthrown side; D, downthrown side

Anticline—Showing trace of axial plane and plunge

Syncline—Showing trace of axial plane and plunge

thickness from 40 to 60 feet. The greater moisture content of the sandstones is reflected by the abundance of vegetation on sandstone dip slopes of the upper part of the Fort Union.

The Fort Union in this part of the Bighorn Basin is overlain conformably by the Eocene Willwood Formation (Van Houten, 1944, 1948, 1952; Bown, 1979, 1980). The Willwood Formation is the youngest Tertiary formation in this portion of the basin. Subsequent formations were apparently removed by erosion. These varicolored red, purple, and gray mudstones have a gradational contact with the underlying gray siltstones and mudstones of the upper part of the Fort Union. They are interbedded with yellowish-brown sandstone beds. Van Houten (1944) measured 2,500 feet of the Willwood in Park County, about 85 miles northwest of the study area, and proposed the first occurrence of red banding in the sediments as the best criterion for distinguishing it from the underlying Fort Union Formation. We have followed this scheme for our mapping purposes. Only the basal 200 to 250 feet of the formation is present in the study area. This is a remnant preserved within the core of the Neiber syncline in secs. 12 and 13, T. 45 N., R. 94 W., and sec. 18, T. 45 N., R. 93 W.

Gravels of Quaternary age overlie earlier rocks along the Bighorn River. These deposits underlie terrace surfaces that reflect former flood plains and runoff conditions (Mackin, 1937; Ritter, 1975; Palmquist, 1983; Reheis and others, in press). Reworked alluvial deposits related to postglacial and modern river systems underlie the modern flood plain. Remnants of earlier alluvial surfaces, underlain by quartzite cobble gravel deposits, are found sporadically on uplands as much as 1,200 feet above the modern flood plains (sec. 35, T. 45 N., R. 94 W.).

Geologic Structure

The geologic structure of the southern Bighorn Basin is important to mineral resource potential in the Cedar Mountain Wilderness Study Area, as it affects not only the distribution of stratigraphic traps for oil and gas (Pierce and others, 1947), but also the distribution of source terranes for detrital minerals. The Bighorn Basin is a downwarped asymmetrical trough whose axis trends northwest-southeast. Along its western margin it is adjacent to or is overridden by the Oregon Basin and Line Creek faults (fig. 4). This faulting, as well as downwarping of the basin, occurred chiefly during the Paleocene. It was contemporaneous with the uplift of the surrounding mountain ranges and deposition of the Fort Union Formation. The Fort Union thickens towards the axis of the basin (Moore, 1961; Bown, 1980; Parker and Jones, 1986). Parker and Jones (1986) indicate that the Oregon Basin fault began moving during deposition of the Lance Formation and continued throughout the Paleocene. Major movement was complete by the time Willwood deposition began. As figure 4 shows, the Oregon Basin fault is about 75 miles long and extends southeastward to the vicinity of Cedar Mountain. Oil and gas well logs (BLM district office, Worland, Wyo.) identify faulting of the Lower Permian Park City Formation that is consistent with movement on the Oregon Basin fault. They also show reverse faulting within the Pennsylvanian Tensleep Sandstone beneath the Neiber anticline and aligned with the Oregon Basin fault. These faults, concealed at depth beneath the north and south portions of the study area, might have created oil and gas traps.

Early research by Stow (1952) indicated structural influences on the occurrence of detrital heavy minerals in the Lance, Fort Union and Willwood Formations. He identified uplifting areas along the flanks of the basin as source terranes. The Lance and Fort Union both

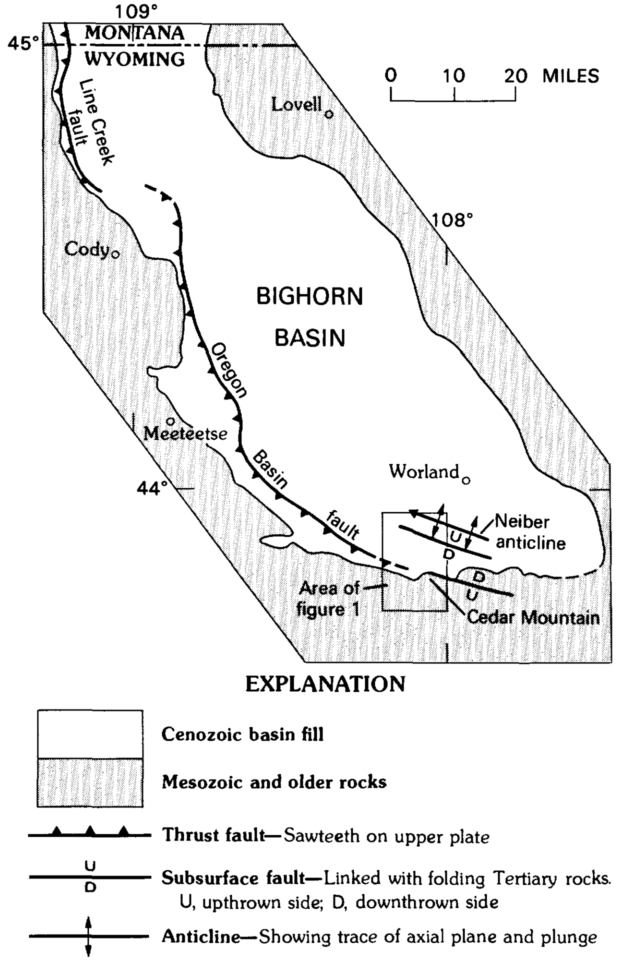


Figure 4. Thrust faulting along the western margin of the Bighorn Basin (modified from Parker and Jones, 1986).

received heavy minerals derived from earlier Mesozoic strata. By the Eocene, however, crystalline basement rocks were exposed, and these supplied hornblende to the Willwood.

Geochemistry

Bulk samples collected from active alluvium at 38 sites in and near the study area were used to produce 38 minus-80-mesh stream-sediment samples and 38 heavy-mineral panned concentrates. These samples were the primary medium selected to represent the heavy-mineral component of rock and soil exposed in the drainage basins upstream from sample sites. Chemical analyses of these stream sediments provide data useful in identifying basins which contain unusually high concentrations of elements that may be related to mineral occurrences. In addition, studies have shown that heavy-mineral concentrates derived from stream sediments are a useful sample medium in arid-semiarid environments or in areas of rugged topography, where mechanical erosion predominates over chemical erosion (Overstreet and Marsh, 1981; Bugrov and Shalaby, 1975).

Fresh, unaltered rock samples were collected from outcrops near 34 of the stream-sediment sample sites. The actual areal extent of terrane represented by geochemical information from a specific sample is not known; the sampling program was designed only to provide some general information on the geochemical nature of the rock units present. A separate suite of 118 grab samples of rock from outcrops was collected along upland traverses. All rock samples were analyzed using the same techniques.

In preparation for analysis, the dry stream-sediment samples were sieved through 80-mesh (0.17-mm) stainless steel sieves. The minus-80-mesh material was retained for analysis and pulverized with ceramic plates to finer than 100 mesh (0.15 mm) prior to analysis.

To produce the heavy-mineral concentrate, bulk stream sediment from active alluvium was first sieved through a 10-mesh (2.0-mm) screen. Approximately 10–15 pounds of the minus-10-mesh sediment was panned to remove most of the quartz, feldspar, organic materials, and clay material. The panned concentrate was then separated into light and heavy fractions using bromoform (heavy liquid, specific gravity 2.86). The light fraction was discarded. The material of specific gravity greater than 2.86 was further separated into three fractions (highly magnetic, weakly magnetic, and nonmagnetic) using a modified Frantz Isodynamic Separator. The nonmagnetic fraction was hand ground and saved for analysis. These procedures result in a sample that contains ore-forming and ore-related minerals. This selective concentration of minerals permits determination of some elements that are not easily detected in bulk stream-sediment samples. Rock samples were crushed and then pulverized to finer than 100 mesh with ceramic plates prior to analysis.

Stream sediments, heavy-mineral panned concentrates, and unaltered rock samples were then analyzed for 31 elements (Ag, As, Au, B, Ba, Be, Bi, Ca, Cd, Co, Cr, Cu, Fe, La, Mg, Mn, Mo, Nb, Ni, Pb, Sb, Sc, Sn, Sr, Th, Ti, V, W, Y, Zn, and Zr) using a six-step semiquantitative emission spectrographic method (Grimes and Marranzino, 1968). Because of the small size of the nonmagnetic heavy-mineral concentrates, they were only analyzed spectrographically. The rock and minus-80-mesh stream-sediment samples were also analyzed for As, Bi, Cd, Sb, and Zn using an inductively coupled argon plasma-atomic emission spectrograph (Crock and others, 1987), and they were analyzed fluorometrically for uranium and by atomic absorption spectrometry for gold (O'Leary and Meier, 1986). A complete listing of all analyses, elements and their lower limits of determination, a sample locality map, and rock sample descriptions are included in Hill and others (1988).

Threshold values, defined as the upper limits of normal background values, were determined for each element by inspection of frequency distribution histograms for all three sample media. Geochemical concentrations higher than the threshold values are considered anomalous and worthy of scrutiny as possible indicators of mineralization.

Geochemical analyses show that the unaltered rock and minus-80-mesh stream-sediment samples are all well within normal background levels, except for two rock samples which show concentrations of 21 and 34 ppm (parts per million) arsenic. The arsenic probably derives from arsenate substituting for phosphate in fluorapatite (Palache and others, 1951), which has been identified by X-ray diffraction analysis in these samples. It is not believed to indicate any mineral deposit.

Geochemical values in nonmagnetic heavy-mineral concentrates reflect high concentrations of barium (all samples had 10,000 ppm or greater), zirconium (all samples had more than 2,000 ppm), and titanium (76 percent of the samples had 2 percent or more). Barite, zircon, and rutile, respectively, were identified by X-ray diffraction as the major mineral constituents of the heavy-mineral concentrates containing these elements. The barite is considered to be authigenic; zircon and rutile are believed to be products of mechanical weathering and erosion of the surrounding surface rocks. All three of these heavy minerals were reported in the Fort Union Formation by Stow (1952). They have been concentrated in stream alluvium and further concentrated by panning. Nominally high strontium concentrations in the heavy-mineral concentrates (1,500 to 3,000 ppm) most likely reflect strontium contained in barite in the concentrates. Yttrium, which has high values of 300 to 1,000 ppm, may reside in both zircon and fluorapatite (Palache and others, 1951). The source of detectable tin (20 to 100 ppm) is not known.

Three high concentrations of gold (20, 30, and 100 ppm) and one high silver value (3 ppm) were detected by emission spectrography in the heavy-mineral concentrates. The areal extent of the gold and silver is very limited. No other gold or silver was detected in any other samples of any type. Even the rock and minus-80-mesh stream-sediment samples, which were analyzed for gold by the more sensitive atomic absorption spectrometric method (lower detection limit of 50 parts per billion), had none.

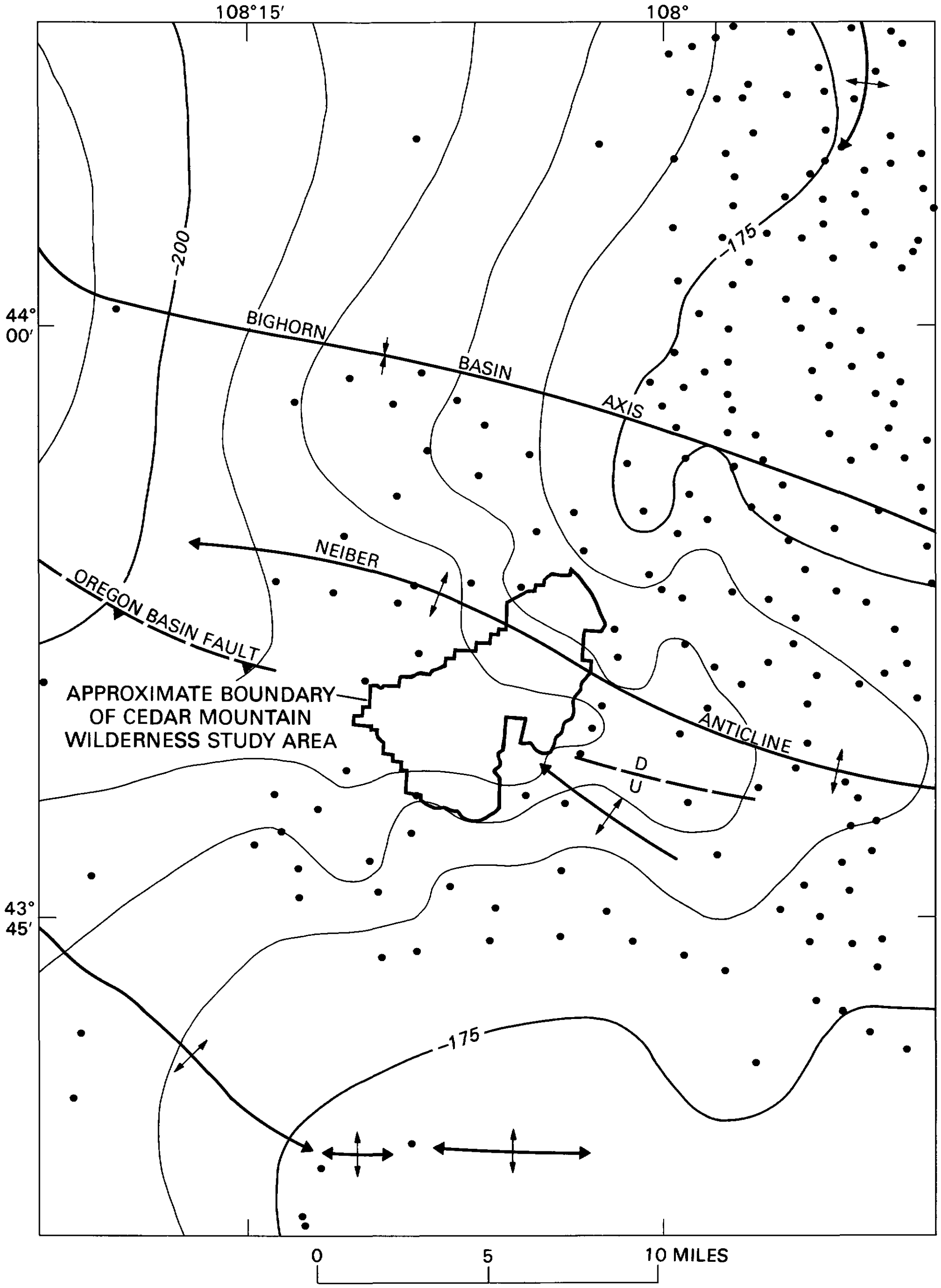
Geophysics

Gravity and magnetic studies undertaken as part of the mineral resource evaluation of the Cedar Mountain Wilderness Study Area provide information on the subsurface distribution of rock masses and the structural framework. The gravity and magnetic data are of a reconnaissance nature and are adequate only to define regional geologic features.

The gravity data were obtained in and adjacent to the study area by D.M. Kulik in 1986 and were supplemented by data maintained in the files of the Defense Mapping Agency of the Department of Defense. Stations measured were established using a Worden gravimeter W-177. The data were tied to the International Gravity Standardization Net 1971 (U.S. Defense Mapping Agency Aerospace Center, 1974) at base station ACIC 16611 at Shoshoni, Wyo., 40 miles south of the study area. Station elevations were obtained from benchmarks, spot elevations, and estimates from topographic maps at 1:24,000 and 1:62,500 scales; most are accurate to within 20 feet, though errors as large as 40 feet are possible for some stations. The error in the Bouguer anomaly resulting from the errors in elevation control is less than 2.5 milligals. Bouguer anomaly values were computed using the 1967 gravity formula (International Association of Geodesy, 1976), a reduction density of 2.67 grams per cubic centimeter, and mathematical formulas given in Cordell and others (1982). Terrain corrections were made by computer for a distance of 100 miles from the station using the method of Plouff (1977). The data are shown in figure 5 as a complete Bouguer anomaly map with a contour interval of 5 milligals.

Magnetic data are from Bendix Field Engineering Corporation (1982). Flight lines were flown east-west at 2- to 5-mile intervals and at 400 feet elevation above the ground. The data are shown in figure 6 as a residual intensity magnetic map with a contour interval of 20 gammas.

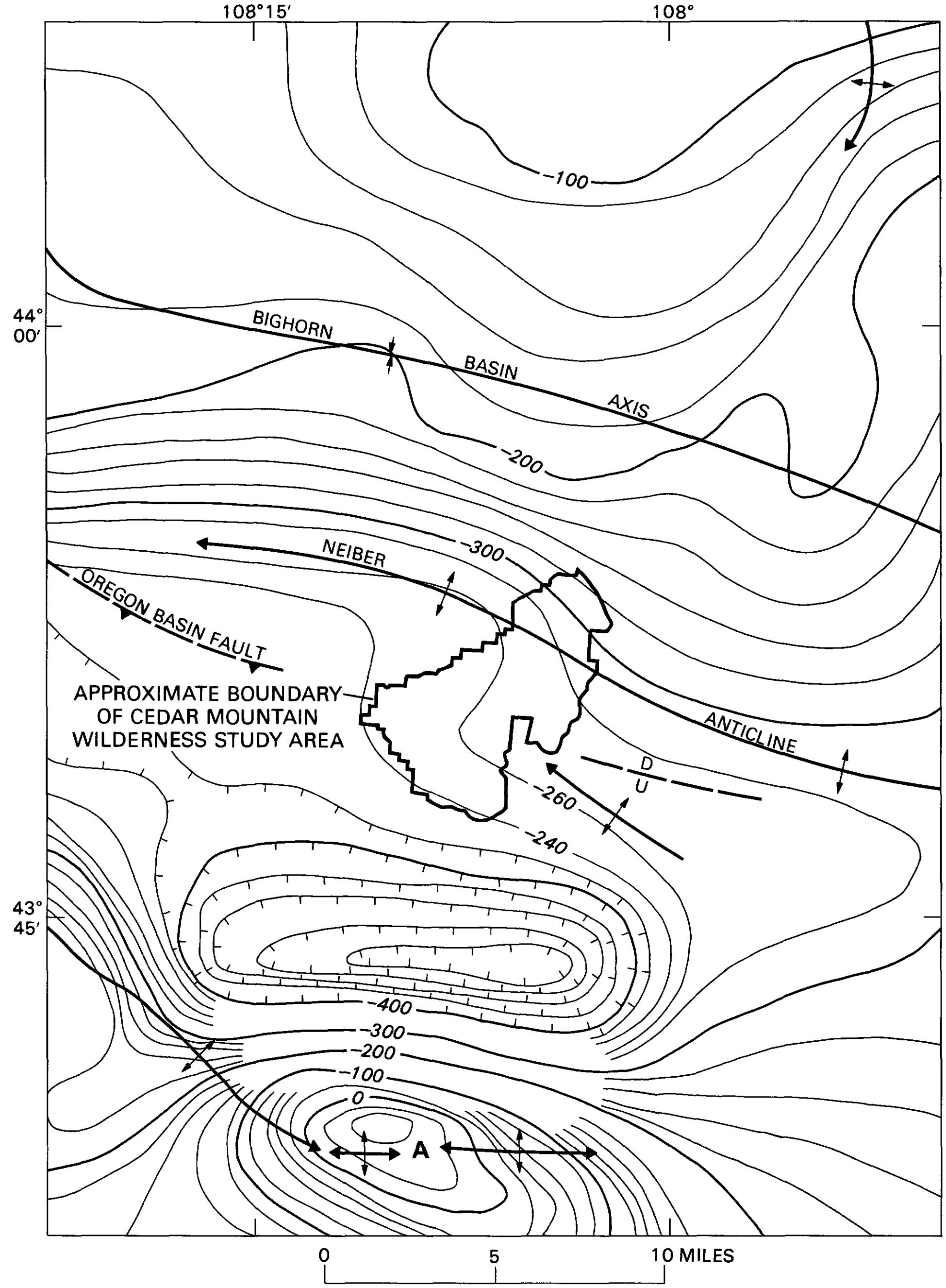
In the central part of the Bouguer anomaly map (fig. 5), low gravity values in the study area reflect the low-density sedimentary rocks of the Bighorn Basin. Higher values north and south of the study area derive from crystalline rocks of the Owl Creek uplift to the south and the Bighorn uplift northeast of the area shown on the maps. These data indicate that the gravity axis of the basin is offset to the south of the mapped axis. This offset suggests either that a deep trough developed in front of the northeastward-directed Oregon Basin fault, or that the sediments shed from the south into this part of the basin were less dense than those deposited elsewhere in the basin. In addition, the data indicate that the basin narrows in the study area and a lobe of higher density rocks extends westward from the Bighorn uplift into the area north of Cedar Mountain. The steep gradient at the southern boundary of the study area suggests that the fault mapped to the east is continuous with the Oregon



EXPLANATION

—-175—	**Gravity contour**—Number shows complete Bouguer anomaly in milligals
•	**Gravity station**
▼ ▼ ▼	**Thrust fault**—Sawteeth on upper plate
D/U	**Subsurface fault**—U, upthrown side; D, downthrown side
→	**Anticline**—Showing trace of axial plane and plunge
→	**Syncline**—Showing trace of axial plane and plunge

Figure 5. Complete Bouguer gravity anomaly and generalized structure in and near Cedar Mountain Wilderness Study Area. Geologic structure modified from Ver Ploeg (1985).



EXPLANATION

-200 **Magnetic contour**—Number shows residual intensity anomaly in gammas

Thrust fault—Sawteeth on upper plate

D/U **Subsurface fault**—U, upthrown side; D, downthrown side

Anticline—Showing trace of axial plane and plunge

Syncline—Showing trace of axial plane and plunge

Figure 6. Residual intensity magnetic anomaly and generalized structure in and near the Cedar Mountain Wilderness Study Area. Letter A marks an anomaly discussed in text. Geologic structure modified from Ver Ploeg (1985).

Basin fault, which is associated with a similar basin-bounding gradient for at least 75 miles to the northwest.

A magnetic high (A) near the southern boundary of figure 6 is part of a more extensive high that extends to the south (Bendix Field Engineering Corporation, 1982) and is caused by crystalline rocks of the Owl Creek uplift. The magnetic low north of magnetic high A probably is due largely to the dipole effect, but may be enhanced by nonmagnetic Paleozoic rocks on the flank of the uplift. The high magnetic values at the north edge of figure 6 reflect the crystalline rocks of the Bighorn uplift a few miles farther to the northeast. The relatively high magnetic values just north of the study area result from crystalline rocks beneath the basin in a westward extension of the Bighorn uplift, as discussed in the previous paragraph. Magnetic values are moderate over the Cedar Mountain area. The offset in the -240 and -260 contours as they cross the area suggests, as do the gravity data, that the fault to the east continues through the study area and connects with the Oregon Basin fault.

Mineral and Energy Resources

Metals

The available geologic and geochemical data suggest that the Cedar Mountain Wilderness Study Area has no resource potential for metals other than gold, with certainty level D. The geologic terrane consists of fine-grained, semi-indurated sedimentary rocks. There are no known plutonic sources for metals or mineralizing fluids in the vicinity. Similarly, the rocks of the area show no evidence of mineralization or hydrothermal alteration.

Minerals present in the surface rocks are mostly detrital. Geochemical analyses show that all metals in these rocks except gold and silver are at or below the normal concentrations for sandstones (Turekian, 1977). Gold was detected in the nonmagnetic heavy-mineral fractions of three samples, and silver in one of these. A sample containing 30 ppm gold and 3 ppm silver was collected at the mouth of a short ravine in sec. 6, T. 45 N., R. 93 W., adjacent to the Bighorn River. Another sample, which had a gold content of 100 ppm, came from a stream drainage in sec. 12, T. 45 N., R. 94 W. A third sample, with 20 ppm gold, was recovered from a stream drainage in sec. 24, T. 45 N., R. 94 W. These drainage basins are shown in figure 1. Inasmuch as gold was absent from all samples of the surrounding rocks, even when they were analyzed by more sensitive atomic absorption spectrometry, it is highly unlikely that the gold was derived from paleoplacer deposits in the Fort Union Formation. It is possible, however, that the gold recovered from section 12 was derived from a basal conglomerate of fine-gravel size in the adjacent Willwood Formation. Fine-grained gold has been reported from conglomerates in the Upper Cretaceous Harebell Formation and the Upper Cretaceous and Paleocene Pinyon Formation of Jackson Hole, 130 miles west of the study area (Antweiler and Love, 1967; Lindsey, 1972). Thus, coarse-grained facies in the Willwood may contain reworked gold from earlier paleoplacers. More likely sources are the Quaternary terrace gravels that once bordered the Bighorn River flood plain, and quartzite cobble gravels that cap the uplands upstream from both of the latter samples. For example, gold was recovered from similar alluvial deposits along the Wind River and Bighorn River south of Thermopolis (Schrader, 1915).

The alluvial deposits derived from the surrounding rocks in this part of the study area are exceedingly thin. Though Quaternary terrace gravels are preserved as remnants along the edges of the Bighorn River valley, none are present at the three sample sites. However, fine-grained gold may have been left as a lag deposit from gravels that were eroded from the area. Another possible source is the small remnant of quartzite-cobble gravels that cap the uplands in sec. 35, T. 45 N., R. 94 W., upstream from two of the sample sites. These deposits, however, are thin and sparsely distributed in the study area. Notwithstanding anomalous gold concentrations in three samples, the combined data suggest only a moderate potential for the occurrence of undiscovered gold resources in the three small drainages these samples represent, at certainty level C. There is no potential for gold resources in the remainder of the study area, at certainty level D.

Oil and Gas

The geologic evidence from this portion of the Bighorn Basin presented by Spencer (1983), the results of previous oil and gas exploration in the study area, and the structural and geophysical data presented here suggest a moderate resource potential for undiscovered oil and gas, with certainty level C, in two parts of the study area. The possible extension of the Oregon Basin thrust fault beneath the southern portion of the study area and the demonstrated reverse faulting of the Neiber anticline, at depth, are subsurface structures that are not readily apparent on the surface. The proximity of known geologic structures and producing oil fields indicates that the subsurface conditions are favorable for the migration and accumulation of oil and gas. Traps could exist at facies changes within the Middle and Upper Pennsylvanian Tensleep Sandstone and within Lower Permian rocks called the Phosphoria Formation by some workers and the Park City Formation by others. Traps might also exist in porous zones created by movement along the Oregon Basin and Neiber anticline faults. Present data do not show whether any accumulations of oil or gas exist in the study area.

Various groups of researchers have evaluated the oil and gas resource potential of the study area with various results. Spencer and Powers (1982) assigned it a moderate potential. Tetra Tech, Inc. (1983), in a consulting study to the BLM, classified the entire study area as "highly favorable for the potential occurrence of oil and gas resources," on the basis of what they considered abundant direct and indirect evidence. The BLM (U.S. Bureau of Land Management, 1986) similarly suggested a high potential, based on the location of the Neiber anticline and the recent lease activity. Nevertheless, our assessment of the available data suggests only a moderate resource potential for undiscovered oil and gas, at certainty level C, along the Neiber anticline and the projection of the Oregon Basin fault. The oil and gas potential in the remainder of the study area is low at certainty level C.

Coal

Coal is found in the Mesaverde Formation at the Cowboy Mine, 2 miles south-southwest of Cedar Mountain. The beds there are eastward extensions of thicker coal beds in the Gebo coal field west of the Bighorn River. The Mesaverde at the Cowboy Mine dips northward at about 10° to 15°, so it probably lies at a depth of 800 to 1,000 feet at the southern boundary of the study area and at still greater depth farther to the north. Coal from this portion of the Mesaverde Formation in the Gebo coal field ranked as subbituminous A and B and had a heat value of 10,632 Btu/lb (Glass and others, 1975, p. 226). Samples taken from the Cowboy Mine by the USBM (Scott, 1986, and this study) gave those coals a comparable rank.

Other coal or lignite beds crop out within the study area, in the Meeteetse and Fort Union Formations. Carbonaceous shales mixed with subbituminous coal in beds as much as 4 to 5 feet thick are exposed at the base of Cedar Mountain. We measured only four thin, 1- to 2-foot beds of lignite within the Fort Union Formation during our field research. The mineral resource potential for coal is low in the southern part of the Cedar Mountain Wilderness Study Area, at a certainty level of C. No resource potential for coal exists in the remainder of the study area, at certainty level D.

Geothermal Energy

Although hot springs occur 10 miles south of the area at Thermopolis, we found no published information regarding geothermal waters or leasing activity. In addition, no geologic evidence, such as sinter or hot springs, has been found to indicate past or present geothermal activity in the study area. These data show the study area has no potential for geothermal resources, with a certainty level D.

Uranium

Tertiary rocks have been a focus of uranium prospecting since Love (1952) reported roll-front uranium concentrations in sandstones of the Eocene Wasatch Formation in the Powder River Basin. The Eocene Willwood Formation and the Paleocene Fort Union Formation in the Bighorn Basin each contain lithologic associations of channel sandstones, lignites, and siltstones that host redox or roll-front type uranium deposits (Boberg, 1981). Samples of rock and stream sediment collected from both of these formations in the study area show concentrations of uranium much less than 1 ppm. These observations are consistent with those of Harris (1983), who reported no uranium anomalies within the Fort Union, Willwood, or Tatman Formations in the Bighorn Basin. The available geologic and geochemical data suggest at a certainty level of D that there is no mineral resource potential for uranium in the Cedar Mountain Wilderness Study Area.

Sand and Gravel

The proximity of the Bighorn River to the study area ensures that ample sand and gravel resources are present nearby. The majority of sand and gravel deposits are beneath the high Pleistocene river terraces, which are generally along the west side of the river, just outside the western border of the study area. Gravels beneath terrace surfaces are prevalent on the east side of the river north of the study area. Indeed, the few sand and gravel deposits within the borders of the wilderness study area occur as perched remnants of earlier land surfaces as much as 1,200 feet above the flood plain of the Bighorn River. There is no industrial mineral resource potential for sand and gravel, at a certainty level of D.

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APPENDIX

DEFINITION OF LEVELS OF MINERAL RESOURCE POTENTIAL AND CERTAINTY OF ASSESSMENT

Definitions of Mineral Resource Potential

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

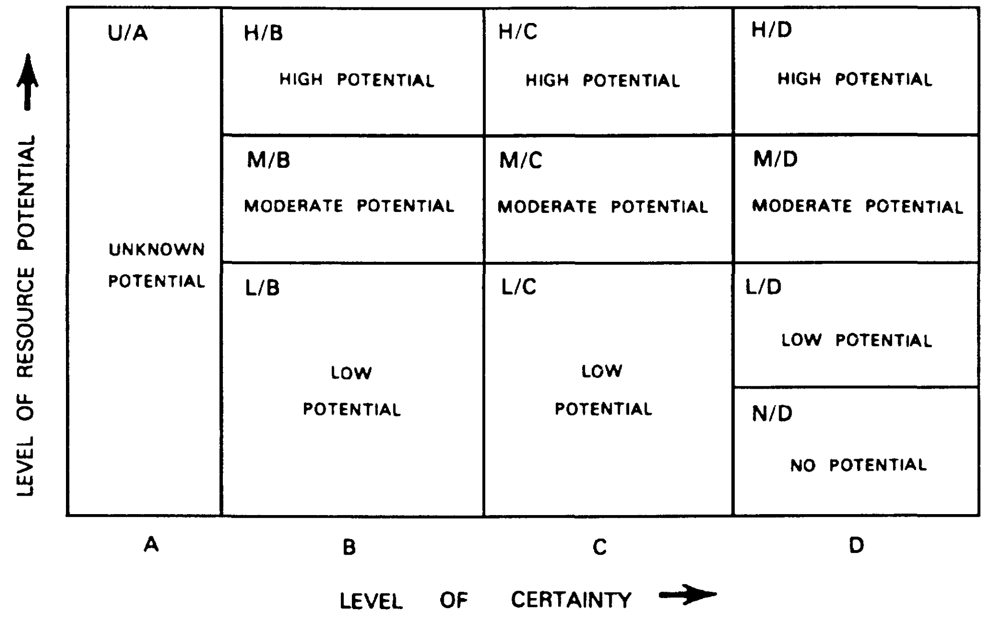
MODERATE mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence, where interpretations of data indicate a reasonable likelihood of resource accumulation, and (or) where an application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

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

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

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

Levels of Certainty



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

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RESOURCE/RESERVE CLASSIFICATION

	IDENTIFIED RESOURCES			UNDISCOVERED RESOURCES	
	Demonstrated		Inferred	Probability Range (or)	
	Measured	Indicated		Hypothetical	Speculative
ECONOMIC	Reserves		Inferred Reserves		
MARGINALLY ECONOMIC	Marginal Reserves		Inferred Marginal Reserves		
SUB-ECONOMIC	Demonstrated Subeconomic Resources		Inferred Subeconomic Resources		

Major elements of mineral resource classification, excluding reserve base and inferred reserve base. Modified from McKelvey, 1972, Mineral resource estimates and public policy: American Scientist, v.60, p.32-40, and U.S. Bureau of Mines and U.S. Geological Survey, 1980, Principles of a resource/reserve classification for minerals: U.S. Geological Survey Circular 831, p.5.

GEOLOGIC TIME CHART

Terms and boundary ages used in this report

EON	ERA	PERIOD		EPOCH	BOUNDARY AGE IN MILLION YEARS
Phanerozoic	Cenozoic	Quaternary		Holocene	0.010
				Pleistocene	1.7
		Tertiary	Neogene Subperiod	Pliocene	5
				Miocene	24
			Paleogene Subperiod	Oligocene	38
				Eocene	55
				Paleocene	66
	Mesozoic	Cretaceous		Late	96
				Early	138
		Jurassic		Late Middle Early	205
		Triassic		Late Middle Early	~ 240
	Paleozoic	Permian		Late Early	290
		Carboniferous Periods	Pennsylvanian	Late Middle Early	~ 330
			Mississippian	Late Early	360
		Devonian		Late Middle Early	410
		Silurian		Late Middle Early	435
		Ordovician		Late Middle Early	500
		Cambrian		Late Middle Early	~ 570[1]
Proterozoic	Late Proterozoic				900
	Middle Proterozoic				1600
	Early Proterozoic				2500
Archean	Late Archean				3000
	Middle Archean				3400
	Early Archean				3800?
pre-Archean[2]					4550

[1] Rocks older than 570 m.y. also called Precambrian, a time term without specific rank.

[2] Informal time term without specific rank.

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